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**Yucca Mountain Site Characterization Project
New Three-Dimensional Far-Field Potential Repository Thermomechanical Calculations**

by

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ABSTRACT

The thermomechanical effect on the exploratory ramps, drifts, and shafts as a result of high-level nuclear waste disposal is examined using a three-dimensional thermo-elastic model. The repository layout modeled is based on the use of mechanical mining of all excavations with equivalent waste emplacement areal power densities of 57 and 80 kW/acre. Predicted temperatures and stress changes for the north and south access drifts, east main drift, east-west exploratory drift, the north and south Calico Hills access ramps, the Calico Hills north-south exploratory drift, and the optional exploratory studies facility and man and materials shafts are presented for times 10, 35, 50, 100, 300, 500, 1000, 2000, 5000, and 10,000 years after the start of waste emplacement. The study indicates that the east-west exploratory drift at the repository horizon is subject to the highest thermomechanical impact because it is located closest the buried waste canisters. For most exploratory openings, the thermally induced temperatures and stresses tend to reach the maximum magnitudes at approximately 1000 years after waste emplacement.

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1.0 INTRODUCTION

This report presents the results of an analysis that evaluates certain thermomechanical effects upon the potential high-level nuclear waste repository and the exploratory drifting at the Yucca Mountain site. The repository layout assumed in this analysis is based on mechanical mining of the exploratory drifts and repository openings and differs from that proposed in the Site Characterization Plan (U.S. Department of Energy (DOE), 1988) and described in the Site Characterization Plan Conceptual Design Report (SCP-CDR) (Sandia National Laboratories (SNL), 1987). All exploratory drifts and subsequent repository openings would be circular with the emplacement drifts perpendicular to the main access drifts. This layout was proposed to facilitate construction using mechanical mining equipment and was selected in conjunction with the exploratory drifting layout as a result of the Exploratory Studies Facility (ESF) Alternatives Study (SNL, 1991). For this study, the waste is assumed to be 30 years (instead of 8.55 years) out of the reactor before emplacement in the repository.

For the thermomechanical analysis, conduction was assumed to be the only heat transfer mechanism. STRES3D (Asgian et al, 1991), the computer code used, models the three-dimensional layout and time-sequential emplacement of the heat-generating high-level nuclear waste in an infinite half-space and assumes temperature-independent thermomechanical properties. The rock mass is assumed elastic, isotropic, and homogeneous.

The objective of the analysis is to predict the temperature and stress changes at all of the exploratory access and drift locations planned for construction during the site characterization studies. Results are required for selected times after waste emplacement so that thermomechanical impacts of the repository on excavations can be assessed in both the preclosure and postclosure periods. The results of this analysis may be used in the design of exploratory drift ground support/reinforcement and may provide an assessment of the repository thermomechanical environment for other repository design and system performance studies.

This report provides a description of the input parameters in the analysis and results for all points of interest. Two densities of waste emplacement are considered. The first places the waste in the emplacement rooms with an areal power density (APD) equivalent to 57 kW/acre for the SCP-CDR repository layout (SNL, 1987). This equivalence takes into consideration the age of the waste at emplacement and the actual APD for the 30-year-old waste of 51.7 kW/acre. The second emplacement layout is based on an APD equivalent to 80 kW/acre for the SCP-CDR repository layout. For the 30-year-old waste, the actual APD is 72.5 kW/acre.

2.0 THEORETICAL BACKGROUND

STRES3D was used to calculate the temperatures and stresses in the elastic half-space representing the repository site. STRES3D is based on the thermoelasticity fundamental solution by Nowacki (1962) in which heat flow is by conduction only. Nowacki presented solutions for temperature and stress in an infinite elastic medium resulting from the instantaneous addition of a finite quantity of heat at a given location. This solution has been used for integration over time to provide solutions for either constant heat sources or exponentially decaying heat sources. Because of the assumption of elasticity, the stresses from more than one such point heat source can be superimposed. STRES3D provides a framework for superposition of multiple heat sources of different exponentially decaying half-lives to simulate the time-varying heat generation of the high-level nuclear waste. By positioning heat sources in different locations with different turn-on times, sequential waste emplacement throughout the repository can be modeled.

To simulate the effect of the ground surface, which is assumed to be stress-free and constant in temperature, Nowacki (1962) suggested using the method of images. This approach is used within STRES3D, where a heat sink is placed at the image location of each heat source to maintain the required surface temperature and normal stress. However, the surface shear stresses are non-vanishing and need to be relieved by applying surface shear stresses of equal magnitude but opposite sign. This is done numerically in STRES3D by defining a grid on the surface, calculating the shear stress at each grid point as a result of the heat sources and sinks, and then applying an equal but oppositely directed shear stress at each point to neutralize the surface shears. Hence, the stress at any point in the elastic half-space can be calculated by summing the contributions from the heat sources, sinks, and surface shears.

3.0 REPOSITORY CONFIGURATION AND INPUT PARAMETERS

The ramp-repository layout was based on drawings provided by Raytheon Services, Nevada and is included in the Problem Definition Memo (PDM) 75-25 (see Appendix A).

3.1 Repository Geometry

The repository geometry is shown in Figures 3-1 through 3-3. The general repository layout and the exploratory drifting for the two ramp access configurations are shown in Figure 3-1. Figure 3-2 shows the slopes of the main access drifts and emplacement rooms and details of main spacings and offsets. Three main access drifts are planned in the north-south direction on 100-ft spacings. For the analysis, a 200-ft standoff is assumed between the mains and the first waste in the emplacement drifts so as to minimize the thermomechanical impact of the heat generated by the waste on the mains.

The exploratory drifts on the Main Test Level to be located in the TSw2 unit are shown in more detail in Figure 3-3. This figure shows the layout of the ramps to the north and south of the potential repository, access ramps to the Calico Hills Level, and excavations planned at the Main Test Area. The elevations of the mains on the potential repository horizon and the exploratory drifting on the Calico Hills Level are shown in Figure 3-4. In the figure, D, D', A and G are the control points for the repository geometry.

The waste emplacement drifts are on 83.3-ft spacings to provide maximum waste spacing in the emplacement rooms while not exceeding a maximum extraction guideline of 30%. The 57-kW/acre equivalent case results in spacing of the waste canisters at 15.4 ft (4.69 m), and 10.9 ft (3.34 m) for the 80-kW/acre equivalent case. Each canister's thermal output at emplacement is 1.52 kW. The in-borehole emplacement scheme is assumed.

The total number of canisters to be stored in the potential repository is 31,283. For the above drift and canister spacings, not all of the repository area outlined in Figure 3-1 is required for emplacement. Waste emplacement will begin at the north of the potential repository area and progress to the south. The waste is scheduled to be emplaced progressively within 25 years with a rate of emplacement of only 200 cans/year for the first 3 years, 447 cans in year 4, 895 cans in year 5, and 1489 cans/year for years 6 through 23. In years 24 and 25, 1340 and 1200 cans/year should be placed, respectively.

Figure 3-5 shows in plan view the length of the emplacement rooms in which canisters would be emplaced and the sequence of emplacement for the 57-kW/acre case. It has been assumed that all available locations will be used for emplacement and that the east-west exploratory drift will not be used for waste storage. The waste will be emplaced in the floor of the emplacement drift from the perimeter drift to within 200 ft of the main access drifts. The unused space within the repository perimeter drift could be used for waste storage should some geologic feature that made some areas unsuitable for waste storage be encountered in the emplacement drifts. For the 57-kW/acre equivalent APD case, a total of 164 drifts would be used for storage. On the southern side of the east-west exploratory drift, a total of 76 emplacement drifts are to be used. In the previously defined repository area, a total of 19 drifts would be developed on each side of the east main drift. The emplacement schedule, shown in Figure 3-5, was approximated assuming that for each drift, waste emplacement will be completed in a single year. The 57-kW/acre case involves placement of 31,732 cans in 25 years.

For the 80-kW/acre equivalent case, the space used for waste storage is narrower because of the higher density of canisters in each drift. The emplacement schedule for the 80-kW/acre case is

Figure 3-2. Variations of Slope Within the Potential Repository

Vertical cross-section view of MTL and CHL

Figure 3-4. Cross-Sectional View of Main Test Level and Calico Hills Level

Areal heat sources

Figure 3-5. Sequence of Waste Emplacement for 57-kW/acre Case

shown in Figure 3-6. For the 80-kW/acre case, a total of 106 drifts are used for storage, with only 18 emplacement drifts used on the southern side of the east-west exploratory drift. The emplacement schedules for both the 57- and 80-kW/acre cases are summarized in Table 3-1.

The waste canisters will be placed in boreholes in the floor of the emplacement drifts. Specific details of the length of the boreholes and canisters are not available for the new repository layout, so the basic canister/borehole geometry of the SCP-CDR was used. Figure 3-7 shows the emplacement room/canister borehole configuration for the SCP-CDR design and that assumed for this layout. From this cross section, the depth of the center of the canister was used to define the elevation of the plate heat sources used for input to STRES3D.

Figure 3-8 shows an isometric schematic of the repository geometry for the 57-kW/acre equivalent case. Also shown are the accesses, emplacement drifts, and repository exploratory drifting.

3.2 Thermal and Mechanical Properties

The temperatures and stresses due to heat generation from the canisters depend on the thermal and mechanical properties of the host rock mass. Presently, the repository is assumed to be located in a homogeneous, isotropic medium with properties of the welded tuff of the TSw2 unit, the unit in which the potential repository would be located. The properties were specified either in PDM 75-25 or the Reference Information Base (RIB), Version 4, Revision 4 (DOE, 1991). The thermal and mechanical parameters are given in Table 3-2 in the units used in the analysis. Both the saturated thermal capacitance and the coefficient of thermal expansion of the welded tuff of the TSw2 unit are temperature-dependent and were recorded as piecewise constants within certain temperature ranges in the RIB. The study value for the saturated thermal capacitance is obtained by averaging the thermal capacitances of 25°, 50°, and 94°C recorded in the RIB. As for the coefficient of thermal expansion, the value for the temperature range between 25° to 50°C was selected as the study value since it is the highest value for temperatures within 25° to 150°C. A comparison between these study values and the current RIB values where available is presented in Table 3-3.

3.3 Thermal Loading

The thermomechanical effect is directly related to the magnitude and decay characteristics of the heat sources. For high-level nuclear waste, the source strength may be represented by the summation of several exponentially decaying components:

$$Q(\tau) = \sum_{i=1}^n Q_i \exp(-b_i \tau) \quad , \quad (3-1)$$

where Q_i = component strength,
 b_i = decay coefficient for component i , and
 τ = total elapsed time after removing the waste from the reactor.

It is convenient to rewrite Equation 3-1 in terms of the time after emplacement (t), and the time after removing the waste from the reactor to time of emplacement (t_0). Hence, substituting $\tau = t + t_0$ into Equation 3-1, we have

$$Q(t + t_0) = Q \sum_{i=1}^n A_i \exp\{-b_i(t + t_0)\} \quad , \quad (3-2)$$

Areal heat sources

Figure 3-6. Sequence of Waste Emplacement for 80-kW/acre Case

TABLE 3-1. EMPLACEMENT SCHEDULE AND TOTAL NUMBER OF CANISTERS IN REPOSITORY AREA FOR 57 AND 80 KW/ACRE

Yr	No. of Canisters Per Year		West Side						East Side					
	Targeted by SNL	Deployed in Analysis	Total No. of Canisters		No. of Canisters		No. of Drifts		No. of Canisters		No. of Drifts		No. of Drifts	
			57	80	57	80	57	80	57	80	57	80	57	80
			kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre	kW/acre
1	200	198	278	278	198	278	198	278	1	0	1	0	0	0
2	200	209	294	294	209	294	209	294	1	0	1	0	0	0
3	200	214	301	301	214	301	214	301	1	0	1	0	0	0
4	447	887	307	307	1,508	1,180	887	307	4	0	1	0	0	0
5	894	896	939	939	2,404	2,119	896	939	4	0	3	0	0	0
6	1,489	1,568	1,575	1,575	3,972	3,694	1,568	1,575	7	0	5	0	0	0
7	1,489	1,568	1,575	1,575	5,540	5,269	1,568	1,575	7	0	5	0	0	0
8	1,489	1,433	1,575	1,575	6,973	6,844	896	1,575	4	537	5	3	3	0
9	1,489	1,465	1,575	1,575	8,438	8,419	896	1,575	4	569	5	3	3	0
10	1,489	1,457	1,384	1,384	9,895	9,803	672	630	3	785	2	4	4	3
11	1,489	1,487	1,473	1,473	11,382	11,276	896	945	4	591	3	3	3	2
12	1,489	1,460	1,450	1,450	12,842	12,726	672	630	3	788	2	4	4	3
13	1,489	1,489	1,497	1,497	14,331	14,223	896	945	4	593	3	3	3	2
14	1,489	1,464	1,460	1,460	15,795	15,683	672	630	3	792	2	4	4	3
15	1,489	1,490	1,499	1,499	17,285	17,182	896	945	4	594	3	3	3	2
16	1,489	1,463	1,461	1,461	18,748	18,643	671	630	3	792	2	4	4	3
17	1,489	1,469	1,501	1,501	20,217	20,144	880	945	4	589	3	3	3	2
18	1,489	1,403	1,464	1,464	21,620	21,608	635	630	3	768	2	4	4	3
19	1,489	1,545	1,501	1,501	23,165	23,109	809	945	4	736	3	4	4	2
20	1,489	1,468	1,466	1,466	24,633	24,575	764	630	4	704	2	4	4	3
21	1,489	1,565	1,500	1,500	26,198	26,075	894	943	5	671	3	4	4	2
22	1,489	1,470	1,444	1,444	27,668	27,519	680	616	4	790	2	5	5	3
23	1,489	1,549	1,414	1,414	29,217	28,933	810	602	5	739	2	5	5	3
24	1,340	1,313	1,399	1,399	30,530	30,332	768	870	5	545	3	4	4	2
25	1,200	1,202	1,078	1,078	31,732	31,410	585	561	4	617	2	5	5	2
Total	31,283	31,732	31,410		19,532	20,516	95	66	12,200	10,894	69	40

SCP-CDR Case

Configuration Assumed
in this Analysis

Figure 3-7. Waste Canister Configuration

Figure 3-8. Isometric View of Potential Repository

TABLE 3-2. THERMAL AND ROCK PARAMETERS OF REPOSITORY SITE

Thermal Diffusivity (ft ² /yr)	Surface Temperature (°F) (°C)		Thermal Gradient (°F/ft)	Thermal Expansion Constant (1/°F)	Rock Mass Young's Modulus (GPa)	Rock Mass Poisson's Ratio
333.2 ^a	65.7	18.7	0.00971	5.05E-6	13.4	0.25

^a *Converted from thermal conductivity and capacitance shown in Table 3-3.*

TABLE 3-3. COMPARISON BETWEEN STUDY VALUES AND THE CURRENT RIB (Version 4, Revision 4) VALUES

Parameter	Study Value	RIB Value	RIB Range or Standard Deviation
Thermal Properties			
Saturated thermal capacitance (J/m ³ - C)			
at 25°C	2.14E+6	2.0324E+6	NA
at 50°C	2.14E+6	2.1280E+6	
at 94°C	2.14E+6	2.2638E+6	
Saturated thermal conductivity (W/m - C)	2.10	2.10	±0.2
Mechanical Properties			
Young's modulus (GPa)	13.4 ^a	32.7 ^b	NA
Poisson's ratio	0.25	0.25 ^c	NA
Coefficient of thermal expansion (m/m°C)			
25 to 50	9.1E-6	9.1E-6	±1.3
50 to 100	9.1E-6	8.2E-6	±0.8
100 to 150	9.1E-6	6.8E-6	±0.5
150 to 200	9.1E-6	9.7E-6	NA
Initial Temperature			
Surface Temperature (°C)	18.7	18.7 ^d	NA

^a *For rock mass, refer to Hardy & Bauer (1991).*

^b *Laboratory derived value.*

^c *Weighted average value.*

^d *Scaled from the temperature versus depth curve.*

where A_i is a set of dimensionless factors equal to Q_i/Q with $\sum_{i=1}^n A_i = 1$. Equation 3-2 can be further simplified to

$$Q(t+t_0) = Q \sum_{i=1}^n a_i \exp(-b_i t) \quad , \quad (3-3)$$

where $a_i = A_i \exp(-b_i t_0)$. For this analysis, a six-component approximation of the high-level waste heat generation was used. This approximation gives an adequate representation of the heat generation for 10,000 years. Table 3-4 lists the Q_i and b_i coefficients for the six component heat sources as specified in PDM75-25.

