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APPENDIX A

TECHNICAL BASIS FOR EVALUATION OF THERMAL GOALS BELOW THE POTENTIAL NUCLEAR WASTE REPOSITORY AT YUCCA MOUNTAIN

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A.1 INTRODUCTION

The establishment of thermal goals, or temperature limits, for two rock units below the potential repository at Yucca Mountain was documented in the *Site Characterization Plan* (DOE 1988). A thermal goal of 115°C was set for the Topopah Spring basal welded unit vitrophyre (TSw3) and for the underlying Calico Hills nonwelded unit (CHn). The rationale for these goals is described in the *Site Characterization Plan Thermal Goals Reevaluation* (M&O 1993). The temperature limits were intended to address a concern that mineralogic changes could occur due to dehydration or recrystallization induced by repository heating and that these changes might have chemical and physical effects that could be detrimental to waste isolation.

The CHn consists of glassy and variably zeolitized nonwelded and partially welded ash flow tuffs and bedded tuffs, extending vertically downward to the water table from the basal vitrophyre in the overlying TSw unit. The CHn is a natural geochemical barrier to radionuclide transport because major portions of the unit, designated Calico Hills nonwelded zeolitic (CHnz), contain abundant clinoptilolite, a zeolite with high sorptive capacities for Cs and Sr (Meijer 1990). Clinoptilolite may provide significant retardation even with only slight preferential sorption of some radionuclides. For example, Robinson et al. (1995) examined the effect of the presence of clinoptilolite on the travel time of Np to the water table. By assuming that Np was only weakly sorbed by zeolitic Calico Hills units and not sorbed by any other rock units, they showed that travel times were delayed by a factor of about 10. The loss of clinoptilolite from the Calico Hills unit might therefore result in significantly decreased travel times for Np. The unsaturated CHnz is a potential hydrologic barrier as well, with higher matrix porosity and lower fracture abundances than the densely welded TSw.

This section summarizes experimental data, thermodynamic calculations, and natural analog studies pertinent to the effects of repository thermal loads on clinoptilolite in the zeolitic Calico Hills unit (CHnz). The CHnz unit is a particularly important geochemical barrier because it contains the largest volume of clinoptilolite in the unsaturated zone below the potential repository. The results of these studies will facilitate an evaluation of TSw3 and CHn thermal goals as they affect the performance of the CHnz.

The long-term stability of clinoptilolite in the potential repository is important to the performance of a repository but difficult to assess quantitatively. Geologic emplacement of high-level radioactive waste will heat the rocks due to heat produced by the radioactive decay of the waste. Studies on the effects of repository-induced heating include research on the dehydration behavior of clays and zeolites in tuffs (Bish 1984, 1988a, b) and on the hydrothermal stability of tuffs (Blacic et al. 1986; Duffy 1983a, 1983b). In an analysis of the thermal constraints on radioactive waste isolation in zeolitic tuffs, Smyth (1982) concluded that the reaction of clinoptilolite to analcime would begin at about 105°C based on data summarized by Iijima (1975), thereby giving rise to volume reductions and significantly reducing the cation sorptive capacity of the rocks (Vaughan 1978). Smyth advised constraining the maximum temperature in zeolitized tuff to 85°C to prevent reaction. Smyth's paper initiated the long-standing programmatic concern with the effects of repository-induced heating on the zeolitic rocks at Yucca Mountain. The transformation of the abundant clinoptilolite to analcime in rocks underlying the host rock at Yucca Mountain would give rise to large decreases in volume leading to increased rock porosity and probably permeability. The reaction would also yield large amounts of water and greatly reduce the total cation-exchange capacity of the zeolite barrier

(Vaniman and Bish 1995). However, the temperature at which the clinoptilolite-to-analcime reaction might occur and the rate of the reaction are difficult to assess experimentally. The reaction is thought to occur in nature at temperatures below 200°C, where reaction rates are very slow. Laboratory research on the long-term effects of heating Yucca Mountain tuffs to relatively low temperatures (<250°C) has been hampered by the slow reaction kinetics. Laboratory experiments either have not reproduced the assemblages observed in Yucca Mountain (Duffy 1983a, 1983b) or only do so at higher temperatures that speed reactions and potentially change reaction mechanisms (Knauss and Beiriger 1984). Furthermore, the reaction is known to be affected greatly by water compositions[1].

A.2 CLINOPTILOLITE AND THE THERMO-HYDROLOGIC EVOLUTION OF YUCCA MOUNTAIN

The thermodynamic properties of clinoptilolite are of significant interest to the Yucca Mountain Project because of the possible effects of clinoptilolite reactions on the transport of radionuclides. Understanding the stability of clinoptilolite under repository conditions is important to calculations that assume clinoptilolite will be effective in the retardation of Cs^+, Sr^{2+}, and Np, among other species. Hydration and dehydration reactions of clinoptilolite may affect pore saturation and therefore the hydrological properties of rocks at Yucca Mountain. Changes in molar volume of clinoptilolite due to cation exchange and hydration/dehydration reactions may also effect the hydrology through changes in rock porosity. Finally, the possible breakdown of clinoptilolite (yielding analcime) could result in a substantial increase in rock porosity and substantial changes in hydrology.

This section reviews the status of the thermodynamic data for clinoptilolite that is used in calculations of reactions involving clinoptilolite. This report also presents new calculations on the total quantity of clinoptilolite that may be affected by the thermal pulse from the potential repository. This volumetric quantity was derived from an unsaturated zone flow and transport model for Yucca Mountain (Robinson et al. 1995). The total volume of clinoptilolite is used as a basis for making bounding calculations of the maximum likely effects of clinoptilolite on the thermo-hydrology of Yucca Mountain. The principal issues addressed in this report include the effect of clinoptilolite on pore saturation, porosity, and temperature.

Summary of the Thermodynamic Properties of Clinoptilolite

The basis for making any calculation of reactions involving clinoptilolite is a thermodynamic expression for the Gibbs free energy of formation. For clinoptilolite, this is a particularly challenging problem because of the extensive compositional variation that occurs in the natural material. For example, the composition of clinoptilolite (and isostructural heulandite) at Yucca Mountain is highly variable, with Si/Al ratio between 3 and 5, exchangeable cation compositions that are combinations of Na^+, K^+, and Ca^{2+}, and significant variation in water content (e.g., Broxton et al. 1987). Consequently, it is evident that a useful thermodynamic model for clinoptilolite must incorporate the effects of compositional variations in order to make reasonably accurate determinations of the stability of clinoptilolite and the effect of reactions involving clinoptilolite on Yucca Mountain.

Since clinoptilolite is the most abundant zeolite at Yucca Mountain, efforts have been focused on determining the thermodynamic properties of this mineral. Research accomplishments include the following:

A. The effect of exchangeable cation on the molar volume of clinoptilolite (Bish 1984).

B. Thermal analysis investigations of the dehydration behavior of clinoptilolite and heulandite (Bish 1988a).

C. The effect of dehydration on molar volume (Bish 1984, 1995).

D. Estimation of the thermodynamic properties of clinoptilolite, heulandite, and other zeolites as a function of chemical composition (Chipera et al. 1995 and Chipera and Bish[1]).

E. Determination of the equilibrium water content of clinoptilolite as a function of exchangeable cation[3].

F. Determination of the energetics of hydration and dehydration processes in clinoptilolite as a function of exchangeable cation[4].

G. The solubility of Na-clinoptilolite[5].

Standard state thermodynamic properties of clinoptilolite and heulandite have been investigated by modeling, calorimetry, and solution chemistry. The various results are difficult to compare directly because of differences in Si/Al ratio, exchangeable cation, and H_2O content of the studied materials (Table A-1). A thermodynamic model for clinoptilolite could incorporate the various results of Table A-1 into a single, more accurate expression. Note that Barnes and Wilkin (1995)[5] conducted solubility measurements on an almost completely exchanged Na-clinoptilolite that should be a very useful end-member in thermodynamic calculations.

The data in Table A-1 provide the basis for calculations on the stability of clinoptilolite relative to phases such as analcime. The difficulty, as emphasized by Chipera et al. (1995), is that the compositions of clinoptilolite at Yucca Mountain are highly variable and are not, in general, represented by any of the data in Table A-1. Another important limitation is that the compositional variation represented in Table A-1 makes it very difficult to judge the consistency of the thermodynamic data and therefore difficult to evaluate the accuracy of calculations based on a particular clinoptilolite composition.

There are enthalpy and entropy data for clinoptilolite that allow calculation of reactions at elevated temperature. In addition, Johnson et al. (1985; 1991) determined the heat capacity of clinoptilolite and heulandite at elevated temperatures; but see Carey (1993) for an alternative interpretation of the heat capacity data. Chipera et al. (1995) have estimated heat capacity functions for clinoptilolite and other zeolites for use in calculations at elevated temperatures.

Table A-1. Summary of Standard State Thermodynamic Data for Clinoptilolite and Heulandite

Reference	Johnson et al. (1991)	Johnson et al. (1991)*	Hemingway and Robie (1984)	Murphy et al. (1996)	Barnes and Wilkin (1995)	Johnson et al. (1985)	Johnson et al. (1985)*
Sample	Malheur, OR Clinoptilolite	Malheur, OR Clinoptilolite	Mojave County, AZ Clinoptilolite	Death Valley Junction, CA Clinoptilolite	Castle Creek, ID Clinoptilolite	Gunnadah, Australia, Heulandite	Ref. State Modified Heulandite
Study Type	Calorimetric	Calorimetric	Calorimetric	Solubility	Solubility	Calorimetric	Calorimetric
Na (72 O)	1.908		0.56	5.412	6.36	1.532	
K	1.086		0.98	0.369	0.18	0.528	
Ca	1.522		1.50	0.009	0	2.34	
Mg	0.248		1.23	0.105	0	0	
Mn	0.004			0	0	0	
Ba	0.124			0	0	0.26	
Sr	0.072			0	0	0.7	
Fe	0.034		0.3	0.132	0	0	
Al	6.900		6.7	5.841	6.6	8.66	
Si	29.066		29	30	29.4	27.34	
O	72		72	72	72	72	
H_2O	21.844		22	22.29	21	24	
Si/A1	4.21		4.33	5.14	4.45	3.16	
Δ G,kJ/mol	-38156.8	-38042.4		-38124	-37506	-39228	-39114
Δ H,kJ/mol	-41290	-41176			-40646	-42490	-42376
S°J/mol-K	2966.10	2966.10	2872.3		2830.32	3068.72	3068.72
high T data**	yes		no	no	yes		yes

*These values have been corrected back to a reference state based on quartz (see Johnson et al., 1992 and discussion in the section on analcime).
**Indicates whether data at temperatures above 25°C were collected.

In the following, a method for analyzing these results will be developed by examination of the thermodynamics of cation-exchange and hydration. These will allow the data in Table A-1 to be corrected to a single reference composition, and therefore allow some evaluation of the internal consistency. The results will be compared to the estimation methods of Chipera et al. (1995).

Thermodynamics of Cation Exchange

The cation exchange properties of clinoptilolite have been investigated by Pabalan (1994) and Pabalan and Bertetti (1994). These studies involved the determination of the energetics of binary cation exchange of K^+, Ca^{2+}, and Sr^{2+} for Na^+ in the same clinoptilolite used by Murphy et al. (1996; Table A-1). Their results allow calculation of the integral Gibbs free energy of exchange for each of these binary pairs (Table A-2). The integral exchange values can be used to recalculate the Gibbs free energy of formation of clinoptilolite with differing exchangeable cations. The effect of the exchange on Gibbs free energy of formation is shown in Table A-2. Note that the exchange energy is approximately given by the difference in the Gibbs free energy of formation of the cations, suggesting a useful approximation in the absence of other data.

Table A-2. Calculated Integral Gibbs Free Energies of Exchange in Clinoptilolite Based on Data in Pabalan (1994) and Pabalan and Bertetti (1994)

	ΔG Binary Exchange for Na J/mol	Difference in ΔG_f of Cations J/mol	Change in ΔG_f Due to Binary Exchange J/mol/Cation
K-Na in clinoptilolite	-7980	-20590	-28570
Ca-2Na in clinoptilolite	-925	-29740	-30665
Sr-2Na in clinoptilolite	-1371	-35640	-37011

As is common with many other natural zeolites, the energetic preference for cations in clinoptilolite is in the order K>Sr>Ca>Na (see Sherry 1969). Pabalan (1994) demonstrated that clinoptilolite is enriched in K relative to Na in aqueous solutions. The situation for the exchange of Ca and Sr for Na is more complex: dilute, Na-rich solutions favor preferential sorption of Ca and Sr; whereas concentrated, Na-poor solutions show enrichment of Na in clinoptilolite. These relations indicate that the presence of K-rich, Ca-poor dilute solutions will result in clinoptilolite with compositions significantly removed from the Na end-member. In such solutions, the activity of the Na-clinoptilolite component will be significantly reduced, which will have the effect of stabilizing clinoptilolite relative to Na-rich minerals that do not readily cation exchange, such as analcime and albite.

Thermodynamics of Si/Al Exchange

The thermodynamics of changes in the Si/Al ratio in clinoptilolite are of great significance because of the extensive variation observed in clinoptilolite at Yucca Mountain. Unfortunately, this variation has not been investigated in clinoptilolite. However, there are data for analcime and faujasite, and there are estimation methods that allow some general conclusions on the approximate energetics of Si/Al variation to be identified.

Barnes and Wilkin (1995) measured the solubility of two Na end-member analcime samples with different Si/Al ratios. The empirical relationship describing the relationship of the Gibbs free energy of formation of analcime as a function of Si/Al ratio is given by (in kJ/mol):

$$\Delta G_f^{analcime} = -3090 + 98.8\left(\frac{Si}{Al} - 2\right) \tag{1}$$

where the exchange reaction may be represented as

$$Na + Al \leftrightarrow Si \tag{2}$$

These results agree well with the Gibbs free energy of formation of an intermediate Si/Al value measured by Johnson et al. (1982), and are consistent with the ideal solution model of Wise (1984) for analcime.

The thermodynamics of Si/Al exchange may also be estimated using the methods of Chermak and Rimstidt (1989) and Chipera et al. (1995) which are based on approximating thermodynamic values as a summation of constituent oxides. Interestingly, the results of these methods are in basic agreement with the direct measurements of Barnes and Wilkin. The equation derived from Chermak and Rimstidt is (in kJ/mol):

$$\Delta G_f^{analcime} = -3099 + 298(Si - 2) \tag{3}$$

and that of Chipera et al. is

$$\Delta G_f^{analcime} = -3094 + 281(Si - 2) \tag{4}$$

Finally, Petrovic and Navrotsky[2] measured the enthalpy of the Si/Al exchange reaction in dehydrated faujasite, which is a large pore zeolite. They found that the increase in the enthalpy of formation per mole of Si is 267 kJ/mol, very similar to the values of 281 and 298 for the Gibbs free energy of formation obtained by estimation (Equations 3 and 4). These results indicate that the energetic effect of variations in Si/Al can be reasonably accounted for by the expressions in Equations 1, 3, or 4.

Thermodynamics of Hydration

Hydration and dehydration of clinoptilolite may have significant consequences for the stability of clinoptilolite and for the hydrology of Yucca Mountain. Dehydration will destabilize clinoptilolite relative to less hydrous mineral assemblages (albite and analcime); release significant amounts of H_2O; have a significant impact on the thermal budget; and result in porosity changes due to changes in molar volume. The experimental data necessary to assess all of these factors have been obtained by Bish (1984, 1995)[3,4].

Equilibrium in the Clinoptilolite-H_2O System

The equilibrium H_2O contents of clinoptilolite as a function of temperature (25-250°C), water-vapor pressure (0-35 mbar), and exchangeable cation (Na^+, K^+, and Ca^{2+}) were determined by Carey and Bish (1996a)[3]. These experiments show that clinoptilolite hydrates and dehydrates reversibly at temperatures ≤215°C (Figure A-1[3]) Above 215°C, Na-clinoptilolite suffers a slight loss in water adsorption capacity. K- and Ca-exchanged clinoptilolite maintain reversibility to temperatures > 250°C. Equilibration time for hydration and dehydration of clinoptilolite powders is on the order of an hour, so that the kinetics of hydration/dehydration do not appear to be relevant to processes at Yucca Mountain. The experimental data demonstrate that models of clinoptilolite behavior should assume completely reversible hydration behavior to temperatures at least as high as 200°C.

The measured H_2O content of clinoptilolite is a smooth function of temperature and pressure (Figure A-2[3]) and there are no discontinuities in the dehydration behavior at the boiling point of water. Clinoptilolite retains substantial H_2O to temperatures >150°C, even in a nominally dry atmosphere. Numerical models incorporating the hydration behavior of clinoptilolite should assume smoothly varying H_2O contents as a function of temperature and water-vapor pressure.

The thermogravimetric equilibrium data were fit to a thermodynamic function describing the reaction:

anhydrous clinoptilolite (aCpt) + H_2O ↔ hydrous clinoptilolite (hCpt) (5)

The equilibrium constant, K_{ideal}, containing ideal mixing terms for this reaction is:

$$K_{ideal} = \left(\frac{\theta}{(1-\theta) f_{H_2O}} \right) \tag{6}$$

where θ is the ratio of the amount of H_2O in clinoptilolite relative to the maximum amount clinoptilolite contains. The thermodynamics of hydration were determined by analysis of the equilibrium constant as a function of temperature and water content (Figure A-3). The variations in K_{ideal} were described with an equation giving the standard state molar Gibbs free energy of hydration ($\Delta\mu_W^o$) enthalpy of hydration ($\Delta\overline{H}_W^o$) and two mixing parameters (W_1 and W_2):

$$-R \ln K_{ideal} = \frac{\Delta\mu_W^o}{T_0} + \Delta\overline{H}_W^o \left(\frac{1}{T} - \frac{1}{T_0} \right) - 3R \left(\ln\left(\frac{T}{T_o} \right) + \left(\frac{T_o}{T} - 1 \right) \right) + \frac{W_1\theta}{T} + \frac{W_2\theta^2}{T} \tag{7}$$

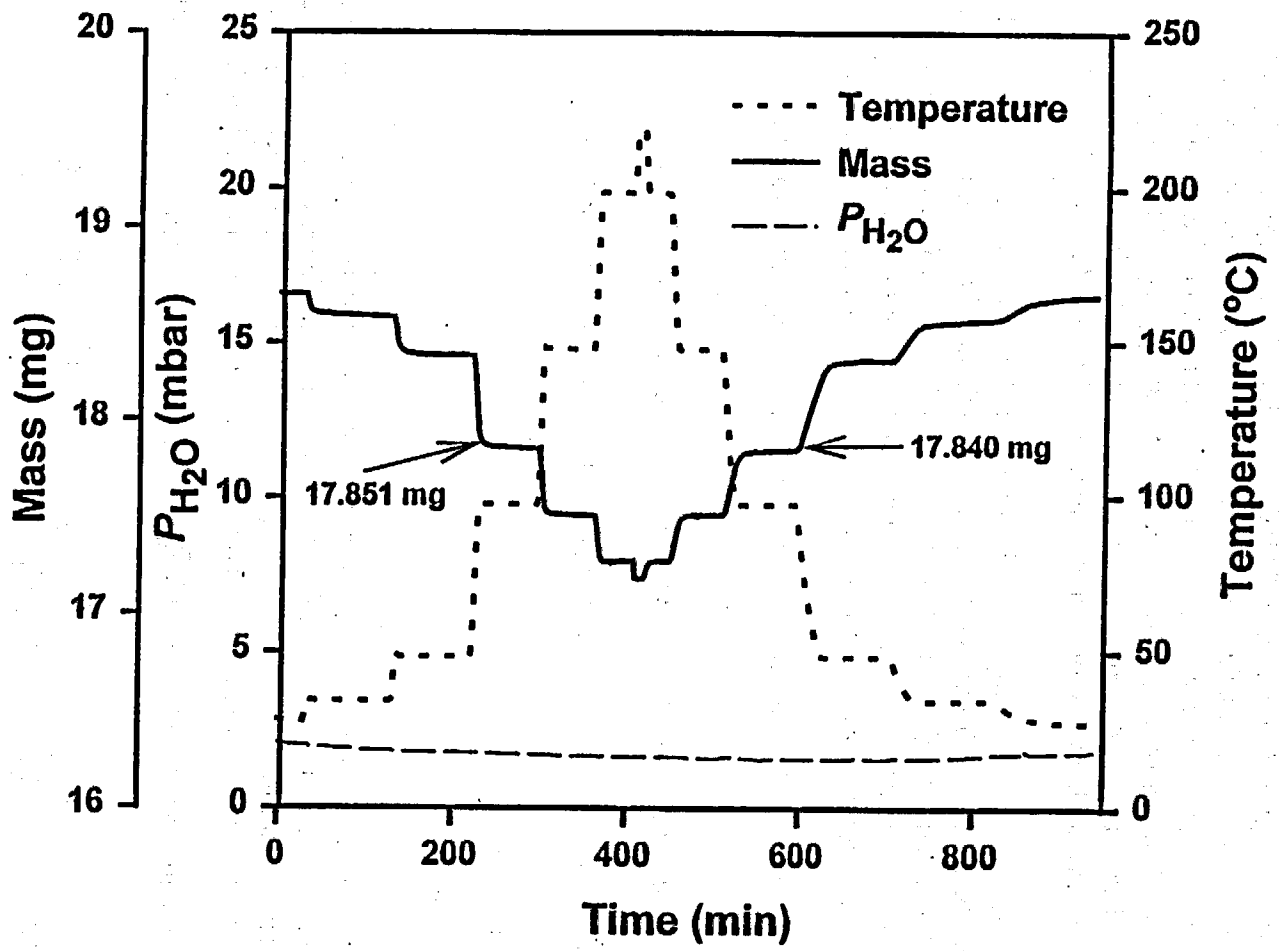

Figure A-1. Results of a single thermogravimetric experiment on Ca-clinoptilolite conducted over a series of isothermal stages from 25 to 220°C at an approximately constant water-vapor pres of 2 mbar[3]. Two mass measurements at 100°C are indicated to illustrate reversible hydration and dehydration.

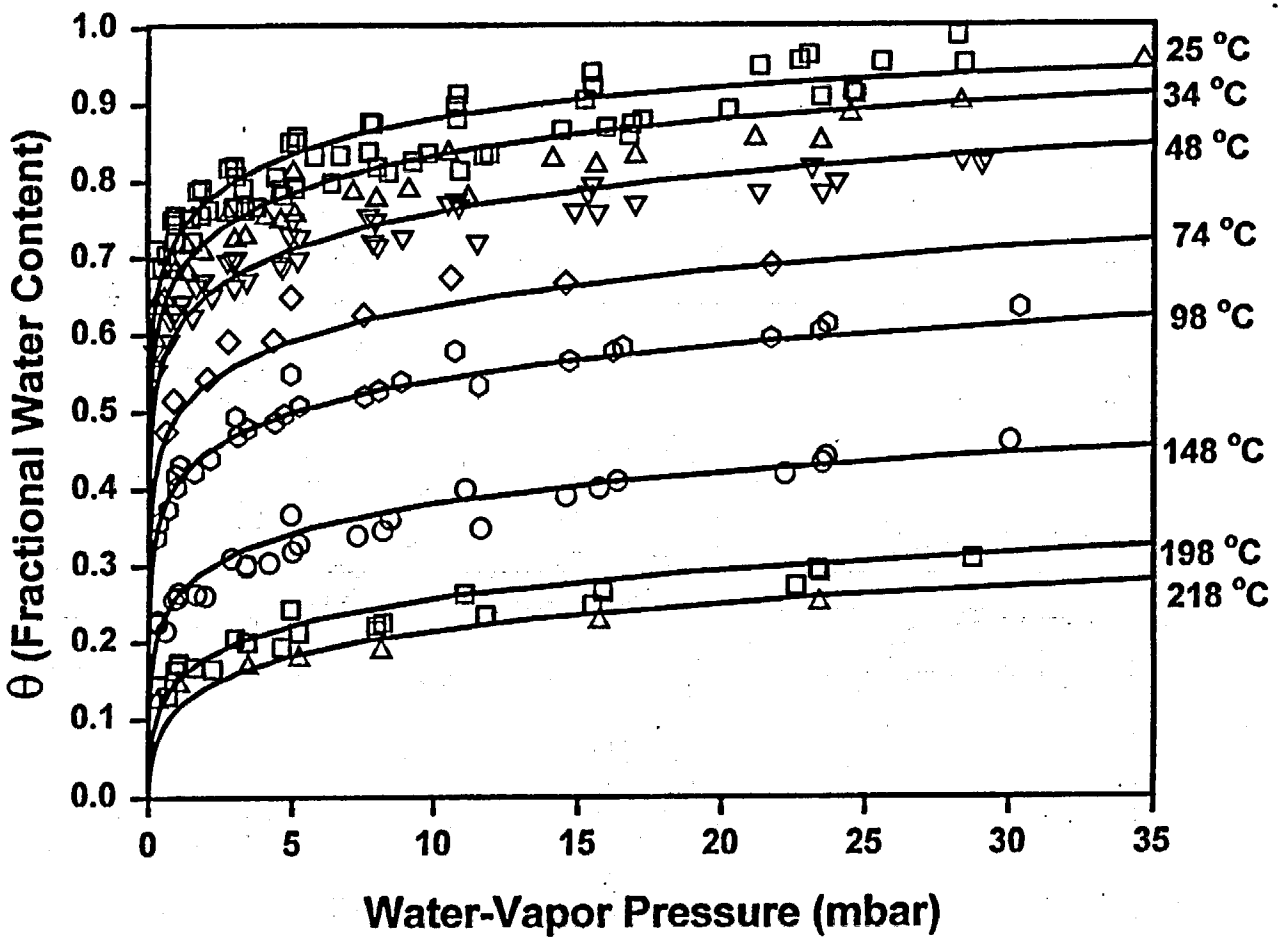

Figure A-2. Equilibrium H O content of Na-clinoptilolite determined by thermogravimetry between 25 and 218°C . The fractional water content, θ, is the observed H_2O content divided by the maximum H_2O content. The calculated lines were derived by a single linear regression of all the data.

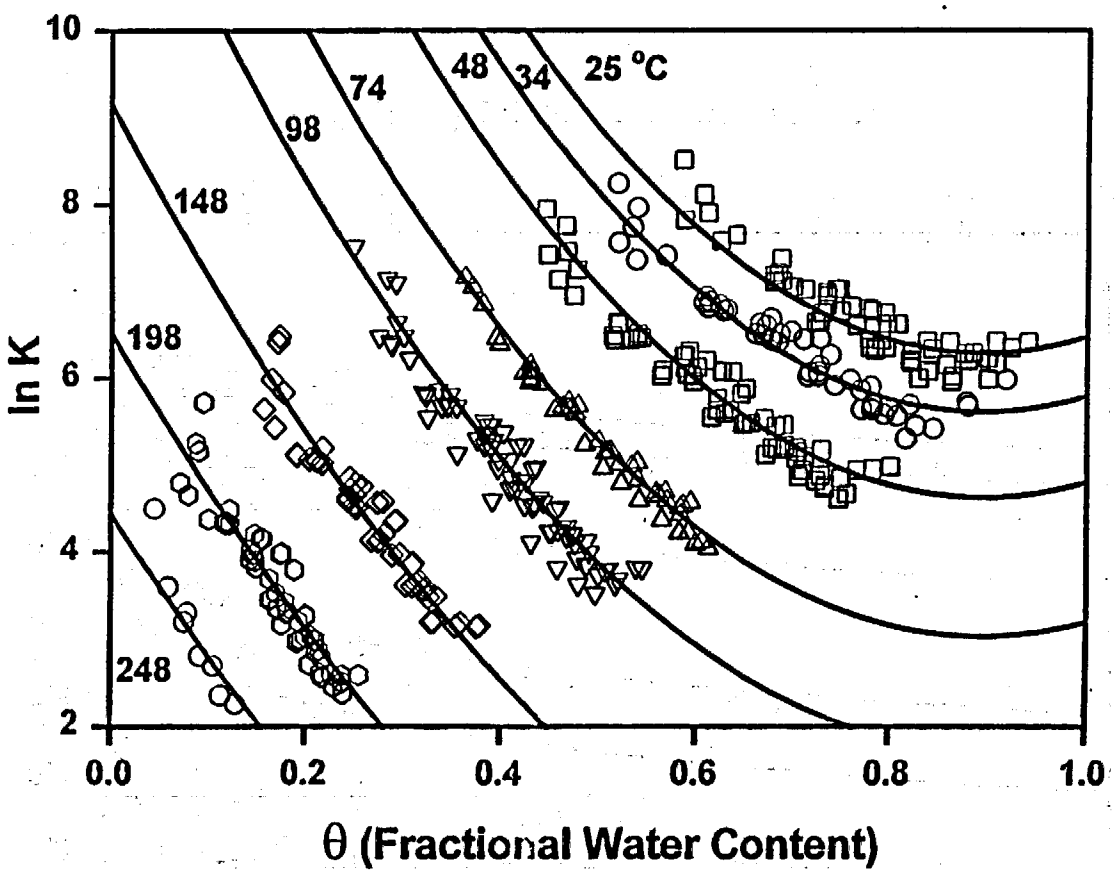

Figure A-3. Comparison of the experimental data for K-clinoptilolite (symbols) with the calculated fit (solid lines) for water content versus equilibrium constant at several temperatures[3]. The nu[illegible]ers labeling the curves are the temperature (°C) of the experiment. [illegible] is defined as ln(θ/(l-θ)/P), and θ is the ratio of the obs[illegible] water content to the maximum water content at 25°C.

where R is the gas constant and T_o is the reference temperature (298.15 K). Fits of the data yielded thermodynamic parameters describing hydration in Na-, K-, and Ca-exchanged clinoptilolite (Table A-3; Figures A-2 and A-3). The results indicate that the energetics of hydration increase from K<Na<Ca clinoptilolite (Table A-4).

Table A-3. Standard-state values for the thermodynamics of hydration in cation-exchanged clinoptilolite with errors derived from regression analysis. The values (except entropy) are used in Equation 4.

Parameter*	Ca-Exchanged		Na-Exchanged		K-Exchanged	
	Value	Std error	Value	Std error	Value	Std error
$(\Delta\mu^o_{Hy})$ (J/mol)	-79685	2414	-55080	3273	-48949.2	1171
$(\Delta\bar{H}^o_{Hy})$ (J/mol)	-120477	2232	-99593	2910	-91183	1031
$(\Delta\bar{S}^o_{Hy})$ (J/mol/K)	-136.82	3.08	-149.30	5.03	-141.65	1.86
W_1 (J/mol)	137070	3332	72214	34123	74649	1277
W_2 (J/mol)	-74935	2129	-32111	2248	-41726	920

*Excess significant figures are retained for calculations.

Table A-4. Molar values of the thermodynamics of hydration for cation-exchanged Clinoptilolite

Material	$\Delta\tilde{G}_{Hy}$ $(kJ/mol\text{-}H_2O)$	$\Delta\tilde{G}_{Hy}$ $(kJ/mol\text{-}H_2O)$	$\Delta\tilde{S}_{Hy}$ $(kJ/mol\text{-}H_2O/K)$
Ca-Cpt	-36.13 ± 3.02	-76.92 ± 2.88	-136.8 ± 3.1
Na-Cpt	-29.68 ± 3.77	-74.19 ± 3.46	-149.3 ± 5.0
K-Cpt	-25.53 ± 1.37	-67.78 ± 1.25	-141.7 ± 1.9

Note: Uncertainties are derived from the standard errors of the regression coefficients.

