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GEOOTHER EVALUATION AND IMPROVEMENT: A PROGRESS REPORT INCLUDING TEST CASES FOR TWO-DIMENSIONAL BWIP ANALYSIS

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EXECUTIVE SUMMARY

OBJECTIVES

The objective of the work is two-fold: 1) to evaluate the GEOTHER code and perform necessary improvements to make it specifically suitable for predicting the environmental conditions of the waste package for the Basalt Waste Isolation Project (BWIP), and 2) to perform resaturation analyses, that is, the analyses of steam formation and condensation, for the repository and waste package using the improved GEOTHER code.

This is a progress report to BWIP documenting the status of GEOTHER code testing, evaluation, and improvements. The computational results documented in this report reflect the current condition of the code and the condition before code improvements. The test cases used are intended for examining the code features in sufficient detail and are not intended to be taken as final conclusions for BWIP applications.

BACKGROUND

The GEOTHER code was originally developed by the U.S. Geological Survey for analyzing geothermal conditions. It was later modified by the Office of Nuclear Waste Isolation for repository analyses. The code was validated for the geothermal applications. In January 1985, Pacific Northwest Laboratory (PNL), under contract to Rockwell Hanford Operations (Rockwell), started to evaluate the GEOTHER code for its applicability to BWIP waste package environmental analysis. A simplified two-dimensional cylindrical geometry was set up for a single container in the BWIP repository. The calculation was carried out to predict the waste package near-field two-phase hydrothermal conditions.

The results indicated that the code gave the expected trends in temperature and pressure as a function of time, i.e., as the waste package starts to heat up the near field, the groundwater temperature and pressure start to increase and eventually approach an asymptotic value as the decay heat diminishes to a

negligible value (refer to Appendix B, Test Case 2, p. B.19). However, it was discovered that the code needed to be modified to be more applicable for use in waste package environment analyses.

This report documents the improvements made to the code and preliminary results of a hydrothermal and resaturation analysis for a single container in a two-dimensional Cartesian configuration. The results presented in this report are preliminary in the sense that the improvements to the code have not been subjected to a thorough verification and validation process. Further improvements are needed for more a realistic simulation of waste package conditions.

CODE EVALUATION

GEOTHER is a three-dimensional geothermal reservoir simulation code. The model describes heat transport and flow of a single-component, two-phase fluid in porous media. It is based on the continuity equations for steam and water, which are reduced to two nonlinear partial differential equations in which the dependent variables are fluid pressure and enthalpy. These equations, written in three-dimensional form are approximated using finite-difference techniques and solved using Newton-Raphson iteration to handle the nonlinear coefficients. An option is also provided for using either upstream or midpoint weighing on the mobility terms.

GEOTHER is used to simulate fluid-thermal physical interactions in rock that can be approximated by a porous media representation. It simulates heat transport and the flow of compressed water, two-phase mixtures, and super-heated steam in porous media over a temperature range of 10°C to 300°C. In addition, it treats the conversion from single- to two-phase flow, and vice versa. It is used for evaluation of groundwater flow and temperature patterns in the waste package and its surroundings over a time scale of a few years to thousands of years. The model is used to understand the two-phase behavior in response to thermal loading by waste materials.

For simplicity in modeling and fast computing time a two-dimensional cylindrical model of a single BWIP container was analyzed. With this simple

model, preliminary results were obtained on the hydrothermal conditions of the host rock and on the capabilities and limitations of the code.

The study of the cylindrical model resulted in the following findings:

- The code yielded reasonable pressure and temperature predictions. This conclusion was based on physical principles because no thorough validation work was performed on the results.
- A transient, continuously varying heat source in GEOTHER is needed. This should eliminate the nonphysical step changes in calculated host rock temperature and sudden change in pressures. GEOTHER allowed step changes only. Also, the nuclear heat source could not be modeled properly. Every node had to have both solid material (rock) and water. Only one type of material was allowed for the entire model, thus preventing separate modeling of the container and packing.
- A generalized boundary condition is needed to realistically simulate the BWIP environment. GEOTHER allowed either Neumann or Dirichlet boundary conditions for both pressures and temperatures in a given node (or block).
- To obtain more detailed hydrothermal conditions in the waste package and its surrounding environment, a multiple material property capability is needed. Only one set of specific heat, density, and thermal conductivity was allowed in the original GEOTHER code.
- The thermodynamic property algorithm of water was not adequate. Further study found that the pressure and enthalpy ranges given in the code were not sufficient for the types of problems encountered in a nuclear repository thermal analysis.
- Non-condensable gas is not included in the mathematical model of the code. No air-filled void space is allowed in a node. This deficiency will result in errors in resaturation time predictions.
- The code can not handle complicated geometries, e.g., mixing of Cartesian and cylindrical coordinate systems. A finite volume approach is required to realistically describe the BWIP waste package and its surrounding environment.

CODE IMPROVEMENTS

Based on the findings of the cylindrical model evaluation, areas of improvement to the code were identified and implemented. The changes that have been made to the code to date fall into two categories, improvements to the code utilities to make the code more user friendly and efficient, and modifications to bring the code to a status that allows modeling of the BWIP waste package.

Code Utility Improvements

Input Format Change

The input format was changed completely. One major difference is that the new input is arranged so that similar parameters are grouped together. For example, in the "TIME" card, all input parameters related to time step control and time of simulation are read in. The new input also reflects the model changes discussed in this section.

Restart Capability

With the addition of a restart option, inputs are automatically read by the code from a restart tape saved from a previous run, thus avoiding the tedious and error-prone manual input.

Code Redimensioning

The common block structure in GEOTHER was completely modified. Common blocks used most frequently were set up as COMDECKS and moved to the front of the program. With this modification, the program can be readily redimensioned to fit different problem storage sizes.

Materials Properties Improvements

Multiproperty Capability

GEOTHER restricts the physical model to a single porous material. With this added capability, the host rock and packing materials can be simulated correctly. Together with the addition of conduction equations (see below), the code can also correctly model the nonporous material

(e.g., waste container). This improvement enhances the code's ability to handle the inhomogeneity of the basalt flow.

Thermodynamic Properties

To avoid violating the very restrictive range limit in GEOTHER, a new property subroutine was put into the code. The properties are now calculated by a single subroutine instead of by several subroutines, making verifications and possible future modifications much easier. The property routine is based on Electric Power Research Institute (EPRI) algorithms and covers pressures ranging from $6.9\text{E}2$ to $4.14\text{E}7$ Pa (0.1 to 6000 psia) and specific enthalpies from approximately $4.65\text{E}5$ to $4.07\text{E}6$ J/kg (200 to 1750 Btu/lbm), which are much larger than the ranges in the original GEOTHER.

Model and Initial and Boundary Conditions Improvements

Three-Equation Model

Instead of modeling a repository system by a water mass continuity equation and a water-rock mixture energy equation, a three-equation model was incorporated in the code. The three equations are water mass and energy equations and a heat conduction equation. With the addition of a conduction equation, nonporous materials such as containers can be simulated realistically.

Water Velocity Calculations

This added feature gives a direct indication of the water flow rate and flow direction as a function of time. This information is important in evaluating the saturation behavior of the repository and waste package.

Time-Dependent Heat Source

During the two-dimensional cylindrical analysis, large fluctuations in pressure and temperature were observed. These fluctuations were partially caused by the step changes in the heat release rate from the blocks where the container was located. In a real situation, the heat release rate from a waste package is a continuously varying process.

The step change feature in the code was removed, and replaced with a continuous transient function. This function is specified from an input as a heat generation table, and linear interpolation is used between table points. This allows realistic representation of the container heat generation in the repository.

APPLICATION TO BWIP SIMULATION

Two simulations of a BWIP single container and surrounding rocks were performed to evaluate the original and the improved GEOTHER and to investigate the hydrothermal behavior around a container. The first analysis case, using a two-dimensional cylindrical model, was performed on the original GEOTHER, mainly to evaluate the code. The second analysis used a two-dimensional Cartesian model. This case, performed on the improved GEOTHER/VT4, was done to evaluate the changes made to the GEOTHER code and to study the saturation behavior.

Two-Dimensional Cylindrical Resaturation Analysis

Numerical simulations for a cylindrical model of a container were performed using the GEOTHER code to study the heat transfer and groundwater migration in the near field of the placement room borehole in a proposed high-level nuclear waste repository of BWIP and to evaluate the code capability in performing these calculations. Sensitivity studies were performed to determine the influence of the cylindrical radius on the pressure profile and the boiling conditions in the host rock.

The model is shown schematically in Figure S.1. Both ends of the cylinder are taken to be symmetrical boundaries; that is, the extension of the model in either lateral direction is a mirror image of the model about the end surface. This dictates that the boundary condition to be applied to these two surfaces in the GEOTHER code will be one of no heat or mass transport across the boundary. The placement room was modeled as a short cylinder in the cylindrical coordinate system.

FIGURE S.1. Two-Dimensional Cylindrical Model

A single container in a cylindrical coordinate system can not model the BWIP design adequately. However, the major objective of this calculation is to evaluate the GEOTHER code. A more realistic model in Cartesian coordinate system is discussed below.

Two parametric studies were performed. One investigated the effect of the distance of the boundary conditions from the container center on the hydrothermal behavior of the host rock, particularly on the saturation time. The second investigated the effect of packing porosity on hydrothermal behavior.

Two-Dimensional Cartesian Resaturation Analysis

In the two-dimensional model the repository was simulated by the vertical plane passing through the lengthwise axis of a waste container and bounded by Cohasset flow top and flow bottom (Figure S.2). By assuming all waste packages to be identical, and by invoking geometric symmetry, we can reduce the repository to the single representative region shown in the figure. Vertical

FIGURE S.2. Two-Dimensional Cartesian Model

symmetrical boundaries are established at the center of the emplacement room and at half the distance between two adjacent emplacement rooms. The Cohasset flow formation is where the current design concept repository will be located (970 m below ground surface at Hanford, Washington).

Three cases were analyzed. In the first (upper bound) case, it was assumed that the host rock between the containers in the Y-direction (east-west direction) has the same heat source strength as the containers, i.e., the heat generation rate per unit volume in the rock that separates the containers is the same as that in the containers, effectively increasing the heat output from the container region. In the second (lower bound) case, the heat sources of the containers were assumed to be spread out to the host rock between the containers in the Y-direction. A third (best-estimate) case was analyzed. In this case, the heat strength of the container was reduced from the upper

bound case until the calculated maximum container temperature matched that from an independent HEATING5 calculation.(a)

The key assumptions of the three cases are summarized below:

- The borehole is at 1 atmosphere pressure and unperturbed temperature ($\sim 52^{\circ}\text{C}$) at the time of waste package emplacement, and the placement room is at 1 atmosphere pressure and unperturbed temperature ($\sim 52^{\circ}\text{C}$) for 50 years after waste package emplacement. (For the lower bound case, a room temperature of 27°C is used.) The current code only allows uniform temperature in a boundary node. Thus, the rock wall is assumed to be at 52°C . A better modeling would have fixed air temperature in the placement room and calculate the wall temperature through a film heat transfers coefficient. This is one of the areas in the code needing improvements.
- The flow top and bottom have no flow resistance (i.e., fixed pressures at the flow top and bottom). The temperatures are also fixed. The pressure and temperature at the flow top are 0.91×10^7 Pa and 50.2°C , respectively. At flow bottom, they are 0.96×10^7 Pa and 52.8°C , respectively.
- The containers are modeled as slabs.
- The placement room is backfilled instantaneously at 50 years after waste package emplacement.

The best-estimate case was calculated to 1,000 years after waste package emplacement. Figures S.3 through S.5 show representative results for water saturation in the packing and host rock surrounding the container. Numbers

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(a) Because of its simplicity, the two-dimensional BWIP model was selected as the test case to demonstrate the capability of the improved GEOTHER. Because of the two-dimensional approximation, the waste package geometry does not reflect the real situation. Instead, it is modeled in a two-dimensional coordinate system with the waste packages placed next to one another. This effectively increases the heat generation rate per unit volume to a much higher value than in a real situation. Without prior knowledge about the correct heat generation rate to use, the best approach is to adjust the rate until the temperatures match those given by a three-dimensional model using the conduction code, HEATING5.

on the contours are the saturation values.(a) Shortly after waste package emplacement, as the container heats up the surrounding packing and host rock, steam starts to form. At 0.7 year (Figure S.3) the container is partially surrounded by two-phase saturated water (in a thermodynamic sense); i.e., the packing next to the container is partially filled with steam. The region inside the contour with a saturation of 0.99 is a steam-water mixture region. The contours inside a container block should be ignored because the saturation is always zero.

As the heat-up process continues, the contours expand outward. When the two-phase zone approaches its maximum (Figure S.4), the contours extend about 0.5 m above and below the container surface.

As the heat generation rate and the heat loss rate become about equal in the near field, the saturation profile stabilizes. This happens from 10 to 50 years after waste package emplacement (Figure S.5). At 50 years, the placement room is backfilled. The loss of pressure sink (i.e., the open placement room) causes the near-field pressure to increase rapidly. This leads to a rapid decrease of two-phase zone right after the placement room closure. The rate of decrease becomes slower as the transient proceeds, due to the slower rate of decrease of decay heat, continued heat loss to the boundary and influx of liquid groundwater. The contour plot at 62 years after waste package emplacement is given in Figure S.6. After this, the steam in the two-phase zone is totally condensed and the near field is resaturated.

Figure S.7 gives the velocities of the liquid groundwater at 0.7 year after the waste package emplacement. The flow is toward the waste package and the placement room. This inward flow is caused by the pressure gradients from the higher pressures at the flow top and bottom and the lower pressure at the placement room. Figures S.8 and S.9 give the groundwater flow at the time of resaturation and at 200 years, respectively. The pressures near the container stay below the boundary pressures even after the placement room is backfilled.

(a) Saturation in this report has two definitions. Without specification it means the liquid water volume fraction in a two-phase water-steam system as is used here. Otherwise, it means thermodynamic saturation (such as saturation line in a pressure-enthalpy diagram).

FIGURE S.3. Contours of Groundwater Saturation, 0.7 Year After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE S.4. Contours of Groundwater Saturation, 10 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE S.5. Contours of Groundwater Saturation, 50 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE S.6. Contours of Groundwater Saturation, 62 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE S.7. Groundwater Velocity (Direction Only)
0.4 Years after Waste Package
Emplacement, Best-Estimate Case

FIGURE S.8. Groundwater Velocity (Direction Only),
62 Years after Waste Package
Emplacement, Best-Estimate Case

FIGURE S.9. Groundwater Velocity (Direction Only), 200 Years after Waste Package Emplacement, Best-Estimate Case

The groundwater flow is toward the container at 200 years. After the near field is resaturated at 62 years, the pressure begins to increase gradually because of the continued heat generation input and the influx of the groundwater. (a) At 250 years, the pressure at the container surface essentially approaches the unperturbed profile. The groundwater flow is always inward and approaching zero in magnitude at the end of simulation. The pressure equalization with the unperturbed pressure at 250 years is believed to be conservative (i.e., too short a time period). The packing material in the calculation is assumed to be saturated with water because the GEOTHER code does not model non-condensable gases, such as air. In a real situation, the

-
- (a) After resaturation, the pressure in the near field will not equilibrate because of the continued heat output from the waste package. As the water in the rock pores is heated, the low permeability of the rock causes high resistance to the release of the pressure resulting from the heatup. The inflow of groundwater is induced by the pressure gradient. The amount of groundwater inflow is very small due to the low compressibility of liquid water.

packing is almost totally unsaturated. This deficiency will be addressed in future code improvements.

Figure S.10 plots the container temperature (volume averaged). This temperature was calculated by the conduction equation added to the code, thus avoiding the difficulty of mixing of container with water as the original GEOTHER code would have. The original GEOTHER equation solves the energy equation for a rock-water system, and does not simulate solid nonporous material correctly. With the addition of the conduction equation for nonporous media, this problem is eliminated. As seen from Figure S.10, the container is at an ambient temperature of 52°C at the time of emplacement. It goes through a rapid heatup after backfill because of the much slower heat loss through the packing and host rock, than through the 52°C temperature sink, it reaches a maximum of about 220°C around 3 years after waste package emplacement. After that, the decay heat generation rate becomes slower than the heat loss rate immediately adjacent to the container, and the container temperature starts to decrease gradually. At the time of placement room backfill, the container

FIGURE S.10. Average Container Temperature as a Function of Time After Emplacement, Best-Estimate Case

temperature starts to increase because of the loss of a temperature sink of 52°C in the placement room. After this increase, the decay heat continues to drop and the container temperature starts to decrease again when the heat loss to boundary is larger than the decay heat. The temperature drops to 70°C at the end of 1,000 years.

As mentioned above, for this calculation, the placement room wall is kept at 52°C for the first 50 years. In reality, most of the placement rooms are allowed to warm up after the waste package emplacement. Therefore, the time when the maximum container temperature occurs should be later than that shown in Figure S.10. In addition, the backfill material at the time of placement room backfill is assumed to be at 52°C instead of room temperature (27°C). Thus, in a more realistic case, the container temperature shortly after 50 years should be lower than that in Figure S.10. These uncertainties may be alleviated by using better definition of the operating and closure scenarios.

Future refinement of the analysis would be using finer mesh sizes near the container surface in both X and Z directions, allowing better resolution of the saturation values and, thus, yielding more accurate prediction of the movement of the phase transition front. In addition, the conservation of mass equations for noncondensable gases needs to be put in the code for better calculations in the preclosure period.

Analysis of the upper bound case yielded much higher container temperatures. The peak container temperature was about 440°C at 4 years after emplacement. As explained before, this high temperature is unrealistic because of the unrealistic heat generation rate used. The steam and two-phase zones were also much larger.

Analysis of the lower bound case yielded no steam zone at any time after waste package emplacement. This was expected because the heat strength per unit volume in the container region is reduced considerably in the lower bound case.

A more realistic analysis using a three-dimensional model will be performed in the next phase of the project. The three-dimensional model will

use the correct heat strength of a container and avoid the approximation on the heat strength made in the two-dimensional case. At this point, it is not easy to evaluate the effects of ignoring the Y-dimension in a two-dimensional study. It is the objective of the three-dimensional study to address this concern.

CONCLUSIONS

The main objectives of this project, namely, evaluation and improvement of the GEOTHER code and preliminary analysis on the steam formation in the near field using the improved code, have been accomplished. The steaming behavior is important in evaluating container corrosion and assessing the near field geochemical conditions.

Code evaluation using a two-dimensional cylindrical model indicated that major changes were necessary to make the code suitable for the high-level waste repository applications. The areas needing improvement are: 1) addition of noncondensable gases, and 2) flexibility in modeling geometries, which requires both Cartesian and cylindrical coordinate systems.

The GEOTHER code was substantially modified, specifically to allow more accurate simulation of a waste container or a group of containers in a repository. The modifications were assessed to make sure the changes were made correctly (see Appendix B). Full-scale verification and validation will be performed in the next phase of the project.

The Cartesian model analysis, performed to check out the changes made to the code, also provided a preliminary analysis on the resaturation phenomenon in the near field of a container.

Since the code is still in its developmental stage, the computational models are restricted by the limitations in the code and can not simulate the reality closely. Also, the material properties used in the computation have large uncertainties and the repository as well as the waste package design are not finalized. All of the computational results are preliminary and can not be used as a conclusive prediction for design and testing programs.

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GEOTHER EVALUATION AND IMPROVEMENT: A PROGRESS REPORT INCLUDING TEST CASES FOR TWO-DIMENSIONAL BWIP ANALYSIS

1.0 INTRODUCTION

The GEOTHER code was originally developed by the U.S. Geological Survey for analyzing geothermal conditions. Later it was modified by the Office of Nuclear Waste Isolation (Faust and Mercer 1983) for repository analyses.

At the request of Westinghouse Hanford Company (Westinghouse), Pacific Northwest Laboratory (PNL) started in January 1985 to evaluate the GEOTHER code for its applicability to Basalt Waste Isolation Project (BWIP) waste package environmental analyses. A simplified two-dimensional cylindrical (r, z) geometry was set up for a single container in the BWIP repository. The calculation was carried out to predict the waste package near-field two-phase hydrothermal conditions. The results indicated that the code gave the right trends in temperature and pressure, which directly yields the amount of steam in the porous medium, as a function of time. However, it was evident at the time that the code needed to be modified to be completely applicable for use in waste package environmental analyses.

The objective of the work is two-fold: 1) to evaluate the GEOTHER code and perform necessary improvements to make it specifically suitable for predicting the hydrothermal conditions of the waste package for the BWIP, and 2) to perform resaturation analyses for the repository and waste package using the improved GEOTHER code. The resaturation time is an important parameter for container corrosion as well as for assessing the near field geochemical conditions. The improved GEOTHER code will be used for assessing the near-field thermal and hydraulic environment for license application analyses.

This report documents the improvements made to the code and presents preliminary results of a hydrothermal and resaturation analysis for a single container in a two-dimensional Cartesian configuration. These results are preliminary because the improvements to the code have not been subjected to a

thorough verification and validation process, and further improvements are anticipated.

The report is organized in the following way: the conclusions are presented in Section 2. Section 3 gives a brief description of the GEOTHER code as originally developed by the Office of Nuclear Waste Isolation and the results of the evaluation based on two-dimensional cylindrical analysis of a BWIP container and surrounding host rock. The resulting improvements to the code are described in Section 4. Section 5 presents the two-dimensional cylindrical and Cartesian models. The cylindrical model was run on the original GEOTHER, the Cartesian model was run on the improved version (GEOTHER/VT4). (a)

(a) In the balance of this report, GEOTHER denotes the original version, while GEOTHER/VT4 refers to the improved version.

2.0 CONCLUSIONS

The main objectives of this project--to evaluate and improve the GEOTHER code, and to perform a preliminary analysis using the improved code--were accomplished.

The code evaluation using a two-dimensional cylindrical model led to the conclusion that major changes were required to make GEOTHER suitable for the high-level waste repository applications. Some of the changes were error corrections; some were improvements over the current model. The improvement effort is continuing. The effort will be concentrated on the addition of equations for including noncondensable gases in the model, and on creating more flexible geometric models.

All of these modifications were made specifically to allow more accurate simulation of a waste container or group of containers in a repository. The modifications were checked to ensure that they worked.

As an example of the improvements made to the code, it was found that in the cylindrical model evaluation the groundwater temperature and pressure in the near field would experience nonphysical step changes and spikes. These phenomena were found to be caused by step changes in the heat source input. A new scheme was set up to allow a continuously varying heat source (which more accurately follows the decay heat curve). This change eliminated the nonphysical phenomena as evidenced in the results of the Cartesian analysis.

Another modification was the inclusion of the multiproperty capability. This feature now allows separate modeling of the host rock, packing, and container materials. It can also model any other potentially different material types such as interflow, vesicular zone, and disturbed rock zone.

The Cartesian model analysis provided both a check of the changes made to the code and a preliminary analysis of the resaturation phenomenon in the near field of a container.

From the preliminary analysis of a simplified two-dimensional model with a best-estimate heat source, a steam-water mixture was found to form in the region next to the container almost immediately after its emplacement. About

10 years after emplacement, the two-phase zone reached maximum size, extending about 0.5 m above and below the container surface. After this period, the saturation profile remained essentially unchanged until about 50 years after waste package emplacement. After that, the two-phase zone began to decrease in size. The near field was completely resaturated at 62 years after the waste package emplacement. From the calculated pressure profile, the groundwater flow is expected to be inward (toward the container) through the entire period of 1000 years when the simulation is terminated. The flow is approaching zero at the end of period because the pressure profile is essentially that of the unperturbed state.

Because this was a developmental project, no full-scale verification or validation processes were performed. These efforts will be undertaken in the next phase of the project.

3.0 CODE EVALUATION

The main objective of this project was to evaluate the GEOTHER code and perform necessary improvements for the resaturation analysis. In this section, the code is briefly described, and the evaluation findings are discussed.

3.1 CODE DESCRIPTION

GEOTHER (Faust and Mercer 1983) is a three-dimensional geothermal reservoir simulation code. The model describes heat transport and flow of a single-component, two-phase fluid in porous media. It is based on the continuity equations for steam and water, which are reduced to two nonlinear partial differential equations in which the dependent variables are fluid pressure and enthalpy. These equations, describing three-dimensional effects, are approximated using finite-difference techniques and solved using Newton-Raphson iteration to handle the nonlinear coefficients. An option is also provided for using either upstream or midpoint weighing on the mobility terms.

GEOTHER is used to simulate fluid-thermal interactions in rock that can be approximated by a porous media representation. It simulates heat transport and the flow of compressed water, two-phase mixtures, and super-heated steam in porous media over a temperature range of 10°C to 300°C. In addition, it treats the conversion from single- to two-phase flow, and vice versa. It is used for evaluation of a near repository spatial scale and a time scale of a few years to thousands of years. The code is being investigated for potential use in estimating temperature and fluid pressure changes in response to thermal loading by waste materials.

The final equations are formulated in terms of the dependent variables, pressure and enthalpy. The fluid velocities in the mass and energy balance equations are replaced in favor of pressures through Darcy's Law. For completeness, the governing equations from Faust and Mercer (1983) are repeated here.

Mass Balance

$$\begin{aligned} \frac{\partial(\Phi\rho)}{\partial t} - \nabla \cdot \left[\frac{\bar{k}k_{rs}\rho_s}{\mu_s} (\nabla p - \rho_s g \nabla D) \right] \\ - \nabla \cdot \left[\frac{\bar{k}k_{rw}\rho_w}{\mu_w} (\nabla p - \rho_w g \nabla D) \right] - q_m' = 0 \end{aligned} \quad (3.1)$$

Energy Balance

$$\begin{aligned} \frac{\partial}{\partial t} [\Phi\rho h + (1 - \Phi)\rho_r h_r] - \nabla \cdot \left[\frac{\bar{k}k_{rs}\rho_s h_s}{\mu_s} (\nabla p - \rho_s g \nabla D) \right] \\ - \nabla \cdot \left[\frac{\bar{k}k_{rw}\rho_w h_w}{\mu_w} (\nabla p - \rho_w g \nabla D) \right] - \nabla \cdot [K_m \left(\frac{\partial T}{\partial p}\right)_h \nabla p] \\ + K_m \left(\frac{\partial T}{\partial h}\right)_p \nabla h - q_h' = 0 \end{aligned} \quad (3.2)$$

The terms in Equations (3.1) and (3.2) are defined as follows:

- ∇ = vector differential operator
- Φ = porosity
- ρ = density of steam and water mixture
- t = time
- $\bar{k}$ = intrinsic permeability tensor of the porous medium
- k_r = relative permeability of the phase
- μ = dynamic viscosity
- g = gravitational constant
- D = depth
- p = fluid pressure
- q_m' = mass source term

h = specific enthalpy of the fluid mixture
 h_r = specific enthalpy of the rock
 K_m = combined isotropic conduction-thermal dispersion
coefficient for the rock and groundwater "mixture"
 T = temperature
 qh' = energy source term.

The subscripts r , w , and s refer to rock, liquid water, and steam, respectively. The relative permeability (K_{rs} to K_{rw}) is a factor to account for the relative velocities between the two phases (steam and water). It is a function of the saturation values (i.e., void volume fraction) of each phase. Two functional forms for K_{rs} and K_{rw} are available in the GEOTHER/VT4 code. One is the linear form, the other is the Corey Correlation (see Faust and Mercer 1983).

Note that Equation (3.1) is the mass balance equation for the water liquid-vapor mixture in a porous medium; Equation (3.2) is the combined energy balance equation for rock and two-phase water.

The three-dimensional equations are discretized based on a finite-difference scheme using a block-centered grid that allows variable spacing and can be used to approximate irregular geometry. For numerical stability considerations, an implicit iteration scheme is used.

The discretized equations in matrix form are solved using the Newton-Raphson iteration method to handle the nonlinearities of the system equations. In the three-dimensional case, each slice (grids with a given constant Y -index) is solved simultaneously with the latest available parameter information on adjacent grids in the Y -direction, making the scheme a direct solution in the X - Z plane and a Gauss-Seidel type in the Y -direction (called slice successive overrelaxation in GEOTHER). The direct solution in each slice is based on the Gauss-Dolittle elimination procedure. The procedures for two-dimensional X - Y and cylindrical models are similar to those of three-dimensional models. The detailed numerical procedure is given in Faust and Mercer (1979a,b).

The key output parameters are water pressure and saturation and system temperature.

3.2 CODE EVALUATION

For simplicity of modeling and fast computing time, a two-dimensional cylindrical model of a single BWIP container was analyzed. With this simple model, preliminary results were obtained on the hydrothermal conditions of the host rock, while the code's capabilities and limitations were checked out. The model setup and the results are discussed in detail in Section 5.0 and Appendix A. Only the evaluation results are presented here.

The study of the cylindrical model resulted in the following findings:

1. The code yielded reasonable pressure and temperature predictions. This conclusion was based on physical principles because no thorough verification work was performed on the results.
2. A transient, continuously varying heat source in GEOTHER was needed. This should eliminate the nonphysical step changes in calculated host rock temperature and sudden change in pressures (see Appendix A). GEOTHER allowed step changes only. Also, the nuclear heat source could not be modeled properly. Every node had to have both solid material (rock) and water.
3. A feature allowing separate type boundary conditions for temperature and pressure is needed to realistically simulate the BWIP environment. GEOTHER allowed either Neumann (constant heat and mass flux) or Dirichlet (constant temperature and pressure) boundary conditions for both pressures and temperatures in a given node (or block).
4. To obtain more detailed hydrothermal conditions in the waste package and its surrounding environment, a multiple material property capability is needed. Only one set of specific heat, density, and thermal conductivity was allowed in the original GEOTHER code.
5. The thermodynamic property range of water was not adequate. A further study found that the pressure and enthalpy ranges given in the code were not sufficient for the types of problems encountered in a nuclear repository thermal analysis. For instance, the temperature upper limit

was 300°C, which might be exceeded for certain types of decay heat sources and waste package designs.

6. Non-condensable gas is not included in the mathematical model of the code. No air-filled void space is allowed in a node. This deficiency will result in errors in resaturation time predictions.
7. The code can not handle complicated geometries, e.g., mixing of Cartesian and cylindrical coordinate systems. A finite volume approach is required to realistically describe the BWIP waste package and its surrounding environment.

4.0 CODE IMPROVEMENTS

From the findings of the cylindrical model evaluation, necessary improvements to the code were identified and implemented. The changes that have been made to the code to date fall into two categories, improvements to the code utilities to make the code more user friendly and efficient, and modifications to bring the code to a status that allows modeling of the BWIP waste package.

4.1 CODE UTILITY IMPROVEMENTS

4.1.1 Input Format Change

The input format has been changed completely. One major difference between the new and old input formats is that the new input is arranged so that similar parameters are grouped together. For example, in the "TIME" card, all input parameters related to time step control and time of simulation are read in. Comment cards may also be added to the input in the new input format, making file identification much easier. The new input also reflects the model changes discussed in Sections 4.1 through 4.3.

Much greater use of character data is used in the input file; each card has a four character mnemonic in columns 1-4. This also allows the data to be read in any order, reducing the number of human errors involved in setting up a problem. To facilitate Q.A. and traceability, an unlimited number of comment or title cards may be put into the input stream at any location. This can be used to document any change to the model as it is being developed. The input record is also written to the output file exactly as it is read so that there is an unambiguous relationship between any output file and the input file used to generate it. This is also very helpful for Q.A. purposes. The detailed input description is given in Appendix B.

4.1.2 Restart Capability

With the addition of the restart capability, considerable input preparation time is saved. Without the restart capability, pressure and temperature arrays (potentially hundreds of blocks for each array) had to be manually

input to the code whenever a new set of conditions such as closure of the borehole was required. With the addition of the restart option, these inputs are automatically read by the code from a restart tape saved from a previous run, thus avoiding the tedious and error-prone manual input.

When a case is run, the pressure and temperature arrays and time step number are dumped onto a logical unit called TAPE2 on the VAX computer system. When a restart option is selected, TAPE2 is copied to a new logical unit called TAPE1. The restart case reads information from TAPE1, together with other input information, to proceed with the calculations. When the restart calculation is done, a new TAPE2 is generated for the next restart, thus allowing continuous calculations without going back to time step one.

4.1.3 Code Redimensioning

The common block structure in GEOTHER was completely modified. The most frequently used common blocks were set up as COMDECKS and moved to the front of the program. These COMDECKS function like subroutines, except they are common block statements. Whenever a COMDECK (i.e., a common block) is needed in a subroutine, a *CALL is used to obtain that common block. With this modification, the program can be redimensioned to fit different storage sizes of different problems. Basically, a COMDECK with all the varying dimensions put into the "PARAMETER" statement performs this work. A single change of dimensions to this "PARAMETER" statement will change the dimensions throughout the entire program.

The detailed redimensioning procedure is given in Appendix B.

4.2 MATERIAL PROPERTIES IMPROVEMENTS

4.2.1 Multiproperty Capability

In GEOTHER the material property input is limited to a single set of values for thermal conductivity, rock specific heat, rock density, and compressibility. This restricts the physical model to a single material composition. In the BWIP near-field analysis, several different types of material are present, e.g., materials in container, backfill, and host rock.

To accommodate the multiproperty requirements of the BWIP analysis, the code was changed to allow different property input to different block locations. The code structure is now extremely flexible. It can accommodate up to 63 different types of materials. They may be arrayed arbitrarily among the block locations. The material properties that can be varied are water thermal conductivity, rock density, rock specific heat, rock compressibility, rock thermal conductivity, rock-to-water heat conductance, porosity, residual water saturation, residual steam saturation, and permeabilities in X, Y, and Z directions. Some of the properties for certain materials are built in (e.g., thermal conductivity for Basalt, see Appendix A).

With this flexibility, the host rock and backfill materials can be modeled separately. Together with the addition of conduction equations (see Section 4.3), the code can also model the nonporous material (e.g., waste container) correctly.

The detailed input descriptions reflecting this capability are given in Appendix B.

4.2.2 Thermodynamic Properties

During the two-dimensional Cartesian single-container analysis, the rock temperature exceeded the upper bound of the temperature limit of 300°C in GEOTHER. To avoid possible violation of the range limit in GEOTHER, which is very restrictive, a new property subroutine was put into the code. The properties are now calculated by a single subroutine instead of several subroutines as before, thus making verifications and possible future modifications much easier. The property routine is based on EPRI algorithms (Stewart, 1983), and covers a range of pressures from 6.9E2 to 4.14E7 Pa and specific enthalpies from approximately 4.65E5 to 4.07E6 J/kg, which are much larger than the ranges in the original GEOTHER. The new property routine gives better property derivatives (e.g., $\partial T/\partial p$ and $\partial T/\partial h$), and it does not calculate negative void fractions (i.e., saturations) as the original GEOTHER did.

The functional forms and coefficients of the properties are given in Appendix B.

4.3 MODEL AND INITIAL AND BOUNDARY CONDITIONS IMPROVEMENTS

4.3.1 Three-Equation Model

A separate conduction equation was added to the model to allow simulation of the regions where there is no water, such as the waste container. In the original GEOTHER, it was assumed that the groundwater exists everywhere. Thus, the equation solves not only heat conduction through rock, but also the heat transfer through water. This is not correct for a region where the waste package is located.

The detailed description of the governing equations, numerical models, and verifications are given in Appendix B.

4.3.2 Water Velocity Calculations

The newly added water velocity feature gives a direct indication of the water flow rate and flow direction as a function of time. The velocities are calculated based on the pressure gradients using Darcy's Law. They are given on each of the six surfaces of a block in the three-dimensional case and on each of the four interface lines surrounding the block in a two-dimensional case, and are printed out as steam and liquid velocities. This information is important in evaluating the near-field saturation behavior of the host rock.

4.3.3 Time-Dependent Heat Source

During the two-dimensional cylindrical analysis, large fluctuations of pressure and temperature were observed. These fluctuations were caused partially by the step changes in the heat release rate from the blocks where the container was located. In a real situation, the heat release rate from a waste container is continuously varying. Recognizing this, the step change heat release restriction in the code was removed. Instead, a table of heat source versus time is now input by the user before a run starts. At each time step during the calculation, the code will look up in the appropriate heat generation table for that block and perform an interpolation to obtain the instantaneous heat source at a given time, thus eliminating large step changes. A similar framework was set up for pressure and temperature versus

time tables. Detailed programming for allowing time varying pressure and temperature boundary conditions could be added to the existing framework in the future.

5.0 APPLICATION TO BWIP SIMULATION

Two cases simulating a BWIP single container and surrounding rocks were performed to evaluate the GEOTHER code and to investigate the hydrothermal behavior around a container. The first case was a two-dimensional cylindrical model. The analysis was performed on GEOTHER, mainly to evaluate the code, as explained in Section 3. The second case, a two-dimensional Cartesian model, was performed on GEOTHER/VT4. It was done to evaluate the changes made to the GEOTHER code and to study the rock resaturation behavior.

5.1 TWO-DIMENSIONAL CYLINDRICAL RESATURATION ANALYSIS

Numerical simulations for a cylindrical model of a single container were performed using the GEOTHER code to study the heat transfer and groundwater migration in the near field of the placement room borehole in a proposed high-level nuclear waste repository, as well as to evaluate the code capability in performing these calculations.

A two-dimensional cylindrical model was chosen because of its simplicity and the fast computing time in analyzing this problem. With this simple model, we were able to obtain preliminary results on the hydrothermal conditions of the host rock and to check out the capabilities and limitations of the GEOTHER code.

The schematic of the model is shown in Figure 5.1. Both the left and right side surfaces are symmetrical; that is, the structures to both the left and right sides are mirror images of the cylinder. This dictates the selection of the boundary conditions on these two surfaces in the GEOTHER code. The placement room was replaced by a cylinder in the cylindrical coordinate system. The thickness of the dish equals half of the tunnel width because of symmetry. With the dish thickness known, the dish radius was calculated to be 2.31 m, so the volume of the placement room in relationship to the container was preserved. The distance from the container to placement room was also preserved.

FIGURE 5.1. Two-Dimensional Cylindrical Model

A single container in a cylindrical coordinate system can not model the BWIP design adequately. However, the major objective of this calculation is to evaluate the GEOTHER code. A more realistic model in Cartesian coordinate system is discussed later.

Two parametric studies were performed. One investigated the effect of the distance of fixed boundary conditions from the container center on the hydrothermal behavior of the host rock, particularly on the saturation time. The second investigated the effect of backfill porosity on the hydrothermal behavior. These parametric studies served as further evaluation of the GEOTHER code in general.

The detailed description of the cases studied, the input parameters, the nodalization, and the calculated results are given in Appendix A.

The study of the cylindrical model using the original GEOTHER code led to the findings presented in Section 3.2.

5.2 TWO-DIMENSIONAL CARTESIAN RESATURATION ANALYSIS

In this section, the preliminary results of the two-dimensional Cartesian single container analysis are presented. The code version used in this analysis is GEOTHER/VT4.

The two-dimensional case models the X-Z cross section of the container and surrounding host rock bounded by Cohasset flow top and flow bottom. By assuming that all waste packages are identical, and by invoking geometric symmetry, the repository was reduced to the single representative region shown in Figure 5.2. All vertical surfaces in the Y-Z plane are taken as adiabatic boundaries. The lengths in the Y-direction extend to infinity in both directions. (In actual code analysis, a finite thickness of 0.713 m in the Y-direction was input to account for correct calculation of the volumetric heat generation.) The horizontal surfaces of this model are taken as constant pressure and temperature boundaries (i.e., flow top and bottom). The cylindrical waste package is replaced by an equivalent rectangular parallelepiped with identical volume. This is due to the GEOTHER/VT4 restriction to the Cartesian system coordinates. (The code modifications are made to Cartesian coordinates only.) This model represents the hydrothermal conditions of most waste packages in the repository except those in the peripheral tunnels where the geometric symmetry assumptions ceases to be approximately valid.

The detailed schematic used in GEOTHER/VT4 is illustrated in Figure 5.3. The upper horizontal surface (flow top) pressure and temperature are set at 0.91×10^7 Pa and 50.2°C , respectively. The lower horizontal surface pressure and temperature are set at 0.96×10^7 Pa and 52.8°C , respectively. These values correspond to the unperturbed basalt hydrostatic pressures and temperatures.

Three cases of the same geometric model were analyzed. In one case, it was assumed that the host rock between the containers in the Y-direction (east-west direction) had the same heat source strength of the containers; i.e., the heat generation rate per unit volume in the rock separating the containers was the same as that in the containers, effectively increasing the

FIGURE 5.2. Two-Dimensional Cartesian Model

heat output from the container region (see Figure 5.4a). This case is termed the upper bound case. Another case was with a lower bound heat source. In this case, it was assumed that the heat sources of the containers were spread out to the host rock between the containers in the Y-direction (see Figure 5.4b). In the third case, the heat source was reduced from the upper bound

FIGURE 5.3. Detailed XZ Plane Dimensions of the Two-Dimensional Cartesian Model

case to a value such that the calculated peak container volume average temperature was the same as that calculated by HEATING5. This will be discussed in detail later.

FIGURE 5.4. Upper and Lower Bound Heat Sources (Map View)

The rest of this section gives the results of Case 1 (upper bound heat generation rate) and Case 3 (best-estimate heat strength). Case 2 (lower bound heat source) results are presented in Appendix C. Figure 5.5 shows the noding arrangement of the two-dimensional model in GEOTHER/VT4. To ensure meaningful temperature predictions, a grid system with finer grid sizes near the container was used. As the distance from the waste package increased (mainly in the Z-direction), the grid size gradually increased. This approach was based on the fact that the pressure and thermal gradients diminish as the distance from the heat source and pressure sink increases. Considerations are also given to accommodate the boundaries for different materials, such as between host rock and backfill, to minimize the total number of grid blocks.

Figure 5.6 gives a blown-up grid structure and dimensions. It should be noted that the top and bottom of Figure 5.6 do not correspond to the flow top

FIGURE 5.5. Nodalization of Two-Dimensional Cartesian Model

FIGURE 5.6. Detailed Grid Arrangement of Two-Dimensional Cartesian Model

and bottom (see Figure 5.5). The key assumptions of Cases 1 through 3 are summarized below:

- The borehole is at 1 atmospheric pressure and unperturbed temperature ($\sim 52^{\circ}\text{C}$) at the time of waste package emplacement, and the placement room is at 1 atmospheric pressure and unperturbed temperature ($\sim 52^{\circ}\text{C}$) for 50 years after waste package emplacement. For the lower bound case, a room temperature of 27°C is used.
- The flow top and bottom have no flow resistance (i.e., fixed pressures at the flow top and bottom). The temperatures are also fixed. The boundary values are given in Figure 5.3.
- The containers are modeled as slabs.
- The placement room is backfilled instantaneously at 50 years after waste package emplacement. This assumption simplifies the computer modeling without affecting temperature and pressure calculations significantly.

The original GEOTHER property routines have limited ranges in temperature and pressure. A new thermodynamic property package had to be incorporated into the code to correctly calculate water properties for broader property ranges. The EPRI package was chosen because of its proven capability in the VIPRE code developed by Battelle. The EPRI package was not designed for very low temperatures (e.g., room temperature); therefore, we chose to use the unperturbed temperature ($\sim 52^{\circ}\text{C}$) in the placement room instead of a room temperature (27°C). This is not important for the near-field hydrothermal predictions because temperature increases in the near field are much larger than the difference in temperature boundary values, as is evidenced in the results that follow.

Other key design parameters that served as the data base for the two-dimensional Cartesian analysis are given in Tables 5.1 and 5.2, and in Figures 5.7 and 5.8. Cases 1 and 3 were calculated to 300 and 1000 years, respectively, after waste package emplacement. Resaturation results for Case 3 are given below because it represents the best-estimate model under the limitation of two-dimensional geometry. Detailed results for the other cases are given in Appendix C.

TABLE 5.1. Data Base for Two-Dimensional Cartesian Analysis

FEATURE	PARAMETER
Container	
Waste form(a)	Westinghouse 15 x 15 spent fuel form filled with crushed basalt
Outside diameter	635 mm
Length	3658 mm
Density	3473 kg/m ³
Thermal conductivity	2.339 W/(m•K)
Specific heat	410.3 J/(kg•K)
Heat generation rate	2069 W/container
Heat decay curve	See Table 5.2
Container shell	
Material	Carbon steel
Inside diameter	635 mm
Outside diameter	805 mm
Density	7800 kg/m ³
Thermal conductivity	40 W/(m•K)
Specific heat	473 J/(kg•K)
Number of containers	40,000 total (not used)
Packing	
Hydraulic conductivity (isotropic)	10 ⁻¹⁰ m/s(b)
Porosity	0.40
Initial dry density	1800 kg/m ³ (a)

- (a) Yung, S. C., et al. 1985. "Waste Package Preliminary Reliability Analysis Report." SD-BWI-TI-287, Rockwell Hanford Operations, Richland, Washington.
- (b) U. S. Department of Energy. 1986. "Environmental Assessment, Reference Repository Location: Hanford Site, Washington." DOE/RW-0070, U.S. Department of Energy, Washington, D.C.

TABLE 5.1. contd.

FEATURE	PARAMETER
Specific heat	615 J/kg•K) (a)
Thermal conductivity	0.55 W/m•K) (c)
Length	5385 mm(c)
Inside diameter	830 mm(c)
Outside diameter	1135 mm(c)
Host rock	Dense basalt
Type	Cohasset flow
Hydraulic conductivity	10-13 m/s(a)
Porosity	0.0001(a)
Specific heat	Function of rock temperature
Thermal conductivity	Function of rock temperature
Density	2.78 x 10 ³ kg/m ³
Emplacement room dimensions	(b)
Borehole depth	970 m below surface(c)

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- (a) U. S. Department of Energy. 1986. "Environmental Assessment, Reference Repository Location: Hanford Site, Washington." DOE/RW-0070, U.S. Department of Energy, Washington, D.C.
- (b) Rockwell Hanford Operations. 1984. "Engineering Study No. 9." SD-BWI-ES-023, Richland, Washington.
- (c) Yung, S. C., et al. 1985. "Waste Package Preliminary Reliability Analysis Report." SD-BWI-TI-287, Rockwell Hanford Operations, Richland, Washington.