TABLE 3-4. HEAT GENERATION FROM WASTE CANISTERS

Waste Component	Source Strength Components Q_i	Time Exponent (years ⁻¹) b_i^a	Equivalent Source Strength (°F ft ³ /yrs) QCA_i^a	
			57 ^b kW/acre	80 ^b kW/acre
1	19.8996	3.92555E-5	2406.79523	3381.643
2	18.0297	4.42918E-4	2154.34625	3026.941
3	174.893	1.94302E-3	19978.38045	28070.42
4	1068.40	2.16836E-2	67503.28788	94844.78
5	468.152	1.659570E-1	390.1785328	548.2162
6	7423.13	5.718320E-1	0.031870246	4.477898E-04

^a STRES3D input parameter.

^b Equivalent actual APD at emplacement 51.6 and 72.5 kW/acre.

The initial APD is used to define the magnitude of the heat sources at emplacement. In STRES3D, the heat sources are modeled by plate sources which require input of the heat source component strength (QCA_i) and the decay constant (b_i). QCA_i is defined as the set of components of the factored APD divided by the volumetric heat capacity of the host medium (C_v). The factored APD depends on the plate geometry used to model the distributions of the heat sources and the APD. The plate model used in this analysis has a length equal to the drift length in which the waste is emplaced and a uniform width equal to 1 ft. The factored APD equivalent to the required APD must be $S \times \text{APD}$ where S is the spacing of the drifts (in feet). Hence, the input to STRES3D is

$$QCA_i = S \times \text{APD} \times K a_i / C_v, \quad (3-4)$$

where K = a constant equal to 72.397 that converts APD from kW/acre to Joules/yr/ft².

QCA_i values are listed in Table 3-4 for two initial APDs for 30-year-old waste ($t_o = 30$).

The initial APDs used in the simulations represent scaled values calculated using a technique that allows for the definition of equivalent thermal loads across a range of waste ages and burnups (Ryder, 1992). The method, known as the equivalent energy density concept (EED), bases its equivalence criteria on the assumption that a given waste will produce worst-case thermomechanical effects equal to those for baseline waste provided that the thermal energy deposited in the host rock over a specified period of time is the same for both waste descriptions. Scaled emplacement densities of 51.6 and 72.5 kW/acre were used in this study's simulations to mimic the near-field peak-temperature behavior of 10-year-old baseline waste (Johnstone et al, 1984) emplaced at 57 and 80 kW/acre, respectively.

Other input parameters include description of source geometry, location, and size of surface elements and are discussed in the next section.

4.0 THERMOMECHANICAL COMPUTATION

The program STRES3D, Version 4.10 was used in the thermomechanical computation. Version 4.0, the PC version of the STRES3D code, is documented in Asgian et al (1991). Version 4.10 of the STRES3D code operates on a DEC work station using the ULTRIX operating system. Compared with Version 4.0, there are two minor coding changes and one coding correction in Version 4.10. Other minor syntax changes were made to the code to accommodate the ULTRIX operating system. The first minor coding change is related to dimensioning. This change was made to accommodate the number of sub-area sources, which for this layout was equal to the number of Gauss points and is significantly higher than for other problems analyzed using STRES3D. The second minor coding change was to modify the location for switching to a subroutine that more accurately calculates the effect of the surface shear relief at locations near the surface. An error was found in STRES3D in evaluating the position of the areal heat sources. The correction made in Version 4.10 results in the correct vertical positioning of the inclined plate heat sources.

4.1 Numerical Integration of Heat Sources

Long thin plate heat sources were used to represent the waste emplaced below each room. In each plate, the Gauss-Legendre quadrature is used to integrate the point heat source solutions. The number of Gauss points controls the accuracy of the solution for temperature and stress, particularly near the Gauss points. To achieve accurate results without substantial computational effort, a sensitivity study was conducted to determine an appropriate number of Gauss points for each emplacement drift. It was found that a total of 9663 Gauss points should be used in calculating the temperatures and stresses at the points of interest throughout the ESF. Figure 4-1 shows the location of the Gauss points used for the ESF analysis for the 57-kW/acre case. For the 80-kW/acre loading, 6868 Gauss points were used.

4.2 Calculation of Surface Shear Stresses

As mentioned earlier, the surface shear stresses due to the effect of heat sources and as a result of superposition of image sources are cancelled by adding a stress field with surface shear stress of opposite sign. For this purpose, a surface shear mesh was generated. The mesh area must be sufficiently large to cover the region in which surface shears generated by the heat sources and image sources are significant. Figure 4-2 represents a plan view of the repository area shielded by a shear stress mesh (16,000 ft by 24,000 ft, each element is 200 ft by 200 ft). This mesh is located at 4500 ft elevation, which is ground elevation. In calculating surface shear stresses, relatively few Gauss points are used in each drift to account for heat sources for each time of interest because the surface elements are a significant distance from the heat sources. The configuration of the Gauss points for the 57-kW/acre loading at the repository horizon (total 876) for calculation of the surface shears is illustrated in Figure 4-3. A total of 624 Gauss points were used to evaluate the surface shears for the 80-kW/acre loading.

4.3 Calculation of Temperature, Stresses, and Displacements

The locations of interest for temperature and stress changes are shown in Figure 4-4. The locations are along the exploratory ramps, exploratory drifts, the optional shaft, and over the Main Test Level. Results of temperature, stress, and strain at the man and materials shaft, a repository opening, are also included. Specifically included are the east main access drift, east-west exploratory drift, and Main Test Area at the Main Test Level; north and south ramps connecting to the east main access drift; Calico Hills north-south drift at the Calico Hills Level; Calico Hills north and south ramps; the ESF optional man and materials shafts. Coordinates of the points shown in Figure 4-4 are given in Table 4-1.

Gauss points for evaluation of heat sources

Figure 4-1. Gauss Points Used to Represent Heat-Generating Waste for 57-kW/acre Case

Figure 4-2. Plan View of Repository Layout Shielded by a Surface Shear Mesh

Figure 4-3. Configuration of Gauss Points to Generate Surface Shear Stresses, 57-kW/acre Case

Figure 4-4. Points and Places of Computation

TABLE 4-1. COORDINATES OF POINTS ILLUSTRATED IN FIGURE 4-4

Names	Point	X	Y	Z
East main (1)	A	758690	558110	3740
East-west drift (1)	B	765655	558225	3558
East-west drift (2)	C	761729	564045	3296
East main (2)	D	767500	564053	3240
Main test area	D'	765939	566366	3093
North portal	E	765324	569875	3684
Calico Hills north ramp	F	767667	564889	3303
Calico Hills drift	G	758166	557757	3130
South portal	H	756520	566351	3927
Main test area (1)	I	765800	562906	3336
Main test area (2)	I'	764240	565219	3190
Line 4 (1)	J	765610	563188	3318
Line 4 (2)	J'	767309	564334	3222
Line 5 (1)	K	765196	563802	3280
Line 5 (2)	K'	766896	564948	3183
Line 2 (1)	L	766447	563342	3299
Line 2 (2)	L'	764886	565655	3153
Line 1 (1)	M	765858	562945	3333
Line 1 (2)	M'	764298	565258	3187
ESF shaft	N	766745	563966	4500
Man & materials shaft	P	759200	557870	4500
Calico Hills south ramp	Q	757744	558624	3802

The temperatures and induced stresses for the places of interest were computed at 10, 35, 50, 100, 300, 500, 1,000, 2,000, 5,000 and 10,000 years after waste emplacement begins. Strain profiles were also generated for the two shafts.

The computation was performed in two steps. The surface shear stresses were developed for each time of interest and stored on files. These files were then addressed by STRES3D along with input data files for each specific location of output. The induced stresses from drifts, ramps, and test lines were rotated in the direction either transverse or axial to the excavations. Strains are converted from stresses using the following relations:

$$\epsilon_x = \{\sigma_x - \nu(\sigma_y + \sigma_z)\} / E \quad ,$$

$$\epsilon_y = \{\sigma_y - \nu(\sigma_x + \sigma_z)\} / E \quad ,$$

$$\epsilon_z = \{\sigma_z - \nu(\sigma_x + \sigma_y)\} / E \quad ,$$

$$\gamma_{xy} = \tau_{xy} / G \quad ,$$

$$\gamma_{yz} = \tau_{yz} / G \quad ,$$

$$\gamma_{zx} = \tau_{zx} / G \quad , \quad (4-1)$$

where G = the shear modulus,
 E = Young's modulus, and
 ν = Poisson's ratio.

5.0 RESULTS OF THERMOMECHANICAL ANALYSIS

5.1 All Results

The distributions of absolute temperatures and induced stresses and strains in the repository area and surrounding rock mass at the locations of interest are presented in graphical form in Appendixes B through L for the 57-kW/acre and 80-kW/acre cases. Appendixes B through J include plots of the maximum compressive principal stress change and the minimum principal stress change. All locations mentioned in the graphs can be found in Figure 4-4. Coordinates for the drifts, which contain waste for the 57-kW/acre case and include all the drifts used for the 80-kW/acre case, are given in Appendix M. The stress results shown in the appendixes are the induced stress resulting from the effects of heat generated by the waste. The induced stress is the change in stress resulting from the thermal loads. Stresses are shown in SI units (MPa) and temperatures are given both in degrees Centigrade and degrees Fahrenheit. Distances are in feet.

The results for drifts, ramps, and test lines in the Main Test Area are presented using a local coordinate system (x' , y' , z') as shown in Figure 5-1. For the ramps, the local coordinate system rotates to follow the direction of the ramp. The stress component profiles for the shafts (Appendixes I and J) and the contour stress component plots for the Main Test Area (Appendix K) are presented relative to the global coordinate system shown in Figure 4-4. The output temperature, stresses, and strains are presented for ten time periods.

The north and south ramps provide access from the MTL to the respective portals. The Calico Hills ramps connect the MTL and CHL as shown in Figures 3-3 and 3-8. There is a curved section of drift in every ramp. It is reflected in the graphs of temperatures and stresses where sharp transitions appear. In addition, because the stresses are computed in either the transverse or axial direction to the drift, the stress orientation varies along the curved portion of the ramp. As a result, the graphs shown do not necessarily reflect the discontinuity of stresses in the vicinity of the transition point from the straight to curved portion of the ramps.

Evaluation of temperature and stresses at the shaft locations other than in the TSw2 and in the Calico Hills exploratory drifting is an approximation to actual conditions due to the assumption that the host rock mass is homogeneous throughout the section. Additional effort was made to compute strains at the shaft locations because the strains can be used as input in calculating loading on the shaft linings (see, e.g., Richardson, 1990) in areas where the host rock is not the TSw2.

5.2 Comparison of Peak Values of Temperatures and Stresses

This section summarizes the results presented in the appendixes by comparing the maximum temperatures or maximum absolute induced stresses at each time period analyzed for particular drifts, ramps, or shafts. From comparison of the maximum temperature and stress change plots, locations subjected to differing degrees of thermal loading may be readily identified. The comparison is made based on absolute values of stress, therefore, irregular curves may occur due to the transitions between tension and compression. Inspection of the stress profiles in the appropriate appendixes for the times of interest around such irregular maximum plots should resolve any uncertainty in the cause of the irregularities.

5.2.1 Comparison of Peak Values for Ramps, Shafts, and Exploratory Drifting

A comparison of maximum temperatures and stresses is made for nine locations—east main drift (e-main), east-west exploratory drift (ew-drift), Calico Hills main drift (ch-drift), north ramp (n-ramp), south ramp (s-ramp), Calico Hills north ramp (chn-rm), Calico Hills south ramp (chs-rm), ESF shaft (n-shaft), and man and materials shaft (s-shaft)—at the period from 10 to 10,000 years

Figure 5-1. Local Coordinate System and Stress Sign Conventions

after waste emplacement. The results are presented both graphically (Figures 5-2 to 5-8 for the 57-kW/acre case and Figures 5-9 to 5-15 for the 80-kW/acre case) and tabularly (Tables 5-1 to 5-9 for the 57-kW/acre case and Tables 5-10 to 5-18 for the 80-kW/acre case).

Figures 5-2 and 5-9 represent comparisons of temperatures for the ramps, shafts, and exploratory drifts. Initial temperatures are in the neighborhood of 80°F (27°C). The east-west exploratory drift has the highest maximum temperature at all times due to its close proximity to the heat sources. The peak temperatures for the drift are 202°F (94°C) and 248°F (120°C) at 500 years for the two thermal loading conditions. Substantially higher temperatures for the 80-kW/acre case than for the 57-kW/acre case indicate the higher density of heat sources located in the vicinity of the east-west exploratory drift in the former case. The east main drift has the second highest temperature magnitudes, which are about 148°F (64°C) and 177°F (81°C)¹ at 1000 years; following is the Calico Hills drift, with 140°F (60°C) and 161°F (72°C) at 2000 years. The temperature changes at the other locations are insignificant. The temperatures in the south ramp stay almost constant at

¹ Where two numbers are given in sequence like this, it should be assumed the first number refers to the 57-kW/acre case and the second, the 80-kW/acre case.