The equation of state for clinoptilolite (Equation 7) can be used to calculate the equilibrium water content of clinoptilolite as a function of temperature and pressure. Such calculations show that under conditions of rising temperature, clinoptilolite dehydrates even in the presence of liquid water along the boiling curve (Figure A-4[3]). However, if the rock units dry out, as may happen if temperatures rise above 100°C, the degree of dehydration of clinoptilolite increases markedly. The equilibrium water content as a function of maximum sustainable water-vapor pressure, is shown in Figure A-4 for maximum pressures ranging between 1 and 20 bars.

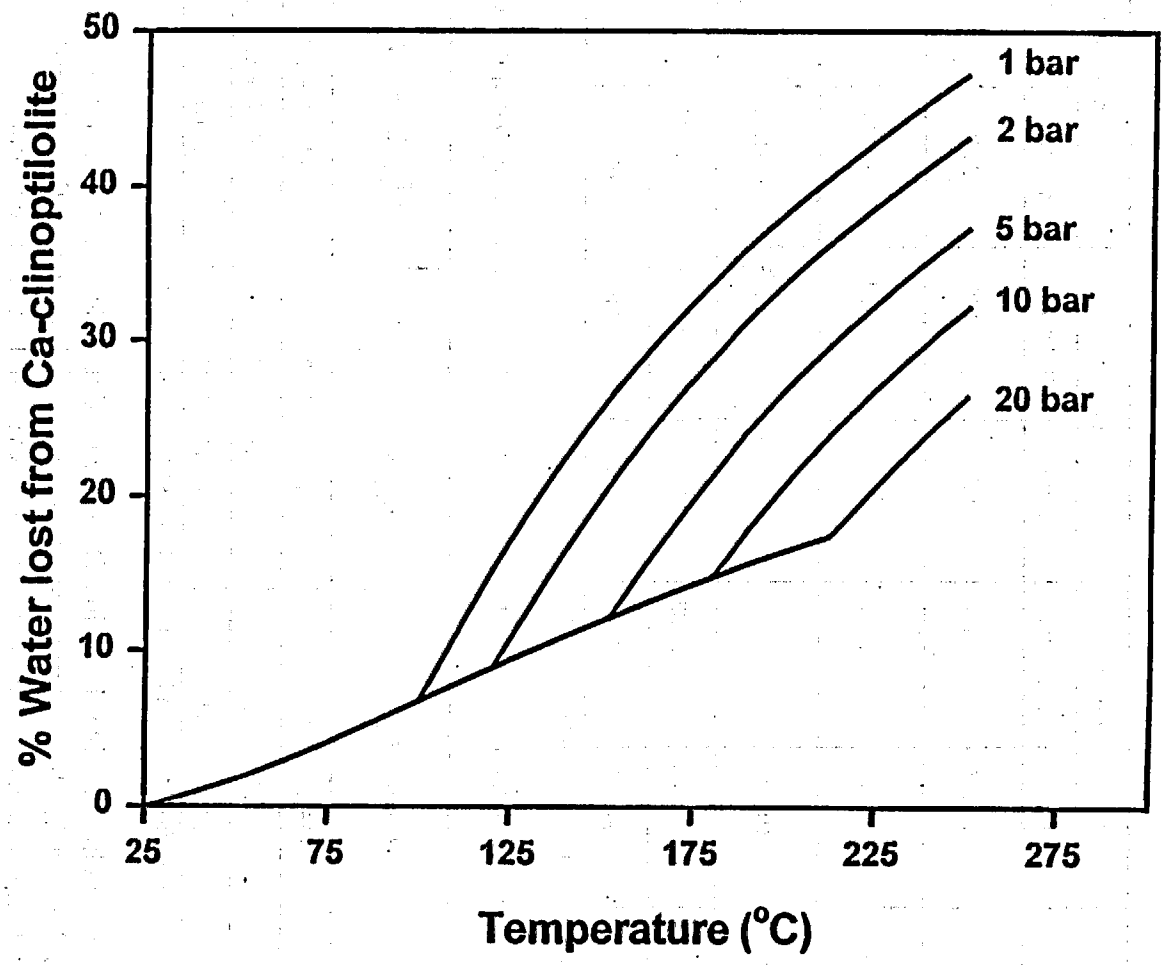

Figure A-4. Calculated dehydration evolution of Ca-clinoptilolite r conditions of rising temperature and differing maximum pres Dehydration occurs along the boiling curve until the m um pressure is reached[3].

Energetics

The energetics of hydration and dehydration of clinoptilolite have been measured calorimetrically[4]. In these experiments, Na-, K-, and Ca-exchanged clinoptilolite samples were partially dehydrated, sealed in an evacuated ampule, and placed in water where the heat of immersion was measured. The enthalpy of hydration (which is equivalent to the heat of immersion in the experiments) increases with decreasing water content in clinoptilolite (Figure A-5[4]). This demonstrates that the energetic requirements to dehydration increase as dehydration proceeds. The partial molar enthalpy of hydration was fit to an equation of the form (Table A-5, Figure A-6[3,4]):

$$\Delta\overline{H}_W = \Delta\overline{H}^o_W + W_1\theta + W_2\theta^2 + 3R(T - T_o) \tag{8}$$

In order to calculate the amount of energy consumed on changing the hydration state of clinoptilolite from θ_1 to θ_2, the following integrated form of Equation 5 should be used:

$$\Delta\tilde{H}_W = n_{max}\left(\Delta\overline{H}^o_{Hy}(\theta_2 - \theta_1) + \frac{W_1}{2}\left(\theta_2^2 - \theta_1^2\right) + \frac{W_2}{3}\left(\theta_2^3 - \theta_1^3\right) + 3R(T - T_o)(\theta_2 - \theta_1)\right) \tag{9}$$

Equation 9, then, provides the basis for calculating the amount of energy consumed on dehydration or released on hydration.

Table A-5. Parameters for the Calculation of the Partial and Integral Molar Enthalpy of Hydration from Calorimetric Data

Clinoptilolite	$\Delta\overline{H}^o_W$ J/mol	W_1 J/mol	W_2 J/mol	$\Delta\tilde{H}_W$ kJ/mol
Ca-exchanged	-101204	53717	0	-74.3
Na-exchanged	-88326	41853	0	-67.4
K-exchanged	-97934	94566	-47168	-66.4

Effect of Clinoptilolite on Thermal Evolution and Pore Saturation

A combination of the equilibrium and calorimetry studies can be used to assess the potential effects of hydration and dehydration processes on heat flow and pore saturation at Yucca Mountain. A simple numerical model was used that considers the thermal and hydrologic evolution of a thermally insulated block of clinoptilolite that receives a constant input of thermal energy. In the model, a 1 m^3 box has 10 percent porosity, is initially at 25°C, 100 percent relative humidity, and receives a thermal

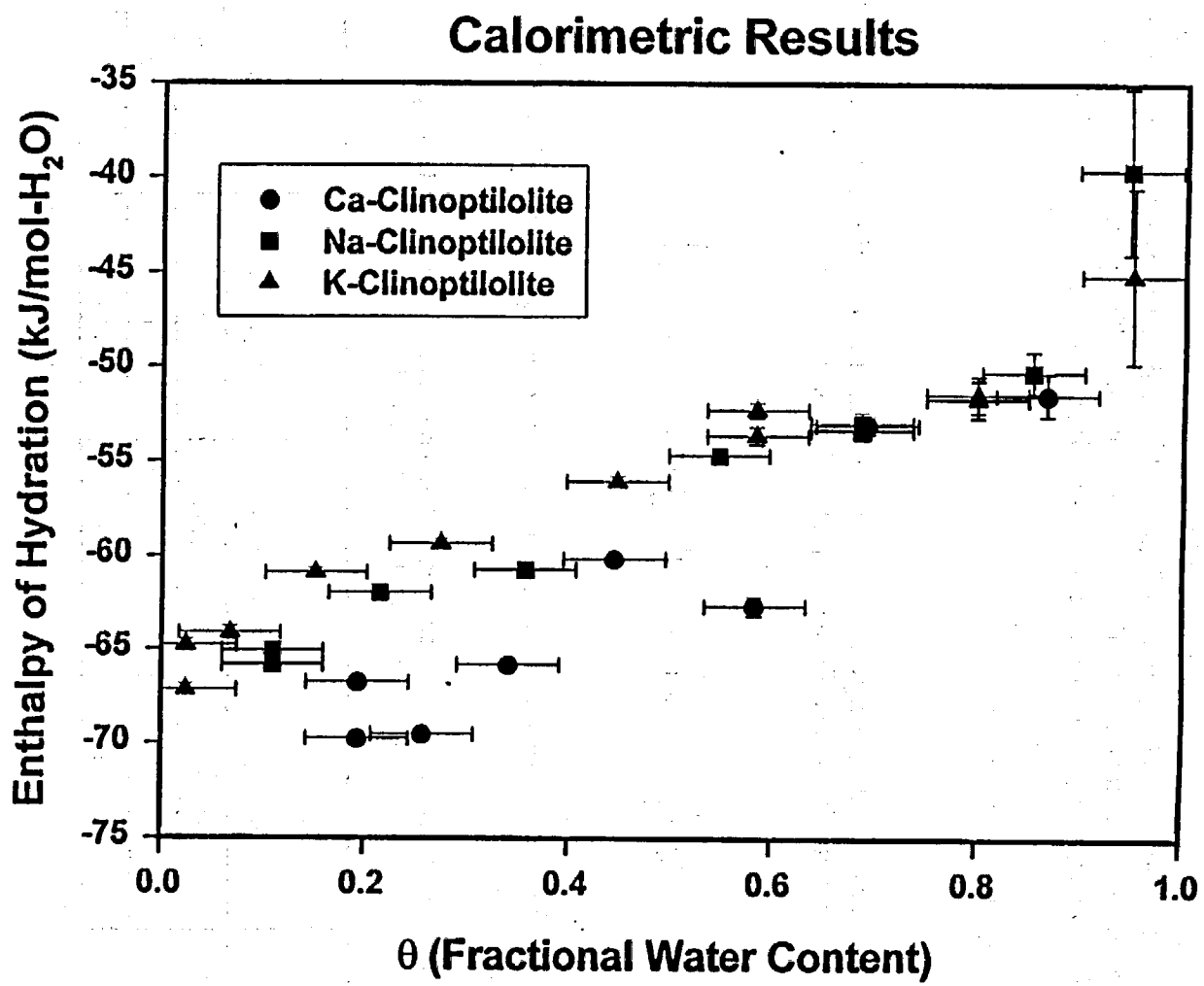

Figure A-5. Calorimetric measurements of the integral heat of immersion of Na-, K-, and Ca = clinoptilolite[3]

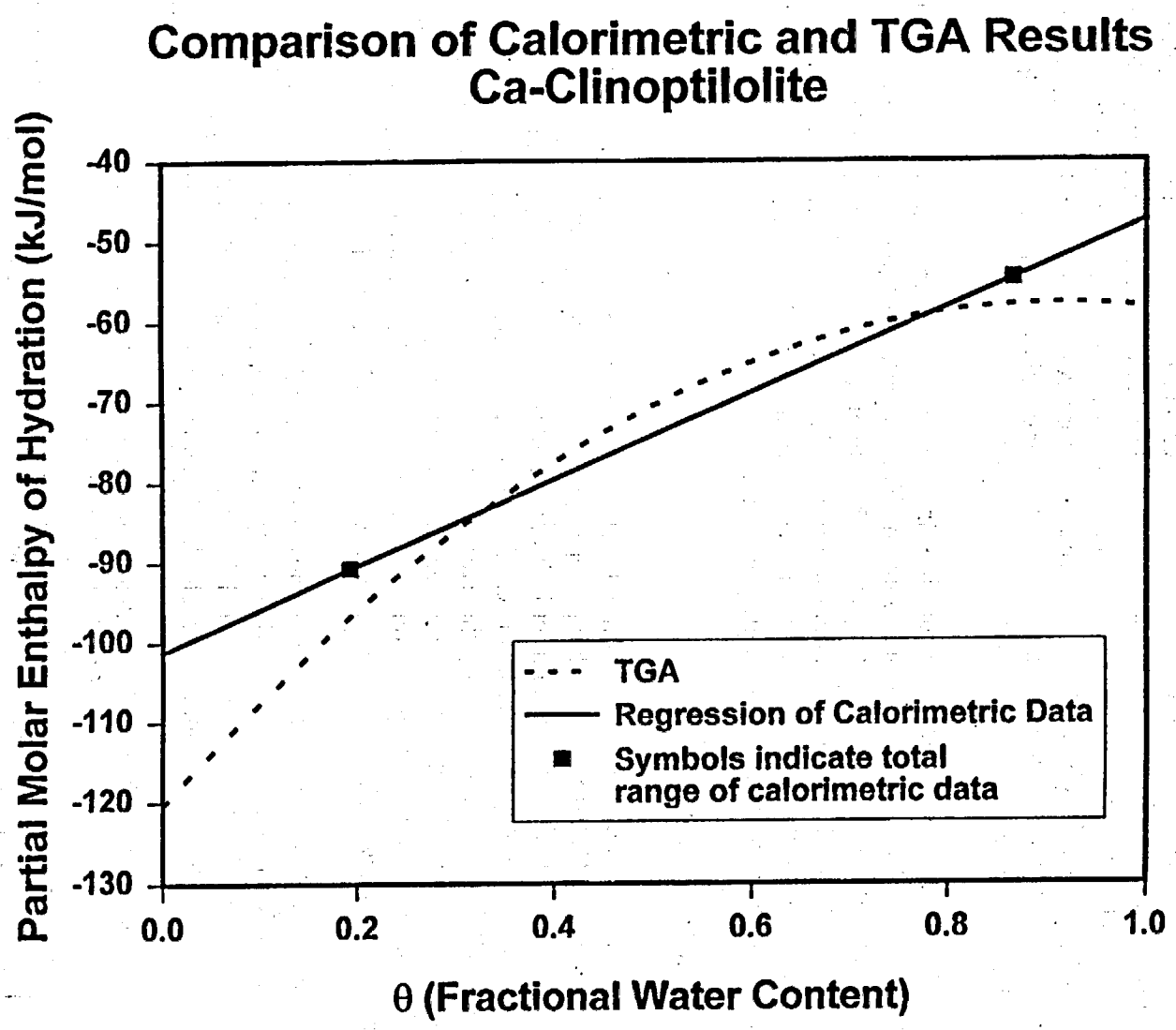

Figure A-6. Partial molar enthalpy of hydration of Ca-clinoptilolite derived from linear regression of the immersion calorimetry data compared to the thermogravimetric results (TGA)[3]

flux of 14 watts (this value is representative of those considered for Yucca Mountain). The thermal flux is consumed by the heat capacity of clinoptilolite and by dehydration processes. It is assume that the box is porous to water vapor and a maximum pressure of 1 bar is attained. The temperature achieved by the box is dramatically lower when clinoptilolite is allowed to dehydrate (Figure A-7[3]).

The model case without dehydration reached 395°C after 844 days, whereas the case allowing dehydration reached only 250°C over the same period. The kink in the temperature evolution at 100°C is the point at which the pores attained the maximum water-vapor pressure of 1 bar. During the dehydration process, the clinoptilolite released 1.63 pore volumes of liquid water. In other words, the model constraints require that an amount of water equal to 16 percent of the rock volume must drain away (10 percent porosity x 1.63 pore volumes).

These calculations demonstrate that dehydration and hydration of clinoptilolite can affect the temperature and saturation field at Yucca Mountain. The magnitude of the effect depends on the interplay of such factors as the rate of heating versus the rate of thermal dissipation and the ratio of water released by clinoptilolite to the amount infiltrating the rock unit in a given period of time. These can be quantitatively addressed using coupled numerical models of clinoptilolite hydration/dehydration and thermo-hydrologic processes.

Molar Volume of Clinoptilolite

The molar volume of clinoptilolite is a sensitive function of temperature, exchangeable cation, and hydration state (Bish 1984; Bish 1995). Changes in molar volume of clinoptilolite may be important in the Calico Hills Formation, where clinoptilolite constitutes from 50 to 70 percent of the rock. Bish (1984, unpublished data) observed that decreases in molar volume on heating to 200°C ranged from about 1.5 to 8.5 percent depending on the exchangeable cation and the partial pressure of H_2O (Table A-6[3,4]). A reasonable estimate of the maximum likely effect of dehydration on the molar volume of clinoptilolite in a repository environment may be taken as 2 percent. This is a larger effect than the maximum observed change of 0.8 percent for cation exchange (K for Ca).

Simple bounding calculations can be made on the effect of dehydration processes in clinoptilolite on porosity. Considering a 2 percent effective change in volume, a rock with 50 volume percent clinoptilolite could develop up to an additional 1 percent rock porosity, depending on the initial porosity. A rock that was pure clinoptilolite could develop up to an additional 2 percent of porosity.

Table A-6. Unit Cell Volume of Clinoptilolite as a Function of Exchangeable Cation, Temperature, and Water-vapor Pressure

Exchange-able Cation	Volume at 25°C (Å³)	ΔV% of Exchange for Na	Volume at 200°C in dry N_2	ΔV% (from 25°C)	Volume at 200°C at 35 mbar H_2O	ΔV% (from 25°C)
Na	2113.6	0	1935.5	8.43	2064.7	2.31
K	2118.3	0.22	2085.2	1.56	2077.7	1.92
Ca	2102.5	0.53	2050.98	2.45	2064.4	1.81

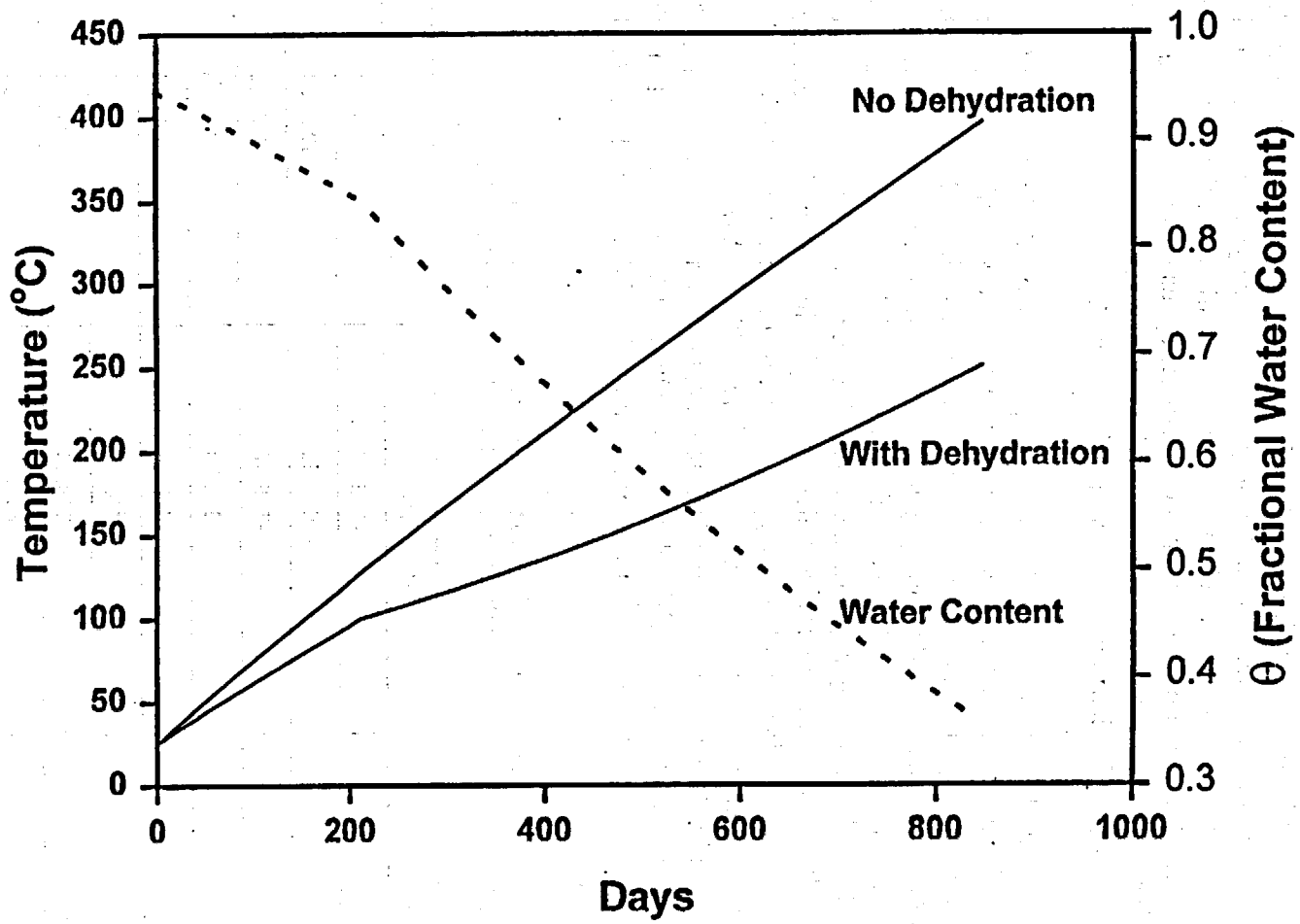

Figure A-7. Calculated thermal and hydrologic evolution of a 1 m^3 block of K-clinoptilolite with 10 percent porosity, insulated boundaries, maximum water-vapor pressure of 1 bar, and receiving 14 watts of thermal energy. The two solid lines show the temperature of a block with K-clinoptilolite that dehydrates and one which does not dehydrate. The dotted line shows the water content of the clinoptilolite in the dehydrating block[4].

Thermodynamic Model for Compositional Variation in Clinoptilolite

The preceding discussion can be used as a basis for developing a model of the thermodynamic properties of clinoptilolite as a function of composition. The approach described here is based upon Chipera et al. (1995) with some modifications. The basic idea adopted here is to evaluate the thermodynamic data for clinoptilolite, choose the single best thermodynamic results, and use that clinoptilolite as a reference composition. The reference composition can then be used to obtain thermodynamic values for clinoptilolite of any composition by using estimation methods that account for the effect of cation exchange and hydration/dehydration reactions. Finally, an estimate of the overall uncertainty of the thermodynamic values is obtained.

Evaluation of the measured thermodynamic data for clinoptilolite (see Table A-1) can be made by comparing measured and estimated thermodynamic values. A set of internally consistent measurements should differ by approximately one percent from the estimated values. On the other hand, inconsistent measurements should differ by greater percentages from the estimates. Estimated values were obtained by the method of Chermak and Rimstidt (1989) as modified by Chipera et al. (1995). These were supplemented by approximate values for MnO, BaO, and SrO obtained as the sum of the Chermak and Rimstidt reference value for Na_2O plus the cation exchange energy approximated by the difference in Gibbs free energy of formation of the cation, Robie et al. (1979); a discussion of cation exchange and Table A-2, results are in Table A-7. A comparison of the estimated and measured values shows that the calorimetric data of Johnson et al. (1985; 1991) are self consistent but the solubility data of Murphy et al. (1996) and Barnes and Wilkin[5] differ by amounts that are large compared to typical differences found by Chipera et al. (1995) for other zeolites (Table A-8).

Table A-7. Contribution of individual oxides to the thermodynamic properties of clinoptilolite (Robie et al. 1979; Cherinak and Rimstidt 1989; Chipera et al. 1995)

Oxide	g_f (kJ/mol)	h_f (kJ/mol)
SiO_2	-853.95	-910.97
Al_2O_3	-1631.32	-1716.24
Fe_2O_3	-776.07	-939.18
Na_2O	-672.50	-683.00
K_2O	-722.94	-735.24
CaO	-710.08	-736.04
MgO	-628.86	-660.06
BaO	-709.44	-740.04
MnO	-376.70	-423.10
SrO	-708.14	-748.20
H_2O	-239.91	-292.37

Table A-8. Comparison of Measured and Estimated Thermodynamic Values for Clinoptilolite from Johnson et al. (1991), Johnson et al. (1985), Barnes and Wilkin (1995), and Murphy et al. (1996)

Study	ΔG_f Measured	ΔG_f Calculated	Diff.	ΔH_f Measured	ΔH_f Calculated	Diff.
J 91	-38042.4	-38114	0.19%	-41176.0	-41283.9	0.26%
J 85	-39116.0	-39216.2	-0.26%	-42376.0	-42509.9	-0.31%
BW 95	-37506	-37731.2	0.60%	-40646	-40824	0.44%
M 96	-38125	-37807.2	-0.83%	n.d.		

A more accurate estimate of thermodynamic values for clinoptilolite can be obtained using Johnson et al.'s (1991) measured value of clinoptilolite as a reference thermodynamic value (Table A-9). Thermodynamic values for clinoptilolite compositions different than that measured by Johnson et al. (1991) are obtained by application of cation exchange reactions based upon the data in Table A-7 and the Si/Al relation of Equation 3. Using this method, the estimated Gibbs free energy and enthalpy of formation for the heulandite discussed in the Johnson study are -39116 and -42378 kJ/mol, which differ by only 0.06 and 0.05 percent respectively. The energetic effect of H_2O for the end-members can then be modeled using Equations 7 and 8 and the data of Tables A-3 and A-5. Calculations at elevated temperature can be made with the heat capacity estimation methods discussed by Chipera et al. (1995).

To illustrate the utility of the estimation method, the effect of differing Al/Si ratio on the solubility of clinoptilolite is considered (Figure A-8). At low activities of silica, aluminous clinoptilolite (or heulandite) is stabilized relative to siliceous clinoptilolite, while at high silica activities, siliceous clinoptilolite is more stable. All but the most siliceous Na-clinoptilolite compositions are stable with respect to analcime at 25°C at the solubility of quartz.

The uncertainties of the estimated values are likely to be less than those associated with the pure estimation methods, which are typically about 0.25 percent and may exceed 0.4 percent, or about 100 to 160 kJ/mol for the clinoptilolite compositions in Table A-9 (see Chermak and Rimstidt 1989). Johnson et al. (1991) give a measured uncertainty of about 27 kj/mol for clinoptilolite and heulandite. If we assume an upper bound for the error associated with the method using the reference value of 0.10 percent, then uncertainties are about 40 kj/mol. This degree of uncertainty still has a significant effect on calculated equilibria between clinoptilolite and analcime (Figure A-9). The range of values for a Na-clinoptilolite with Si/Al of 4.14 permits a range of assemblages from stable clinoptilolite regardless of the silica phase to conditions where clinoptilolite is replaced by analcime where silica activities drop below amorphous silica to quartz solubility.

Table A-9. Estimated Thermodynamic Data (in Kj/mol) for End-member Clinoptilolite
Using the Calorimetric Reference Value of Johnson et al. (1991) and Estimation Methods of Chipera et al. (1995)

Cation	6 Na	6K	3 Ca	7 Na	7 K	3.5 Ca	8 Na	8 K	4 Ca	9 Na	9 K	4.5 Ca
Al	6	6	6	7	7	7	8	8	8	9	9	9
Si	30	30	30	29	29	29	28	28	28	27	27	27
H_2O	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
ΔG_f	-37699	-37850	-37812	-37997	-38173	-38128	-38295	-38497	-38445	-38593	-38820	-38762
ΔH_f	-40801	-40962	-40965	-41094	-41277	-41280	-41383	-41592	-41595	-41671	-41907	-41910

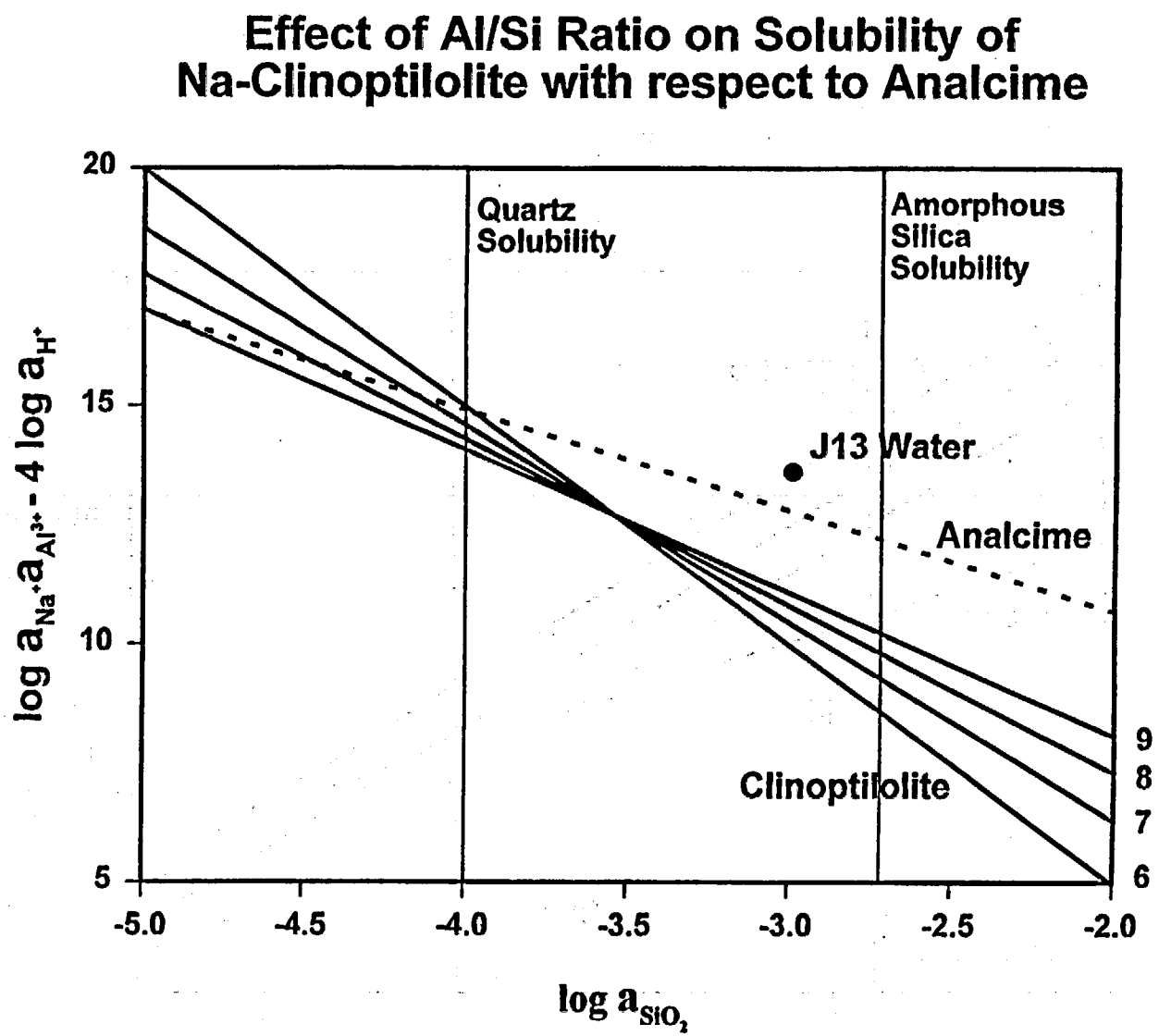

Figure A-8. Calculated solubility of Na-clinoptilolite at 25°C as function of Al/Si ratio. The solid curves are labeled with the number of Al (or Na) in a 72 oxygen formula unit of clinoptilolite (see Table A-9). Also shown are the solubilities of quartz, amorphous silica (Rimstidt and Barnes 1980), quartz and analcime (EQ3/6 com database), and the composition of J-13 well water (EQ3 calculation).