TABLE 5.2. Spent Fuel Decay Power (Q) Summary

<u>Time out of reactor, yr</u>	<u>Time in repository, yr</u>	<u>Q W/MTU(a)</u>	<u>Q W/assembly</u>	<u>Q/Q₀(b)</u>
10	0	1,555.0	517.4	1.0
15	5	982.5	440.2	0.851
20	10	878.7	393.7	0.761
25	15	798.5	357.7	0.691
30	20	731.1	327.5	0.633
40	30	621.0	278.2	0.538
60	50	465.0	208.3	0.403
80	70	364.0	163.1	0.315
100	90	297.0	133.1	0.257
200	190	170.0	76.2	0.147
300	290	134.5	60.3	0.116
400	390	114.0	51.1	0.099
500	490	99.0	44.4	0.086
700	690	77.0	34.5	0.067
1,000	990	56.0	25.1	0.049
2,000	1,990	27.0	12.1	0.023
6,000	5,990	15.5	6.9	0.013
10,000	9,990	12.7	5.7	0.011

(a) Westinghouse PWR (15x15), 3.1% enrichment, 32,700 Mwd/MTU, 0.448 MTU/assembly.

(b) Q_0 = 1,155 W/MTU, initial decay power at emplacement.

FIGURE 5.7. Measured Fluid Temperature Versus Depth in Selected Boreholes in the Hanford Site. The line represents a linear regression fit to available borehole temperature data.

FIGURE 5.8. Calculated Pressure Versus Depth in Selected Boreholes in the Hanford Site. The line represents a linear regression fit to available borehole hydrostatic head measurements.

As discussed previously, the upper bound case will yield results with higher container temperatures and larger amounts of steam generation on the container than will a realistic case. On the other hand, the lower bound case will yield lower container temperatures, thus lower steam generation. (As documented in Appendix C, the lower bound case did not produce any steam.) To obtain a better estimate of the steam behavior, the heat generation rate for the upper bound case was reduced to a value so that the GEOTHER/VT4 predicted peak container temperature matched the values calculated by a three-dimensional HEATING5 model (Yung et al. 1985). This required an iterative process. It was found that the GEOTHER/VT4 and HEATING5 gave the same peak temperature (about 220°C) if the upper bound heat source was reduced to 34.3%.

Figure 5.9 shows container volume average temperature versus time after waste package emplacement. This temperature is calculated by the conduction equation added to the code, thus avoiding the difficulty of mixing container and water temperatures as the original GEOTHER model would have. As seen in Figure 5.9, the container is at an ambient temperature of 52°C at the time of emplacement. It heats up rapidly after the borehole is backfilled and reaches a peak temperature of 220°C at about 3 years after emplacement. After that, the heat loss to the flow top and bottom and to the placement room is greater than the decay heat, and the container temperature starts to decrease. At 50 years after emplacement, the placement room is backfilled. This is equivalent to a loss of heat sink (the placement room is assumed to be kept at 1 atm and 52°C before closure), and the container temperature increases rapidly. At about 60 years, the heat loss once again is larger than the heat generation rate and the container temperature starts to decrease. This gradual decrease continues until the end of the calculation. At 1000 years, the temperature decreases to 70°C. It should be noted that through the transient, the heat conduction through the rock dominates heat transfer by water convection through the pores because the water moves very slowly. For the first 50 years when the placement room is open, the heat convection from the rock and backfill to the placement room is neglected through the assumption of a fixed rock wall

FIGURE 5.9. Container Temperature vs. Time for Case 3 (Best-Estimate Heat Source)

temperature in the room. This assumption would allow more heat transfer from the rock to the placement room than in a real situation, thus making the container temperature predictions lower than they should be. Another uncertainty is that most of the placement rooms are allowed to warm up after the waste package emplacement in a real situation. Therefore, the time when the maximum container temperature occurs should be later than that shown in Figure 5.9. In addition, the backfill material at the time of placement room backfill is assumed to be at 52°C instead of room temperature (27°C). Thus, in a more realistic case, the container temperature shortly after 50 years should be lower than that in Figure 5.9. These uncertainties may be alleviated by using better boundary conditions.

Figures 5.10 through 5.30 show water saturation in the packing and host rock surrounding the container. Numbers in the captions are the saturation

values.(a) Contour lines that go into the containers and the placement room should be ignored. (The code gives saturation values in the container blocks with no physical meaning.) The contours go into the placement room blocks because of the large blocks used in the regions surrounding the container and the interpolation schemes used in the contour program.

Because of the assumption of constant pressure and temperature at flow top and bottom and the pressure sink of 1 atm at the borehole, the host rock at the time of waste package emplacement is fully saturated. As the container heats up to the surrounding packing and host rock, steam starts to form. This occurs shortly after waste package emplacement. At 0.7 years (Figure 5.10) the container is partially surrounded by two-phase saturated (in the thermodynamic sense) water.

As time increases, the two-phase saturated mixture (steam and water) zone increases also. The saturation contour plots are given such that the region inside the 0.99 contour line is a two-phase mixture region; the region outside of it is liquid water. As seen from Figures 5.11 through 5.24, the two-phase zone reaches a maximum at about 10 years after emplacement. This zone extends about 0.5 m above and below the container surfaces. It stays stable until the end of the 50-year period (Figure 5.24). At 50 years, the placement room is backfilled and the pressure in the near field is increased due to the loss of the pressure sink (i.e., open placement room). This causes the condensing of the steam in the mixture zone which starts to reduce in size (Figure 5.25). The continued pressure increase and gradual decrease in container temperature lead to continued condensation (Figures 5.26 through 5.30) until complete resaturation at the surface of the container. This occurs at about 62 years after waste package emplacement (Figure 5.30). In some of the plots, the saturation contours show discontinuity in slopes. This is caused by certain combinations of saturation values that cause the contour fitting procedure to yield slope discontinuity.

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- (a) Saturation in this report has two definitions. Without specification it means the liquid water volume fraction in a two-phase water/steam system as is used here. Otherwise, it means thermodynamic saturation (such as the saturation line in a pressure-enthalpy diagram).

It should be noted that the time when maximum two-phase zone occurs is different from the time the maximum container temperature occurs (Figure 5.9). This difference is caused by the time delay of the temperature profile diffusing from the container to the host rock in the near field and because of the changing pressure distribution in the surrounding host rock.

Future refinement of the analysis would be finer mesh sizes near the container surface in both X and Z directions allowing better resolution of the saturation values. This improved resolution would yield more accurate prediction of the movement of the phase transition front, smoother saturation contours, and better definition of the steam and two-phase boundaries.

Figures 5.31 through 5.63 give the velocity vector plots for the liquid groundwater flow. The results show that the flow is always toward the container and the placement room through the 1000 years of simulation. It is apparent that the heat input from the container to the near field is never large enough to cause the pressure in the near field to be more than the boundary pressures at the flow top and bottom, as discussed in Appendix C. Towards the end of the simulation, the pressures are essentially equal to the unperturbed pressures (0.6% maximum difference). So the inward groundwater flow velocity is close to zero. (Figure 5.63 is not to indicate any mass sink exists.)

Since the code is still in its developmental stage, the computational models are restricted by the limitations in the code and can not simulate the reality closely. Also, the material properties used in the computation have large uncertainties and the repository as well as the waste package design are not finalized. All of the computational results are preliminary and can not be used as a conclusive prediction for design and testing programs.

FIGURE 5.10. Contours of Groundwater Saturation, 0.7 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.11. Contours of Groundwater Saturation, 1.3 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.12. Contours of Groundwater Saturation, 2.9 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.13. Contours of Groundwater Saturation, 5.6 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.14. Contours of Groundwater Saturation, 7.2 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.15. Contours of Groundwater Saturation, 10.2 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.16. Contours of Groundwater Saturation, 12.1 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.17. Contours of Groundwater Saturation, 15.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.18. Contours of Groundwater Saturation, 20.5 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.19. Contours of Groundwater Saturation, 25.6 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.20. Contours of Groundwater Saturation, 30.2 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.21. Contours of Groundwater Saturation, 35.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.22. Contours of Groundwater Saturation, 40.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.23. Contours of Groundwater Saturation, 45.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.24. Contours of Groundwater Saturation, 50.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.25. Contours of Groundwater Saturation, 52.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.26. Contours of Groundwater Saturation, 54.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.27. Contours of Groundwater Saturation, 56.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.28. Contours of Groundwater Saturation, 58.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.29. Contours of Groundwater Saturation, 60.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.30. Contours of Groundwater Saturation, 62.0 Years After Waste Package Emplacement, Best-Estimate Case (contour line saturation value is 0.99)

FIGURE 5.31. Liquid Velocity Vector, 0.7 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.32. Liquid Velocity Vector, 1.3 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.33. Liquid Velocity Vector, 2.9 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.34. Liquid Velocity Vector, 5.6 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.35. Liquid Velocity Vector, 7.2 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.36. Liquid Velocity Vector, 10.2 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.37. Liquid Velocity Vector, 12.1 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.38. Liquid Velocity Vector, 15.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.39. Liquid Velocity Vector, 20.5 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.40. Liquid Velocity Vector, 25.6 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.41. Liquid Velocity Vector, 30.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.42. Liquid Velocity Vector, 35.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.43. Liquid Velocity Vector, 40.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.44. Liquid Velocity Vector, 45.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.45. Liquid Velocity Vector, 50.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.46. Liquid Velocity Vector, 52.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.47. Liquid Velocity Vector, 54.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.48. Liquid Velocity Vector, 56.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.49. Liquid Velocity Vector, 58.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.50. Liquid Velocity Vector, 60.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.51. Liquid Velocity Vector, 62.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.52. Liquid Velocity Vector, 66.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.53. Liquid Velocity Vector, 70.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.54. Liquid Velocity Vector, 76.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.55. Liquid Velocity Vector, 80.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.56. Liquid Velocity Vector, 86.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.57. Liquid Velocity Vector, 90.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.58. Liquid Velocity Vector, 100.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.59. Liquid Velocity Vector, 150.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.60. Liquid Velocity Vector, 200.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.61. Liquid Velocity Vector, 300.0 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.62. Liquid Velocity Vector 500 Years After Waste Package Emplacement, Best-Estimate Case

FIGURE 5.63. Liquid Velocity Vector 1000 Years After Waste Package Emplacement, Best-Estimate Case

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APPENDIX A

TWO-DIMENSIONAL CYLINDRICAL MODELING RESULTS

APPENDIX A

TWO-DIMENSIONAL CYLINDRICAL MODELING RESULTS

OBJECTIVE

The GEOTHER code was developed by the Office of Nuclear Waste Isolation (ONWI) for analyzing two-phase fluid flow and heat transport phenomena in porous media. The objective of this task was to evaluate GEOTHER, as received from ONWI for application in handling various thermal conditions and geometrical configurations in a nuclear waste repository in basalt. This evaluation provided primary information with which to determine whether further assessment and/or development of GEOTHER is warranted. As discussed elsewhere in this report, the code was subsequently modified based on the findings of this evaluation.

This appendix reports the results obtained from the evaluation of a two-dimensional cylindrical geometry in a two-phase environment.

EVALUATION PROCESS

Numerical simulations for a cylindrical model of a single container were performed using the GEOTHER code to study the heat transfer and groundwater migration in the near field of the placement room borehole in a proposed high-level nuclear waste repository and to evaluate the code capability in performing these calculations. Sensitivity studies were performed to determine the influence of the cylindrical radius on the pressure profile and the boiling conditions in the host rock.

Model Setup

A two-dimensional cylindrical model was chosen because of its simplicity in modeling and the fast computing time in analyzing this problem. With this simple model, we were able to obtain preliminary results on the hydrothermal conditions of the host rock and check out the capabilities and limitations of the GEOTHER code.

The schematic of the model is shown in Figure A.1. Both the left and right side surfaces are symmetrical; that is, the structures to both left and right sides are mirror images of the cylinder. This dictates the selection of the boundary conditions on these two surfaces in the GEOTHER code, which will be discussed later. The placement room was replaced by a dish shape in the cylindrical coordinate system. The thickness of the dish equals half of the tunnel width due to symmetry. With the dish thickness known, the dish radius was calculated such that the volume of the placement room per container was preserved, so the radius is 2.31 m.

Figure A.2 shows the discretized two-dimensional mesh structure used in the code analysis. Index I represents the node in the radial (X) direction; index K represents the node in the axial (Z) direction. Because the axial direction is horizontal in this case (because of horizontal containers), the gravity effect was neglected in the calculation by setting g equal to zero.

FIGURE A.1. Schematic Representation of the Two-Dimensional Axisymmetric Model

FIGURE A.2. Discretized Noding Scheme to the Two-Dimensional Axisymmetric Model

This is also necessitated by the lack of azimuthal variation in the cylindrical model in GEOTHER (only R-Z directions are allowed). Card images of the cases evaluated with GEOTHER are presented in Appendices A.1 and A.2 at the end of this appendix.

Material Properties and Operational Conditions

Adiabatic boundary conditions were used for the left and right surfaces because of symmetry. Constant pressure and temperature boundary conditions were used for the outer radial surface. The fictitious nodes at $I = 8$ were used for this purpose. The pressure and temperature at the surfaces of the cylinder were set at 129 bars and 54°C, respectively, throughout the calculation.

The rock properties of Cohasset basalt as supplied by Rockwell in document SD-BWI-TY-001 Rev. 0 were used for this analysis. Certain parameters, such as properties of backfill material, were obtained from a Lawrence Berkeley Laboratory study. These are summarized in Table A.1. The

TABLE A.1. Nominal Parameters Used In GEOTHER Analysis

Parameter	Cohasset	Backfill
Horizontal permeability (m ²)	5.3×10^{-21}	1.0×10^{-16}
Vertical permeability (m ²)	5.3×10^{-21}	1.0×10^{-16}
Hydraulic conductivity (m/s)	1×10^{-13}	1.9×10^{-9}
Porosity	0.001	0.25
Thermal conductivity (w/m°K)	1.6	1.6
Specific heat (J/kg°K)	7.62×10^2	7.62×10^2
Density (kg/m ³)	2.78×10^3	2.78×10^3

original GEOTHER code, on which this study was based, allowed only one set of values for thermal conductivity, specific heat, and density. Therefore, the values for the Cohasset flow were used also for the backfill material.

RESULTS AND DISCUSSION

Base Case

The base case was started from excavation time and run for 10 years with the borehole and placement room open to the atmospheric pressure to establish the pressure profile in the near field of the borehole. Table A.2 gives the overall repository schedule (Anderson 1984).

Figures A.3 through A.10 show the pressures and temperatures for blocks in the fourth column of Figure A.2. The time starts from the excavation time. The identification for the block location in the plot is (I,4) as shown in Figure A.2 where I varies. Therefore block (1,4) is located at I = 1, and K = 4. Figures A.3 through A.10 represent eight blocks along the column of K = 4 in Figure A.2. Block (1,8), seen in Figure A.10, is a fictitious block to provide the fixed pressure and temperature boundary condition.

Figure A.3 shows that the borehole stays at 27°C (assumed room temperature) and 1 atm because it is not backfilled. Figures A.4 through A.7 show that the host rock initially is at 54°C and 129 bars (before excavation). The pressure and temperature initially change relatively

TABLE A.2. Overall Repository Schedule

<u>Year</u>	<u>Event</u>
0-6	Repository construction (not considered part of the waste package design life).
6	Start initial emplacement operations. This study shall assumed that the complete waste package (packing and container) is installed at emplacement.
6-28	Repository operation and receipt of 70,000 metric tons of heavy metal (MTHM) waste.
6-56	Retrievability period of the emplaced waste packages. Retrieval could be initiated at any time after emplacement up to a period of 50 years after initial packages are emplaced.
56	Either (1) backfill, seal and decommission the repository or (2) retrieve the waste packages. For this study, option 1 is assumed. For design purposes, the latest time (year 56) should be used. Since 10 CFR 60 does not preclude start of closure operations at an earlier time, these operations could occur as early as year 28, when all waste packages have been emplaced.
56-90	Retrieval operations period, if retrieval of the waste packages is assumed to start at the end of the "retrieval" period.
Permanent Closure Time + 1000	Containment period (1,000 year after permanent closure of the repository).
Containment Time + 10,000	Controlled release period for radionuclides, lasting for 10,000 years.

Note: This schedule shall be used in design to represent the maximum time between emplacement of the first and retrieval of the last waste package of 84 years. Retrieval could occur between year 6 and year 56, or permanent closure could occur between year 28 and year 56, as noted.

rapidly, and then approach an asymptotic value; the magnitudes of the asymptotic values depend on the distances from the container and from the cylinder outer boundaries. As shown by Figures A.3 through A.10, the

FIGURE A.3. Pressure and Temperature Versus Time for Block (1,4)

FIGURE A.4. Pressure and Temperature Versus Time for Block (2,4)

FIGURE A.5. Pressure and Temperature Versus Time for Block (3,4)

FIGURE A.6. Pressure and Temperature Versus Time for Block (4,4)

FIGURE A.7. Pressure and Temperature Versus Time for Block (5,4)

FIGURE A.8. Pressure and Temperature Versus Time for Block (6,4)

FIGURE A.9. Pressure and Temperature Versus Time for Block (7,4)

FIGURE A.10. Pressure and Temperature Versus Time for Block (8,4)

pressure and temperature profiles approach a "steady-state" value within about 2 years from the time of excavation. For the entire stage of calculation (i.e., before container placement), the host rock is thermodynamically saturated with groundwater because the rock temperature stays between 27°C and 54°C. Figure A.11 shows the spatial variation of the pressure at 0.3 years from excavation for column 9 (i.e., column of $K = 9$ in Figure A.2).

The large pressure undershoots in Figures A.5 through A.9 are believed to be a numerical phenomenon induced by rapid temperature changes.

The second stage of calculation started at the time of waste package emplacement with the placement room left open. The pressure and temperature profiles of the near-field host rock were obtained from the stage one calculation at time = 2 years after excavation. As discussed before, these profiles are almost the same as the asymptotic values.

According to data from Lawrence Berkeley Laboratory, the container heat generation rate is 2.21 kW per 3.2 m. Container initial temperature is

FIGURE A.11. Pressure Versus Distance From Centerline of Borehole, Base Case, Room End of Container Hole

300°C. The heat decay curve is tabulated in Table A.3. Values at 0, 5, 10, 15, 20, 30, 50, and 60 years were used in the calculations.

The results are given in Figures A.12 through A.19. Again, these are the time history plots of pressures and temperatures for blocks in column 4 (column K = 4 in Figure A.2). The initial temperature for Block (1,4), the block at one end of the borehole, was at 300°C. After emplacement, it dropped to about 135°C in less than a month's time because of the large initial temperature difference between the container (300°C) and the adjacent host rock (54°C). After this short period of temperature drop, the temperature difference between the container and host rock, thus the heat loss, was reduced, and the heat generation inside the waste package caused the waste package temperature to increase again. It peaked at about 2 years with a value of 210°C. After that, it started to decrease due to the decaying heat source and the fixed boundary condition of 54°C at the outer boundary.

The step changes in the temperature curve were partly due to the step changes the input heat source (the original GEOTHER uses constant heat source between the input intervals). The pressure of the container block started at 1 atm and continued to increase after backfill. The periodical dips of the

TABLE A.3. Relative Heat Generation Rates for 10-Year Old Spent Fuel

<u>Time After Emplacement, yrs</u>	<u>Relative Heat Generation Rates</u>
0	1.0
5	0.849
10	0.723
15	0.621
20	0.539
30	0.424
40	0.361
50	0.330
70	0.285
90	0.132
990	0.009
9990	0.0008

FIGURE A.12. Temperature and Pressure After Borehole Backfill, Base Case, Block (1,4)

FIGURE A.13. Temperature and Pressure After Borehole Backfill, Base Case, Block (2,4)

FIGURE A.14. Temperature and Pressure After Borehole Backfill, Base Case, Block (3,4)

FIGURE A.15. Temperature and Pressure After Borehole Backfill, Base Case, Block (4,4)

FIGURE A.16. Temperature and Pressure After Borehole, Backfill, Base Case, Block (5,4)

FIGURE A.17. Temperature and Pressure After Borehole Backfill, Base Case, Block (6,4)

FIGURE A.18. Temperature and Pressure After Borehole Backfill, Base Case, Block (7,4)

FIGURE A.19. Temperature and Pressure After Borehole Backfill, Base Case, Block (8,4)

pressure curves are believed to be caused by the step changes of the temperatures. For the rest of column 4 data (Figures A.13 through A.19), the pressure and temperature behaved as expected; namely, the temperatures decreased with distance away from the container and the pressures increased until reaching the outer boundary, which was 54°C and 129 bars. Again, the step changes in temperatures and the dips in pressures were partially caused by step changes in heat source input and were nonphysical.

A new graphics program, GEOPLOT, was written to do the spatial plots using the data stored on TAPE11. The results are given in Figures A.20 through A.43. The plots give the pressure, temperature, and saturation as a function of the distance from container center at 0, 0.2, 0.8, and 50 years, respectively. Columns 4 and 9 were selected for the spatial plots. Column 4 is for $K = 4$ in Figure A.2, which lies at one end of the container; column 9 is for $K = 9$ and lies at the other end of the container (next to the placement room).

Figures A.20 through A.23 are the pressure versus distance plots for column 4 at four different times. Figures A.24 through A.27 are the same plots, but for column 9.

As one can see, the pressure profiles for column 9 are lower than those for column 4. This is because column 9 is next to the placement room where the pressure was kept at 1 atm all the time.

Figures A.28 through A.31 are the temperature versus distance plots for column 4. Figures A.32 through A.35 are the same plots for column 9. One can see from these two sets of plots that the temperatures for column 4 are higher than those for column 9. This is because column 9 is next to the placement room where the temperature has been kept at 27°C. In Figure A.28, the host rock temperature drops to a minimum at about 100 cm from the container center. This happens because the initial temperature profile (just before container placement) is 27°C at the container surface and increases as the distance from container increases, finally approaching 54°C at the outer boundary. When the container at 300°C is emplaced, the near-field temperature, which was below 54°C, has not had enough time to be heated to

FIGURE A.20. Pressure Versus Distance from Borehole Centerline, Base Case, Column 4, 0.0 years

FIGURE A.21. Pressure Versus Distance from Borehole Centerline, Base Case, Column 4, 0.2 years

FIGURE A.22. Pressure Versus Distance from Borehole Centerline, Base Case, Column 4, 0.8 years

FIGURE A.23. Pressure Versus Distance from Borehole Centerline, Base Case, Column 4, 50 years

FIGURE A.24. Pressure Versus Distance from Borehole Centerline, Base Case, Column 9, 0.0 years

FIGURE A.25. Pressure Versus Distance from Borehole Centerline, Base Case, Column 9, 0.2 years

FIGURE A.26. Pressure Versus Distance from Borehole Centerline, Base Case, Column 9, 0.8 years

FIGURE A.27. Pressure Versus Distance from Borehole Centerline, Base Case, Column 9, 50 years

FIGURE A.28. Temperature Versus Distance From Borehole Centerline, Base Case, Column 4, 0.0 years

FIGURE A.29. Temperature Versus Distance From Borehole Centerline, Base Case, Column 4, 0.2 years

FIGURE A.30. Temperature Versus Distance From Borehole Centerline, Base Case, Column 4, 0.8 years

FIGURE A.31. Temperature Versus Distance From Borehole Centerline, Base Case, Column 4, 50 years

FIGURE A.32. Temperature Versus Distance from Borehole Centerline, Base Case, Column 9, 0.0 years

FIGURE A.33. Temperature Versus Distance from Borehole Centerline, Base Case, Column 9, 0.2 years

FIGURE A.34. Temperature Versus Distance from Borehole Centerline, Base Case Column 9, 0.8 years

FIGURE A.35. Temperature Versus Distance from Borehole Centerline, Base Case Column 9, 50 years

above 54°C. This results in a temperature profile with a minimum slope. This is also apparent in Figure A.32.

Figures A.36 through A.43 are the saturation values for column 4 and column 9. The figures indicate that steam exists in the backfill area surrounding the container at the time of, and shortly after, container emplacement. This is because the region near the container is at low pressure and high temperature (initial pressure at the time of backfill is close to 1 atm). As time goes on, the pressure starts to build up and the region surrounding the container is resaturated with liquid groundwater. These figures indicate that it takes longer for the container end next to the placement room to saturate than the other end. This is caused by the low fixed pressure boundary condition at 1 atm in the placement room.

The calculated saturation time for this model with one container is about 3.6 years. It should be emphasized that this value is based on an oversimplified two-dimensional cylindrical model using the original GEOTHER.

Variations from Base Case

Sensitivity Study of Cylinder Radius on Hydrothermal Conditions

A sensitivity study on the cylinder radius was performed to investigate the effect of the distance of fixed boundary conditions from the container center on the hydrothermal behavior of the host rock, particularly on the saturation time.

A different case with the cylinder radius increased by a factor of 4 from the base case was analyzed. The new case has a radius of 32.3 cm. Other dimensions are unchanged (cf. Figure A.1, the schematic for the base case).

Figures A.44 through A.75 give the calculated results. Figures A.44 through A.51 are time history plots for column 4, and Figures A.52 through A.75 are spatial plots at four selected times.

The time histories of the pressures and temperatures are very similar to those of the base case (Figures A.12 through A.19). The differences between the two cases increase as the block location moves farther away from the

FIGURE A.36. Saturation Versus Distance from Borehole Centerline, Base Case, Column 4, 0.0 years

FIGURE A.37. Saturation Versus Distance from Borehole Centerline, Base Case, Column 4, 0.2 years

FIGURE A.38. Saturation Versus Distance from Borehole Centerline, Base Case, Column 4, 0.8 years

FIGURE A.39. Saturation Versus Distance from Borehole Centerline, Base Case, Column 4, 50 years

FIGURE A.40. Saturation Versus Distance from Borehole Centerline, Base Case, Column 9, 0.0 years

FIGURE A.41. Saturation Versus Distance from Borehole Centerline, Base Case, Column 9, 0.2 years -

FIGURE A.42. Saturation Versus Distance from Borehole Centerline, Base Case, Column 9, 0.8 years

FIGURE A.43. Saturation Versus Distance from Borehole Centerline, Base Case, Column 9, 50 years

FIGURE A.44. Temperature and Pressure Borehole, Backfill, 4x Radius Case, Block (1,4)

FIGURE A.45. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (2,4)

FIGURE A.46. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (3,4)

FIGURE A.47. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (4,4)

FIGURE A.48. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (5,4)

FIGURE A.49. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (6,4)

FIGURE A.50. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (7,4)

FIGURE A.51. Temperature and Pressure After Borehole Backfill, 4x Radius Case, Block (8,4)

container. The pressure histories are considerably different. This is expected, because the locations for the fixed pressure and temperature boundaries are different for the two cases.

Figure A.50 shows that the temperature change rate is smaller than in the base case (Figure A.18). This is again because the distance between Block (7,4) and the heat sources (container) is much larger than the base case (32.3 m versus 8.1 m).

Figures A.52 through A.59 show the spatial variation of the pressure at four different times for both column 4 and column 9. Comparing these figures with Figures A.20 through A.27 for the base case leads to the observation that the pressure at a given distance from the container is much lower for the 4x radius case than for the base case. This lower pressure profile results in a considerable increase in the time required for the liquid to resaturate around the container. From the analysis of the computer output, the saturation time was increased from 3.6 years for the base case to 5.9 years for the 4x radius case.

FIGURE A.52. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.0 years

FIGURE A.53. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.2 years

FIGURE A.54. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.8 years

FIGURE A.55. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 50 years

FIGURE A.56. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.0 years

FIGURE A.57. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.2 years

FIGURE A.58. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.8 years

FIGURE A.59. Pressure Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 50 years

FIGURE A.60. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.0 years

It should be noted that these saturation times are based on the two-dimensional cylindrical model. They may be different when a detailed three-dimensional model is analyzed. However, the sensitivity of the saturation time to the boundary distance where the pressure and temperature values are fixed is obvious. Therefore, the selection of boundary location and boundary condition is very important in the prediction of the saturation time.

Figures A.60 through A.75 give the saturation profiles for columns 4 and 9. As mentioned before, the backfill area surrounding the container is totally saturated in 5.9 years from the time of container placement and backfilling.

FIGURE A.61. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.2 years

FIGURE A.62. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.8 years

FIGURE A.63. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 50 years

FIGURE A.64. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.0 years

FIGURE A.65. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.2 years

FIGURE A.66. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 0.8 years

FIGURE A.67. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 9, 50 years

FIGURE A.68. Temperature Versus Distance from Borehole Centerline, 4x Radius Case, Column 4, 0.0 years

FIGURE A.69. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 4, 0.2 years

FIGURE A.70. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 4, 0.8 years

FIGURE A.71. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 4, 50 years

FIGURE A.72. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 9, 0.0 years

FIGURE A.73. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 9, 0.2 years

FIGURE A.74. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 9, 0.8 years

FIGURE A.75. Saturation Versus Distance from Borehole Centerline, 4x Radius, Column 9, 50 years

Figures A.76 through A.79 were plotted to directly compare the pressure profiles of the base case (solid line) and the 4x radius case (dotted line). These are to reaffirm the discussion made earlier on the differences of the profiles. Several more observations can be made from these plots. At the time of placement, the pressure profiles for both cases have positive gradients at the container channel surface (Figure A.76). As time increases, the pressure gradient (dp/dx) for the reference case becomes zero at about 3.6 years (Figure A.77) when the area surrounding the container is totally saturated. The pressure gradient for the 4x radius case becomes zero at about 5.9 years (Figure A.78). At the end of the analysis (60 years from canister placement), the pressure gradient at the container surface is considerably negative for both cases. However, the pressure gradient at the outer region ($R > 200$ cm) becomes positive, indicating that the groundwater flow beyond this region is still toward the container. This result could be significant in the consideration of the groundwater flow direction in the near field. Again, these results and observations are based on the two-dimensional model. More accurate results are expected from a three-dimensional model.

Sensitivity of Hydrothermal Conditions to Backfill Porosity

Porosity values for the backfill of 0.112 (base case) and 0.25 were used in the analysis. These values are the effective porosities of the container channel; that is, they are volume-weighted average of the porosities of the backfill material and the container (having zero porosity). The results of pressure, temperature, and saturation at 0.5 years after container placement are given in Table A.4. The effect of porosity on pressure and temperature is small but not negligible in the container vicinity. The effect on saturation, however, is quite significant. This indicates that the pressure and temperature combination is very important for predicting the saturation values.

FIGURE A.76. Pressure Comparison Between Base and 4x Radius Cases, at Backfill, Column 9

FIGURE A.77. Pressure Versus Distance, Base Case, Column 9, T = 3.63 years

FIGURE A.78. Pressure for Base and 4x Radius Cases, T = 6 years

FIGURE A.79. Pressure for Base and 4x Radius Cases, T = 60 years

TABLE A.4. Sensitivity of Container Channel Porosity on Pressure, Temperature, and Saturation at 0.5 Year After Container Placement

<u>Pressure (bars)</u>		<u>Distance from Container Center</u>							
<u>Porosity</u>	<u>Column</u>	<u>0.45 m</u>	<u>0.58 m</u>	<u>0.95 m</u>	<u>1.74 m</u>	<u>2.69 m</u>	<u>4.02 m</u>	<u>6.52 m</u>	<u>8.57 m</u>
0.112	4	11.9	16.2	33.9	59.8	79.0	97.1	117.8	129.0
0.25	4	9.9	14.3	32.4	59.0	78.7	97.1	117.8	129.0
0.112	9	7.6	9.5	18.3	35.3	58.4	83.4	113.1	129.0
0.25	9	6.6	8.6	17.6	34.8	58.3	83.4	113.1	129.0
<u>Temperature (°C)</u>									
0.112	4	187.6	163.9	132.2	98.1	78.5	65.1	56.5	54.0
0.25	4	179.5	162.9	130.9	96.7	77.3	64.3	56.2	54.0
0.112	9	168.6	131.0	103.5	75.9	63.6	57.0	54.1	54.0
0.25	9	163.0	129.7	102.4	74.9	62.8	56.4	53.9	54.0
<u>Saturation</u>									
0.112	4	0.11	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.25	4	0.07	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.112	9	0.70	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.25	9	0.23	1.0	1.0	1.0	1.0	1.0	1.0	1.0

CONCLUSIONS

The GEOTHER code was used to model a single container in the basalt Cohasset flow using a simplified two-dimensional cylindrical model. The results in pressure, temperature, and saturation values were analyzed to evaluate the capability of the GEOTHER code. It was found that the predicted results were reasonable, given the limits of the two-dimensional model. Several items to improve the codes for better analysis of the host rock conditions in BWIP were identified. They are given below.

1. A continuously varying heat source in GEOTHER was needed. This should eliminate the nonphysical step changes in calculated host rock

temperature and sudden change in pressures. GEOTHER allows step changes only.

2. A generalized boundary condition is needed to realistically simulate the BWIP environment. GEOTHER allows either Neumann or Dirichlet boundary conditions for both pressures and temperatures in a given node (or block).
3. To obtain more detailed hydrothermal conditions in the container channel, multiple material property capability is needed. Only one set of specific heat, density, and thermal conductivity is allowed in the original GEOTHER code.
4. The thermodynamic property algorithm of water was not adequate. A further study found that the pressure and enthalpy ranges given in the code are not sufficient for the types of problems encountered in a nuclear repository thermal analysis.
5. The nuclear heat source cannot be modeled properly. Every node has to have both solid material (rock) and water. Only one type of material is allowed for the whole model, preventing separate modeling of the container and backfill.
6. Non-condensable gas is not included in the mathematical model of the code. No air-filled void space is allowed in a node. This deficiency will result in errors in resaturation time predictions.
7. The code can not handle complicated geometries, e.g., mixing of Cartesian and Cylindrical coordinate systems. A finite volume approach is required to realistically describe the BWIP waste package and its surrounding environment.

Further improvements may be identified when the three-dimensional Cartesian modeling and calculation are performed.

CARD IMAGE OF CYLINDRICAL REFERENCE CASE USING GEOTHER

(Borehole and Placement Room Open)

8,1,10,0
BWIP LBL CYLINDRIC MODEL 1/4 SYMM, NO CANISTER, MOST COHASSETT PARAMETER
2,40,20,1,1,4,0,20
60
1,2,3,4,5,6,7,-1
8,9,10,11,12,13,14,-1
15,16,17,18,19,20,21,-1
-1,22,23,24,25,26,27,-1
-1,28,29,30,31,32,33,-1
-1,34,35,36,37,38,39,-1
-1,40,41,42,43,44,45,-1
-1,46,47,48,49,50,51,-1
-1,52,53,54,55,56,57,-1
-1,-1,-1,-1,58,59,60,-1
1.2,0.01,1,1,0
COREY
0.3,0.05
33.,806.6
44.5,58.3,94.5,174.0,269.1,402.4,652.2,856.6
1.6E5,7.62E6,2.78,0.0,0.0
PRESSURE
FREE
8*1.29E8
8*1.29E8
8*1.29E8
1.013E6,7*1.29E8
1.013E6,7*1.29E8
1.013E6,7*1.29E8
1.013E6,7*1.29E8
1.013E6,7*1.29E8
1.013E6,7*1.29E8
4*1.013E6,4*1.29E8
ENTHALPY
FREE
8*54.0
8*54.0
8*54.0
27.0,7*54.0
27.0,7*54.0
27.0,7*54.0
27.0,7*54.0
27.0,7*54.0
27.0,7*54.0
4*27.0,4*54.0
XPERMEABILITY

FREE
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
YPERMEABILITY
FREE
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
ZPERMEABILITY
FREE
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
8*5.3E-17
POROSITY
FREE
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
8*0.001
YSPACING
CONSTANT
1.0

ZSPACING
 FREE
 236.3,199.8,147.4,164.6,121.0,102.3,86.6,73.2,61.9,339.9
 PRESSURE
 ENTHALPY
 TEMPERATURE
 SATURATION
 8
 1,1,4
 2,1,4
 3,1,4
 4,1,4
 5,1,4
 6,1,4
 7,1,4
 8,1,4
 2.E6,0.03,1.5,3.15E7,0,0
 2.E6,0.03,1.5,6.31E7,0,0
 4.E6,0.03,1.5,1.58E8,0,0
 1.E7,0.03,1.5,3.15E8,0,0
 1.E7,0.03,1.5,-1.0,0,0

CARD IMAGE OF CYLINDRICAL REFERENCE CASE USING GEOTHER

(Borehole Backfilled and Placement Room Open)

8,1,10,0
 BWIP LBL CYL. MODEL 1/4 SYMM, WITH CANISTER, PLACEMENT ROOM OPEN
 2,800,20,1,5,4,0,14
 66
 1,2,3,4,5,6,7,-1
 8,9,10,11,12,13,14,-1
 15,16,17,18,19,20,21,-1
 22,23,24,25,26,27,28,-1
 29,30,31,32,33,34,35,-1
 36,37,38,39,40,41,42,-1
 43,44,45,46,47,48,49,-1
 50,51,52,53,54,55,56,-1
 57,58,59,60,61,62,63,-1
 -1,-1,-1,-1,64,65,66,-1
 1.2,0.01,1,1,0
 COREY
 0.3,0.05
 33.,806.6
 44.5,58.3,94.5,174.0,269.1,402.4,652.2,856.6
 1.6E5,7.62E6,2.78,0.0,0.0
 PRESSURE

FREE

.11589E9,.11592E9,.11608E9,.11679E9,.11808E9,.12041E9,.12542E9,.129E9
.10841E9,.10850E9,.10894E9,.11070E9,.11338E9,.11738E9,.12440E9,.129E9
.88151E8,.88758E8,.91400E8,.98285E8,.10522E9,.11279E9,.12295E9,.129E9
.10130E7,.20967E8,.50565E8,.78970E8,.95089E8,.10769E9,.12139E9,.129E9
.10130E7,.16837E8,.42401E8,.70539E8,.88387E8,.10331E9,.11989E9,.129E9
.10130E7,.15356E8,.38815E8,.65544E8,.83647E8,.99862E8,.11867E9,.129E9
.10130E7,.14015E8,.35496E8,.60676E8,.79080E8,.96688E8,.11760E9,.129E9
.10130E7,.12358E8,.31347E8,.54588E8,.74082E8,.93669E8,.11666E9,.129E9
.10130E7,.10171E8,.25757E8,.46025E8,.68511E8,.90858E8,.11587E9,.129E9
4*.10130E7,.47927E8,.82104E8,.11358E9,.129E9

ENTHALPY

FREE

50.8,50.9,50.9,51.1,51.4,51.9,53.1,54.0
49.0,49.0,49.1,49.5,50.2,51.1,52.9,54.0
44.3,44.5,45.0,46.5,48.1,49.9,52.5,54.0
300.,30.3,35.9,42.0,45.7,48.7,52.1,54.0
300.,29.6,34.3,40.1,44.1,47.6,51.7,54.0
300.,29.4,33.6,39.1,43.0,46.7,51.4,54.0
300.,29.2,33.0,38.0,42.0,46.0,51.1,54.0
300.,28.9,32.3,36.8,40.9,45.3,50.9,54.0
300.,28.5,31.3,35.1,39.7,44.6,50.7,54.0
4*27.0,35.6,42.7,50.1,54.0

XPERMEABILITY

FREE

8*5.3E-17
8*5.3E-17
8*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17

8*5.3E-17

YPERMEABILITY

FREE

8*5.3E-17
8*5.3E-17
8*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17
1.0E-12,7*5.3E-17

8*5.3E-17

ZPERMEABILITY

FREE

8*5.3E-17

8*5.3E-17
 8*5.3E-17
 1.0E-12,7*5.3E-17
 1.0E-12,7*5.3E-17
 1.0E-12,7*5.3E-17
 1.0E-12,7*5.3E-17
 1.0E-12,7*5.3E-17
 1.0E-12,7*5.3E-17
 8*5.3E-17
 POROSITY
 FREE
 8*0.001
 8*0.001
 8*0.001
 0.112,7*0.001
 0.112,7*0.001
 0.112,7*0.001
 0.112,7*0.001
 0.112,7*0.001
 0.112,7*0.001
 8*0.001
 YSPACING
 CONSTANT
 1.0
 ZSPACING
 FREE
 236.3,199.8,147.4,164.6,121.0,102.3,86.6,73.2,61.9,339.9
 PRESSURE
 ENTHALPY
 TEMPERATURE
 SATURATION
 8
 1,1,4
 2,1,4
 3,1,4
 4,1,4
 5,1,4
 6,1,4
 7,1,4
 8,1,4
 1.E5,0.05,1.5,1.58E8,0,6
 1,1,4,1.14E10
 1,1,5,0.84E10
 1,1,6,0.71E10
 1,1,7,0.598E10
 1,1,8,0.506E10
 1,1,9,0.428E10
 1.E6,0.05,1.5,3.15E8,0,6
 1,1,4,9.68E9
 1,1,5,7.13E9

1,1,6,6.03E9
 1,1,7,5.08E9
 1,1,8,4.29E9
 1,1,9,3.63E9
 4.E6,0.05,1.5,4.73E8,0,6
 1,1,4,8.24E9
 1,1,5,6.07E9
 1,1,6,5.13E9
 1,1,7,4.32E9
 1,1,8,3.66E9
 1,1,9,3.09E9
 4.E6,0.05,1.5,6.31E8,0,6
 1,1,4,7.08E9
 1,1,5,5.22E9
 1,1,6,4.41E9
 1,1,7,3.71E9
 1,1,8,3.14E9
 1,1,9,2.66E9
 1.E7,0.05,1.5,9.46E8,0,6
 1,1,4,6.14E9
 1,1,5,4.53E9
 1,1,6,3.83E9
 1,1,7,3.22E9
 1,1,8,2.73E9
 1,1,9,2.31E9
 1.E7,0.05,1.5,1.577E9,0,6
 1,1,4,4.83E9
 1,1,5,3.56E9
 1,1,6,3.01E9
 1,1,7,2.54E9
 1,1,8,2.15E9
 1,1,9,1.81E9
 1.E7,0.05,1.5,1.892E9,0,6
 1,1,4,3.76E9
 1,1,5,2.77E9
 1,1,6,2.34E9
 1,1,7,1.97E9
 1,1,8,1.67E9
 1,1,9,1.41E9
 1.E7,0.05,1.5,-1.0,0,6

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APPENDIX B

GEOETHER/VT4 DESCRIPTION

APPENDIX B

GEOTHER/VT4 DESCRIPTION

The GEOTHER/VT4 code is being developed at Pacific Northwest Laboratory for the Basalt Waste Isolation Project (BWIP). This code is a modified version of the GEOTHER code (Faust and Mercer 1983) developed by the U.S. Geological Survey and later modified by Battelle's Office of Nuclear Waste Isolation (ONWI) for nuclear waste repository simulation.

The original GEOTHER code was used for a basalt cylindrical model calculation (see Section 5 of the main body of the report) to evaluate the code's capabilities for applications in handling the thermal and geometrical conditions in a BWIP. During this evaluation, it was found that the temperature parameters in the conduction term in the mixture energy equation (water-rock mixture) were expressed as a function of water pressure and enthalpy. This is unrealistic for blocks in which no water exists, such as the blocks where waste containers are located. In addition, this approximation could cause discontinuities in the water-rock temperature calculations when the water saturation line (either liquid or vapor) is crossed. To alleviate these potential problems, the two-equation model of the original GEOTHER was modified by adding a conduction equation to the model. In addition, several other changes were made to the code. These changes were discussed in Section 4 of the main body of the report.

The first three sections of this appendix give the detailed derivation of the three-equation model, the numerical solution method, and code verification. In the fourth section, the input to GEOTHER/VT4 is described. The fifth section describes the EPRI water property package underlying the water property functions used in GEOTHER/VT4. Input listings for the benchmark cases used to verify the code are presented in the sixth and seventh sections. The twelve new subroutines added to the code are described in the eighth section. These descriptions are followed by section that include sample output, a discussion of graphics programs for the code,

program redimensioning, and bit packing. The final section in this appendix discusses quality assurance and configuration management for the GEOTHER code.

MODEL DEVELOPMENT

A general mathematical model of a waste repository system that describes the three-dimensional flow of groundwater and/or steam and transport of heat from nuclear waste in a porous medium is presented in this section.

Governing Equations

The conservation equations for mass, momentum, and energy must first be considered for liquid and vapor phases and for rock and/or nonaqueous heating elements in the repository system. Using a set of constitutive relationships, these balance equations are reduced to three nonlinear partial differential equations in terms of the dependent variables pressure, enthalpy, and rock temperature.

Mass Balance

The mass balance for steam s and water w may be written as

$$\frac{\partial(\phi S_s \rho_s)}{\partial t} + \nabla \cdot (\rho_s \mathbf{V}_s) - q'_s - d_v = 0 \quad (\text{B.1})$$

and

$$\frac{\partial(\phi S_w \rho_w)}{\partial t} + \nabla \cdot (\rho_w \mathbf{V}_w) - q'_w + d_v = 0 \quad (\text{B.2})$$

where boldface type indicates a vector quantity and ∇ is the vector differential operator. In the above equations, ϕ is the porosity, S is the volumetric saturation, ρ is the density, d_v is the gain of steam mass due to the vaporization (loss of liquid water), q' is a source term, and $\mathbf{v}$ is the averaged phase velocity.