Figure 5-2. Comparison of Maximum Temperature Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-3. Comparison of Maximum Transverse Stress ($\Delta\sigma_{xx}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-4. Comparison of Maximum Axial Stress ($\Delta\sigma_{yy}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-5. Comparison of Maximum Vertical Stress ($\Delta\sigma_{zz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-6. Comparison of Maximum Shear Stress ($\Delta\sigma_{xy}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-7. Comparison of Maximum Shear Stress ($\Delta\sigma_{yz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-8. Comparison of Maximum Shear Stress ($\Delta\sigma_{xz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 57-kW/acre Case

Figure 5-9. Comparison of Maximum Temperature Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-10. Comparison of Maximum Transverse Stress ($\Delta\sigma_{xx}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-11. Comparison of Maximum Axial Stress ($\Delta\sigma_{yy}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-12. Comparison of Maximum Vertical Stress ($\Delta\sigma_{zz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-13. Comparison of Maximum Shear Stress ($\Delta\sigma_{xy}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-14. Comparison of Maximum Shear Stress ($\Delta\sigma_{yz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

Figure 5-15. Comparison of Maximum Shear Stress ($\Delta\sigma_{xz}$) Histories Along Exploratory Drifts, Ramps, and Shafts, 80-kW/acre Case

TABLE 5-1. PEAK VALUES OF TEMPERATURE/STRESSES FOR EAST MAIN DRIFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.2	0.1	0.2	0.1	0.0	0.0
35	79	26	2.0	0.4	1.9	0.7	0.1	0.3
50	82	28	2.8	0.3	2.6	1.0	0.2	0.4
100	93	34	4.4	0.6	3.4	1.3	0.3	0.5
300	121	49	6.0	2.3	3.1	1.3	0.4	0.5
500	135	57	6.4	3.1	2.7	1.3	0.5	0.5
1000	148	64	6.3	3.9	1.9	1.1	0.5	0.4
2000	145	63	5.1	3.6	0.9	0.7	0.6	0.4
5000	125	52	3.1	2.3	0.3	0.4	0.5	0.3
10000	111	44	2.0	1.5	0.2	0.3	0.4	0.2

TABLE 5-2. PEAK VALUES OF TEMPERATURE/STRESSES FOR EAST-WEST EXPLORATORY DRIFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	77	25	0.0	0.0	0.0	0.0	0.0	0.0
35	118	48	5.8	3.3	2.4	0.2	0.7	0.4
50	142	61	7.9	5.3	2.4	0.3	0.8	0.5
100	176	80	10.0	7.8	3.5	0.3	0.8	0.5
300	196	91	10.3	8.8	3.3	0.3	0.7	0.5
500	202	95	10.2	8.8	2.9	0.3	0.7	0.5
1000	198	92	9.0	7.8	2.0	0.3	0.7	0.4
2000	173	78	6.4	5.9	1.0	0.3	0.7	0.3
5000	137	58	3.6	3.5	0.4	0.2	0.6	0.3
10000	119	48	2.4	2.4	0.3	0.1	0.5	0.2

TABLE 5-3. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS DRIFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	83	28	0.0	0.0	0.0	0.0	0.0	0.1
35	83	28	0.3	0.3	0.4	0.2	0.2	0.3
50	83	28	0.3	0.5	0.6	0.3	0.3	0.5
100	83	29	0.6	0.7	1.1	0.5	0.5	0.7
300	97	36	1.9	0.6	1.7	0.8	0.9	1.0
500	111	44	2.8	0.9	1.7	0.9	0.8	1.0
1000	130	54	4.4	2.9	1.1	0.9	0.6	0.8
2000	140	60	4.2	3.2	0.7	0.6	0.2	0.3
5000	131	55	3.2	2.7	0.3	0.3	0.2	0.1
10000	118	48	2.2	1.9	0.2	0.2	0.2	0.1

TABLE 5-4. PEAK VALUES OF TEMPERATURE/STRESSES FOR NORTH RAMP, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	78	26	0.5	0.4	0.2	0.3	0.3	0.3
35	78	26	0.3	0.3	0.5	0.4	0.0	0.0
50	78	26	0.4	0.4	0.6	0.6	0.0	0.1
100	79	26	0.6	0.7	0.9	0.8	0.0	0.1
300	85	29	0.9	1.2	0.9	1.1	0.1	0.1
500	88	31	1.0	1.5	0.8	1.1	0.1	0.2
1000	93	34	1.0	1.8	0.7	1.0	0.1	0.2
2000	95	35	0.9	1.7	0.5	0.7	0.2	0.2
5000	93	34	0.7	1.3	0.2	0.5	0.3	0.2
10000	90	32	0.5	0.9	0.1	0.4	0.3	0.2

TABLE 5-5. PEAK VALUES OF TEMPERATURE/STRESSES FOR SOUTH RAMP, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	73	23	0.0	0.0	0.0	0.0	0.0	0.0
35	73	23	0.1	0.1	0.0	0.1	0.0	0.0
50	73	23	0.2	0.2	0.0	0.1	0.0	0.0
100	73	23	0.3	0.3	0.0	0.2	0.1	0.1
300	73	23	0.6	0.6	0.0	0.4	0.1	0.1
500	73	23	0.8	0.8	0.0	0.5	0.2	0.1
1000	73	23	1.0	1.0	0.0	0.6	0.2	0.1
2000	73	23	0.9	0.9	0.0	0.6	0.1	0.1
5000	74	23	0.7	0.7	0.0	0.5	0.0	0.0
10000	74	24	0.5	0.5	0.0	0.4	0.1	0.1

TABLE 5-6. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS NORTH RAMP DRIFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	83	28	0.0	0.0	0.0	0.0	0.0	0.0
35	83	28	0.1	0.1	0.2	0.2	0.1	0.2
50	83	28	0.1	0.1	0.2	0.3	0.2	0.2
100	83	28	0.2	0.2	0.3	0.4	0.3	0.4
300	85	30	0.3	0.4	0.5	0.7	0.5	0.5
500	88	31	0.4	0.5	0.5	0.8	0.5	0.5
1000	93	34	0.5	0.8	0.5	0.8	0.4	0.4
2000	96	36	0.7	1.1	0.4	0.6	0.2	0.2
5000	98	36	0.7	1.2	0.3	0.4	0.2	0.2
10000	96	35	0.6	0.9	0.2	0.3	0.2	0.1

TABLE 5-7. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS SOUTH RAMP DRIFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	79	26	0.0	0.0	0.0	0.0	0.0	0.0
35	79	26	0.0	0.1	0.0	0.0	0.0	0.0
50	79	26	0.1	0.1	0.0	0.1	0.0	0.0
100	79	26	0.1	0.3	0.0	0.1	0.1	0.0
300	79	26	0.2	0.5	0.0	0.2	0.1	0.0
500	79	26	0.2	0.6	0.0	0.3	0.2	0.0
1000	79	26	0.3	0.8	0.0	0.3	0.2	0.1
2000	79	26	0.3	0.8	0.0	0.3	0.1	0.1
5000	80	26	0.3	0.6	0.1	0.2	0.1	0.0
10000	80	27	0.3	0.4	0.0	0.2	0.0	0.0

TABLE 5-8. PEAK VALUES OF TEMPERATURE/STRESSES FOR ESF SHAFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	90	32	0.0	0.0	0.1	0.0	0.0	0.0
35	90	32	0.1	0.2	0.4	0.1	0.2	0.1
50	90	32	0.1	0.3	0.5	0.2	0.2	0.1
100	90	32	0.2	0.5	0.8	0.2	0.3	0.2
300	90	32	0.3	1.0	1.2	0.3	0.6	0.3
500	90	32	0.3	1.2	1.3	0.2	0.7	0.3
1000	93	34	0.7	1.5	1.1	0.3	0.7	0.2
2000	99	37	1.0	1.6	0.8	0.4	0.7	0.1
5000	104	40	1.0	1.3	0.3	0.3	0.5	0.1
10000	104	40	0.8	1.0	0.2	0.2	0.4	0.1

TABLE 5-9. PEAK VALUES OF TEMPERATURE/STRESSES FOR MAN AND MATERIALS SHAFT, 57-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	85	30	0.0	0.0	0.0	0.0	0.0	0.0
35	85	30	0.1	0.0	0.0	0.1	0.0	0.0
50	85	30	0.2	0.1	0.0	0.2	0.0	0.0
100	85	30	0.3	0.1	0.0	0.3	0.1	0.1
300	85	30	0.7	0.2	0.0	0.6	0.1	0.1
500	85	30	0.9	0.3	0.0	0.8	0.1	0.2
1000	85	30	1.0	0.3	0.1	0.9	0.1	0.2
2000	86	30	0.9	0.2	0.2	0.9	0.1	0.1
5000	88	31	0.5	0.1	0.2	0.7	0.0	0.1
10000	88	31	0.3	0.2	0.1	0.5	0.1	0.1

TABLE 5-10. PEAK VALUES OF TEMPERATURE/STRESSES FOR EAST MAIN DRIFT, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.2	0.1	0.2	0.1	0.0	0.0
35	79	26	2.7	0.6	2.5	1.0	0.1	0.4
50	83	28	3.9	0.5	3.5	1.3	0.3	0.5
100	100	38	6.2	0.7	4.7	1.8	0.5	0.7
300	139	59	8.6	2.8	4.0	1.9	0.6	0.6
500	158	70	9.3	3.8	3.3	1.8	0.7	0.6
1000	177	81	9.2	4.6	2.2	1.5	0.8	0.5
2000	171	77	7.4	4.3	1.1	1.0	0.9	0.5
5000	141	61	4.4	2.7	0.4	0.5	0.7	0.4
10000	121	49	2.9	1.7	0.2	0.3	0.6	0.3

TABLE 5-11. PEAK VALUES OF TEMPERATURE/STRESSES FOR EAST-WEST EXPLORATORY DRIFT, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	77	25	0.0	0.0	0.0	0.0	0.0	0.0
35	123	51	7.4	3.8	3.4	0.2	0.8	0.6
50	163	73	10.8	7.3	3.3	0.3	1.0	0.7
100	217	103	13.8	11.6	4.3	0.6	1.1	0.8
300	244	118	13.4	13.0	3.5	1.1	1.0	0.8
500	248	120	12.8	12.8	2.8	1.3	1.0	0.8
1000	233	112	10.7	10.9	2.0	1.4	1.0	0.9
2000	192	89	7.4	7.7	1.4	1.2	0.9	0.9
5000	146	63	4.1	4.4	0.7	0.7	0.7	0.7
10000	126	52	2.7	3.0	0.5	0.5	0.5	0.5

TABLE 5-12. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS DRIFT, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	83	28	0.1	0.1	0.0	0.0	0.0	0.1
35	83	28	0.3	0.5	0.5	0.3	0.2	0.5
50	83	28	0.5	0.7	0.7	0.5	0.4	0.6
100	83	28	1.0	1.1	1.3	0.8	0.7	1.0
300	103	39	2.8	0.6	1.9	1.2	1.1	1.4
500	122	50	4.2	0.9	2.0	1.3	1.0	1.4
1000	149	65	5.8	2.6	1.6	1.2	0.7	1.0
2000	161	72	6.1	3.7	0.9	0.8	0.2	0.4
5000	145	63	4.4	3.1	0.4	0.4	0.3	0.1
10000	128	53	3.0	2.1	0.2	0.3	0.3	0.1

TABLE 5-13. PEAK VALUES OF TEMPERATURE/STRESSES FOR NORTH RAMP, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.1	0.1	0.1	0.1	0.0	0.0
35	78	26	0.4	0.4	0.6	0.6	0.0	0.1
50	78	26	0.6	0.6	0.8	0.8	0.0	0.1
100	80	27	0.9	0.9	1.2	1.2	0.1	0.1
300	88	31	1.3	1.6	1.3	1.5	0.1	0.2
500	92	33	1.4	2.0	1.2	1.6	0.1	0.2
1000	99	37	1.5	2.3	0.9	1.4	0.2	0.3
2000	102	39	1.3	2.2	0.6	0.9	0.4	0.3
5000	99	37	1.0	1.6	0.3	0.6	0.5	0.3
10000	95	35	0.7	1.1	0.2	0.4	0.4	0.3

TABLE 5-14. PEAK VALUES OF TEMPERATURE/STRESSES FOR SOUTH RAMP, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	73	23	0.0	0.0	0.0	0.0	0.0	0.0
35	73	23	0.1	0.1	0.0	0.0	0.0	0.0
50	73	23	0.1	0.1	0.0	0.1	0.0	0.0
100	73	23	0.2	0.2	0.0	0.1	0.0	0.0
300	73	23	0.4	0.4	0.0	0.2	0.1	0.1
500	73	23	0.5	0.5	0.0	0.3	0.1	0.1
1000	73	23	0.6	0.6	0.0	0.3	0.1	0.1
2000	73	23	0.6	0.6	0.0	0.4	0.1	0.1
5000	73	23	0.6	0.5	0.0	0.3	0.1	0.1
10000	73	23	0.5	0.4	0.0	0.3	0.0	0.0

TABLE 5-15. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS NORTH RAMP, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	83	28	0.0	0.0	0.0	0.1	0.0	0.1
35	83	28	0.1	0.1	0.2	0.3	0.2	0.2
50	83	28	0.1	0.1	0.3	0.4	0.2	0.3
100	83	28	0.2	0.2	0.5	0.6	0.4	0.5
300	86	30	0.4	0.5	0.7	0.9	0.6	0.7
500	90	32	0.6	0.6	0.8	1.1	0.6	0.7
1000	96	36	0.8	1.0	0.8	1.1	0.5	0.5
2000	102	39	1.0	1.4	0.6	0.8	0.2	0.2
5000	104	40	1.1	1.5	0.4	0.5	0.3	0.2
10000	101	38	0.9	1.2	0.2	0.4	0.3	0.2

TABLE 5-16. PEAK VALUES OF TEMPERATURE/STRESSES FOR CALICO HILLS SOUTH RAMP, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	79	26	0.0	0.0	0.0	0.0	0.0	0.0
35	79	26	0.0	0.1	0.0	0.0	0.0	0.0
50	79	26	0.0	0.1	0.0	0.0	0.0	0.0
100	79	26	0.1	0.2	0.0	0.1	0.0	0.0
300	79	26	0.1	0.3	0.0	0.1	0.1	0.0
500	79	26	0.2	0.4	0.0	0.1	0.1	0.0
1000	79	26	0.2	0.5	0.0	0.2	0.1	0.0
2000	79	26	0.2	0.5	0.0	0.2	0.1	0.0
5000	79	26	0.2	0.5	0.0	0.2	0.1	0.0
10000	79	26	0.2	0.4	0.0	0.1	0.0	0.0

TABLE 5-17. PEAK VALUES OF TEMPERATURE/STRESSES FOR ESF SHAFT, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	90	32	0.0	0.0	0.1	0.1	0.0	0.0
35	90	32	0.1	0.3	0.5	0.2	0.2	0.1
50	90	32	0.2	0.4	0.7	0.3	0.3	0.1
100	90	32	0.2	0.7	1.1	0.4	0.5	0.2
300	90	32	0.4	1.3	1.7	0.5	0.8	0.3
500	90	32	0.5	1.7	1.8	0.5	1.0	0.4
1000	96	32	0.8	2.1	1.6	0.2	1.1	0.2
2000	105	32	1.3	2.2	1.1	0.2	1.0	0.1
5000	110	32	1.4	1.8	0.5	0.2	0.8	0.2
10000	109	32	1.2	1.4	0.3	0.1	0.6	0.2

TABLE 5-18. PEAK VALUES OF TEMPERATURE/STRESSES FOR MAN AND MATERIALS SHAFT, 80-KW/ACRE CASE

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	85	29	0.0	0.0	0.0	0.0	0.0	0.0
35	85	29	0.1	0.0	0.0	0.0	0.0	0.0
50	85	29	0.1	0.0	0.0	0.1	0.0	0.0
100	85	29	0.2	0.0	0.0	0.2	0.0	0.1
300	85	29	0.3	0.1	0.0	0.3	0.1	0.1
500	85	29	0.4	0.1	0.1	0.4	0.1	0.1
1000	85	29	0.5	0.1	0.1	0.5	0.1	0.1
2000	85	29	0.5	0.1	0.0	0.5	0.1	0.1
5000	85	29	0.5	0.1	0.0	0.5	0.0	0.1
10000	86	30	0.3	0.0	0.1	0.4	0.0	0.0

all times. The ESF shaft (n-shaft), ranked fourth in temperature value, is subjected to only maximum temperature changes of 14°F (8°C) and 19°F (11°C). In general, peak temperatures occur between 500 and 2000 years for the drifts with significant temperature changes. The maximum temperatures are delayed beyond 2000 years for those places with insignificant temperature changes.