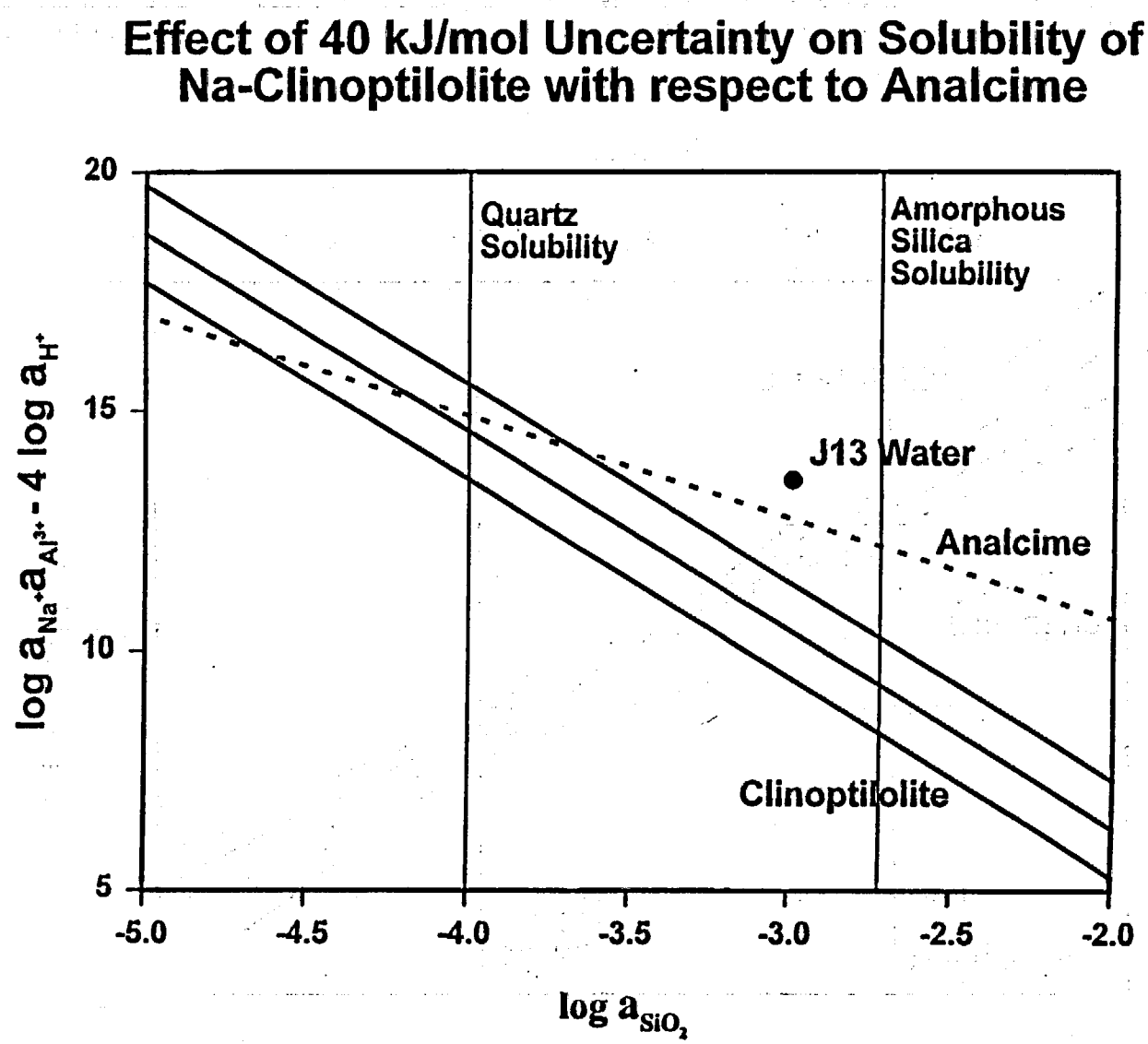

Figure A-9. Calculated solubility of Na-clinoptilolite at 25°C with +40, 0, and -40 kJ/mol uncertainty in the estimated Gibbs free energy of formation (Si/Al ratio of 4.14, see Table A-9). Also shown are the solubility of quartz, amorphous silica (Rimstidt and Barnes 1980), quartz, analcime (EQ3/6 com database), and J-13 well water (this calculation).

Breakdown to Analcime

Thermodynamic modeling[2] and natural- and self-analog studies indicate that clinoptilolite breakdown reactions may begin at temperatures near 100°C (see previous discussion). Chipera and Bish found a considerable range of stability of Yucca Mountain clinoptilolite with respect to analcime because of the large range of compositions at Yucca Mountain. They noted that calculations indicated that at least some compositions were unstable at 100°C with silica activities corresponding to quartz. However, it was also noted that some compositions were stable with respect to analcime at 150°C in the presence of quartz.

The breakdown reaction of clinoptilolite to analcime is:

$$8\ Na_6Al_6Si_{30}O_{72}{\cdot}24H_2O = 3\ Na_{16}Al_{16}Si_{32}O_{96}{\cdot}16H_2O + 144\ SiO_2(aq) + 144\ H_2O \qquad (10)$$

The solid volume reduction change of this reaction is 53 percent (assuming that all silica is aqueous) or 1.5 percent (if the silica is precipitated as quartz). The very large volume change makes the breakdown of clinoptilolite one of the most significant reactions that could affect Yucca Mountain hydrology and retardation capability (see following section).

Bounding Calculations

A method of developing useful bounding calculations for processes involving clinoptilolite may be obtained from a recent model of unsaturated zone flow at Yucca Mountain (Robinson et al. 1995). The model included three separate zeolitic units in the CHnz functional unit that contain, on average, 50 percent clinoptilolite and have a porosity of 29 percent. The finite element representation of Yucca Mountain developed by Robinson et al. allows calculation of the total volume of zeolitic rock and therefore the total volume of clinoptilolite in the model. The calculation considers only that part of the CHnz that might experience significantly elevated temperatures. The affected region was defined as occurring to the east of the Solitario Canyon Fault, to the west of the Ghost Dance Fault, and extending 100 m north and south of the repository itself. The results utilizing the nominal zeolite abundances of Robinson et al. show that there are approximately 300 million m^3 of clinoptilolite or about 200 billion moles of clinoptilolite in the area below the repository. This clinoptilolite occupies a total rock volume of 800 million m^3.

The potential impact of dehydration processes may be examined by considering the maximum likely temperature of 150°C for clinoptilolite in the CHnz. The amount of dehydration depends on the water-vapor pressure. For the purposes of these bounding calculations, a water vapor pressure of 1 atm has been assumed. The water lost from clinoptilolite also depends on the exchangeable cation and is 27 percent, 33 percent, and 23 percent, for Na^+, K^+, and Ca^{2+} end-member clinoptilolites[3]. A calculation based on an average value of the maximum water content for clinoptilolite of 24 H_2O/72 framework oxygens yields an average water loss of about 6.5 H_2O/mole of clinoptilolite. This implies a loss of about 1.5 trillion moles of H_2O or about 30 million m^3 of water. This quantity would fill about 3 percent of the available porosity in the zeolitic units of the CHnz. For comparison, this quantity of water would require on the order of 3,000 years to infiltrate into the mountain assuming an infiltration rate of 1 mm/yr into the defined area of interest. Thus, although

the amount of dehydration is not large with respect to the storage capacity of the rocks (i.e., the available porosity), it is a potentially significant source of water relative to what is added to the mountain through infiltration from the standpoint of dilution.

The amount of energy required to achieve this degree of dehydration can be calculated from Equation 9. Considering a change of water content from $\theta = 0.95$ to $\theta = 0.68$, an average of about 55 kJ/mol-H_2O is required to dehydrate clinoptilolite. Integrating this value for the total amount of water released yields approximately 100 trillion kJ to accomplish this dehydration. For the assumed area of 8 million m^2, or 2,050 acres, this corresponds to an energy consumption of 10 million kJ/m^2 or 40 billion kJ/acre. Considering a high thermal load of 110.5 MTU/acre or 114 kw/acre for the repository, this represents about 10 years of thermal energy from the repository.

The decomposition of clinoptilolite to analcime in the CHnz results in a volume decrease of 22 to 53 percent, depending on whether quartz or aqueous silica is a reaction product (see preceding discussion). In this area of interest, the decomposition will result in 60 to 160 million m^3 of potential void space. This corresponds to a porosity increase of 8 to 19 percent, giving a total of 37 to 48 percent porosity. In either case, very significant changes in the hydrologic properties of the CHnz may occur as a consequence of the formation of analcime from clinoptilolite.

These calculations are summarized in Table A-10[3,4] and provide a basis for making similar bounding calculations using variations on the assumed values. The data may also be used to incorporate the effects of clinoptilolite dehydration and recrystallization into numerical models of repository thermal regimes.

A.3 SUMMARY ON THE STATUS OF NATURAL ANALOG STUDIES PERTINENT TO CLINOPTILOLITE STABILITY

Because of the difficulties in experimentally reproducing the clinoptilolite-to-analcime reaction, we have examined the possibility of using natural geologic systems as analogs to the conditions that might be expected near a high-level radioactive waste repository at Yucca Mountain. The use of such analogs is based on the presence of rock sequences containing clinoptilolite grading into analcime, coupled with information on the temperatures and timing of past mineral reaction.

We have used clinoptilolite occurrences in rocks at Yellowstone National Park to provide information on the compositional and temperature effects on clinoptilolite stability. In addition, we have used the large amount of mineralogical information available from Yucca Mountain cores. Bish (1989) and Bish and Aronson (1993) studied the clay mineralogy of tuffs from Yucca Mountain, Nevada, in order to understand the alteration history of the rocks and to predict potential future alterations. Bulk-rock samples and clay-mineral separates from three drill holes at Yucca Mountain (USW G-1, USW G-2, and USW GU-3/G-3) were studied using X-ray powder diffraction, and supporting temperature information was obtained using fluid inclusion data from calcite. The predominant clay minerals in the Yucca Mountain tuffs are interstratified illite/smectite (I/S) with minor amounts of chlorite and interstratified chlorite/smectite. The I/S reactions observed as a function of depth are similar to those observed for pelitic rocks; I/S transforms from R=0 interstratifications through R=1 and R>3 interstratifications to illite in USW G-2 and to R>3 I/S in

Table A-10. Parameters and Values Used for Bounding Calculations. (Volume and area of Yucca Mountain and zeolitic Calico Hills unit obtained by analysis of the nominal zeolite case described by Robinson et al. (1995). Values for properties of zeolites from Carey and Bish[3,4] and Bish (1984)).

Parameter	Value
Volume of Yucca Mountain in the entire model (m^3)	2.1560E+10
Volume of zeolitic units within the area of interest (m^3)	8.3579E+08
Porosity	29%
Average abundance of clinoptilolite in zeolitic units	50%
Total volume of clinoptilolite in zeolitic units (m^3)	2.9671E+08
Molar volume of clinoptilolite (cm^3/mol; 72 oxygen basis)	1260
Total clinoptilolite (mol)	2.3499E+ 11
Average H_2O lost at 15°C and 1 atm (mol/mol-cpt)	6.48
Total H_2O lost (mol)	1.5227E+12
Total H_2O lost as water (m3)	2.7432E+07
Ratio of H_2O lost to volume of zeolitic units	0.033
Area of model assumed to be affected by repository heat (m^2)	8.2950E+06
Infiltration rate (m/yr)	0.001
Annual infiltration flux through area of interest (M^3/yr)	8295
Time for infiltration flux to equal H_2O lost by clinoptilolite (years)	3300
Average energy to dehydrate clinoptilolite to 150°C at 1 atm (kJ/mol-H_2O)	55
Total energy to dehydrate clinoptilolite (kJ)	8.3751E+13
Area power density of repository region (kW/acre)	114
Total area of interest (acres)	2050
Energy per unit area to dehydrate clinoptilolite (kJ/acre)	4.0859E+10
Time for repository to supply sufficient heat to dehydrate clinoptilolite (years)	11
Volume reduction for breakdown of clinoptilolite to analcime + aqueous silica	53%
Volume reduction for breakdown of clinoptilolite to analcime + quartz	21.50%
Volume created by breakdown of clinoptilolite: aqueous silica case (m^3)	1.5725E+08
Volume created by breakdown of clinoptilolite: quartz case (m^3)	6.3792E+07
New porosity: aqueous silica case	19%
New porosity: quartz case	8%

USW G-1. The R=0 I/S clays in USW GU-3/G-3 have not significantly transformed. Both IS geothermometry and fluid inclusion data suggest that the rocks at depth in USW G-2 were subjected to post-depositional temperatures of at least 275°C, those in USW G-1 reached 200°C, and rocks from USW GU-3/G-3 probably did not exceed 100°C. Thus, at Yucca Mountain, mineralogical data can be used to provide paleotemperatures to which the rocks have been subjected.

Yellowstone Caldera

Meijer[6] (1987) reviewed a variety of natural geological and geochemical analogs to repository-induced alteration at Yucca Mountain. Of four potential sites in the continental United States, he concluded that the Yellowstone caldera most closely duplicates the details of the volcanic rocks at Yucca Mountain and the conditions anticipated in the potential repository. The Yellowstone caldera is an active hydrothermal system in silicic ash-flow tuffs, and considerable data on present-day water compositions and temperatures are available. This situation contrasts with most other potential natural analogs, for which temperatures and water compositions must be approximated from geological and geochemical information. Zeolites are common in many drill holes at Yellowstone, and clinoptilolite is the most common zeolite, followed by mordenite and analcime. According to Meijer, clinoptilolite commonly occurs as a replacement of glass, as a cement in volcanic sediments, and as a fracture filling. Just as at Yucca Mountain, clinoptilolite usually occurs with the less stable silica minerals although it occasionally occurs with quartz.

Although Yucca Mountain waters are not expected to become acid, Meijer (1987)[6] concluded that acid vapor-dominated systems usually contain opal and cristobalite, with quartz crystallization apparently inhibited. In addition, Yellowstone rocks that coexist with acid waters usually contain clay minerals rather than zeolites. This suggests that development of lower pH waters in and around the repository horizon would destabilize zeolites. In the neutral to alkaline waters in Yellowstone rocks, zeolites coexist with clays and K-feldspars, and K-feldspars, analcime, and quartz appear to represent a stable higher temperature assemblage. Meijer concluded that this assemblage resulted from the interaction of clinoptilolite/mordenite-bearing rocks with thermal waters of low aqueous silica activity. At temperatures above 165°C, K-feldspar, mordenite, and quartz often coexist. Clinoptilolite and K-feldspar usually coexist only with cristobalite rather than quartz and always at temperatures <165°C. Thus, in the Yellowstone system, clinoptilolite appears to have an upper temperature stability limit of ~165°C. In addition, clinoptilolite, unlike mordenite, is not stable at silica activities below cristobalite saturation at any temperature. Meijer also observed that clinoptilolite is restricted to units that either contain glass or were once glassy, suggesting that crystallization kinetics are important in its formation. He concluded that as long as the aqueous silica activity in Yucca Mountain groundwater remains at or above cristobalite saturation with neutral or alkaline pH, neither clinoptilolite nor mordenite will react to form analcime.

Yucca Mountain as a Self Analog

Geochemical Constraints

Valuable data concerning possible zeolite reactions in tuffs at Yucca Mountain can be obtained by examining the changes in bulk mineralogy with depth at Yucca Mountain and correlating these changes with the I/S reactions and the estimated paleotemperatures documented by Bish (1989) and

Bish and Aronson (1993). Important variations in mineralogy with depth in a number of drill holes t Yucca Mountain include the gradation from unaltered volcanic glass to clinoptilolite mordenite o analcime and finally to authigenic albite. This sequence was first emphasized for these tuffs by Smyth (1982), who related these mineralogic changes to those documented by Iijima (1975, 1980). Smyth correlated the temperatures at which some of these reactions occurred (clinoptilolite-analcime, analcime-albite) to the aqueous Na concentration. In contrast, Kerrisk (1983) conducted reaction-path calculations of mineral formation in tuffs near Yucca Mountain and concluded that aqueous silica activity was the controlling variable in the mineral evolution. He was unable to reproduce the observed mineral assemblages by varying the aqueous Na concentration. Duffy (1984) also concluded that the aqueous silica concentration was the variable controlling the stability of clinoptilolite and mordenite in Yucca Mountain. He used thermodynamic calculations to show that clinoptilolite is not stable with respect to albite or analcime at any temperature when the chemical potential of silica is controlled by quartz. Thus, in agreement with the Yellowstone observations, the stability of clinoptilolite appears to depend on whether the silica activity is controlled by cristobalite (or another relatively soluble polymorph) or quartz. The time interval over which clinoptilolite would remain stable would thus be determined by the rate of reaction of cristobalite (or glass, opal-CT) to quartz.

Recently, Chipera and Bish[2] conducted thermodynamic modeling of potential zeolite reactions at Yucca Mountain. Thermodynamic modeling of clinoptilolite-analcime equilibria was conducted with the program Ge0-Calc PTA-SYSTEM using estimated thermodynamic data for measured chemical compositions of clinoptilolite and analcime from Yucca Mountain. $\mathrm{Log}[(a,K^+)^2/aCa^{2+}]$ versus $\log[(aNa^+)^2/aCa^{2+}]$ diagrams were calculated to model the conditions under which clinoptilolite may transform to analcime. They concluded that temperature, relative cation abundances, and silica activity are all important factors in determining clinoptilolite-analcime equilibria. Increased Ne concentrations in either clinoptilolite or the fluid phase, increased clinoptilolite K^+ concentration, increased temperature, and decreased aqueous silica activity all stabilize analcime relative to clinoptilolite, assuming present-day Yucca Mountain water compositions. However, increased Ca^{2+} concentrations in either clinoptilolite or the fluid phase, increased aqueous K^+ concentration, and increased Al:Si ratios in clinoptilolite (i.e., heulandite), all stabilize clinoptilolite with respect to analcime. The models suggest that the geochemical factors controlling the reaction of clinoptilolite to analcime are more complex than those inferred in the Yellowstone natural analog study.

Using these results[2] and assuming Well J-13 water as the analog chemistry for Yucca Mountain water, clinoptilolite should remain stable with respect to analcime if temperatures in the clinoptilolite-bearing horizons do not significantly exceed 100°C. Even if temperatures rise significantly (e.g., to 150°C), not all clinoptilolite should alter to analcime, consistent with the observations from Yellowstone. Perhaps more importantly, thermodynamic modeling suggests that some Yucca Mountain clinoptilolites, particularly those rich in Ca and Al, will remain stable at elevated temperatures, even with an aqueous silica activity at quartz saturation.

Paleogeothermal Conditions at Yucca Mountain

Numerous authors have demonstrated the dependence of I/S structure and composition (i.e., degree of ordering and percentage of collapsed layers) on temperature. For example, Perry and Hower

(1970) showed this relationship in comparing data from a number of Gulf Coast wells. Many subsequent studies have confirmed this temperature dependence in a variety of rock types, and Hower and Altoner (1983) illustrated this using data from both pelitic rocks and from several geothermal areas. Consistent trends emerge for a variety of rock types younger than Cretaceous age. The trends in I/S mineralogy with depth in the three Yucca Mountain drill holes may be compared with Hower and Altoner's (1983) compilation to estimate maximum temperatures to which the Yucca Mountain rocks have been subjected. Briefly, they showed that R=1 I/S (ordered 1:1 illite:smectite interstratification) is attained at 90-100°C for reaction times $>10^7$ yrs and at 130-150°C for times $< 10^6$ yrs. They also concluded that data from geothermal areas are consistent with those from pelitic rocks, showing that R>3 I/S (ordered ISII interstratification) is attained at ~175°C, illite appears at ~260°C, and muscovite occurs at ~310°C. Comparison of these trends with the data in Bish (1989) yields the schematic paleotemperature profiles illustrated in Figure A-10. Present-day measured geothermal gradients (Sass et al. 1983) are shown on this figure for comparison. The schematic profiles for USW G- I and G-2 in Figure A-10 are considerably steeper than present-day gradients, and it is apparent that a significant thermal event has occurred in the northern end of Yucca Mountain but has not significantly affected the southern end. The schematic paleotemperatures in Figure A-10 assume reaction times long enough so that kinetic effects were not limiting, and the temperatures in the deeper portions of USW G-1 and G-2, where R>3 I/S and mite occur, were apparently high enough that the smectite-to-illite reaction was not kinetically limited.

The few fluid inclusion data reported by Bish (1989) support the I/S temperatures. Lack of evidence to support elevated alteration temperatures in GU-3/G-3 suggests that the higher temperature inclusions observed at 31 and 130.8 m in USW GU-3, may have formed during the initial cooling of the tuffs. Alternatively, and more likely, the relatively high homogenization temperatures in the shallow calcites result from re-equilibration or variable initial vapor-to-liquid ratios due to deposition in the vadose zone (Goldstein 1986). Fluid inclusions below the SWL in G-2 (524.9 m) and GU-3/G-3 (750.3 m) were not influenced by these effects.

Long-Term Mineral Stability

Zeolites. Given the estimated paleotemperatures published by Bish and Aronson (1993), potentially valuable data concerning mineral reactions in tuffs may be obtained by examining the changes in bulk mineralogy with depth. Important variations in mineralogy with depth in Yucca Mountain drill cores include the gradation from unaltered volcanic glass to clinoptilolite ± mordenite to analcime and finally to authigenic albite.

Approximate upper temperature limits at which zeolites have broken down in Yucca Mountain can be obtained from the mineralogic data in Bish (1989) and the estimated paleotemperatures. For example, it is clear from the USW G-1 and G-2 data that clinoptilolite was not part of the stable mineral assemblage at the depth/temperature at which ordered I/S interstratifications occur. This implies a maximum long-term temperature of stability of 90 to 100°C. Mordenite disappears in USW G-2 below 1,091-m depth, suggesting an upper stability limit of 100 to 130°C. Finally, analcime is rare below 1,097 m and virtually absent below 1,372 m in USW G-2. Its disappearance

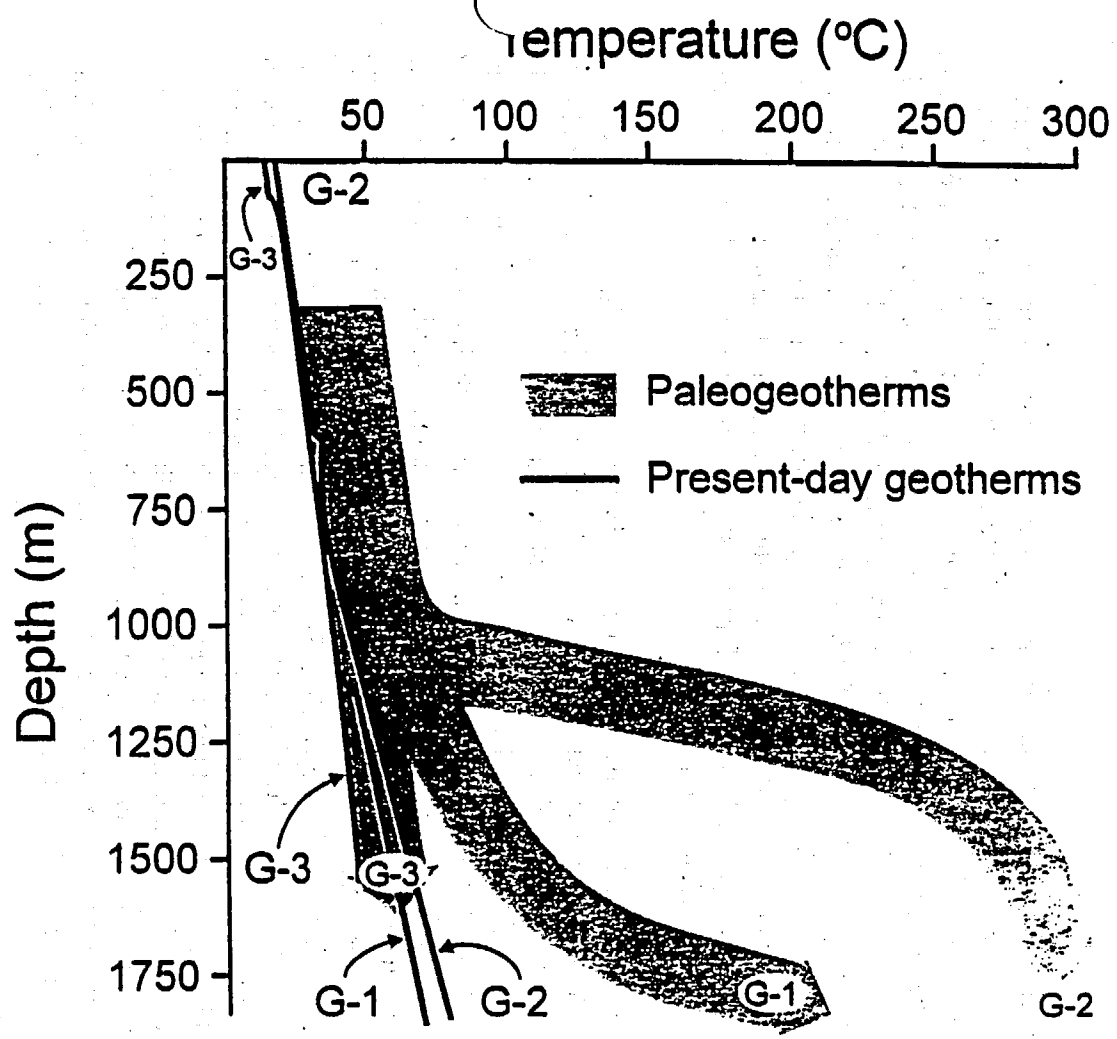

Figure A-10. Schematic paleotemperatures (broad arrowed lines) for USW G-1, G-2, and GU-3/G-3 estimated from I/S mineralogy and composition and fluid-inclusion data, together with the present-day measured temperature profiles from Sass et al. (1983) (solid narrow lines)

as a major phase near the first appearance of R>3 I/S implies an upper stability limit for analcime of 175 to 200°C, in agreement with experimental data (Liou 1971). The zeolite mineralogy in USW GU-3/G-3 shows the trends obvious in USW G-I and G-2, but the I/S mineralogy suggests that temperatures have not been significantly elevated in GU-3/G-3. It is therefore likely that the additional compositional factors outlined above, including kinetics and water chemistry (e.g., decreasing Si activity with depth), were controlling factors in zeolite reactions in USW GU-3/G-3 in the absence of significantly elevated temperatures. The observations from Yellowstone and the thermodynamic modeling both suggest that Si activity played a role in zeolite reaction in all Yucca Mountain drill holes.

The reaction of clinoptilolite to analcime at Yucca Mountain coincides with the appearance of significant amounts of calcite and minor amounts of chlorate and interstratified chlorite/smectite. The increase in calcite with depth is contrary to what is observed in pelitic rocks (e.g., Hower et al. 1976), reflecting either the differences in mineral assemblages or perhaps an increase in a (CO_2) with depth (Zen 1961) that may have been contributed by geothermal fluids. It is likely that the breakdown of clinoptilolite provided the source of at least some of the Mg for chlorite formation and the source of some of the Ca for calcite formation, although the formation of one or both of these minerals may have been associated with the hydrothermal fluids circulating at the time of alteration. The clinoptilolite probably also provided the source for at least some of the K in the deeper I/S clays and some or all of the Na for analcime and albite.

Silica Phases. Several transformations between silica phases in Yucca Mountain are obvious in the data of Bish (1989). Among these transformations are the disappearance of glass, opal-CT, tridymite, and cristobalite with depth. The disappearance of volcanic glass and opal with depth in tuffs from other areas is well documented (Iijima 1978), as is the instability of tridymite and cristobalite during alteration of volcanic rocks (Ernst and Calvert 1969; Kano 1983). As noted above, Kerrisk (1983) and Duffy (1984) concluded that decreasing aqueous silica activity, from the shallow rocks containing tridymite, cristobalite, opal, and glass, to the deeper rocks containing quartz, appeared to be the most important factor in zeolite evolution in volcanic rocks at the Nevada Test Site. The X-ray diffraction data for USW G-1, G-2, and GU-3/G-3 (Bish, 1989) are consistent with their ideas. It is noteworthy that the disappearance of clinoptilolite and mordenite as major phases coincides closely with the disappearance of cristobalite as a major phase, supporting the conclusions of Kerrisk (1983). The deepest occurrence of cristobalite in USW G-2 core corresponds to an I/S temperature of about 100°C. If temperature is the controlling variable in the transformation of cristobalite to quartz (Ernst and Calvert, 1969; Kano and Taguchi, 1982), then this reaction may have provided an indirect temperature control on the clinoptilolite-to-analcime reaction. The disappearance of cristobalite as a major phase would have resulted in a lower aqueous silica activity, thus destabilizing clinoptilolite.

Summary of Natural Analog Data

Both Yellowstone caldera and Yucca Mountain appear to be reasonable natural analogs to repository-induced thermal alterations. The temperatures at which zeolite reactions occur are affected by fluid composition (including the activity of water). Water compositional data from Yellowstone suggest that acid water would destabilize clinoptilolite. Use of Yucca Mountain as a natural analog assumes that future fluid compositions at the site will be approximately the same as

those present during the alteration ~11M years ago. This is probably a reasonable assumption, as fluid-inclusion waters are dilute. However, although present-day waters are also dilute, waters surrounding the repository environment may vary significantly from the present composition, particularly if they are concentrated by evaporation. Given these caveats, the I/S data from Yucca Mountain suggest an upper temperature stability of 90° to 100°C for clinoptilolite, 100° to 130°C for mordenite, and 175° to 200°C for analcime. Natural analog information from Yellowstone rocks suggests that clinoptilolite is stable to ~165°C. The discrepancy between Yucca Mountain and Yellowstone inferences probably reflects both differences in water compositions and kinetic effects. The assemblages at Yucca Mountain have equilibrated over millions of years, whereas the Yellowstone assemblages are probably still actively reacting. This situation would have the effect of causing clinoptilolite to appear to be stable to higher temperatures.

Combination of these data with models of the thermal profiles around a repository in tuff as a function of time (Buscheck et al. 1994), and with the mineral distribution data[1], shows that the reaction of clinoptilolite to analcime could potentially occur in the thick, zeolitized CHnz underlying the candidate repository horizon at high waste loadings. The calculations of Buscheck et al. (1994) predict temperatures in portions of the Calico Hills Formation exceeding 100°C for areal mass loadings of 83.4 and 110.5 MTU/acre. Predicted temperatures in the Calico Hills Formation do not exceed 100°C for a waste loading of 55.3 MTU/acre. Details of what temperatures are reached by the clinoptilolite and some discussion of the impact of this on the mineralogy is discussed in Section 3, Volume I.