Momentum

It is assumed that Darcy's equation for multiphase flow may be used as simplified momentum balances. For steam and water these are as follows:

$$V_s = - \frac{K \kappa_{rs}}{\mu_s} \cdot (\nabla P_s - \rho_s g \nabla D) \quad (B.3)$$

and

$$V_w = - \frac{K \kappa_{rw}}{\mu_w} \cdot (\nabla P_w - \rho_w g \nabla D) \quad (B.4)$$

where sans serif type indicates a second-order tensor quantity. In these equations, K is the intrinsic permeability tensor of the porous medium, κ_r is the relative permeability of the phase, μ is the dynamic viscosity, g is the gravitational constant, D is the depth, and P is the phase pressure. The relative permeability K_r is a factor to account for the relative velocities between the two phases (steam and water). It is a function of the saturation values of each phase. Two fundamental forms for K_r are available in the GEOTHER/VT4 code. One is the linear form; the other is the Corey correlation (see Faust 1983).

Energy Balance

Simplified energy equations for steam, water, and rock r may be written as

$$\begin{aligned} \frac{\partial(\phi S_s \rho_s h_s)}{\partial t} + \nabla \cdot (\rho_s h_s V_s) + \nabla \cdot \lambda_{ds} - \frac{\partial(\phi S_s P_s)}{\partial t} \\ - V_s \cdot \nabla P_s - Q'_s - q'_s h'_s - q'_{hs} = 0 \end{aligned} \quad (B.5)$$

$$\begin{aligned} \frac{\partial(\phi S_w \rho_w h_w)}{\partial t} + \nabla \cdot (\rho_w h_w V_w) + \nabla \cdot \lambda_{cw} + \nabla \cdot \lambda_{dw} - \frac{\partial(\phi S_w P_w)}{\partial t} \\ - V_w \cdot \nabla P_w - Q'_w - q'_w h'_w - q'_{hw} = 0 \end{aligned} \quad (B.6)$$

and

$$\frac{\partial[(1-\phi)\rho_r h_r]}{\partial t} + \nabla \cdot \lambda_{cr} + Q'_r = 0 \quad (B.7)$$

where h is specific enthalpy, λ_c is the heat conduction vector, λ_d is the dispersion (thermal mixing) vector, q'_h is the external heat source term, and Q'_w , Q'_s and Q'_r are the interphase energy exchange terms.

In these equations, kinetic energy (viscous dissipation) and potential energy are neglected (Faust and Mercer 1979).

Constitutive Relationships

The balance equations (B.1) through (B.7) are not sufficient to describe the geothermal system; consequently, additional equations are required. These are in the form of constitutive relationships that are based on the following assumptions:

1. Capillary pressure effects are negligible.
2. Thermal equilibrium exists between steam and water.
3. The fluid is single-component water consisting of either one or two phases.
4. Relative permeability is a function of liquid volume saturation; hysteresis is neglected.
5. Viscosities are considered functions of temperature.
6. Porosity is a linear function of pressure, given by

$$\phi = \phi_i + \beta(p - p_i) \quad (B.8)$$

where ϕ_i and p_i are the initial porosity and pressure, respectively, and β is the intergranular vertical compressibility coefficient.

7. Rock density, and intrinsic permeability are functions of space.

The detailed justifications of these assumptions are given in Faust and Mercer (1979).

With negligible capillary pressure effects, fluid pressures in the steam and water phases are equal. Equations (B.1) and (B.2) may be combined to eliminate the vaporization terms.

$$\frac{\partial(\phi\rho)}{\partial t} + \nabla \cdot (\rho_s v_s) + \nabla \cdot (\rho_w v_w) - q'_s - q'_w = 0 \quad (\text{B.9})$$

where ρ is the density of the total steam-water mixture, defined as

$$\rho = S_w \rho_w + S_s \rho_s \quad (\text{B.10})$$

The volume saturations are defined so that they sum to 1.

$$S_s + S_w = 1 \quad (\text{B.11})$$

and phase velocities can now be expressed in terms of a single pressure p .

The conduction-dissipation terms in Equations (B.5) and (B.6) are lumped together by a Fourier-type equation:

$$\lambda_{cs} + \lambda_{cw} + \lambda_{ds} + \lambda_{dw} = - K_m \nabla T \quad (\text{B.12})$$

where the medium conduction-dispersion coefficient K_m is isotropic. This simplifying assumption is made because data on the tensor nature of thermal dispersion are generally unavailable. In addition to the limitation of combining the effects of conduction and dispersion, Equation (B.12) neglects the important effect of temperature on thermal conductivity. This effect may be important in a purely conductive system; however, in this study these effects are neglected. It will become obvious later that the water conduction term of Equation (B.12) is negligible when compared with the rock conduction term $K_r \nabla T_r$ in Equation (B.19). In general, one uses the water thermal conductivity as the value for K_m .

Invoking these assumptions concerning thermal equilibrium and dispersion, the energy balance equations (B.5) and (B.6) for water may be combined, yielding

$$\begin{aligned} \frac{\partial}{\partial t} (\phi \rho h) + \nabla \cdot (\rho_s h_s \bar{V}_s) + \nabla \cdot (\rho_w h_w \bar{V}_w) - \nabla \cdot (K_m \nabla T) \\ - q'_{h_{sw}} - h_{rw} (T_r - T) - \left[\frac{\partial \phi P}{\partial t} + (\bar{V}_s + \bar{V}_w) \right] \cdot \nabla P = 0 \end{aligned} \quad (B.13)$$

in which h is the enthalpy of the steam-water mixture and is defined as

$$h = (S_s \rho_s h_s + S_w \rho_w h_w) / \rho \quad (B.14)$$

$q'_{h_{sw}}$ is the heat input to water by pumping/discharge ($q'_s h'_s + q'_w h'_w$) and by external heat source ($q'_{hs} + q'_{hw}$), and $h_{rw} (T_r - T)$ is the heat exchange from rock to water ($=_s Q' +_w Q'$). The coupling coefficient h_{rw} is proportional to the rock-water heat transfer coefficient, h_c , through the relationship

$$h_{rw} = \frac{A_{IF}}{V_b} h_c \quad (B.15)$$

where A_{IF} is the total interface area between rock and water passages in one block, V_b is the total block volume, and T_r and T are rock and mixture water temperatures, respectively.

The relationship of h_{rw} to the geohydraulic properties is not well known. For most practical purposes, a large value is used to yield the same temperatures for water and rock in a porous medium. For a solid, it is set to zero.

The last term in Equation (B.13) is the pressure material derivative, which in part comprises the compressible work term. Moench (1976) points out that the term for compressible work is negligible except for conditions of

low water saturation. The same characteristics can be shown for the rest of the pressure material derivative; and for this application it is neglected.

Thermodynamic Properties

Additional expressions are needed to relate the thermodynamic properties of pure water and steam to the dependent variables pressure and enthalpy. These expressions are functional in form. This approach avoids the necessity of searching for and interpolating data from tables. The necessary relationships for this development are as follows:

1. Saturated steam enthalpy h_s and saturated water enthalpy h_w are treated as functions of pressure.
2. Temperature is treated as a function of pressure and enthalpy for the compressed-water region and the superheated-steam region, and is treated as a function of pressure in the two-phase region.
3. Total density ρ and steam and water densities ρ_s and ρ_w are considered functions of pressure and enthalpy.
4. Phase saturations are functions of enthalpy and pressure in the two-phase region. Water saturation in the compressed-water region is assumed to be 1; in the superheated-steam region it is assumed to be 0. In the steam-water region, water saturation is obtained from Equations (B.10), (B.11), and (B.14) as

$$S_w = \frac{\rho_s(h_s - h)}{h(\rho_w - \rho_s) - (h_w\rho_w - h_s\rho_s)} \quad (B.16)$$

and S_s is determined using Equation (B.11).

Final Three-Dimensional Equations

The final equations are formulated in terms of the dependent variables pressure and enthalpy for water and temperature for rock, because these variables uniquely define the thermodynamic state of the system. With the assumptions of zero capillary pressure and thermal equilibrium, the number of balance equations was reduced to five [Equations (B.3), (B.4), (B.7), (B.9),

and (B.13)]. These can be reduced further by substituting Equations (B.3) and (B.4) into Equations (B.9) and (B.13) and by expanding the temperature derivative in Equation (B.13) to yield

$$\begin{aligned} \frac{\partial(\phi\rho)}{\partial t} - \nabla \cdot \left[\frac{K_r \rho_s \mu_s}{\mu_s} (\nabla p - \rho_s g \nabla D) \right] \\ - \nabla \cdot \left[\frac{K_r \rho_w \mu_w}{\mu_w} (\nabla p - \rho_w g \nabla D) \right] - q'_m = 0 \end{aligned} \quad (B.17)$$

and

$$\begin{aligned} \frac{\partial}{\partial t} \phi \rho h - \nabla \cdot \left[\frac{K_r \rho_s \mu_s h_s}{\mu_s} (\nabla p - \rho_s g \nabla D) \right] \\ - \nabla \cdot \left[\frac{K_r \rho_w \mu_w h_w}{\mu_w} (\nabla p - \rho_w g \nabla D) \right] - \nabla \cdot \left[K_m \left(\frac{\partial T}{\partial p} \right)_h \nabla p \right. \\ \left. + K_m \left(\frac{\partial T}{\partial h} \right)_p \nabla h \right] - q'_{hsw} - h_{rw} (T_r - T) = 0 \end{aligned} \quad (B.18)$$

where the pressure material derivative has been neglected.

Equation (B.7) is rewritten as

$$\frac{\partial}{\partial t} [(1 - \phi) \rho_r c_r T_r] - \nabla \cdot K_r \nabla T_r - q'_{hr} + h_{rw} (T_r - T) = 0 \quad (B.19)$$

where C_r is the rock specific heat, K_r is the rock thermal conductivity, and q'_{hr} is the heat input to rock by external heat sources such as nuclear waste

decay heat. In the code, C_r and K_r are considered as functions of rock/solid temperatures.

These final three-dimensional equations describe the two-phase flow of heat in a steam-water-rock system.

Source Terms

The mass and energy source terms q_m' and $q_{h_{sw}}'$ for water represent the amount of mass and heat lost (or gained) to source sinks. In the two-phase region, the mass rate loss to a source sink is defined as

$$q_m' = q_s' + q_w' \quad (B.20)$$

and the heat rate loss (or gain) to a source sink is

$$q_{h_{sw}}' = h_s' q_s' + h_w' q_w' + q_{h_s}' + q_{h_w}' \quad (B.21)$$

where a negative rate indicates a loss from the repository. The steam production rate may be determined by the fractional flow of the steam phase as follows:

$$q_s' = a_s q_m' \quad (B.22)$$

and

$$a_s = \kappa_{rs} / [\kappa_{rs} + (\rho_w \mu_s / \rho_s \mu_w) \kappa_{rw}]$$

Because h_s' and h_w' are known functions of pressure and the mass flux q_m' is specified, q_s' is calculated using Equation (B.22), and $q_{h_{sw}}'$ is calculated using Equation (B.21).

Boundary Conditions

Equations (B.17), (B.18), and (B.19) together comprise a set of nonlinear second-order partial-differential equations. Three conditions, one in terms of pressure, one in terms of enthalpy, and one in terms of rock temperature, are required at the boundaries. Two types of boundary conditions are currently used in the code. The first is a zero flux type, indicating a no-flow (for both mass and heat) boundary. The second type is a constant parameter, in which water pressure, enthalpy, and rock temperature are fixed at the boundary.

Model Assumptions and Limitations

The major assumptions made through the model derivatives are:

1. Capillary pressure effects are negligible.
2. Thermal equilibrium exists among the steam and water.
3. The system is single-component water consisting of either one or two phases.
4. Relative permeability is a function of liquid volume saturation; hysteresis is neglected.
5. Viscosities are considered functions of temperature.
6. Porosity is a linear function of hydrostatic pressure.
7. Rock density and intrinsic permeability are functions of space.
8. Rock enthalpy is a linear function of temperature.
9. Flow is in a porous medium system.
10. Darcy's equation for multiphase flow is valid.
11. Kinetic and potential energy and the pressure material derivative are negligible.
12. Thermal conductivity is combined for the steam and water. It is a constant, isotropic lumped parameter that represents both conduction and thermal dispersion.

Discussions and justifications of these assumptions are given in Faust and Mercer (1979).

The code has six primary limitations:

1. The model cannot treat systems that vary greatly from pure water. For example, if the fluid is a brine or contains large quantities of dissolved carbon dioxide, GEOTHER/VT4 would need to be modified.
2. The model does not perform any well-bore calculations.
3. The model can treat systems that behave as porous medium. If a fractured system does not behave in this fashion, then GEOTHER cannot be used. Discrete fractures with simple geometry can be treated as a line of finite-difference blocks.
4. The model has no thermomechanical capabilities.
5. The water thermodynamic property functions are valid in the range of pressures from 700 to 4×10^7 Pa and specific enthalpies from approximately 5×10^5 to 4×10^6 J/kg.
6. The model neglects the presence of noncondensable gases. If significant amounts of gases such as air, methane, carbon dioxide, hydrogen, or oxygen are present in dynamic equilibrium with the water, use of GEOTHER could lead to inaccurate results.

SOLUTION METHODS

Finite-Difference Form

The numerical techniques used to solve Equations (B.19), (B.20) and (B.21) are the same as given in Faust and Mercer (1983). The three-dimensional model uses finite-difference approximations with fully implicit Newton-Rahpson iteration applied to a block-centered grid that allows variable spacing and can be used to simulate irregular geometry. The discretized finite-difference equations are

$$\Delta [(T_w + T_s) \Delta p^{n+1}] - \Delta [(T_w \rho_w g + T_s \rho_s g) \Delta D]$$

$$+ V_b q'_m - (V_b/\Delta t) (M^{n+1} - M^n) = 0 \quad (B.23)$$

$$\Delta (T_h \Delta p^{n+1}) + \Delta (T_c \Delta h^{n+1}) - \Delta [(T_w h_w \rho_w g + T_s h_s \rho_s g) \Delta D] \\ + V_b q'_{h_{sw}} + V_b h_{rw} (T_r^{n+1} - T^{n+1}) - (V_b/\Delta t) (E^{n+1} - E^n) = 0 \quad (B.24)$$

and

$$\Delta (T_{Cr} \Delta T_r^{n+1}) + V_b q'_{hr} - V_b h_{rw} (T_r^{n+1} - T^{n+1}) \\ - (V_b/\Delta t) (E_r^{n+1} - E^n) = 0 \quad (B.25)$$

where the last term on the left-hand side of each of the above three equations is the accumulation term for water mass, energy, and rock energy, respectively. The transmissibility terms are defined as

$$T_w = (kA/l) \rho_w k_{rw} / \mu_w \\ T_s = (kA/l) \rho_s k_{rs} / \mu_s \\ T_h = T_w h_w + T_s h_s + (K_m A/l) (\partial T / \partial p)_h \\ T_c = (K_m A/l) (\partial T / \partial h)_p \\ T_{Cr} = (A/l) K_r$$

and the mass and energy terms are

$$M = \phi \rho \\ E = \phi \rho h \\ E_r = (1-\phi) \rho_r C_r T_r$$

where V_b , A , and l are the grid block volume, the cross-sectional area perpendicular to the flow direction, and the length increment in the flow direction, respectively. The difference operator Δ is defined for three dimensions, but, as an example, acts as follows in the X direction:

$$\Delta_x(T_{wx}\Delta_x p^{n+1}) = T_{wx_{i+\frac{1}{2},j,k}}(p_{i+1,j,k}^{n+1} - p_{i,j,k}^{n+1}) + T_{wx_{i-\frac{1}{2},j,k}}(p_{i,j,k}^{n+1} - p_{i-1,j,k}^{n+1}) \quad (B.26)$$

where i , j , and k are indices in the X , Y , and Z direction, respectively, and n is the index for the time level. Interblock transmissibilities (those evaluated at $i \pm \frac{1}{2}$, $j \pm \frac{1}{2}$, and $k \pm \frac{1}{2}$) require averaging or weighing of their various components. Density, viscosity, and the derivatives $(\partial T / \partial p)_h$ and $(\partial T / \partial h)_p$ are evaluated as arithmetic averages of the values in the adjacent blocks. Relative permeabilities and enthalpies are usually assigned the upstream value (that is, the value at the grid block having the higher fluid potential). Other terms, such as (kA/l) and $(K_m A/l)$, that are space-dependent are determined as harmonic means of the values in the two adjacent blocks. For example,

$$(kA/l)_{i+\frac{1}{2}} = \frac{2k_i A_i k_{i+1} A_{i+1}}{k_i A_i l_{i+1} + k_{i+1} A_{i+1} l_i} \quad (B.27)$$

The difference equations (B.23), (B.24), and (B.25) are nonlinear in the transmissibility, accumulation, and source terms. These terms can lead to serious numerical instabilities if not treated properly. For isothermal, multiphase flow applications, the techniques that have demonstrated the least severe stability restrictions are those that treat nonlinear terms implicitly and use upstream weighing on relative permeability terms (Blair and Weinaug 1967; Peaceman 1977). The same techniques are used here to achieve stable solutions.

Implicit treatment of nonlinear terms in Equations (B.23), (B.24), and (B.25) require that these terms be evaluated at the new time level $(n+1)$. This leads to a system of $3N$ nonlinear equations (N being the number of grid

blocks) for each time step. Each grid block is connected to, at most, six adjacent blocks (three-dimensional case), so that each equation has a maximum of seven unknown grid block value for pressure, enthalpy, and rock temperature, or 21 unknowns per equation. This set of equations is linearized using a residual formulation with Newton-Raphson iteration. Rewriting equations (B.23), (B.24), and (B.25) in vector form,

$$R(X) = 0 \quad (B.28)$$

where R is the vector of nonlinear difference equations (B.23), (B.24), and (B.25) written for each grid block and X is the vector of unknown pressure, enthalpy, and temperature values at each grid block. Application of the Newton-Raphson procedure involves approximating Equation (B.28) with a Taylor's series expansion about an assumed solution. This leads to the linearized matrix equation

$$\left[\frac{\partial R(X^m)}{\partial X} \right] \{\delta X\} = - \{R(X^m)\} \quad (B.29)$$

where m is the iteration level and $\{\delta X\} = \{X^{m+1} - X^m\}$. For the first iteration in each time step, the values of p , h , and T_r at the old time level are used as the initial solution. Convergence is checked by calculating global mass and energy balance errors and comparing them to specified criteria.

Application of the Newton-Raphson procedure to the nonlinear difference equations produces a system of linear equations in the form of Equation (B.29) that require a solution for each iteration. For many problems, solving this matrix equation is the most time-consuming part of the simulation process. Hence, it is essential that this operation be performed as efficiently as possible.

Matrix Solution

The three-dimensional model is severely nonlinear due to gravity terms; hence, Newton-Raphson iteration is required for spatial as well as source and accumulation terms. This fully implicit treatment yields a coefficient matrix that is nonsymmetric. To solve this linearized matrix equation, we use slice successive overrelaxation (Wattenbarger and Thurnau 1976; Woo and Emanuel 1976) embedded in the Newton-Raphson iteration.

This method is similar to line successive overrelaxation in two dimensions for coupled equations, except that instead of each row being solved implicitly, each vertical cross section of the grid is solved implicitly. Each of the three-dimensional equations has 21 unknowns because pressure, enthalpy, and rock temperature are solved simultaneously. Subroutine SSOR blocks the matrix such that each slice has 15 unknowns per equation. Hence, in this iterative scheme, 15 coefficients are treated implicitly and only 6 are treated explicitly. The bandwidth of the matrix equation for each slice is proportional to the number of horizontal layers rather than to the number of grid blocks in a slice, as is the case for direct solution of the full three-dimensional equations. Each of these matrix equations is solved using a banded Gauss-Dolittle method with normal ordering. Because SSOR is embedded in the Newton-Raphson iteration, only linearized equations are solved. Therefore, the matrix decomposition for each slice is required only on the first SSOR iteration of each Newton-Raphson iteration. On subsequent SSOR iterations, only back substitution is necessary. In addition, because the SSOR is imbedded in the Newton-Raphson iteration, the convergence criterion need not be small. The convergence is checked by calculating

$$\delta p^* = \max \left| \frac{p_{ijk}^m - p_{ijk}^{m-1}}{p_{ijk}^1 - p_{ijk}^0} \right| \quad \forall ijk$$
$$\delta h^* = \max \left| \frac{h_{ijk}^m - h_{ijk}^{m-1}}{h_{ijk}^1 - h_{ijk}^0} \right| \quad \forall ijk$$

where the superscripts m , $m-1$, 1 and 0 refer to SSOR iteration levels. The convergence criterion for δp^* and δh^* is 0.001, which is usually reached in only six to ten iterations. Although this tolerance may seem somewhat large, subsequent Newton-Raphson iterations correct any error. Also, because of the large tolerance, selection of an overrelaxation parameter presents no difficulty (a factor between 1.0 and 1.7 is normally used).

CODE VERIFICATION

The purpose of verification testing is to ensure the appropriate implementation of the improved models to the original GEOTHER. This is accomplished by comparing the GEOTHER/VT1 solutions with results from the original GEOTHER and analytical solutions for the modified parts of the code.

Verification of Water Parameters - Test Case 1

A calculation to verify the portions of the code for water pressure and temperature prediction was performed. The two-dimensional model using four active nodes separated by two constant nodes (i.e., boundary nodes) is shown in Figure B.1. The outer boundary of the nodes is adiabatic, i.e., no heat or mass flow occurs on the outer boundary. The active nodes are initially at a condition of water pressure (p) equal to 1.0×10^7 Pa, water temperature (T) equal to 50°C , and rock temperature (T_r) equal to 50°C . The two center boundary nodes (nodes "-1") have a fixed p of 0.1×10^7 Pa, a fixed T of 30°C , and a fixed T_r of 30°C . Rock properties based on basalt are used. The dimensions of each block are 100 cm by 100 cm. There is no heat input or discharge.

The main parameters and their values are given in Table B.1.

FIGURE B.1. Test Case 1 Node Diagram

The simulation was carried out by decoupling the heat exchange between rock and water. This was accomplished by setting $h_{rw} = 0$ for all blocks. Table B.2 gives the comparisons of the calculations using GEOTHER and GEOTHER/VT1.

GEOTHER/VT1 is an earlier version of GEOTHER/VT4. It has the original GEOTHER thermodynamic property routines instead of the EPRI thermodynamic properties. This will make the verification of the effect of the three-equation model change on the water pressures and temperatures meaningful. The rock conduction equation calculations in version VT1 and VT4 are not changed.

TABLE B.1. Property Values for Benchmark Case 1

Medium thermal conductivity ^(a)	2.0	J/s•°C
Rock specific heat ^(b)	0.8×10^3	J/kg•°C
Rock density	3×10^3	kg/m ³
Permeability (for all three directions)	0.5×10^{-12}	m ²
Initial porosity	0.1×10^{-2}	

(a) In GEOTHER, this is lumped thermal conductivity for water-rock mixture; in GEOTHER/VT1, it is water thermal conductivity. Rock (basalt) thermal conductivity is calculated by the code as a function of rock temperature.

(b) This value is used in GEOTHER for all blocks. The rock specific heat for basalt is internally calculated in GEOTHER/VT1 for each block, again as a function of rock temperature.

GEOTHER calculation resulted in a slower fluid temperature decrease than that of GEOTHER/VT1. This is because the thermal capacitance for GEOTHER/VT1 includes only water ($\phi \rho h$) (the rock temperature calculation is decoupled), whereas in the original GEOTHER, the thermal capacitance is that of both water and rock [$\phi \rho h + (1-\phi) \rho_r C_r T_r$]. The latter has much larger capacitance than the former, and thus yields a slower temperature decrease.

The rock temperatures calculated by GEOTHER/VT1 are given in Table B.2. Because the original GEOTHER does not calculate rock temperatures, no values are given. The rock temperatures GEOTHER/VT1 are very close to the water/rock mixture temperatures from GEOTHER (compare fourth and ninth columns). This is consistent with the discussions for water temperature calculations. In this case, the rock thermal capacitance in GEOTHER/VT1, $(1-\phi)\rho_r C_r T_r$, is very close to the thermal capacitance of the rock/water mixture, $\phi\rho h + (1-\phi)\rho_r C_r T_r$, in GEOTHER. Thus, the temperatures are also close. The differences in pressure calculations in Table B.2 are believed to be caused by the temperature differences, because temperature and pressure are coupled for water.

TABLE B.2. Comparison of Case 1 Results

Time (years)	Pressure, dynes/cm ²		Water Temperature, °C		Saturation		Rock Temperature, °C	
	Old(a)	VT1(b)	Old	VT1	Old	VT1	Old	VT1
0	1×10^8	1×10^8	50	50	1.0	1.0	-	50
0.32	9.63×10^6	9.49×10^6	32.145	30.004	1.0	1.0	-	32.298
0.79	9.924×10^6	9.997×10^6	30.159	30.000	1.0	1.0	-	30.183
0.95	9.985×10^6	1.0000×10^7	30.031	30.000	1.0	1.0	-	30.038

(a) Original GEOTHER.

(b) GEOTHER/VT1.

Table B.3 gives a comparison of the mass and energy balances calculated by the two codes. It is clear that both codes give converged mass and energy balances for water in the global system (i.e., for all blocks). The differences in the net mass and energy flows for the two cases are again due to the differences of the heat capacitance defined in the two codes. It is also clear that the increased size of the matrices in the three-equation model increases the required number of iterations for convergence.

Verification of Rock Parameters - Test Case 2

A two-dimensional model with 42 blocks was used to check the rock temperatures calculated by GEOTHER/VT1. The node diagram is given in Figure B.2. All blocks have the same dimensions of 4.878 cm x 100 cm.

The X-direction grid size (4.878 cm) was chosen so that the total distance from left side to the midpoint of the right boundary node was 100 cm. This would facilitate the comparison with analytical results.

The rock density was set to 3.0 gm/cm^3 ; the rock thermal conductivity (K) and specific heat (C_p) were kept constant throughout the calculation. They are for basalt at 50°C , $k = 1.99 \times 10^5 \text{ erg/cm-s-}^\circ\text{C}$, $C_p = 8.62 \times 10^5 \text{ erg/g-}^\circ\text{C}$. (The functional relationships between K, C_p , and rock temperature existing in the code were suppressed to make comparisons between code and

TABLE B.3. Comparison of Mass and Energy Balance For Water in the Global System

Time, years	Mass Balance			Energy Balance			No. of Newton Raphson Iterations
	Change in Storage	Net Mass Flow Out	Percent Error	Change in Storage	Net Energy Flow Out	Percent Error	
	gm	gm		ergs	ergs		
0.32	-0.1267	0.1267	-0.16×10^{-2}	$+0.33 \times 10^{11}$	-0.33×10^{11}	-0.77×10^{-4}	2
0.79	-0.11×10^{-2}	0.11×10^{-2}	0.13×10^{-2}	$+0.38 \times 10^7$	-0.38×10^7	0.42×10^{-2}	1
0.95	-0.56×10^5	0.56×10^{-5}	-0.17×10^{-4}	-1.49×10^4	1.49×10^4	-0.27×10^{-4}	1

Time, years	Mass Balance			Energy Balance			No. of Newton Raphson Iterations
	Change in Storage	Net Mass Flow Out	Percent Error	Change in Storage	Net Energy Flow Out	Percent Error	
	gm	gm		ergs	ergs		
0.32	-0.97×10^{-1}	0.97×10^{-1}	0.35×10^{-2}	0.17×10^{14}	-0.17×10^{14}	0.31×10^{-4}	2
0.79	-0.28×10^{-1}	0.28×10^{-1}	-0.94×10^{-9}	0.19×10^{13}	-0.19×10^{13}	-0.34×10^{-8}	2
0.95	-0.19×10^{-2}	0.19×10^{-2}	0.64×10^{-10}	1.12×10^{12}	-0.12×10^{12}	0.83×10^{-11}	2

FIGURE B.2. Node Diagram of Test Case 2

analytical solutions meaningful). The calculation starts with Blocks 1 through 40 set at an initial uniform temperature of 50°C . All boundaries except the right side are adiabatic. The right surface is fixed at 30°C . The time step size for the first ten steps is 5×10^3 seconds; after that, it is increased to 5×10^4 seconds.

Figure B.3 shows the calculated results at $t = 1.5 \times 10^5 \text{ s}$, $3.5 \times 10^5 \text{ s}$, and $5.5 \times 10^5 \text{ s}$. Also shown are the analytical results obtained by solving the conduction heat transfer equation for an infinite plate with fixed surface temperature (Schneider 1955). The analytical form of the solution is given as

$$\frac{T - T_o}{T_i - T_o} = \frac{4}{\pi} \sum_{n=1}^{\infty} e^{-\left(\frac{n\pi}{2}\right)^2 \theta} \sin \frac{n\pi}{L} x$$

FIGURE B.3. Comparison of GEOTHER/VT1 Rock Temperatures with Analytical Results

where the coordinate system is shown in Figure B.4, $n = 1, 3, 5, \dots$, $\theta = (4\alpha/L^2)t$, α is thermal diffusivity, t is time, T_i is initial uniform temperature in the plate, and T_0 is the temperature on both surfaces. For this case, $T_i = 50^\circ\text{C}$, $T_0 = 30^\circ\text{C}$. The GEOTHER/VT1 model of Figure B.2 corresponds to the right half of the analytical model in Figure B.4. The plot in Figure B.3 is based on the coordinate system of Figure B.4.

FIGURE B.4. Coordinate System for Analytical Solutions

Figure B.3 shows that the calculated rock temperatures by GEOTHER/VT1 match the analytical solution reasonably well. The small differences are believed to be caused by the finite sizes of X-grid discretization and time steps.

The Newton-Raphson iteration for the conduction heat transfer equation converges much faster than those for water mass and water energy. This is expected because the matrix coefficients (jacobian) for the conduction equation are much less nonlinear than those for water mass and energy balances.

Verification of Rock Parameters - Test Case 3

A two-dimensional model with 42 blocks was used to check the rock temperatures in the presence of a uniformly distributed heat source. The version used to check this case is GEOTHER/VT3. This version has the same heat transfer model as Version VT4.

The node diagram of Case 3 is given in Figure B.5. All the active blocks have the same dimensions of 0.760 cm x 1 cm. The two boundary blocks have the dimensions of 0.1 cm. x 1 cm.

The solid density was set to 3.0 gm/cm^3 , with a thermal conductivity (k) of $3.461 \times 10^6 \text{ erg/s-cm-}^\circ\text{C}$, a specific heat (c_p) of $2.235 \times 10^7 \text{ erg/gm-}^\circ\text{C}$,

FIGURE B.5. Node Diagram of Test Case 3

and a heat generation rate (q_0''') of 4.14×10^6 erg/s-cm³. The calculation starts with Blocks 1 through 40 set at an initial uniform temperature of 15.56°C (60°F). All boundaries except the right side are adiabatic. The right surface is fixed at 0°C. The time step is set to 180 seconds. Figure B.6 shows the calculated results at $t = 3, 6$, and 9 minutes. Also shown are the analytical results obtained by solving the conduction heat transfer equation for an infinite plate with fixed surface temperature and a uniformly distributed heat source (Schneider 1955). The analytical form of the solution is given as

$$\frac{T - T_0}{(q_0''' L^2/k)} = \frac{1}{2} \left[\left(\frac{x}{L} \right) - \left(\frac{x}{L} \right)^2 \right] + \left(\frac{4K}{\pi q_0''' L^2} \right) \sum_{n=1}^{\infty} \frac{1}{n} \left(T_i - T_0 - \frac{q_0''' L^2}{n^2 \pi^2 k} \right)$$

$$\bullet e^{- (n\pi/L)^2 \alpha t} \sin n\pi \left(\frac{x}{L} \right); n = 1, 3, 5 \dots$$

FIGURE B.6. Comparison of GEOTHER/VT3 Rock Temperature with Analytical Results (Heat Generation Case)

The coordinate system of the above equation is the same as that shown in Figure B.4, except here we have a uniformly distributed heat source of q_0''' . The plot of Figure B.6 is based on the coordinate system of Figure B.4.

Figure B.6 shows that the rock temperatures calculated by GEOTHER/VT4 compare reasonably well with the analytical solution. The differences are believed to be caused by the finite sizes of X-grid discretization, time steps, and the nonzero thickness of the boundary nodes. Ideally, one would like to have a zero-thickness boundary node to simulate the real situation which the exact solution matches. (Note: In Test Case 2, the plate thickness could be changed to account for the nonzero thickness of the boundary nodes because there was no heat generation.)

Based on test cases 2 and 3, it is concluded that the incorporation of the third conduction equation to the GEOTHER model has been carried out correctly in the mathematical governing form and in numerical solutions.

GEOTHER/VT4 INPUT DESCRIPTION

The input format for GEOTHER/VT4 has been completely rewritten. The new input is more logical and more user friendly because of its copious use of character variables to identify each card, and the logical grouping of related input parameters on the same card. Additionally, the input cards may come in any order. The new input formula also makes it much easier to add future improvements to GEOTHER. Finally, the new input also allows any number of comment cards in any locations throughout the input which enhances readability and quality assurance. All these changes, however, have been accomplished in an upward compatible manner so that all old GEOTHER input decks will still work. Of course, old decks will not be able to utilize the new features of GEOTHER VT/4.

GEOTHER/VT4 reads the input from cards^(a) which may occur in any order. Each card has a unique character identifier in columns 1-4. This identifier serves as a mnemonics helping the user to more rapidly learn the new

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(a) The word "card" here means an 80 column input record.

GEOTHER/VT4 input, and facilitating minor changes after the basic input has been constructed. As much as possible, all related input parameters occur on the same card. For example, all parameter controlling the iterative solution techniques in GEOTHER occur on the card with the character identifier "ITER," in columns 1-4. The individual cards identified with a mnemonics are: "GRID," "TIME," "REST," "INPU," "ITER," "MISC," "XTRA," "AOUT," "DEBUG," "PRNT," "PROP," "DELR," "DELX," "DELY," "DELZ," "MESH," and "TABL." The function of each of these cards is described in greater detail below.

The "GRID," card identifies the coordinate system type (Cartesian or Cylindrical) and the number of blocks in each coordinate direction. The current version does not allow the cylindrical coordinate option. Only a Cartesian system can be used. The "TIME," card is for time step control. The "REST," card is to restart a previous case. The "INPU," card is to select input option for groundwater temperature or enthalpy. The "ITER," card is for the parameters that control the numerical iterations. The "MISC," card is for miscellaneous input parameters, such as the upstream weighting option and the number of boundary nodes. The "XTRA," card is for extra input parameters. It is not used in the current version. The "AOUT," card is for the output printing option. The output arrays that may be selected for printouts are pressure, saturation, water temperature, enthalpy, and rock temperature. The "DEBUG," card is to print out debug information. Its primary function is to facilitate debugging from the code development standpoint. The "PRNT," card is to control the frequency of printed output, such as the number of time steps between printing. The "PROP," card is to input material properties. Up to 63 material types ($MAT \leq 63$) may be input. The "DELR," card is to input node spacings in the radial direction in a cylindrical coordinate system. Currently, the cylindrical coordinate option is not available, so this card should not be used. The "DELX," card group reads block spacings in the X-direction in a Cartesian coordinate system. The "DELY," and "DELZ," card groups read block spacings in the Y- and Z-directions, respectively. The "MESH," card is to set up block types. It requires the user to assign cell type (boundary or active cell), material type, heat generation type and the location of the cell in the grid system.

It is noted that the boundary cell (i.e., cell with constant pressure and temperatures) can be located anywhere in the grid system, whether exterior or interior. The code is structured to allow up to 63 cell types (even though only 4 cell types are needed), 63 material types, and 63 heat generation tables. The "TABL," card group reads inputs needed to set up tables. Currently, only heat generation versus time table is available in the code. Several other cards in addition to the ones described above are needed to run a case. They are discussed in the detailed input description as follows.

Card 0.0 - Comment Card

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-4 (or 77-80)		Input ****, When program sees four asterisks, it ignores this card.
5-76		Any descriptive statements.

Note: This card may be inserted at any card group location. However, it should not be used after Card 16.0. The comment card can be inserted only between card groups. It cannot be used within a card group (e.g., it can be inserted between Card 11.0 and Card 12.0, but not between Card 11.0 and Card 11.1).

Card 1.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-9		Read "NEW-INPUT" to activate new input format.

Card 2.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "GRID," to identify coordinate system selected.
6-10		Read "CYLN," for cylindrical coordinate system (this option is not available for GEOTHER version VT3). Read "CART," for Cartesian coordinate system.
11-15	NX	Number of grids in X-direction (columns).
16-20	NY	Number of grids in Y-direction (slices).
21-25	NZ	Number of grids in Z-direction (rows).

<u>Column</u>	<u>Variable</u>	<u>Description</u>
26-30	MBW	Bandwidth of equation matrix. If set to zero, program will calculate maximum value (constant nodes are ignored in matrix setup).
66-70	GRAV	Gravitational constant (default = 980.0).
72-80		Any identification symbols except asterisks in last four fields (not read by code).

Card 3.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "TIME," for time step control parameters.
6-10		Leave blank.
11-15	NT	Final time step.
16-20	ITEROP	Optimum number of iterations (not used).
21-25	TIME	Initial simulation time.
26-30	DELTI	Time step used initially. (If set to zero, code will calculate an initial time step. However, this is not recommended).
31-35	TSTOP	Total simulation time.
36-40	DTYMAX	Maximum time step allowed.
41-45	DTFAC	Maximum factor for time step increase.
46-50	SWC	Maximum saturation change for time step control.
71-73	UNITS	Read "SEC" for time in seconds. Read "MIN" for time in minutes. Read "HRS" for time in hours. Read "DAY" for time in days. Read "WKS" for time in weeks. Read "MON" for time in months. Read "YRS" for time in years. (Default is CGS unit.)

Card 4.0 (Skip if the case is not a restart)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "REST," for restart option.
6-10		Leave blank.
11-15	IRST	Time step number from which to restart.

This card is omitted if the run is not a restart run.

Card 5.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "INPU," for selecting input option for groundwater temperature or enthalpy.
6-10		Input "TEMP," if temperature array is read. Input "ENTH," if enthalpy array is read. In a restart case, the enthalpy array is read regardless of which option is chosen here. To avoid confusion, always input "ENTH," in a restart case.
72-80		Any identification symbols except asterisks in last four fields (not read by code).

Card 6.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "ITER," for iteration control parameters.
6-10		Leave blank.
11-15	NJ	Maximum number of Newton-Raphson iterations (MAXNJ ≥ 2).
16-20	NIT	Maximum number of slice SOR (SSOR) iterations per time step.
21-25	W0	Relaxation factor in SSOR iterations (default = 1.2).
26-30	TOL	Tolerance for SSOR iteration (default = 0.01).
31-35	TOLNR	Tolerance for Newton-Raphson iteration in percent (default = 0.02).

<u>Column</u>	<u>Variable</u>	<u>Description</u>
36-40	IREGIM	IREGIM = 1 block will be set to new phase regime through the remaining Newton-Raphson iterations in a time step when a phase change is detected. IREGIM = 0 phase regime of each block will be updated in each Newton-Raphson iteration using the latest (P,h) combination. (IREGIM=1 is recommended.)
41-45		Leave blank.
46-50		Leave blank.
51-55	FACNR	Factor in smoothing the property coefficients at phase transition (suggested values 0.1 - 1.0). If input zero or left blank, no smoothing will be done.
72-80		Any identification symbols except asterisks in last four fields (not read by code).

Note: FACNR is used to smooth the transition of the property coefficients for a given block at phase change from old time step to new time step inside Newton-Raphson iteration. A small value allows a slower transition, large values a faster transition. The coefficients are set to a new phase without smoothing after five Newton-Raphson iterations.

Card 6a.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DAMP," for damping in Newton-Raphson iteration damping.
6-10		Read "PRES," for pressure damping factor input; "ENTH," for enthalpy damping factor input; "ROCT," for rock/solid temperature damping factor input.
11-15	I_1	Starting Newton-Raphson iteration number.
16-20	I_2	Ending Newton-Raphson iteration number.
21-25	DAMP1	Damping factor used for Newton-Raphson iteration numbers from I_1 to I_2 .
26-30	I_3	Starting Newton-Raphson iteration number.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
31-35	I ₄	Ending Newton-Raphson iteration number.
36-40	DAMP2	Damping factors used for Newton-Raphson iteration numbers from I ₃ to I ₄ .
41-45	I ₅	Starting Newton-Raphson iteration number.
46-50	I ₆	Ending Newton-Raphson iteration number.
51-55	DAMP3	Damping factors used for Newton-Raphson iteration numbers from I ₅ to I ₆ .
56-60	I ₇	Starting Newton-Raphson iteration number.
61-65	I ₈	Ending Newton-Raphson iteration number.
66-70	DAMP4	Damping factors used for Newton-Raphson iteration numbers from I ₇ to I ₈ .

Card 6a.0 may be repeated as many times as needed until all damping factors are read. However, the maximum number of damping factors is MAXNJ (see Program Redimensioning for definition of MAXNJ) for each of the three types (pressure, enthalpy, and rock temperature). If a damping factor for a given Newton-Raphson iteration is not input, it will be defaulted to 1.0 (i.e., no damping).

Card 7.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "MISC," for miscellaneous input parameters.
11-15	IOPT	IOPT = 1 for upstream weighing on pressure (recommended). IOPT = 2 for midpoint weighing.
16-20	NHPC	Number of constant nodes (i.e., boundary nodes).
72-80		Any identification symbols except asterisks in last four fields (not read by code).

Card 8.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "XTRA," for extra input parameters. Not used in this version.

Card 9.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "AOUT," for output print options.
6-10		Read "PRES,", "SATU,", "TEMP,", "ENTH," or "ROCT,", "XVEL," "YVEL," or "ZVEL," (or any combination of them) to have printout of pressure saturation, water temperature or enthalpy, and rock temperature arrays, X-, Y-, and Z-direction velocities, respectively.
11-15		
16-20		
21-25		
26-30		
31-35		
35-40		
72-80		Any identification symbols except asterisks in last four fields.

Card 10.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DEBUG," for debug printout.
6-10		Blank.
11-15	IDBUG(1)	Debug flag for dumping input information on debug file "BUGOUT." IDBUG(1) = 0 - No debug dump. IDBUG(1) = 1 - Debug dump.
16-20	IDBUG(2)	Debug flag for dumping bit packing information on debug file "BUGOUT." IDBUG(2) = 0 - No debug dump. IDBUG(2) = 1 - Debug dump.
21-25	IDBUG(3)	Debug flag for dumping thermodynamic properties (in PRPTY) on output file. IDBUG(3) = 0 - No debug dump. IDBUG(3) = 1 - Debug dump.
26-30	IDBUG(4)	Debug flag for dumping matrix elements and matrix solutions. IDBUG(4) = 0 - No debug dump.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
		IDBUG(4) = 1 - Debug dump.
31-35	IDBUG(5)	Debug flag for dumping energy balance parameters (in BALNCE).
		IDBUG(5) = 0 - No debug dump.
		IDBUG(5) = 1 - Debug dump.

Card 11.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "PRNT," for output control.
6-10		Leave blank.
11-15	IPRT	Number of time steps between printing output.
16-20	NA	Number of arrays to be printed (i.e., number of entries in Card 9.0).
21-25	JPRT	Number of time steps between graphics dump to Tape 11.
26-30	NAVE	NAVE = 1 to print depth-averaged values of arrays. NAVE = 0 otherwise.
72-80		Any identification symbols except asterisks in the last four fields.

Card 12.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "PROP," for property input.
11-13		Read "MAT" for material type input that follows.
16-20	MAT	Read material type identification number (for basalt, MAT = 51).
26-30	ITYPE	Read "COREY" for Corey-type relative permeability, read "LINEA" for linear relative permeability.
71-72	UNITS	Option applies to length only. Read "ES" if engineering units are used. Read "IN" if length input is in inches. Read "SI" if SI units are used. Read "CM" if CGS units are used. (Default is CGS unit).

Card 12.1 (For material type MAT)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-8		Any Hollerith identification.
9-10	IGRP	Data group number (IGRP = 1 to 4).
16-20		Any Hollerith identification.
21-30	PROP1	PROP1 = water thermal conductivity for IGRP = 1 PROP1 = rock or solid material compressibility for IGRP = 2 PROP1 = porosity for IGRP = 3 PROP1 = X-direction permeability for IGRP = 4
36-40		Any Hollerith identification.
41-50	PROP2	PROP2 = rock or solid material density for IGRP = 1 PROP2 = rock or solid material thermal conductivity ^(a) for IGRP = 2 PROP2 = residual water saturation for IGRP = 3 PROP2 = Y-direction permeability for IGRP = 4
56-60		Any Hollerith identification.
61-70	PROP3	PROP3 = rock or solid material specific heat ^(a) for IGRP = 1 PROP3 = rock to water heat transfer parameter (HRW) for IGRP = 2 PROP3 = residual steam saturation for IGRP = 3 PROP3 = Z-direction permeability for IGRP = 4
71-72	UNITS	Option applies to length only Read "ES" if engineering units is input. Read "IN" if length input is in inches. Read "SI" if SI unit is input. Read "CM" if CGS unit is input. (Default is CGS unit).

(a) If MAT = 51, leave blank; code will calculate these values for basalt.

Card 12.1 is read four times, starting with IGRP = 1 and ending with IGRP = 4. Repeat Card set 12.0 and 12.1 for as many times as there are material types.

Card 13.0 (Read this card only if "CYLN," option is used in GRID card (Card 2.0))

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DELR," for input of node radial spacing in a cylindrical coordinate system.
6-10		Input "AUTO," for automatic calculation of radial spacing. Input "SING," for user input of radial spacings (skip to Card 13.1). Leave blank for compressed input (skip to Card 13.2).