Figures 5-3 and 5-10 compare the maximum transverse stress ($\Delta\sigma_{xx}'$) for the two thermal loadings. Similar to the temperature profile, the east-west exploratory drift leads the others with maximum stress changes of 10.3 MPa at 300 years and 13.8 MPa at 100 years. The steep increase is a typical feature of the stress profile. The second highest stresses occur within the east main drift, with 6.4 and 9.3 MPa at 500 years. The Calico Hills drift attains the third highest peak stresses of 4.4 MPa at 1000 years and 6.1 MPa at 2000 years. The Calico Hills south ramp has the lowest stress magnitude among these nine locations.

For the maximum axial stresses ($\Delta\sigma_{yy}'$), Figures 5-4 and 5-11 depict a somewhat different scenario. The east-west exploratory drift has the highest peak stresses of 8.8 and 13.0 MPa at 500 years, which is more than twice the peak stresses either within the east main drift (3.9 and 4.6 MPa at 1000 years) or the Calico Hills north-south drift (3.2 and 6.1 MPa at 2000 years). It should be noted that the maximum absolute axial stress change in the Calico Hills main drift undergoes a transition from tension to compression between 100 and 500 years; the minimum absolute axial stress change occurs in the south shaft.

The peak vertical stresses, shown in Figures 5-5 and 5-12, represent a somewhat different trend. It should be noted that the area of maximum stress also includes the central distress zone of the main drifts. The east-west exploratory drift still has the highest peak stress change value of 3.5 MPa at 100 years for the 57-kW/acre case. For the 80-kW/acre case, the east main drift has the highest peak stress change of 4.7 MPa, also at 100 years. The Calico Hills main drift and north shaft have the third and fourth highest peak values, respectively, for the 57-kW/acre case, but in reversed order for the 80-kW/acre case. The maximum values in the Calico Hills main drift and the north ramp all peak at 500 years for both the 57- and 80-kW/acre thermal loadings. In contrast, no obvious stress changes occur at the south ramp and Calico Hills south ramp.

Comparison of maximum horizontal shear stresses ($\Delta\sigma_{xy}$) is shown in Figures 5-6 and 5-13. The east main drift has the highest values of 1.3 and 1.9 MPa at 300 years, followed by the north ramp with 1.1 and 1.6 MPa at 500 years.

For vertical shear stresses ($\Delta\sigma_{yz}$) (Figures 5-7 and 5-14), the Calico Hills north-south drift has the highest value of 0.9 MPa at 100 years for the 57-kW/acre case. For the 80-kW/acre case, the Calico Hills north-south and east-west exploratory drifts have the highest values of 1.1 MPa at 100 and 300 years, respectively. Figures 5-8 and 5-15 show peak vertical shear stresses ($\Delta\sigma_{xz}$), of which the Calico Hills north-south drift has the highest values of 1.0 and 1.4 MPa at 300 years.

5.2.2 Comparison of Peak Values for Five Lines in Main Test Area

The positions of all five lines within the Main Test Area can be found in Figure 4-4. The maximum temperatures and stresses for each individual line are listed in Tables 5-19 through 5-23 for the 57-kW/acre case and Tables 5-24 through 5-28 for the 80-kW/acre case. Comparison of the five lines is illustrated in Figures 5-16 to 5-22 for the 57-kW/acre case and Figures 5-23 to 5-29 for the 80-kW/acre case.

**TABLE 5-19. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 1,
57-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	78	26	0.1	0.1	0.1	0.1	0.0	0.0
35	81	27	1.6	0.9	1.4	0.8	0.1	0.2
50	85	29	2.2	1.3	1.7	1.0	0.1	0.2
100	95	35	3.2	2.1	2.5	1.3	0.2	0.2
300	112	44	3.9	3.3	2.5	1.3	0.2	0.2
500	118	48	4.1	3.7	2.2	1.3	0.2	0.3
1000	122	50	3.8	3.9	1.5	1.2	0.2	0.3
2000	125	52	3.0	3.5	0.8	0.9	0.3	0.4
5000	113	45	1.9	2.2	0.3	0.6	0.2	0.4
10000	104	40	1.4	1.5	0.2	0.4	0.2	0.3

**TABLE 5-20. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 2,
57-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	79	26	0.0	0.1	0.1	0.0	0.0	0.0
35	79	26	0.2	0.7	0.9	0.1	0.1	0.0
50	79	26	0.3	1.0	1.2	0.2	0.1	0.0
100	80	27	0.5	1.5	1.8	0.3	0.2	0.1
300	91	33	1.0	2.3	2.0	0.6	0.3	0.1
500	99	37	1.5	2.6	1.9	0.8	0.3	0.1
1000	109	43	2.1	2.8	1.5	0.9	0.4	0.1
2000	113	45	2.3	2.5	0.9	0.8	0.4	0.3
5000	106	41	1.6	1.6	0.4	0.5	0.3	0.3
10000	99	37	1.1	1.1	0.2	0.4	0.2	0.3

**TABLE 5-21. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 3,
57-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	78	26	0.2	0.1	0.2	0.1	0.0	0.0
35	78	26	1.0	0.2	1.3	0.6	0.0	0.1
50	78	26	1.5	0.2	1.8	0.8	0.0	0.1
100	84	29	2.4	0.3	2.5	1.2	0.1	0.2
300	102	39	3.6	1.5	2.5	1.3	0.1	0.3
500	112	44	4.0	2.1	2.2	1.2	0.1	0.3
1000	125	52	4.2	2.8	1.5	1.0	0.1	0.4
2000	127	53	3.6	2.8	0.8	0.7	0.2	0.4
5000	114	46	2.3	2.0	0.3	0.4	0.3	0.3
10000	104	40	1.5	1.3	0.2	0.3	0.3	0.2

**TABLE 5-22. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 4,
57-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.1	0.2	0.2	0.1	0.0	0.0
35	86	30	0.6	1.9	1.3	0.8	0.3	0.1
50	91	33	1.0	2.4	1.6	1.0	0.3	0.1
100	100	38	2.0	2.8	1.9	1.3	0.2	0.1
300	110	43	3.1	2.9	2.2	1.3	0.2	0.1
500	116	47	3.5	3.0	2.1	1.3	0.2	0.2
1000	123	51	3.7	3.1	1.6	1.0	0.2	0.2
2000	124	51	3.3	2.8	0.9	0.6	0.3	0.3
5000	113	45	2.1	2.0	0.4	0.3	0.4	0.3
10000	104	40	1.4	1.4	0.2	0.2	0.3	0.2

**TABLE 5-23. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 5,
57-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	79	26	0.0	0.2	0.2	0.0	0.0	0.0
35	87	31	0.7	2.3	1.6	0.1	0.3	0.1
50	93	34	1.2	3.0	1.8	0.1	0.3	0.2
100	107	42	2.2	3.9	1.9	0.2	0.3	0.2
300	122	50	3.2	4.4	1.7	0.3	0.3	0.3
500	126	52	3.5	4.4	1.6	0.4	0.3	0.3
1000	128	53	3.5	3.9	1.3	0.5	0.3	0.2
2000	123	51	3.0	3.1	0.8	0.5	0.4	0.1
5000	112	44	2.0	2.1	0.4	0.3	0.4	0.2
10000	103	39	1.4	1.4	0.2	0.3	0.3	0.2

**TABLE 5-24. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 1,
80-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.0	0.1	0.1	0.1	0.0	0.0
35	81	27	2.1	1.2	1.9	1.0	0.1	0.2
50	86	30	2.9	1.7	2.4	1.4	0.2	0.3
100	102	39	4.3	2.9	3.5	1.8	0.2	0.3
300	125	52	5.3	4.7	3.5	1.9	0.3	0.4
500	134	57	5.5	5.4	3.1	1.8	0.3	0.5
1000	141	61	5.0	5.7	2.2	1.5	0.3	0.6
2000	144	62	3.9	5.1	1.1	1.1	0.4	0.7
5000	127	53	2.4	3.3	0.4	0.6	0.3	0.5
10000	113	45	1.7	2.2	0.2	0.4	0.3	0.4

**TABLE 5-25. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 2,
80-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	79	26	0.0	0.1	0.1	0.1	0.0	0.0
35	79	26	0.2	1.0	1.2	0.2	0.1	0.0
50	79	26	0.4	1.4	1.7	0.2	0.2	0.0
100	81	27	0.6	2.2	2.5	0.4	0.3	0.1
300	97	36	1.2	3.3	2.8	0.8	0.4	0.1
500	108	42	1.7	3.7	2.7	0.9	0.4	0.2
1000	122	50	2.6	4.0	2.2	1.1	0.5	0.3
2000	127	53	2.8	3.7	1.3	0.9	0.5	0.5
5000	117	47	2.0	2.4	0.5	0.6	0.4	0.5
10000	106	41	1.4	1.7	0.3	0.4	0.3	0.4

**TABLE 5-26. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 3,
80-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	78	26	0.2	0.1	0.2	0.1	0.0	0.0
35	78	26	1.4	0.3	1.8	0.9	0.1	0.1
50	79	26	2.0	0.3	2.5	1.2	0.1	0.2
100	86	30	3.4	0.3	3.5	1.6	0.1	0.3
300	112	44	5.1	1.8	3.5	1.8	0.1	0.4
500	127	53	5.8	2.6	3.1	1.7	0.2	0.4
1000	144	62	6.1	3.5	2.2	1.4	0.3	0.5
2000	147	64	5.3	3.6	1.1	0.9	0.4	0.5
5000	129	54	3.4	2.4	0.4	0.5	0.5	0.4
10000	114	46	2.2	1.6	0.2	0.4	0.4	0.3

**TABLE 5-27. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 4,
80-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{xz}$ (MPa)
10	78	26	0.1	0.1	0.1	0.0	0.0	0.0
35	88	31	0.7	2.5	1.8	1.0	0.4	0.1
50	96	36	1.4	3.2	2.2	1.4	0.4	0.2
100	109	43	2.8	3.8	2.7	1.8	0.4	0.2
300	123	51	4.4	3.7	3.1	1.9	0.3	0.2
500	131	55	5.0	3.8	3.0	1.8	0.4	0.2
1000	142	61	5.4	3.9	2.3	1.5	0.4	0.3
2000	143	62	4.8	3.6	1.3	0.9	0.5	0.4
5000	127	53	3.1	2.5	0.5	0.5	0.5	0.4
10000	113	45	2.1	1.6	0.3	0.3	0.4	0.3

**TABLE 5-28. PEAK VALUES OF TEMPERATURE/STRESSES FOR TEST LINE 5,
80-KW/ACRE CASE**

Year	Temperature (°F) (°C)		$\Delta\sigma_{xx}$ (MPa)	$\Delta\sigma_{yy}$ (MPa)	$\Delta\sigma_{zz}$ (MPa)	$\Delta\sigma_{xy}$ (MPa)	$\Delta\sigma_{yz}$ (MPa)	$\Delta\sigma_{zx}$ (MPa)
10	78	26	0.0	0.0	0.0	0.0	0.0	0.0
35	89	32	0.9	3.0	2.2	0.1	0.4	0.2
50	99	37	1.6	4.0	2.4	0.1	0.5	0.2
100	119	48	3.2	5.3	2.6	0.3	0.5	0.3
300	140	60	4.6	5.9	2.4	0.5	0.5	0.3
500	146	63	5.0	5.8	2.3	0.5	0.5	0.3
1000	149	65	5.1	5.1	1.9	0.7	0.6	0.2
2000	142	61	4.4	4.0	1.2	0.6	0.7	0.2
5000	125	52	2.9	2.6	0.5	0.4	0.5	0.3
10000	112	44	2.0	1.8	0.3	0.3	0.4	0.2

Figure 5-16. Comparison of Maximum Temperature Histories at the Main Test Level, 57-kW/acre Case

Figure 5-17. Comparison of Maximum Transverse Stress ($\Delta\sigma_{xx}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-18. Comparison of Maximum Axial Stress ($\Delta\sigma_{yy}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-19. Comparison of Maximum Vertical Stress ($\Delta\sigma_{zz}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-20. Comparison of Maximum Shear Stress ($\Delta\sigma_{xy}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-21. Comparison of Maximum Shear Stress ($\Delta\sigma_{yz}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-22. Comparison of Maximum Shear Stress ($\Delta\sigma_{xz}$) Histories at the Main Test Level, 57-kW/acre Case

Figure 5-23. Comparison of Maximum Temperature Histories at the Main Test Level, 80-kW/acre Case

Figure 5-24. Comparison of Maximum Transverse Stress ($\Delta\sigma_{xx}$) Histories at the Main Test Level, 80-kW/acre Case

Figure 5-25. Comparison of Maximum Axial Stress ($\Delta\sigma_{yy}$) Histories at the Main Test Level, 80-kW/acre Case

Figure 5-26. Comparison of Maximum Vertical Stress ($\Delta\sigma_{zz}$) Histories at the Main Test Level, 80-kW/acre Case

Figure 5-27. Comparison of Maximum Shear Stress ($\Delta\sigma_{xy}$) Histories at the Main Test Level, 80-kW/acre Case

Figure 5-28. Comparison of Maximum Shear Stress ($\Delta\sigma_{yz}$) Histories at the Main Test Level, 80-kW/acre Case

Figure 5-29. Comparison of Maximum Shear Stress ($\Delta\sigma_{xz}$) Histories at the Main Test Level, 80-kW/acre Case

The comparison of maximum temperatures for the five lines is given in Figures 5-16 and 5-23. Line 5, positioned in the center region, has the highest temperatures of 128°F (53°C) and 149°F (65°C) at 1000 years. The peak temperatures for the other four lines occur at 2000 years. The minimum temperatures occur in line 2 with values of 113°F (45°C) and 127°F (53°C).

The peak normal stresses ($\Delta\sigma_{xx}$) shown in Figures 5-17 and 5-24 reflect similar characteristics as the temperature profiles. Line 3 appears to have the highest stresses of 4.2 and 6.0 MPa at 1000 years, followed closely by line 1 with peak values of 4.1 and 5.5 MPa at 500 years. Line 2 attains the lowest peak values of 2.3 and 2.8 MPa at 2000 years.

Line 5 leads the peak axial stresses ($\Delta\sigma_{yy}$) with 4.4 and 5.9 MPa at 300 years, followed by line 1 with 3.9 and 5.7 MPa at 1000 years (Figures 5-18 and 5-25). Line 3 appears to have the lowest overall axial stresses. Line 3 tops the peak vertical stresses ($\Delta\sigma_{zz}$) with 2.5 and 3.5 MPa at 100 years (Figures 5-19 and 5-26). In terms of peak horizontal shear stresses (Figures 5-20 and 5-27), lines 1 and 4 both appear to be the highest. Line 5 maintains minimum peak values of 0.5 and 0.7 MPa at 1000 years. For vertical shear stresses, some lines fluctuate during certain periods (Figures 5-21, 5-22 and 5-28, 5-29). The stress fluctuation reflects the transition between tension and compression. Lines 5 and 1 have the highest value of $\Delta\sigma_{yz}$, while line 1 has the highest $\Delta\sigma_{zx}$ with 0.4 and 0.7 MPa at 2000 years.

6.0 CONCLUDING REMARKS

The preliminary evaluation of the potential thermomechanical effects on underground structures caused by waste emplacement at Yucca Mountain provides information that may be useful to future engineering design. This information can be briefly summarized in the following:

- The facilities subject to the highest thermomechanical effects are the east-west exploratory drift, east main drift, and Calico Hills main drift all of which are relatively close to the waste. The least affected areas will be the south ramp, Calico Hills south ramp, and man and materials shaft. The maximum anticipated temperature change is 120°F (67°C), and the maximum anticipated horizontal stress change is 13.8 MPa, both occur in the east-west exploratory drift.
- The maximum thermomechanical impact will apparently occur in most of the exploratory drifts in the neighborhood of 1000 years after waste emplacement. Significant temperature and stress increases will not occur in most areas during the preclosure period (0 to 100 years); however, the rate of the temperature and stress change is substantially higher at locations close to the emplaced heat generating waste, as in the case of the east-west exploratory drift.
- The emplacement configuration considered in this study was proposed and selected by the ESF alternative study (SNL, 1991). Temperatures and stresses induced by the heat-generating waste of this configuration are predicted to be uniformly distributed in the vicinity of the storage area. The problem of local stress concentration and uneven temperature gradient using this configuration tend to be less severe than using the SCP-CDR layout.