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Note: See following Endnotes for unpublished references.

ENDNOTES

1. Found in article by S. J. Chipera and D. L. Bish. "Equilibrium Modeling of Clinoptilolite-analcime Equilibria at Yucca Mountain, Nevada." Accepted for publication by *Clays and Clay Minerals.*

2. Found in article submitted by I. Petrovic and A. Navrotsky in 1995 to *Microporous Materials* titled "Thermochemistry of Na-faujasites with Varying Si/Al Ratios."

3. Found in article by J. W. Carey and D. L. Bish titled "Equilibrium Modeling of Clinoptilolite-analcime Equilibria at Yucca Mountain, Nevada." Submitted for publication in *American Mineralogist.*

4. Found in article by J. W. Carey and D. L. Bish submitted to *Clays and Clay Minerals* titled "Calorimetric Measurement of the Enthalpy of Hydration of Clinoptilolite."

5. Found in final report from Los Alamos National Laboratory for fiscal year 1995 to the Yucca Mountain project by H. L. Barnes and R. T. Wilkin titled *Kinetic Measurements on the Silicates of the Yucca Mountain Potential Repository.*

6. Found in report from Los Alamos National Laboratory in 1987 by A. Meijer titled "Investigations of National Geologic and Geochemical Analogs in Relation to a Potential Nuclear Waste Repository at Yucca Mountain, Nevada."

APPENDIX B

THERMAL-MECHANICAL EVALUATION OF THE 200°C DRIFT-WALL TEMPERATURE GOAL

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THERMAL-MECHANICAL EVALUATION OF THE 200°C DRIFT-WALL TEMPERATURE GOAL

B.1 BACKGROUND

Temperature-based criteria, *thermal goals,* have historically been used by the Yucca Mountain Site Characterization Project to evaluate the viability of repository design options. Many of these goals were established during the development of the *Site Characterization Plan* (SCP, DOE 1988) as surrogate criteria for specific phenomena related to the performance of the potential repository. One such criterion is the limitation of rock-mass temperatures 1-m radially from a borehole wall to below 200°C. This goal was established because of the potential for silica phase inversions at temperatures above 200°C that might adversely effect rock stability. Changes in emplacement strategies have eliminated borehole waste emplacement from the baseline repository designs; however, the potential for silica phase inversions remains a concern. For this reason, a 1993 reevaluation of the SCP thermal goals (CRWMS M&O 1993) recognized the importance of limiting near-field temperatures for the current waste emplacement option, *in-drift emplacement,* by recommending a drift wall temperature limit of 200°C.

The 1993 reevaluation of the SCP thermal goals also discussed the fact that drift stability may be sensitive not only to peak temperature, but also to temperature gradient. It is the purpose of this study to examine the sensitivity of a modeled emplacement drift to various temperature gradients and to propose a refinement of the 200°C drift-watt temperature limit, if appropriate.

B.2 PROBLEM DESCRIPTION

This investigation is intended to provide bounds on the allowable temperatures and temperature gradients near an emplacement drift based on predicted structural responses to imposed thermal fields. As such, it is not necessary to generate thermal profiles that can be directly linked to a given thermal design (e.g., a given areal mass loading and waste stream). Instead, the thermal component for this investigation is generated independent of any specific repository thermal design. The shapes of the imposed gradients, however, are consistent with expected responses around a central emplacement drift.

For predicting structural response, the JAC2D model (Biffle and Blanford 1994) was chosen. The majority of the calculations performed use the elastic constitutive model in the JAC2D code; however, limited comparison runs were made using a jointed-rock model.

B.2.1 GEOMETRY

The two-dimensional geometry examined is presented in Figure B-1. The modeled drift is assumed to be 5.0 m in diameter, with 30.5 m between the centerlines of drifts. The vertical extent of the model is assumed to be 21 m both above and below the centerpoint of the modeled drift. Due to symmetry, only half of the drift and half of the space between drifts are modeled. The two-dimensional model was discretized into 5,271 nodes as shown in Figure B-2. This discretization was used for all structural modeling presented in this report.

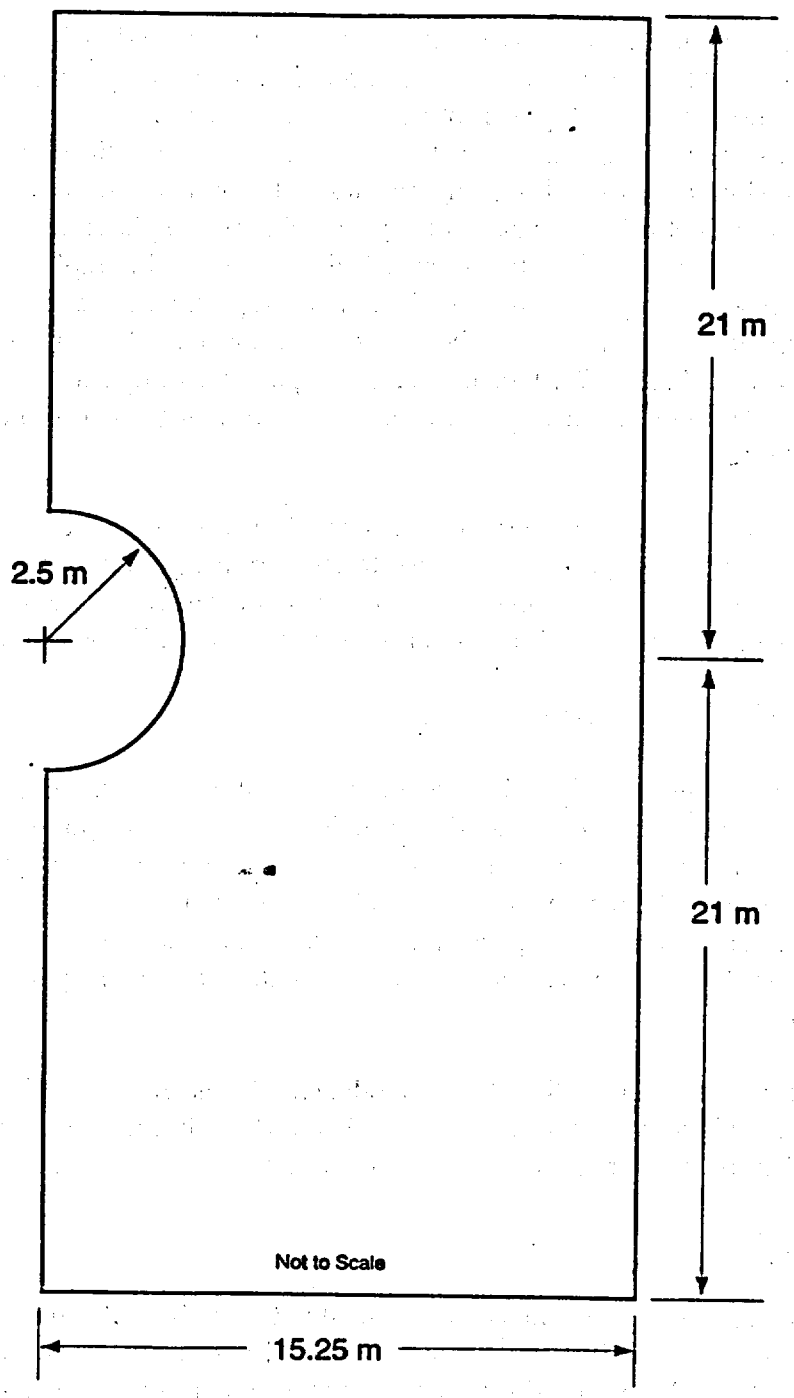


Figure B-1. Modeled Geometry

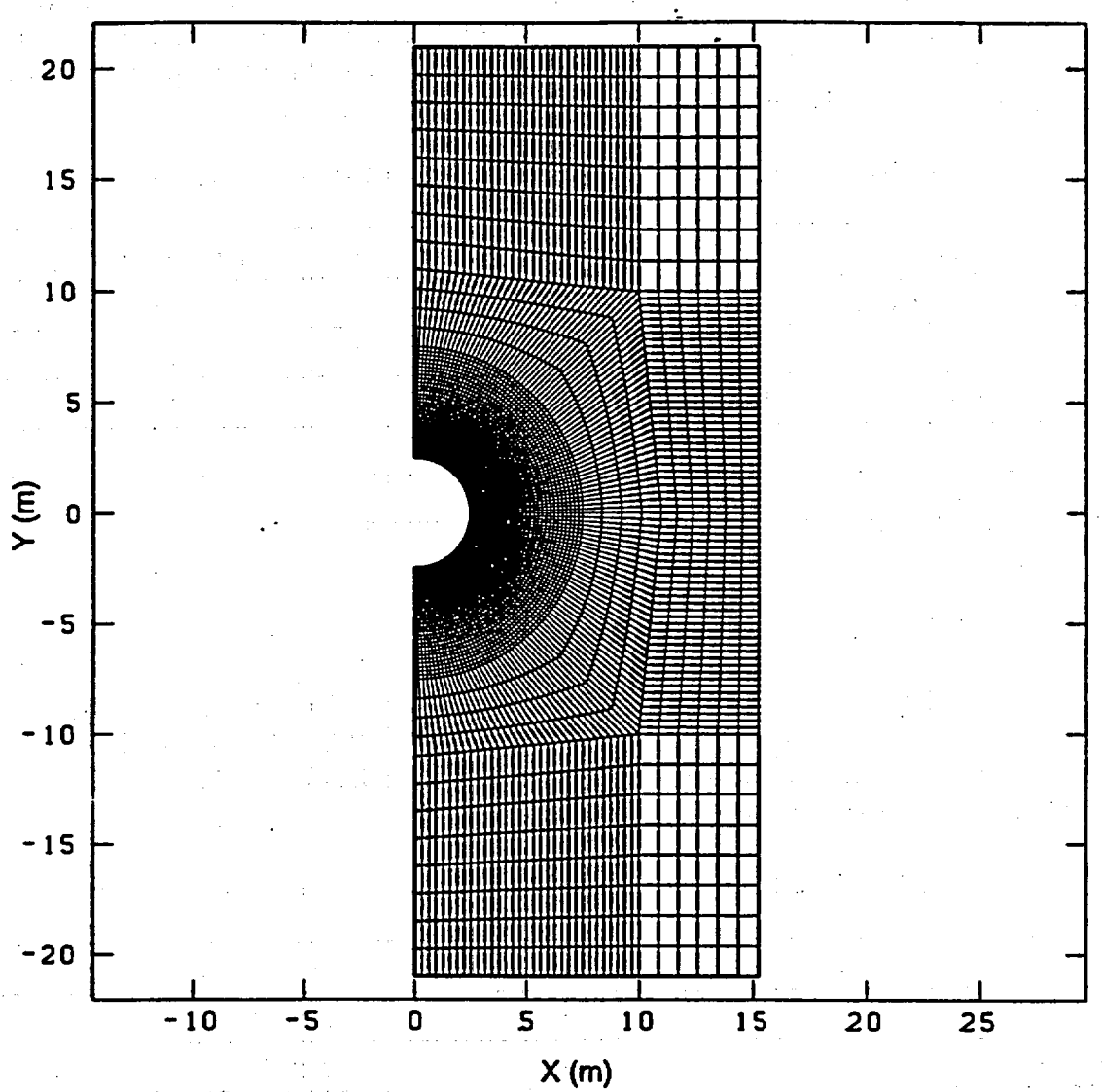


Figure B-2. Mechanical Mesh

B.2.2 BOUNDARY CONDITIONS

Both of the vertical and the lower horizontal boundaries of the model were assumed to be represented by roller conditions. An overburden pressure of 7.84 MPa was applied to the upper horizontal surface of the model. The overburden pressure was calculated using the stratigraphic unit thickness reported for drill hole USW G-4 and the densities presented in Table B-1. The information in Table B-1 was obtained from the Reference Information Base (RIB) (DOE 1995b). For the purposes of this study, it is assumed that the density of the unconsolidated overburden is the same as that for TCw, and that the mean dry densities reported in the RIB are representative of the various stratigraphic units. The upper boundary of the model is assumed to be 182 m below the TSwl/TSw2 stratigraphic interface (i.e., at the maximum assumed depth of the repository below the contact). Body forces consistent with a domain composed of TSw2 are also applied.

Table B-1. Assumed Densities and Stratigraphic Unit Thicknesses (RIB)

Stratigraphic Unit	Mean Dry Density (g/cm^3)	Unit Thickness (m)
Unconsolidated Overburden	2.132[a]	9.14
TCw	2.132	26.8
PTn	1.386	38.1
TSw1	2.053	130.1
TSw2	2.219	182[b]

[a]Assumed to be the same as TCw
[b]Assumed depth from TSw1 to the top of modeled region

B.2.3 MATERIAL PROPERTIES

For the elastic calculations performed for this study, nominal values for Young's Modulus, Poisson's Ratio, and density were assumed for the modeled TSw2 (Table B-2). As will be discussed later, limited calculations examining the sensitivity of results to variations in Young's Modulus and Poisson's Ratio were also completed.

Table B-2. Mechanical Properties Used to Represent an Elastic TSw2 Rock Mass

Property	Nominal Value
Young's Modulus[a]	12.66 GPa
Poisson's Ratio[b]	0.22
Density[c]	2.297 g/cm^3

[a]Consistent with the reported 12.55 GPa reported in Brechtel et al. 1995
[b]Mean value for TSw2 reported in the RIB
[c]Mean value for TSw2 reported in the RIB for in situ saturation

B.2.4 COEFFICIENT OF THERMAL EXPANSION

The assumed coefficient of thermal expansion was obtained from available site specific thermal expansion data for samples from North Ramp Geologic (NRG) drill holes 5 and 6 (TDIFs 303285 and 304353). Test data for TSw2 samples from NRG 5 and NRG 6, that were subjected to various initial preparations and test processes, were examined (Table B-3). Figure B-3 presents the measured coefficients of thermal expansion (CTE) for these samples.

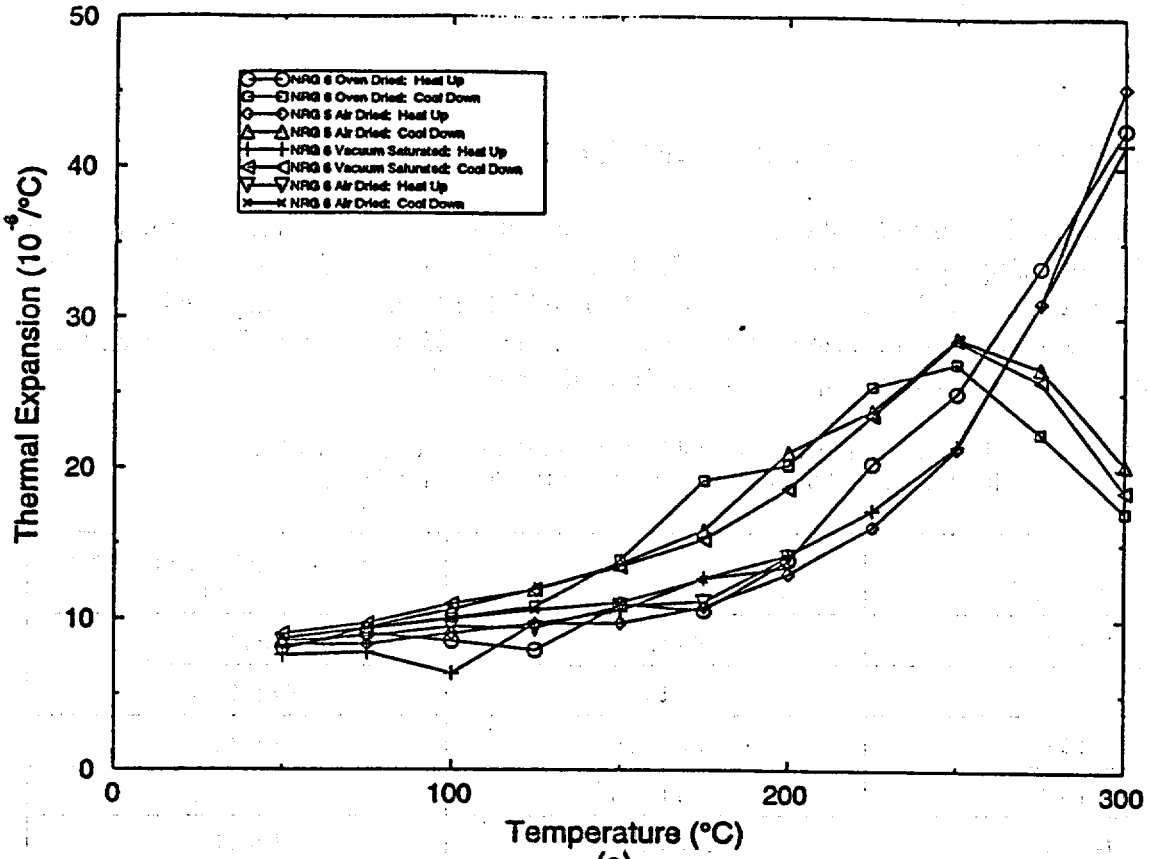
Table B-3. Summary of Thermal Expansion Samples Used to Define the Coefficient of Thermal Expansion for Use in the Model

Source of Sample	Initial Sample Preparation State	Process During Which Data Were Taken
NRG 5	Air Dried	Heat Up
NRG 5	Air Dried	Cool Down
NRG 6	Air Dried	Heat Up
NRG 6	Air Dried	Cool Down
NRG 6	Oven Dried	Heat Up
NRG 6	Oven Dried	Cool Down
NRG 6	Vacuum Saturated	Heat Up
NRG 6	Vacuum Saturated	Cool Down

As shown in Figure B-3, the NRG 6 oven dried data appear to be representative of the entirety of the CTE data and were therefore selected as the baseline CTE data for use in evaluating the effect of the near-field mechanical response to an imposed temperature field. Figure B-3b shows the relationship between the NRG-6 oven dried data and overall maximum and minimum data points. Simulations examining the effect an alternate definition of CTE will be presented later.

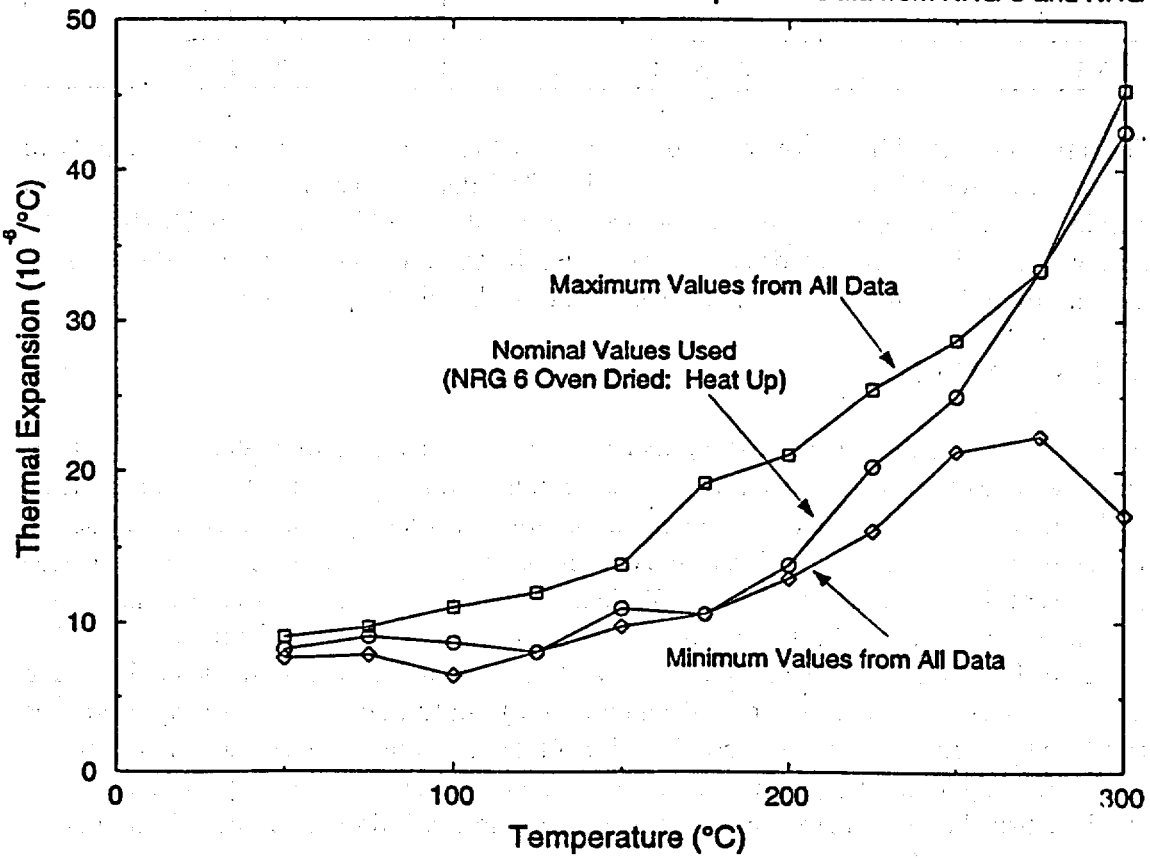
B.2.5 THERMAL FIELD

To realistically approximate the steep near-field thermal gradients that are anticipated at early times in the repository, an algorithm was created to generate imposed temperature fields. The algorithm is based loosely on the solution to the time-dependent, one-dimensional cylindrical heat conduction equation. The solution of the spatial portion of the one-dimensional problem is a linear combination of Bessel functions of the first and second kind (Wylie and Barrett 1982). For extreme values of the argument, in this case position, the functions can be approximated as exponentials. For other regions, the Bessel functions may be approximated as linear combinations of sines, cosines, and hyperbolic sines and cosines (Abramowitz and Stegun 1972). In turn, each of these trigonometric functions can be approximated by some combination of exponentials. Given that it is not the purpose of this investigation to provide a detailed temperature solution, but instead to assess near-field stability based on reasonable temperature distributions within the solution domain, the



(a)

Figure B-3a. Instantaneous Coefficient of Thermal Expansion Data from NRG-5 and NRG-6



(b)

Figure B-3b. Nominal and Bounding Thermal Expansion Data

algorithm for generating the imposed temperature was formulated as a simple exponential. The imposed temperature is determined as a function of distance, r, from the center of the drift as:

$$T = \left(T_{drift} - T_{ambient}\right) e^{\left[\mu\left(1-\frac{r}{R_o}\right)\right]} + T_{ambient} \tag{1}$$

where R_o is the drift radius, T_{drift} is the temperature at the drift wall, $T_{ambient}$ the initial ambient temperature within the rock mass, and μ is a multiplier to impose different gradients.

Four values of μ were investigated in this study: 0.5, 1.0, 2.0, and 3.0. As an example of the shapes of the radial profiles generated using these μ values, Figure B-4 was generated for a drift-wall temperature of 225°C and an ambient rock temperature of 25°C. It is clear that large μ represents the steep gradients expected at early times following waste emplacement. As μ decreases, the imposed thermal profiles become more similar in shape to later-time host-rock responses. Thus, μ is proportional to the inverse of time.

B.2.6 FAILURE CRITERIA

The compressive failure criterion for the TSw2 rock mass was developed based on the approach described in Hardy and Bauer (1991). This approach uses the intact rock strengths, the rock mass quality indices, and two empirical rock mass strength criteria proposed by Hoek and Brown (1988) and Yudhbir et al. (1983). A power law relationship of the form:

$$\sigma_1 = A + B\sigma_3^C \tag{2}$$

is developed by fitting the resulting average strength envelopes to describe the strength confinement response; where σ_3 is the confinement pressure or overburden; A, B and C are fitted constants, and σ_1 is the rock-mass compressive strength. Table B-4 presents the power law coefficients for TSw2 based on available NRG site data (TDIF 303849). For this study, a rock mass category of 3 (Hardy and Bauer 1991) was chosen to represent nominal conditions expected at the Yucca Mountain Site.

Using the power law coefficients for a rock mass category of 3 in equation 1 results in a rock-mass compressive strength of 56 MPa.

In addition to a rock-mass compressive failure criterion, a tensile failure criterion is needed. The tensile stress criterion of one-half the joint criterion, adopted in Hardy and-Bauer (1991), will be used in this study. The joint cohesion for TSw2 of 18.9 MPa, defined in Lin et al. (1993), was used to define a compressive failure criterion of 9.4 MPa.

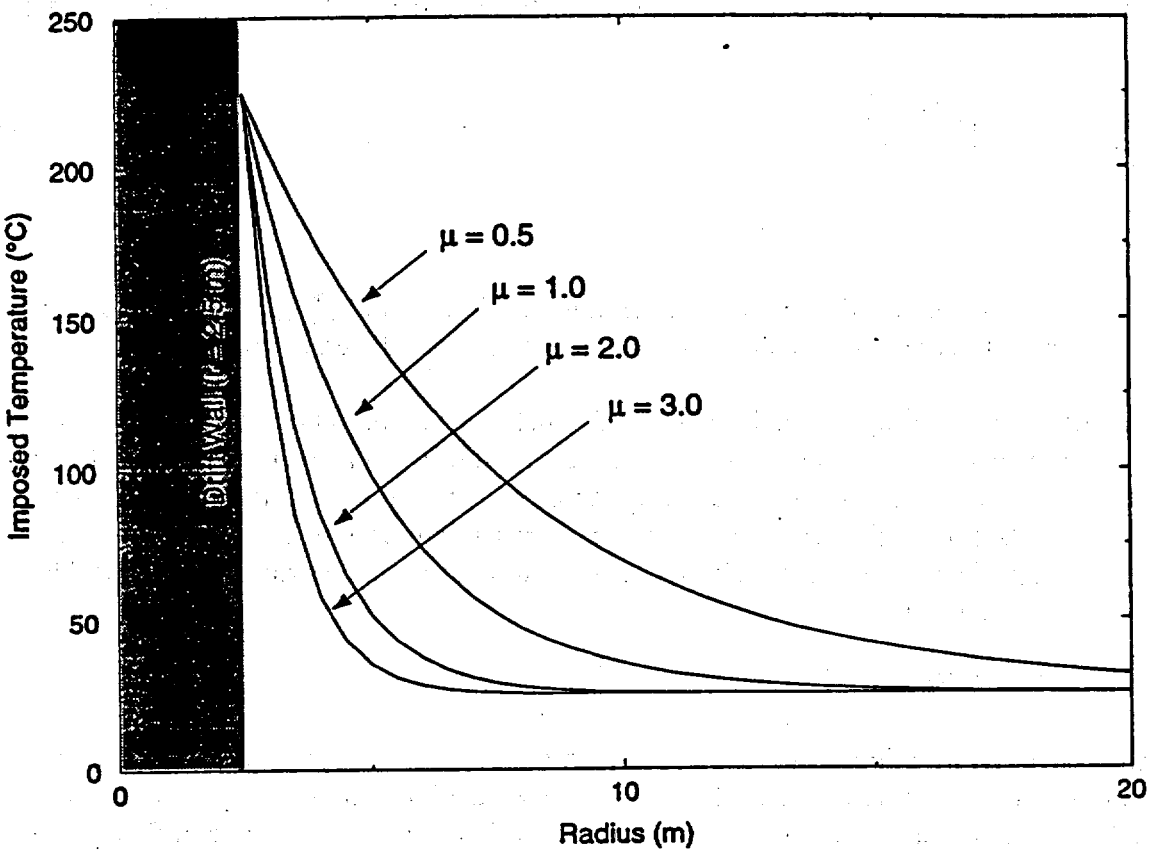


Figure B-4. Example of Gradients Examined in Study

Table B-4. Power Law Constants for TSw2 Rock Mass Strength

	Rock Mass Category				
Coefficient	1	2	3	4	5
A (MPa)	4.56	6.58	9.53	12.99	18.88
B (MPa)	10.68	10.65	10.55	10.40	10.17
C	0.69	0.70	0.72	0.73	0.74
σ_1(MPa)	48.8	51.6	56.0	59.8	65.6

B.3 RESULTS

Figures B-5 through B-8 present the maximum principal stress contours for imposed temperature gradients defined by a drift wall temperature of 200°C, an ambient rock temperature of 25°C, and the four values of μ discussed in Section B.2.5. No tensile failure is predicted in the modeled domain.

Figures B-9 through B-12 are constructed to provide contours at the compressive failure values, thereby identifying regions of compressive failure. As shown in the compressive failure plots (Figures B-9 through B-12), no significant compressive failure is predicted near the drift.

Increasing the drift wall temperature to 225°C, Figures B-13 through B-16 present the maximum principal stress contours for the four gradients examined. As with the previous case, no tensile failure is predicted for these simulations. Applying the compressive failure criterion, however, results in an increase in predicted compressive failure zones for all gradients examined (Figures B-17 through B-20); the greater the volume of rock heated the more expansion is produced and the greater the failure.

These results which assume conservative boundary conditions, tend to indicate that a 200°C drift-wall temperature goal is appropriate for limiting the potential for near-field rock failure regardless of gradient. For drift wall temperatures above 200°C, compressive failure is predicted, the amount of which is dependent upon temperature gradient. The initiation of significant failure appears to be primarily linked to the drift wall temperature, the transition from no failure to significant failure occurring somewhere between 200°C and 225°C. This conclusion is based on a number of assumptions related to material properties and constitutive models. The following sections will examine the sensitivity of this conclusion to changes in the coefficient of thermal expansion, Poisson's Ratio, Elastic Modulus, and constitutive model.

B.3.1 SENSITIVITY TO ASSUMED CTE

While the NRG 6 oven-dried, heat-up data were chosen as representative of the CTE for TSw2, Figure B-3 presents a relatively wide range of data values. To provide an understanding of the effect alternate values for CTE might have on predicted failure, the simulations presented in Figures B-5 through B-20 were repeated with the maximum values of CTE (Figure B-3b) used instead of the NRG 6 oven-dried data.

Figures B-21 through B-24 present the predicted compressive failure zones for the four values of μ assuming a drift wall temperature of 200°C. Comparing these figures to Figures B-9 through B-12, it is apparent that using the upper-bound of the CTE data results in significant predicted failure at a temperature that was previously showing no failure. This trend is echoed in Figures B-25 through B-28, which show an increase in predicted failure over that presented in Figures B-17 through B-20 for the four values of μ and a drift-wall temperature of 225°C. The relative amounts of compressive failure increase with decreasing μ (i.e., shallower gradients).

This result is not surprising. A higher coefficient of thermal expansion will produce more stress for a given temperature field. Examination of the maximum principal stress plots for the 200°C wall temperature cases based on the NRG 6 CTE description, shows that the maximum principal stresses generated are close to the compressive failure criterion. Thus, there is only a small factor of safety associated with these results, and small increases in the assumed coefficient of thermal expansion is sufficient to result in predictions of compressive failure.