If option "AUTO" is input in Columns 6-10, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-20		Any Hollerith identification symbols.
21-30	RSQ(1)	Well radius.
31-40		Any Hollerith identification symbols.
41-50	RSQ(NXX)	Maximum reservoir radius.
51-60		Any Hollerith identification symbols.
61-70	DX(1)	Radius of first node from well.
71-72	UNITS	Read "ES" if input is in engineering units. Read "IN" if length input is in inches. Read "SI" if SI units are used. Read "CM" if CGS units are used. (Default is CGS unit.)
73-80		Any Hollerith symbols except asterisks in last 4 columns.

Note: Code will calculate the radius increments on a logarithmic scale using RSQ(NXX) and DX(1) as the radius limits.

If option "SING," is read in Columns 6-10, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	N1	Starting radial-direction index.
16-20	N2	Ending radial-direction index.
21-30	DELTA(1)	The next five DELTA inputs are the radial spacing inputs.
31-40	DELTA(2)	
41-50	DELTA(3)	
51-60	DELTA(4)	
61-70	DELTA(5)	
71-72	UNITS	Read "ES" if input is in engineering units. Read "IN" if length input is in inches. Read "SI" if SI units are used. Read "CM" if CGS units are used. (Default is CGS unit.)

Card 13.0 with the "SING," option may be repeated as many times as needed to read all DR(I)s.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
73-80		Any Hollerith symbols except asterisks in last four columns.

If Columns 6-10 are left blank, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	I ₁	Starting radial direction index.
16-20	I ₂	Ending radial direction index.
21-30	DELR1	Radial direction spacing DX(I) for blocks with radial indices from I ₁ to I ₂ (i.e., DR(I ₁) = DR(I ₁ +1) = ... = DR(I ₂)).
31-35	I ₃	Starting radial direction index.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
36-40	I ₄	Ending radial direction index.
41-50	DELR2	Radial direction spacing for blocks with radial indices from I ₃ to I ₄ .
51-55	I ₅	Starting radial direction index.
56-60	I ₆	Ending radial direction index.
61-70	DELR3	Radial direction spacing for blocks with radial indices from I ₅ to I ₆ .
71-72	UNITS	Option applies to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default is CGS unit.)

Card 13.0 with the "BLANK" option may be repeated as many times as needed to read all DR(I)s.

Card 14.0 (Read this card only if "CART," option is used in GRID card, i.e., Card 2.0).

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DELX," for input of block spacings in X-direction in a Cartesian coordinate system.
6-10		Input "AUTO," for automatic calculation of X-direction spacing (this option is not available for this version). Input "SING," for user input of X-direction spacings. Leave blank for compressed input.

If option "SING," is read in Columns 6-10, read the following in Columns 11-80.

Column	Variable	Description
11-15	N1	Starting X-direction index.
16-20	N2	Ending X-direction index where $N_2 \leq N_1+4$.
21-30	DELTA(1)	The next (N_2-N_1+1) DELTA inputs are the X spacing inputs.
31-40	DELTA(2)	(i.e. $DELTA(1) = DX(N_1)$, $DELTA(2) = DX(N_1+1)$, etc.,
41-50	DELTA(3)	until $DELTA(N_2-N_1+1) = DX(N_2)$
51-60	DELTA(4)	
61-70	DELTA(5)	
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default CGS unit.)
73-80		Any Hollerith symbols except asterisks in last four columns.

Card 14.0 with the "SING," option may be repeated as many times as needed until all X spacings $DX(I)$ are read.

If Columns 6-10 are blank, read the following in Columns 11-80.

Column	Variable	Description
11-15	I_1	Starting X-direction index.
16-20	I_2	Ending X-direction index.
21-30	DELX1	X-direction spacing for blocks with X indices from I_1 to I_2 .
31-35	I_3	Starting X-direction index.
36-40	I_4	Ending X-direction index.
41-50	DELX2	X-direction spacing for blocks with X indices from I_3 to I_4 .
51-55	I_5	Starting X-direction index.
56-60	I_6	Ending X-direction index.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
61-70	DELX3	X-direction spacing for blocks with X indices from I_5 to I_6 .
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default is CGS unit.)

Card 14.0 with the "blank" option may be repeated as many times as needed until all X spacings $DX(I)$ are read.

Card 15.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DELY," for input of block spacings in Y-direction in a Cartesian coordinate system.
6-10		Input "AUTO," for automatic calculation of Y-direction spacing (this option is not available for this version). Input "SING," for user input of Y-direction spacings. Leave blank for compressed input.

If option "SING" is read in Columns 6-10, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	N1	Starting Y-direction index.
16-20	N2	Ending Y-direction index where $N_2 \leq N_1+4$.
21-30	DELTA(1)	The next (N_2-N_1+1) DELTA inputs are the Y spacing inputs;
31-40	DELTA(2)	(i.e., $DELTA(1) = DX(N_1)$, $DELTA(2) = DX(N_1+1)$, etc.,
41-50	DELTA(3)	until $DELTA(N_2-N_1+1) = DX(N_2)$
51-60	DELTA(4)	
61-70	DELTA(5)	

Column	Variable	Description
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default CGS unit.)
73-80		Any Hollerith symbols except asterisks in last four columns.

Card 15.0 with the "SING," option may be repeated as many times as needed until all Y spacings DY(I) are read.

If Columns 6-10 are blank, read the following in Columns 11-80.

Column	Variable	Description
11-15	I ₁	Starting Y-direction block index.
16-20	I ₂	Ending Y-direction block index.
21-30	DELY1	Y-direction spacing for blocks with Y indices from I ₁ to I ₂ .
31-35	I ₃	Starting Y-direction index.
36-40	I ₄	Ending Y-direction index.
41-50	DELY2	Y-direction spacing for blocks with Y indices from I ₃ to I ₄ .
51-55	I ₅	Starting Y-direction index.
56-60	I ₆	Ending Y-direction index.
61-70	DELY3	Y-direction spacing for blocks with Y indices from I ₅ to I ₆ .
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default is CGS unit.)

Card 15.0 with the "blank" option may be repeated as many times as needed until all Y spacings DY(I) are read.

Card 16.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "DELZ," for input of block spacings in Z-direction in a Cartesian coordinate system.
6-10		Input "AUTO," for automatic calculation of Z-direction spacing (this option is not available for this version). Input "SING," for user input of Z-direction spacings. Leave blank for compressed input.

If option "SING" is read in Columns 6-10, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	N1	Starting Z-direction index.
16-20	N2	Ending Z-direction index where $N_2 \leq N_1 + 4$.
21-30	DELTA(1)	The next $(N_2 - N_1 + 1)$ DELTA inputs are the Z spacing inputs;
31-40	DELTA(2)	(i.e., $DELTA(1) = DZ(N_1)$, $DELTA(2) = DZ(N_1 + 1)$, etc.,
41-50	DELTA(3)	until $DELTA(N_2 - N_1 + 1) = DZ(N_2)$
51-60	DELTA(4)	
61-70	DELTA(5)	
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default CGS unit.)
73-80		Any Hollerith symbols except asterisks in last four columns.

Card 16.0 with the "SING," option may be repeated as many times as needed until all Z spacings DZ(I) are read.

If Columns 6-10 are blank, read the following in Columns 11-80.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	I_1	Starting Z-direction block index.
16-20	I_2	Ending Z-direction block index.
21-30	DELZ1	Z-direction spacing for blocks with Z indices from I_1 to I_2 .
31-35	I_3	Starting Z-direction index.
36-40	I_4	Ending Z-direction index.
41-50	DELZ2	Z-direction spacing for blocks with Z indices from I_3 to I_4 .
51-55	I_5	Starting Z-direction index.
56-60	I_6	Ending Z-direction index.
61-70	DELZ3	Z-direction spacing for blocks with Z indices from I_5 to I_6 .
71-72	UNITS	Options apply to length input only. Read "ES" for engineering unit. Read "IN" for length input in inches. Read "SI" for SI unit. Read "CM" for CGS unit. (Default is CGS unit.)

Card 16.0 with the "blank" option may be repeated as many times as needed until all Z spacings DZ(I) are read.

Card 17.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "MESH" for setting up blocks types.
6-10		Leave blank.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
11-15	ICT	Block cell type. ICT = 0 for Dirichlet type boundary cells. The temperature and pressure input for this cell are used as fixed boundary conditions. ICT = 1 for Neumann type boundary cells. Current version allows only adiabatic and no flow boundary conditions. ICT = 2 for active porous interior cell. ICT = 3 for active nonporous internal cell (solid material cell).
16-20	MAT	Material type. This input corresponds to the property set in the "PROP" card.
21-25	L ₁	Table type for heat table input.
26-30	L ₂	Table type for temperature table input.
31-35	L ₃	Table type for pressure table input.
36-40	L ₄	Table type for mass source table input.
41-45	I1	Starting X index of blocks with cell ICT, material type MAT, and table type NTAB.
46-50	I ₂	Ending X-index of blocks with cell type ICT, material type MAT, and table type NTAB.
51-55	K ₁	Starting Z-index of blocks with cell type ICT, material type MAT, and table type NTAB.
55-60	K ₂	Ending Z-index of blocks with cell type ICT, material type MAT, and table type NTAB.
61-65	J ₁	Starting Y-index of blocks with cell type ICT, material type MAT, and table type NTAB.
66-70	J ₂	Ending Y-index of blocks with cell type ICT, material type MAT, and table type NTAB.

Card 17.0 may be repeated as many times as needed until all blocks are input.

Card 18.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-5		Read "TABL," for table input.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
6-10		Read "QGEN," for heat generation table input (currently, only heat generation table input is allowed).
11-15		Read "INIT," for initial parameter input (see below for details). Read "F10" for input of table values in F format of field length 10. (Input is right-adjusted.) Read "F5" for input of table values in F format of table values in F format of field length 5. (Input is right-adjusted.)

(Note: Option "INIT," must be selected once for each table. However, either or both of the format options may be selected.)

If option "INIT," is read in Columns 11-15, read the following in Columns 16-40.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
16-20	ATAB	Read table identification number (an integer).
21-25	AENT	Read number of entries for table ATAB (an integer).
31-40	VINIT	Read initial value for table ATAB (in erg per second per block).
71-72	VUNITS	Not used.

If option "F10" is read in Columns 13-15, read the following in Columns 16-73.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
16-20	NTAB	Read table number. This corresponds to ATAB above.
21-25	N_1	Input starting entry point.
26-30	N_2	Input ending entry point (two entries per card, i.e., $N_1 \leq N_2 \leq N_1 + 1$).
31-40	TM(1)	Input time at starting entry point. Unit depends on the "UNITS" option read in Columns 71-73.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
41-45	VAL(1)	Input fractional value of table NTAB at time TM(1).
51-60	TM(2)	Input time at ending entry point. Unit depends on the "UNITS" option read in Columns 71-73.
61-70	VAL(2)	Input fractional value of table NTAB at time TM(2).
71-73	UNITS	Read "SEC" for time in seconds. Read "MIN" for time in minutes. Read "HRS" for time in hours. Read "DAY" for time in days. Read "WKS" for time in weeks. Read "MON" for time in months. Read "YRS" for time in years. (Default is CGS unit.)

If option "F5" is read in Columns 14-15, read the following in Columns 16-73.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
16-20	NTAB	Read table number. This corresponds to ATAB above.
21-25	N ₁	Read starting entry point.
26-30	N ₂	Read ending entry point (four entries per card, i.e., $N_1 \leq N_2 \leq N_1 + 3$).
31-35	TM(1)	The next (N ₂ - N ₁ + 1) pairs of (TM, VAL) inputs are the time versus fractional values inputs for table NTAB. The unit of TM depends on "UNITS" input in Columns 71-73.
36-40	VAL(1)	
41-45	TM(2)	
46-50	VAL(2)	
51-55	TM(3)	
56-60	VAL(3)	
61-65	TM(4)	
66-70	VAL(4)	
71-73	UNITS	Read "SEC" for time in seconds. Read "MIN" for time in minutes. Read "HRS" for time in hours. Read "DAY" for time in days.

<u>Column</u>	<u>Variable</u>	<u>Description</u>
		Read "WKS" for time in weeks.
		Read "MON" for time in months.
		Read "YRS" for time in years.
		(Default is CGS unit.)

Repeat Card 18.0 until all tables are read in.

Card 19.0 (Skip Card Group 19 if case is a restart)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-8		Read "PRESSURE" for pressure array input.

Card 19.1

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-10		Read "FREE" starting in column 1 for free format input of pressure array in Card 19.2.
		Read "CONSTANT" if array is constant. Read only one value in Card 19.2 using free format.
		Read specified format. If a fixed format is required, such as 8F10.3, read (8F10.3). The format must consist of a list of format specifications enclosed in parentheses, but without the word FORMAT. The specific format will be used for Card 19.2.

Note: If a single constant value is input (i.e., "CONSTANT" option is used), program will calculate the initial hydrostatic pressure distribution assuming the top row ($K=NZ$) has the input pressure value. If an array is input for every block (i.e., FREE or fixed format option), the input pressure distribution is used as the initial pressure conditions.

Card 19.2

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-80	P(ICK)	Input values to fill the pressure array. If constant (i.e., option "CONSTANT" is used in Card 19.1), only one value is read. Otherwise, read arrays in the order of blocks with X-index changing first, then Z-index, then Y-index. Start a new card with each new Z or Y index. Unit is in dynes/cm ² .

Repeat Card 19.2 as many times as needed to fill the pressure array.

Card 20.0 (Skip Card Group 20 if case is a restart)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-8		Read "ENTHALPY" for enthalpy or temperature array input.

Card 20.1

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-10		Read "FREE" starting in column 1 for free format input of enthalpy or temperature array in Card 19.2. Read "CONSTANT" if array is constant. Read only one value in Card 19.2 using free format. Read specified format. If a fixed format is required, such as 8F10.3, read (8F10.3). The format must consist of a list of format specifications enclosed in parentheses, but without the word FORMAT. The specific format will be used for Card 20.2.

Card 20.2

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-80	H(ICK)	Input values to fill the enthalpy or temperature array. If constant (i.e., option "CONSTANT" is used in Card 20.1), only one value is read. Otherwise, read arrays in the order of blocks with X-index

<u>Column</u>	<u>Variable</u>	<u>Description</u>
		changing first, then Z-index, then Y-index. Start a new card with each new Z or Y index. If "TEMP," is selected in Card 5.0, input temperature array in °C. If "ENTH," is selected, input enthalpy array in erg/g.

Repeat Card 20.2 as many times as needed to fill the enthalpy or temperature array.

Card 21.0 (Skip Card Group 21 if case is a restart)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-8		Read "ROCKTEMP," for rock temperature array input.

Card 21.1

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-10		Read "FREE" starting in column 1 for free format input of rock temperature array in Card 21.2. Read "CONSTANT" if array is constant. Read only one value in card 21.2 using free format. Read specified format. If a fixed format is required, such as 8F10.3, read (8F10.3). The format must consist of a list of format specifications enclosed in parentheses, but without the word FORMAT. The specific format will be used for Card 21.2.

Card 21.2

<u>Column</u>	<u>Variable</u>	<u>Description</u>
1-80	TR(ICK)	Input values to fill the rock temperature array. If constant (i.e., option "CONSTANT" is used in Card 21.1), only one value is read. Otherwise, read arrays in the order of blocks with X-index changing first, then Z-index, then Y-index. Start a new card with each new Z or Y index. Unit is °C.

Repeat Card 21.2 as many times as needed to fill the rock temperature array.

Card 22.0

<u>Column</u>	<u>Variable</u>	<u>Description</u>
Free ^(a)	NTP	Number of grid blocks for which data is saved on Tape 12.

Card 22.1 (Skip if NTP = 0)

<u>Column</u>	<u>Variable</u>	<u>Description</u>
Free	I	Input three integers in free format. The three indices define the grid block whose data are saved on Tape 12.
Free	J	
Free	K	

Repeat Card 22.1 NTP times.

EPRI WATER PROPERTY PACKAGE

Water property functions used in GEOTHER/VT4 were developed by the Electric Power Research Institute (EPRI 1981). The EPRI package correlates water temperature and specific volume as functions of pressure and specific enthalpy, saturated liquid and vapor enthalpies as functions of pressure, and thermal conductivity and dynamic viscosity as functions of temperature and density. The expressions for temperature and specific volume are valid in the range of pressures from 0.1 to 6000 psia and enthalpies from approximately 200 to 1750 Btu/lbm. It is recommended that the functions not be used outside this range. Most of the functional fittings are in terms of the British units. These units must be converted so they will fit the GEOTHER calculation which is done in CGS units.

The average errors in the expressions for temperature and specific volume are approximately 0.15% and 0.4%, respectively. The expressions for the saturated liquid and vapor specific enthalpies are valid in the range

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(a) Input value is free format.

from 0.1 psia to the critical pressure (3208.2 psia). The saturation^(a) values are generally within 0.04% of the 1967 ASME values, but the errors approach 1% in the vicinity of the critical point.

Saturated Liquid and Saturated Vapor Enthalpies as Functions of Pressure

The specific enthalpy of saturated liquid, h_f , or saturated vapor, h_g , is a function of only pressure, p . The relationships may be adequately approximated throughout the range of pressures from 0.1 psia to the critical pressure of 3208.2 psia (p_{CRIT}) by the following functions:

$$\sum_{i=1}^9 CF1_i (\ln(p))^i \quad \text{if } 0.1 \text{ psia} \leq p \leq 950 \text{ psia} \quad (B.30)$$

$$h_f = \sum_{i=1}^9 CF2_i (\ln(p))^i \quad \text{if } 850 \text{ psia} \leq p \leq 2550 \text{ psia} \quad (B.31)$$

$$\sum_{i=1}^9 CF3_i ((p_{CRIT} - p)^{0.41})^i \quad \text{if } 2350 \text{ psia} \leq p \leq p_{CRIT} \quad (B.32)$$

and

$$\sum_{i=1}^{12} CG1_i (\ln(p))^i \quad \text{if } 0.1 \text{ psia} \leq p \leq 1550 \text{ psia} \quad (B.33)$$

$$h_g = \sum_{i=1}^9 CG2_i (\ln(p))^i \quad \text{if } 950 \text{ psia} \leq p \leq 2650 \text{ psia} \quad (B.34)$$

$$\sum_{i=1}^7 CG3_i ((p_{CRIT} - p)^{0.41})^i \quad \text{if } 2550 \text{ psia} \leq p \leq p_{CRIT} \quad (B.35)$$

The constant coefficients, CFn_i and CGn_i , in Equations B.30 through B.35 are listed in Table B.4. The resulting specific enthalpy is in units of Btu/lbm.

(a) The term "saturation" in this section is used in the thermodynamic sense.

Note that the subintervals overlap. Within each region, either of the two corresponding expressions yields a good approximation.^(a)

Liquid and Vapor Temperature as Functions of Enthalpy and Pressure

The temperature of water is approximated by the following function of pressure and enthalpy:

$$T_l = \sum_{i=1}^{i=2} \sum_{j=1}^{j=4} CT1_{i,j} p^i h^j \quad \text{if } p < p_{CRIT} \text{ and } h \leq h_f(p) \quad (B.36)$$

(Liquid Region)

$$T_l = \sum_{i=1}^{i=5} \sum_{j=1}^{j=5} CT2_{i,j} p^i h^j \quad \text{if } p \geq p_{CRIT} \text{ and } h \leq h_f(p_{CRIT}) \quad (B.37)$$

(Critical Region)

$$T_v = \sum_{i=1}^{i=5} \sum_{j=1}^{j=5} CT3_{i,j} p^i h^j \quad \text{if } p < p_{CRIT} \text{ and } h \geq h_g(p) \quad (B.38)$$

(Vapor Region)

$$T_v = \sum_{i=1}^{i=5} \sum_{j=1}^{j=5} CT4_{i,j} p^i h^j \quad \text{if } p \geq p_{CRIT} \text{ and } h > h_g(p_{CRIT}) \quad (B.39)$$

(Critical Region)

TABLE B.4. Constants for Saturated Liquid and Vapor Enthalpies as Functions of Pressure

i	CF1 _i	CF2 _i	CF3 _i
1	0.6970887859E2	0.8408618802E6	0.9060030436E3
2	0.3337529994E2	0.3637413208E6	-0.1426813520E2
3	0.2318240735E1	-0.4634506669E6	0.1522233257E1
4	0.1840599513E0	0.1130306339E6	-0.6973992961E0
5	-0.5245502284E-2	-0.4350217298E3	0.1743091663E0
6	0.2878007027E-2	-0.3898988188E4	-0.2319717696E-1
7	0.1753652324E-2	0.6697399434E3	0.1694019149E-2
8	-0.4334859620E-3	-0.4730726377E2	-0.6454771710E-4
9	0.3325699282E-4	0.1265125057E1	0.1003003098E-5

(a) In GEOTHER, the transitions for h_f are 950 psia for Equations (B.30) to (B.31), 2550 psia for Equations (B.31) to (B.32), 950 psia for Equations (B.33) to (B.34), and 2650 psia for Equations (B.34) to (B.35).

TABLE B.4. contd.

i	CG1 _i	CG2 _i	CG3 _i
1	0.1105836875E4	-0.2234264997E7	0.9059978254E3
2	0.1436943768E2	0.1231247634E7	0.5561957539E1
3	0.8018288621E0	-0.1978847871E6	0.3434189609E1
4	0.1617232913E-1	0.1859988044E2	-0.6406390628E0
5	-0.1501147505E-2	-0.2765701318E1	0.5918579484E-1
6	0.0000000000E0	0.1036033878E4	-0.2725378570E-2
7	0.0000000000E0	-0.2143423131E3	0.5006336938E-4
8	0.0000000000E0	0.1690507762E2	
9	0.0000000000E0	-0.4864322134E0	
10	-0.1237675562E-4		
11	0.3004773304E-5		
12	-0.2062390734E-6		

The constant coefficients, $CT_{i,j}$, in Equations (B.36) through (B.39) are listed in Table B.5. The resulting water temperature is in units of degrees F. The values for p_{CRIT} and $h(p_{CRIT})$ are 3208.2 psia and 906 Btu/lbm, respectively.

The two-phase region is described by the criteria that $0.1 \text{ psia} < p \leq p_{CRIT}$ and $h_f(p) < h < h_g(p)$. Temperature is constant along lines of constant pressure across this region. Thus, within the two-phase region,

$$T_f = \sum_{i=1}^{i=2} \sum_{j=1}^{j=4} CT_{i,j} p^i [h_f(p)]^j \quad (\text{Two-Phase Region}) \quad (B.40)$$

Specific Volume of Liquid and Vapor as Functions of Enthalpy and Pressure

The specific volume, v , of water is approximated by the following function of pressure and enthalpy:

$$v_L = \exp \left(\sum_{i=1}^3 \sum_{j=1}^5 CN_{i,j} p^i h^j \right) \quad \begin{array}{l} \text{if } p < p_{CRIT} \text{ and } h_f \leq h(p) \\ \text{of if } p \geq p_{CRIT} \text{ and } h < 1000 \text{ Btu/lbm} \end{array} \quad (B.41)$$

(Liquid Region)

$$v_v = \left(\sum_{i=1}^4 \sum_{j=1}^3 CN2_{i,j} p^i h^j \right) \quad \begin{array}{l} \text{if } p < p_{CRIT} \text{ and } h_f \geq h(p) \\ \text{or if } p \geq p_{CRIT} \text{ and } h > 1000 \text{ Btu/lbm} \\ \text{(Vapor Region)} \end{array} \quad (B.42)$$

The constant coefficients, $CNn_{i,j}$, in Equations (B.41) and (B.42) are listed in Table B.6. The resulting specific volume, v , is in units of ft^3/lbm . The critical pressure division value is 3208.2 psia and the saturation enthalpy boundary functions, h_f and h_g .

The two-phase region bounded by the liquid and vapor saturation lines requires the quality, x , which is defined under thermal equilibrium conditions as

$$x = \frac{h - h_f(p)}{h_g(p) - h_f(p)} \quad (B.43)$$

When the quality is greater than zero, the specific volume of the two-phase mixture is expressed by

$$v = N_\ell(p, h_\ell) + x [N_g(p) - N_\ell(p, h_\ell)] \quad (B.44)$$

where

$$N_\ell(p, h) \equiv \exp \left(\sum_{i=1}^3 \sum_{j=1}^5 CN1_{i,j} p^i h_\ell^j \right) \quad (B.45)$$

and

$$N_g(p) \equiv \sum_{i=1}^4 \sum_{j=1}^3 CN2_{i,j} p^i [h_g(p)]^j \quad (B.46)$$

TABLE B.5. Constants for Temperature as a Function of Pressure and Enthalpy

$CT1_{i,j}$

i/j	1	2	3	4
1	0.3276275552E2	0.9763617000E0	0.1857226027E-3	-0.4682674330E-6
2	0.3360880214E-2	-0.5595281760E-4	0.1618595991E-6	-0.1180204381E-9

$CT2_{i,j}$

i/j	1	2	3	4	5
1	0.6390801208E3	-0.3055217235E1	0.8713231868E-2	-0.6269403683E-5	-0.9844700000E-17
2	-0.4302857237E0	0.2673303442E-2	-0.5198380474E-5	0.3037825558E-8	0.3309704045E-17
3	0.1174524584E-3	-0.6839200986E-6	0.1168011772E-8	-0.4260074181E-12	-0.2732087163E-15
4	-0.1473977290E-7	0.8018858166E-10	-0.1164901355E-12	0.4559400289E-17	0.5825511142E-19
5	0.7104327342E-12	-0.3649500626E-14	0.4457387575E-17	0.1678398723E-20	-0.3756804091E-23

$CT3_{i,j}$

i/j	1	2	3	4	5
1	-0.1179100862E5	0.2829274345E2	-0.2678181564E-1	0.1218742752E-4	-0.2092033147E-8
2	0.1256160907E3	-0.3333448850E0	0.3326901268E-3	-0.1477890326E-6	0.2463258371E-10
3	-0.1083713369E0	0.2928177730E-3	-0.2972436458E-6	0.1342639113E-9	-0.2275585718E-13
4	0.3278071846E-4	-0.8970959364E-7	0.9246248312E-10	-0.4249155515E-13	0.7338316751E-13
5	-0.3425564927E-8	0.9527692453E-11	-0.1001409043E-13	0.4703914404E-17	-0.8315044742E-21

$CT4_{i,j}$

i/j	1	2	3	4	5
1	0.3795256853E4	-0.6347031007E1	0.2867228326E-2	0.5953599813E-8	0.4798207438E-10
2	-0.3910086240E1	0.1222747819E-1	-0.1404664699E-4	0.7505679464E-8	-0.1608693653E-11
3	0.3410500159E-4	0.7010900113E-9	-0.1030201866E-9	0.5731099333E-14	0.3720795449E-16
4	0.1527377542E-8	-0.5356866315E-9	0.6823225984E-12	-0.3668096142E-15	0.6946004624E-19
5	-0.1437179752E-10	0.5006731336E-13	-0.6365519546E-16	0.3473711350E-19	-0.6842306083E-23

TABLE B.6. Constants for Specific Volume as a Function of Pressure and Enthalpy

i/j	<u>CN1_{i,j}</u>				
	1	2	3	4	5
1	-0.4117961750E1	-0.3811294543E-3	0.4308265942E-5	-0.9160120130E-8	0.8017924673E-11
2	-0.4816067020E-5	0.7744786733E-7	-0.6988467605E-9	0.1916720525E-11	-0.1760288590E-14
3	-0.1820625039E-8	0.1440785930E-10	-0.2082170753E-13	-0.3603625114E-16	0.7407124321E-19

i/j	<u>CN2_{i,j}</u>		
	1	2	3
1	-0.1403086182E4	0.1802594763E1	-0.2097279215E-3
2	0.3817195017E0	-0.5394444747E-3	0.1855203702E-6
3	-0.6449501159E-4	0.8437637660E-7	-0.2713755001E-10
4	0.7823817858E-8	-0.1053834646E-10	0.3629590764E-14

Thermal Conductivity as a Function of Temperature and Density

The thermal conductivity of water, k , may be correlated to its temperature, T , and density, ρ . The correlation utilized was formulated under the auspices of the International Association for the Properties of Steam as reported by Kestin (1978). For completeness, this correlation is described below in SI units:

$$k = \lambda_0 + \bar{\lambda} + \Delta\lambda \quad (\text{B.47})$$

where

$$\lambda_0 \equiv \left(\frac{T}{T^*}\right)^{1/2} \sum_{i=1}^4 a_i \left(\frac{T}{T^*}\right)^i \quad (\text{B.48})$$

$$\bar{\lambda} \equiv b_1 + b_2 \left(\frac{\rho}{\rho^*}\right) + b_3 \exp [B_1 \left(\frac{\rho}{\rho^*} + B_2\right)^2] \quad (\text{B.49})$$

$$\begin{aligned}
\Delta\lambda \equiv & [d_1 \left(\frac{T^*}{T}\right)^{10} - d_2] \left(\frac{\rho}{\rho^*}\right)^{1.8} + \exp \{C_1 [1 - \left(\frac{\rho}{\rho^*}\right)^{2.8}]\} \\
& + d_3 S \left(\frac{\rho}{\rho^*}\right)^Q \exp \left\{ \frac{Q}{R} [1 - \left(\frac{\rho}{\rho^*}\right)^R] \right\} \\
& + d_4 \exp \left[C_2 \left(\frac{T}{T^*}\right)^{1.5} + C_3 \left(\frac{\rho^*}{\rho}\right)^5 \right]
\end{aligned} \tag{B.50}$$

and

$$Q \equiv 2.0 + C_5 (\Delta T^*)^{-6} \tag{B.51}$$

$$R \equiv Q + 1.0 \tag{B.52}$$

$$\begin{aligned}
S = & (\Delta T^*)^{-1} \text{ for } T/T^* \geq 1.0 \\
& C_6 (\Delta T^*)^{-0.6} \text{ for } T/T^* < 1.0
\end{aligned} \tag{B.53}$$

with

$$\Delta T^* = \left| \frac{T}{T^*} - 1.0 \right| + C_4 \tag{B.54}$$

The constants in these expressions are as follows:

$T^* = 647.3 \text{ K}$	$\rho^* = 317.7 \text{ kg/m}^3$
$a_1 = 1.02811 \times 10^{-2} \text{ W/}^\circ\text{K-m}$	$d_1 = 7.01309 \times 10^{-2} \text{ W/}^\circ\text{K-m}$
$a_2 = 2.99621 \times 10^{-2} \text{ W/}^\circ\text{K-m}$	$d_2 = 1.18520 \times 10^{-2} \text{ W/}^\circ\text{K-m}$
$a_3 = 1.56146 \times 10^{-2} \text{ W/}^\circ\text{K-m}$	$d_3 = 1.69937 \times 10^{-3} \text{ W/}^\circ\text{K-m}$
$a_4 = -4.22464 \times 10^{-3} \text{ W/}^\circ\text{K-m}$	$d_4 = 1.02000 \text{ W/}^\circ\text{K-m}$
$b_1 = -3.97070 \times 10^{-1} \text{ W/}^\circ\text{K-m}$	$C_1 = 6.42857 \times 10^{-1}$

$$\begin{aligned}
b_2 &= 4.00302 \times 10^{-1} \text{ W/}^\circ\text{K-m} & C_2 &= -4.11717 \\
b_3 &= 1.06000 \text{ W/}^\circ\text{K-m} & C_3 &= -6.17937 \\
B_1 &= -1.71587 \times 10^{-1} & C_4 &= 3.08976 \times 10^{-3} \\
B_2 &= 2.39219 & C_5 &= 8.22994 \times 10^{-2} \\
& & C_6 &= 1.00932 \times 10^1
\end{aligned}$$

With these coefficients, the thermal conductivity given by Equation (B.47) has units of (W/K-m).

Dynamic Viscosity as a Function of Temperature and Density

The dynamic viscosity of water, μ , may be correlated to its temperature, T , and density, ρ . As in the case of thermal conductivity, a correlation (B.31) is utilized that was formulated under the auspices of the International Association for the Properties of Steam. This correlation in SI units is as follows:

$$\mu = \mu_0 \exp \left[\frac{\rho}{\rho^*} \sum_{i=1}^6 \sum_{j=1}^5 b_{ij} \left(\frac{T}{T^*} - 1 \right)^i \left(\frac{\rho}{\rho^*} - 1 \right)^j \right] \quad (\text{B.55})$$

where

$$\mu_0 \equiv 10^{-6} \left(\frac{T}{T^*} \right)^{1/2} \left[\sum_{k=1}^4 a_k \left(\frac{T}{T^*} \right)^k \right]^{-1} \quad (\text{B.56})$$

The constants appearing in these expressions have the numerical values given below and in Table B.7 for the b_{ij} .

$$\begin{aligned}
T^* &= 647.27 \text{ }^\circ\text{K} \\
\rho^* &= 317.763 \text{ kg/m}^3 \\
a_1 &= 0.0181583 \\
a_2 &= 0.0177424 \\
a_3 &= 0.0105287 \\
a_4 &= -0.0036744
\end{aligned}$$

The dynamic viscosity computed from Equation B.55 has units of ($\mu\text{Pa-s}$).

TABLE B.7. Coefficients b_{ij} for Dynamic Viscosity

i=	1	2	3	4	5	6
j=1	0.501 938	0.162 888	-0.130 356	0.907 919	-0.551 119	0.146 543
2	0.235 622	0.789 393	0.673 865	1.207 552	0.067 0665	-0.084 3370
3	-0.274 637	-0.743 539	-0.959 456	-0.687 343	-0.497 089	0.195 286
4	0.145 831	0.263 129	0.347 247	0.213 486	0.100 754	-0.032 932
5	-0.027 0448	-0.025 3093	-0.026 7758	-0.082 2904	0.060 2253	-0.020 2595

BENCHMARK CASE 1 INPUT LIST

The following list is test case file TEST2EQ2.INP. This input list was used in the GEOTHER code to establish baseline data for comparison with the results from GEOTHER/VT1, as discussed earlier in this appendix.

```

3,1,2,0
TEST CASE, RECTANGULAR 2-D MODEL
5,3,20,1,1,4,0,2
4
1,-1,2
3,-1,4
1.2,0.01,1,0,0
COREY
0.3,0.05
2.0E5,8.0E6,3.0,0.0,0.0
PRESSURE
FREE
0.1E9,0.1E8,0.1E9
0.1E9,0.1E8,0.1E9
ENTHALPY
FREE
50.0,30.0,50.0
50.0,30.0,50.0
XPERMEABILITY
CONSTANT
5.0E-17
YPERMEABILITY
CONSTANT
5.0E-17
ZPERMEABILITY
CONSTANT
5.0E-17
POROSITY
CONSTANT

```

```

0.001
YSPACING
CONSTANT
1.0
ZSPACING
CONSTANT
100.0
XSPACING
CONSTANT
100.0
PRESSURE
ENTHALPY
TEMPERATURE
SATURATION
0
1.E7,0.03,1.5,3.E7,0,0
1.E7,0.03,1.5,-1.0,0,0

```

The following list is test case file TEST3EQ2.INP. This input list was used for the GEOTHER/VT1 calculation described earlier.

```

3,1,2,0
TEST CASE, RECTANGULAR 2-D MODEL, 3-EQUATION MODEL
15,3,20,1,1,5,0,2
4
1,-1,2
3,-1,4
1.2,0.01,1,0,0
COREY
0.3,0.05
2.0E5,8.0E6,3.0,0.0,0.0
PRESSURE
FREE
0.1E9,0.1E8,0.1E9
0.1E9,0.1E8,0.1E9
ENTHALPY
FREE
50.0,30.0,50.0
50.0,30.0,50.0
ROCKTEMP
FREE
50.0,30.0,50.0
50.0,30.0,50.0
XPERMEABILITY
CONSTANT
5.0E-17
YPERMEABILITY
CONSTANT

```

5.0E-17
 ZPERMEABILITY
 CONSTANT
 5.0E-17
 POROSITY
 CONSTANT
 0.001
 YSPACING
 CONSTANT
 1.0
 ZSPACING
 CONSTANT
 100.0
 XSPACING
 CONSTANT
 100.0
 PRESSURE
 ENTHALPY
 TEMPERATURE
 SATURATION
 ROCKTEMP
 0
 1.E7,0.03,1.5,3.E7,0,0
 1.E7,0.03,1.5,-1.0,0,0

BENCHMARK CASE 2 INPUT LIST

21,1,2,0
 TEST CASE 2, RECTANGULAR 2-D MODEL,40 NODES, 3-EQUATION MODEL,40 NODES
 15,20,20,2,1,5,0,2
 40
 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,-1
 21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,-1
 1.2,0.01,1,0,0
 COREY
 0.3,0.05
 2.0E5,8.0E6,3.0,0.0,0.0
 PRESSURE
 FREE
 20*0.1E9,0.1E8
 20*0.1E9,0.1E8
 ENTHALPY
 FREE
 20*50.0,30.0
 20*50.0,30.0
 ROCKTEMP
 FREE
 20*50.0,30.0


```

20*50.0,30.0
XPERMEABILITY
CONSTANT
5.0E-15
YPERMEABILITY
CONSTANT
5.0E-15
ZPERMEABILITY
CONSTANT
5.0E-15
POROSITY
CONSTANT
0.001
YSPACING
CONSTANT
1.0
ZSPACING
CONSTANT
100.0
XSPACING
CONSTANT
4.878
PRESSURE
ENTHALPY
TEMPERATURE
SATURATION
ROCKTEMP
0
0.5E4,0.03,1.0,5.0E4,0,0
0.5E5,0.03,1.0,5.5E5,0,0
0.5E5,0.03,1.0,-1.0,0,0

```

GEOOTHER/VT4 CODE STRUCTURE

Twelve subroutines were added to the original code GEOOTHER. These new subroutines are briefly described below:

- ERROR - a diagnostic subroutine for printing out error messages
- INPUT - subroutine to read input in new format
- INTERP - subroutine for linear interpolation between points of a table input
- PRPTY1 - subroutine for thermodynamic properties calculations needed for velocity calculations
- ROCPRO - subroutine for calculating rock or solid (e.g., container) properties

SETARR - subroutine for setting permeability and porosity arrays based on input information
TABLES - subroutine to set QHEAT(ICF) array, i.e., heat generation rate for every block, if any, at each time step
TCALCR - subroutine for calculating rock/solid transmissibility terms
WPROP - subroutine for calculating water properties
VELOC - subroutine for calculating groundwater velocities
VERSION - subroutine for printing out version information
WRITEV - subroutine for printing out groundwater velocities

In addition to the above 12 subroutines, major changes were made to the following subroutines:

BALNCE, FORMEQ, GDATA, MAIN, PHREG, PRPTY, SSOR, UPSTRE

The flow chart of the subroutine calling sequence is given in Figure B.7.

FIGURE B.7. GEOTHER/VT4 Subroutine Calling Sequence

SAMPLE OUTPUT

```

*****
****      GEOTHR_VT4.EXE
****      CODE VERSION VT4
****      PARENT VERSION VT3
****
*****

****
****
****      ADDED FEATURES FROM PARENT
****
****      1 THIS VERSION HAS EPRI THERMODYNAMIC PROPERTY FUNCTIONS
*****

```

```

**** 2-D SINGLE CONTAINER (SLAB) WITH FLOW TOP AND FLOW BOTTOM AS VERTICAL      1
**** BOUNDARIES IN CARTESIAN COORDINATES                                     2
**** REVISED ON 5/15/86 (CORRECTION ON LENGTH IN X DIRECTION)                 3
**** THE EMPLACEMENT ROOM AND BOREHOLES ARE AT UNDISTURBED TEMPERATURES      4
**** AND 1 ATM BEFORE CONTAINER PLACEMENT (6/7/86)                           5
NEW-INPUT                                                                    6
GRID,CART,      8      1      15      0                                       6
TIME,           10      1.E66.3E7 1.E7  1.5 0.03                             7
INPU,TEMP,                                           8
ITER,          5      20      1.2 0.01                                       9
MISC,           1      30                                                     10
ADUT,PRES,SATU,TEMP,ENTH,ROCT,                    5                         11
PRNT,           1      5                                                     12
PROP,      MAT      51      LINEA                                           13
  GROUP 1      K H20      6.4E4      RDEN      2.78      CP                                           14
  GROUP 2      BETA      0.0      KROCK                                           HRW      100.      15
  GROUP 3      PHI      0.0001      RWS      0.3      RSS      0.05      16
  GROUP 4      XPER 5.339E-17      YPER 5.339E-17      ZPER 5.339E-17      17
DELX,SING,      1      5      340.0      182.9      182.9      172.7      200.      18
DELX,SING,      6      8      200.      200.      396.                                           19
DELY,           1      1      71.3                                           20
DELZ,SING,      1      5      800.      600.      300.      125.      72.9      21
DELZ,SING,      6      10      16.5      71.3      16.5      72.9      125.      22
DELZ,SING,      11      15      300.      600.      900.      1200.      1600.      23
MESH,           2      51      0      0      0      0      1      8      2      4      1      1      24

```

MESH,	2	51	0	0	0	0	2	8	5	5	1	1	25
MESH,	2	51	0	0	0	0	5	8	6	8	1	1	26
MESH,	2	51	0	0	0	0	2	8	9	9	1	1	27
MESH,	2	51	0	0	0	0	1	8	10	14	1	1	28
MESH,	0	51	0	0	0	0	1	8	1	1	1	1	29
MESH,	0	51	0	0	0	0	1	1	5	5	1	1	30
MESH,	0	51	0	0	0	0	1	4	6	8	1	1	31
MESH,	0	51	0	0	0	0	1	1	9	9	1	1	32
MESH,	0	51	0	0	0	0	1	8	15	15	1	1	33
**** END OF NEW INPUT													34
PRESSURE													35

END NEW INPUT CARDS

LENGTH OF FIXED BLANK COMMON	29729
LENGTH OF VARIABLE BLANK COMMON	38520
TOTAL LENGTH	86347

TOTAL NUMBER OF HEAT GENERATION TABLES - NTABQ= 0

FINITE DIFFERENCE DATA

NUMBER OF - COLUMNS	8
- ROWS	15
- VERT SLICES	1
- MAXIMUM ITERATIONS	5
- MAXIMUM TIME STEPS	10
- MAX SSOR ITERATIONS	20
- WEIGHTING OPTION	1
- PRINTING OPTION	1
- ARRAYS PRINTED	5
- CONSTANT NODES	30

RADIAL NODE LOCATIONS

340.0	182.9	182.9	172.7	200.0	200.0	200.0	396.0

***** TIME CARD VALUES *****

```

***** MAXSTEP= 10
***** ITEROP= 5
***** DELTI= 1.00000E+06
***** TSTOP= 6.30000E+07
***** DTYMAX= 1.00000E+07
***** DTFAC= 1.50000E+00
***** SWC= 3.00000E-02

```

ACTIVE BLOCKS IN EACH SLICE

J = 1 90 BLOCKS

GRID NUMBERS

SLICE 1

ROW 15	-1	-1	-1	-1	-1	-1	-1	-1
ROW 14	83	84	85	86	87	88	89	90
ROW 13	75	76	77	78	79	80	81	82
ROW 12	67	68	69	70	71	72	73	74
ROW 11	59	60	61	62	63	64	65	66
ROW 10	51	52	53	54	55	56	57	58
ROW 9	-1	44	45	46	47	48	49	50
ROW 8	-1	-1	-1	-1	40	41	42	43
ROW 7	-1	-1	-1	-1	36	37	38	39
ROW 6	-1	-1	-1	-1	32	33	34	35
ROW 5	-1	25	26	27	28	29	30	31
ROW 4	17	18	19	20	21	22	23	24
ROW 3	9	10	11	12	13	14	15	16
ROW 2	1	2	3	4	5	6	7	8
ROW 1	-1	-1	-1	-1	-1	-1	-1	-1

PRES\$

FREE

ARRAY CARDS READ HERE

X SPACING READ HERE

Y SPACING READ HERE

Z SPACING READ HERE

ENTH*0*0*0

FREE

ARRAY CARDS READ HERE

X SPACING READ HERE

Y SPACING READ HERE

Z SPACING READ HERE

ROCK0*0*0*0

FREE

37

38

39

40

41

43

44

45

46

47

49

ARRAY CARDS READ HERE	50
X SPACING READ HERE	51
Y SPACING READ HERE	52
Z SPACING READ HERE	53

NUMBER OF ARRAYS: 3

SPACING IN X-DIRECTION

340.0	182.9	182.9	172.7	200.0	200.0	200.0	396.0

SPACING IN Z-DIRECTION

800.0	600.0	300.0	125.0	72.90	16.50	71.30	16.50	72.90	12
300.0	600.0	900.0	1200.	1600.					