The repository layout analyzed is not a mature design and will be refined or modified as other related designs and strategies emerge. Waste age, emplacement configuration, drift spacings, and APD could all be modified before final design. Details of the exploratory layout such as standoff distances, area, positioning of ramps and shafts, and slopes and elevations of drifts will affect the resulting temperatures and stress changes in the repository. The present analysis provides estimates of temperature and stress change for two potential APDs and can be used in the decision making process for detailed design of repository components and for some performance assessment studies. Ultimately, reanalysis of the final repository layout will be required.

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APPENDIX A

PDM 75-25—New 3-D Far-Field Repository Thermomechanical Calculations

PDM 75-25
Rev. 0
Page 1 of 7

WBS: 124232
QA

SANDIA NATIONAL LABORATORIES
YUCCA MOUNTAIN PROJECT
PROBLEM DEFINITION MEMO (PDM)

APPROVAL SHEET

FOR

PDM 75-25

Stephen J. Sauer
Principal Investigator

63/3
Organization

1/24/92
Date

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Date

Problem Definition Memo Title: New 3-D Far-Field Repository

Thermomechanical Calculations

PDM No: 75-25 Date PDM No. Assigned: 1/15/92 WBS No.: 124232

The work performed by this PDM is identified in

Work Plan No.: 124232 (FY90) Revision No.: 0

Title & No. of Planning Cost Account/Task: Underground Access

Analysis (3.1)

OAGR cited: S124232A

Case and Subcase No.: 2378.680

Quality Affecting Work: Yes

Task Leader: E. E. Ryder

Principal Investigator: S. J. Bauer

YMP Milestone: TBD

Contractor/Contract No.: Agapito/42-0096

Contract Task Identification No. & Title: Task 11 of CR# 05 Implementation
of Drift Design Methodology

PROBLEM DEFINITION:

The purpose of this set of calculations is to provide 3-D linear elastic, homogeneous far-field thermal and thermomechanical values for temperature, stress, and strain for the Exploratory Studies Facility (ESF). The calculations are to simulate thermal and thermomechanical conditions over a 10,000-year period, following the time sequenced emplacement of waste in the repository. The far-field model will not include any exploratory excavations although time-dependent outputs will be required at selected excavation locations.

The results will serve the primary purpose of providing an estimate of the temperatures, strains, and stresses expected along and in the vicinity of potential exploratory excavations. This will establish loading conditions which will be imposed on the facility excavations.

The details necessary to perform the 3-D elastic far-field modeling and the desired products of the effort follow.

DESCRIPTION OF PROBLEM:

The problem description to be developed for this PDM is similar to the problem solved and the philosophical approach for PDM 75-13 (and revisions), and the subject of SLTR90-7005. That work was developed and completed for the same purpose as the current work, this PDM is to use an updated repository layout, ESF, etc., as described below.

The geometries necessary to do the analyses are illustrated in the attached figures transmitted to SNL 10/18/91 from Raytheon Services Nevada (RSN), (memo Bullock to Blejwas, dated 10/18/91 with 3 figures). The figures are identified by their titles: (1) Repository General Layout and Plan Using Revised Repository North Entry Point with Elevation at 3240.00', (2). ESF General Arrangement- Subsurface Access General Arrangement- PLAN, and (3) YMP Repository/Main Test Area Boundary Interface - Plans and Cross sections Using Revised Repository North Entry Point with Elevation at 3240.00'. In addition to these figures, two additional figures are presented (4) which provides the Emplacement Schedule time and location in years and was developed by the analyst in conjunction with the PI, and (5) which provides Details of Repository locations, slopes and grades and was developed following conversations with RSN staff. These drawings will aid in selecting the areas in which output will be presented.

The panels are to be sequentially loaded and modeled using finite length line heat sources.

SPECIFIC GOALS OF ANALYSIS:

The specific goals of the analyses are to provide complete temperature, stress, and strain states at 0, 10, 35, 50, 100, 300, 500, 1000, 2000, 5000, and 10,000 years after waste emplacement throughout the test horizon and along the accesses. In locations where maximum temperature and stress states have been achieved beyond 100 years, output is not required (for reporting) beyond the time that the maxima occurred. However, in all cases output will be required to 100 years. The purpose is to provide maximum temperature and stress states for various locations in the ESF. This data should be presented in both table and graph form. The graphs will not be limited to but should include the contour plots of temperatures and stresses at the ESF horizon, the ESF accesses, and other planned underground openings of interest.

This information will be presented in the form of a SAND report, if the information is considered valuable to the Project upon its completion. This determination will be made by the PI.

REVIEW REQUIREMENTS:

An analysis-review, as specified in QAIP 2-4, is necessary for this analysis because it is quality affecting. This review will consist of one or two interim reviews by the PI, followed by a review by a committee upon the analysis completion. Please inform the PI of the analysis completion and the review meeting will be scheduled. Technical reviews will also be done, as required by DOP 6-2, for the SAND report that documents the analysis performed in this PDM.

TYPE OF ANALYSIS:

The STRES3D code (Asgian et al, 1991), Version 4.0, will be used. The code will exercise one or more of the heat elements available to adequately simulate the 3-D geometry. The ESF excavations are not modeled, however the imposed stress, strain, and temperature state at the excavation locations is requested as output. Boundary elements will simulate the repository surface.

QA REQUIREMENTS:

The analyses are to be performed as quality affecting. The requirements to perform the analyses are documented in the current Agapito Quality Assurance Program Plan and implementing procedures. According to SNL QAIP 3-2, the principal investigator (SNL) must certify the codes being used as appropriate for the analyses being performed. Code requirements for quality affecting analyses are documented in QAIP 3-2. This requires documentation of the code in accordance with QAIP 3-2. The required documentation of the STRES3D code in accordance with QAIP 3-2 is complete.

ASSUMPTIONS:

The model will assume linear elastic and isotropic behavior. A homogenous medium (TSw2) is assumed as the repository domain.

LOADING:

Thermal loading due to the waste and loading that reflects the in situ stress states at the repository horizon will be incorporated into the modeling.

LOAD DESCRIPTION:

Both in situ and thermal loading with design-basis areal power densities of approximately 57 kW/acre and 80 kW/acre will be used.

Waste Characteristics: These values were obtained from E. E. Ryder of Division 6313. One of Mr. Ryder's many duties includes determination of these characteristics. It should be understood that these values are not "fixed" by the Project. These values will, however, allow for these calculations to be made in a referencable manner such that another can trace and replicate the procedures followed.

Decay Curve Characteristics

a_i	b_i
19.8996	0.392555E-4
18.0297	0.442918E-3
174.893	0.194302E-2
1068.40	0.216836E-1
468.152	0.165957
7423.13	0.571832

Areal Power Density: 80 kW/acre scaled to 72.5 kW/acre, and
 57 kW/acre scaled to 51.6 kW/acre.

Average Age: 30 years out of reactor

Emplacement Drift Spacing 25.4 m $\approx$ 83.3 ft (center to center)

Standoff distance from mains 200 ft $\approx$ 61.0 m

MATERIAL PROPERTIES DATA:

The thermal and mechanical properties used in the study are listed below from the current RIB or referenced to the current RIB values (Version 4) except as noted.

THERMAL AND MECHANICAL PROPERTIES

Please note that the rock mass is modeled as a single homogeneous, isotropic elastic medium. The rock mass properties used for the analysis are values for the TSw2 even though the area consists of a layered sequence of rocks.

In Situ Stress State - see definition in RIB

Surface Elevation (avg.)	4500 ft $\approx$ 1372 m	*1
Surface temperature, F	65.7 $\approx$ 18.7 C	*2
(scaled from USW G-4 data in RIB)		
Thermal gradient	0.0971 F/ft $\approx$ 0.177 C/m	*3
(scaled from USW G-4 data in RIB)		

Thermal Diffusivity	333.2 ft ² /yr $\approx$ 30.97 m ² /yr	*4
calculated from values in the RIB		

Young's Modulus,	1.943E ⁶ psi $\approx$ 13,400	
(Rock mass quality 3, please see Hardy & Bauer, 1991)		
Poisson's Ratio (avg)	0.25	*5
Coefficient of Thermal Expansion 25-50°C	5.05E-6/°F $\approx$ 9.1E-6/°C	

*1- Estimated mean elevation of surface at proposed repository location as determined from USGS Busted Butte Quad. Map.

*2- From straight line fit to USW G-4 temperature vs depth data in RIB.

*3- See *2.

*4- Computed from saturated thermal conductivity divided by thermal capacitance for TSw2 unit, using mean of thermal capacitance for TSw2 from 25 to 94°C.

*5- Average value from three holes given in RIB.

BOUNDARY CONDITIONS:

Semi-infinite half space.

MESH CONSTRAINTS:

Not Applicable.

REFERENCES

Agapito, J. F. T. & Assoc., Inc., 1991. Preliminary Evaluation: Three-Dimensional Far-Field Analysis for the Exploratory Shaft Facility, SLTR90-7005, Sandia National Laboratories, Albuquerque, NM

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U. S. Department of Energy, "Yucca Mountain Project Reference Information Base, Version 4", and its revisions which are current to the date of this PDM. US DOE, NVO, Yucca Mountain Project Office, Las Vegas, NV (Dec., 1989)

Memo Bullock to Blejwas dated October 18, 1991: Transmittal of Information Requested from RSN for Thermal Analyses.

APPENDIX B

Temperature and Stress Change Profiles for the East Main Drift for 57- and 80-kW/acre Equivalent APD

B.1 EAST MAIN DRIFT

Three north-south main access drifts are planned through the center of the repository layout (Figure 3-1). The east main drift, located on the east side, will be constructed first as part of the exploratory drifting for the site characterization (Figure 4-4 of the main text). Figures B-1 and B-2 indicate the temperature profiles along the east main drift from 10 to 10,000 years after the start of waste emplacement. The starting point of the plots, point A, is to the south of the repository area. Waste is emplaced to within 2683 ft of point A for the 57-kW/acre case and 4132 ft for the 80-kW/acre case. To the north, the Main Test Area is encountered at 8590 ft, and the first waste is emplaced at the end of the east main at 10,640 ft from point A. Noticeable temperature changes begin after 35 years from the start of waste emplacement.

Temperatures increase significantly after 100 years until the maximum temperatures are reached at 1000 years. Afterwards, the temperatures drop rapidly. For the 57-kW/acre case as the temperature drops after 2000 years, the east-west exploratory drift no longer influences the temperature profile.

The maximum value for the induced horizontal compressive stresses ($\Delta\sigma_{xx}$) (perpendicular to the axis of the drift) is reached at 500 years (Figures B-3 and B-4). Small tensile stress changes in the axial stresses ($\Delta\sigma_{yy}$) occur adjacent to the emplacement drifts containing waste (Figures B-5 and B-6). The change in vertical stresses (Figures B-7 and B-8) appears to occur at earlier times than the horizontal stresses. The maximum change of the vertical stress at 35 years is almost 50% of the maximum overall value, which is at 100 years. Changes in shear stresses are depicted in Figures B-9 to B-14. The shear in the horizontal direction ($\Delta\sigma_{xy}$) (Figures B-9 and B-10) is significant at the borders of the heated area. Vertical shear stresses (Figures B-11 and B-12 for $\Delta\sigma_{yz}$ and Figures B-13 and B-14 for $\Delta\sigma_{zx}$) are distributed more uniformly along the drift.

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
Date plotted: 6/ 9/92

Figure B-1. Temperature Profile for the East Main Drift, 57-kW/acre Case

Date plotted: 6/11/92

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT

Date plotted: 6/ 9/92

Figure B-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
Date plotted: 6/11/92

Figure B-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
 Date plotted: 6/ 9/92

Figure B-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
 Date plotted: 6/11/92

Figure B-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
Date plotted: 6/ 9/92

Figure B-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
 Date plotted: 6/11/92

Figure B-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
 Date plotted: 6/ 9/92

Figure B-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT

Date plotted: 6/11/92

Figure B-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
Date plotted: 6/ 9/92

Figure B-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
Date plotted: 6/11/92

Figure B-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
 Date plotted: 6/ 9/92

Figure B-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT

Date plotted: 6/11/92

Figure B-14. Shear Stress ($\Delta\sigma_{xz}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
Date plotted: 11/23/92

Figure B-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
Date plotted: 11/23/92

Figure B-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the East Main Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, EAST MAIN DRIFT
Date plotted: 11/23/92

Figure B-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the East Main Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, EAST MAIN DRIFT
Date plotted: 11/23/92

Figure B-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the East Main Drift, 80-kW/acre Case

APPENDIX C

Temperature and Stress Change Profiles for the East-West Exploratory Drift for 57- and 80-kW/acre Equivalent APD

C.1 EAST-WEST EXPLORATORY DRIFT

The location for the east-west exploratory drift is shown in Figure 4-4 of the main text. The changes in temperatures and stresses are expected to be substantial in this drift because of close proximity to heat sources. The temperatures start to change dramatically after waste emplacement is completed (35 years, Figures C-1 and C-2). Peak values are reached at 500 years.

The maximum change in transverse horizontal stresses ($\Delta\sigma_{xx}$) occurs at 300 years for the 57-kW/acre case and at 100 years for the 80-kW/acre case (Figures C-3 and C-4). Note that the stress changes in the west side of the east-west drift are similar to the changes to the east side. The induced axial stress profile ($\Delta\sigma_{yy}$) appears to be similar to the induced transverse stress profile, with the highest stress period for all stresses at 300 years (Figures C-5 and C-6). The highest vertical stress changes appear at the intersection of the east-west experimental drift and the east main drifts. Excluding the intersection location, the maximum induced compressive stresses (Figures C-7 and C-8) occur at the east end of the drift at 35 years. For horizontal shear stresses (Figures C-9 and C-10), a different trend for the 57- and 80-kW/acre cases may be observed. The trend appears similar for vertical shear stresses (Figures C-11 through C-14).

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT

Date plotted: 6/ 9/92

Figure C-1. Temperature Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT

Date plotted: 6/11/92

Figure C-2. Temperature Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT

Date plotted: 6/ 9/92

Figure C-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 6/ 9/92

Figure C-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 6/ 9/92

Figure C-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 6/ 9/92

Figure C-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 6/ 9/92

Figure C-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 6/ 9/92

Figure C-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 6/11/92

Figure C-14. Shear Stress ($\Delta\sigma_{zx}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 11/23/92

Figure C-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 11/23/92

Figure C-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, E-W EXP DRIFT
Date plotted: 11/23/92

Figure C-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the East-West Exploratory Drift, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, E-W EXP DRIFT
Date plotted: 11/23/92

Figure C-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the East-West Exploratory Drift, 80-kW/acre Case

APPENDIX D

Temperature and Stress Change Profiles for the Calico Hills Level for 57- and 80-kW/acre Equivalent APD

D.1 CALICO HILLS LEVEL

The Calico Hills north-south drift is situated directly below the east main drift, with an average difference in elevation of 538 ft between the two levels (Figures 3-4 and 4-4 of the main text). As expected, the magnitudes of temperature and stresses are lower than those in the Main Test Level due to greater distance from the heat sources.