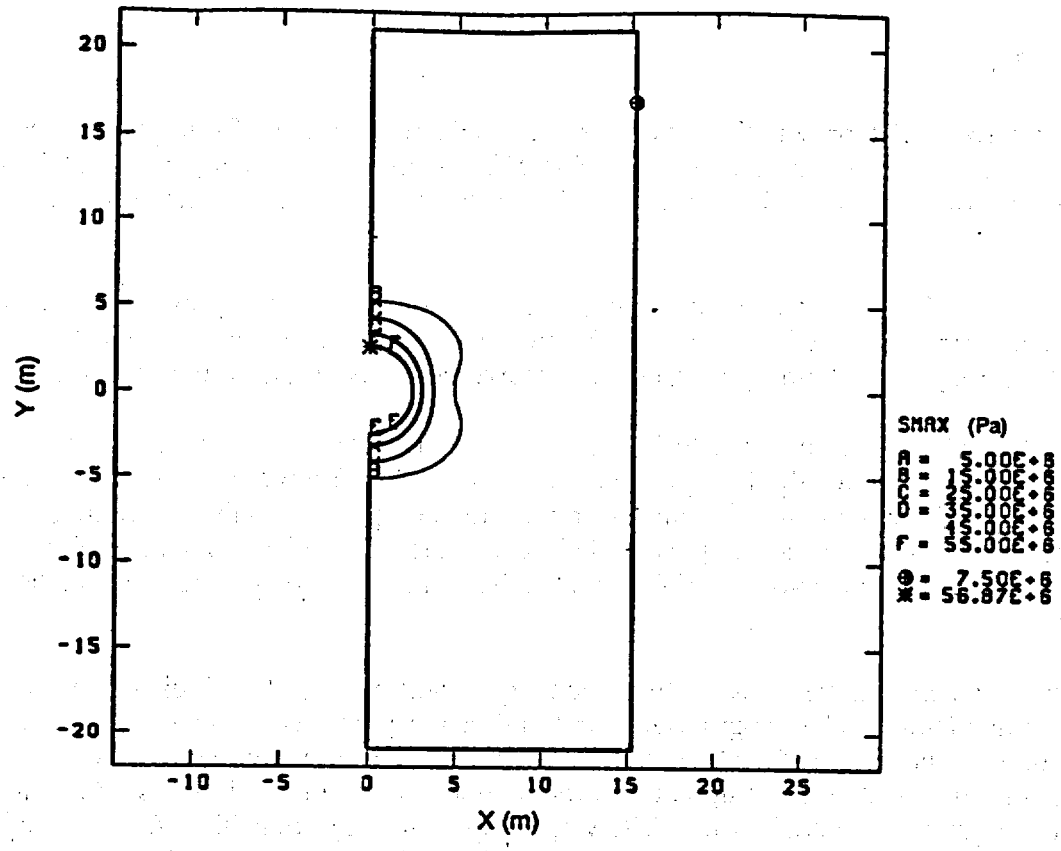


Figure B-5. Maximum Principal Stresses for a Drift Temperature of 200°C and a μ of 0.5

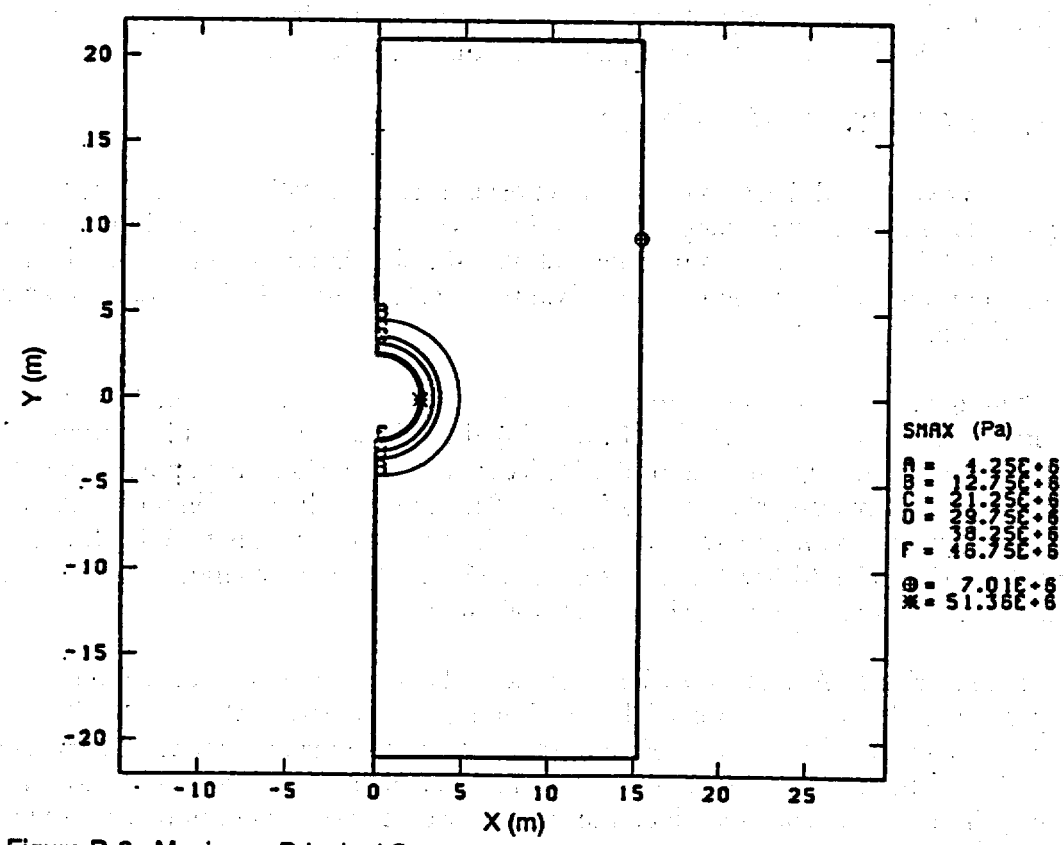


Figure B-6. Maximum Principal Stresses for a Drift Temperature of 200°C and a μ of 1.0

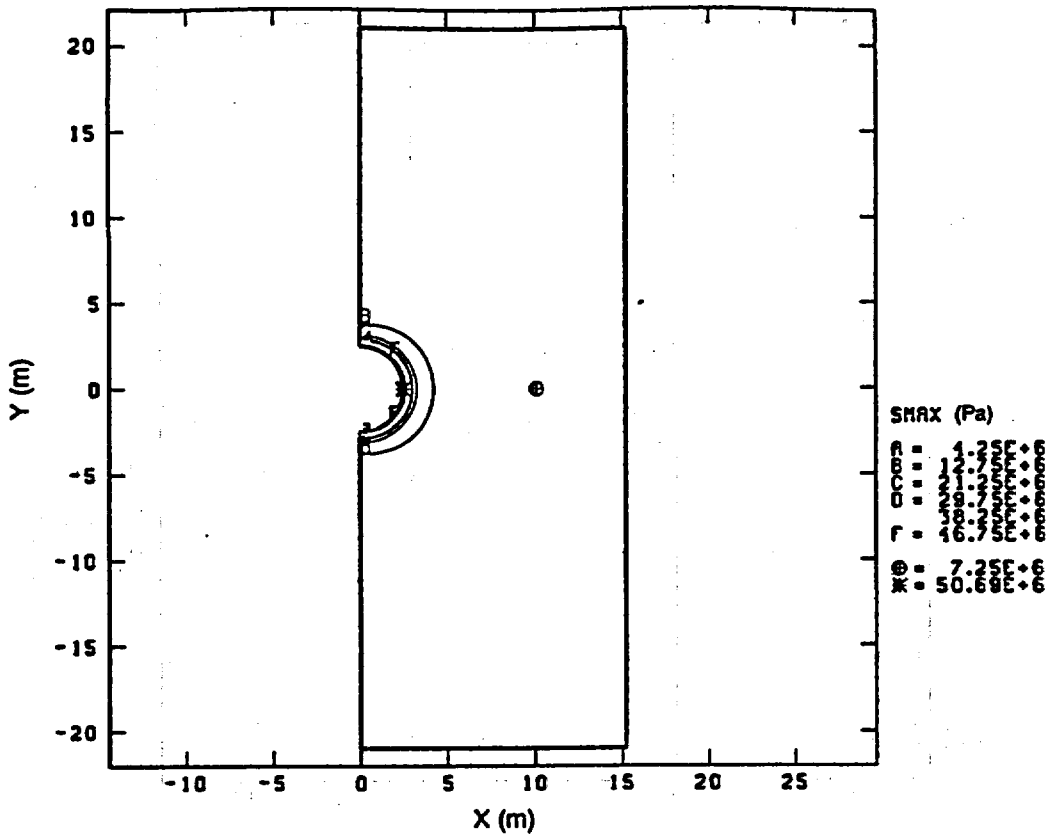


Figure B-7. Maximum Principal Stresses for a Drift Temperature of 200°C and a μ of 2.0

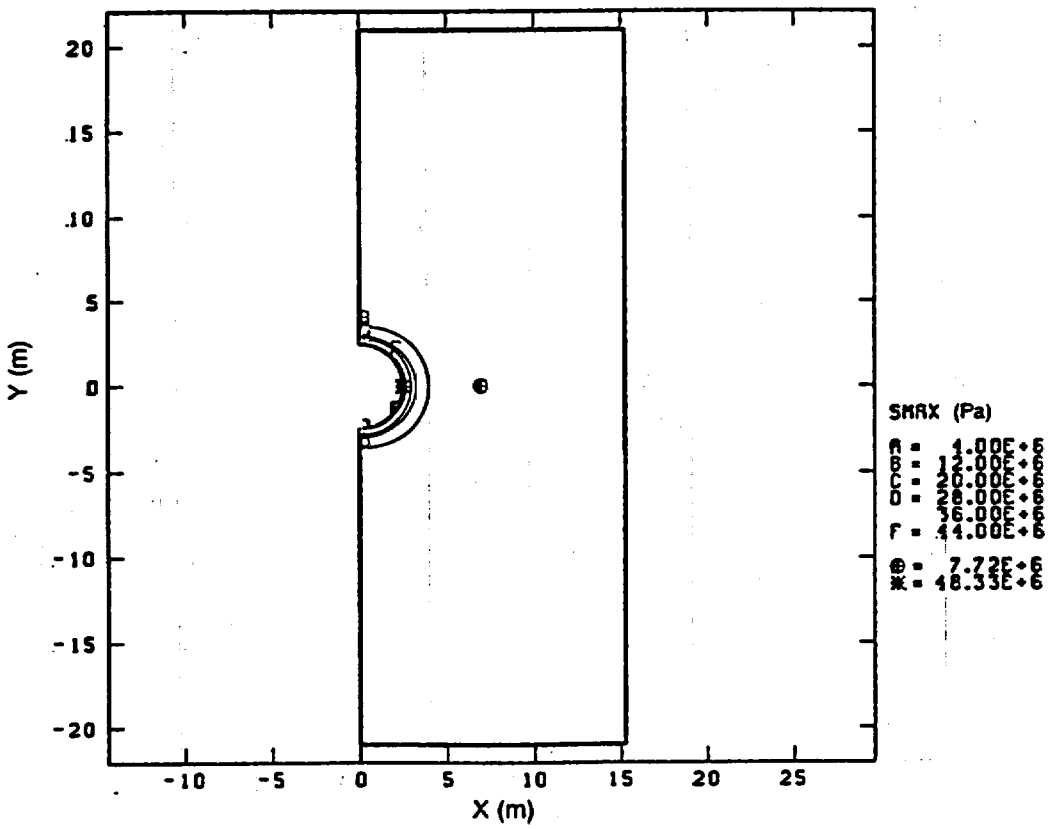


Figure B-8. Maximum Principal Stresses for a Drift Temperature of 200°C and a μ of 3.0

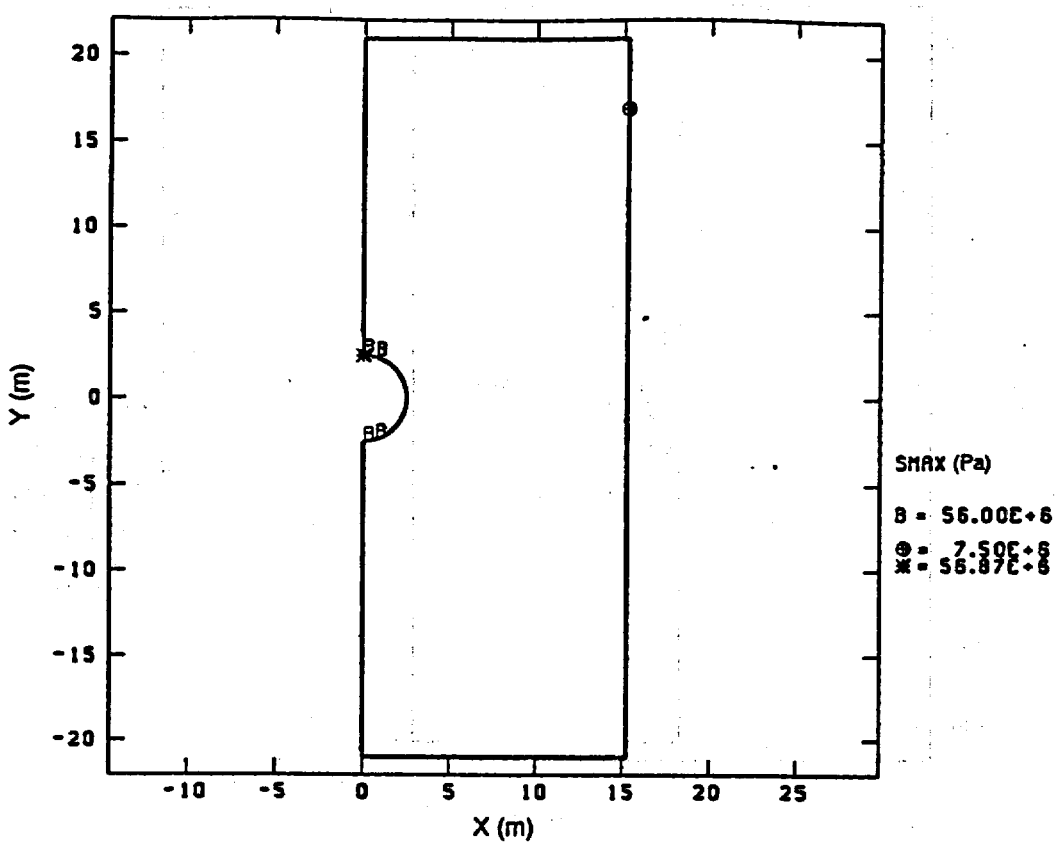


Figure B-9. Compressive Failure Zones for a Drift Temperature of 200°C and a μ of 0.5

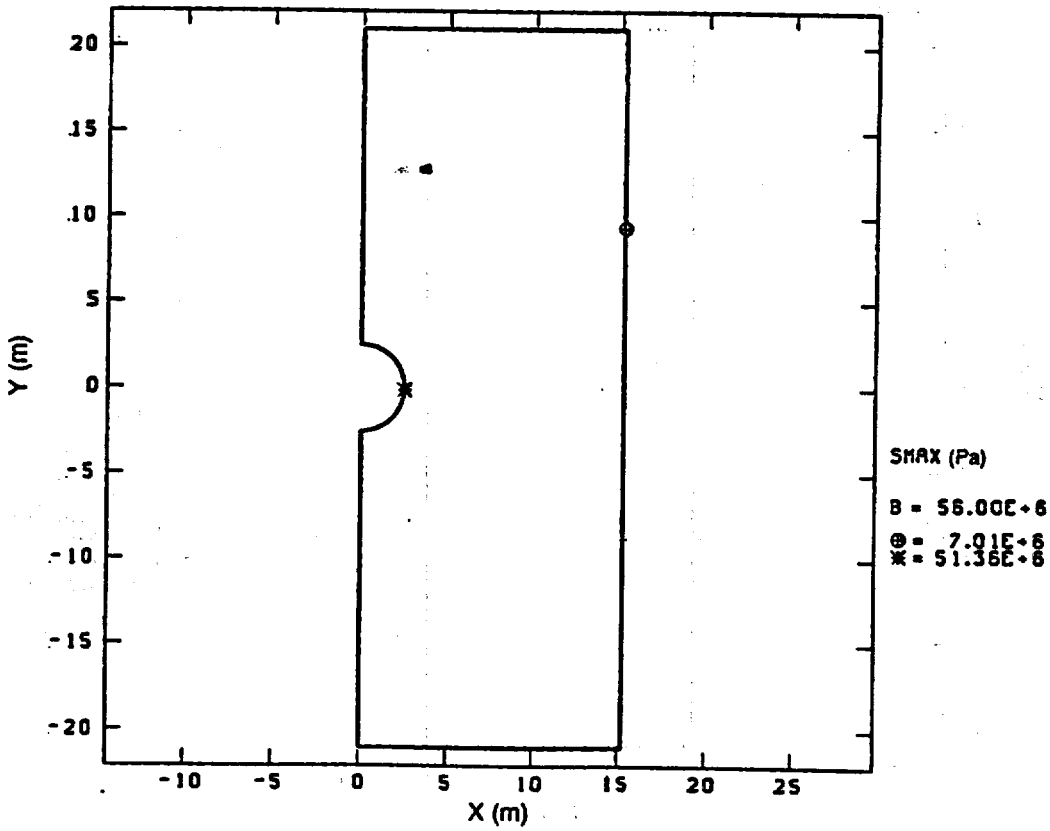


Figure B-10. Compressive Failure Zones for a Drift Temperature of 200°C and a μ of 1.0

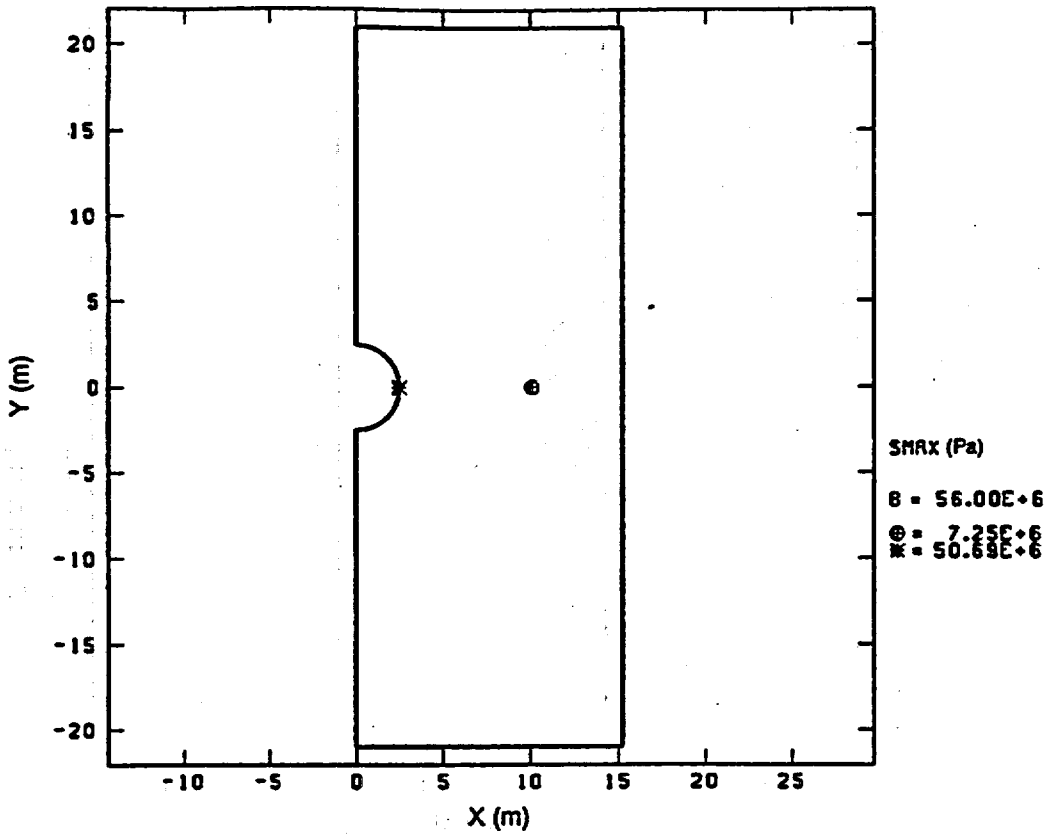


Figure B-11. Compressive Failure Zones for a Drift Temperature of 200°C and a μ of 2.5

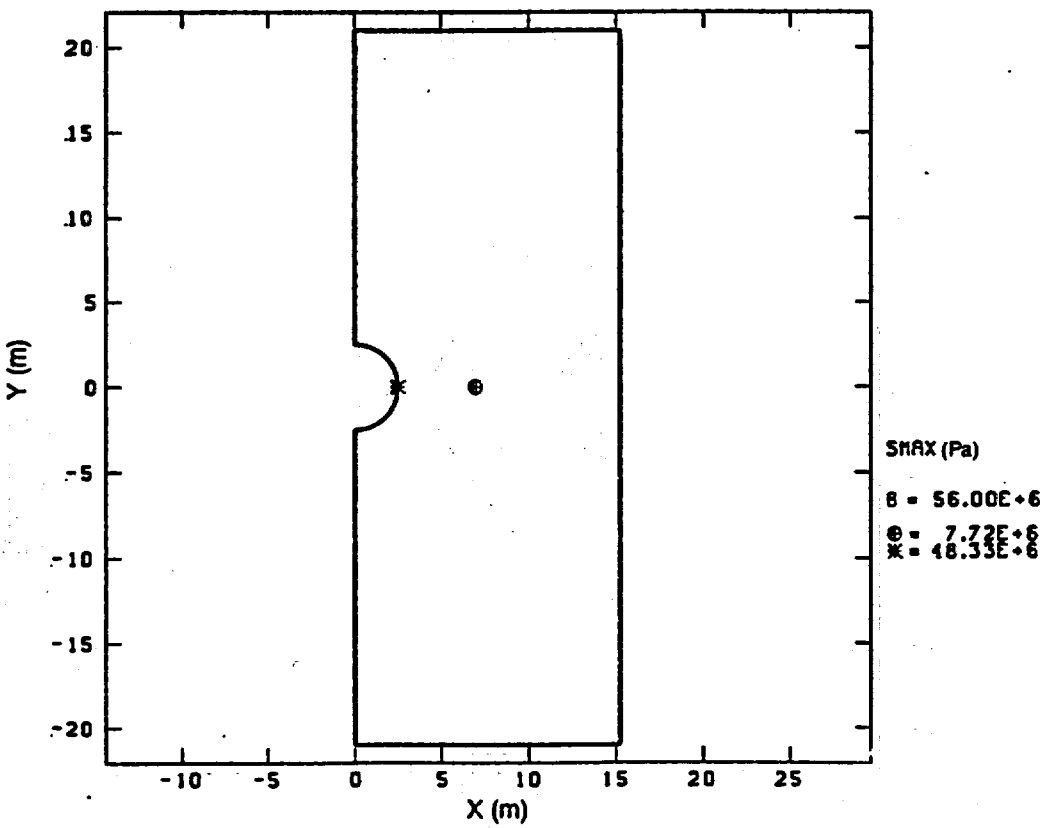


Figure B-12. Compressive Failure Zones for a Drift Temperature of 200°C and a μ of 3.0

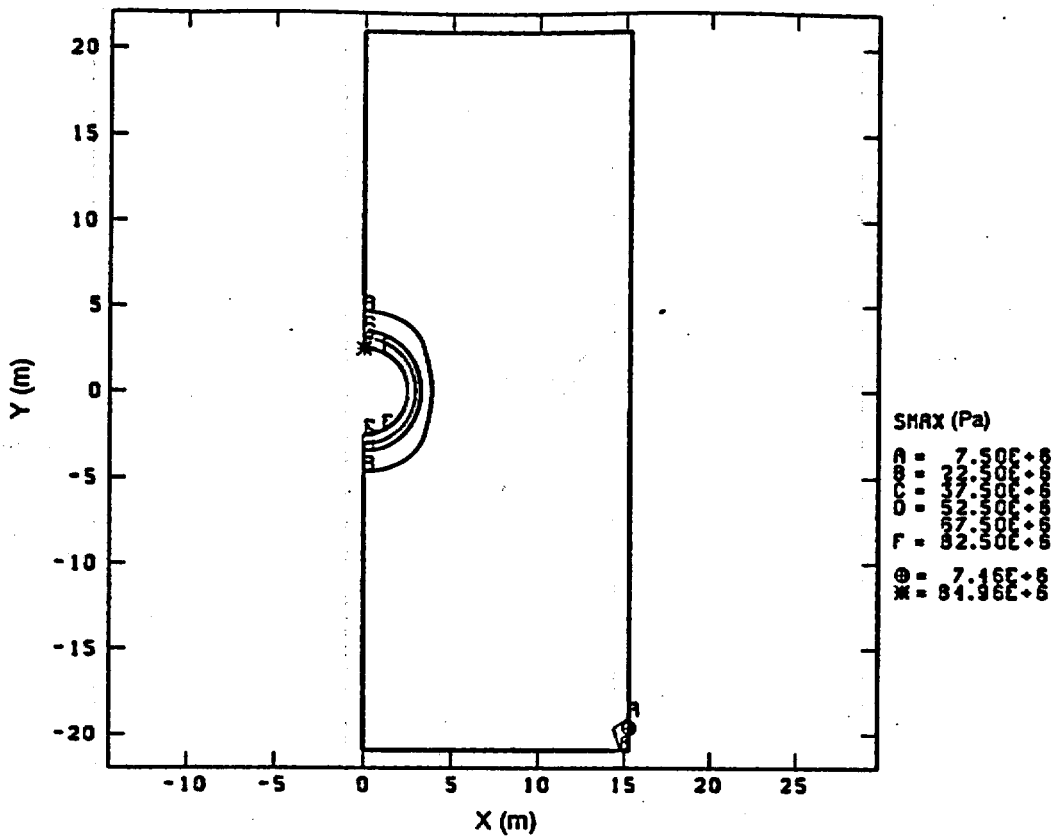


Figure B-13. Maximum Principal Stresses for a Drift Temperature of 225°C and μ of 0.5

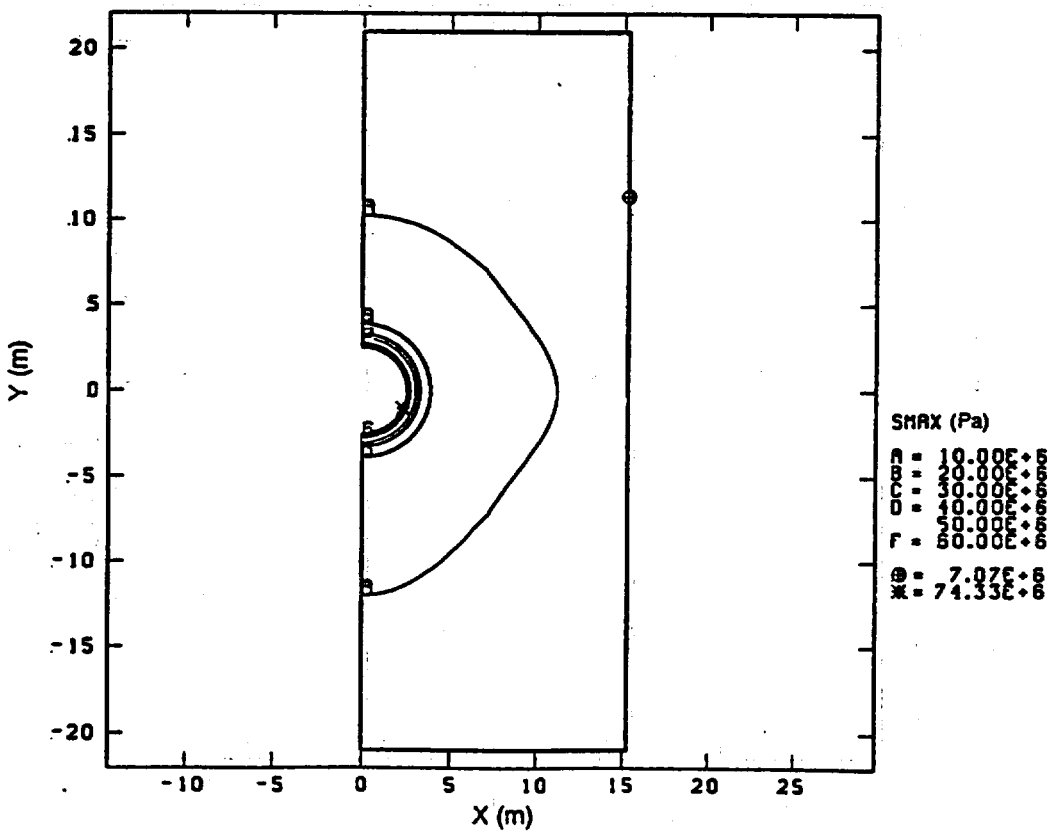


Figure B-14. Maximum Principal Stresses for a Drift Temperature of 225°C and μ of 1.0

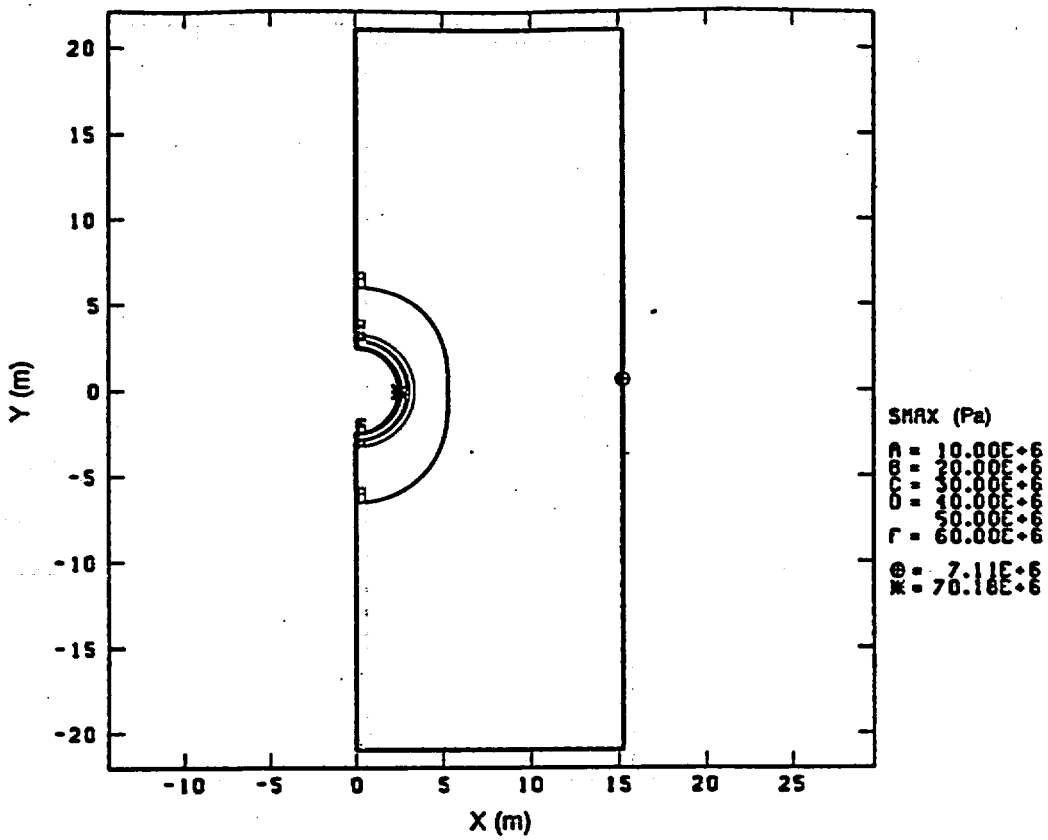


Figure B-15. Maximum Principal Stresses for a Drift Temperature of 225°C and μ of 2.0