SPACING IN Y-DIRECTION

71.30

INITIAL PRESSURE

SLICE 1

ROW 15

+ 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08

ROW 14

+ 0.92300E+08 0.92300E+08 0.92300E+08 0.92300E+08 0.92300E+08 0.92300E+08 0.92300E+08 0.92300E+08

ROW 13

+	0.93300E+08	0.93300E+08	0.93300E+08	0.93300E+08	0.93300E+08	0.93300E+08	0.93300E+08	0.93300E+08
	ROW 12							
+	0.94000E+08	0.94000E+08	0.94000E+08	0.94000E+08	0.94000E+08	0.94000E+08	0.94000E+08	0.94000E+08
	ROW 11							
+	0.94500E+08	0.94500E+08	0.94500E+08	0.94500E+08	0.94500E+08	0.94500E+08	0.94500E+08	0.94500E+08
	ROW 10							
+	0.94700E+08	0.94700E+08	0.94700E+08	0.94700E+08	0.94700E+08	0.94700E+08	0.94700E+08	0.94700E+08
	ROW 9							
+	0.10130E+07	0.94800E+08	0.94800E+08	0.94800E+08	0.94800E+08	0.94800E+08	0.94800E+08	0.94800E+08
	ROW 8							
+	0.10130E+07	0.10130E+07	0.10130E+07	0.10130E+07	0.94800E+08	0.94800E+08	0.94800E+08	0.94800E+08
	ROW 7							
+	0.10130E+07	0.10130E+07	0.10130E+07	0.10130E+07	0.94900E+08	0.94900E+08	0.94900E+08	0.94900E+08
	ROW 6							
+	0.10130E+07	0.10130E+07	0.10130E+07	0.10130E+07	0.94900E+08	0.94900E+08	0.94900E+08	0.94900E+08
	ROW 5							
+	0.10130E+07	0.95000E+08	0.95000E+08	0.95000E+08	0.95000E+08	0.95000E+08	0.95000E+08	0.95000E+08
	ROW 4							
+	0.95100E+08	0.95100E+08	0.95100E+08	0.95100E+08	0.95100E+08	0.95100E+08	0.95100E+08	0.95100E+08
	ROW 3							
+	0.95300E+08	0.95300E+08	0.95300E+08	0.95300E+08	0.95300E+08	0.95300E+08	0.95300E+08	0.95300E+08
	ROW 2							
+	0.95700E+08	0.95700E+08	0.95700E+08	0.95700E+08	0.95700E+08	0.95700E+08	0.95700E+08	0.95700E+08
	ROW 1							
+	0.96400E+08	0.96400E+08	0.96400E+08	0.96400E+08	0.96400E+08	0.96400E+08	0.96400E+08	0.96400E+08

INITIAL WATER TEMPERATURE

SLICE 1

ROW 15

+	50.200	50.200	50.200	50.200	50.200	50.200	50.200	50.200

ROW 14

+	50.700	50.700	50.700	50.700	50.700	50.700	50.700	50.700
	ROW 13							
+	51.100	51.100	51.100	51.100	51.100	51.100	51.100	51.100
	ROW 12							
+	51.600	51.600	51.600	51.600	51.600	51.600	51.600	51.600
	ROW 11							
+	51.900	51.900	51.900	51.900	51.900	51.900	51.900	51.900
	ROW 10							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 9							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 8							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 7							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 6							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 5							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 4							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 3							
+	52.400	52.400	52.400	52.400	52.400	52.400	52.400	52.400
	ROW 2							
+	52.500	52.500	52.500	52.500	52.500	52.500	52.500	52.500
	ROW 1							
+	52.800	52.800	52.800	52.800	52.800	52.800	52.800	52.800

INITIAL ENTHALPY

SLICE 1

ROW 15

+ 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10

ROW 14

```

+      0.21444E+10 0.21444E+10 0.21444E+10 0.21444E+10 0.21444E+10 0.21444E+10 0.21444E+10 0.21444E+10
ROW 13
+      0.21613E+10 0.21613E+10 0.21613E+10 0.21613E+10 0.21613E+10 0.21613E+10 0.21613E+10 0.21613E+10
ROW 12
+      0.21821E+10 0.21821E+10 0.21821E+10 0.21821E+10 0.21821E+10 0.21821E+10 0.21821E+10 0.21821E+10
ROW 11
+      0.21946E+10 0.21946E+10 0.21946E+10 0.21946E+10 0.21946E+10 0.21946E+10 0.21946E+10 0.21946E+10
ROW 10
+      0.21988E+10 0.21988E+10 0.21988E+10 0.21988E+10 0.21988E+10 0.21988E+10 0.21988E+10 0.21988E+10
ROW 9
+      0.21649E+10 0.21989E+10 0.21989E+10 0.21989E+10 0.21989E+10 0.21989E+10 0.21989E+10 0.21989E+10
ROW 8
+      0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21989E+10 0.21989E+10 0.21989E+10 0.21989E+10
ROW 7
+      0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21990E+10 0.21990E+10 0.21990E+10 0.21990E+10
ROW 6
+      0.21690E+10 0.21690E+10 0.21690E+10 0.21690E+10 0.22030E+10 0.22030E+10 0.22030E+10 0.22030E+10
ROW 5
+      0.21690E+10 0.22031E+10 0.22031E+10 0.22031E+10 0.22031E+10 0.22031E+10 0.22031E+10 0.22031E+10
ROW 4
+      0.22032E+10 0.22032E+10 0.22032E+10 0.22032E+10 0.22032E+10 0.22032E+10 0.22032E+10 0.22032E+10
ROW 3
+      0.22155E+10 0.22155E+10 0.22155E+10 0.22155E+10 0.22155E+10 0.22155E+10 0.22155E+10 0.22155E+10
ROW 2
+      0.22199E+10 0.22199E+10 0.22199E+10 0.22199E+10 0.22199E+10 0.22199E+10 0.22199E+10 0.22199E+10
ROW 1
+      0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10

```

INITIAL ROCK/SOLID TEMPERATURE

SLICE 1

ROW 15

```

+      50.200      50.200      50.200      50.200      50.200      50.200      50.200      50.200

```

ROW 14

+	50.700	50.700	50.700	50.700	50.700	50.700	50.700	50.700
	ROW 13							
+	51.100	51.100	51.100	51.100	51.100	51.100	51.100	51.100
	ROW 12							
+	51.600	51.600	51.600	51.600	51.600	51.600	51.600	51.600
	ROW 11							
+	51.900	51.900	51.900	51.900	51.900	51.900	51.900	51.900
	ROW 10							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 9							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 8							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 7							
+	52.000	52.000	52.000	52.000	52.000	52.000	52.000	52.000
	ROW 6							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 5							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 4							
+	52.100	52.100	52.100	52.100	52.100	52.100	52.100	52.100
	ROW 3							
+	52.400	52.400	52.400	52.400	52.400	52.400	52.400	52.400
	ROW 2							
+	52.500	52.500	52.500	52.500	52.500	52.500	52.500	52.500
	ROW 1							
•	52.800	52.800	52.800	52.800	52.800	52.800	52.800	52.800

X-PERMEABILITY

SLICE 1

ROW 15

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 14

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 13

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 12

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 11

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 10

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 9

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 8

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 7

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 6

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 5

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 4

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 3

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 2

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 1

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

Z-PERMEABILITY

SLICE 1

ROW 15

+ 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16

ROW 14

ROW 13	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 12	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 11	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 10	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 9	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 8	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 7	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 6	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 5	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 4	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 3	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 2	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
ROW 1	
+	0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16 0.53390E-16
INITIAL POROSITY	

SLICE 1	
ROW 15	
+	0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
ROW 14	
+	0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03

ROW 13
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 12
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 11
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 10
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 9
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 8
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 7
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 6
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 5
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 4
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 3
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 2
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 ROW 1
 + 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03 0.10000E-03
 NTP = 0 54

TIME PARAMETERS

 INITIAL TIME STEP IN SECONDS 1000000.0
 MAXIMUM CHANGE IN SATURATION PER TIME STEP 0.3000E-01
 MAXIMUM TIME STEP INCREASE FACTOR 1.500
 NEXT PUMPING PERIOD BEGINS 63072000.
 PUMPING PERIOD 1
 NUMBER OF SOURCES 0

SOURCES

NEWTON-RAPHSON ITERATION 1

AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
AT SSOR ITERATION 2 ERROR MAX IS 0.20642D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.62469E-04	93.704	0.37284E+06	0.55925E+12	0.21398E+08	0.32097E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.19150E+09	0.28725E+15	-0.19150E+09	-0.28725E+15
CONSTANT NODES	-0.80515E-04	-120.77	-0.43079E+08	-0.64619E+14	0.20568E+08	0.30853E+14
PERCENT ERROR		-28.887		77.548		-356.31

NEWTON-RAPHSON ITERATION 2

AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
AT SSOR ITERATION 2 ERROR MAX IS 0.19199D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.64289E-04	96.433	0.38010E+06	0.57014E+12	0.23900E+08	0.35850E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.45692E+08	0.68539E+14	-0.45692E+08	-0.68539E+14
CONSTANT NODES	-0.64298E-04	-96.447	-0.46018E+08	-0.69026E+14	0.22337E+08	0.33505E+14
PERCENT ERROR		-0.14445E-01		0.11897		1.1771

NEWTON-RAPHSON ITERATION 3

AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
AT SSOR ITERATION 2 ERROR MAX IS 0.11565D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.64295E-04	96.443	0.38006E+06	0.57009E+12	0.23524E+08	0.35286E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.45677E+08	0.68515E+14	-0.45677E+08	-0.68515E+14
CONSTANT NODES	-0.64295E-04	-96.443	-0.46057E+08	-0.69085E+14	0.22222E+08	0.33333E+14
PERCENT ERROR		-0.19047E-04		-0.30323E-06		0.15179

NEWTON-RAPHSON ITERATION 4
 AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
 AT SSOR ITERATION 2 ERROR MAX IS 0.18894D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.64296E-04	96.443	0.38005E+06	0.57008E+12	0.23462E+08	0.35193E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.45681E+08	0.68522E+14	-0.45681E+08	-0.68522E+14
CONSTANT NODES	-0.64296E-04	-96.443	-0.46061E+08	-0.69092E+14	0.22207E+08	0.33311E+14
PERCENT ERROR		-0.23029E-05		0.83752E-06		-0.25794E-01

NEWTON-RAPHSON ITERATION 5
 AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
 AT SSOR ITERATION 2 ERROR MAX IS 0.11444D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.64296E-04	96.443	0.38005E+06	0.57008E+12	0.23470E+08	0.35205E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.45681E+08	0.68521E+14	-0.45681E+08	-0.68521E+14
CONSTANT NODES	-0.64296E-04	-96.443	-0.46061E+08	-0.69091E+14	0.22209E+08	0.33313E+14
PERCENT ERROR		0.23009E-06		-0.12654E-06		-0.39006E-02

STEP NUMBER 1 SIMULATION TIME IN SECONDS 0.150D+07
 ***** IN MINUTES 0.250D+05
 IN HOURS 0.417D+03
 IN DAYS 0.174D+02
 IN YEARS 0.476D-01

PRESSURE VALUES

SLICE 1

ROW 15

+ 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08

ROW 14

+ 0.79923E+08 0.80010E+08 0.80096E+08 0.80198E+08 0.80313E+08 0.80434E+08 0.80541E+08 0.80659E+08

ROW 13
 + 0.64632E+08 0.65102E+08 0.65575E+08 0.66140E+08 0.66790E+08 0.67402E+08 0.68088E+08 0.68758E+08

 ROW 12
 + 0.43236E+08 0.44726E+08 0.46308E+08 0.48330E+08 0.50785E+08 0.53425E+08 0.55682E+08 0.58105E+08

 ROW 11
 + 0.21434E+08 0.23814E+08 0.26511E+08 0.30766E+08 0.37250E+08 0.43882E+08 0.48973E+08 0.53914E+08

 ROW 10
 + 0.79635E+07 0.10540E+08 0.12576E+08 0.17143E+08 0.30173E+08 0.40746E+08 0.47640E+08 0.53708E+08

 ROW 9
 + 0.10130E+07 0.39559E+07 0.47903E+07 0.73275E+07 0.27679E+08 0.40203E+08 0.47696E+08 0.54073E+08

 ROW 8
 + 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.27241E+08 0.40308E+08 0.47931E+08 0.54368E+08

 ROW 7
 + 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.27068E+08 0.40496E+08 0.48209E+08 0.54687E+08

 ROW 6
 + 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.27963E+08 0.41075E+08 0.48701E+08 0.55134E+08
 ROW 5
 + 0.10130E+07 0.47696E+07 0.56756E+07 0.82778E+07 0.29150E+08 0.41751E+08 0.49251E+08 0.55618E+08

 ROW 4
 + 0.10173E+08 0.13247E+08 0.15404E+08 0.20075E+08 0.33387E+08 0.44038E+08 0.50935E+08 0.56980E+08

 ROW 3
 + 0.28240E+08 0.30775E+08 0.33537E+08 0.37833E+08 0.44359E+08 0.50983E+08 0.56033E+08 0.60907E+08

 ROW 2
 + 0.59609E+08 0.60970E+08 0.62413E+08 0.64261E+08 0.66508E+08 0.68919E+08 0.70968E+08 0.73154E+08

 ROW 1
 + 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08

ENTHALPY VALUES

SLICE 1

 ROW 15
 + 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10

 ROW 14
 + 0.21409E+10 0.21409E+10 0.21409E+10 0.21409E+10 0.21409E+10 0.21410E+10 0.21410E+10 0.21410E+10

 ROW 13

```

+      0.21556E+10 0.21557E+10 0.21558E+10 0.21559E+10 0.21560E+10 0.21561E+10 0.21562E+10 0.21563E+10

ROW 12
+      0.21728E+10 0.21731E+10 0.21734E+10 0.21738E+10 0.21742E+10 0.21747E+10 0.21752E+10 0.21756E+10

ROW 11
+      0.21805E+10 0.21811E+10 0.21816E+10 0.21825E+10 0.21839E+10 0.21852E+10 0.21863E+10 0.21872E+10

ROW 10
+      0.21796E+10 0.21809E+10 0.21814E+10 0.21825E+10 0.21861E+10 0.21885E+10 0.21900E+10 0.21912E+10

ROW 9
+      0.21649E+10 0.21773E+10 0.21776E+10 0.21784E+10 0.21866E+10 0.21897E+10 0.21913E+10 0.21926E+10

ROW 8
+      0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21870E+10 0.21904E+10 0.21921E+10 0.21934E+10

ROW 7
+      0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21877E+10 0.21912E+10 0.21929E+10 0.21942E+10

ROW 6
+      0.21690E+10 0.21690E+10 0.21690E+10 0.21690E+10 0.21891E+10 0.21924E+10 0.21941E+10 0.21954E+10

ROW 5
+      0.21690E+10 0.21826E+10 0.21830E+10 0.21837E+10 0.21907E+10 0.21937E+10 0.21953E+10 0.21966E+10

ROW 4
+      0.21876E+10 0.21894E+10 0.21900E+10 0.21910E+10 0.21942E+10 0.21966E+10 0.21981E+10 0.21993E+10

ROW 3
+      0.22020E+10 0.22026E+10 0.22032E+10 0.22041E+10 0.22055E+10 0.22069E+10 0.22080E+10 0.22090E+10

ROW 2
+      0.22147E+10 0.22150E+10 0.22153E+10 0.22157E+10 0.22162E+10 0.22167E+10 0.22171E+10 0.22176E+10

ROW 1
+      0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10

```

TEMPERATURE VALUES

```

SLICE 1

ROW 15
+      50.249      50.249      50.249      50.249      50.249      50.249      50.249      50.249

ROW 14
+      50.701      50.701      50.701      50.701      50.701      50.701      50.701      50.701

ROW 13
+      51.105      51.105      51.105      51.105      51.105      51.105      51.105      51.105

```

ROW 12								
+	51.599	51.599	51.599	51.599	51.599	51.600	51.600	51.600
ROW 11								
+	51.879	51.880	51.881	51.883	51.886	51.888	51.889	51.889
ROW 10								
+	51.918	51.936	51.939	51.944	51.971	51.979	51.982	51.982
ROW 9								
+	51.599	51.881	51.885	51.891	51.994	52.010	52.013	52.013
ROW 8								
+	51.599	51.599	51.599	51.599	52.006	52.026	52.029	52.030
ROW 7								
+	51.599	51.599	51.599	51.599	52.022	52.044	52.047	52.048
ROW 6								
+	51.696	51.696	51.696	51.696	52.051	52.069	52.072	52.073
ROW 5								
+	51.696	52.004	52.009	52.012	52.083	52.095	52.098	52.098
ROW 4								
+	52.098	52.127	52.130	52.133	52.148	52.154	52.155	52.156
ROW 3								
+	52.354	52.357	52.358	52.359	52.361	52.362	52.362	52.363
ROW 2								
+	52.502	52.502	52.502	52.502	52.502	52.502	52.503	52.503
ROW 1								
+	52.733	52.733	52.733	52.733	52.733	52.733	52.733	52.733

SATURATION VALUES

SLICE 1

ROW 15								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 14								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 13								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ROW 12								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 11								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 10								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 9								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 8								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 7								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 6								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 5								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 4								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 3								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 2								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 1								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ROCK/SOLID TEMPERATURE

SLICE 1

ROW 15								
+	50.200	50.200	50.200	50.200	50.200	50.200	50.200	50.200
ROW 14								
+	50.700	50.700	50.700	50.700	50.700	50.700	50.700	50.700
ROW 13								
+	51.105	51.105	51.105	51.105	51.105	51.105	51.105	51.105
ROW 12								

+	51.599	51.599	51.599	51.599	51.599	51.600	51.600	51.600
ROW 11								
+	51.880	51.881	51.882	51.883	51.887	51.888	51.889	51.889
ROW 10								
+	51.935	51.941	51.943	51.948	51.972	51.980	51.982	51.983
ROW 9								
+	52.000	51.936	51.936	51.941	51.995	52.009	52.012	52.013
ROW 8								
+	52.000	52.000	52.000	52.000	52.010	52.025	52.028	52.029
ROW 7								
+	52.000	52.000	52.000	52.000	52.026	52.042	52.045	52.046
ROW 6								
+	52.100	52.100	52.100	52.100	52.058	52.069	52.072	52.073
ROW 5								
+	52.100	52.058	52.060	52.062	52.084	52.095	52.098	52.098
ROW 4								
+	52.113	52.128	52.131	52.134	52.146	52.152	52.153	52.154
ROW 3								
+	52.356	52.359	52.360	52.361	52.362	52.363	52.364	52.364
ROW 2								
+	52.502	52.502	52.502	52.502	52.502	52.502	52.502	52.502
ROW 1								
+	52.800	52.800	52.800	52.800	52.800	52.800	52.800	52.800

GROUNDWATER VELOCITIES IN X-DIRECTION

STEAM VELOCITY

SLICE 1

ROW 15									
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 14									
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 13									

+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 12								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 11								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 10								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 9								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 8								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 7								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 6								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 5								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 4								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 3								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 2								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 1								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

LIQUID VELOCITY

SLICE 1

	ROW 15								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 14								
+	0.0000E+00	- .3276E-11	- .4643E-11	- .5609E-11	- .6062E-11	- .5971E-11	- .5220E-11	- .3892E-11	0.0000E+00
	ROW 13								

+	0.0000E+00	- .1776E-10	- .2560E-10	- .3148E-10	- .3450E-10	- .3425E-10	- .2995E-10	- .2225E-10	0.0000E+00
	ROW 12								
+	0.0000E+00	- .5689E-10	- .8635E-10	- .1135E-09	- .1315E-09	- .1318E-09	- .1126E-09	- .8111E-10	0.0000E+00
	ROW 11								
+	0.0000E+00	- .9136E-10	- .1480E-09	- .2401E-09	- .3491E-09	- .3326E-09	- .2553E-09	- .1663E-09	0.0000E+00
	ROW 10								
+	0.0000E+00	- .9904E-10	- .1118E-09	- .2581E-09	- .7026E-09	- .5311E-09	- .3463E-09	- .2045E-09	0.0000E+00
	ROW 9								
+	0.0000E+00	- .1130E-09	- .4581E-10	- .1433E-09	- .1098E-08	- .6294E-09	- .3765E-09	- .2150E-09	0.0000E+00
	ROW 8								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	- .1415E-08	- .6569E-09	- .3832E-09	- .2171E-09	0.0000E+00
	ROW 7								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	- .1406E-08	- .6753E-09	- .3878E-09	- .2185E-09	0.0000E+00
	ROW 6								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	- .1455E-08	- .6596E-09	- .3836E-09	- .2171E-09	0.0000E+00
	ROW 5								
+	0.0000E+00	- .1446E-09	- .4984E-10	- .1473E-09	- .1128E-08	- .6342E-09	- .3773E-09	- .2150E-09	0.0000E+00
	ROW 4								
+	0.0000E+00	- .1185E-09	- .1189E-09	- .2648E-09	- .7198E-09	- .5365E-09	- .3473E-09	- .2042E-09	0.0000E+00
	ROW 3								
+	0.0000E+00	- .9803E-10	- .1527E-09	- .2442E-09	- .3540E-09	- .3347E-09	- .2551E-09	- .1652E-09	0.0000E+00
	ROW 2								
+	0.0000E+00	- .5270E-10	- .7985E-10	- .1052E-09	- .1221E-09	- .1220E-09	- .1037E-09	- .7423E-10	0.0000E+00
	ROW 1								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

GROUNDWATER VELOCITIES IN Z-DIRECTION

STEAM VELOCITY

SLICE 1

COLUMN 1

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 2

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 3

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 4

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 5

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 6

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 7

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 8

+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

LIQUID VELOCITY

SLICE 1

COLUMN 1

+ 0.0000E+00 0.5234E-09 0.6951E-09 0.8468E-09 0.9229E-09 -.9703E-11 -.9688E-11 -.9688E-11 -.9688E-11 -.7154E-09
-.6459E-09 -.4960E-09 -.2920E-09 -.1526E-09 -.8660E-10 0.0000E+00

COLUMN 2

+ 0.0000E+00 0.5037E-09 0.6687E-09 0.8216E-09 0.8537E-09 0.8358E-09 -.9688E-11 -.9688E-11 -.6700E-09 -.6779E-09

-.6366E-09 -.4761E-09 -.2785E-09 -.1491E-09 -.8599E-10 0.0000E+00

COLUMN 3

+ 0.0000E+00 0.4828E-09 0.6390E-09 0.8503E-09 0.9811E-09 0.1040E-08 -.9688E-11 -.9688E-11 -.8583E-09 -.7998E-09
-.6678E-09 -.4512E-09 -.2639E-09 -.1454E-09 -.8538E-10 0.0000E+00

COLUMN 4

+ 0.0000E+00 0.4560E-09 0.5839E-09 0.8324E-09 0.1192E-08 0.1625E-08 -.9688E-11 -.9688E-11 -.1428E-08 -.1006E-08
-.6530E-09 -.4014E-09 -.2446E-09 -.1411E-09 -.8467E-10 0.0000E+00

COLUMN 5

+ 0.0000E+00 0.4234E-09 0.4877E-09 0.5105E-09 0.4216E-09 0.2575E-09 0.1955E-09 -.4936E-10 -.1083E-09 -.2631E-09
-.3439E-09 -.3115E-09 -.2208E-09 -.1361E-09 -.8386E-10 0.0000E+00

COLUMN 6

+ 0.0000E+00 0.3885E-09 0.3930E-09 0.3194E-09 0.2231E-09 0.1426E-09 0.1228E-09 0.3342E-10 0.1387E-10 -.6492E-10
-.1578E-09 -.2225E-09 -.1951E-09 -.1308E-09 -.8301E-10 0.0000E+00

COLUMN 7

+ 0.0000E+00 0.3588E-09 0.3255E-09 0.2318E-09 0.1617E-09 0.1140E-09 0.1029E-09 0.5403E-10 0.4300E-10 -.4087E-11
-.7261E-10 -.1593E-09 -.1733E-09 -.1261E-09 -.8226E-10 0.0000E+00

COLUMN 8

+ 0.0000E+00 0.3271E-09 0.2851E-09 0.1763E-09 0.1288E-09 0.9927E-10 0.9250E-10 0.6325E-10 0.5654E-10 0.2733E-10
-.1945E-10 -.1031E-09 -.1502E-09 -.1209E-09 -.8143E-10 0.0000E+00

NEWTON-RAPHSON ITERATION 1

AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01

AT SSOR ITERATION 2 ERROR MAX IS 0.15361D-16

MASS BALANCE

ENERGY BALANCE
(WATER)

ENERGY BALANCE
(ROCK)

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.12499E-04	28.123	79316.	0.17846E+12	0.15612E+08	0.35126E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.57363E+08	0.12907E+15	-0.57363E+08	-0.12907E+15
CONSTANT NODES	-0.12953E-04	-29.144	-0.44235E+08	-0.99529E+14	0.28063E+08	0.63143E+14
PERCENT ERROR		-3.6318		22.992		-31.339

NEWTON-RAPHSON ITERATION 2

AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01

AT SSOR ITERATION 2 ERROR MAX IS 0.19900D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.12626E-04	28.408	79901.	0.17978E+12	0.16476E+08	0.37071E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.44153E+08	0.99345E+14	-0.44153E+08	-0.99345E+14
CONSTANT NODES	-0.12626E-04	-28.408	-0.44232E+08	-0.99523E+14	0.28144E+08	0.63323E+14
PERCENT ERROR		-0.62254E-03		0.15671E-02		1.0452

NEWTON-RAPHSON ITERATION 3
 AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
 AT SSOR ITERATION 2 ERROR MAX IS 0.13410D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.12627E-04	28.410	79842.	0.17964E+12	0.16133E+08	0.36300E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.44177E+08	0.99398E+14	-0.44177E+08	-0.99398E+14
CONSTANT NODES	-0.12627E-04	-28.410	-0.44257E+08	-0.99578E+14	0.28066E+08	0.63149E+14
PERCENT ERROR		-0.48561E-04		0.65976E-05		0.51493E-01

NEWTON-RAPHSON ITERATION 4
 AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
 AT SSOR ITERATION 2 ERROR MAX IS 0.12573D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)
CHANGE IN STORAGE	0.12627E-04	28.410	79839.	0.17964E+12	0.16104E+08	0.36235E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.44178E+08	0.99400E+14	-0.44178E+08	-0.99400E+14
CONSTANT NODES	-0.12627E-04	-28.410	-0.44258E+08	-0.99580E+14	0.28063E+08	0.63142E+14
PERCENT ERROR		-0.22663E-05		0.27765E-06		-0.23427E-01

NEWTON-RAPHSON ITERATION 5
 AT SSOR ITERATION 1 ERROR MAX IS 0.10000D+01
 AT SSOR ITERATION 2 ERROR MAX IS 0.11952D-16

	MASS BALANCE		ENERGY BALANCE (WATER)		ENERGY BALANCE (ROCK)	
	-----		-----		-----	
	RATE (GM/SEC)	TOTAL (GM)	RATE (ERGS/S)	TOTAL (ERGS)	RATE (ERGS/S)	TOTAL (ERGS)

CHANGE IN STORAGE	0.12627E-04	28.410	79841.	0.17964E+12	0.16112E+08	0.36252E+14
SOURCE/SINK	0.00000E+00	0.00000E+00	0.44177E+08	0.99399E+14	-0.44177E+08	-0.99399E+14
CONSTANT NODES	-0.12627E-04	-28.410	-0.44257E+08	-0.99579E+14	0.28065E+08	0.63145E+14
PERCENT ERROR		0.10148E-05		-0.15654E-06		-0.18321E-02

STEP NUMBER 2   SIMULATION TIME IN SECONDS 0.375D+07
 *****
                                          IN MINUTES 0.625D+05
                                          IN HOURS 0.104D+04
                                          IN DAYS 0.434D+02
                                          IN YEARS 0.119D+00

PRESSURE VALUES

SLICE 1

ROW 15

+ 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08 0.90900E+08

ROW 14

+ 0.69817E+08 0.69903E+08 0.69989E+08 0.70090E+08 0.70203E+08 0.70324E+08 0.70429E+08 0.70546E+08

ROW 13

+ 0.49856E+08 0.50280E+08 0.50708E+08 0.51219E+08 0.51805E+08 0.52431E+08 0.52980E+08 0.53589E+08

ROW 12

+ 0.30336E+08 0.31574E+08 0.32891E+08 0.34576E+08 0.36622E+08 0.38834E+08 0.40738E+08 0.42796E+08

ROW 11

+ 0.14315E+08 0.16129E+08 0.18247E+08 0.21610E+08 0.26734E+08 0.32044E+08 0.36178E+08 0.40247E+08

ROW 10

+ 0.54079E+07 0.71726E+07 0.87173E+07 0.12248E+08 0.22269E+08 0.30585E+08 0.36120E+08 0.41077E+08

ROW 9

+ 0.10130E+07 0.28845E+07 0.35044E+07 0.54504E+07 0.20931E+08 0.30745E+08 0.36748E+08 0.41952E+08

ROW 8

+ 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.20876E+08 0.31121E+08 0.37229E+08 0.42482E+08

ROW 7

+ 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.21022E+08 0.31564E+08 0.37747E+08 0.43034E+08

ROW 6

+ 0.10130E+07 0.10130E+07 0.10130E+07 0.10130E+07 0.22020E+08 0.32343E+08 0.38464E+08 0.43718E+08

ROW 5
 + 0.10130E+07 0.41469E+07 0.48845E+07 0.69408E+07 0.23259E+08 0.33213E+08 0.39241E+08 0.44446E+08

 ROW 4
 + 0.88256E+07 0.11383E+08 0.13140E+08 0.16862E+08 0.27354E+08 0.35830E+08 0.41401E+08 0.46357E+08

 ROW 3
 + 0.24777E+08 0.26891E+08 0.29166E+08 0.32661E+08 0.37937E+08 0.43320E+08 0.47464E+08 0.51506E+08

 ROW 2
 + 0.55180E+08 0.56351E+08 0.57585E+08 0.59158E+08 0.61066E+08 0.63115E+08 0.64864E+08 0.66739E+08

 ROW 1
 + 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08 0.96400E+08

ENTHALPY VALUES

SLICE 1

 ROW 15
 + 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10 0.21231E+10

 ROW 14
 + 0.21391E+10 0.21391E+10 0.21391E+10 0.21392E+10 0.21392E+10 0.21392E+10 0.21392E+10 0.21392E+10

 ROW 13
 + 0.21532E+10 0.21533E+10 0.21533E+10 0.21534E+10 0.21535E+10 0.21537E+10 0.21538E+10 0.21539E+10

 ROW 12
 + 0.21702E+10 0.21705E+10 0.21707E+10 0.21711E+10 0.21715E+10 0.21719E+10 0.21723E+10 0.21727E+10

 ROW 11
 + 0.21780E+10 0.21784E+10 0.21789E+10 0.21797E+10 0.21811E+10 0.21823E+10 0.21832E+10 0.21841E+10

 ROW 10
 + 0.21778E+10 0.21787E+10 0.21791E+10 0.21802E+10 0.21838E+10 0.21861E+10 0.21875E+10 0.21885E+10

 ROW 9
 + 0.21649E+10 0.21764E+10 0.21767E+10 0.21774E+10 0.21850E+10 0.21880E+10 0.21895E+10 0.21906E+10

 ROW 8
 + 0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21857E+10 0.21890E+10 0.21905E+10 0.21916E+10

 ROW 7
 + 0.21649E+10 0.21649E+10 0.21649E+10 0.21649E+10 0.21866E+10 0.21900E+10 0.21915E+10 0.21927E+10

 ROW 6

```

+      0.21690E+10 0.21690E+10 0.21690E+10 0.21690E+10 0.21880E+10 0.21912E+10 0.21927E+10 0.21939E+10

ROW 5
+      0.21690E+10 0.21823E+10 0.21827E+10 0.21833E+10 0.21896E+10 0.21925E+10 0.21939E+10 0.21951E+10

ROW 4
+      0.21871E+10 0.21890E+10 0.21895E+10 0.21905E+10 0.21935E+10 0.21957E+10 0.21970E+10 0.21981E+10

ROW 3
+      0.21995E+10 0.22002E+10 0.22007E+10 0.22015E+10 0.22028E+10 0.22040E+10 0.22050E+10 0.22058E+10

ROW 2
+      0.22138E+10 0.22140E+10 0.22143E+10 0.22146E+10 0.22150E+10 0.22155E+10 0.22159E+10 0.22162E+10

ROW 1
+      0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10 0.22326E+10

```

TEMPERATURE VALUES

```

SLICE 1

ROW 15
+      50.249      50.249      50.249      50.249      50.249      50.249      50.249      50.249

ROW 14
+      50.701      50.701      50.701      50.701      50.701      50.701      50.701      50.701

ROW 13
+      51.112      51.112      51.112      51.112      51.112      51.112      51.112      51.112

ROW 12
+      51.596      51.596      51.596      51.597      51.597      51.598      51.598      51.598

ROW 11
+      51.851      51.853      51.855      51.859      51.868      51.873      51.876      51.877

ROW 10
+      51.887      51.899      51.903      51.912      51.951      51.969      51.975      51.978

ROW 9
+      51.599      51.864      51.868      51.876      51.986      52.013      52.020      52.023

ROW 8
+      51.599      51.599      51.599      51.599      52.003      52.034      52.042      52.045

ROW 7
+      51.599      51.599      51.599      51.599      52.023      52.056      52.064      52.066

```

ROW 6								
+	51.696	51.696	51.696	51.696	52.053	52.081	52.088	52.091
ROW 5								
+	51.696	52.000	52.005	52.010	52.085	52.107	52.113	52.116
ROW 4								
+	52.093	52.124	52.130	52.136	52.157	52.170	52.175	52.177
ROW 3								
+	52.312	52.317	52.320	52.323	52.327	52.331	52.333	52.334
ROW 2								
+	52.501	52.502	52.502	52.502	52.503	52.503	52.503	52.503
ROW 1								
+	52.733	52.733	52.733	52.733	52.733	52.733	52.733	52.733

SATURATION VALUES

SLICE 1								
ROW 15								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 14								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 13								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 12								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 11								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 10								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 9								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 8								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 7								

+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 6								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 5								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 4								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 3								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 2								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ROW 1								
+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ROCK/SOLID TEMPERATURE

SLICE 1								
ROW 15								
+	50.200	50.200	50.200	50.200	50.200	50.200	50.200	50.200
ROW 14								
+	50.701	50.701	50.701	50.701	50.701	50.701	50.701	50.701
ROW 13								
+	51.112	51.112	51.112	51.112	51.112	51.112	51.112	51.112
ROW 12								
+	51.596	51.596	51.597	51.597	51.598	51.598	51.598	51.598
ROW 11								
+	51.852	51.854	51.856	51.860	51.868	51.874	51.876	51.877
ROW 10								
+	51.902	51.902	51.905	51.915	51.952	51.970	51.976	51.978
ROW 9								
+	52.000	51.917	51.918	51.924	51.987	52.013	52.020	52.023
ROW 8								
+	52.000	52.000	52.000	52.000	52.007	52.034	52.041	52.044

ROW 7								
+	52.000	52.000	52.000	52.000	52.028	52.055	52.063	52.066
ROW 6								
+	52.100	52.100	52.100	52.100	52.057	52.080	52.087	52.090
ROW 5								
+	52.100	52.052	52.055	52.059	52.086	52.106	52.113	52.115
ROW 4								
+	52.108	52.126	52.131	52.137	52.157	52.170	52.175	52.177
ROW 3								
+	52.313	52.318	52.321	52.324	52.328	52.332	52.334	52.335
ROW 2								
+	52.502	52.502	52.502	52.503	52.503	52.503	52.503	52.503
ROW 1								
+	52.800	52.800	52.800	52.800	52.800	52.800	52.800	52.800

GROUNDWATER VELOCITIES IN X-DIRECTION

STEAM VELOCITY

SLICE 1

ROW 15								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 14								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 13								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 12								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 11								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 10								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ROW 9								

+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 8								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 7								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 6								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 5								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 4								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 3								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 2								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 1								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

LIQUID VELOCITY

SLICE 1

	ROW 15								
+	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	ROW 14								
+	0.0000E+00	-.3248E-11	-.4603E-11	-.5559E-11	-.6007E-11	-.5917E-11	-.5175E-11	-.3860E-11	0.0000E+00
	ROW 13								
+	0.0000E+00	-.1607E-10	-.2314E-10	-.2845E-10	-.3118E-10	-.3100E-10	-.2716E-10	-.2022E-10	0.0000E+00
	ROW 12								
+	0.0000E+00	-.4727E-10	-.7193E-10	-.9463E-10	-.1096E-09	-.1104E-09	-.9507E-10	-.6895E-10	0.0000E+00
	ROW 11								
+	0.0000E+00	-.6965E-10	-.1162E-09	-.1898E-09	-.2759E-09	-.2663E-09	-.2074E-09	-.1369E-09	0.0000E+00
	ROW 10								
+	0.0000E+00	-.6779E-10	-.8482E-10	-.1994E-09	-.5404E-09	-.4178E-09	-.2780E-09	-.1671E-09	0.0000E+00

ROW 9	+	0.0000E+00 - .7186E-10 - .3403E-10 - .1099E-09 - .8352E-09 - .4934E-09 - .3018E-09 - .1755E-09 0.0000E+00
ROW 8	+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 - .1072E-08 - .5153E-09 - .3072E-09 - .1773E-09 0.0000E+00
ROW 7	+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 - .1080E-08 - .5304E-09 - .3110E-09 - .1785E-09 0.0000E+00
ROW 6	+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 - .1135E-08 - .5196E-09 - .3080E-09 - .1774E-09 0.0000E+00
ROW 5	+	0.0000E+00 - .1206E-09 - .4057E-10 - .1164E-09 - .6818E-09 - .5011E-09 - .3035E-09 - .1758E-09 0.0000E+00
ROW 4	+	0.0000E+00 - .9858E-10 - .9684E-10 - .2110E-09 - .5675E-09 - .4272E-09 - .2807E-09 - .1676E-09 0.0000E+00
ROW 3	+	0.0000E+00 - .8172E-10 - .1257E-09 - .1987E-09 - .2861E-09 - .2719E-09 - .2093E-09 - .1370E-09 0.0000E+00
ROW 2	+	0.0000E+00 - .4533E-10 - .6834E-10 - .8958E-10 - .1036E-09 - .1037E-09 - .6853E-10 - .6369E-10 0.0000E+00
ROW 1	+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

GROUNDWATER VELOCITIES IN Z-DIRECTION

STEAM VELOCITY

SLICE 1

COLUMN 1

+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 2

+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 3

+	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 4
+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 5
+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 6
+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 7
+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

COLUMN 8
+ 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

LIQUID VELOCITY

SLICE 1

COLUMN 1
+ 0.0000E+00 0.5876E-09 0.6743E-09 0.7488E-09 0.7857E-09 -.9703E-11 -.9688E-11 -.9688E-11 -.9688E-11 -.4557E-09
-.4303E-09 -.3653E-09 -.2674E-09 -.1964E-09 -.1563E-09 0.0000E+00

COLUMN 2
+ 0.0000E+00 0.5706E-09 0.6531E-09 0.7278E-09 0.7273E-09 0.6956E-09 -.9688E-11 -.9688E-11 -.4300E-09 -.4450E-09
-.4326E-09 -.3525E-09 -.2566E-09 -.1933E-09 -.1557E-09 0.0000E+00

COLUMN 3
+ 0.0000E+00 0.5527E-09 0.6297E-09 0.7523E-09 0.8312E-09 0.8617E-09 -.9688E-11 -.9688E-11 -.5693E-09 -.5388E-09
-.4597E-09 -.3347E-09 -.2449E-09 -.1901E-09 -.1551E-09 0.0000E+00

COLUMN 4
+ 0.0000E+00 0.5299E-09 0.5864E-09 0.7415E-09 0.1001E-08 0.1325E-08 -.9688E-11 -.9688E-11 -.1006E-08 -.6997E-09
-.4518E-09 -.2974E-09 -.2294E-09 -.1862E-09 -.1544E-09 0.0000E+00

COLUMN 5
+ 0.0000E+00 0.5023E-09 0.5105E-09 0.4934E-09 0.4073E-09 0.2695E-09 0.2189E-09 0.2372E-10 -.2201E-10 -.1457E-09

-.2205E-09 -.2291E-09 -.2101E-09 -.1818E-09 -.1536E-09 0.0000E+00

COLUMN 6

+ 0.0000E+00 0.4726E-09 0.4355E-09 0.3463E-09 0.2569E-09 0.1860E-09 0.1688E-09 0.9186E-10 0.7498E-10 0.6428E-10
-.7858E-10 -.1604E-09 -.1891E-09 -.1771E-09 -.1528E-09 0.0000E+00

COLUMN 7

+ 0.0000E+00 0.4472E-09 0.3816E-09 0.2785E-09 0.2102E-09 0.1651E-09 0.1547E-09 0.1089E-09 0.9854E-10 0.5406E-10
-.1251E-10 -.1109E-09 -.1712E-09 -.1729E-09 -.1520E-09 0.0000E+00

COLUMN 8

+ 0.0000E+00 0.4201E-09 0.3328E-09 0.2350E-09 0.1848E-09 0.1541E-09 0.1471E-09 0.1166E-09 0.1097E-09 0.7910E-10
0.2946E-10 -.6625E-10 -.1521E-09 -.1683E-09 -.1512E-09 0.0000E+00

GRAPHICS PROGRAMS FOR GEOTHER/VT4

Three graphics programs were written to transform the output of GEOTHER/VT4 into two-dimensional plots (water pressure, water temperature, or saturation versus time or location) and contour plots (contours of water pressure, water temperature, saturation, and solid material such as rock and container). The three programs are GEOPLOT, POSTPRO, and MANPLT. In addition, an existing program, SEQUEL, which was developed by PNL, is used for the contour plotting. Through an interpolation method, SEQUEL calculates the contour points using the parameters of interest at each grid location.

Brief descriptions of the three new programs mentioned above, along with the listings and the procedures for plotting two-dimensional curves and contours, are given in the following subsections.

Two-Dimensional Curve Plotting

Program GEOPLOT plots pressures, temperatures, or saturations from TAPE11s produced from code GEOTHER using DISSPLA. Because several plots are produced from one TAPE11, an open statement is used in program GEOPLOT. The statement will need to be changed and the program recompiled if one uses a TAPE11 that differs from what is specified.

GEOPLOT is set up to run in an interactive mode only. After entering RUN GEOPLOT, the user will be queried for several bits of information about the type of plot to be produced. Following is the list of questions one will be asked after initiating execution of GEOPLOT. Examples and clarification of questions will be provided.

Spatial Plot

The spatial plot gives plots of pressure, temperature, or saturation versus distance at a given time. The distance is in either the X, Y, or Z direction, depending on user-selected option.

1. DO YOU WANT TO PLOT 1 TIME STEP (TAPE 11) OR THE ENTIRE FILE (TIME PLOT). ENTER A 0 FOR ONLY 1 TIME STEP; A 1 FOR THE ENTIRE FILE. (A 0 will allow you to plot in only one time step at a certain NX, NY, and NZ location. If you entered a 1 here, go to step 9.)
2. DO YOU WANT TO PLOT PRESSURES, SATURATIONS, OR TEMPERATURES? Enter a 0 for pressure, a 1 for temperature, or a 2 for saturation. (GEOTHER writes out a time step, pressures, temperatures, saturations, next time step, etc.)
3. DO YOU WANT TO PLOT IN THE NX, NY, OR NZ DIRECTIONS? ENTER A 0 FOR NX, A 1 FOR NY, OR A 2 FOR THE NZ DIRECTION.
(NX=I, NY=J, NZ=K)
4. ENTER STEP NUMBER YOU WISH TO PLOT.
(Before each time step of pressure, temperature, and saturation data, the STEP NUMBER and SIMULATION TIME IN SECONDS is identified.)
5. ENTER NUMBER OF POINTS YOU WISH TO PLOT.
(Example: NX=8, NY=1, NZ=10 if you want to plot NX at NX=4, the number of points you want to plot are 8. NX=8, NY=1, NZ=10, if you want to plot in the NZ direction from 1 to 4, NX=3, the number of points you want to plot is 4).
6. YOU ARE PLOTTING IN THE NX (NY OR NZ) DIRECTION, WHICH NX, NY, AND NZ POSITION DO YOU WANT TO PLOT? ENTER NX, NY, AND NZ SEPARATED BY COMMAS.

(Example: NX=8, NY=1, NZ=10, and you want to plot NX from 1 to 8 at NZ=4, enter 1,1,4.

7. ENTER VALUES FOR NX, NY, AND NZ FROM GEOTHR.

(Example: If runs from 1 to 8, J=1, and K=1, enter 8,1,10).

8. ENTER OUTPUT DEVICE FOR PLOTTING:

1 - Tek4054   2 - Tex4663   3 - Ramtek
4 - Rm9400   5 - Hp2647   6 - Hp2648
7 - Calcomp

(The Tek4054 is the Tektronix CRT, the Tek4663 is the Tektronix plotter, the Rm8400 is the Ramtek, Hp2647 and Hp2648 are Hewlett-Packards, and the Calcmp is the Calcomp plotter on the VAX 11/780.)

Time Plots

The time plot gives plots of pressure, temperature, or saturation versus time at a given block location.

9. ENTER NUMBER OF STEP NUMBERS IN DATA FILES

(Enter total step numbers or only the amount you wish to plot.)

10. ENTER THE NX, NY, AND NZ LOCATION YOU WANT TO PLOT

(See Step 6.)

11. ENTER VALUES FOR NX, NY, AND NZ FROM GEOTHR

(See Step 7.)

12. DO YOU WANT TO PLOT PRESSURES, SATURATIONS, OR TEMPERATURES? Enter a 0 for pressure, a 1 for temperature, or a 2 for saturation.

(See Step 2.)