Temperatures change very slowly within the preclosure period (0 to 100 years, Figures D-1 and D-2); however, they begin to increase rapidly thereafter and reach maximum values at 2000 years.

The stresses calculated at this level are based on the TSw2 unit thermomechanical properties because of the assumption of uniform thermomechanical properties in STRES3D. The Calico Hills nonwelded tuffs have a significantly lower elastic modulus than the TSw2 unit and, hence, the thermally induced stresses in the Calico Hills Level will be lower than shown here. A reasonable approximation of the thermal stresses can be calculated from the strain changes using the Calico Hills elastic properties.

Normal stresses ($\Delta \sigma_{xx}$) depict a similar trend as temperatures (Figures D-3 and D-4). Stresses become slightly tensile near the south border. The maximum stress changes which occur at 1000 years for the 57-kW/acre case and at 2000 years for the 80-kW/acre case are approximately two-thirds of those for the east main drift. The stress profiles for $\Delta \sigma_{yy}$ are of interest (Figures D-5 and D-6). During the preclosure period (0 to 100 years), stresses are mostly tensile below the repository area. At 300 years after emplacement, stresses almost vanish in the area, then increase steadily until reaching a maximum value at 2000 years before declining. Vertical stresses ($\Delta \sigma_{zz}$) appear to be a little peculiar (Figures D-7 and D-8). Dominant peak stresses are situated in the middle of the drift accompanied by two small peak stresses on each side. The maximum vertical stress changes are reached at about 300 years, then begin to decline rapidly. Stresses nearly disappear at 5000 years. The horizontal shear stress profiles are shown in Figures D-9 and D-10. Vertical shear stresses are given in Figures D-11 through D-14. The shear stresses attain their maximum values at 300 to 500 years.

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-1. Temperature Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 6/11/92

Figure D-2. Temperature Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 6/11/92

Figure D-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 6/11/92

Figure D-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 6/11/92

Figure D-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
 Date plotted: 6/ 9/92

Figure D-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 6/11/92

Figure D-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
 Date plotted: 6/11/92

Figure D-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 6/ 9/92

Figure D-13. Shear Stress ($\Delta\sigma_{zx}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
 Date plotted: 6/11/92

Figure D-14. Shear Stress ($\Delta\sigma_{xz}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 11/23/92

Figure D-15. Maximum Principal Stress ($\Delta\sigma_{max}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 11/23/92

Figure D-16. Maximum Principal Stress ($\Delta\sigma_{max}$) Profile for the Calico Hills Level, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, C-H EXP DRIFT
Date plotted: 11/24/92

Figure D-17. Minimum Principal Stress ($\Delta\sigma_{min}$) Profile for the Calico Hills Level, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, C-H EXP DRIFT
Date plotted: 11/23/92

Figure D-18. Minimum Principal Stress ($\Delta\sigma_{min}$) Profile for the Calico Hills Level, 80-kW/acre Case

APPENDIX E

Temperature and Stress Change Profiles for the North Ramp for 57- and 80-kW/acre Equivalent APD

E.1 NORTH RAMP

The north ramp begins at the end of the straight portion of the east main access drift, curves initially, then straightens until connecting to the north portal. The plots in this appendix show the temperature and stress changes from point D, which is the transition point from the east main access drift (see Figure 4-4 in the main text) to the north portal. The curved portion of the ramp ends at 800 ft from point D.

Figures E-1 and E-2 show the temperature profiles along the ramp for times ranging from 10 to 10,000 years after emplacement. Temperatures start to increase after 100 years of emplacement, especially in the curved portion. Maximum temperatures are reached at 2000 years. Basically, the north portal is unaffected during the entire period.

For the transverse stresses ($\Delta\sigma_{xx}$), tension appears along the curved ramp before 2000 years. Maximum tension is reached in the middle of the curved ramp. Compared with the stresses in the straight ramp, significant changes in stress at the curved ramp may be identified from the rest of the stress components (Figures E-3 through E-14). Maximum values occur from 300 ($\Delta\sigma_{xx}$) to 5000 ($\Delta\sigma_{yy}$) years.

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/10/92

Figure E-1. Temperature Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP

Date plotted: 6/11/92

Figure E-2. Temperature Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/ 9/92

Figure E-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/ 9/92

Figure E-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/ 9/92

Figure E-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/ 9/92

Figure E-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 6/ 9/92

Figure E-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP

Date plotted: 6/ 9/92

Figure E-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 6/11/92

Figure E-14. Shear Stress ($\Delta\sigma_{zx}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 11/23/92

Figure E-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 11/23/92

Figure E-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, NORTH RAMP
Date plotted: 11/23/92

Figure E-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, NORTH RAMP
Date plotted: 11/23/92

Figure E-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the North Ramp, 57-kW/acre Case

APPENDIX F

Temperature and Stress Change Profiles for the South Ramp for 57- and 80-kW/acre Equivalent APD

F.1 SOUTH RAMP

The location for the south ramp is shown in Figure 4-4 of the main text. The analysis output for the south ramp is presented in Figures F-1 through F-14, in which the data is plotted from the south portal down to connect with the southern portion of the east main access drifts. The curved portion of the ramp begins at 7935 ft from the south portal. There is no change in temperature throughout the south ramp until 2000 years for the 57-kW/acre case (Figure F-1) and 5000 years for the 80-kW/acre case (Figure F-2). The maximum temperature is reached at 10,000 years. There are essentially no influential temperature changes at the south portal.

Due to the south ramp's relatively distant position from heat sources, stress changes are insignificant (Figures F-3 through F-14). The maximum stresses occur between 1000 and 5000 years after emplacement.

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/10/92

Figure F-1. Temperature Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP

Date plotted: 6/11/92

Figure F-2. Temperature Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/ 9/92

Figure F-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 6/11/92

Figure F-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP

Date plotted: 6/ 9/92

Figure F-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 6/11/92

Figure F-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/ 9/92

Figure F-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 6/11/92

Figure F-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/ 9/92

Figure F-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
 Date plotted: 6/11/92

Figure F-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/ 9/92

Figure F-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 6/11/92

Figure F-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 6/ 9/92

Figure F-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 6/11/92

Figure F-14. Shear Stress ($\Delta\sigma_{zx}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 11/23/92

Figure F-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 11/23/92

Figure F-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, SOUTH RAMP
Date plotted: 11/23/92

Figure F-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, SOUTH RAMP
Date plotted: 11/23/92

Figure F-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the South Ramp, 80-kW/acre Case

APPENDIX G

Temperature and Stress Change Profiles for the Calico Hills North Ramp for 57- and 80-kW/acre Equivalent APD

G.1 CALICO HILLS NORTH RAMP

The Calico Hills north ramp intersects the north ramp at point F (Figure 4-4 of the main text), ramps down to the north for 2374 ft, then rotates through 180° to proceed south to the main exploratory drift at the Calico Hills Level (point D). The temperatures (Figures G-1 and G-2) start to increase after 300 years near point D at the Calico Hills Level. The maximum temperatures occur at 5000 years at the Calico Hills Level. Temperatures at 10,000 years do not decline uniformly throughout the ramp.

The stress profiles along the ramp show dramatic changes as the ramp rotates through 180°. Tension dominates the normal stresses ($\Delta\sigma_{xx}$) (Figures G-3 and G-4) with a maximum value at 1000 years. In most cases, compressive stresses occur along the curved portion of the ramp and at point D of the Calico Hills Level after 300 years. Noticeable stress changes at the curved ramp may be a typical feature of all stress profiles.

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-1. Temperature Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-2. Temperature Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-12. Shear Stress ($\Delta\sigma_{yx}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/ 8/92

Figure G-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 6/11/92

Figure G-14. Shear Stress ($\Delta\sigma_{xz}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 11/23/92

Figure G-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
 Date plotted: 11/23/92

Figure G-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 11/23/92

Figure G-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the Calico Hills North Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS NORTH RAMP
Date plotted: 11/23/92

Figure G-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the Calico Hills North Ramp, 80-kW/acre Case

APPENDIX H

Temperature and Stress Change Profiles for the Calico Hills South Ramp for 57- and 80-kW/acre Equivalent APD

H.1 CALICO HILLS SOUTH RAMP

The Calico Hills south ramp is similar to the north ramp in that the ramp starts on the south ramp at Q (Figure 4-4 of the main text), ramps down to the south for 3155 ft, curves through 180° to 4093 ft, and connects with the Calico Hills Level exploratory drift at G. Compared to the Calico Hills north ramp, the temperatures and stresses in the south ramp show similar patterns with smaller magnitude due to its position further away from the heat sources. There are no temperature changes until 5,000 years for the 57-kW/acre case and 10,000 years for the 80-kW/acre case (Figures H-1 and H-2). The highest temperatures are only a few degrees over the original values.

Similar to the Calico Hills north ramp, the transverse horizontal stresses ($\Delta \sigma_{xx}$) (Figures H-3 and H-4) are mostly tensile except at the curved ramps. Maximum stresses appear at 2000 years. For other stress components (Figures H-5 through H-14), maximum values occur between 1000 and 5000 years. Peak values are either at the intersection with the south ramp or with the Calico Hills north-south drift.

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP

Date plotted: 6/ 8/92

Figure H-1. Temperature Profile for the Calico Hills South Ramp, 57-kW/acre

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/11/92

Figure H-2. Temperature Profile for the Calico Hills South Ramp, 80-kW/acre

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/ 8/92

Figure H-3. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
 Date plotted: 6/11/92

Figure H-4. Transverse Stress ($\Delta\sigma_{xx}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/ 8/92

Figure H-5. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/11/92

Figure H-6. Axial Stress ($\Delta\sigma_{yy}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP

Date plotted: 6/ 8/92

Figure H-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
 Date plotted: 6/11/92

Figure H-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/ 8/92

Figure H-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/11/92

Figure H-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/ 8/92

Figure H-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
 Date plotted: 6/11/92

Figure H-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/ 8/92

Figure H-13. Shear Stress ($\Delta\sigma_{xz}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 6/11/92

Figure H-14. Shear Stress ($\Delta\sigma_{xz}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 11/25/92

Figure H-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 11/25/92

Figure H-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 11/25/92

Figure H-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the Calico Hills South Ramp, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, CALICO HILLS SOUTH RAMP
Date plotted: 11/25/92

Figure H-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the Calico Hills South Ramp, 80-kW/acre Case

APPENDIX I

Temperature and Stress and Strain Change Profiles for the Exploratory Studies Facility Shaft for 57- and 80-kW/acre Equivalent APD

I.1 EXPLORATORY STUDIES FACILITY SHAFT

The ESF shaft is an optional component of the ESF and is planned to penetrate the Main Test Area (Figure 4-4 in the main text). Temperatures (Figures I-1 and I-2) begin to increase at about 300 years, and reach maximum values at 5000 years. The Main Test Level, where the heat sources are located, is between 3240 and 3740 ft elevation; and the Calico Hills Level is between 2700 and 3130 ft elevation. It appears from Figures I-1 and I-2 that both levels are subject to temperature changes.

The stresses shown in Figures I-3 through I-14 are for the global coordinate system with x oriented north. Horizontal stresses (Figures I-3 through I-6) show similar patterns. Compression dominates most parts of the shaft. For $\Delta\sigma_x$ (Figures I-3 and I-4), tension appears to start at 2,000 years at about 300 ft depth from the surface, and at 10,000 years at about 400 ft depth. For $\Delta\sigma_y$ (Figures I-5 and I-6), tension starts at 5,000 years at about 400 ft depth from the surface, and at 10,000 years at about 500 ft depth. Maximum vertical stresses occur at 500 years (Figures I-7 and I-8). Shear stresses (Figures I-9 through I-14) might be of interest in shaft design. Noticeable vertical shear stresses appear at shallower depth (Figures I-11 and I-12) with maximum values at 500 and 1000 years.

Strain components calculated by Equation 4-1 (in the main text) are shown in Figures I-15 through I-25. In general, strains are linearly related to stresses. For the ESF shaft, all six strain components resemble their stress counterparts with only minor modifications.

POWER DENSITY: 57KW/ACRE, ESF SHAFT

Date plotted: 6/18/92

Figure I-1. Temperature Profile for the ESF Shaft, 57-kW/acre

POWER DENSITY: 80KW/ACRE, ESF SHAFT

Date plotted: 6/18/92

Figure I-2. Temperature Profile for the ESF Shaft, 80-kW/acre

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-3. Normal Stress ($\Delta\sigma_{xx}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-4. Normal Stress ($\Delta\sigma_{xx}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT

Date plotted: 6/18/92

Figure I-5. Normal Stress ($\Delta\sigma_{yy}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-6. Normal Stress ($\Delta\sigma_{yy}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-7. Normal Stress ($\Delta\sigma_{zz}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT

Date plotted: 6/18/92

Figure I-8. Normal Stress ($\Delta\sigma_{zz}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT

Date plotted: 6/18/92

Figure I-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-13. Shear Stress ($\Delta\sigma_x$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
 Date plotted: 6/18/92

Figure I-14. Shear Stress ($\Delta\sigma_{zx}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 11/25/92

Figure I-15. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 11/25/92

Figure I-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 11/25/92

Figure I-17. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 11/25/92

Figure I-18. Minimum Principal Stress ($\Delta\sigma_{\min}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-19. Normal Strain ($\Delta \epsilon_{xx}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-20. Normal Strain ($\Delta\epsilon_{xx}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-21. Normal Strain ($\Delta \epsilon_{yy}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-22. Normal Strain ($\Delta \epsilon_{yy}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-23. Normal Strain ($\Delta \epsilon_{zz}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-24. Normal Strain ($\Delta \epsilon_{zz}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-25. Shear Strain ($\Delta\epsilon_{xy}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-26. Shear Strain ($\Delta\epsilon_{xy}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-27. Shear Strain ($\Delta\epsilon_{yz}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-28. Shear Strain ($\Delta\epsilon_{yz}$) Profile for the ESF Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, ESF SHAFT
Date plotted: 6/18/92

Figure I-29. Shear Strain ($\Delta\epsilon_{xz}$) Profile for the ESF Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, ESF SHAFT
 Date plotted: 6/18/92

Figure I-30. Shear Strain ($\Delta\epsilon_x$) Profile for the ESF Shaft, 80-kW/acre Case

APPENDIX J

Temperature and Stress and Strain Change Profiles for the Man and Materials Shaft for 57- and 80-kW/acre Equivalent APD

J.1 MAN AND MATERIALS SHAFT

The man and materials shaft is located outside the repository southern border (Figure 4-4 in the main text) and will not be constructed until after the site characterization phase. Due to its position away from repository heat sources, the thermomechanical effect on this shaft is much less than on the ESF shaft. Figures J-1 and J-2 show that the temperature does not change until 2,000 years for the 57-kW/acre case and 10,000 years for the 80-kW/acre case. The maximum temperatures are reached at 10,000 years with only a few degrees increase from the initial states.

The distribution of horizontal stresses ($\Delta\sigma_{xx}$) depicts an interesting phenomenon (Figures J-3 and J-4). Except for years 10 and 10,000 for the 57-kW/acre case and 10,000 years for the 80-kW/acre case, stresses reach the maximum values on the surface, with maximum stress at 1,000 years for the 57-kW/acre case and 2,000 years for the 80-kW/acre case. The study of areal and cross-sectional contours in the repository area shows that the man and materials shaft is situated outside the transition zone where horizontal stresses ($\Delta\sigma_{xx}$) appear greater at shallower depth. Horizontal stresses ($\Delta\sigma_{yy}$) (Figures J-5 and J-6) represent a similar trend as $\Delta\sigma_{xx}$, except that for the 57-kW/acre case, tension appears at 10,000 years. The vertical and shear stresses depict different profiles (Figures J-7 through J-14) with maximum values at 1000 to 2000 years. Horizontal shear stresses (Figures J-9 and J-10) resemble horizontal stresses ($\Delta\sigma_{xx}$) in their distributions.