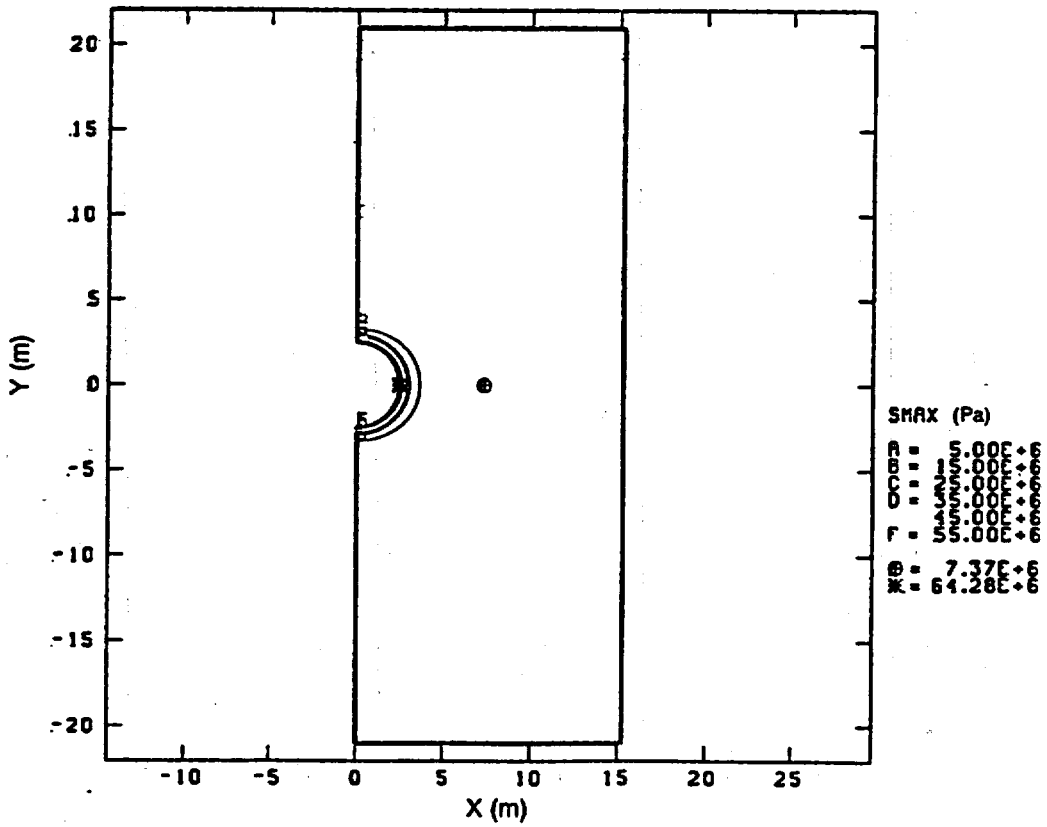


Figure B-16. Maximum Principal Stresses for a Drift Temperature of 225°C and μ of 3.0

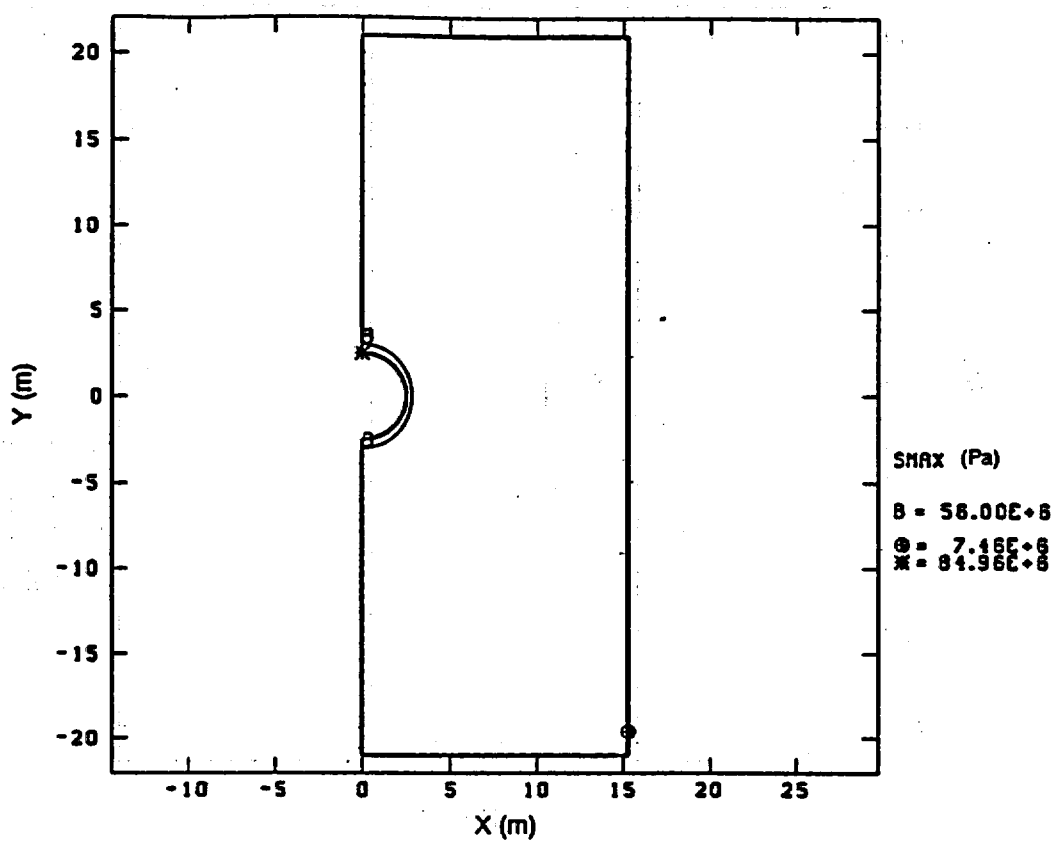


Figure B-17. Compressive Failure Zones for a Drift Temperature of 225°C and a μ of 0.5

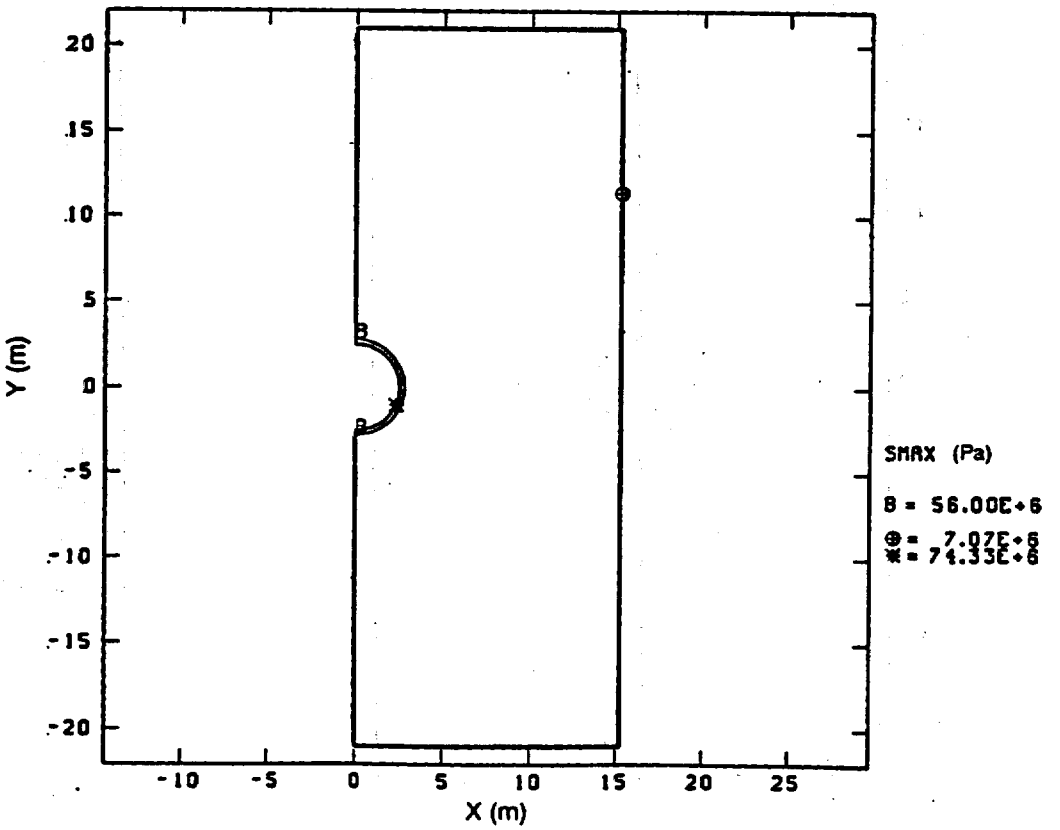


Figure B-18. Compressive Failure Zones for a Drift Temperature of 225°C and a μ of 1.0

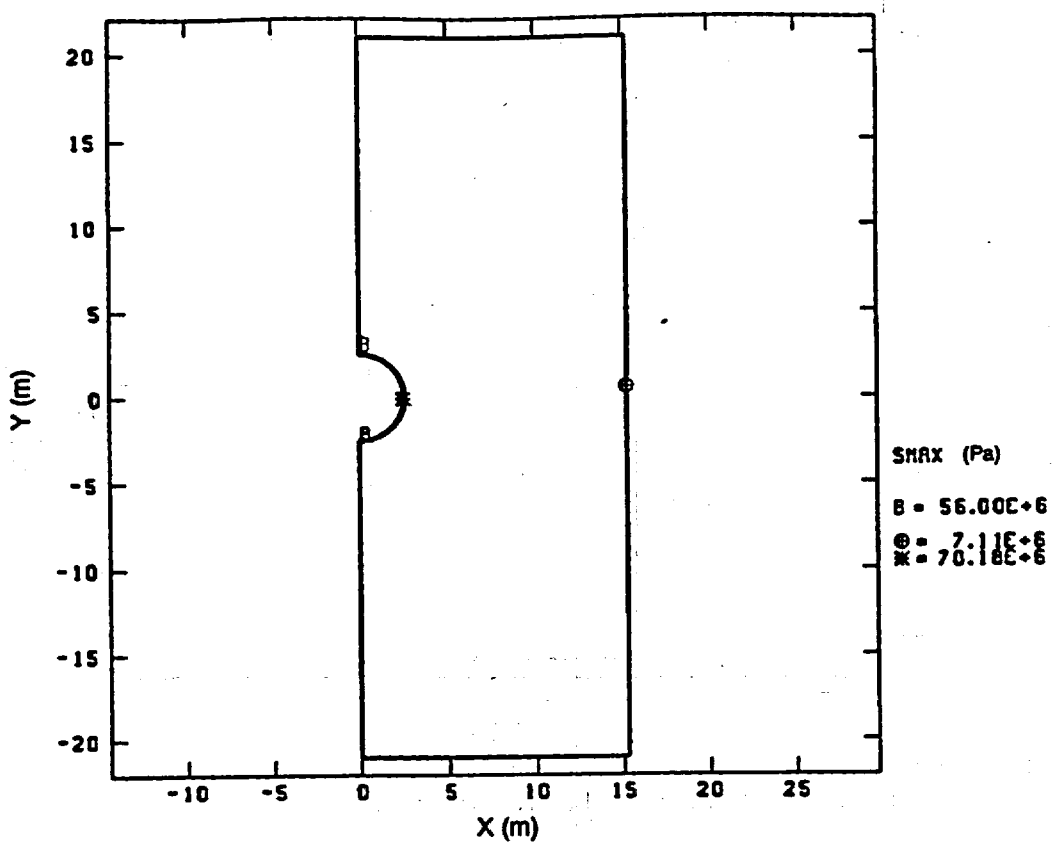


Figure B-19. Compressive Failure Zones for a Drift Temperature of 225°C and a μ of 2.0

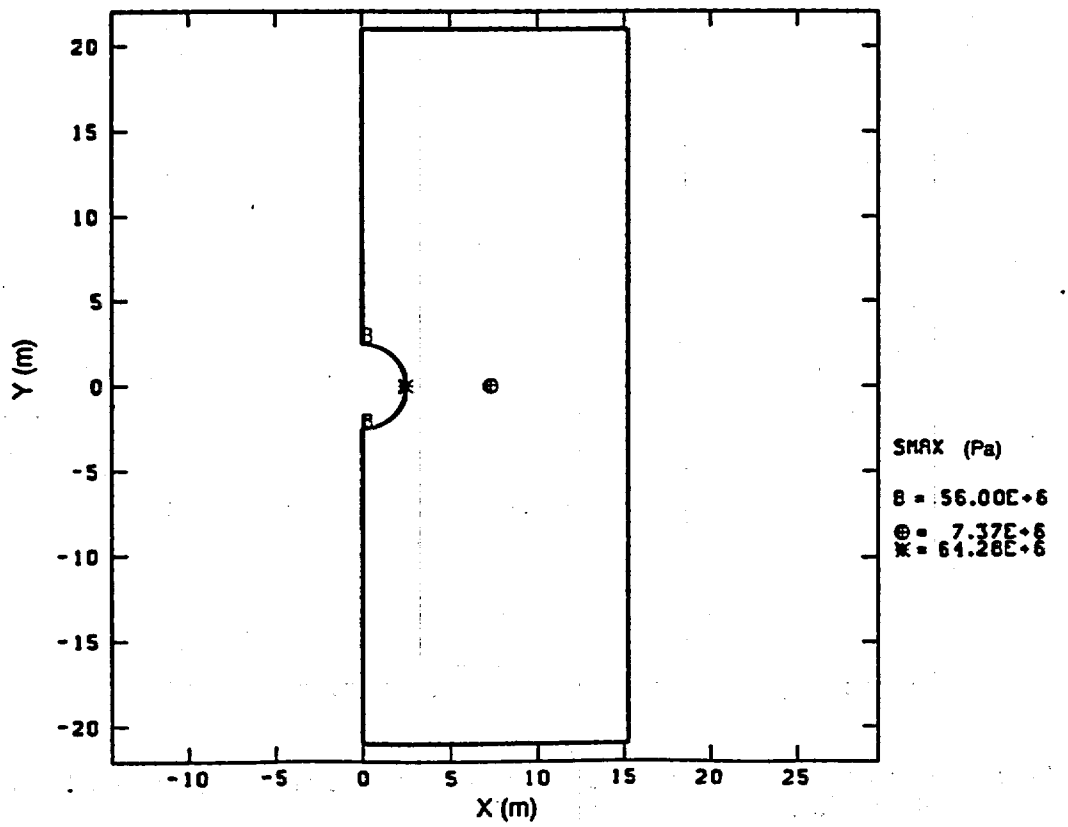


Figure B-20. Compressive Failure Zones for a Drift Temperature of 225°C and a μ of 3.0

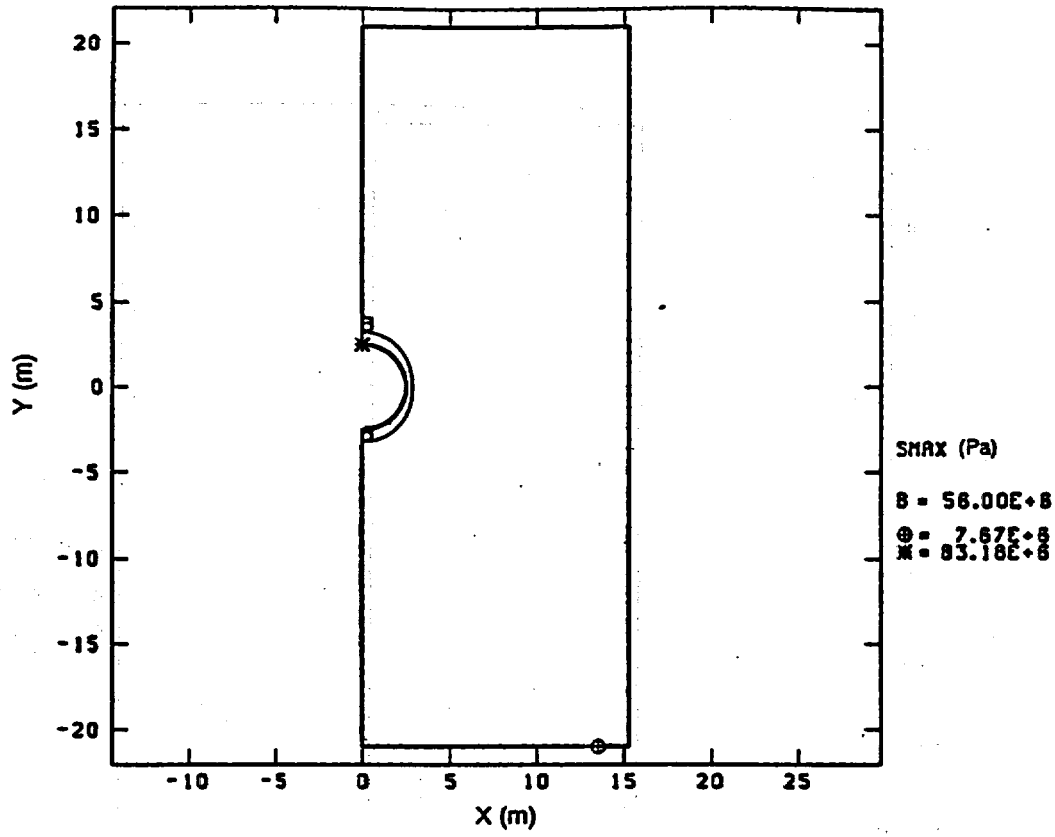


Figure B-21. Compressive Failure Zones for a Drift Temperature of 200°C, a μ of 0.5, and Maximum Values for the Coefficient of Thermal Expansion

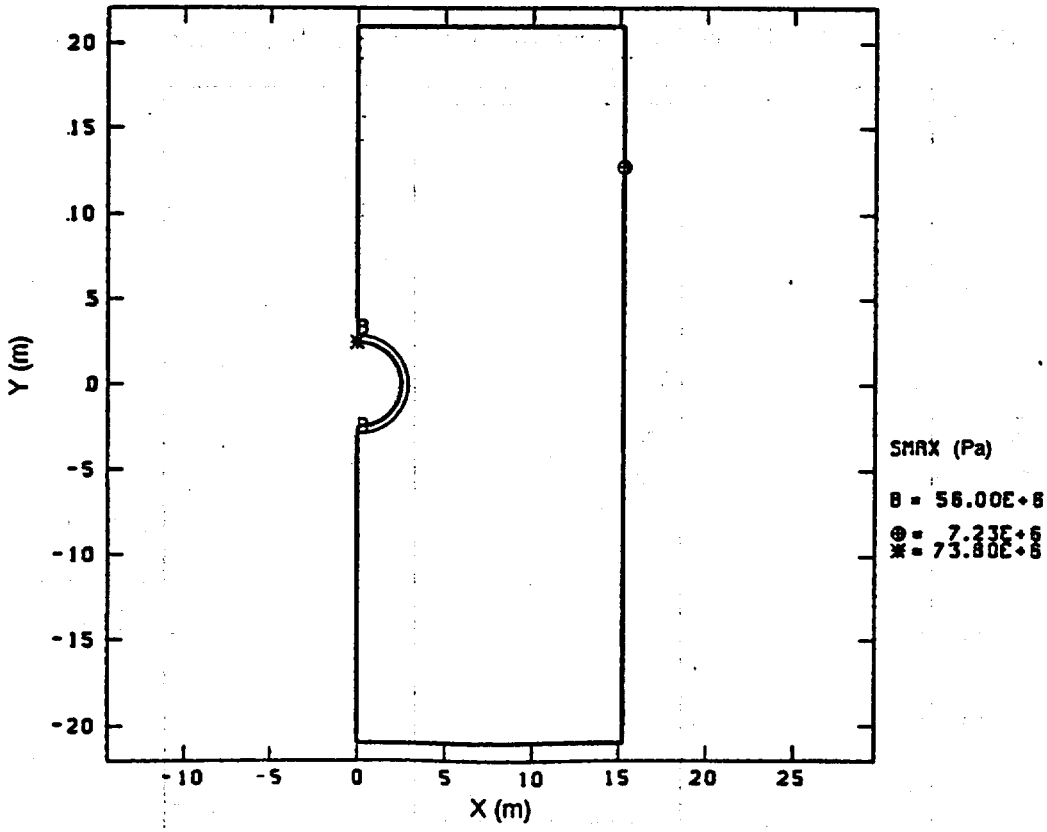


Figure B-22. Compressive Failure Zones for a Drift Temperature of 200°C, a μ of 1.0, and Maximum Values for the Coefficient of Thermal Expansion

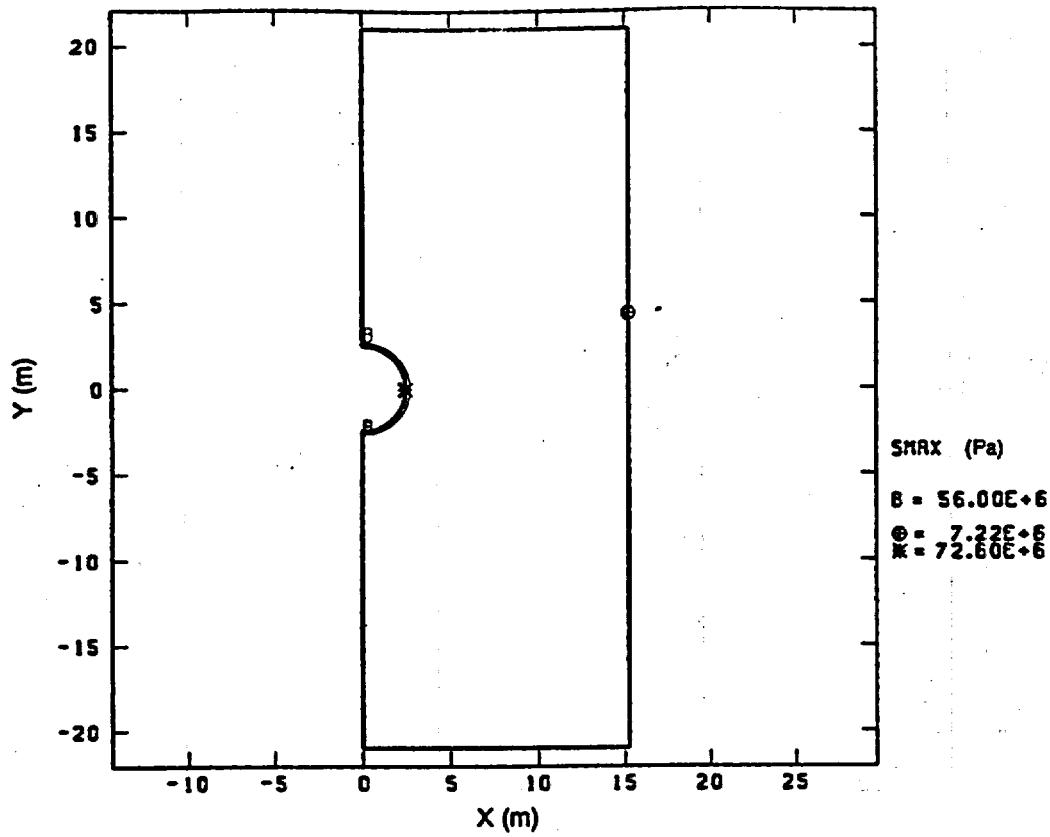


Figure B-23. Compressive Failure Zones for a Drift Temperature of 200°C, a μ of 2.0, and Maximum Values for the Coefficient of Thermal Expansion

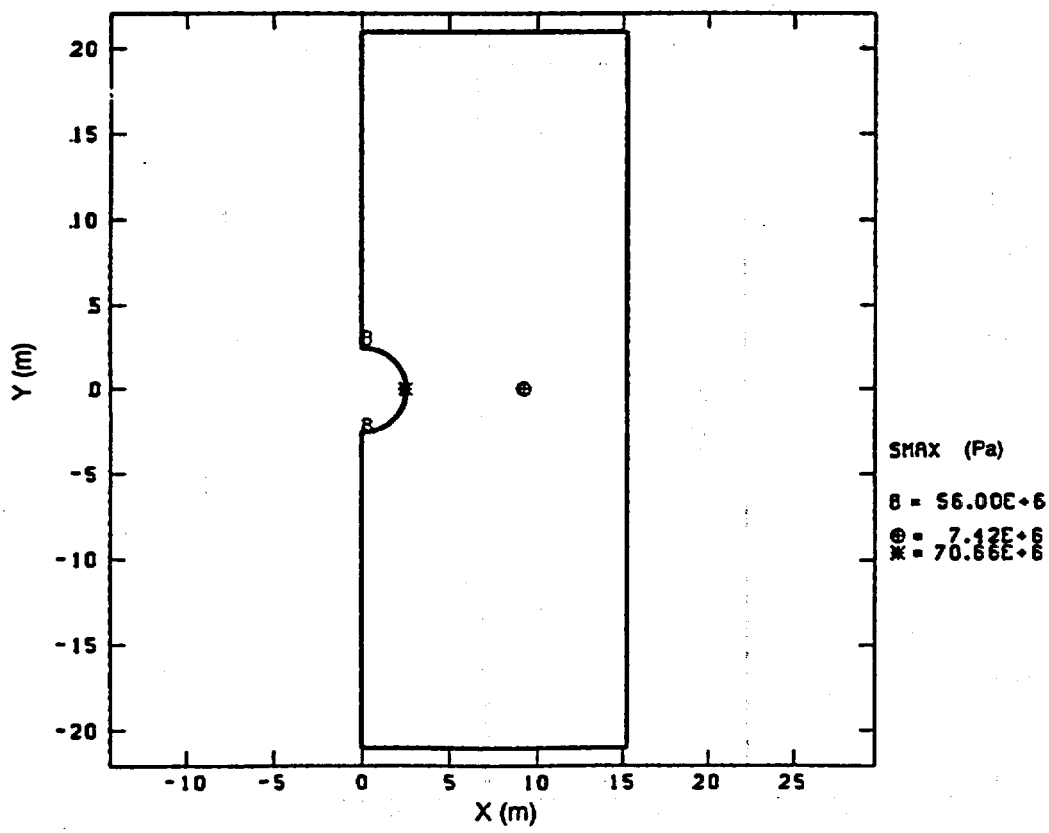


Figure B-24. Compressive Failure Zones for a Drift Temperature of 200°C, a μ of 3.0, and Maximum Values for the Coefficient of Thermal Expansion

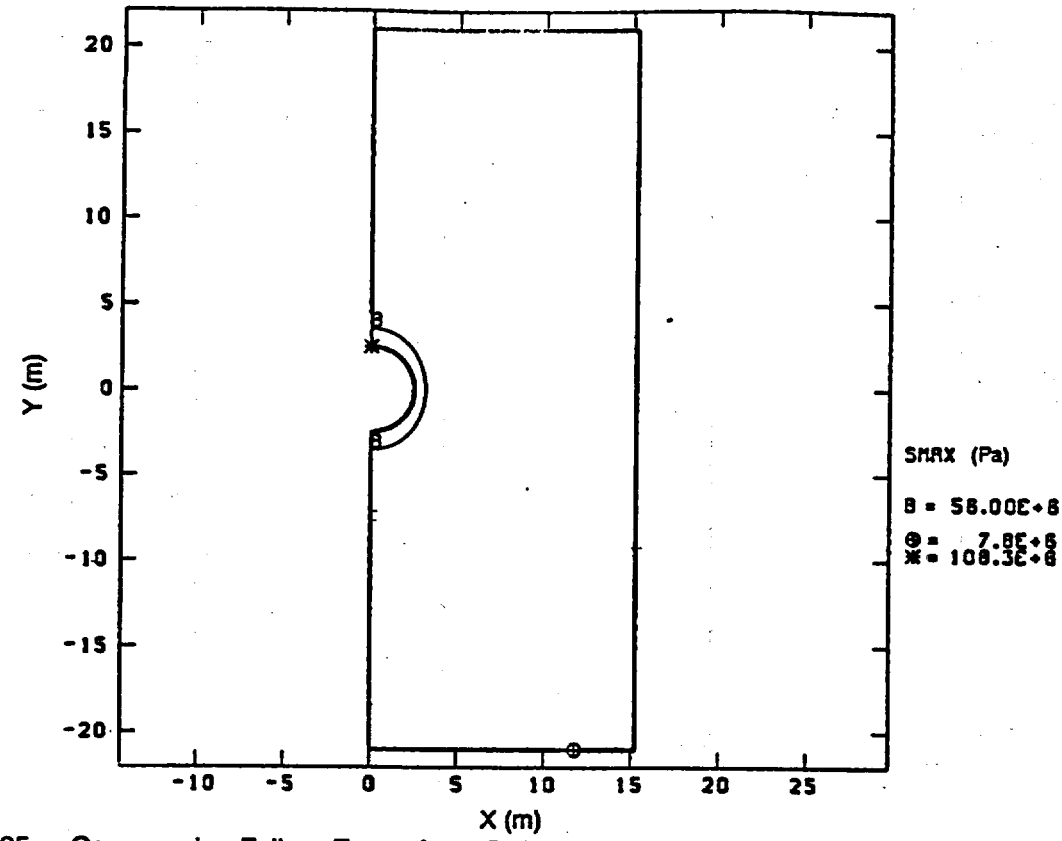


Figure B-25. Compressive Failure Zones for a Drift Temperature of 225°C, a μ of 0.5, and Maximum Values for the Coefficient of Thermal Expansion