FORTRAN Listing of GEOPLOT

```
C
C THIS PROGRAM WILL PLOT PRESSURES, TEMPERATURES, OR SATURATIONS FOR
C TAPE11 PRODUCED FROM GEOHEAT
C
  DIMENSION IPAK(500),PLTARAY(100),XDIR(10),
1      P(5000),SW1(5000),P1(500),TEMP2(500),
2      DX(100),DY(100),DZ(100),PARRAY(100),SARRAY(100),TARRAY(100)
C
C ALL OPEN STATEMENTS SHOULD BE HERE
```

```

C      OPEN(UNIT=4,NAME='GEO4T11.OUT',TYPE='OLD',FORM='FORMATTED',
1      READONLY)
C      OPEN(UNIT=7,NAME='READ.CHK',TYPE='NEW')
C      SET VARIABLES TO 0
C      NTP = 0
      NT = 1
C
C      ASK USER FOR PLOTTING INSTRUCTIONS
C      WRITE(6,100)
100    FORMAT(' DO YOU WANT TO PLOT 1 TIME STEP (TAPE11) OR THE ENTIRE
1      FILE (TIME PLOT)'/,' ENTER A 0 FOR ONLY 1 TIME STEP, A 1 FOR THE
2      ENTIRE FILE'/)
C
C      CALL FREEF
      READ(10,200) IANS
200    FORMAT(I5)
C      IF (IANS .NE. 0) CALL TIMPLT
C
C
C
C
C
300    CONTINUE
      IF (IANS .EQ. 1) GO TO 9000
C
C      PRESSURE, SATURATIONS, OR TEMPERATURES????????????????
C      (SET IFLAG TO 0,1, OR 2)
C      WRITE(6,400)
400    FORMAT(' DO YOU WANT TO PLOT PRESSURES, SATURATIONS, '
1      ' OR TEMPERATURES'/' ENTER A 0 FOR PRESSURE, A 1 FOR
2      TEMPERATURE, OR A 2 FOR SATURATION'/)
C
      READ(5,200) IFLAG
C
C      PLOTTING IN THE NX, NY, OR NZ DIRECTION???????
C      WRITE(6,500)
500    FORMAT(' DO YOU WANT TO PLOT IN THE NX, NY OR NZ DIRECTION?'/
1      ' ENTER A 0 FOR NX, A 1 FOR NY, OR A 2 FOR THE NZ DIRECTION'/)
C
      CALL FREEF
      READ(10,200) IDIR
C

```



```

C
C  WHICH STEP # DO YOU WANT TO PLOT??????????????
C
    WRITE(6,600)
600  FORMAT(' ENTER STEP NUMBER YOU WISH TO PLOT'/)
C
    CALL FREEF
    READ(10,700) ISTEP
C
C
    WRITE(6,750)
750  FORMAT(1X,' ENTER NUMBER OF POINTS YOU WISH TO PLOT')
C
    CALL FREEF
    READ(10,775)NPTS
775  FORMAT(I5)
700  FORMAT(I5)
C
C
C  ENTER I, J, AND K
C
800  CONTINUE
C
    IF (IDIR .EQ. 0) INC = 1
    IF (IDIR .EQ. 1) INC = 1
    IF (IDIR .EQ. 2) INC = 80
C
    IF (IDIR .EQ. 0) WRITE(6,900)
C
    IF (IDIR .EQ. 1) WRITE(6,1000)
C
    IF (IDIR .EQ. 2) WRITE(6,1100)
C
C
900  FORMAT(' YOU ARE PLOTTING IN THE NX DIRECTION, WHICH NX, NY, AND
1  NZ POSTION''DO YOU WANT TO PLOT? ENTER NX, NY, AND NZ SEPARATED
2  BY COMMAS'/)
C
1000 FORMAT(' YOU ARE PLOTTING IN THE NY DIRECTION, WHICH NX, NY, AND
1  NZ POSITION'' DO YOU WANT TO PLOT? ENTER NX, NY, AND NZ SEPARATED
2  BY COMMAS'/)
C
1100 FORMAT(' YOU ARE PLOTTING IN THE NZ DIRECTION, WHICH NX, NY, AND
1  NZ POSITION'' DO YOU WANT TO PLOT? ENTER NX, NY, AND NZ SEPARATED
2  BY COMMAS'/)
C
    CALL FREEF
    READ(10,1150) NXLOC,NYLOC,NZLOC
C
    L = NXLOC

```

```

M = NYLOC
N = NZLOC
C
  ISTART = NXLOC * NYLOC * NZLOC
C
  INC = 1
  IF (IDIR .EQ. 2) INC = 8
C
  IF (NZLOC .GT. 1 .AND. NXLOC .EQ. 1) NXLOC = 8
  IF (IDIR .EQ. 2) ISTART = (NZLOC - 1) * 8 + NXLOC
  IF (IDIR .EQ. 2) ISTART = NZLOC
  IF (IDIR .EQ. 2) IEND = 80
  IF (NZLOC .GT. 1) ISTART = (NZLOC-1) * NXLOC * NYLOC + 1
  IF (IDIR .EQ. 0) IEND = ISTART +NPTS -1
  IF (IDIR .EQ. 2) ISTART = NXLOC
  WRITE(6,1175)
1175 FORMAT(' ENTER VALUES FOR NX, NY, AND NZ FROM GHEAT')
C
  CALL FREEF
  READ (10,1150) NX,NY,NZ
1150 FORMAT(3I5)
C
  INC = 8
C
  IF (IDIR .EQ. 0) GO TO 1200
  IF (IDIR .EQ. 1) GO TO 1300
  IF (IDIR .EQ. 2) GO TO 1400
C
1200 CONTINUE
C
C ENTER THE DISTANCE ARRAY
C
  WRITE(6,1220)
1220 FORMAT(' ENTER THE DX ARRAY')
  CALL FREEF
  READ(10,1240) (DX(I),I=ISTART,IEND)
1240 FORMAT(10F10.2)
  GO TO 1450
C
1300 CONTINUE
  WRITE(6,1320)
1320 FORMAT(' ENTER THE DY ARRAY')
  CALL FREEF
  READ(10,1240) (DY(I),I=1,NPTS)
  GO TO 1450
C
1400 CONTINUE
  WRITE(6,1420)
1420 FORMAT(' ENTER THE DZ ARRAY')

```

```

      CALL FREEF
      READ(10,1240) (DZ(I),I=1,NPTS)
      DZ(1) = 118.15
      DZ(2) = 336.2
      DZ(3) = 509.8
      DZ(4) = 665.8
      DZ(5) = 808.6
      DZ(6) = 920.3
      DZ(7) = 1014.7
      DZ(8) = 1094.6
      DZ(9) = 1162.2
      DZ(10) = 1363.1
1450 CONTINUE
C
C
C   START READING DATA
C
C      READ(4,1500)NTP,TIME
1500 FORMAT(/13X,I4,36X,G12.5/)
C
1600 FORMAT(5D14.7)
C
C
1650 FORMAT(5(D14.7,I5))
      DO 1700 J=1,NY
      DO 1700 K=1,NZ
      IK1 = (K-1)*NX+1+(J-1)*NX*NZ
      IK2 = IK1 + NX - 1
      READ (4,1600) (P(ICK),ICK=IK1,IK2)
      WRITE (7,1650) (P(ICK),ICK,ICK=IK1,IK2)
1700 CONTINUE
C
1725 CONTINUE
      DO 1730 I=ISTART,IEND,INC
      PARRAY(I) = P(I)
1730 CONTINUE
C
C   READ TEMPERATUE DATA
C
C
      DO 1750 J=1,NY
      DO 1750 K=1,NZ
      IK1 = (K-1)*NX+1+(J-1)*NX*NZ
      IK2 = IK1 + NX - 1
      READ(4,1600) (TEMP2(ICK),ICK=IK1,IK2)
      WRITE(7,1600) (TEMP2(ICK),ICK=IK1,IK2)
1750 CONTINUE
C
      DO 1775 I=ISTART,IEND,INC

```

```

      TARRAY(I) = TEMP2(I)
1775 CONTINUE
C
C   READ SATURATION DATA
C
      DO 1800 J=1,NY
      DO 1800 K=1,NZ
      IK1 = (K-1) *NX+1+(J-1)*NX*NZ
      IK2 = IK1 +NX - 1
      READ (4,1600) (SW1(ICK),ICK=IK1,IK2)
      WRITE(7,1600) (SW1(ICK),ICK=IK1,IK2)
1800 CONTINUE
C
      DO 1900 I=ISTART,IEND
      SARRAY(I) = SW1(I)
1900 CONTINUE
C
      IF (ISTEP .NE. NTP) GO TO 1450
C
C   CONVERT TIME IN SECONDS TO TIME IN YEARS
C
2000 CONTINUE
      TIME = TIME/(3600.*24.*365.)
      WRITE(6,56)TIME
56   FORMAT(5X,'TIME = ',F10.5)
C
C
C
C   FIND MAXIMUM AND MINIMUM VALUES IN P, SW1, AND TEMP2 ARRAYS
C
      TMAX = 0.0
      DO 2200 II=ISTART,IEND
      IF (TARRAY(II) .GT. TMAX) TMAX=TARRAY(II)
2200 CONTINUE
      TMIN = TARRAY(1)
C
      DO 2300 II=ISTART,IEND
      IF (TARRAY(II) .LT. TMIN) TMIN = TARRAY(II)
2300 CONTINUE
C
C   PRESSURE MAX AND MINS
C
C   CONVERT PRESSURE IN DYNES/CM2 TO BARS
C
      DO 2100 I=ISTART,IEND,INC
      PARRAY(I) = PARRAY(I)/1.0D6
2100 CONTINUE
      PMAX = 0.0
      DO 2400 II=ISTART,IEND
      IF (PARRAY(II) .GT. PMAX) PMAX = PARRAY(II)

```

```

2400 CONTINUE
C
    PMIN = PARRAY(1)
    DO 2500 II=ISTART,IEND
        IF (PARRAY(II) .LT. PMIN) PMIN = PARRAY(II)
2500 CONTINUE
C
C   SATURATION MAX AND MINS
C
    SMAX = 0.0
    DO 2600 II=ISTART,IEND
        IF (SARRAY(II) .GT. SMAX) SMAX = SARRAY(II)
2600 CONTINUE
C
    SMIN = SARRAY(1)
    DO 2700 II=ISTART,IEND
        IF (SARRAY(II) .LT. SMIN) SMIN = SARRAY(II)
2700 CONTINUE
C
C
C   ADD A BIT TO PLOT DIMENSIONS FOR BETTER LOOKS
C
    TMAX = TMAX + 10.0 * (TMAX - TMIN)
    TMIN = TMIN - 10.0 * (TMAX - TMIN)
    IF (TMIN .LE. 0.0) TMIN = 0.0
C
C
    PMAX = PMAX + 0.1 * (PMAX - PMIN)
    PMIN = PMIN - 0.1 * (PMAX - PMIN)
    IF (PMIN .LE. 0.0) PMIN = 0.0
C
    SMAX = SMAX + 0.1 * (SMAX - SMIN)
    SMIN = SMIN - 0.1 * (SMAX - SMIN)
    IF (SMIN .LE. 0.0) SMIN = 0.0
C
C   HARDWARE FOR POSSIBILITY OF THE DATA BEING ALL ONE VALUE
C
    IF (TMAX .NE. TMIN) GO TO 2800
    IF (PMAX .NE. PMIN) GO TO 2800
    IF (SMAX .NE. SMIN) GO TO 2800
C
    TMAX = TMAX + 10.
    TMIN = TMIN - 10.
    PMAX = PMAX + 1.
    PMIN = PMIN - 1.
    SMAX = SMAX + 1.
    SMIN = SMIN - 1.
2800 CONTINUE
C
C   ENTER DEVICE TO USE

```

```

C
WRITE(6,2900)
2900 FORMAT (' ENTER OUTPUT DEVICE FOR PLOTTING'/'
$ 1-TEK4054 2-TEK4663 3-PRNTRX'/'4-RM9400 5-HP2647 6-HP2648
$ 7-CALCMP'/'/)
C
READ(5,3000)ITYTERM
3000 FORMAT(I1)
C
C
IF (ITYTERM .EQ. 1) CALL TK4054(1)
C
IF (ITYTERM .EQ. 2) CALL TK4663(0,0,36)
C
IF (ITYTERM .EQ. 4) CALL RM9400
C
IF (ITYTERM .EQ. 5) CALL HP2647
C
IF (ITYTERM .EQ. 6) CALL HP2648
C
IF (ITYTERM .NE. 7) GO TO 3200
C
C
C
C MAKE NTP NUMBER OF PLOTS
C CALL TO COMPRS SENDS PLOT FILE TO DISSPOP.POP
C
3100 CONTINUE
CALL RESET ('ALL')
CALL COMPRS
3200 CONTINUE
CALL RESET ('ALL')
CALL PAGE (11.0,8.5)
CALL NOBRDR
CALL AREA2D(8.0,6.0)
CALL FRAME
CALL THKFRM (0.10)
CALL SETDEV(11,12)
C
C SET FONT TYPE AND CHARACTER HEIGHT FOR AXES NAME
C
CALL SWISSM
CALL HEIGHT (0.25)
C
C WRITE APPROPRIATE TITLES
C
IF (IFLAG .EQ. 1) GO TO 3400
IF (IFLAG .EQ. 2) GO TO 3500
C
C IFLAG = 0 (PLOTTING PRESSURE)

```

```

C
  J = 1
3300 CONTINUE
  PMIN = 0.0
  PMAX = 130.
  DO 3325 I=ISTART,IEND,INC
    PLTARAY(J) = PARRAY(I)
    XDIR(J) = DX(I)
    J = J + 1
3325 CONTINUE
  DO 3340 K=1,NPTS
    WRITE (6,5240)PLTARAY(K),DZ(K)
5240 FORMAT(2(5X,F15.5))
3340 CONTINUE
    CALL HEIGHT (0.20)
    CALL XNAME ('DISTANCE, CM$',100)
    CALL YNAME ('PRESSURE, BAR$',100)
    CALL MESSAG ('CANISTER IN, ROOM OPEN, (ROOM IS
1 AT RIGHT SIDE)$',100,.20,6.4)
    IF (IDIR .EQ. 0) CALL GRAF(0.0,'SCALE',XDIR(NPTS),PMIN,'SCALE',PMAX)
    IF (IDIR .EQ. 2) CALL GRAF (0.0,'SCALE',DZ(NPTS),PMIN,'SCALE',PMAX)
    CALL HEIGHT (0.14)
    CALL MESSAG ('LOCATION $',100,5.0,5.8)
    IF (IDIR .EQ. 2) CALL MESSAG ('I = $',100,5.0,5.5)
    IF (IDIR .EQ. 2) CALL INTNO (L,'ABUT','ABUT')
    IF (IDIR .EQ. 0 .OR. IDIR .EQ. 2 ) CALL MESSAG ('J = $',100,4.95,5.3)
    IF (IDIR .EQ. 0 .OR. IDIR .EQ. 2 ) CALL INTNO (M,'ABUT','ABUT')
    IF (IDIR .EQ. 0 ) CALL MESSAG ('K = $',100,5.0,5.2)
    IF (IDIR .EQ. 0 ) CALL INTNO (N,'ABUT','ABUT')
    CALL MESSAG ('TIME = $',100,5.0,5.0)
    CALL REALNO (TIME,1,5.7,5.0)
    IF (ISTEP .LE.73) CALL MESSAG ('YEARS$',100,6.2,5.0)
    IF (ISTEP .GT. 74) CALL MESSAG ('YEARS$',100,6.3,5.0)
    IF (IDIR .EQ. 0) CALL CURVE (XDIR,PLTARAY,NPTS,1)
    IF (IDIR .EQ. 1) CALL CURVE (DY,PARRAY,NPTS,1)
    IF (IDIR .EQ. 2) CALL CURVE (DZ,PLTARAY,NPTS,1)
    GO TO 9000
C
3400 CONTINUE
C
C IFLAG = 1 (PLOTING TEMPERATURE)
C
  TMIN = 0.0
  TMAX = 300.
  J = 1
  DO 3425 I=ISTART,IEND,INC
    PLTARAY(J) = TARRAY(I)
    WRITE(6,5240)PLTARAY(J),DZ(J)
    XDIR(J) = DX(I)
    J = J + 1

```

```

3425 CONTINUE
  CALL HEIGHT (0.20)
  CALL XNAME ('DISTANCE, CM$',100)
  CALL YNAME ('TEMPERATURE, C$',100)
  CALL MESSAG ('CANISTER IN, ROOM OPEN, (ROOM IS
1 AT RIGHT SIDE)$',100,.2,6.4)
  IF (IDIR .EQ. 0) CALL GRAF (0.0,'SCALE',XDIR(NPTS),TMIN,'SCALE',TMAX)
  IF (IDIR .EQ. 2) CALL GRAF (0.0,'SCALE',DZ(NPTS),TMIN,'SCALE',TMAX)
  CALL HEIGHT (0.14)
  CALL MESSAG('LOCATION  $',100,5.0,5.8)
  IF (IDIR .EQ. 2) CALL MESSAG ('I = $',100,5.0,5.5)
  IF (IDIR .EQ. 2) CALL INTNO (L,'ABUT','ABUT')
  IF (IDIR .EQ. 0 .OR. IDIR .EQ. 2) CALL MESSAG ('J = $',100,4.95,5.3)
  IF (IDIR .EQ. 0 .OR. IDIR .EQ. 2) CALL INTNO (M,'ABUT','ABUT')
  IF (IDIR .EQ. 0) CALL MESSAG ('K = $',100,5.0,5.2)
  IF (IDIR .EQ. 0) CALL INTNO (N,'ABUT','ABUT')
  CALL MESSAG ('TIME = $',100,5.0,5.0)
  CALL REALNO (TIME,1,5.7,5.0)
  IF (ISTEP .LE. 73) CALL MESSAG ('YEARS$',100,6.2,5.0)
  IF (ISTEP .GE. 74) CALL MESSAG ('YEARS$',100,6.3,5.0)
  IF (IDIR .EQ. 0) CALL CURVE (XDIR,PLTARAY,NPTS,1)
  IF (IDIR .EQ. 1) CALL CURVE (DY,TARRAY,NPTS,1)
  IF (IDIR .EQ. 2) CALL CURVE (DZ,PLTARAY,NPTS,1)
  GO TO 9000

```

```

C
C IFLAG = 2 (PLOTING SATURATIONS)
C

```

```

3500 CONTINUE
  J = 1
  DO 3525 I=ISTART,IEND
    PLTARAY(J) = SARRAY(I)
    XDIR(J) = DX(I)
    J = J + 1
3525 CONTINUE
  CALL HEIGHT (0.20)
  CALL XNAME ('DISTANCE, CM$',100)
  CALL YNAME ('SATURATION$',100)
  CALL GRAF (0.0,'SCALE',XDIR(NPTS),SMIN,'SCALE',SMAX)
  CALL HEIGHT (0.14)
  CALL MESSAG('LOCATION  $',100,5.0,1.6)
  IF (IDIR .EQ. 0) CALL MESSAG ('J = $',100,5.0,1.4)
  IF (IDIR .EQ. 0) CALL INTNO (M,'ABUT','ABUT')
  IF (IDIR .EQ. 0) CALL MESSAG ('K = $',100,5.0,1.2)
  IF (IDIR .EQ. 0) CALL INTNO (N,'ABUT','ABUT')
  CALL MESSAG ('TIME = $',100,5.0,1.0)
  CALL REALNO (TIME,1,5.7,1.0)
  CALL MESSAG ('YEARS$',100,6.2,1.0)
  IF (IDIR .EQ. 0) CALL CURVE (XDIR,PLTARAY,NPTS,1)
  IF (IDIR .EQ. 1) CALL CURVE (DY,SARRAY,NPTS,1)
  IF (IDIR .EQ. 2) CALL CURVE (XDIR,SARRAY,NPTS,1)

```



```

C
5000 CONTINUE
C
9000 CONTINUE
      CALL PHYSOR (-11.0,8.65)
      CALL DONEPL
      CALL ENDPL (0)
      END
      SUBROUTINE TIMPLT
C
      DIMENSION TIMES(1000), PLTARRAY(1000),XDIR(1000),P(1000),SW1(1000),
C
      1      P1(1000),TEMP2(1000),PARRAY(1000),SARRAY(1000),TARRAY(1000)
C
50  CONTINUE
C
      INC = 80
      WRITE(6,125)
125  FORMAT(' ENTER NUMBER OF STEP NUMBERS IN DATA FILE')
C
      CALL FREEF
      READ(10,150) ISTEP
150  FORMAT(I5)
C
      WRITE(6,200)
200  FORMAT(' ENTER THE NX, NY, AND NZ LOCATION YOU WANT TO PLOT')
C
      CALL FREEF
C
      READ(10,250) NXLOC,NYLOC,NZLOC
250  FORMAT(3I5)
C
      L = NXLOC
      M = NYLOC
      N = NZLOC
      WRITE(6,300)
300  FORMAT(' ENTER VALUES FOR NX, NY, AND NZ FROM GEOHEAT')
C
      CALL FREEF
      READ(10,250) NX,NY,NZ
C
      ISTART = (NZLOC - 1) * 8 + NXLOC
C
C
      IPCK = ISTART
      WRITE(6,99) IPCK
99  FORMAT(5X,'IPCK = ',I5)
      II = 1
      DO 1000 I=1,ISTEP
C

```

```

C
  READ(4,400) NTP,TIMES(I)
400  FORMAT(/13X,I4,36X,G12.5/)
C
100  FORMAT(5D14.7)
C
  DO 600 J=1,NY
  DO 600 K=1,NZ
  IK1 = (K-1)*NX+1+(J-1)*NX*NZ
  IK2 = IK1 + NX - 1
  READ(4,100) (P(ICK),ICK=IK1,IK2)
  WRITE(7,100) (P(ICK),ICK=IK1,IK2)
600  CONTINUE
C
  PARRAY(II) = P(IPCK)
C
C
  DO 700 J=1,NY
  DO 700 K=1,NZ
  IK1 = (K-1)*NX+1+(J-1)*NX*NZ
  IK2 = IK1+NX-1
  READ(4,100) (TEMP2(ICK),ICK=IK1,IK2)
  WRITE(7,100) (TEMP2(ICK),ICK=IK1,IK2)
700  CONTINUE
  TARRAY(II) = TEMP2(IPCK)
C
  DO 800 J=1,NY
  DO 800 K=1,NZ
  IK1 = (K-1)*NX+1+(J-1)*NX*NZ
  IK2 = IK1+NX-1
  READ(4,100) (SW1(ICK),ICK=IK1,IK2)
  WRITE(7,100) (SW1(ICK),ICK=IK1,IK2)
800  CONTINUE
  SARRAY(II) = SW1(IPCK)
  II = II + 1
1000 CONTINUE
C
  J = 1
C
C
C  PRESSURES, SATURATIONS, OR TEMPERATURES????????????????
C  (SET IFLAG TO 0,1, OR 2)
C
  WRITE (6,1400)
1400 FORMAT(' DO YOU WANT TO PLOT PRESSURES, SATURATIONS, '
1      'OR TEMPERATURES'/' ENTER A 0 FOR PRESSURE, A 1 FOR
2      TEMPERATURE, OR A 2 FOR SATURATION'/)
C
  CALL FREEF
  READ(10,1500) IFLAG

```

```

1500 FORMAT(I5)
C
C  CONVERT SECONDS TO YEARS
C
      DO 1600 I=1,ISTEP
      TIMES(I) = TIMES(I)/(3600.*24.*365.)
1600 CONTINUE
C
C  PRESSURE MAX AND MINS
C
C  CONVERT PRESSURE IN DYNES/CM2 TO BARS
C
      DO 1700 I=1,ISTEP
      PARRAY(I) = PARRAY(I)/1.0D6
1700 CONTINUE
C
      PMIN = PARRAY(1)
      PMAX = 0.0
C
      DO 1800 I=1,ISTEP
      IF (PARRAY(I) .GT. PMAX) PMAX = PARRAY(I)
      IF (PARRAY(I) .LT. PMIN) PMIN = PARRAY(I)
1800 CONTINUE
C
C  TEMPERATURE MAX AND MINS
C
      TMIN = TARRAY(1)
      TMAX = 0.0
C
      DO 1900 I=1,ISTEP
      IF (TARRAY(I) .GT. TMAX) TMAX = TARRAY(I)
      IF (TARRAY(I) .LT. TMIN) TMIN = TARRAY(I)
1900 CONTINUE
C
      SMIN = SARRAY(1)
      SMAX = 0.0
      DO 2000 I=1,ISTEP
      IF (SARRAY(I) .GT. SMAX) SMAX = SARRAY(I)
      IF (SARRAY(I) .LT. SMIN) SMIN = SARRAY(I)
2000 CONTINUE
C
C  ADD A BIT TO PLOT DIMENSIONS FOR BETTER LOOKS
C
      PMAX = PMAX + 0.1 * (PMAX - PMIN)
      PMIN = PMIN - 0.1 * (PMAX - PMIN)
      IF (PMIN .LE. 0.0) PMIN = 0.0
C
      TMAX = TMAX + 10.0 * (TMAX - TMIN)
      TMIN = TMIN - 10.0 * (TMAX - TMIN)
      IF (TMIN .LE. 0.0) TMIN = 0.0

```

```

C      SMAX = SMAX + 0.1 * (SMAX - SMIN)
      SMIN = SMIN - 0.1 * (SMAX - SMIN)
      IF (SMIN .LE. 0.0) SMIN = 0.0
C
      IF (PMAX .NE. PMIN) GO TO 2100
      IF (TMAX .NE. TMIN) GO TO 2100
      IF (SMAX .NE. SMIN) GO TO 2100
C
      PMAX = PMAX + 1.
      PMIN = PMIN - 1.
      TMAX = TMAX + 10.
      TMIN = TMIN - 10.
      SMAX = SMAX + 1.
      SMIN = SMIN - 1.
2100 CONTINUE
C
C      CALL TO COMPRS SENDS PLOT FILE TO DISSPOP.POP
C
      CALL COMPRS
      CALL RESET ('ALL')
      CALL PAGE(11.0,8.5)
      CALL NOBRDR
      CALL AREA2D(8.0,6.0)
      CALL FRAME
      CALL THKFRM(0.10)
      CALL SETDEV(11,12)
      CALL SWISSM
      CALL HEIGHT(0.20)
      IF (IFLAG .EQ. 1) GO TO 3000
      IF (IFLAG .EQ. 2) GO TO 3100
C
C      IFLAG = 0 (PLOTING PRESSURE)
C
      PMIN = 0.0
      PMAX = 100.0
2600 CONTINUE
      CALL HEIGHT (0.20)
      CALL XNAME ('TIME, YEARS$',100)
      CALL YNAME ('PRESSURE, BARS$',100)
      CALL GRAF (0.0,'SCALE',TIMES(ISTEP),PMIN,'SCALE',PMAX)
      CALL MESSAG ('CANISTER IN, ROOM OPEN, 4 X RADIUS (ROOM IS
1AT RIGHT SIDE$',100,0.0,6.2)
      CALL HEIGHT (0.14)
      CALL MESSAG ('LOCATION $',100,5.0,1.8)
      CALL MESSAG ('I = $',100,5.0,1.5)
      CALL INTNO (L,'ABUT','ABUT')
      CALL MESSAG ('J = $',100,5.0,1.3)
      CALL INTNO (M,'ABUT','ABUT')

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```

      CALL MESSAG ('K = $',100,5.0,1.1)
      CALL INTNO (N,'ABUT','ABUT')
      CALL CURVE (TIMES,PARRAY,ISTEP,1)
      GO TO 10000
3000 CONTINUE
C
C   IFLAG = 1 (PLOTING TEMPERATURE)
C
      TMIN = 0.0
      TMAX = 240.
      CALL HEIGHT (0.20)
      CALL XNAME ('TIME, YEARS$',100)
      CALL YNAME ('TEMPERATURE, DEGREES C$',100)
      CALL MESSAG ('CANISTER IN ROOM OPEN, 4 X RADIUS (ROOM IS
1AT RIGHT SIDE$',100,0.0,6.2)
      CALL GRAF (0.0,'SCALE',TIMES(ISTEP),TMIN,'SCALE',TMAX)
      CALL HEIGHT(0.14)
      CALL MESSAG ('LOCATION $',100,5.0,5.8)
      CALL MESSAG ('I = $',100,5.0,5.5)
      CALL INTNO (L,'ABUT','ABUT')
      CALL MESSAG ('J = $',100,5.0,5.3)
      CALL INTNO (M,'ABUT','ABUT')
      CALL MESSAG ('K = $',100,5.0,5.1)
      CALL INTNO (N,'ABUT','ABUT')
      CALL CURVE (TIMES,TARRAY,ISTEP,1)
      GO TO 10000
C
C   IFLAG = 2 (PLOTING SATURATIONS)
C
3100 CONTINUE
      CALL HEIGHT (0.20)
      CALL XNAME ('TIME, YEARS$',100)
      CALL YNAME ('SATURATION$',100)
      CALL MESSAG ('CANISTER IN PLACEMENT ROOM OPEN, 4 X RADIUS$',100,
$      .2,6.2)
      CALL GRAF (0.0,'SCALE',TIMES(ISTEP),SMIN,'SCALE',SMAX)
      CALL HEIGHT (0.14)
      CALL MESSAG ('LOCATION $',100,5.0,5.8)
      CALL MESSAG ('I = $',100,5.0,5.5)
      CALL INTNO (L,'ABUT','ABUT')
      CALL MESSAG ('J = $',100,5.0,5.3)
      CALL INTNO (M,'ABUT','ABUT')
      CALL MESSAG ('K = $',100,5.0,5.1)
      CALL INTNO (N,'ABUT','ABUT')
      CALL CURVE (TIMES,SARRAY,ISTEP,1)
10000 CONTINUE
      RETURN
      END
      SUBROUTINE FREEF

```

FREE

C**		FREE
3		
C**	THIS SUBROUTINE TRANSLATES	FREE
4		
C**	FREE FIELD INPUT AND WRITES	FREE
5		
C**	IT TO LOGICAL UNIT 10	FREE
6		
C**		FREE
7		
	LOGICAL DEC, NUM, ALPHA	FREE
8		
	DIMENSION IN(80), ICOM(80)	FREE
9		
C**		FREE
10		
	INTEGER COMMA, DOT, DIG(10), OUT(80), SPACE, ASC(26)	FREE
11		
C**		FREE
12		
	DATA COMMA /1H,/, DOT /1H./, SPACE /1H /	FREE
13		
C**		FREE
14		
	DATA DIG /1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/	FREE
15		
	DATA ASC /1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ/	FREE
16		
17		
C**		FREE
18		
	DO 100 I = 1,80	FREE
19		
	IN(I) = SPACE	FREE
20		
	OUT(I) = SPACE	FREE
21		
	100 CONTINUE	FREE
22		
C**		FREE
23		
	READ (5,330) IN	FREE
24		
C**		FREE
25		
C**	PUT A COMMA AT END OF INPUT LINE IF THERE'S	FREE
26		
C**	NOT ALREADY ONE THERE.	FREE
27		

C**		FREE
28		
	DO 120 I = 1,80	FREE
29		
	II = 80-I+1	FREE
30		
	IF (IN(II).EQ.SPACE) GO TO 120	FREE
31		
C**		FREE
32		
	IF (IN(II).EQ.COMMA) GO TO 130	FREE
33		
	IF (IN(II).EQ.DOT) IN(II+1)=COMMA	FREE
34		
	IF (IN(II).EQ.DOT) GO TO 130	FREE
35		
C**		FREE
36		
	DO 110 J = 1,10	FREE
37		
	IF (IN(II).NE.DIG(J)) GO TO 110	FREE
38		
C**		FREE
39		
	IN(II+1) = COMMA	FREE
40		
	GO TO 130	FREE
41		
C**		FREE
42		
	110 CONTINUE	FREE
43		
C**		FREE
44		
	120 CONTINUE	FREE
45		
C**		FREE
46		
	130 CONTINUE	FREE
47		
C**		FREE
48		
	IO = 0	FREE
49		
C**		FREE
50		
C**	LOOK FOR COMMAS AND REMEMBER	FREE
51		
C**	WHERE THEY ARE	FREE
52		

C**		FREE
53		
	NCOM = 0	FREE
54		
	DO 140 I = 1,80	FREE
55		
	IF (IN(I).NE.COMMA) GO TO 140	FREE
56		
	NCOM = NCOM+1	FREE
57		
	ICOM(NCOM)=I	FREE
58		
	140 CONTINUE	FREE
59		
C**		FREE
60		
	IF (NCOM.GT.0) GO TO 160	FREE
61		
	WRITE(10,340,IOSTAT=IERR,ERR=150) (IN(I),I=1,80)	VAXU
38		
	GO TO 160	VAXU
39		
C**		FREE
64		
	150 CONTINUE	FREE
65		
C**		FREE
66		
	STOP	FREE
67		
C**		FREE
68		
	160 CONTINUE	FREE
69		
C**		FREE
70		
	IF (NCOM.LE.0) GO TO 320	FREE
71		
C**		FREE
72		
C**	PROCESS DATA BETWEEN COMMAS	FREE
73		
C**		FREE
74		
	DO 270 N = 1,NCOM	FREE
75		
	IF (N.EQ.1) IFRST=1	FREE
76		
	IF (N.GT.1) IFRST=ICOM(N-1)+1	FREE
77		

C**		FREE
78	ILAST = ICOM(N)-1	FREE
79		FREE
C**		FREE
80	NUM = .FALSE.	FREE
81	DEC = .FALSE.	FREE
82	ALPHA = .FALSE.	FREE
83		FREE
C**		FREE
84	DO 200 I = IFRST,ILAST	FREE
85		FREE
C**		FREE
86	DO 170 II=1,26	FREE
87	IF (IN(I).NE.ASC(II)) GO TO 170	FREE
88	ALPHA = .TRUE.	FREE
89	GO TO 210	FREE
90		FREE
C**		FREE
91	170 CONTINUE	FREE
92		FREE
C**		FREE
93	DO 180 II=1,10	FREE
94	IF (IN(I).NE.DIG(II)) GO TO 180	FREE
95	NUM = .TRUE.	FREE
96	GO TO 190	FREE
97	180 CONTINUE	FREE
98		FREE
C**		FREE
99	190 CONTINUE	FREE
100		FREE
C**		FREE
101	IF (IN(I).EQ.DOT) DEC=.TRUE.	FREE
102		

C**		FREE
103		
200	CONTINUE	FREE
104		
C**		FREE
105		
210	CONTINUE	FREE
106		
C**		FREE
107		
	IF (.NOT.NUM) GO TO 250	FREE
108		
C**		FREE
109		
	IF (.NOT.DEC) GO TO 230	FREE
110		
C**		FREE
111		
C**	THIS IS A REAL VARIABLE,	FREE
112		
C**	MOVE IT INTO A 10 POSITION FIELD	FREE
113		
C**		FREE
114		
	IOP = IO+10	FREE
115		
	DO 220 I = IFRST, ILAST	FREE
116		
	INN = ILAST-I+IFRST	FREE
117		
	OUT(IOP) = IN(INN)	FREE
118		
	IOP = IOP-1	FREE
119		
220	CONTINUE	FREE
120		
C**		FREE
121		
	IO = IO+10	FREE
122		
	GO TO 270	FREE
123		
C**		FREE
124		
230	CONTINUE	FREE
125		
C**		FREE
126		
C**	THIS MUST BE AN INTEGER,	FREE
127		

C** MOVE IT INTO A 5 POSITION FIELD	FREE
128	
C**	FREE
129	
IOP = IO+5	FREE
130	
DO 240 I = IFRST,ILAST	FREE
131	
INN = ILAST-I+IFRST	FREE
132	
OUT(IOP) = IN(INN)	FREE
133	
IOP = IOP-1	FREE
134	
240 CONTINUE	FREE
135	
C**	FREE
136	
IO = IO+5	FREE
137	
GO TO 270	FREE
138	
C**	FREE
139	
250 CONTINUE	FREE
140	
C**	FREE
141	
C** NOT NUMERIC DATA, LEAVE IT AS IT IS.	FREE
142	
C**	FREE
143	
ILST = ILAST+1	FREE
144	
IKN = 1	FREE
145	
DO 260 I = IFRST,ILST	FREE
146	
OUT(IO+IKN)=IN(I)	FREE
147	
IKN = IKN+1	FREE
148	
260 CONTINUE	FREE
149	
C**	FREE
150	
IF (IN(ILST).EQ.COMMA) OUT(IO+IKN-1)=SPACE	FREE
151	
IO = IO+ILST-IFRST+1	FREE
152	

C**		FREE
153		
	270 CONTINUE	FREE
154		
C**		FREE
155		
C**	PROCESS DATA AFTER LAST COMMA	FREE
156		
C**		FREE
157		
	IFRST = ICOM(NCOM)+1	FREE
158		
	DO 280 I = IFRST,80	FREE
159		
	IO = IO+1	FREE
160		
	IF (IO.GT.80) GO TO 290	FREE
161		
	OUT(IO) = IN(I)	FREE
162		
	280 CONTINUE	FREE
163		
C**		FREE
164		
	290 CONTINUE	FREE
165		
C**		FREE
166		
	WRITE(10,340,IOSTAT=IERR,ERR=300) (OUT(I),I=1,80)	VAXU
40		
	GO TO 310	VAXU
41		
C**		FREE
168		
C**		FREE
170		
	300 CONTINUE	FREE
171		
C**		FREE
172		
	STOP	FREE
173		
C**		FREE
174		
	310 CONTINUE	FREE
175		
C**		FREE
176		
	320 CONTINUE	FREE
177		

C**		FREE
178		
	BACKSPACE 10	FREE
179		
C**		FREE
180		
	RETURN	FREE
181		
C**		FREE
182		
C		FREE
183		
	330 FORMAT (80A1)	FREE
184		
	340 FORMAT (80A1)	FREE
185		
	END	FREE
186		

Contour Plotting

GEOTHR creates a TAPE11 file that is used as input for the post-processing program POSTPRO. POSTPRO creates an unformatted file that is necessary to execute SEQUEL, which, in turn, creates the input for MANPLT that produces the actual contour plot. The step-by-step procedure to create graphics on the PNL VAX 11/780 and the Los Alamos National Laboratory CDC systems is as follows:

Transform TAPE11 file to standard text form on the VAX 11/780.

```
$ STEXT TAPE11.DAT TAPE11.LSL
```

On one of the CDC 7600s at Los Alamos, transmit the file from the VAX to LANL via magic.

Enter:

```
magic
```

```
? default sdir=[rhoshb] smach=pnlb "rhoshb password"
```

```
? copy tape11.lsl tape
```

```
? end
```

Change tape back to native text form

```
ntext tape postinp - lc
```

(POSTINP is the required name to be used to execute POSTPRO.)

If a change to POSTPRO should become necessary, get the compilable form POSTPRO, make the change, and recompile by entering

```
ftn (i=postpro,cname=postpro)
```

Execute post-processor postpro by entering

```
postbin
```

After execution of POSTPRO there will now be a file in local file space called REPOST. This file will be used in addition to another input file required as input for SEQUEL. Following is a line-by-line description of the contents of the SEQINP file acquired from the TEMPEST POST-PROCESSING GRAPHICS PREPARATION USING SEQUEL AND MANPLT CODES document.

Line 1 FORMAT(A4):

PLAN   Alphanumeric identifier occurs in Columns 1-4.

Line 2 FORMAT(A4,1X,A3,1X,A4,1X,A4,1X,A4):

POPT,XSEC,COPT,POLR,GRD

where

POPT: Plot option, specify

         VECT for vector-only plot

         CONT for contour-only plot

         BOTH for both

         BOUN for material boundaries only, or

         blank for none of the above (e.g., do GRD only)

XSEC: Cross-section of plot plane, specify

         R=Z for RZ plot plane (X = constant)

         Z-X for ZX plot plane (R = constant)

         R-X for RX plot plane (Z = constant)

Note: The designation of R-Z implies TEMPEST R-coordinate direction is to be the plot abscissa (x-axis) and Z-coordinate direction is to be the plot ordinate (y-axis). Inputting Z-R is not an option. Z-X and R-X coordinates correspond to abscissa-ordinate, respectively.

COPT: Contour variable, specify:

TCON for isotherms
 PCON for isobars
 QGEN for heat generation rate
 TKIN for kinetic energy
 TDIS for dissipation
 EDDY for turbulent viscosity
 blank if not contouring
 POLR: Geometry if plane, specify:
       CART for all but polar plot in R-X plane
       POLR for polar (R-X plane only). In this case,
           abscissa (x-axis) corresponds to radius and ordinate
           corresponds to θ angle (y-axis)
 GRD: Draw grid lines, specify
       GRID for drawing grid lines (material boundaries
           high-lighted if BOUN is also selected)
       blank for no grid lines.

Line 3 (FORMAT(8F10.0):

XSIZE, YSIZE, RSTART, XSTART, VLEN

where

XSIZE: Plot size of horizontal axis. Diameter of plot if R-X POLR (inches).

YSIZE: Plot size of vertical axis. Not used if R-X and POLR.

RSTART: For polar plot in R-X plane only. Specifies distance (in TEMPEST simulation length units) to east face of first cell, such as for annular flow. If used, this value must equal RSTART variable on Card Type 1, Group 4, of TEMPEST input deck. (Default = 0.)

XSTART: For polar plot in R-X plane only. Specifies rotation angle to simulation X-coordinate. If used, this value may be set equal to XSTART variable on Card Type 1, Group 4 of TEMPEST input. Other values will simply rotate the plot on paper, then the user has to remember which way gravity is acting. (Default = 0.)

VLEN: Length of maximum velocity vector (inches). Length of all other velocity vectors are scaled appropriately. Note: if multiple

planes are to be plotted in a three-dimensional simulation,
velocity vectors are scaled to maximum in whole simulation.

Line 4 FORMAT(16I5):

INT, ISTR, IFIN, IFLIPX, IFLIPY

where

INT: Post-processing file number to plot (from TEMPEST output)

ISTR: Start with plane number

IFIN: End with plane number

(Note: for two-dimensional calculation, ISTR=1, IFIN=1. For three-dimensional calculation, e.g., if ISTR=2, IFIN=5, it will plot contours for plane 2, 3, 4, and 5 separately in one run).

IINC: And do in increments of

Note: For two-dimensional simulations, ISTR=IEND=IINC=1

For three-dimensional simulations, ISTR=3, IEND=12,

IINC=3 would plot planes I=3, 6, 9, 12 if plot plane is

R-Z, for example. Similar definition holds if Z-X or R-X is the plot plane.

IFLIPX: = 0 for no x-axis flip

= 1 for flip of x-axis (i.e., interchange of 1 to NX and NX to 1).

This is very useful if planes I=2 and I=NX-1 are to be put together as in upper and lower half of R-Z plane of a three-dimensional cylindrical geometry.

IFLIPY: = 0 for no y-axis flip

= 1 for flip of y-axis

Note: Flipping an axis causes the axis to be reversed instead of being from XMIN to XMAX; it will occur with the limits being XMAX to XMIN, e.g., flipped.

Line 5 FORMAT(16I5):

NP

where

NP: Total number of planes to plot. In above three-dimensional example NP would be 4.

Line 6 FORMAT(16I5)P:

(ISS(I),ISE(I),ITS(I),ITE(I),I=1,NP)

where

ISS(I):R-direction counter start

ISE(I):R-direction counter end

ITS(I):Z-direction counter start

ITE(I):Z-direction counter end

Notes: These are used for reduced region blowup. More than one card may be required if $NP > 4$. Defaulting all variables to zero will plot whole plane from 1 to NR and 1 to NZ if plane is R-Z. For example, if the plot is to be without the row of phantom (boundary) cells surrounding the simulation, then $ISS=2$, $ISE=NR-1$, $ITS=2$, and $ITE=NZ-1$. Similar definitions hold for R-X and Z-X planes.

Line 7 FORMAT(16I5):

NLABL: Number of labels

Line 8, 9, 10 FORMAT(4F10.0,10A4)

XPOS(I),YPOS(I),SIZ(I),ROT(I),(LABL(J),J=1,10)

(same as label description of MONITOR plots. Omit card(s) if NLABL=0)

Line 11 FORMAT(1yI5):

NLEV,ISP

where

NLEV: Number of contour levels. (Omit card if POPT is VECT or BOUN or blank)

ISP: (not used, set = 0)

Line 12 FORMAT(8F10.0):

(clev(i),i=1,nlev)

where

CLEV(I):Contour value (e.g., °C for temperature). More than one card may be required. Omit card if POPT is VECT or BOUN or blank:

Following is a sample SEQINP file used to create a contour plot from results of GEOTHER.

```
1  plan
2  cont,r=x,pcon,cart,grid
3  3.000e+00 5.000e+00 0.000e+00
4  1  1  5  1  0  0
5  5
6  2  5  2  5  2  5  2  5  2  5  2  5  2  5
2  5
7  2  5  2  5
8  3
9  -0.300 5.500 0.150 0.000plane:geotherm
10 -0.600 -0.250 0.080 0.000radial direction
11 -0.1800 1.200 0.080 90.000vertical direction
12  3
13  0.2e+0.8 0.7e+0.8 0.129e+0.9
```

Upon execution of SEQUEL, the user will be queried whether he or she wants to enter a setup or run mode. After entering seqbin3 to execute sequel a prompt will be received.

Do you want to setup a plot input file or run an existing plot input file? input set or run

If you already have your SEQINP file created, enter r for run or s if you wish to generate an interactive file.

After SEQUEL is executed it will have created a file called SEQOUT in your local file space. This file now contains correctly formatted data for preparation of a plot using the MANPLT program.

Due to MANPLT being site dependent, it is necessary to transfer the file SEQOUT to the VAX. Again, change the SEQOUT file to standard text form.

stext seqout set

Enter: magic

? default sdir=[rhoshb.clb] smach=pnlb "rhoshb password"

? copy seq seqnew.lsl

? end

After logging on to VAX, switch the input file transmitted from LANL back to native text and upper case

NTEXT SEQNEW.LSL SEQNEW.OUT -UC

To run MANPLT to generate a hard copy plot

Enter: RUN MANPLT3A0

The next prompts will be:

SEQUEL GENERATED FILE NAME OR DATAONLY FOR DATA ONLY MODE

Enter. SEQNEW.OUT

Are data to be plotted with the TEMPEST results?