Horizontal strain distributions (Figures J-15 through J-18) are similar to the corresponding stresses. The vertical strains (Figures J-19 and J-20), however, are very different from the vertical stresses. One obvious difference is that unlike stresses, the strains in most time spans do not vanish on the surface. This is due to the effect of relatively large horizontal stresses (refer to Equation 4-1 in the main text). Shear strains (Figures J-21 through J-26) are similar in profile to their corresponding stresses.

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-1. Temperature Profile for the Man and Materials Shaft, 57-kW/acre

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-2. Temperature Profile for the Man and Materials Shaft, 80-kW/acre

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-3. Normal Stress ($\Delta\sigma_{xx}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-4. Normal Stress ($\Delta\sigma_{xx}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-5. Normal Stress ($\Delta\sigma_{yy}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-6. Normal Stress ($\Delta\sigma_{yy}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-7. Normal Stress ($\Delta\sigma_{zz}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-8. Normal Stress ($\Delta\sigma_{zz}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-9. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-10. Shear Stress ($\Delta\sigma_{xy}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-11. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-12. Shear Stress ($\Delta\sigma_{yz}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-13. Shear Stress ($\Delta\sigma_{zx}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-14. Shear Stress ($\Delta\sigma_{xx}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 11/25/92

Figure J-15. Maximum Principal Stress ($\Delta\sigma_{max}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 11/25/92

Figure J-16. Maximum Principal Stress ($\Delta\sigma_{\max}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 11/25/92

Figure J-17. Minimum Principal Stress ($\Delta\sigma_{min}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 11/25/92

Figure J-18. Minimum Principal Stress ($\Delta\sigma_{min}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-19. Normal Strain ($\Delta\epsilon_{xx}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-20. Normal Strain (ΔE_{xx}) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-21. Normal Strain ($\Delta\epsilon_{yy}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-22. Normal Strain ($\Delta\epsilon_{yy}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-23. Normal Strain ($\Delta \epsilon_{zz}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-24. Normal Strain ($\Delta \epsilon_{zz}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-25. Shear Strain ($\Delta\epsilon_{xy}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-26. Shear Strain ($\Delta\epsilon_{xy}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-27. Shear Strain ($\Delta\epsilon_{yz}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-28. Shear Strain ($\Delta\epsilon_{yz}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

POWER DENSITY: 57KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-29. Shear Strain ($\Delta \epsilon_{xx}$) Profile for the Man and Materials Shaft, 57-kW/acre Case

POWER DENSITY: 80KW/ACRE, M&M SHAFT
Date plotted: 6/18/92

Figure J-30. Shear Strain ($\Delta\epsilon_{zx}$) Profile for the Man and Materials Shaft, 80-kW/acre Case

APPENDIX K

Temperature and Stress Change Contours for the Main Test Area for 57- and 80-kW/acre Equivalent APD

K.1 MAIN TEST AREA

Four point in time were selected for the plotting of contours of temperature and stresses in the Main Test Area: 10, 35, 50 and 100 years after waste emplacement. Temperatures at these four times are shown in Figures K-1 through K-8. At 10 years, contour lines resemble the initial thermal gradient in the Main Test Area. Starting from 35 years, steep thermal changes appear in the vicinity of the south edge of the Main Test Area near the waste emplacement drifts. It seems that the area affected by heating of the repository drifts is confined to approximately 250 ft from the south edge of the Main Test Area. Little effect is observed in other areas of the Main Test Area during the preclosure period.

Horizontal stresses are illustrated in Figures K-9 to K-12 ($\Delta\sigma_{xx}$) and K-17 to K-20 ($\Delta\sigma_{yy}$) for the 57-kW/acre case, and Figures K-13 to K-16 and K-21 to K-24 for the 80-kW/acre case. Significant stress changes occur between 10 and 35 years near the south border of the Main Test Area. From 35 to 100 years, stress changes continue in this area, but at a lower rate of increase. For the horizontal stresses ($\Delta\sigma_{yy}$), some stress concentration is observed on the left (west) border as well as along the south border of the Main Test Area.

Vertical stresses, which are distributed relatively more uniformly in the Main Test Area (Figures K-25 through K-32), reflect a decrease in compressive stress. The peak tensile stress changes appear mostly at the lower left corner. Dramatic stress changes both in magnitude and profile occur for the 80-kW/acre case between 10 and 35 years (about 15 times). The rate of stress change slows after 35 years. A maximum stress change occurs in the southwest corner of the Main Test Area at 100 years.

The horizontal shear stresses, given in Figures K-33 through K-40, reflect a change in the stress sign near the lower left corner. A significant change in the shear stresses occurs between 10 and 35 years. At 100 years, the shear stress magnitude is about twice that at 35 years. Vertical shear stresses show similar changes over the preclosure period (Figures K-41 to K-56). Stress concentration occurs primarily in the region approximately 300 ft from the bottom line that is near the heat sources.

Temperature in test area at 10 years (F)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-1. Temperature Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Temperature in test area at 35 years (F)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-2. Temperature Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Temperature in test area at 50 years (F)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-3. Temperature Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Temperature in test area at 100 years (F)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-4. Temperature Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Temperature in test area at 10 years (F)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-5. Temperature Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Temperature in test area at 35 years (F)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-6. Temperature Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Temperature in test area at 50 years (F)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-7. Temperature Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Temperature in test area at 100 years (F)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-8. Temperature Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xx} in test area at 10 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-9. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xx} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-10. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xx} in test area at 50 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-11. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xx} in test area at 100 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-12. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

• Optional ESF Shaft
 — Proposed MTL Excavations

K-15

Stress S_{xx} in test area at 35 years (MPa)

LEGEND

- ⊗ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-14. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xx} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-15. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xx} in test area at 100 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-16. North Horizontal Stress ($\Delta\sigma_{xx}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{yy} in test area at 10 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-17. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{yy} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-18. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{yy} in test area at 50 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-19. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{yy} in test area at 100 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-20. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{yy} in test area at 10 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-21. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{yy} in test area at 35 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-22. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{yy} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-23. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{yy} in test area at 100 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-24. West Horizontal Stress ($\Delta\sigma_{yy}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zz} in test area at 10 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-25. West Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zz} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-26. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zz} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-27. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zz} in test area at 100 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-28. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zz} in test area at 10 years (MPa)

LEGEND

- ⊗ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-29. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zz} in test area at 35 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-30. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zz} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-31. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zz} in test area at 100 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-32. Vertical Stress ($\Delta\sigma_{zz}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xy} in test area at 10 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-33. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xy} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-34. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xy} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-35. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xy} in test area at 100 years (MPa)

LEGEND

- ⊙ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-36. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{xy} in test area at 10 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-37. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xy} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-38. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xy} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-39. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{xy} in test area at 100 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-40. Shear Stress ($\Delta\sigma_{xy}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress σ_{yz} in test area at 10 years (MPa)

LEGEND

- ⊗ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-41. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Strees Syz in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-42. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Strees Syz in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-43. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress σ_{yz} in test area at 100 years (MPa)

LEGEND

- ⊗ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-44. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Stress σ_{yz} in test area at 10 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-45. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Stress σ_{yz} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-46. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress σ_{yz} in test area at 50 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-47. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress σ_{yz} in test area at 100 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-48. Shear Stress ($\Delta\sigma_{yz}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zx} in test area at 10 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-49. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zx} in test area at 35 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-50. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zx} in test area at 50 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-51. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zx} in test area at 100 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-52. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 57-kW/acre Case

Stress S_{zx} in test area at 10 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-53. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 10 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zx} in test area at 35 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-54. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 35 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zx} in test area at 50 years (MPa)

LEGEND

- ⊕ Optional ESF Shaft
- Proposed MTL Excavations

Figure K-55. Shear Stress ($\Delta\sigma_{xz}$) Contour in the Main Test Area After 50 Years of Waste Emplacement, 80-kW/acre Case

Stress S_{zx} in test area at 100 years (MPa)

LEGEND

- Optional ESF Shaft
- Proposed MTL Excavations

Figure K-56. Shear Stress ($\Delta\sigma_{zx}$) Contour in the Main Test Area After 100 Years of Waste Emplacement, 80-kW/acre Case

APPENDIX L

Temperature and Stress Change Profiles for the Lines in the Main Test Area for 57- and 80-kW/acre Equivalent APD

L.1 LINES IN MAIN TEST AREA

Five lines in the specific locations depicted in Figure 4-4 (in the main text) were selected for thermomechanical analysis. They partially correspond to the test drifts in the Main Test Area as indicated in the previous contouring graphs. All the results were analyzed over ten time periods. Stresses were rotated to the direction either transverse or axial to the line.

Line 1 -- Of the five lines, this line is located closest to the heat sources to the south side of the Main Test Area. Figures L-1 and L-2 depict the temperature distributions along line 1 during different time periods for the 57- and 80-kW/acre cases. The temperatures start to increase rapidly at about 100 years. The rate of increase slows after 300 years, and the temperatures reach maximum values at 1000 years. Temperatures then begin to decline in a somewhat different fashion, particularly in the position near point M.

Normal stresses ($\Delta\sigma_{xx}$) are given in Figures L-3 and L-4. Compressive stresses increase rapidly at about 10 years, and attain maximum values at 500 years. Significant stress variation in the position closest to point M reflects an asymmetric thermomechanical impact from both the west and south sides of the repository drifts. Beyond 500 years, normal stresses decrease more uniformly. For other stress components (Figures L-5 through L-14), maximum values were attained ranging from 100 to 1000 years. In general, the center of line 1 is either the position of maximum stress or the transition point of shear stress.

Line 2 -- Line 2 is parallel to line 1 and is further away from heat sources to the south but is influenced by heat sources on the east side. Figures L-15 and L-16 represent the temperature distributions along line 2. Clearly, there is very little temperature variation before closure (100 years). The gradual increase in temperatures starts around 300 years, until they reach a peak value at 2000 years.

Normal stresses ($\Delta\sigma_{xx}$) depict a slightly different picture from that of line 1 (Figures L-17 and L-18). The stresses increase gradually and reach a peak value at 2000 years. In view of the axial ($\Delta\sigma_{yy}$) and vertical ($\Delta\sigma_{zz}$) stresses, the change takes place primarily at the section near the east main drift (Figures L-19 through L-22). In other words, the stress changes are largely affected by the heat coming from the west side emplacement drifts. Maximum stresses ($\Delta\sigma_{yy}$) are reached at 1000 years. Maximum shear stresses occur at 300 to 5000 years (Figures L-23 through L-28).

Line 3 -- Line 3 is actually part of the east main drift. At point I in Figure 4-4 (in the main text), line 3 is affected by the heating from both the west and east sides. For temperature and most stresses, maximum values occur at point I (Figures L-29 through L-42). Temperatures begin to increase rapidly after closure (100 years) and reach a maximum value at 2000 years. The maximum normal stress ($\Delta\sigma_{xx}$) change occurs at 1000 years. Vertical stresses ($\Delta\sigma_{zz}$) reach maximum values at 100 and 300 years, and the stresses almost return to their original state at 10,000 years.

Line 4 -- Line 4 parallels line 3 and is further away from the heat sources of the west side. The temperature and stresses follow similar patterns as those in line 3, but with slightly smaller magnitudes (Figures L-43 through L-56). Maximum temperature changes occur at 2000 years. The maximum stress change is 3.6 MPa at 1000 years.

Line 5 -- Line 5 is parallel to both lines 3 and 4. The induced temperatures and stresses are illustrated in Figures L-57 through L-70. Since it is situated closer to the center of the test area, it is subjected to greater influence from the east side of the heated drifts, particularly at point K (Figure 4-4). Maximum temperature changes are similar to line 3 but occur at 1000 years (Figure L-57). The maximum stress change is 5.9 MPa at 300 years (Figure L-62).

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1

Date plotted: 6/10/92

Figure L-1. Temperature Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1

Date plotted: 6/11/92

Figure L-2. Temperature Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-3. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/11/92

Figure L-4. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-5. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/11/92

Figure L-6. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-7. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/11/92

Figure L-8. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-9. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
 Date plotted: 6/11/92

Figure L-10. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-11. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/11/92

Figure L-12. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/ 9/92

Figure L-13. Shear Stress ($\Delta\sigma_{zx}$) Profile Along Line 1 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-1
Date plotted: 6/11/92

Figure L-14. Shear Stress ($\Delta\sigma_{xz}$) Profile Along Line 1 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/10/92

Figure L-15. Temperature Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-16. Temperature Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-17. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-18. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-19. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-20. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-21. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-22. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-23. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-24. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-25. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-26. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/ 9/92

Figure L-27. Shear Stress ($\Delta\sigma_{zx}$) Profile Along Line 2 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-2
Date plotted: 6/11/92

Figure L-28. Shear Stress ($\Delta\sigma_{xz}$) Profile Along Line 2 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
 Date plotted: 6/10/92

Figure L-29. Temperature Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
 Date plotted: 6/11/92

Figure L-30. Temperature Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/ 9/92

Figure L-31. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/11/92

Figure L-32. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/ 9/92

Figure L-33. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/11/92

Figure L-34. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/ 9/92

Figure L-35. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/11/92

Figure L-36. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
 Date plotted: 6/ 9/92

Figure L-37. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 3 in Main Test Area, 57-kW/acre AFD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/11/92

Figure L-38. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/ 9/92

Figure L-39. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
 Date plotted: 6/11/92

Figure L-40. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/ 9/92

Figure L-41. Shear Stress ($\Delta\sigma_{xz}$) Profile Along Line 3 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-3
Date plotted: 6/11/92

Figure L-42. Shear Stress ($\Delta\sigma_{xz}$) Profile Along Line 3 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4

Date plotted: 6/10/92

Figure L-43. Temperature Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/11/92

Figure L-44. Temperature Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-45. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/11/92

Figure L-46. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-47. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/11/92

Figure L-48. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-49. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/11/92

Figure L-50. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-51. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
 Date plotted: 6/11/92

Figure L-52. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 4 in Main Test Area, 80-kW/acre AFD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-53. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/11/92

Figure L-54. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-4
Date plotted: 6/ 9/92

Figure L-55. Shear Stress ($\Delta\sigma_{zx}$) Profile Along Line 4 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-4
 Date plotted: 6/11/92

Figure L-56. Shear Stress ($\Delta\sigma_{zx}$) Profile Along Line 4 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/10/92

Figure L-57. Temperature Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5

Date plotted: 6/11/92

Figure L-58. Temperature Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-59. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-60. Transverse Horizontal Stress ($\Delta\sigma_{xx}$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-61. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-62. Axial Horizontal Stress ($\Delta\sigma_{yy}$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-63. Vertical Stress ($\Delta\sigma_{zz}$) Profile Along Line 5 in Main Test Area, 57-kw/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-64. Vertical Stress ($\Delta\sigma_z$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-65. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-66. Shear Stress ($\Delta\sigma_{xy}$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-67. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-68. Shear Stress ($\Delta\sigma_{yz}$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

POWER DENSITY: 57KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/ 9/92

Figure L-69. Shear Stress ($\Delta\sigma_{xz}$) Profile Along Line 5 in Main Test Area, 57-kW/acre APD

POWER DENSITY: 80KW/ACRE, MAIN TEST AREA LINE-5
Date plotted: 6/11/92

Figure L-70. Shear Stress ($\Delta\sigma_{zx}$) Profile Along Line 5 in Main Test Area, 80-kW/acre APD