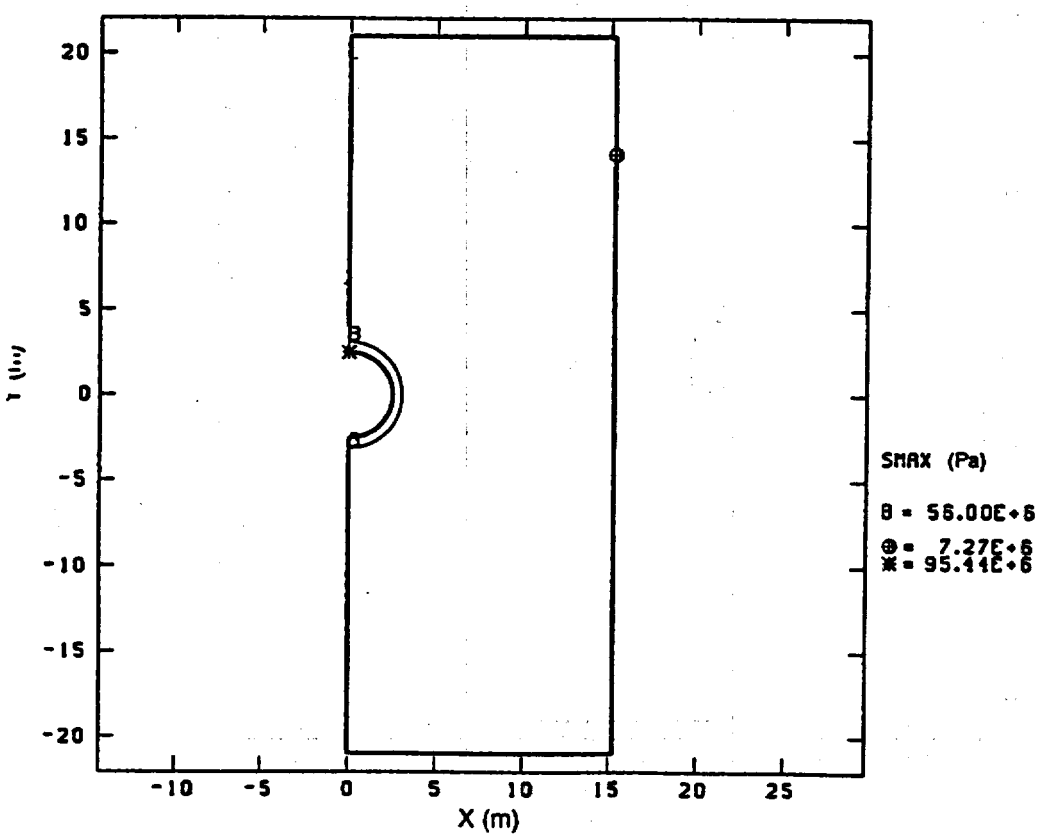


Figure B-26. Compressive Failure Zones for a Drift Temperature of 225°C, a μ of 1.0, and Maximum Values for the Coefficient of Thermal Expansion

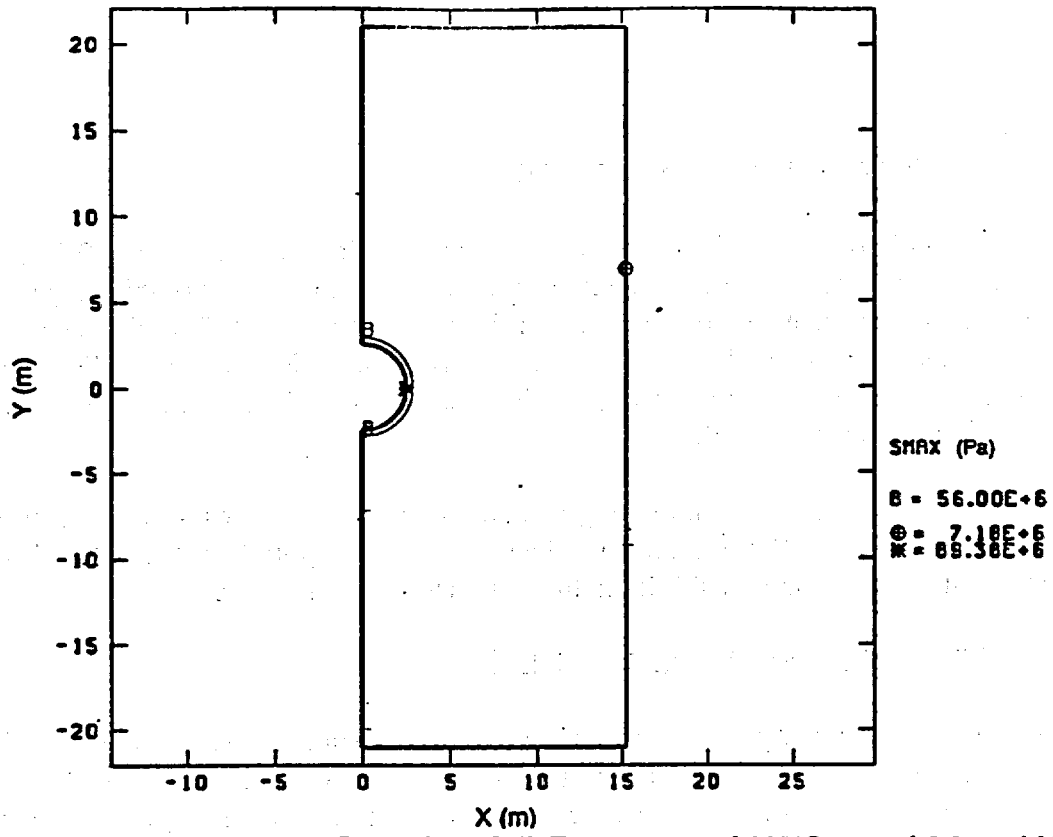


Figure B-27. Compressive Failure Zones for a Drift Temperature of 225°C, a μ of 2.0, and Maximum Values for the Coefficient of Thermal Expansion

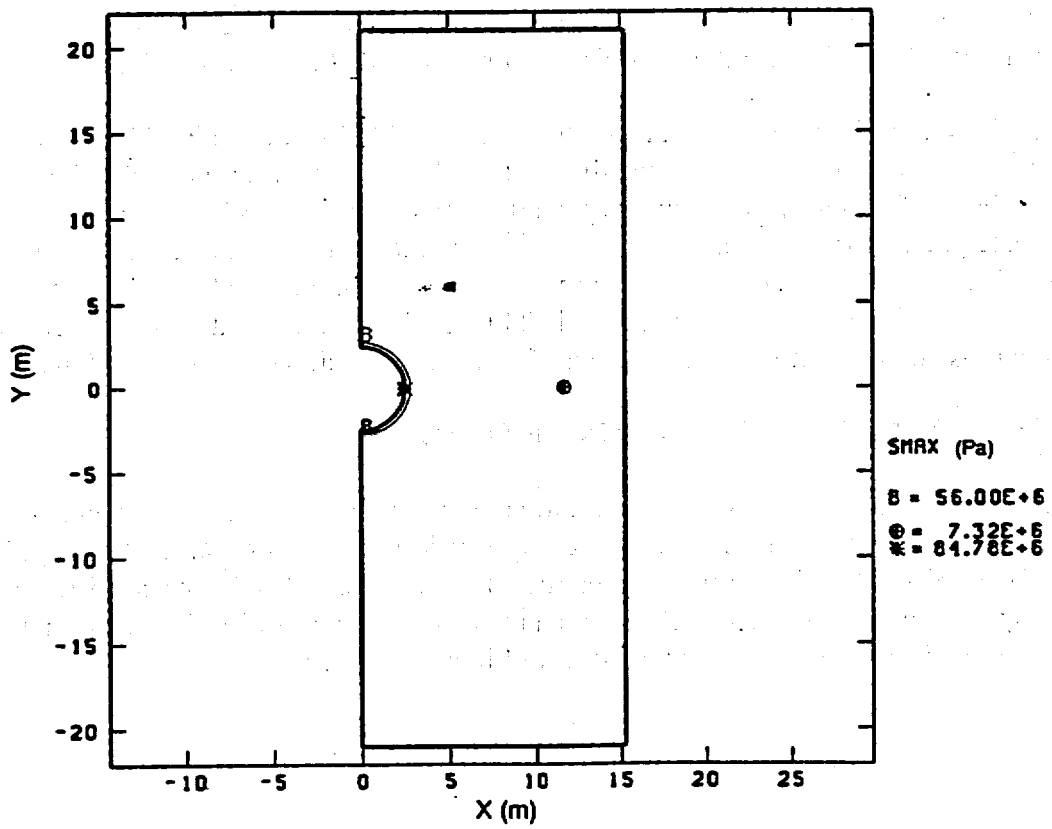


Figure B-28. Compressive Failure Zones for a Drift Temperature of 225°C, a μ of 3.0, and Maximum Values for the Coefficient of Thermal Expansion

B.3.2 SENSITIVITY TO POISSON'S RATIO

Available data for Poisson's Ratio from the NRG drill holes indicate that a range of 0.10 to 0.40 has been observed for TSw2. In order to quickly assess the potential impact of this range, a single branch case using a value of $\nu = 0.40$ was run. This branch case used a drift-wall temperature of 225°C, an ambient temperature of 25°C, a μ of 0.5, and an elastic modulus of 12.66 MPa. Two runs were made to assess the effect of Poisson's Ratio, the first assuming the nominal value of 0.22 and the second the extreme value of 0.40.

Figures B-29 and B-30 present the maximum principal compressive stresses for the two cases. As expected, increasing Poisson's Ratio results in an increase in the magnitude of the induced stresses. This indicates that there is some sensitivity in the results to Poisson's Ratio.

B.3.3 SENSITIVITY TO YOUNG'S MODULUS

In order to assess the sensitivity of the results presented in Section B.3 to the assumed Young's Modulus, a single case was run using a range of elastic moduli. An analysis of available site data (Brechtel et al. 1995) indicates that the TSw2 rock-mass elastic modulus can vary from 6.37 to 23.51 GPa, depending on rock mass category (Table B-5). Adopting this range for investigation, all other inputs were kept constant. To eliminate the previously observed sensitivity to CTE, the solution domain was assumed to be at a uniform temperature of 225°C. The assigned CTE for these runs was obtained from the NRG 6 data for the oven-dried sample during the heat-up cycle.

The predicted stresses in a uniform temperature field of 225°C are high. The point of this comparison, however, is to show the sensitivity of predicted results on Young's Modulus. As expected, the factor of 3.7 change in Young's Modulus over the range of rock-mass categories results in, approximately, a factor of 3.7 change in the x-component stresses. Thus, the results presented in Section B.3 should be considered sensitive to modulus. Given that the factor of safety is small for most cases where the drift wall temperature is 200°C, this indicates that minor increases in the assumed modulus could result in the generation of compressive failure zones around the drift.

B.3.4 SENSITIVITY TO CONSTITUTIVE MODEL

To assess the importance of the assumed constitutive model to the results presented in Section B.3 of this document, a run was made using the compliant-joint model option in the JAC2D code (Biffle and Blanford 1994). The compliant-joint model run was formulated to be consistent with the elastic runs by assuming a domain of TSw2 with a rock-mass category of 3. The material property input for the jointed rock model was obtained from Lin et al. (1993).

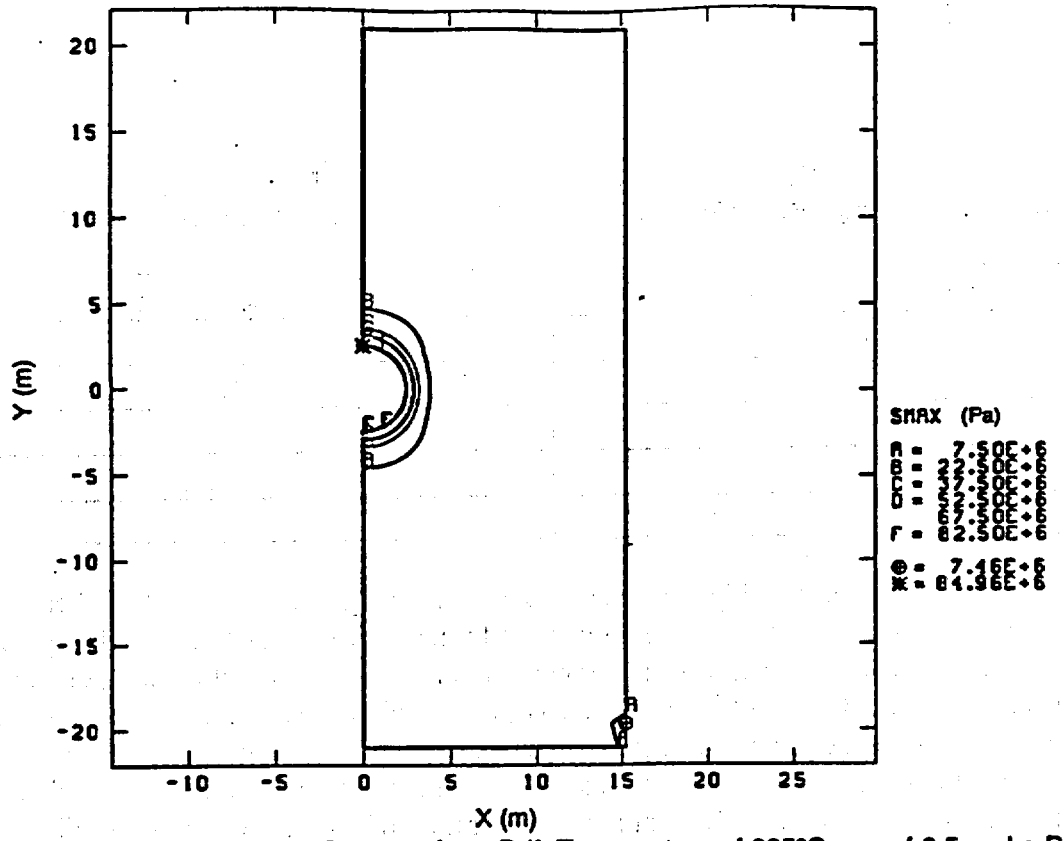


Figure B-29. Maximum Principal Stresses for a Drift Temperature of 225°C, a μ of 0.5 and a Poisson's Ratio of 0.22

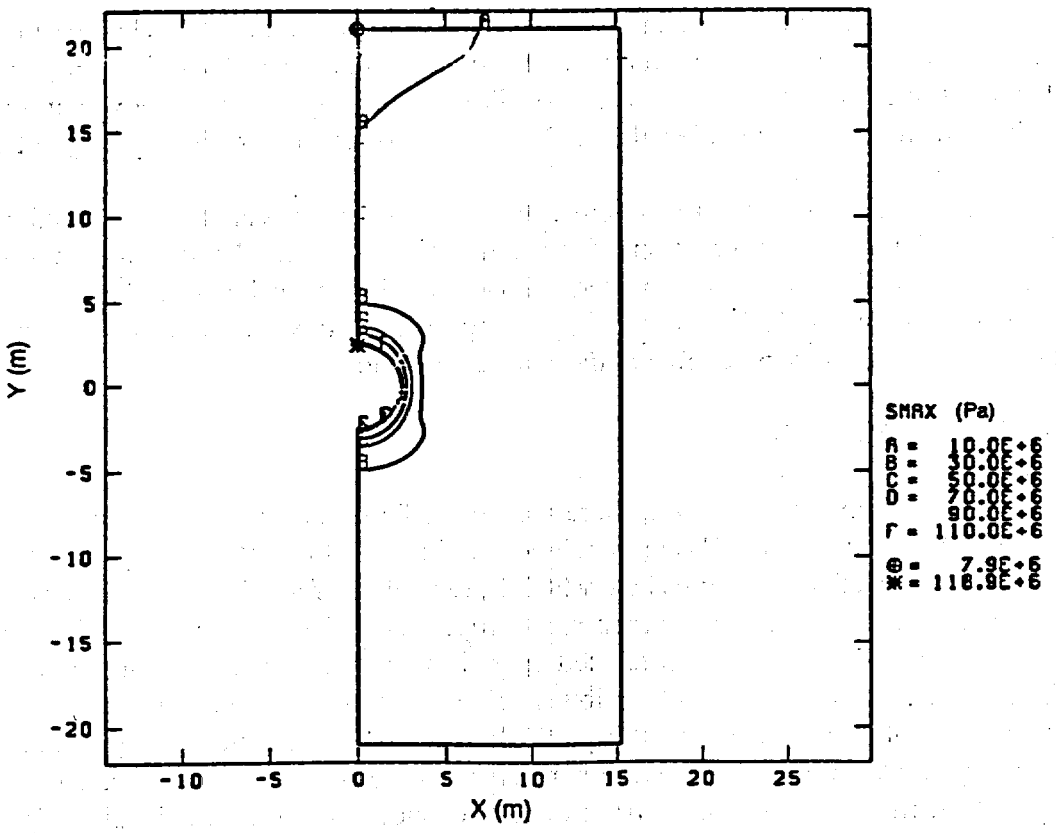


Figure B-30. Maximum Principal Stresses for a Drift Temperature of 225°C, a μ of 0.5 and a Poisson's Ratio of 0.40

Table B-5. Young's Moduli for Various Rock Mass Categories (Brechtel et al. 1995)

Rock Mass Category	Young's Modulus (GPa)
1	6.37
2	8.96
3	12.55
4	17.11
5	23.51

The compliant-joint model is a highly non-linear model. Imposing a steep thermal gradient directly to the model requires the definition of a gradual path to the desired *end-state* (in this case a steep thermal gradient). To assess the effects of a thermal field in a more expedient manner, the following approach is used. An elastic calculation previously performed is used to provide the compressive stresses along the solution boundary. The stresses are averaged along each continuous boundary to apply the thermal load as a boundary condition to the system. The temperature field was formulated for a wall temperature of 225°C, an ambient rock temperature of 25°C, and a μ of 2.0. Figure B-31 is a plot of the maximum compressive stresses predicted using the compliant-joint model.

The elastic solution obtained for a wall temperature of 225°C, a μ of 2.0, and NRG 6 coefficient of thermal expansion data, predicts maximum principal stresses on the order of 70 MPa (Figure B-15) and a small amount of elastic failure (Figure B-19). The compliant-joint model however, predicts maximum principal stresses on the order of 33 MPa (Figure B-31), and no significant joint slip.

The reason for the reduction in maximum principal stresses is that stresses are being relieved by joint closure. It is noted that the observation of no significant slip may be due to the assumed joint-orientations. Small changes in modeled joint-orientation have been known to result in significant increases in predicted slip. Therefore, pending further study, these results should not be interpreted to mean that no slip is possible at these assumed loads.

B.4 RECOMMENDATIONS

Based on the results of this investigation, there appears to be no compelling reason to alter the current drift-wall temperature limit. Elastic calculations indicate that a drift opening should exhibit minimal failure for drift wall temperatures below 200°C, regardless of gradient. The factor of safety at 200°C, however, is small. Variations in rock-mass properties (Poisson's Ratio, Elastic Modulus, and CTE) can result in a degradation in predicted opening stability. It is noted that application of a more realistic jointed-rock model results in lower principal stresses and no significant joint-slip for a wall temperature of 200°C. Thus, for this particular case, the elastic model may be predicting conservatively high rock-mass stresses. Even with the possible conservatism associated with the elastic model, the drift-wall temperature limit of 200°C should be used cautiously. Expected conditions within the region of the repository under investigation should be considered during any application of the 200°C wall temperature goal in a viability assessment.

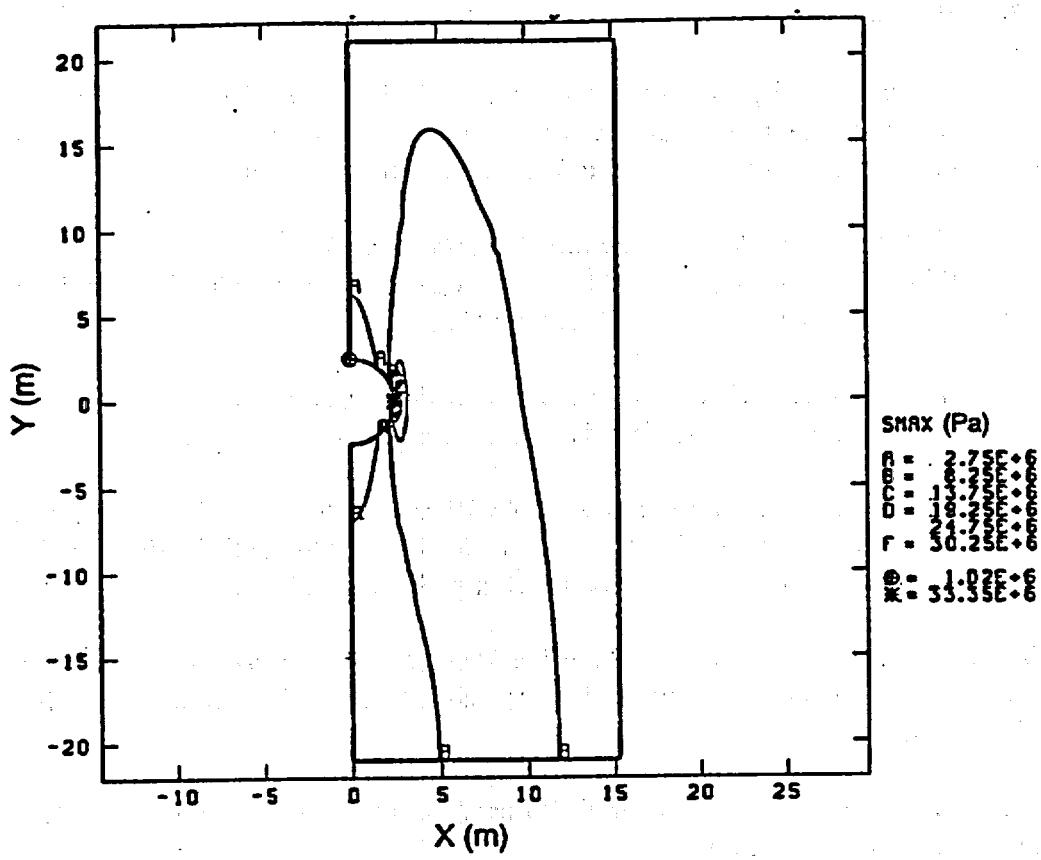


Figure B-31. Maximum Principal Stresses Predicted by the Compliant-Joint Model for a Drift Wall Temperature of 225°C and a μ of 2.0

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APPENDIX C

EVALUATION OF GROUND STABILITY AND SUPPORT

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EVALUATION OF GROUND STABILITY AND SUPPORT

C.1 INTRODUCTION

Thermomechanical analysis has been performed for evaluation of the 200°C rock temperature criterion in repository design. The analysis was accomplished using numerical modeling with the ANSYS and FLAC programs. Three different thermal loads, 83, 100 and 115 MTU/acre, with two values of waste package initial heat output, 9.21 and 14.2 kW/package, were assumed in the modeling. Rock temperatures were calculated with the ANSYS program, while displacements and stresses in rock due to in situ and thermal loads were evaluated with FLAC for continuous rock masses.

C.2 ANALYSIS INPUTS

Modeling inputs include geologic information, thermal/mechanical properties, repository layout design parameters, ground support types, in situ stress, thermal loads, and temperature histories. Sources for this information, mainly CRWMS M&O and CRWMS M&O/Sandia reports, are referenced. Some of these data are qualified sources and some are not; however, these data are considered the most appropriate data for the modeling that was performed.

C.2.1 LOADING CONDITIONS

C.2.1.1 In Situ Stress

Components of the in situ-stress state at the approximate depth of the repository are given in Table C-1. These stresses, caused by the weight of the overlying geologic units, lateral confinement, and past stress history, are the initial stress condition for modeling. The vertical normal stress σ_v is considered equal to the weight of the overlying rock and is expressed as

$$\sigma_v = -\sum_{i=1}^{n} \rho_i g Y_i \qquad (1)$$

where ρ_i = the average density of ith layer rock, kg/m^3
g = the gravitational acceleration, m/s^2
Y_i = the average thickness of ith layer rock, m
n = number of overlying rock layers

The magnitude of the horizontal stress σ_h is expressed as a function of the vertical stress and given as the horizontal-to-vertical stress ratio K, which is

$$K = \frac{\sigma_h}{\sigma_v} \qquad (2)$$

Values for the ratio K are given in Table C-1 and show that horizontal stresses are expected to be lower than the vertical stress. Minimum and maximum horizontal stress ratios are close in value and indicate a weak horizontal stress anisotropy. A value of $K = 0.5$ has been assumed to be representative of initial horizontal repository stress and is used for this analysis. As shown in Table 1, in situ stress at the proposed repository horizon is an average vertical stress of 7.0 MPa and a horizontal stress of 3.5 MPa.

Table C-1. Rock In Situ Stress at Proposed Repository Horizon
(Source: *Controlled Design Assumption Document*, TDSS-001 (CRWMS M&O 1996f))

Parameter	Average Value	Range
Vertical Stress (MPa)	7.0	5.0 - 10.0
Minimum Horizontal/Vertical Stress Ratio	0.5	0.3 - 0.8
Maximum Horizontal/Vertical Stress Ratio	0.6	0.3 - 1.0
Bearing - Minimum Horizontal Stress	N57W	N50W - N65W
Bearing - Maximum Horizontal Stress	N32E	N25E - N40E

C.2.1.2 Thermal Loads

Thermal loads of 83, 100 and 115 metric tons of uranium (MTU)/acre are used in modeling. Drift spacings and waste package spacings associated with these thermal loads are listed in Table C-2, based on the horizontal in-drift emplacement mode and the areal mass loading (AML) approach. Waste package initial heat outputs of 9.21 and 14.2 kW per package are assumed as representatives for the average and extreme cases.

Table C-2. Drift and Waste Package Spacings Used in Analysis
(Source: Extrapolation from reference case of 83 MTU/acre for constant heat output (CRWMS M&O 1996a))

Spacing	Thermal Load (MTU/acre)		
	83	100	115
Drift (m)	22.5	22.5	22.5
Waste Package (m)	19.12	15.88	13.81

C.2.2 THERMAL AND MECHANICAL ROCK PROPERTIES

Thermal and mechanical properties for the Yucca Mountain strata are listed in Tables C-3 through C-6. As shown in Table C-6, mechanical properties are given for rock mass quality categories (RMQ) ranging from 1 to 5. The RMQ categories, first presented by Hardy and Bauer (SNL 1991)

Table C-3. Contact Depths, Thermal Conductivity, and Capacitance of Thermal/ Mechanical Units (Source: RIB, Rev. 3, Sections: 1.1326a (DOE 1995))

Units	Upper Contact (m)	Lower Contact (m)	Thermal Conductivity (W/m·°C)	Thermal Capacitance ($J/cm^3 \cdot °C$) (averaged over temperature range)		
				T≤94°C	94°C≤T≤114°C	T>114°C
TCw	0	36.0	1.65	2.0313	9.3748	2.0979
PTn	36.0	74.1	0.85	2.2286	29.3110	1.5236
TSw1	74.1	204.2	1.60	2.0775	12.2655	2.0219
TSw2	204.2	393.5	2.10	2.1414	10.4786	2.1839
TSw3	393.5	409.3	1.28	2.0530	4.5193	2.5535
CHn1v	409.3	414.5	1.20	2.5651	35.3680	1.6702
CHn1z	414.5	518.5	1.28	2.6709	35.3854	2.2835
CHn2	518.5	535.2	1.56	2.5512	22.3349	1.9599

Table C-4. Thermal Expansion Coefficient for TSw2 Thermal/Mechanical Unit (Linear interpolation was used between temperatures) (Source: SNL 1995)

Temperature Range (°C)	Thermal Expansion Coefficient (10^{-6}/°C)
25	5.07
50	7.30
100	8.19
150	8.97
200	10.16
250	14.19
>250	14.19

Table C-5. Rock In Situ Density of Thermal/Mechanical Units (g/cm^3)
(Source: DOE 1995, Sec. 1.1325a)

Thermal/Mechanical Unit	At In Situ Saturation
TCw	2.200
PTn	1.642
TSw1	2.146
TSw2	2.297
TSw3	2.271
CHn1v	1.972
CHn1z	1.886
CHn2	2.070

Table C-6. Rock Mass Mechanical Properties for TSw2 Thermal/Mechanical Unit
(Source: CRWMS M&O 1995m)

Rock Mass Mechanical Properties		Rock Mass Quality Category				
		1	2	3	4	5
Q		0.3	0.65	1.91	3.75	8.44
Average RMR		42	48	54	59	65
Elastic Modulus (GPa)		6.37	8.95	12.55	17.11	23.51
Poisson's Ratio		0.21	0.21	0.21	0.21	0.21
Mohr-Coulomb Strength Parameters	Cohesion (MPa)[1]	1.3	1.6	2.2	2.8	3.8
	Friction Angle (degree)[1]	49	49	50	50	50
	Dilation Angle (degree)[1]	25	25	25	25	25
Tensile Strength (MPa)[2]		0.65	0.8	1.1	1.4	1.9

[1] Data not qualified.
[2] Assumed to be one half of cohesion.

and used for Exploratory Studies Facility analyses (CRWMS M&O 1995o) represent the distribution of rock properties for a given rock unit. Each category is associated with a frequency of occurrence of a certain range of Q-values. For example, category RMQ=3 for rock unit TSw2 has a typical Q-value of 1.91 for which rock properties have been derived and ground support categories have been developed (Table C-6). Also, category RMQ=3 is considered representative of the most frequently occurring range of Q-values and is thus used as a reference case for this study.

C.2.3 LAYOUT PARAMETERS

Emplacement drift orientation is a feature of the layout design that has a potential impact on ground control. Typically, a stable drift orientation is one that minimizes the occurrence of open joints or faults parallel to the drift axis, especially in rock with low horizontal stresses. As stated by Design Concept Subsurface (DCSS)-001 and explained in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design Report* (CRWMS M&O 1994c, Section 8.2.1.3), emplacement drifts will be oriented at least 30 degrees from the dominant strike of vertically-dipping joints, and maintainable drifts and accesses will be oriented, if practicable, to have intersections of 70-90 degrees with the dominant strike of the joint systems. However, in situ lateral stresses at Yucca Mountain are expected to be low (CRWMS M&O 1994c, Section 5.1.3), resulting in low confining stress and reduced joint strength during excavation. This condition is expected to be improved as thermally-induced horizontal stress increases following emplacement of waste packages. Both the excavation stress condition and the post-emplacement stress condition are examined by numerical stress analysis.

Horizontal center-in-drift emplacement is the reference emplacement mode, based on preliminary assessments of waste package design and repository criteria and requirements (CRWMS M&O 1996f), Key Assumption 011. The current conceptual layout shows emplacement drift excavation by TBMs, which produce drifts with a circular cross section. The 5.0-m-diameter drift used in the stability analyses was chosen based on waste package size, emplacement equipment size, and invert and ground support considerations. Waste package length and diameter are assumed to be 5.68 m and 1.80 m, respectively, based on the CDA (EBDRD 3.7.1.J.1). These two parameters were used in numerical modeling with ANSYS to determine rock-mass temperature distributions.

C.2.4 GROUND SUPPORT TYPES

Permanent ground support materials considered for emplacement drifts consist primarily of concrete (precast segments or cast in place) and structural steel sets. These two ground support types were used for these analyses and are used as examples to provide guidance in determining likely support behavior:

- Concrete lining, 200 mm thick
- Structural steel sets, W5×19, spaced at 1.2 m intervals

Parameters and properties used to characterize the ground support elements include cross-sectional area, elastic modulus, strength, and moment of inertia for both concrete liner and steel sets. Values for these parameters, grouped by ground support type, are listed below in Table C-7.

Table C-7. Ground Support Parameters and Values (Sources: CRWMS M&O 1995n; AISC 1989)

Parameter	Value
Concrete (200-mm thick):	
• Cross-Sectional Area (m^2/meter of drift)	0.20
• Moment of Inertia (m^4/meter of drift)	6.67×10^{-3}
• Elastic Modulus (GPa)	27.58
• Compressive Strength (MPa)	34.5
Steel Set (W5x19):	
• Cross-Sectional Area (m^2)	3.57×10^{-3}
• Moment of Inertia (m^4)	1.09×10^{-6}
• Elastic Modulus (GPa)	200.0
• Strength (MPa)	248.0

C.3 NUMERICAL MODELING

C.3.1 COMPUTER PROGRAMS

Two commercially available computer programs, ANSYS and FLAC (described below), were used for the numerical analysis of rock temperature and opening stability. The ANSYS program is installed on a SGI Indigo^2 Power Extreme workstation with 320 MB RAM, and the FLAC code runs on 90-MHz Pentium microcomputers. The release of the ANSYS program used in the thermal analysis is Revision 5.2. ANSYS Revision 5.1 has been verified and validated according to the QAP-SI-series of CRWMS M&O *Computer Software Quality Assurance* procedures, but Revision 5.2 has not been verified and validated. The FLAC code, Version 3.22, on the other hand, is approved for design use in accordance with the Quality Assurance procedures and carries the appropriate CSCI number (given below).