Enter - NO

Enter pen number

Enter - 1

Paging mode. Enter auto or manual

Enter - AUTO

Listing of POSTPRO

C

```
PROGRAM POSTPRO (POSTINP,READCHK,TAPE11=POSTINP,TAPE7=
$READCHK,TTY,TAPE5=TTY,TAPE6=TTY,REPOST,TAPE2=REPOST,
1 GARBAGE,TAPE8=GARBAGE)
```

C

C A POST PROCESSOR WRITTEN TO READ TAPE11 FROM GEOTHERM

C AND CREATE A REPOST FILE FOR SEQUEL TO PLOT CONTOURS

C CL BARTLEY - 9/12/85

C

C*****

FORTTRAN Listing of POSTPRO

```
COMMON/INT/NY,NZ,NX,MAXMAT,DX(102),X(102),NT(2500),MT(2500),
$      MP(52),PLOTTER(30),VERSION,DATVER(2),MODNUM,
$      DATMOD(2),TINT(3),DMYR(3),
$      P(2500),TEMP2(2500),SW1(2500),TR(2500),
$      DY(1000),DZ(1000),DUMMY(10000)
```

C

```

C      LOGICAL PLOTTER
C
C      READ TAPE11
C
C      READ(11,300) NX,NY,NZ
300    FORMAT(3(5X,I4)///)
C
C
C      CHANGES TO COUNTERS TO CORRESPOND WITH TEMPEST NODING
C
C      NXST =MINO(2,NX)
C      NYST = MINO(2,NY)
C      NZST = MINO(2,NZ)
C
C      IF (NX .NE. 1) NX = NX + 2
C      IF (NY .NE. 1) NY = NY + 2
C      IF (NZ .NE. 1) NZ = NZ + 2
C
C      NXM1 = MAXO(1,NX-1)
C      NYM1 = MAXO(1,NY-1)
C      NZM1 = MAXO(1,NZ-1)
C
C      DX(1) = DX(2)
C      DX(NX) = DX(NXM1)
C
C      DY(1) = DY(2)
C      DY(NY) = DY(NYM1)
C
C      DZ(1) = DZ(2)
C      DZ(NZ) = DZ(NZM1)
C      WRITE(7,300) NX,NY,NZ
C
C      READ(11,400) (DX(I),I=NXST,NXM1)
400    FORMAT(5E14.7)
C
C      READ (11,450)
450    FORMAT(/)
C
C
C      WRITE(7,400) (DX(I),I=NXST,NXM1)
C
C      READ(11,400) (DY(I),I=NYST,NYM1)
C
C      READ(11,450)
C
C      WRITE(7,400) (DY(I),I=NYST,NYM1)
C
C      READ(11,400) (DZ(I),I=NZST,NZM1)
C

```

```

WRITE(7,400) (DZ(I),I=NZST,NZM1)
C
C
C FIND OUT STEP NUMBER TO BE WRITTEN OUT FOR PLOTTING LATER
C
WRITE(6,525)
525  FORMAT(" ENTER THE STEP NUMBER TO BE PROCESSED FOR THIS RUN")
C
READ (5,*) ISTEP
C
500  CONTINUE
C
C
C
C
READ(11,600) L,TYME
600  FORMAT(/13X,I4,36X,E12.5/)
C
IFLAG = 1
IF (ISTEP .NE. L)   IFLAG = 0
C
IF(ABS(EOF(11)) .NE. 0.0) GO TO 1100
C
C CONVERT TYME IN SECONDS TO TYME IN YEARS
C
TYME = TYME/(3600.*24.*365.)
C
WRITE(7,600) L,TYME
C
DO 800 J=NYST,NYM1
DO 800 K=NZST,NZM1
IK1 = (K-1)*NX+2+(J-1)*NX*NZ
IK2 = IK1 + NX - 3
IF ( IFLAG .EQ. 0) GO TO 750
READ(11,700) (P(ICK),ICK=IK1,IK2)
700  FORMAT(5E14.7)
C
WRITE(7,700) (P(ICK),ICK=IK1,IK2)
GO TO 800
750  CONTINUE
READ (11,700) (DUMMY(ICK),ICK=IK1,IK2)
800  CONTINUE
C
DO 900 J=NYST,NYM1
DO 900 K=NZST,NZM1
IK1 = (K-1)*NX+2+(J-1)*NX*NZ
IK2 = IK1 + NX - 3
IF (IFLAG .EQ. 0) GO TO 850
READ(11,700) (TEMP2(ICK),ICK=IK1,IK2)
C

```

```

        WRITE(7,700) (TEMP2(ICK),ICK=IK1,IK2)
        GO TO 900
C
850    CONTINUE
        READ (11,700) (DUMMY(ICK),ICK=IK1,IK2)
900    CONTINUE
C
        DO 1000 J=NYST,NYM1
        DO 1000 K=NZST,NZM1
        IK1 = (K-1)*NX+2+(J-1)*NX*NZ
        IK2 = IK1 + NX - 3
        IF ( IFLAG .EQ. 0) GO TO 950
        READ(11,700) (SW1(ICK),ICK=IK1,IK2)
C
        WRITE(7,700) (SW1(ICK),ICK=IK1,IK2)
        GO TO 1000
C
950    CONTINUE
C
        READ (11,700) (DUMMY(ICK),ICK=IK1,IK2)
C
1000   CONTINUE
        DO 1050 J=NYST,NYM1
        DO 1050 K=NZST,NZM1
        IK1 = (K-1)*NX+2+(J-1)*NX*NZ
        IK2 = IK1 + NX - 3
C
        IF (IFLAG .EQ. 0) GO TO 1025
C
        READ(11,700) (TR(ICK),ICK=IK1,IK2)
C
        WRITE(7,700) (TR(ICK),ICK=IK1,IK2)
        GO TO 1050
C
C
1025   CONTINUE
        READ (11,700) (DUMMY(ICK),ICK=IK1,IK2)
1050   CONTINUE
C
        IF ( IFLAG .EQ. 1) GO TO 1100
C
        GO TO 500
C
1100   CONTINUE
C
C  FILL ARRAYS AND VARIABLES NOT WRITTEN OUT BY GEOTHERM
C
        VERSION = "0000"
        MODNUM = 0
        DATVER(1) = 0.0

```

```

        DATVER(2) = 0.0
        DATMOD(1) = 0.0
        DATMOD(2) = 0.0
        TINT(1)   = 0.0
        TINT(2)   = 0.0
        TINT(3)   = 0.0
        DMYR(1)   = .09
        DMYR(2)   = .19
        DMYR(3)   = .85
        ITTPD = 1
        NSTEP = 1
        MAXMAT = 52
        MP(1) = 1
        DO 1200 N=2,MAXMAT
        MP(N) = 52
1200    CONTINUE
        IF(MAXMAT.EQ.0) GO TO 2500
C
C   FILL PLOTTER ARRAY
C
C
        DO 1300 N=1,30
        PLOTTER(N) = .FALSE.
1300    CONTINUE
        NTOTAL = 2500
        PLOTTER(4) = .TRUE.
        PLOTTER(5) = .TRUE.
        PLOTTER(10) = .TRUE.
        PLOTTER(11) = .TRUE.
1500    CONTINUE
        DO 1700 N=1,NTOTAL
        NT(N) = 0
        MT(N) = 0
1700    CONTINUE
C
C   DX'S INTO X
C
        DO 2100 I=1,NX
        X(I) = DX(I)
2100    CONTINUE
C
C   DZ'S INTO X
C
        NSTART = NX + 1
        NZTOT = NX + NZ
        J = 1
        DO 2200 I=NSTART,NZTOT
        X(I) = DZ(J)
        J = J + 1
2200    CONTINUE

```

```

99      FORMAT(2I10)
C
C  DY'S INTO X
C
      NSTART = NZTOT + 1
      NYTOT = NX + NZ + NY
      K = 1
      DO 2300 I=NSTART,NYTOT
      X(I) = DY(K)
      K = K + 1
2300    CONTINUE
C
C
C  WRITE TAPE2
C
      WRITE(2) NX,NY,NZ,MAXMAT,X,X,NT,MT,MP,PLOTER,VERSION,DATVER,
$        MODNUM,DATMOD,TINT,DMYR
C
      WRITE(2) ITTPD,NSTEP,TYME
C
      WRITE(2) P
      WRITE(2) TEMP2
      WRITE(2) SW1
      WRITE(2) TR
2500    CONTINUE
      END

```

Listing of MANPLT

```

C**  PLOT PROGRAM DRIVER
C**
C**  COMMON BLOCK ONE IS USED DIFFERENTLY IN EACH SUBROUTINE
C**
      COMMON /ONE/DUMB(20160)
      COMMON /TWO/XSIZE,YSIZE,XMIN,XMAX,YMIN,YMAX
      COMMON /THR/AUTOPG,DATAPL,IDONIT,XPAGE,YPAGE
      LOGICAL AUTOPG,DATAPL
      INTEGER DONE
      CHARACTER*1 ANSWER
      CHARACTER*30 FNAME
      CHARACTER*4 TYPE
C**
C**  RETURN HERE FOR DATA PLOTS ONLY
C**
      CALL PLOTS(0.0,0.0,7)
C**
      2 CONTINUE
      XPAGE = 11.0
      YPAGE = 8.6

```



```

        FNAME      = '      '
        NPEN       = 1
        NOD        = 1
        IDIDIT     = 0
        DATAPL     = .FALSE.
C**
C**  READ FILE FROM SEQUEL PROGRAM
C**
        WRITE(6,1000)
1000  FORMAT(/,' ENTER. SEQUEL GENERATED FILE NAME OR',/,
1      '          DATAONLY FOR DATA ONLY MODE ')
        READ(5,1001) FNAME
1001  FORMAT(A30)
        WRITE(6,1006)
1006  FORMAT(/,' ARE DATA TO BE PLOTTED WITH THE THE TEMPEST RESULTS?')
        READ(5,1004) ANSWER
        IF(ANSWER.EQ.'Y') DATAPL=.TRUE.
C**  INITIALIZE PLOTTER
        WRITE(6,1009)
1009  FORMAT(/,' ENTER PEN NUMBER ')
        READ(5,1010) NPEN
1010  FORMAT(I1)
        CALL NEWPEN(NPEN)
C**  AUTOPAGING MODE IS DEFAULT FOR PLOTS
        IDONIT     = 0
        AUTOPG     = .TRUE.
        WRITE(6,1003)
1003  FORMAT(/,1X,'PAGING MODE. ENTER AUTO OR MANUAL')
        READ(5,1004) ANSWER
1004  FORMAT(A1)
        IF(ANSWER.EQ.'M') AUTOPG = .FALSE.
C**
C**      DATA PLOT ONLY ?
C**
        IF(FNAME.EQ.'DATAONLY'.OR.FNAME.EQ.' '.OR.FNAME.EQ.'D') GO TO 500
        OPEN(UNIT=2,NAME=FNAME,TYPE='OLD',FORM='FORMATTED',READONLY)
5      CONTINUE
C**  RETURN HERE
10     CONTINUE
C**  PLOT TYPE
        READ(2,2000,END=999) TYPE,IOPTN
2000  FORMAT(A4,I6)
        IF(IOPTN.LT.0) GO TO 998
        GO TO (100,200,300,300) IOPTN
100   CONTINUE
        CALL MONITOR(IOPTN)
        GO TO 400
200   CONTINUE
        CALL PLANE(IOPTN)
        GO TO 400

```

```

300 CONTINUE
    CALL LINE(IOPTN)
400 CONTINUE
    GO TO 10
C**
C**  DATA ONLY PLOTTING
C**
500 CONTINUE
    WRITE(6,1011)
1011 FORMAT(/, ' DATA ONLY PLOTTING MODE',/,
1  ' THE FOLLOWING ARE DEFAULTS.',/,
2  '   XSIZ=8.000 INCHES, PLOT ABSCISSA SIZE',/,
3  '   YSIZ=5.000 INCHES, PLOT ORDINATE SIZE',/,
4  '   XMIN=0.000          PLOT ABSCISSA MINIMUM VALUE',/,
5  '   XMAX=1.000          PLOT ABSCISSA MAXIMIM VALUE',/,
6  '   YMIN=0.000          PLOT ORDINATE MINIMUM VALUE',/,
7  '   YMAX=1.000          PLOT ORDINATE MAXIMIM VALUE',/,
8  '   CFAC=1.000          PLOT ORDINATE SCALE FACTOR')
    XSIZ   = 8.
    YSIZ   = 5.
    XMIN    = 0.
    XMAX    = 1.
    YMIN    = 0.
    YMAX    = 1.
    CFAC    = 1.
    WRITE(6,1012)
1012 FORMAT(/, ' ENTER. XSIZ=VALUE (F5.0) FOR ONES TO BE CHANGED',/,
1  '           DONE WHEN DONE')
515 CONTINUE
    READ(5,1013) TYPE,VALUE
1013 FORMAT(A4,1X,F5.0)
    IF(TYPE.EQ.'DONE') GO TO 520
    IF(TYPE.EQ.'XSIZ') XSIZ = VALUE
    IF(TYPE.EQ.'YSIZ') YSIZ = VALUE
    IF(TYPE.EQ.'XMIN') XMIN = VALUE
    IF(TYPE.EQ.'XMAX') XMAX = VALUE
    IF(TYPE.EQ.'YMIN') YMIN = VALUE
    IF(TYPE.EQ.'YMAX') YMAX = VALUE
    IF(TYPE.EQ.'CFAC') CFAC = VALUE
    WRITE(6,1014) TYPE,VALUE
1014 FORMAT(' CHANGED ',A4,' TO ',F10.3)
    GO TO 515
520 CONTINUE
C**
C**  CENTER DATA PLOT
C**
    XR      = (XPAGE-XSIZ)/2.
    YR      = (YPAGE-YSIZ)/2.
    CALL PLOT(XR,YR,-3)
550 CONTINUE

```

```

      CALL DATPLT(XSIZ,YSIZ,XMIN,XMAX,YMIN,YMAX,CFAC,NOD)
C**
C**      MORE ON THIS PLOT?
C**
      WRITE(6,1015)
1015  FORMAT(//,'ENTER.  YES TO PLOT MORE DATA ON THIS PLOT',/,
1      '      '      NEXT TO PLOT MORE DATA ON THE NEXT PLOT',/,
2      '      '      DONE TO QUIT PLOTTING')
      READ(5,1004) ANSWER
      IF(ANSWER.EQ.'D'.OR.ANSWER.EQ.' ') GO TO 999
      CALL PLOT(0.,0.,3)
      IF(ANSWER.EQ.'Y') GO TO 550
      CALL PLOT(-XR,YPAGE-YR,-3)
      GO TO 2
998  CONTINUE
      WRITE(6,1002) FNAME
1002  FORMAT('ERROR IN DATA ON FILE      ',A30)
      GO TO 10
999  CONTINUE
      CLOSE (UNIT=2)
      CALL PLOTND
      STOP
      END
      SUBROUTINE LINE(IOPTN)
C**
C**      THIS PROGRAM PLOTS INFORMATION
C**
      CHARACTER*40 FNAME,LABL(10),LAB
      CHARACTER*3 ANSWER,YES
      CHARACTER*4 VTYPE
      CHARACTER*1 DIR
      BYTE STRNG(40)
      DIMENSION IS(12),IT(12)
      DIMENSION VERNON(40)
      INTEGER VERNON
      COMMON /ONE/ XPOS(10),YPOS(10),ROT(10),X(1500),Y(1500)
1      , SIZ(10)
2      , XM(200),YM(200)
      COMMON /THR/AUTOPG,DATAPL,IDONIT,XPAGE,YPAGE
      LOGICAL AUTOPG,DATAPL
      DATA YES/'YES'/
C**      READ DATA HERE
C**
      NTICX      = 0
      NTICY      = 0
      READ(2,10039) (VERNON(J),J=1,20)
10039  FORMAT(20A4)
      READ(2,10040) NVAR,INT
10040  FORMAT(16I5)
C**

```

```

C**      READ FOR EACH VARIABLE
      DO 1200 IVAR = 1,NVAR
      READ(2,10040) NCURVE,NLABL,ISP,NTICX,NTICY,INSYMB
      IF(INSYMB.EQ.0) INSYMB = 1
      IF(NLABL.EQ.0) GO TO 30
      READ(2,10060) (XPOS(N),YPOS(N),SIZ(N),ROT(N),
1      LABL(N),N=1,NLABL)
C**
10060 FORMAT(4F10.3,A40)
      30 CONTINUE
      READ(2,10078) VTYPE,DIR
10078 FORMAT(1X,A4,4X,A1)
      READ(2,10080) TYME,XSIZE,YSIZE,XMIN,XMAX,YMIN,YMAX,CFACT
10080 FORMAT(8F10.0)
      READ(2,10040) (IS(I),IT(I),I=1,NCURVE)
C**
C**
C** BEGIN PLOTTING
C**
C** CENTER PLOT ON PAGE: CURRENTLY SET UP FOR AUTOPAGING WITH
C**      11.0 INCH PAGE LENGTH ALIGNED WITH X-AXIS
C**
C**
      XR=(XPAGE / 2.0) - (XSIZE / 2.0)
      YR=(YPAGE / 2.0) - (YSIZE / 2.0)
      CALL PLOT(XR,YR,-3)
      IF(IOPTN.NE.4) CALL SYMBOL(0.2,YSIZE+0.1,0.06,'TEMPEST',0.0,7)
      IF(IOPTN.NE.4) CALL SYMBOL(0.6,YSIZE+0.1,0.06,VERSION,0.0,80)
      IF(IOPTN.EQ.4) CALL SYMBOL(0.2,YSIZE+0.1,0.06,VERSION,0.0,80)
C**
C**
210 CONTINUE
C**
      CALL PLOT(0.0,0.0,3)
      IF(IOPTN.EQ.4) GO TO 57
      CALL SYMBOL(0.2,YSIZE+.20,0.08,'PLOT AT TIME = ',0.0,15)
      CALL NUMBER(1.5,YSIZE+.20,0.08,TYME,0.0,3)
      CALL SYMBOL(1.9,YSIZE+.20,0.08,'SECONDS',0.0,7)
57 CONTINUE
C**
      IF(NTICX.EQ.0) NTICX=XSIZE
      IF(NTICY.EQ.0) NTICY=YSIZE
C**
      XNUM=XMIN
      XADD=(XMAX - XMIN) / NTICX
      YNUM=YMIN
      YADD=(YMAX - YMIN) / NTICY
C**
      XDIF=XMAX - XMIN

```

```

      YDIF=YMAX - YMIN
C**
      ALOGX=ALOG10(XDIF)
      ALOGY=ALOG10(YDIF)
      IF(ALOGX.LT.-3.) NDIGX = -999
      IF(ALOGX.GE.-3.) NDIGX = ABS(ALOGX) + 3
      IF(ALOGX.GE. 0.) NDIGX = 2
      IF(ALOGX.GE. 2.) NDIGX = 1
      IF(ALOGX.GT. 4.) NDIGX = -999
C**
      IF(ALOGY.LT.-3.) NDIGY = -999
      IF(ALOGY.GE.-3.) NDIGY = ABS(ALOGY) + 3
      IF(ALOGY.GE. 0.) NDIGY = 2
      IF(ALOGY.GE. 2.) NDIGY = 1
      IF(ALOGY.GT. 4.) NDIGY = -999
C**
      IF(NDIGX.EQ.-999) GO TO 227
C**
      CALL NUMCHR(-0.1,-0.20,0.10,XNUM,-0.1,NDIGX)
      CALL PLOT(0.0,0.0,3)
      XNUM=XNUM + XADD
C**
      DO 225 I=1,NTICX
      XX=(XNUM-XMIN)/XDIF*FSIZE
      CALL PLOT(XX,0.0,2)
      CALL PLOT(XX,0.05,2)
      CALL PLOT(XX,0.0,2)
      CALL NUMCHR(XX-0.17,-0.20,0.10,XNUM,0.0,NDIGX)
      CALL PLOT(XX,0.0,3)
      XNUM=XNUM + XADD
225  CONTINUE
C**
      GO TO 235
C**
227  CONTINUE
C**
C**  X-AXIS LABELS IN POWER OF 10 FORM
C**
      NPOW=0
      IF(XNUM.NE.0.0) NPOW=ALOG10(XNUM)
      AMULT=10.0 ** NPOW
      XN=XNUM / AMULT
      CALL NUMCHR(0.0,-0.25,0.10,XN,0.0,1)
      CALL SYMBOL(0.24,-0.25,0.1,'X 10',0.0,4)
      CALL NUMCHR(0.70,-0.21,0.10,FLOAT(NPOW),0.0,-1)
      CALL PLOT(0.0,0.0,3)
      XNUM=XNUM + XADD
C**
      DO 230 I=1,NTICX
      XX=(XNUM-XMIN)/XDIF*FSIZE

```

```

CALL PLOT(XX,0.0,2)
CALL PLOT(XX,0.05,2)
CALL PLOT(XX,0.0,2)
NPOW=0
IF(XNUM.NE.0.0) NPOW=ALOG10(XNUM)
AMULT=10.0 ** NPOW
XN=XNUM / AMULT
CALL NUMCHR(XX,-0.25,0.10,XN,0.0,1)
CALL SYMBOL(XX + 0.24,-0.25,0.10,'X 10',0.0,4)
CALL NUMCHR(XX + 0.50,-0.21,0.10,FLOAT(NPOW),0.0,-1)
XNUM=XNUM + XADD
CALL PLOT(XX,0.0,3)
230 CONTINUE
C**
235 CONTINUE
C**
C**
CALL PLOT(0.0,0.0,3)
C**
IF(NDIGY.EQ.-999) GO TO 252
C**
C**
CALL NUMCHR(-0.1,-.10,0.10,YNUM,90.,NDIGY)
CALL PLOT(0.0,0.0,3)
C**
YNUM=YNUM + YADD
C**
DO 250 I=1,NTICY
YY=(YNUM-YMIN)/YDIF*YSIZE
CALL PLOT(0.0,YY,2)
CALL PLOT(0.05,YY,2)
CALL PLOT(0.0,YY,2)
CALL NUMCHR(-0.1,YY-0.17,0.10,YNUM,90.,NDIGY)
CALL PLOT(0.0,YY,3)
YNUM=YNUM + YADD
250 CONTINUE
C**
GO TO 260
C**
252 CONTINUE
C**
C** Y-AXIS LABELS IN POWER OF 10 FORM
C**
NPOW = 0
IF(YNUM.NE.0.0) NPOW=ALOG10(YNUM)
AMULT=10.0 ** NPOW
YN=YNUM/AMULT
CALL NUMCHR(-0.60,-0.05,0.10,YN,0.00,1)
CALL SYMBOL(-0.36,-0.05,0.10,'X 10',0.0,4)
CALL NUMCHR(-0.10,0.0,0.10,FLOAT(NPOW),0.00,-1)

```

```

      YNUM=YNUM+YADD
      CALL PLOT(0.0,0.0,3)
      DO 255 I=1,NTICY
      YY=(YNUM-YMIN)/YDIF*YSIZE
      CALL PLOT(0.0,YY,2)
      CALL PLOT(0.05,YY,2)
      CALL PLOT(0.0,YY,2)
      NPOW=0
      IF(YNUM.NE.0.0) NPOW=ALOG10(YNUM)
      AMULT=10.0 ** NPOW
      YN=YNUM / AMULT
      CALL NUMCHR(-0.60,YY - 0.05,0.10,YN,0.0,1)
      CALL SYMBOL(-0.36,-0.05,0.10,'X 10',0.0,4)
      CALL NUMCHR(-0.10,YY,0.10,FLOAT(NPOW),0.0,-1)
      YNUM=YNUM + YADD
      CALL PLOT(0.0,YY,3)
C**
255   CONTINUE
C**
260   CONTINUE
C**
      CALL PLOT(0.0,YSIZE,3)
      CALL PLOT(XSIZE,YSIZE,2)
      CALL PLOT(XSIZE,0.0,2)
C**
      IF(YMIN.LT.0.0.AND.YMAX.GT.0.0) GO TO 270
      IF(YMIN.GE.0.0) GO TO 290
      IF(YMIN.LT.0.0.AND.YMAX.LT.0.0) GO TO 290
C**
270   CONTINUE
C**
C**   FIND WHERE ZERO IS
C**
      YFACT=YSIZE / (YMAX - YMIN)
      YZERO=(0.0-YMIN) * YFACT
      CALL PLOT(0.0,YZERO,3)
      CALL PLOT(0.0,YZERO,2)
      CALL PLOT(XSIZE,YZERO,2)
      CALL PLOT(XSIZE,YZERO,3)
C**
290   CONTINUE
C**
C**   LABELS
C**
      IF(NLABL.EQ.0) GO TO 310
      DO 300 N=1,NLABL
C**
      LAB=LABL(N)
C**
      DO 275 I=1,40

```

```

      STRNG(I)=ICHAR(LAB(I:I))
275  CONTINUE
C**
      CALL SYMBOL(XPOS(N),YPOS(N),SIZ(N),STRNG,ROT(N),40)
300  CONTINUE
310  CONTINUE
C**
      NSYM=5
      CALL PLOT(0.,0.,3)
      DO 1000 NCRV=1,NCURVE
C**
      READ(2,10040) NPTS,ICRV,ISYMB
      IF(NPTS.EQ.0) GO TO 1000
C**
      READ(2,10050) (X(I),Y(I),I=1,NPTS)
10050 FORMAT(8F10.3)
C**
C**
C** PLOT THE POINTS
C**
C**
C**      FOR ISYMB = 0, DO LINES ONLY
C**          ISYMB = -1, DO SYMBOLS ONLY
C**          ISYMB = +1, DO LINE AND SYMBOLS
C**
C**      SYMBOLS
C**
      IF(ISYMB.EQ.0) GO TO 320
      CALL PLOT(X(1),Y(1),3)
      DO 315 I = 1,NPTS,INSYMB
      CALL SYMBOL(X(I),Y(I),0.08,ICRV,0.0,-1)
315  CONTINUE
      IF(NCRV+3.GT.NLABL) GO TO 320
      CALL SYMBOL(XPOS(NCRV+3)-0.3,YPOS(NCRV+3)+0.04,0.08,ICRV,0.0,-1)
320  CONTINUE
C**
C**      LINES
C**
      IF(ISYMB.EQ.-1) GO TO 330
      CALL PLOT(X(1),Y(1),3)
      DO 325 I = 1,NPTS
      CALL PLOT(X(I),Y(I),2)
325  CONTINUE
      IF(NCRV+3.GT.NLABL) GO TO 330
      CALL PLOT(XPOS(NCRV+3)-0.5,YPOS(NCRV+3)+0.04,3)
      CALL PLOT(XPOS(NCRV+3)-0.5,YPOS(NCRV+3)+0.04,2)
      CALL PLOT(XPOS(NCRV+3)-0.1,YPOS(NCRV+3)+0.04,2)
330  CONTINUE
1000  CONTINUE
C**

```



```

C** CALL DATPLT IF NEEDED
C**
C** IF(DATAPL) CALL DATPLT(XSIZE,YSIZE,XMIN,XMAX,YMIN,YMAX,CFACT,NOD)
C**
C** ALL DONE WITH NCURVES - ADVANCE PAGE
C**
C** CALL PLOT(-XR,YPAGE-YR,-3)
1200 CONTINUE
C**
C** ALL DONE WITH NVARIABLES
C**
1500 CONTINUE
2000 CONTINUE
RETURN
END
SUBROUTINE MONITOR(IOPTN)
C**
C** THIS PROGRAM READS PLOTTING INFORMATION
C** SAVED BY MONPLT AND PRODUCES THE PLOTS...
C**
C**
C** DIMENSION VERNON(20)
C** INTEGER VERNON
C** INTEGER DONE
C** COMMON /ONE/ X(10000),Y(10000),XL(10),YL(10),HL(10),RL(10),
1 IL(10),LABL(10,10),LABEL(10),AX(5),AY(5)
C** COMMON /THR/AUTOPG,DATAPL,IDONIT,XPAGE,YPAGE
C** LOGICAL AUTOPG,DATAPL
C**
C** READ(2,10039) (VERNON(J),J=1,20)
10039 FORMAT(20A4)
C** START READING MONITOR PLOT STUFF
C**
C** READ(2,10100) XSIZE,YSIZE,XMIN,XMAX,YMIN,YMAX,CFACT
10100 FORMAT(8F10.3)
C** IF(CFACT.EQ.0.0) CFACT = 1.0
C** READ(2,10102) NCURVE,NLABL,NTICX,NTICY
10102 FORMAT(16I5)
C**
C** CENTER PLOT ON PAGE
C**
C** XR = (XPAGE-XSIZE)/2.
C** YR = (YPAGE-YSIZE)/2.
C** CALL PLOT(XR,YR,-3)
C** CALL SYMBOL(0.2,YSIZE+0.1,0.06,'TEMPEST',0.0,7)
C** CALL SYMBOL(0.6,YSIZE+0.1,0.06,VERNON,0.0,80)
C** NTIC=XSIZE
C** IF(NTICX.NE.0) NTIC=NTICX
C** CALL PLOT(0.0,0.0,3)
C** XNUM=XMIN

```

```

XADD=(XMAX - XMIN) / FLOAT(NTIC)
XDIF= XMAX-XMIN
CALL NUMBER(-0.12,-0.20,0.10,XNUM,0.0,2)
XNUM=XNUM + XADD
CALL PLOT(0.0,0.0,3)

C**
DO 225 I=1,NTIC
XX= (XNUM-XMIN)/XDIF*XSIZE
CALL PLOT(XX,0.0,2)
CALL PLOT(XX,YSIZE,2)
CALL PLOT(XX,0.0,2)
CALL PLOT(XX-0.12,-0.25,3)
CALL NUMBER(XX-0.12,-0.25,0.10,XNUM,0.0,2)
CALL PLOT(XX,0.0,3)
XNUM=XNUM + XADD
225 CONTINUE

C**
NTIC=YSIZE
IF(NTICY.NE.0) NTIC=NTICY
CALL PLOT(0.0,0.0,3)
YNUM=YMIN
YADD=(YMAX - YMIN) / FLOAT(NTIC)
YDIF = YMAX-YMIN
CALL NUMBER(-0.10,-.17,0.10,YNUM,90.,2)
YNUM=YNUM + YADD
CALL PLOT(0.0,0.0,3)

C**
DO 250 I=1,NTIC
YY = (YNUM-YMIN)/YDIF*YSIZE
CALL PLOT(0.0,YY,2)
CALL PLOT(XSIZE,YY,2)
CALL PLOT(0.0,YY,2)
CALL PLOT(-0.20,YY-0.17,3)
CALL NUMBER(-0.1,YY-0.17,0.10,YNUM,90.,2)
CALL PLOT(0.0,YY,3)
YNUM=YNUM + YADD
250 CONTINUE

C**
CALL PLOT(0.0,YSIZE,3)
CALL PLOT(XSIZE,YSIZE,2)
CALL PLOT(XSIZE,0.0,2)
CALL PLOT(0.0,0.0,3)

C**
IF(NLABL.LE.0) GO TO 325

C**
DO 300 N=1,NLABL
READ(2,10105) XL(N),YL(N),HL(N),RL(N),(LABL(I,N),I=1,10)
10105 FORMAT(4F10.0,10A4)
DO 280 I=1,10
LABEL(I)=LABL(I,N)

```

```

280  CONTINUE
C**
C**
      CALL PLOT(XL(N),YL(N),3)
      CALL SYMBOL(XL(N),YL(N),HL(N),LABEL,RL(N),40)
300  CONTINUE
C**
325  CONTINUE
C**
C**
      DO 1200 N=1,NCURVE
C**
      READ(2,10110) NPT,NNUM
      NSYM          = NPT/1
10110 FORMAT(2I5)
      READ(2,10115) (X(I),Y(I),I=1,NPT)
10115 FORMAT(8F10.3)
C**
C**
      CALL PLOT(X(1),Y(1),3)
C**
      DO 1100 I=1,NPT
      CALL PLOT(X(I),Y(I),2)
      IF(MOD(I,NSYM).EQ.0) CALL NUMBER(X(I)+.05,Y(I)+.05,0.07,
1      FLOAT(NNUM),0.0,-1)
      IF(MOD(I,NSYM).EQ.0) CALL PLOT(X(I),Y(I),3)
1100  CONTINUE
C**
C**
1200 CONTINUE
C**
C**
      CALL DATPLT IF WANTED
C^@**
      IF(DATAPL) CALL DATPLT(XSIZE,YSIZE,XMIN,XMAX,YMIN,YMAX,CFACT,NOD)
1500 CONTINUE
C**
C**
      MOVE PEN TO NEW PAGE ORIGIN
C**
      CALL PLOT(-XR,YPAGE-YR,-3)
      RETURN
      END
      SUBROUTINE PLANE(IOPTN)
C**
C**
      THIS PROGRAM READS PLOTTING INFORMATION
C**
      SAVED BY SEQUEL AND PRODUCES THE PLOTS...
C**
C**
      PLOTS OF VELOCITY VECTORS (IN BOTH POLAR AND CARTESIAN
C**
      COORDINATES) AND CONTOURS (IN BOTH POLAR AND CARTESIAN
C**
      COORDINATES) CAN BE PLOTTED
C**

```

```

C**
C**
C**
    DIMENSION VERNON(20)
    INTEGER VERNON
    INTEGER DONE
    COMMON /ONE/ X(100),Y(100),XL(10),YL(10),HL(10),RL(10),
1      IL(10),LABL(10,10),LABEL(4),AX(5),AY(5)
2      , XXP(20),YYP(20)
    COMMON /THR/AUTOPG,DATAPL,IDONIT,XPAGE,YPAGE

C**
C**
    CHARACTER*1 ANSWER
    CHARACTER*30 FNAME
    CHARACTER*5 PTYPE
    LOGICAL AUTOPG,DATAPL,POLR

C**
    IFLIPX      = 0
    IFLIPY      = 0

C**
C**      AUTOPAGING IS DEFAULT MODE.  IF MANUAL MODE IS CHOSEN
C**      PEN MUST BE MOVED TO NEW ORIGIN  AFTER EACH PLOT
C**
C**
    READ(2,10039) (VERNON(J),J=1,20)
10039 FORMAT(20A4)
    READ(2,10100)PTYPE
10100 FORMAT(A5)
    READ(2,10120) XSIZE,YSIZE,TYME,VMAX,VSCAL
    READ(2,10101) NLABL,IPLOPT,IFLIPX,IFLIPY
10101 FORMAT(16I5)

C**
C** SET "POLR" FOR POLAR COORDINATES
C**
    POLR = .FALSE.
    IF (PTYPE.EQ.'POLAR') POLR = .TRUE.
    IF(AUTOPG) GO TO 55
    WRITE(6,10040)
10040 FORMAT(//,1X,'ENTER X-AXIS ORIGIN(INCHES RELATIVE TO LAST ORIGIN)'
1      ,/,1X,'(F5.0)')
    READ(5,10042) XOMAN
10042 FORMAT(F5.0)
    WRITE(6,10044)
10044 FORMAT(//,1X,'ENTER Y-AXIS ORIGIN(INCHES RELATIVE TO LAST ORIGIN)'
1      ,/,1X,'(F5.0)')
    READ(5,10042) YOMAN
    CALL PLOT(XOMAN,YOMAN,-3)
55 CONTINUE

C**
C**      MOVE PEN TO NEW ORIGIN IF AUTO PAGING

```

```

C**      IDIDIT      = 0
        XS          = (XPAGE-XSIZE)/2.
        IF(POLR) XS = XS+XSIZE/2.
        IF(POLR) YSIZE = XSIZE
        YS          = (YPAGE-YSIZE)/2.
        IF(POLR) YS = YS+YSIZE/2.
        IF(YS.LE.0.0) YS = 2.
        IF(IDIDIT.EQ.0.AND.AUTOPG) CALL PLOT(XS,YS,-3)
        IDIDIT      = 1
        YLMAX       = 0.

C**
C**      WRITE TIME
C**
        IF(IDONIT.GT.0) GO TO 54
        CALL SYMBOL(0.2,YSIZE+0.1,0.06,'TEMPEST',0.0,7)
        CALL SYMBOL(0.6,YSIZE+0.1,0.06,VERSION,0.0,80)
        CALL SYMBOL(0.2,YSIZE+.20,0.08,'PLOT AT TIME = ',0.0,15)
        CALL NUMBER(1.5,YSIZE+.20,0.08,TYME,0.0,3)
        CALL SYMBOL(1.9,YSIZE+.20,0.08,'SECONDS',0.0,7)
        IF(IPLOPT.LE.1) GO TO 53
        CALL SYMBOL(XSIZE+0.25,3.0,0.1,'VMAX = ',90.,7)
        CALL NUMBER(XSIZE+0.25,3.8,0.1,VMAX,90.,4)
        CALL PLOT(XSIZE+0.32,3.00,3)
        CALL PLOT(XSIZE+0.38,3.00,2)
        CALL PLOT(XSIZE+0.35,3.00,2)
        CALL PLOT(XSIZE+0.35,3.00+VSCAL,2)
        CALL PLOT(XSIZE+0.33,2.95+VSCAL,2)
        CALL PLOT(XSIZE+0.35,3.00+VSCAL,2)
        CALL PLOT(XSIZE+0.37,2.95+VSCAL,2)
        CALL PLOT(XSIZE+0.35,3.00+VSCAL,2)
53      CONTINUE
        IF(.NOT.AUTOPG) IDONIT      = 1
54      CONTINUE

C**
C**      DRAW AXES
C**
        IF(POLR) GO TO 70

C**
C**      CARTESIAN COORDINATE AXES...
C**
        CALL PLOT(0.0,0.0,3)
        CALL PLOT(XSIZE,0.0,2)
        CALL PLOT(XSIZE,YSIZE,2)
        CALL PLOT(0.0,YSIZE,2)
        CALL PLOT(0.0,0.0,2)
        GO TO 80

C**
70      CONTINUE
C**

```

```

C** POLAR COORDINATES...
C**
      CALL PLOT(-.1,0.0,3)
      CALL PLOT(+.1,0.0,2)
      CALL PLOT(0.0,-.1,3)
      CALL PLOT(0.0,+.1,2)
C**
      80 CONTINUE
C**
C**
C** LABEL PLOT
C**
      IF(NLABL.LE.0) GO TO 127
      DO 125 I=1,NLABL
      READ(2,10105) XL(I),YL(I),HL(I),RL(I),(LABL(N,I),N=1,10)
      YLMAX = AMAX1(YLMAX,ABS(YL(I)))
10105 FORMAT(4F10.0,10A4)
      DO 110 J=1,10
      LABEL(J)=LABL(J,I)
      110 CONTINUE
      CALL SYMBOL(XL(I),YL(I),HL(I),LABEL,RL(I),40)
      125 CONTINUE
C**
      127 CONTINUE
C**
C** COORDINATE POSITION OF PLOT REGION
C**
      IF(POLR) GO TO 129
      READ(2,10120) XMIN,XMAX,YMIN,YMAX,X1,X2,Y1,Y2
      IF(IFLIPX.NE.1) GO TO 126
      XDUM = X2
      X2 = X1
      X1 = XDUM
      126 CONTINUE
      IF(IFLIPY.NE.1) GO TO 128
      YDUM = Y2
      Y2 = Y1
      Y1 = YDUM
      128 CONTINUE
      CALL PLOT(X1,0.0,3)
      CALL PLOT(X1,-.1,2)
      CALL NUMBER(X1-.1,-.26,0.10,XMIN,0.0,2)
      CALL PLOT(X2,0.0,3)
      CALL PLOT(X2,-.1,2)
      CALL NUMBER(X2-.1,-.26,0.10,XMAX,0.0,2)
      CALL PLOT(0.0,Y1,3)
      CALL PLOT(-.1,Y1,2)
      CALL NUMBER(-.16,Y1-.1,0.10,YMIN,90.,2)
      CALL PLOT(0.0,Y2,3)
      CALL PLOT(-.1,Y2,2)

```

```

      CALL NUMBER(-.16,Y2-.1,0.10,YMAX,90.,2)
C**
129  CONTINUE
C**
      IF(IPLOPT.EQ.-1) GO TO 290
      IF(IPLOPT.EQ.2) GO TO 225
C**
C**  DO CONTOUR PLOT
C**
130  CONTINUE
      READ(2,10110) DONE,LEG
10110 FORMAT(A4,1X,I5)
      IF(DONE.EQ.'DONE') GO TO 200
      READ(2,10120) (X(I),Y(I),I=1,LEG)
10120 FORMAT(8F10.0)
      IF(IFLIPX.EQ.1) X(1) = XSIZE-X(1)
      IF(IFLIPY.EQ.1) Y(1) = YSIZE-Y(1)
      CALL PLOT(X(1),Y(1),3)
      DO 150 I=1,LEG
      IF(I.NE.1.AND.IFLIPX.EQ.1) X(I) = XSIZE-X(I)
      IF(I.NE.1.AND.IFLIPY.EQ.1) Y(I) = YSIZE-Y(I)
      CALL PLOT(X(I),Y(I),2)
150  CONTINUE
C**
      GO TO 130
C**
200  CONTINUE
C**
      IF(IPLOPT.NE.3) GO TO 290
C**
225  CONTINUE
C**
C**  DO VECTOR PLOT
C**
      READ(2,10150) DONE,DX1,DY,DXX,DYY
      IF(DONE.EQ.'DONE') GO TO 290
      READ(2,10151) (AX(K),AY(K),K=1,5)
10150 FORMAT(A4,F6.0,7F10.0)
10151 FORMAT(10F7.0)
      IF(IFLIPX.NE.1) GO TO 227
      DX1      = XSIZE-DX1
      DXX      = XSIZE-DXX
      DO 226 K = 1,5
      AX(K)    = XSIZE-AX(K)
226  CONTINUE
227  CONTINUE
      IF(IFLIPY.NE.1) GO TO 229
      DY      = YSIZE-DY
      DYY      = YSIZE-DYY
      DO 228 K = 1,5

```

```

      AY(K)      = YSIZE-AY(K)
228 CONTINUE
229 CONTINUE
      CALL PLOT(DX1,DY,3)
      CALL PLOT(DXX,DYY,2)
      CALL PLOT(AX(1),AY(1),3)
      DO 250 K=2,5
      CALL PLOT(AX(K),AY(K),2)
250 CONTINUE
      GO TO 225
C**
C**  DO MATERIAL TYPE BOUNDARIES
C**
      290 CONTINUE
      IF(.NOT.POLR) GO TO 300
C**
C**  POLAR COORDINATES...
C**
      READ(2,10155) DONE,NSEGS
10155 FORMAT(A4,I6)
      IF(DONE.EQ.'DONE') GO TO 500
      READ(2,10156) (XXP(K),YYP(K),K=1,NSEGS)
10156 FORMAT(8F10.0)
      X1      = XXP(1)
      Y1      = YYP(1)
      CALL PLOT(X1,Y1,3)
      DO 295 I = 2,NSEGS
      X2      = XXP(I)
      Y2      = YYP(I)
      CALL PLOT(X2,Y2,2)
      295 CONTINUE
C**
      GO TO 290
C**
      300 CONTINUE
C**
C**  CARTESIAN COORDINATES...
C**
      READ(2,10160) DONE,XX,YY,XX1,YY1
10160 FORMAT(A4,F6.0,3F10.0)
      IF(DONE.EQ.'DONE') GO TO 500
      IF(IFLIPX.EQ.1) XX = XSIZE-XX
      IF(IFLIPY.EQ.1) YY = YSIZE-YY
      IF(IFLIPX.EQ.1) XX1= XSIZE-XX1
      IF(IFLIPY.EQ.1) YY1= YSIZE-YY1
      CALL PLOT(XX,YY,3)
      CALL PLOT(XX1,YY1,2)
      GO TO 300
C**
      500 CONTINUE

```



```

        IF(AUTOPG) GO TO 510
        CALL PLOT(0.0,0.0,3)
        GO TO 999
510    CONTINUE
        YMOVE = YPAGE-YS
        IF(YSIZE+YLMAX.GT.YPAGE) YMOVE = 2.*YPAGE-YS
        IF(YSIZE+YLMAX.GE.2.*YPAGE) YMOVE = 3.*YPAGE-YS
        IF(YSIZE+YLMAX.GE.3.*YPAGE) YMOVE = 4.*YPAGE-YS
        IF(IDIDIT.NE.0) CALL PLOT(-XS,YMOVE,-3)
999    CONTINUE
C**
        RETURN
        END
        SUBROUTINE NUMCHR(X1,Y1,SIZ,VAL,ANG,NPR)
C**
C**    THIS ROUTINE WRITES THE NUMBERS WITH SYMBOL
C**
        BYTE B(10)
        SMALL=1.E-6
        IF(ABS(VAL).LE.SMALL) M=1
        IF((ABS(VAL).LE.SMALL).AND.(NPR.NE.-1)) M= 3 + NPR
        IF(ABS(VAL).LE.SMALL) GO TO 100
        IF(NPR.EQ.-1) M=ALOG10(ABS(VAL))+1.
        IF(NPR.NE.-1) M=ALOG10(ABS(VAL))+FLOAT(NPR+3)
100    IF(NPR.NE.-1.AND.M.EQ.NPR) M = NPR+1
        CONTINUE
        IVAL = AINT(VAL)
        IF(VAL.LT.0.) M = M + 1
        IF(NPR.EQ.-1) ENCODE(M,300,B)IVAL
        IF(NPR.NE.-1) ENCODE(M,400,B)VAL
300    FORMAT(I<M>)
400    FORMAT(F<M>.<NPR>)
C**
        IF(X1.NE.999.) GO TO 50
        CALL WHERE(XP,YP,IP)
        X1 = XP
50    CONTINUE
        IF(Y1.NE.999.) GO TO 60
        CALL WHERE(XP,YP,IP)
        Y1 = YP
60    CONTINUE
        CALL SYMBOL(X1,Y1,SIZ,B,ANG,M)
        RETURN
        END
        SUBROUTINE DATPLT(XS,YS,XMN,XXM,YMN,YMX,CFAC,NOD)
C**
C**    SUBROUTINE READS DATA FILE AND PLOTS DATA
C**
        DIMENSION X(1000),Y(1000),LABEL(80)
        LOGICAL LINE,SYMB

```

```

        CHARACTER*1 LABEL
        CHARACTER*32 FILE
        INTEGER DONE
        LINE      = .FALSE.
        SYMB      = .TRUE.

C**
C**  OPEN DATA FILE
C**
        NFILE      = 0
10  CONTINUE
        REWIND 9
        NSYMB      = 0
        NFILE      = NFILE+1
        WRITE(6,1000)
1000 FORMAT(/, ' READY TO PLOT DATA',/, ' ENTER DATA FILE NAME.  OR'
1      ,/, '          NONE IF NO DATA FOR THIS PLOT')
        READ(5,1001) FILE
1001 FORMAT(A32)
        IF(FILE.EQ.'NONE') RETURN
        OPEN(UNIT=9,NAME=FILE,TYPE='OLD',FORM='FORMATTED',READONLY)

C**
C**  PLOT DATA WITH LINES, SYMBOLS, OR BOTH
C**
        WRITE(6,1007)
1007 FORMAT(/, ' DATA PLOTTING OPTIONS',/,
1      ' ENTER.  LINE FOR LINE ONLY',/,
2      '          SYMB FOR SYMBOLS ONLY' (DEFAULT)',/,
3      '          BOTH FOR BOTH')
        READ(5,1006) LABEL(1)
        IF(LABEL(1).NE.'L') GO TO 12
        LINE      = .TRUE.
        SYMB      = .FALSE.
        GO TO 14
12  CONTINUE
        IF(LABEL(1).NE.'B') GO TO 14
        LINE      = .TRUE.
        SYMB      = .TRUE.
14  CONTINUE
20  CONTINUE

C**
C**  SCALE DATA TO PLOT SIZE
C**
        NSYMB      = NSYMB+1
        XSCAL      = XS/(XMX-XMN)
        YSCAL      = YS/(YMX-YMN)

C**
C**  READ DATA
C**
        IERROR      = 0
        READ(9,1002,END=999) LABEL

```

```

1002 FORMAT(80A1)
      DO 30 I=1,1000
      READ(9,1004,END=35) DONE,X(I),Y(I)
1004  FORMAT(A3,2F12.0)
      NP      = I
      IF(X(I).LT.XMN) X(I) = XMN
      IF(X(I).GT.XMX) X(I) = XMX
      IF(Y(I).LT.YMN) Y(I) = YMN
      IF(Y(I).GT.YMX) Y(I) = YMX
      X(I)      = (X(I)-XMN)*XSCAL
      Y(I)      = (Y(I)-YMN)*YSCAL
      IF(DONE.EQ.'END') GO TO 40
      IF(I.EQ.1000) IERROR=1
30    CONTINUE
35    CONTINUE
      NP      = I-1
40    CONTINUE
C**
C**  PLOT POINTS
C**
      CALL PLOT(X(1),Y(1),3)
      IF(SYMB.AND..NOT.LINE) GO TO 60
      IF(.NOT.SYMB.AND.LINE) GO TO 70
      DO 50 I=1,NP
      CALL PLOT(X(I),Y(I),2)
      CALL SYMBOL(X(I),Y(I),0.08,NSYMB,0.0,-1)
50    CONTINUE
      GO TO 80
60    CONTINUE
      DO 65 I=1,NP
      CALL PLOT(X(I),Y(I),2)
      CALL SYMBOL(X(I),Y(I),0.08,NSYMB,0.0,-1)
      CALL PLOT(X(I),Y(I),3)
65    CONTINUE
      GO TO 80
70    CONTINUE
      DO 75 I=1,NP
      CALL PLOT(X(I),Y(I),2)
75    CONTINUE
80    CONTINUE
      CALL PLOT(0.,0.,3)
      IF(IERROR.NE.1) GO TO 900
      WRITE(6,1003)NP,FILE,LABLE
1003  FORMAT(//,'MORE THAN',I5,'POINTS ON FILE',A32,/,
1      'DATA SET TITLE IS ',//,80A1,//,'EXITING DATA PLOTTING')
      NOD      = -1
      RETURN
900  CONTINUE
C**
C**  PLOT ANOTHER DATA FILE?