APPENDIX M

Repository Drift Coordinates

TABLE M-1. REPOSITORY DRIFT COORDINATES (ft)

No.	Xb	Yb	Zb	Xe	Ye	Ze
1	767690.90	563698.10	3244.27	769398.60	561163.60	3324.95
2	767621.80	563651.50	3248.20	769426.80	560971.70	3333.50
3	767552.80	563604.90	3252.13	769402.40	560863.20	3339.44
4	767483.70	563558.40	3256.06	769364.60	560766.30	3344.93
5	767414.60	563511.80	3259.99	769323.10	560676.90	3350.21
6	767345.60	563465.30	3263.92	769267.30	560617.90	3354.61
7	767276.50	563418.70	3267.85	769212.50	560552.10	3359.17
8	767207.40	563372.10	3271.78	769142.80	560506.40	3363.07
9	767138.40	563325.60	3275.71	769070.80	560457.80	3367.00
10	767069.30	563279.00	3279.64	769005.30	560413.70	3370.93
11	767000.30	563232.40	3283.56	768931.70	560364.10	3374.86
12	766931.20	563185.90	3287.49	768866.30	560320.00	3378.79
13	766862.10	563139.30	3291.42	768792.60	560270.40	3382.71
14	766793.10	563092.80	3295.35	768727.20	560226.30	3386.64
15	766724.00	563046.20	3299.28	768661.80	560182.30	3390.57
16	766654.90	562999.60	3303.21	768588.10	560132.60	3394.50
17	766585.90	562953.10	3307.14	768522.70	560088.60	3398.43
18	766516.80	562906.50	3311.07	768449.10	560038.90	3402.36
19	766447.80	562859.90	3315.00	768383.60	559994.90	3406.29
20	766378.70	562813.40	3318.93	768310.00	559945.30	3410.22
21	766309.60	562766.80	3322.86	768244.60	559901.20	3414.15
22	766240.60	562720.30	3326.79	768170.90	559851.60	3418.07
23	766171.50	562673.70	3330.72	768105.50	559807.50	3422.00
24	766102.40	562627.10	3334.65	768040.10	559763.40	3425.93
25	766033.40	562580.60	3338.58	767966.40	559713.90	3429.86
26	765964.30	562534.00	3342.51	767901.00	559669.80	3433.79
27	765895.30	562487.40	3346.44	767827.40	559620.20	3437.72
28	765826.20	562440.90	3350.37	767761.90	559576.10	3441.65
29	765757.10	562394.30	3354.30	767688.30	559526.50	3445.58
30	765688.10	562347.80	3358.23	767622.90	559482.40	3449.51
31	765619.00	562301.20	3362.16	767549.30	559432.80	3453.43
32	765549.90	562254.60	3366.09	767483.80	559388.80	3457.36
33	765480.90	562208.10	3370.02	767410.20	559339.10	3461.29
34	765411.80	562161.50	3373.95	767344.80	559295.10	3465.22
35	765342.80	562114.90	3377.88	767279.30	559250.90	3469.15
36	765273.70	562068.40	3381.81	767205.80	559201.40	3473.08
37	765204.60	562021.80	3385.74	767140.30	559157.30	3477.01
38	765135.60	561975.30	3389.67	767066.70	559107.70	3480.94
39	765066.50	561928.70	3393.60	767001.30	559063.60	3484.87
40	764997.40	561882.10	3397.53	766927.60	559014.00	3488.79
41	764928.40	561835.60	3401.46	766862.20	558969.90	3492.72
42	764859.30	561789.00	3405.39	766788.60	558920.30	3496.65
43	764790.30	561742.40	3409.31	766723.10	558876.30	3500.58
44	764721.20	561695.90	3413.24	766657.70	558832.20	3504.51
45	764652.10	561649.30	3417.17	766584.10	558782.60	3508.44
46	764583.10	561602.80	3421.10	766518.60	558738.50	3512.37
47	764514.00	561556.20	3425.03	766445.00	558688.90	3516.30
48	764444.90	561509.60	3428.96	766379.60	558644.80	3520.23
49	764375.90	561463.10	3432.89	766305.90	558595.30	3524.15
50	764306.80	561416.50	3436.82	766240.50	558551.10	3528.08

TABLE M-1. REPOSITORY DRIFT COORDINATES (ft) (continued)

No.	Xb	Yb	Zb	Xe	Ye	Ze
51	764237.80	561369.90	3440.75	766166.90	558501.60	3532.01
52	764168.70	561323.40	3444.68	766101.40	558457.40	3535.94
53	764099.60	561276.80	3448.61	766036.00	558413.40	3539.87
54	764030.60	561230.30	3452.54	765962.40	558363.80	3543.80
55	763961.50	561183.70	3456.47	765896.90	558319.70	3547.73
56	763892.40	561137.10	3460.40	765824.80	558273.80	3551.60
57	763823.40	561090.60	3464.33	765743.30	558237.80	3555.11
58	763685.30	560997.40	3472.19	765589.30	558179.80	3561.97
59	763616.20	560950.90	3476.12	765499.10	558163.30	3564.93
60	763547.10	560904.30	3480.05	765408.90	558146.80	3567.89
61	763478.10	560857.80	3483.98	765314.40	558140.80	3570.55
62	763409.00	560811.20	3487.91	765214.60	558135.30	3573.13
63	763339.90	560764.60	3491.84	765120.90	558125.60	3575.89
64	763270.90	560718.10	3495.77	765027.20	558115.80	3578.65
65	763201.80	560671.50	3499.70	764937.20	558103.90	3581.51
66	763132.80	560624.90	3503.63	764845.90	558089.30	3584.41
67	763063.70	560578.40	3507.56	764754.80	558075.30	3587.31
68	762994.60	560531.80	3511.49	764660.10	558065.60	3590.05
69	762925.60	560485.30	3515.42	764565.40	558055.90	3592.80
70	762856.50	560438.70	3519.35	764472.90	558046.00	3595.58
71	762787.40	560392.10	3523.28	764379.80	558035.90	3598.35
72	762718.40	560345.60	3527.21	764286.80	558025.90	3601.13
73	762649.30	560299.00	3531.14	764191.60	558012.40	3603.95
74	762580.30	560252.40	3535.06	764104.60	557998.20	3606.91
75	762511.20	560205.90	3538.99	764015.10	557976.70	3609.99
76	762442.10	560159.30	3542.92	763931.00	557951.00	3613.24
77	762373.10	560112.80	3546.85	763845.10	557929.80	3616.36
78	762304.00	560066.20	3550.78	763762.40	557909.70	3619.51
79	762234.90	560019.60	3554.71	763675.80	557886.30	3622.68
80	762165.90	559973.10	3558.64	763591.40	557860.60	3625.92
81	762096.80	559926.50	3562.57	763510.50	557836.00	3629.20
82	762027.80	559879.90	3566.50	763426.10	557810.30	3632.44
83	761958.70	559833.40	3570.43	763341.70	557784.60	3635.69
84	761889.60	559786.80	3574.36	763260.80	557759.90	3638.97
85	761820.60	559740.30	3578.29	763176.40	557734.20	3642.21
86	761751.50	559693.70	3582.22	763092.00	557708.50	3645.46
87	761682.40	559647.10	3586.15	763007.60	557682.80	3648.71
88	761613.40	559600.60	3590.08	762926.80	557658.10	3651.98
89	761544.30	559554.00	3594.01	762842.30	557632.40	3655.23
90	761475.30	559507.40	3597.94	762757.90	557606.70	3658.48
91	761406.20	559460.90	3601.87	762677.00	557582.10	3661.75
92	761337.10	559414.30	3605.80	762592.60	557556.40	3665.00
93	761268.10	559367.80	3609.73	762508.20	557530.60	3668.24
94	761199.00	559321.20	3613.66	762427.30	557506.00	3671.52
95	761129.90	559274.60	3617.59	762342.90	557480.30	3674.77
96	765559.80	562984.60	3333.34	764050.20	565222.30	3191.89
97	765490.80	562938.00	3337.27	763946.20	565222.90	3192.75
98	765421.70	562891.40	3341.20	763842.30	565223.60	3193.60
99	765352.60	562844.90	3345.13	763747.80	565224.10	3194.74
100	765283.60	562798.30	3349.06	763643.80	565224.80	3195.60

TABLE M-1. REPOSITORY DRIFT COORDINATES (ft) (continued)

No.	Xb	Yb	Zb	Xe	Ye	Ze
101	765214.50	562751.80	3352.99	763548.90	565215.60	3197.14
102	765145.40	562705.20	3356.91	763461.30	565195.50	3199.38
103	765076.40	562658.60	3360.84	763381.60	565161.50	3202.46
104	765007.30	562612.10	3364.77	763306.80	565122.90	3205.87
105	764938.30	562565.50	3368.70	763242.10	565081.00	3209.73
106	764869.20	562518.90	3372.63	763171.30	565035.00	3213.58
107	764800.10	562472.40	3376.56	763101.10	564989.40	3217.44
108	764731.10	562425.80	3380.49	763030.90	564943.80	3221.29
109	764662.00	562379.30	3384.42	762960.60	564898.20	3225.14
110	764592.90	562332.70	3388.35	762890.40	564852.60	3228.99
111	764523.90	562286.10	3392.28	762820.20	564806.90	3232.86
112	764454.80	562239.60	3396.21	762750.00	564761.40	3236.71
113	764385.80	562193.00	3400.14	762679.80	564715.80	3240.56
114	764316.70	562146.40	3404.07	762609.60	564670.10	3244.42
115	764247.60	562099.90	3408.00	762539.30	564624.60	3248.26
116	764178.60	562053.30	3411.93	762469.10	564578.90	3252.13
117	764109.50	562006.80	3415.86	762398.90	564533.30	3255.98
118	764040.40	561960.20	3419.79	762334.50	564491.50	3259.84
119	763971.40	561913.60	3423.72	762264.30	564445.90	3263.69
120	763902.30	561867.10	3427.65	762194.10	564400.30	3267.55
121	763833.30	561820.50	3431.58	762123.80	564354.70	3271.40
122	763764.20	561773.90	3435.51	762049.80	564306.60	3275.25
123	763695.10	561727.40	3439.44	761980.10	564261.40	3279.10
124	763626.10	561680.80	3443.37	761914.60	564215.10	3283.13
125	763557.00	561634.30	3447.30	761849.00	564163.80	3287.36
126	763487.90	561587.70	3451.23	761783.10	564113.40	3291.55
127	763349.80	561494.60	3459.09	761659.30	564000.60	3300.68
128	763280.80	561448.00	3463.02	761595.40	563950.50	3304.92
129	763211.70	561401.40	3466.95	761531.00	563888.50	3309.66
130	763142.60	561354.90	3470.88	761478.50	563820.00	3315.03
131	763073.60	561308.30	3474.81	761428.10	563752.40	3320.42
132	763004.50	561261.80	3478.74	761373.30	563677.80	3325.98
133	762935.40	561215.20	3482.66	761323.70	563605.50	3331.60
134	762866.40	561168.60	3486.59	761273.40	563532.90	3337.21
135	762797.30	561122.10	3490.52	761222.40	563460.80	3342.78
136	762728.30	561075.50	3494.45	761168.10	563386.10	3348.36
137	762659.20	561028.90	3498.38	761118.80	563318.10	3353.80
138	762590.10	560982.40	3502.31	761064.70	563248.80	3359.16
139	762521.10	560935.80	3506.24	761010.10	563179.30	3364.51
140	762452.00	560889.30	3510.17	760960.50	563108.50	3370.06
141	762382.90	560842.70	3514.10	760905.40	563028.80	3375.84
142	762313.90	560796.10	3518.03	760857.60	562956.90	3381.49
143	762244.80	560749.60	3521.96	760810.40	562885.10	3387.16
144	762175.80	560703.00	3525.89	760757.00	562806.10	3392.96
145	762106.70	560656.40	3529.82	760707.80	562733.90	3398.58
146	762037.60	560609.90	3533.75	760653.00	562659.40	3404.15
147	761968.60	560563.30	3537.68	760602.50	562589.30	3409.64
148	761899.50	560516.80	3541.61	760551.60	562516.90	3415.23
149	761830.40	560470.20	3545.54	760500.30	562445.80	3420.74
150	761761.40	560423.60	3549.47	760445.40	562371.20	3426.30

TABLE M-1. REPOSITORY DRIFT COORDINATES (ft) (concluded)

No.	Xb	Yb	Zb	Xe	Ye	Ze
151	761692.30	560377.10	3553.40	760396.10	562304.10	3431.70
152	761623.30	560330.50	3557.33	760343.20	562227.80	3437.40
153	761554.20	560283.90	3561.26	760295.30	562148.70	3443.36
154	761485.10	560237.40	3565.19	760246.40	562071.80	3449.20
155	761416.10	560190.80	3569.12	760206.60	561991.30	3455.46
156	761347.00	560144.30	3573.05	760162.70	561908.80	3461.69
157	761277.90	560097.70	3576.98	760112.40	561823.70	3467.84
158	761208.90	560051.10	3580.91	760067.90	561741.60	3474.04
159	761139.80	560004.60	3584.84	760025.70	561662.00	3480.19
160	761070.80	559958.00	3588.77	759980.30	561577.30	3486.47
161	761001.70	559911.40	3592.70	759937.90	561485.60	3493.14
162	760932.60	559864.90	3596.63	759889.80	561408.90	3499.00
163	760863.60	559818.30	3600.56	759841.40	561328.80	3504.98
164	760794.50	559771.80	3604.49	759803.10	561244.70	3511.45

Drift numbering for 57 kW/acre case

Figure M-1. Drift Numbering for 57-kW/acre Case

APPENDIX N

**Information from, and Candidate Information for, the Site and Engineering
Property Database and the Reference Information Base**

N.1 Information from the Reference Information Base Used in this Report

This report is based on information from the RIB where available.

Table N-1 lists the values used in this study, the RIB mean value, and standard deviation.

N.2 Candidate Information for the Reference Information Base

The report contains no candidate information for the RIB.

N.3 Candidate Information for the Site and Engineering Properties Database

This report contains no candidate information for the Site and Engineering Properties Database.

TABLE N-1. COMPARISON BETWEEN STUDY VALUES AND THE CURRENT RIB (Version 4, Revision 4) VALUES

Parameter	Study Value	RIB Value	RIB Range or Standard Deviation
Thermal Properties			
Saturated thermal capacitance ($\text{J/m}^3 - \text{C}$)			
at 25°C	2.14E+6	2.0324E+6	NA
at 50°C	2.14E+6	2.1280E+6	
at 94°C	2.14E+6	2.2638E+6	
Saturated thermal conductivity ($\text{W/m} - \text{C}$)	2.10	2.10	± 0.2
Mechanical Properties			
Young's modulus (GPa)	13.4 ^a	32.7 ^b	NA
Poisson's ratio	0.25	0.25 ^c	NA
Coefficient of thermal expansion ($\text{m/m}^\circ\text{C}$)			
25 to 50	9.1E-6	9.1E-6	± 1.3
50 to 100	9.1E-6	8.2E-6	± 0.8
100 to 150	9.1E-6	6.8E-6	± 0.5
150 to 200	9.1E-6	9.7E-6	NA
Initial Temperature			
Surface Temperature ($^\circ\text{C}$)	18.7	18.7 ^d	NA

^a For rock mass, refer to Hardy & Bauer (1991).

^b Laboratory derived value.

^c Weighted average value.

^d Scaled from the temperature versus depth curve.

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