```

C**

```
      WRITE(6,1005)
1005  FORMAT(/,' ENTER YES TO PLOT ANOTHER DATA FILE. CR IF NOT')
      READ(5,1006) LABLE(1)
1006  FORMAT(A1)
      IF(LABLE(1).EQ.'Y') GO TO 10
      999 CONTINUE
      RETURN
      END
```

GEOTHER/VT4 PROGRAM REDIMENSIONING

Allocation of array storage in GEOTHER/VT4 is accomplished through a set of COMDECKs using the automated configuration management program WITNESS. The COMDECK "PARAM" contains array variables that can be redimensioned by assigning the desired values of the dimension parameters in the COMDECK. The PARAMETER statements used for this purpose contain dimension parameters instead of numbers defining the arrays.

The PARAM COMDECK is followed by other COMDECKS consisting of all the arrays to be redimensioned.

An example of a typical set of COMDECKS IS

*COMDECK PARAM

```
      PARAMETER (MA=1, MB=10, MC=100)
```

*COMDECK DUMMY

```
      COMMON/DUMMY/ A(MA,MB),B(MC)
```

With the combination of these two statements, the array size of A and B are defined. In this case, A has a size of A(1,10), B of B(100). When a case requires redimensioning, the user needs only to change the values in the PARAMETER statements; the code is then recompiled. Because these statements are in a COMDECK, the dimensions are changed once. All the arrays using those dimension parameters will be changed accordingly throughout the code when the code is compiled.

Currently, there are 20 dimension parameters in GEOTHER/VT4. Among them, 14 parameters are in use. The rest are for future expansion purposes. The PARAM COMDECK is given below.

*COMDECK PARAM

```

PARAMETER (MA=3,MB=7,MC=10,MD=25,ME=50,MF=51,MG=400,MH=450,MI=480)
PARAMETER (MZ=1000000)
PARAMETER (MAXMAT=100)
PARAMETER (MAXCEL=500)
PARAMETER (MAXQT=300)
PARAMETER (MAXTT=300)
PARAMETER (MAXPT=300)
PARAMETER (MAXMT=300)
PARAMETER (MAXQC=100)
PARAMETER (MAXTC=100)
PARAMETER (MAXPC=100)
PARAMETER (MAXMC=100)

```

The definitions of the 20 dimension parameters in the above PARAMETER statements are given in Table B.8.

TABLE B.8. Dimensioning Parameters

<u>Parameter</u>	<u>Definition</u>
MA	Second dimension parameter of the IJKTP array which stores the block location indices for which data is saved on Tape 12. Always set to 3 (representing the I, J, K, indices).
MB	Number of printing control flags KOD(MB). Always set to 7.
MC	First dimension parameter of the IJKTP array, It is the maximum number of blocks for which data is saved on TAPE12.
MD	Maximum number of grid points in Y-direction.
ME	Maximum number of grid points in X or Z direction.
MF	Maximum number of grid points in X direction plus 1(i.e., ME+1).
MG	Total number of blocks in the problem (NX*NY*NZ).

TABLE B.8. contd.

<u>Parameter</u>	<u>Definition</u>
MH	Total number of block interfaces in the Y-direction (=NX*NY*NZ).
MI	Total number of block interfaces in the X or Z directions (maximum of NX*NY*NZ+NY*NZ-1 and NX*NY*NZ+NZ*NY-NX).
MZ	Maximum number of the U array. Since U array contains essentially all dimensional arrays in the code, MZ is the total storage size of the problem. In a virtual memory system, a large number such as 1,000,000 is suggested.
MAXMAT	Maximum number of material types.
MAXCEL	Maximum number of blocks (=MG).
MAXQT	Maximum of ATAB+2*AENT+3 where ATAB is the heat source table identification number. AENT is the number of entries for table ATAB.
MAXTT	Maximum of (temperature table ID number) + 2 (number of entries for the table) + 3. Currently not active, set to 1.
MAXPT	Maximum of (pressure table ID number) + 2 (number of entries for the table) + 3. Currently not active, set to 1.
MAXMT	Maximum of (mass table ID number) + 2 (number of entries for the table) + 3. Currently not active, set to 1.
MAXQC	Total number of block locations that have heat source tables.
MAXTC	Total number of block locations that have temperature tables. Currently not active, set to 1.
MAXPC	Total number of block locations that have pressure tables. Currently not active, set to 1.
MAXMC	Total number of block locations that have mass tables. Currently not active, set to 1.

BIT PACKING FOR STORAGE OF CELL INFORMATION

One of the features in the new version of GEOTHER is the use of bit packing or Boolean operations on integers. There is no ANSI FORTRAN-77

capability to do Boolean operations, although all computers seem to be able to do it and provide the Boolean operations as various extensions. The bit packing in GEOTHER has been accomplished in as standard and transportable a manner as possible. Through the use of the WITNESS COMDECK directive (like an INCLUDE statement on the VAX and PRIME FORTRAN) all of the nonstandard bit packing is accomplished by statement functions and maintained in a separate deck called VAXFUNCS. A similar deck will be created for the PRIME and CRAY versions of the code. The total number of cards in this COMDECK is three. Only two of these are used for bit packing, SHIFTR and SHIFTL, which correspond to right and left circular shifts, but by bit. The third card in the VAXFUNCS COMDECK is the LOC function, which is used in both the current and the old version of the code to facilitate the dynamic dimensioning.

The new version of GEOTHER uses a number of integer variables that could be different for every cell in the model. These new variables are the cell type, the material type, the time-dependent heat generation table, the time-dependent temperature table, and the time-dependent pressure table. If bit packing were not used and the same degree of generality were required, five integer arrays dimensioned to be the size of the field variables would be required. With the bit packing as implemented in GEOTHER, all these variables are stored in a simple integer array called the cell flag.

Cell Flag Storage Scheme

The cell flag, designated by the FORTRAN variable ICF in GEOTHER, is a 32-bit integer array on the VAX or PRIME (64-bit integer array on the CRAY). The rightmost 2 octal (6 binary) bits are reserved for the cell type.^(a) The next two octal bits to the left of the cell type are reserved for the material types, and the two octal digits to the left of that are reserved for the heat generation time-dependent table number. Because there are as many elements of ICF as there are grid blocks or cells, all of the information contained in the cell flag can be specified on a cell by cell basis with great flexibility regardless of the particular problem. The location of the various parts of the cell flag is shown in Figure B.8.

(a) Cell, node, and block are used interchangeably in this report.

Cell Flag Takes the Place of Multiple Integer Arrays

64 Different

Cell Types

Material Types

Heat Generation Tables

FIGURE B.8. Cell Flag

Cell Flag Use

The appropriate information can be stored and extracted from the cell flag by the use of Boolean operations on the cell flag and special decoders, which will now be discussed. For purposes of illustration, we shall assume the cell flag to be composed of only 18 bits, just enough to represent the cell type, the material type, and the time-dependent heat generation table number. Furthermore, numbers enclosed in square brackets with a subscript will be used to indicate the base of the number being represented. For example, $[37]_8$ will be used to represent the octal (base 8) number 37 that corresponds to the decimal number 31, which would be represented $[31]_{10}$. The decoders that we will need (one for the cell type, one for the material type, and one for the heat generation table) are:

- cell type decoder = $[77]_8$
- material type decoder = $[7700]_8$

- heat generation table number decoder = $[770000]_8$.

A cell flag word that has not been set or is all zeros is, of course, represented by cell flag = $[000000]_8$.

A non-empty cell flag might look like cell flag = $[031745]_8$, which would indicate that the particular cell grid block associated with this element of the cell flag array was a type 45 cell, with a type 17 material, and a heat generation table number of 3. Parts of the cell flag can be cleared (set to zero) through the use of a Boolean .AND. operation. For example:

$$[031745]_8 \text{ .AND. } [777700]_8 \text{ yields } [031700]_8$$

In this example, the cell flag element has been "anded" with the complement of the cell type decoder, which zeroes the bits associated with the cell flag and leaves all other bits the same.

Bits that are zero in the cell flag can be reset to any desired quantity by the Boolean .OR. operation:

$$[031700]_8 \text{ .OR. } [000026]_8 = [031726]_8$$

The preceding two examples have resulted in the original cell type of 45 being reset to a cell type of 26.

When needed, information (bits) can be extracted from the cell flag through the Boolean operation .AND. and possibly requiring a right circular shift. For example:

$$[013726]_8 \text{ .AND. } [007700]_8 = [001700]_8$$

followed by a right shift of 2 octal (6 binary) bits

$$[001700]_8 \rightarrow \text{Right Shift } 2 \text{ octal bits} \rightarrow [000017]_8$$

extracts the material type from the cell flag and right-justifies it. Similarly, to set the material type, it would be necessary to do a left shift before the bit resetting example on the previous page. The requirements to use the left and right shifts causes "system dependence" because each operating system has a different intrinsic function name for the left and right shifts. However, the left and right shifts are defined by statement functions so that only two cards needs to be changed when going from one machine to another. As shown below, the left and right shift are defined for several different machines. The first argument is the computer word to undergo bit shifting, and the second argument is the number of bits to shift.

<u>Machine</u>	<u>Left Shift</u>	<u>Right Shift</u>
VAX	ISHFT(IA1,+IA2)	ISMFT(IA1,-IA2)
CRAY	SHIFTL(IA1,+IA2)	SHIFTR(IA1,IA2)
PRIME	LS(IA1,IA2)	RS(IA1,IA2)
CDC	SHIFT(IA1,+IA2)	SHIFT(IA1,-IA2)

CONFIGURATION MANAGEMENT AND QUALITY ASSURANCE PROCEDURES FOR GEOTHER

Configuration management and quality assurance (QA) traceability for GEOTHER/VT4 were accomplished with the aid of WITNESS, an automated text processing tool developed at PNL to emulate the UPDATE utility on CDC and HISTORIAN, which is available at Los Alamos. To put a code under configuration management, WITNESS is run in the "creation" mode. The input file to WITNESS is simply the usual FORTRAN text coding, augmented by a few *DECK and *COMDECK commands, which precedes subroutines or COMMON blocks called a WITNESS source file. Output from WITNESS includes a 96-column FORTRAN file ready to be compiled. Columns 81-90 contain a character string (defined by the *DECK card mentioned earlier, usually the name of the subroutine) and a unique integer. In this fashion every FORTRAN line of code receives a unique WITNESS identifier (character string plus integer) that can be used for later reference.

Another output file from WITNESS is the Old Program Library file. This is a direct access formatted file that contains all the FORTRAN source code,

the unique identifier, and audit version information indicating which records (FORTRAN source code lines) are active or inactive, and audit identification information showing how records become inactive. On a creation run, all records will be active. However, WITNESS can be run in the correction mode where an existing Old Program Library can be modified; new records can be added and old records can be deleted. (Actually, no records are deleted from the Old Program Library. They are flagged as inactive, and only active records are sent to the FORTRAN compiler.) All of this information can be retrieved for QA traceability.

The original version of GEOTHER was procured from the Office of Nuclear Waste Isolation, Battelle-Columbus, Ohio. Currently it resides on the PNL BVAX disk with the name:

DISK3: [GEOTHER]GEOTHER.SRC

This file is in CDC update (or WITNESS) source format. From this initial version (which was CDC-compatible but would not run on a VAX), a base version, the A0 version, was created. These files are stored on the path:

DISK3: [GEOTHER.VA0]

and have the following names and function:

GEOTHR_VA0.SRC	WITNESS Source File
GEOTHR_VA0.OPL	WITNESS Old Program Library
GEOTHR_VA0.OLB	Vax Object Library
GEOTHR_VA0.FOR	FORTTRAN Source File
GEOTHR_VA0.LIS	FORTTRAN Listing File (cross reference map)
GEOTHR_VA0.UPD	WITNESS Update Changes
	Input to version VA0 to create version VA1
GEOTHR_VA0.HIS	History text file describing how this version was created.

Successive changes to GEOTHER versions created the VA2, VA3, and VA4 series of files, each stored on its own subdirectory. The VA4 version of GEOTHER incorporated an entire subroutine, VERNON, dedicated to recording and tracking various versions of the code for QA maintenance. This subroutine

prints out on the output file the current code version, the parent version (where the current version came from), and important changes in the current version compared to the parent version.

Version A4 had the new input specification, the multiproperty capability, and the time-dependent table for heat generation. These capabilities were installed, debugged, and tested. The A4 version was then used as a base to install the three-equation model (two energy equations and a water/steam flow equation) and the improved EPRI thermodynamic property functions. This new code was designated VT4 to differentiate it from the A4 version of GEOTHER, and was stored in the same manner as the previous versions of the code in its own subdirectory. The current VT4 directory holds the following files:

GEOTHR_VT4.SRC	WITNESS Source File
GEOTHR_VT4.OPL	WITNESS Old Program Library
GEOTHR_VT4.OLB	VAX Object Library
GEOTHR_VT4.FOR	FORTTRAN Source Code
GEOTHR_VT4.LIS	FORTTRAN Listing File (cross reference map)
GEOTHR_VT4.UPD	WITNESS Update Changes
GEOTHR_VT4.EXE	Absolute executable image
GEOTHR_VT4.HIS	GEOTHER history text file explaining the creation sequence of the VT4 version from its parent VT3.

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APPENDIX C

TWO-DIMENSIONAL CARTESIAN MODELING RESULTS

APPENDIX C

TWO-DIMENSIONAL CARTESIAN MODELING RESULTS

This appendix documents the analysis of a BWIP two-dimensional single container model. The objectives of the two-dimensional Cartesian analysis were to use the modified code, GEOTHER/VT4, to compute a case consisting of specified geometric configuration, and to assess the resaturation time of the near field as a test case for the improved code. This work was limited to the investigation of the code and did not extend to production runs for use in BWIP design or licensing.

By analyzing the two-dimensional Cartesian case with GEOTHER/VT4, and comparing the results with those performed on GEOTHER (see Appendix A), the effects of the code changes as mentioned in Section 4 can be evaluated.

MODEL SETUP

A two-dimensional Cartesian model was chosen for its simplicity and for its capability of better simulating the boundary conditions than the cylindrical model as discussed in Section 5.1 and Appendix A. In the Cartesian model, a single container is simulated in the X-Z directions, where Z is the vertical direction and X is the north-south direction in the BWIP repository. By ignoring the Y-direction (east-west) we are assuming that the repository extends to infinity in that direction. This assumption would yield realistic results for containers located not too close to the periphery of the repository, provided that other parameters, such as heat generation rate, are chosen carefully.

The container is located 970 m below ground surface in the Cohasset flow. The model extends to and stops at the flow top above the containers and the flow bottom below it (see Figures 5.2 through 5.5 in Section 5.2). Within the flow top and bottom, we assumed that the pressure and temperature values stay constant. It is equivalent to assuming that the groundwater flow resistance in the flow top and bottom are negligible and the heat transfer

rate in the flow top and bottom are very large. The effects of those assumptions on the results will be discussed later. We assumed that the borehole is at 1 atm and the unperturbed temperature ($\sim 52^{\circ}\text{C}$) at the time of waste package emplacement, and that the placement room is at 1 atm and the unperturbed temperature ($\sim 52^{\circ}$) for a period of 50 years after waste package emplacement. The 50-year period was established to allow container retrieval, if necessary, at any time after emplacement within this period (see Table A.2 of Appendix A).

For simplicity, the interflow, vesicular zone, and disturbed rock zone were ignored. Instead, the near-field region was modeled with two zones: backfill and host rock. The addition of the different regions to the model can be accomplished readily once the geological data are available.

The data on the geometry and the material properties are given in Table 5.1 of Section 5.2. As noted, Westinghouse 15x15 spent fuel was selected as the representative waste form. The time since fuel removal from a reactor was 10 years. This determined the initial heat output level from the waste package. Other waste forms (i.e., consolidated spent fuel and West Valley high-level waste) could be modeled similarly with corresponding changes in dimensions, heat sources, decay curves, and thermal properties.

Some of the base data used in the cylindrical model (Section 5.1) and the Cartesian model (Section 5.2) are different because more data became available after the cylindrical model analysis was performed. The differences, however, are small and do not affect the evaluation of the code. To apply the data to the two-dimensional Cartesian system, certain approximations and modifications were made. The placement room was approximated by a rectangularly-shaped space (see Figure 5.3 in Section 5.2). The dimension of the room is 6.8 m x 2.5 m. This preserved the total cross-sectional area of the room. One-half of the room was modeled in this study due to symmetry. The container cross section area was changed from a circle to a square to fit the two-dimensional grid system. The side of the square was 0.713 m. This length was derived from the requirement that the square have the same area as the cross section of a container.

The room-to-room distance was 123 ft (37.49 m). Again, one-half of this distance was modeled because of symmetry. The Cohasset flow top was 48.5 m above the container, and the flow bottom was 19.5 m below. The packing thickness was taken as one-half of the difference between packing OD and container OD, i.e., 0.165 m. Packing length was 5.385 m.

The pressure at the flow top was the unperturbed pressure at the depth of the flow top (921.5 m); the pressure at the flow bottom was the unperturbed pressure at the depth of the flow bottom (989.5 m). The unperturbed pressures are given in Figure 5.8 in Section 5.2.

The temperatures at the flow top and bottom were the unperturbed temperatures at their given depths. The unperturbed values are given in Figure 5.7 of Section 5.2.

As discussed in Section 5.2, the heat source was set to three values. The upper bound (Case 1) was established by assuming that the host rock between the containers has the same unit volume heat generation rate as the container (see Figure 5.4 of Section 5.2), which has a heat source of 2069 W. The lower bound case (Case 2) was established by assuming that 2069 W heat is distributed uniformly among the containers and the rocks between, effectively reducing the per unit volume heat strength. Case 3 used 34.3% of the upper bound heat strength to match the calculated peak container temperature (220°C) with that from the HEATING5 calculating (see Section 5 for details). The results of these two cases are presented in the following sections.

The thermal conductivities and specific heat of the basalt host rock were calculated by the code as a function of temperature. They were updated at each time step as temperature changes. The thermal conductivities and specific heat for other materials, i.e., backfill and water, were input as constants.

Certain material properties were the homogeneous properties derived from combining those of the shell and waste form. The homogenization process is the same as that described in Yung et al. (1985). For thermal conductivity and density, volume weighting was used. For specific heat, mass weighting was used.

RESULTS AND DISCUSSION

Best-Estimate Case (Case 3)

As discussed in Section 5.2, the calculation was carried out to 1000 years after waste package emplacement. The results on saturation in the near field are given in Section 5.2. More detailed results are discussed in this appendix.

The grid system and the location of the container and packing zone are given in Figures 5.5 and 5.6 in Section 5.2.

The calculation was initiated with the assumption that the placement room and borehole were at 1 atm and unperturbed temperature, and that all other block (grid) locations are at the unperturbed state. A new asymptotic pressure profile was established after about 2 years from excavation with no container in place. This pressure profile (Figure C.1) was used as the initial condition for the calculation with the containers in place. The placement room is kept at 1 atm and 52°C for 50 years after waste package emplacement.

Figures C.1 through C.34 give the pressure contour plots from the time of waste package emplacement to the end of 200 years. At the time of emplacement, the pressure on the borehole surface is at 1 atm and gradually increases as one traverses into the interior of the host rock until it reaches the maximum at the flow top and bottom. As the container is emplaced and backfilled, the pressure sink at the borehole location is lost. This factor, combined with rapid heatup of the regions immediately next to the container, causes pressure increases and larger pressure gradients in a region close to the container (Figures C.2 through C.4).

The pressure gradients in the placement room should be ignored. The nonphysical contours inside the placement room are due to the pressure values associated with each block being at the center of the block. Large block size and the discrete pressure value cause the contour program to calculate a pressure gradient inside the placement room. After about 1 year, the gradual release of pressure through groundwater flow to the placement room, which continues to be a pressure sink at 1 atm, reduces the pressure gradient

(Figure C.5). As time passes, the heated zone diffuses into the interior of the host rock, causing the pressure in the interior to increase. As the decay heat continues to decrease but at a slower rate, the pressure profile changes slowly. Figures C.6 through C.16 show these phenomena.

At the time of, and shortly after, placement room backfill, the loss of pressure sink (open placement room) causes the pressure in the near field to increase rapidly (Figures C.17 through C.22). After the initial rapid increase, the rate slows, but the pressure in the near field continues to increase because of the influx of the liquid water from flow top and flow bottom. This process continues until the end of the calculation at 1000 years after emplacement (Figures C.23 through C.34).

FIGURE C.1. Contours of Groundwater Pressure, 0 Years After Emplacement, Best-Estimate Case

FIGURE C.2. Contours of Groundwater Pressures, 0.7 Year after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.3. Contours of Groundwater Pressures, 1.3 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

C.7

FIGURE C.4. Contours of Groundwater Pressures, 2.9 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.5. Contours of Groundwater Pressures, 5.6 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.6. Contours of Groundwater Pressures, 7.2 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.7. Contours of Groundwater Pressures, 10.2 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.8. Contours of Groundwater Pressures, 12.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.9. Contours of Groundwater Pressures, 15.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.10. Contours of Groundwater Pressures, 20.5 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.11. Contours of Groundwater Pressures, 25.6 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.12. Contours of Groundwater Pressures, 30.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.13. Contours of Groundwater Pressure 35.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.14. Contours of Groundwater Pressures, 40.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.15. Contours of Groundwater Pressures, 45.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.16. Contours of Groundwater Pressures, 50.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.17. Contours of Groundwater Pressures, 52.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.18. Contours of Groundwater Pressures, 54.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.19. Contours of Groundwater Pressures, 56.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.20. Contours of Groundwater Pressures, 58.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.21. Contours of Groundwater Pressures, 60.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.22. Contours of Groundwater Pressures, 62.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.23. Contours of Groundwater Pressures, 66.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.24. Contours of Groundwater Pressures, 70.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.25. Contours of Groundwater Pressures, 76.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.26. Contours of Groundwater Pressures, 80.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.27. Contours of Groundwater Pressures, 86.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.28. Contours of Groundwater Pressures, 90.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.29. Contours of Groundwater Pressures, 100.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

PLOT FOR TIME = 202.800

DEPTH BELOW GROUND SURFACE (M)

-921.50

-938 m

-959 m

-970 m

-976 m

-982 m

-989.50

0.00 3.4 m 7.1 m 8.8 m 18.75

HORIZONTAL DIRECTION (M)

FIGURE C.31. Contours of Groundwater Pressures, 200.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.32. Contours of Groundwater Pressures, 300.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.33. Contours of Groundwater Pressures, 500.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

FIGURE C.34. Contours of Groundwater Pressure, 1000.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in MPa: 9.0, 8.0, 7.0, 6.0, 5.0, 4.0, 3.0, 1.0, 0.5)

Figures C.35 through C.67 give the temperature contours from 0.7 years to 1000 years after waste package emplacement. Temperatures at the time of waste package emplacement were not plotted because they were the unperturbed temperatures and would have been straight horizontal lines if plotted. As can be seen from Figures C.35 and C.37, the near-field rock zone is heated up rapidly. The heat gain to the zone is larger than the heat loss to the ambient. As the decay heat decreases, the heatup process is slowed and the temperature profiles do not change as fast as before. This is seen in Figures C.38 through C.41. As the decay heat continues to decrease, the heat gain is less than the heat loss and the temperature gradually decreases, as evidenced in Figures C.42 through C.49. After emplacement room backfill (Figures C.50 through C.67), the loss of temperature sink of the open room leads to rapid increase of the container and near-field temperatures (Figures C.50 through C.53). After the initial increase, the decay heat is once again balanced by

FIGURE C.35. Contours of Groundwater Temperatures, 0.7 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.36. Contours of Groundwater Temperatures, 1.3 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.37. Contours of Groundwater Temperatures, 2.9 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.38. Contours of Groundwater Temperatures, 5.7 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.39. Contours of Groundwater Temperatures, 7.2 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.40. Contours of Groundwater Temperatures, 10.2 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.41. Contours of Groundwater Temperatures, 12.1 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.42. Contours of Groundwater Temperatures, 15 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.43. Contours of Groundwater Temperatures, 20.5 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.44. Contours of Groundwater Temperatures, 25.6 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.45. Contours of Groundwater Temperatures, 30.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.46. Contours of Groundwater Temperatures, 35.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200, 220)

FIGURE C.47. Contours of Groundwater Temperatures, 40.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140)

FIGURE C.48. Contours of Groundwater Temperatures, 45.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140)

FIGURE C.49. Contours of Groundwater Temperatures, 50.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.50. Contours of Groundwater Temperatures, 52.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.51. Contours of Groundwater Temperatures, 54.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.52. Contours of Groundwater Temperatures, 56.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160)

FIGURE C.53. Contours of Groundwater Temperatures, 58.0 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.54. Contours of Groundwater Temperatures, 60 Years after Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.55. Contours of Groundwater Temperatures, 62.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160)

FIGURE C.56. Contours of Groundwater Temperatures, 66.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.57. Contours of Groundwater Temperatures, 70.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100, 120)

FIGURE C.58. Contours of Groundwater Temperatures, 76.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.59. Contours of Groundwater Temperatures, 80.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.60. Contours of Groundwater Temperatures, 86.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.61. Contours of Groundwater Temperatures, 90.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.62. Contours of Groundwater Temperatures, 100.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90)

FIGURE C.63. Contours of Groundwater Temperatures, 150.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90)

FIGURE C.64. Contours of Groundwater Temperatures, 200.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80, 90, 100)

FIGURE C.65. Contours of Groundwater Temperatures, 300.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75, 80)

FIGURE C.66. Contours of Groundwater Temperatures, 500.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65, 70, 75)

FIGURE C.67. Contours of Groundwater Temperatures, 1000.0 Years After Emplacement, Best-Estimate Case (values from outer to inner contours in °C: 52, 55, 60, 65)

the heat loss and the temperature in the near field starts to decrease (see Figures C.54 through C.67, as well as Section 5.2 and Figure 5.9).

It should be noted that the temperature contours in all of the plots are not symmetric in Z-direction because of the nonuniform temperature distribution in an unperturbed state (see Figure 5.7).

Figure C.68 is the pressure versus time for the block of $I = 2$, $K = 8$ (see Figure 5.5 of Section 5.2). Block(2,8) is located above the containers in the packing region. The pressure in the near field increases rapidly within a few months after emplacement because of the loss of pressure sink at the borehole location and the rapid heatup of the container. After this period, the release of pressure through groundwater outflow to the placement room causes the decrease of pressure. That is, the pressure spiking is being reduced by its trying to equilibrate with lower pressures in the far field. As the

FIGURE C.68. Groundwater Pressure In Packing (Block2,8) Versus Time Best-Estimate Case

decay heat decreases, the pressure also decreases. When the heat loss stabilizes, the pressure decreases monotonically for the period of 10 to 50 years. At the time of emplacement room backfill, the pressure starts to increase rapidly, due to the loss of pressure sink and the influx of groundwater from the flow top and bottom. At 250 years, the backfill pressure essentially reaches the unperturbed pressure. The pressure equalization with the unperturbed pressure at 250 years is believed to be conservative (i.e., too short a time period). The backfill material in the calculation is assumed to be saturated with water. This restriction is applied because GEOTHER does not model non-condensable gases such as air. In a real situation, the backfill is almost totally unsaturated. This deficiency will be addressed in future code improvements.

Figure C.69 gives the temperature versus time for block (2,8). As discussed before, the near-field region is heated up rapidly. As the decay heat

FIGURE C.69. Groundwater Temperature in Packing (Block 2,8) Versus Time
Best Estimate Case

decreases, the heatup process is slowed and the temperature reaches a maximum. This occurs at around 3 years after emplacement for both block locations.

When the heat gain is less than the heat loss, the temperature decreases. This occurs from about 3 to 50 years. As in the container temperature history (Figure 5.9), the packing temperature increases rapidly at placement room closure, reaches a peak, and then gradually decreases as the decay heat is less than the heat loss to the boundaries. Comparing the pressure and temperature versus time results from GEOTHER/VT4 (this appendix) with those from GEOTHER (Appendix A), it is clear that the nonphysical step changes in temperatures (see e.g., Figure A.12) and the large pressure spikes do not appear in the GEOTHER/VT4 results. This supports the conclusions made in the cylindrical model analysis that one of the causes of the spikes and step changes in pressure and temperature in GEOTHER originates from the step change in input of heat

generation rate. The step change input was modified using an algorithm of continuous code interpolation in GEOTHER/VT4.

The behavior of the rock saturation in the near field is dictated by the pressure and temperature combination of each block. The results and their interpretations are given in Section 5.2.

Effect of Fixed Boundary Conditions at Flow Top and Bottom on Saturation

Based on available information, it is not clear how good an approximation the assumption of fixed pressure and temperature in the Cohasset flow top and bottom is. If the flow top and bottom have non-negligible resistance to groundwater flow and heat conduction, then this assumption might not hold, and the initial pressure in the near field would be lower than presented here. The pressure throughout the transient would also be lower. This is because the fixed pressure boundary location would have to be farther above and below the flow top and bottom respectively, and because the pressure gradient for at least the first 50 years is directed from top and bottom boundaries to the placement room.

The assumption would not affect the initial temperature profile because the unperturbed temperatures were used. As the transient proceeds, and if we allow a finite amount of heat conduction at the flow top and bottom, the temperatures in the near field would be slightly higher than the case with fixed temperatures at flow top and bottom.

The reduced pressures and increased temperatures in a case with boundary location farther above and below the flow top and bottom would very likely yield a larger unsaturated region surrounding the container. Thus, the assumption of the flow top and bottom as the boundaries is conservative (in the sense of resulting in less unsaturated area and shorter resaturation time).

Effect of Assumption of No Air in Backfill on Saturation

At the time of backfill, the backfill media are low in moisture and are filled with air. However, in GEOTHER/VT4, air is not modeled. Instead, the porous backfill material is modeled to be filled with liquid water or steam or a mixture of the two, depending on the initial pressure/temperature

combination. In this analysis, the condition at the time of backfill was 1 atm and 52°C. Therefore, the code takes the backfill as saturated with liquid water. It becomes unsaturated later in the transient because the water is heated by the containers. Because of this modeling approach, the results on saturation are expected to result in a resaturation period that is shorter than in a realistic situation where air is modeled.

Effect of Container Initial Temperature on Saturation

The container at the time of emplacement was assumed to have an average temperature equal to the ambient temperature (~52°C). In reality, the temperature in the interior of the container was higher than the ambient temperature. By using a lower initial temperature, we have assumed less stored energy at the beginning of the transient. This yields a resaturation time that is shorter than in a case with a more accurate initial temperature.

Upper Bound Case (Case 1)

This case used the same geometric model and boundary conditions as the best-estimate case. However, the heat strength of the container was set at 100% of the volumetric container heat source. As explained in Section 5.2, this value will yield a larger steam zone than in an actual case.

The calculated results on saturation are presented in Figures C.70 through C.79. Contour lines that go into the containers and the placement room should be ignored. (The code gives saturation values in the container blocks with no physical meaning.)

Because of the assumption of constant pressure and temperature at flow top and bottom and the pressure sink of 1 atm at the borehole, the host rock at the time of waste package emplacement is fully saturated. As the container heats up the surrounding backfill and host rock, steam starts to form. This occurs shortly after waste package emplacement. At 0.24 year (Figure C.70) the container is partially surrounded by two-phase saturated (in thermodynamic sense) water.

As the heat-up process continues, the contours expand outward. This is evidenced by the plots in Figures C.71 and C.72. In the plots, there are

discontinuities in the contour lines. These are caused by the discrete and large block sizes of the model, thus allowing discontinuous saturation values from block to block to occur, by the oscillatory behavior of the temperature and pressure iterations, although they are small (a few percent), causing oscillations in saturation, and by the curve-fitting scheme in the graphics program SEQUEL. In Figure C.72, when the steam zone is approaching its maximum, it extends about 2 m above and below the container surface, and about 2.5 m into the side of the container (horizontal X-direction). The two-phase zone extends farther into the host rock (~8 m above the container, ~3 m below it, and ~4.5 m on the side).

The shape of the contours is elongated in the vertical direction. This is caused by the enlarged scale in the vertical direction for better resolution in that direction. If they are plotted with the same scale in both directions, the contours should be more square-shaped, as one would have expected in the actual situation.

FIGURE C.70. Groundwater Saturation Contours, 0.4 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.71. Groundwater Saturation Contours,
1.5 Years After Waste Package
Emplacement, Upper Bound Case

FIGURE C.72. Groundwater Saturation Contours,
10 Years After Waste Package
Emplacement, Upper Bound Case

FIGURE C.73. Groundwater Saturation Contours, 50 Years After Waste Package Emplacement, Upper Bound Case

As the heat generation rate and heat loss rate become about equal in the near field, the saturation profiles stabilize. This happens at about 14 to 15 years after waste package emplacement. After this, the heat loss rate is increasingly greater than the heat generation rate, the rock temperatures decrease more rapidly, and the steam and two-phase zones start to decrease. This is seen in Figure C.71. The steam zone at the end of year 50 extends about 1 m above and below the container, 0.7 m below it, and 1 m on the side. The two-phase zone extends about 3.5 m above the container, 1.5 m below it, and 2.5 m on the side.

Figure V.74 shows the saturation contours at 60 years, which is 10 years after placement room backfill. As in the best-estimate case, pressure in the near field increases rapidly after placement room closure, causing the steam and two-phase zone to collapse, as seen Figure C.74. As time increases, the

FIGURE C.74. Groundwater Saturation Contours, 60 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.75. Groundwater Saturation Contours, 120 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.76. Groundwater Saturation Contours, 150 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.77. Groundwater Saturation Contours, 200 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.78. Groundwater Saturation Contours, 250 Years After Waste Package Emplacement, Upper Bound Case

FIGURE C.79. Groundwater Saturation Contours, 300 Years After Waste Package Emplacement, Upper Bound Case

continued heat loss leads to decrease in pressure and increase in steam and two-phase zone. Figure C.75 shows this effect. As the transient progresses, the gradual cooldown and the influx of groundwater cause buildup of pressure and drop in temperature. These effects result in slow reduction of the unsaturated zone. The simulation was stopped at 300 years because of the expenses in computing time.

The groundwater velocities are given in Figures C.80 through C.92. They indicate the direction of flow, not the magnitude. As seen from the figures, the flow is initially toward the container and the placement room (Figure C.80). As the near field heats up, the pressure near the container becomes higher than at the flow top and bottom, and the flow reverses. This occurs at 0.5 year after emplacement. As the pressure buildup slows and the pressure sink at the placement room causes the pressure in the near field to drop, the flow becomes inward again. This occurs at about 1.5 years (Figure C.82). The inward flow is kept until shortly after placement room backfill. The loss of pressure and temperature sink causes a large increase in near-field pressure, which leads to the reversal of the groundwater flow for a short time (Figure C.86). After that, the flow is toward the container through the end of the simulation of 300 years. This is because of the continuous condensation of the vapor zone that keeps the near-field pressure low.

Figures C.93 through C.103 give the pressure contours for the upper bound case. Figures C.104 through C.113 give the temperature contours. These contours are consistent with the saturation contours and velocity vector plots discussed earlier.

Lower Bound Case (Case 2)

In the lower bound case, the heat sources of the containers are spread out to the host rock between the containers in the Y-direction (east-west direction, see Figure 5.4 in Section 5.2). In addition to the differences in the heat generation rate per unit volume for the upper and lower bound cases, the initial temperatures of the borehole and the placement room are 27°C instead of 52°C. The lower bound case was run on GEOTHER/VT3, which has the original thermodynamic properties for water, whereas the upper bound case was run on

$T = 0$ YEARS

FIGURE C.80. Groundwater Velocity Vector, 0.0 Year After Emplacement, Upper Bound Case

$T = 0.5$ YEARS

FIGURE C.81. Groundwater Velocity Vector, 0.5 Year After Emplacement, Upper Bound Case

T = 1.5 YEARS

FIGURE C.82. Groundwater Velocity Vector, 1.5 Year After Emplacement, Upper Bound Case

T = 10 YEARS

FIGURE C.83. Groundwater Velocity Vector, 10 Years After Emplacement, Upper Bound Case

T = 50 YEARS

FIGURE C.84. Groundwater Velocity Vector, 50 Years After Emplacement, Upper Bound Case

T = 55 YEARS

FIGURE C.85. Groundwater Velocity Vector, 55 Years After Emplacement, Upper Bound Case

T = 60 YEARS

FIGURE C.86. Groundwater Velocity Vector, 60 Years After Emplacement, Upper Bound Case

T = 80 YEARS

FIGURE C.87. Groundwater Velocity Vector, 80 Years After Emplacement, Upper Bound Case

T = 120 YEARS

FIGURE C.88. Groundwater Velocity Vector, 120 Years After Emplacement, Upper Bound Case

FIGURE C.89. Groundwater Velocity Vector, 150 Years After Emplacement, Upper Bound Case

FIGURE C.90. Groundwater Velocity Vector, 200 Years After Emplacement, Upper Bound Case

FIGURE C.91. Groundwater Velocity Vector, 250 Years After Emplacement, Upper Bound Case

FIGURE C.92. Groundwater Velocity Vector, 300 Years After Emplacement, Upper Bound Case

FIGURE C.93. Groundwater Pressure Contours, 0.0 Year After Emplacement, Upper Bound Case

FIGURE C.94. Groundwater Pressure Contours, 0.5 Year After Emplacement, Upper Bound Case

FIGURE C.95. Groundwater Pressure Contours, 1.5 Year After Emplacement, Upper Bound Case

FIGURE C.96. Groundwater Pressure Contours,
10 Years After Emplacement, Upper
Bound Case

FIGURE C.97. Groundwater Pressure Contours,
50 Years After Emplacement, Upper
Bound Case

FIGURE C.98. Groundwater Pressure Contours, 55 Years After Emplacement, Upper Bound Case

FIGURE C.99. Groundwater Pressure Contours, 120 Years After Emplacement, Upper Bound Case

FIGURE C.100. Groundwater Pressure Contours,
150 Years After Emplacement,
Upper Bound Case

FIGURE C.101. Groundwater Pressure Contours,
200 Years After Emplacement,
Upper Bound Case

FIGURE C.102. Groundwater Pressure Contours, 250 Years After Emplacement, Upper Bound Case

FIGURE C.103. Groundwater Pressure Contours, 300 Years After Emplacement, Upper Bound Case

FIGURE C.104. Groundwater Temperature Contours,
0.5 Years After Emplacement, Upper
Bound Case

FIGURE C.105. Groundwater Temperature Contours,
10 Years After Emplacement, Upper
Bound Case

FIGURE C.106. Groundwater Temperature Contours, 50 Years After Emplacement, Upper Bound Case

FIGURE C.107. Groundwater Temperature Contours, 55 Years After Emplacement, Upper Bound Case

FIGURE C.108. Groundwater Temperature Contours, 80 Years After Emplacement, Upper Bound Case

FIGURE C.109. Groundwater Temperature Contours, 120 Years After Emplacement, Upper Bound Case

FIGURE C.110. Groundwater Temperature Contours,
 150 Years After Emplacement, Upper
 Bound Case

FIGURE C.111. Groundwater Temperature Contours,
 200 Years After Emplacement, Upper
 Bound Case

FIGURE C.112. Groundwater Temperature Contours, 250 Years After Emplacement, Upper Bound Case

FIGURE C.113. Groundwater Temperature Contours, 300 Years After Emplacement, Upper Bound Case

GEOTHER/VT4, which has the EPRI thermodynamic properties. Using GEOTHER/VT3 for the lower bound case posed no problem because the water temperatures in the lower bound case never exceeded 300°C, the limit for the property range in the original GEOTHER thermodynamic property function. For the upper bound case the EPRI properties had to be used because of much higher temperatures. The room temperature of 27°C was used for the lower bound case because the original GEOTHER property functions allowed a lower temperature than the EPRI functions did.

Other input parameters were the same as the upper bound case. The calculation was carried out to 18 years after waste package emplacement. It was not proceeded further because it was evident that the near field would not become unsaturated with increasing time.

Figures C.114 through C.119 show the results with the lower bound heat rate. As expected, the pressure increased initially as the near field is heated up in the first few years (Figures C.114 and C.115). Since the heat generation rate is small and decreasing, it is not a dominant factor in the pressure behavior calculation as the transient proceeds. Figures C.115 and C.116 indicate that the pressure profile does not change after about 4 years from waste package emplacement.

Figures C.117 through C.119 give the temperature contours. Unlike the upper bound case, the initial temperature contours are not straight lines (Figure C.117) because a temperature of 27°C instead of 52°C was used for the placement room and borehole. As the heatup process starts, the near field is heated up, as shown in Figure C.118. As the decay heat diminishes, the heat gain is less than the heat loss and the temperature starts to drop. Figure C.119 shows lower temperatures at 18 years than at 4 years. The water in the near field never reaches the two-phase line; it is fully saturated at all times, so no saturation contours were plotted. In fact, the highest temperature in the backfill region is about 83°C.

FIGURE C.114. Contours of Groundwater Pressures, Lower Bound Heat Source, 0 Year After Waste Package Emplacement

FIGURE C.115. Contours of Groundwater Pressures, Lower Bound Heat Source, 4 Years After Waste Package Emplacement

FIGURE C.116. Contours of Groundwater Pressures, Lower Bound Heat Source, 18 Years After Waste Package Emplacement

FIGURE C.117. Contours of Groundwater Temperatures, Lower Bound Heat Source, 0 Years After Waste Package Emplacement

FIGURE C.118. Contours of Groundwater Temperatures, Lower Bound Heat Source, 4 Years After Waste Package Emplacement

FIGURE C.119. Contours of Groundwater Temperatures, Lower Bound Heat Source, 18 Years After Waste Package Emplacement

REFERENCES

Yung, S. C., et al. 1985. Waste Package Preliminary Reliability Analysis Report. SD-BWI-TI-287, Rockwell Hanford Operations, Richland, Washington.