ANSYS, introduced in 1970 by Dr. John Swanson and Swanson Analysis Systems, Incorporated (SASI), is a general-purpose program, meaning that the program can be used in many disciplines of engineering, that deal with topics including structural, geotechnical, mechanical, thermal, and fluids. The ANSYS Revision 5.2 is a menu-driven computer program and uses the Graphical User Interface (GUI) of the Unix X Window System (ANSYS 1995).

FLAC (Fast Lagrangian Analysis of Continua) is a two-dimensional explicit finite difference code that simulates the behavior of structures built of soil, rock, and other materials that are subjected to static, dynamic, and thermally induced loads (Itasca 1993). Modeled materials respond to applied forces or boundary restraints according to prescribed linear or non-linear stress/strain laws, and undergo plastic flow when a limiting yield condition is reached. FLAC is based on a Lagrangian calculation scheme, especially suited for modeling large displacements, and has several built-in constitutive models that permit the simulation of highly non-linear, irreversible responses typical of many geologic materials. The FLAC program was initially developed by Dr. Peter Cundall and Itasca Consulting Group, Inc. in 1986. The program version used to analyze opening stability is Version 3.22 (CSCI # 20.93.3001-AAu3.22), which has been verified and validated in accordance with applicable CRWMS M&O procedures.

C.3.2 FEATURES OF THE MODEL

C.3.2.1 Yield Criterion

The Mohr-Coulomb yield criterion was used in the analysis to judge whether or not the rock mass experiences failure. The criterion is defined as

$$\tau = c - \sigma_n \tan\phi \qquad (3)$$

where τ = shear stress on a failure or yield plane, Pa
σ_n = normal stress on a failure plane (tensile stress is positive), Pa
c = cohesion, Pa
ϕ = friction angle, degrees

The yield criterion is used to represent the rock mass strength in FLAC. The ratio of Mohr-Coulomb strength to rock stress (strength/stress ratio) is evaluated for every element and is especially useful in assessing rock mass stability in the vicinity of the drift. An element is considered to perform satisfactorily when its strength/stress ratio is larger than 1.0 and is thought to fail structurally if the strength/stress ratio is equal to or less than 1.0.

The concept of factor-of-safety was used as the criterion to assess ground support performance under in situ stress and thermal loads. The factor-of-safety for ground support components is defined as the ratio of material strength to stress or force. A ground support component is in a stable state when its strength/stress (or force) ratio is larger than 1.0 and is of structural failure if the strength/stress ratio is equal to or less than 1.0.

C.3.2.2 Initial and Boundary Conditions

Initial Conditions

Initial stress condition in the analysis is assumed to be consistent with the in situ stress given in Table C-1. Initial temperature in the thermal/mechanical units is based on a rock temperature at the ground surface of 18.7°C and a rock thermal gradient as listed in Table C-8.

Table C-8. Rock Mass Thermal Gradient (Source: CRWMS M&O 1996f, TDSS-002)

Depth (m)	Thermal Gradient (°C/m)
0 - 150	0.019
150 - 400	0.018
400 - 541	0.030

Boundary Conditions for Thermomechanical Model

Boundary conditions for the thermomechanical model with FLAC are illustrated in Figure C-1. The half-drift-spacing geometry is appropriate for the thermomechanical model because the model is symmetric along a vertical plane through the center of the drift. The model dimension in the vertical dimension is the entire thickness of the TSw2 unit. As shown by the bar-and-roller symbols along the sides and bottoms of the models (Figure C-1), displacements in the horizontal direction on two vertical boundaries and in the vertical direction at the TSw2 lower boundary are zero (or fixed). Overburden stress is applied to the TSw2 upper contact, which is free to move vertically. The surface of the drift is stress and constraint free.

Rock temperatures after waste emplacement are time-dependent and were evaluated with the ANSYS program. Due to limitations of the thermal options in the FLAC code, rock temperature distributions are calculated based on the boundary temperature histories obtained from the thermal analyses with ANSYS. Based on thermal symmetry, the vertical model boundaries are prescribed as adiabatic, or zero heat flow, boundaries.

C.3.2.3 Sign Convention

In the FLAC program, the sign convention for stress and strain is "tension is positive and compression is negative" (as indicated in Figure C-2). For shear stress, also shown in Figure C-2, a positive shear stress points in the positive direction of the coordinate axis if the shear stress acts on a surface with the outward normal in the positive direction. Conversely, if the outward normal of the surface is in the negative direction, then the positive shear stress points in the negative direction of the coordinate axis. All stresses shown in Figure C-2 are positive. For displacement or seismic velocity, positive displacement or velocity is upward and to the right. Axial forces in ground support elements are negative in tension and positive in compression. For consistency, the sign of axial forces and stresses of structural members discussed in this section are reversed to positive for tension and negative for compression, unless otherwise specified.

C.4 THERMALLY-INDUCED OPENING AND GROUND SUPPORT BEHAVIOR

Two-dimensional modeling for emplacement drifts has been carried out with ANSYS and FLAC. Thermally-induced displacements and stresses in the rock mass and in ground support elements were calculated for up to 150 years after waste emplacement.

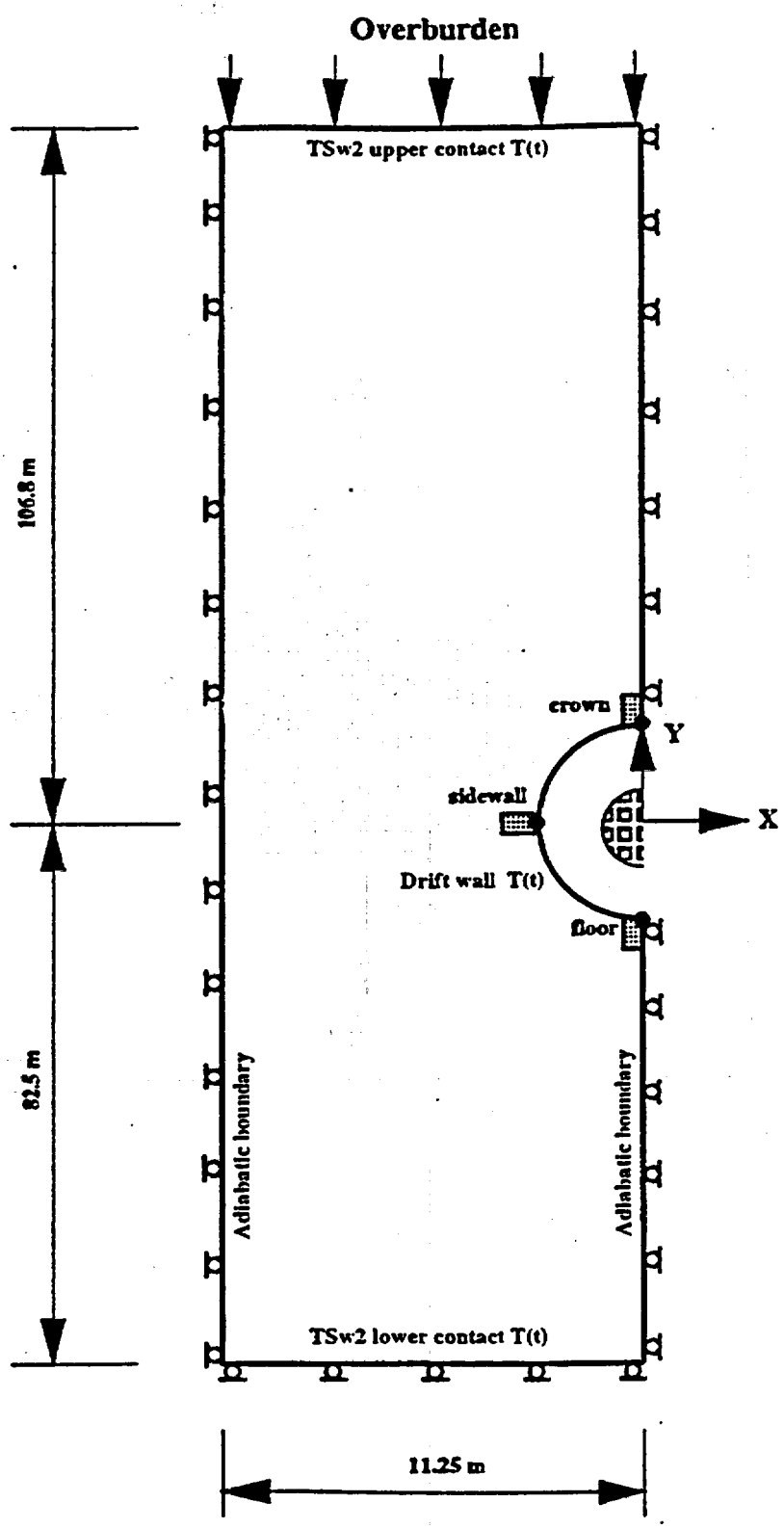


Figure C-1. Geometry and Boundary Conditions for Thermomechanical Modeling Using FLAC

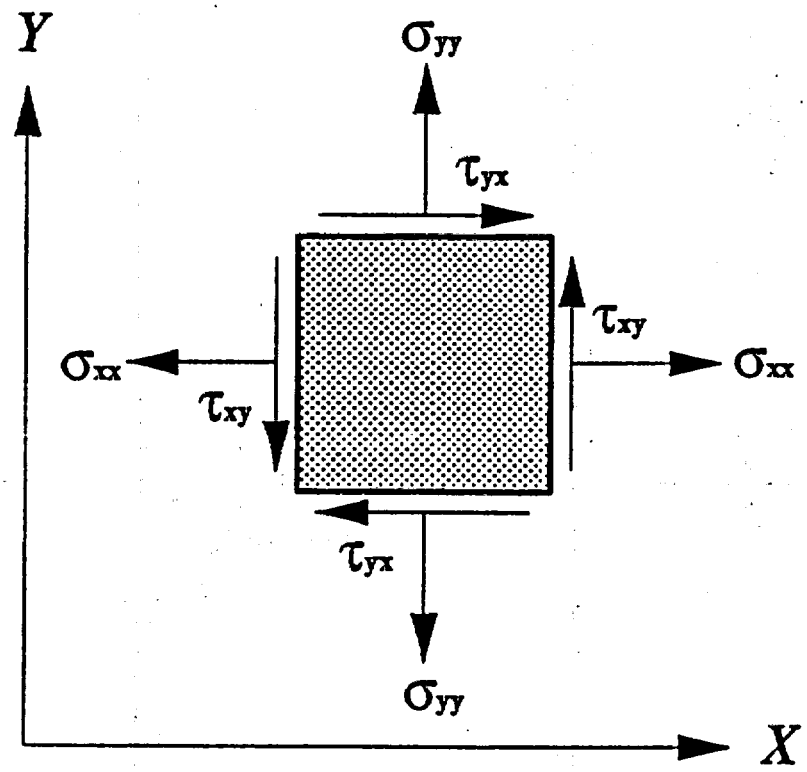


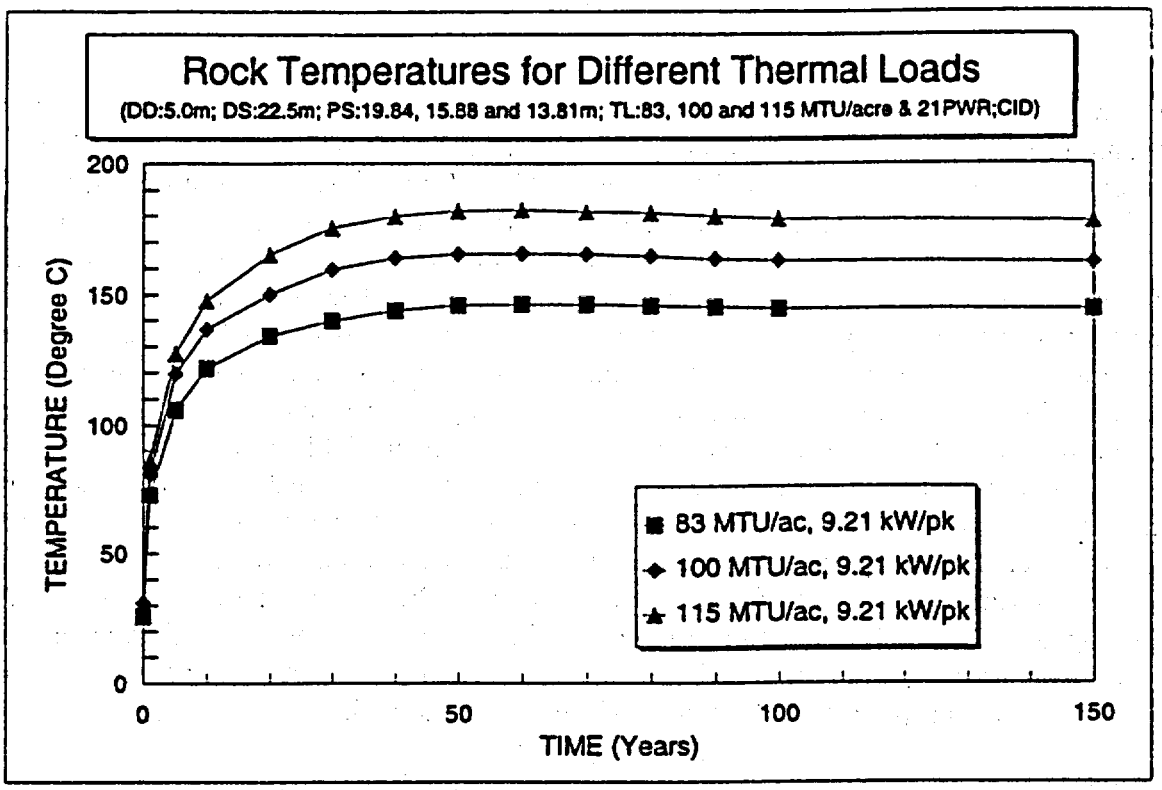
Figure C-2. Sign Convention for Positive Stresses

Temperature histories of the drift wall and TSw2 boundary contacts due to the thermal loads of 83, 100 and 115 MTU/acre from waste emplacement for the initial heat outputs of 9.21 and 14.2 kW/package, respectively, were calculated with the ANSYS code. The heat transfer mechanism in modeling with ANSYS involves both radiation and conduction, and the thermal radiation process is simulated explicitly. Thermal analyses for FLAC models calculate time-dependent temperature distributions resulting from boundary temperature inputs, and the heat transfer mechanism involved is limited to conduction only. Coupled thermomechanical analyses with FLAC have been performed for a period of 150 years after waste emplacement. This period of time, called the overall thermal time, is divided into a number of thermal time steps. At each thermal time step, the temperature distributions are determined first, and stress and displacement fields around the supported drift opening, strength-to-stress ratios, and axial forces or moments if applicable in ground supports are then obtained by conducting a quasi-static mechanical analysis. Owing to temperature dependence of thermomechanical properties of rock, such as specific heat and thermal expansion coefficient, each thermal time step has been further divided into a number of sub-thermal time steps. At the beginning of each sub-thermal time step, the values of specific heat and thermal expansion coefficient are updated for every zone based on its corresponding temperature and the temperature dependence of the properties, as illustrated in Tables C-3 and C-4.

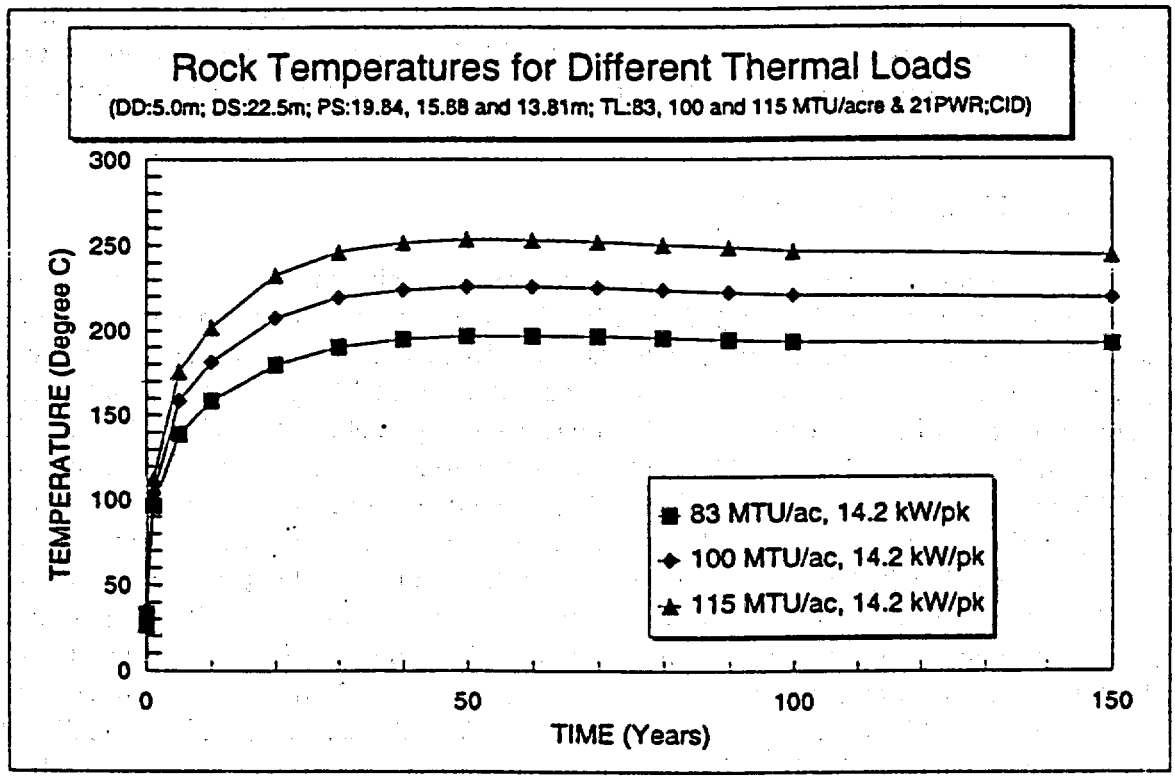
Depending upon mechanical properties and the magnitude of thermomechanical loads, the continuous rock model used in FLAC may behave elastically or elasto-plastically. The Mohr-Coulomb failure criterion is used in the analysis to judge whether or not the stress level reaches the yield limit, which varies with the rock mass quality (RMQ) categories. In this analysis, only the RMQ category of 3 was selected to evaluate the rock mass response to the elevated temperatures after waste emplacement.

C.4.1 ROCK TEMPERATURE

Two-dimensional analysis with ANSYS shows that average peak temperatures experienced on the drift wall, as shown in Figure C-3a, are about 146°C, 166°C, and 183°C for an average initial heat output of 9.21 kW/package and the thermal loads of 83, 100, and 115 MTU/acre, respectively. With a higher value of waste package initial heat output of 14.2 kW/package, the average peak temperature on the drift wall, as shown in Figure C-3b, go up to about 197°C, 227°C, and 254°C for the thermal loads of 83, 100, and 115 MTU/acre, respectively. A high value of initial heat output of 14.2 kW/package results in the maximum rock temperatures at or above 200°C, while an average value of initial heat output of 9.21 kW/package causes the rock temperatures to reach to about or above 150°C but below 200°C. Table C-9 summarizes the results from temperature calculation with ANSYS, and indicates that rock peak temperatures occur at about 50 to 65 years after waste emplacement for all cases considered. It is also indicated, as shown in Figures C-4a and C-4b and Table C-9, that the rock temperatures at the center of the pillar (11.25 m from the drift center) vary from 134°C to 164°C for the initial heat output of 9.21 kW/package and from 176 °C to 224 °C for the initial heat output of 14.2 kW/package, indicating that the temperature gradient in rock between the drift wall and pillar center is small after the peak temperature is reached. The variation in rock temperature between the drift wall and pillar center is only about 10 to 30°C, depending on the thermal loads and waste package initial heat outputs.

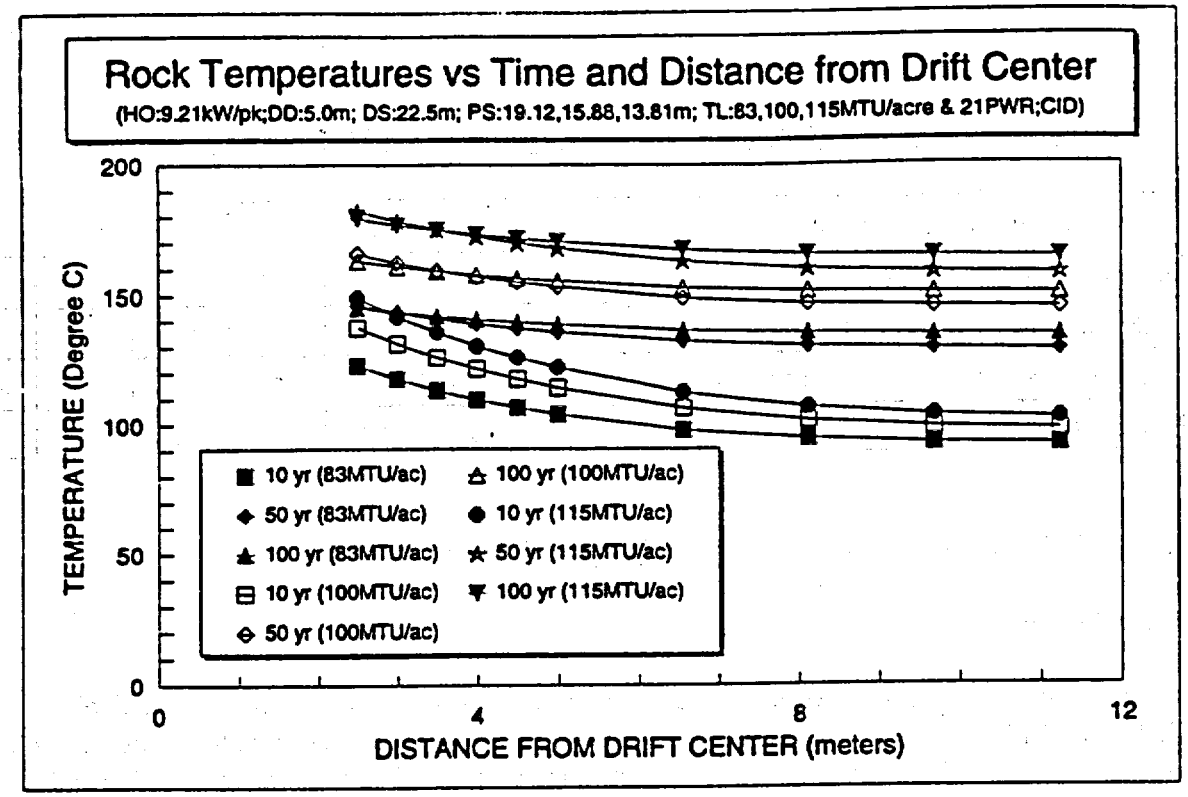


(a)

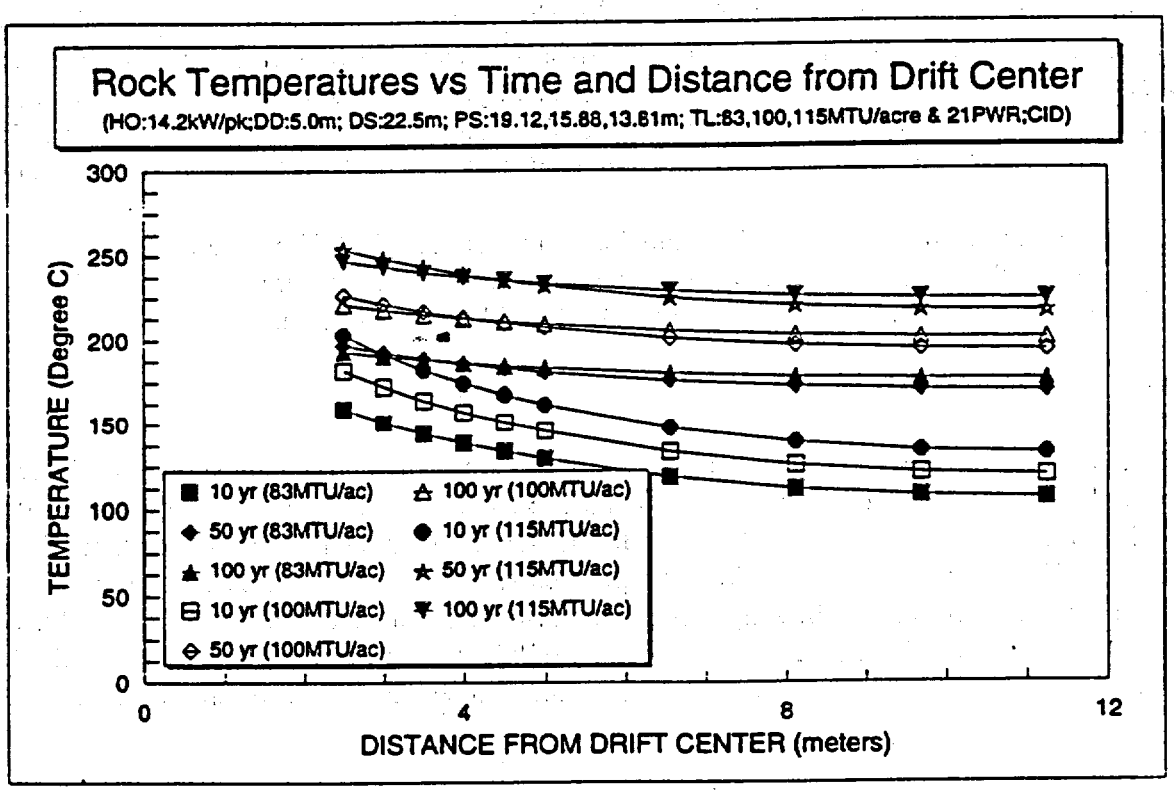


(b)

Figure C-3. Temperature Histories of Drift Wall for 83, 100, and 115 MTU/acre: (a) 9.21 kW/package; (b) 14.2 kW/package



(a)



(b)

Figure C-4. Temperature Distribution in Rock Pillar for 83, 100, and 115 MTU/acre: (a) 9.21 kW/package; (b) 14.2 kW/package

Table C-9. Results from ANSYS Models for Different Thermal Loads and Package Heat Outputs

Initial Heat Output (kW/package)	9.21			14.2		
Thermal Load (MTU/acre)	83	100	115	83	100	115
Drift Wall Peak Temperature (°C)	146	166	183	197	227	254
Temperature at Center-of-Pillar at 100 yr (°C)	134	150	164	176	201	224
Time to Peak (years)	64	57	57	57	56	52

C.4.2 DRIFT CLOSURE AND ROCK MASS YIELD

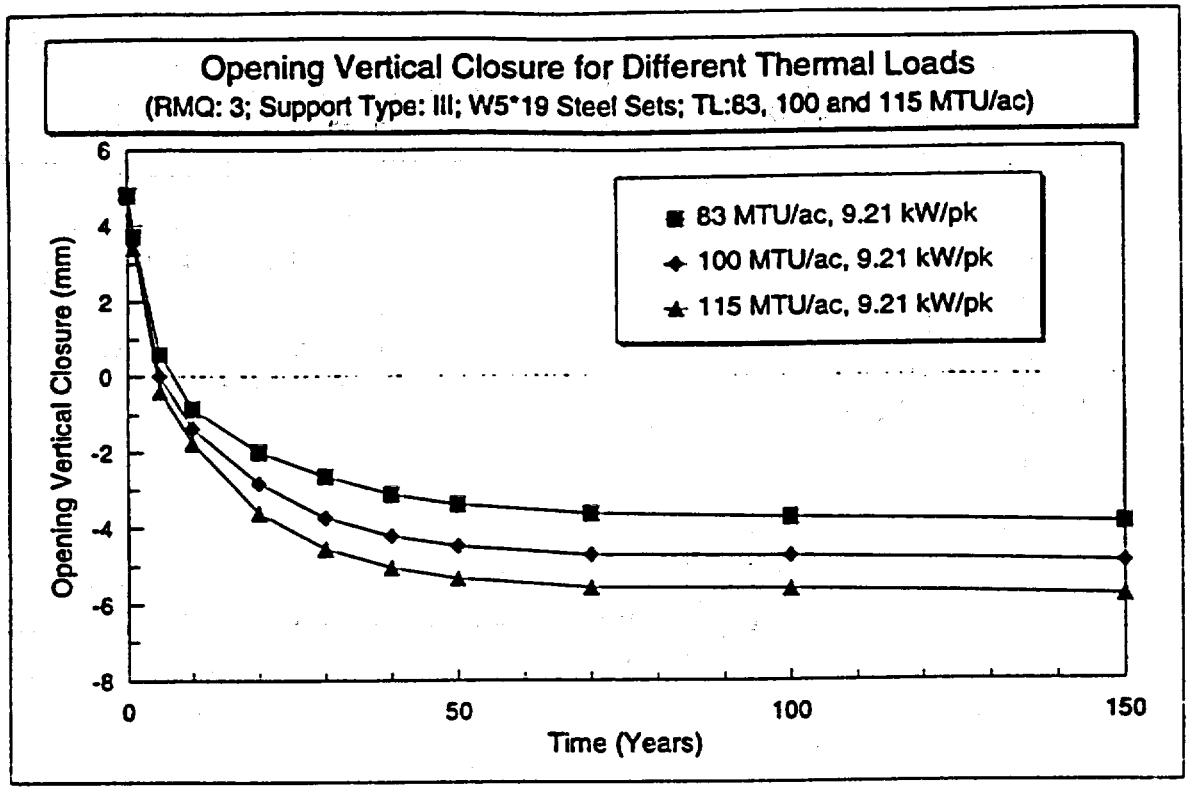
Drift Closure

Thermally-induced vertical closures, as illustrated in Figures C-5a and C-5c and on Table C-10, for 83, 100, and 115 MTU/acre and steel sets ground support, are in the opposite direction to closures induced by in situ loads at excavation. Maximum vertical closures induced by thermal load are about 8 to 10 mm outward for the initial heat output of 9.21 kW/package, and about 11 to 14 mm outward for the initial heat output of 14.2 kW/package. Combined in situ and thermal loads result in net vertical closures of about 4 to 6 mm outward and about 7 to 9 mm outward for the cases of 9.21 kW/package and 14.2 kW/package, respectively. Combined in-situ stress and thermally-induced horizontal closures, as shown in Figures C-5b and C-5d, are inward and are about 10 to 15 mm and 17 to 26 mm for the initial heat outputs of 9.21 and 14.2 kW/package, respectively.

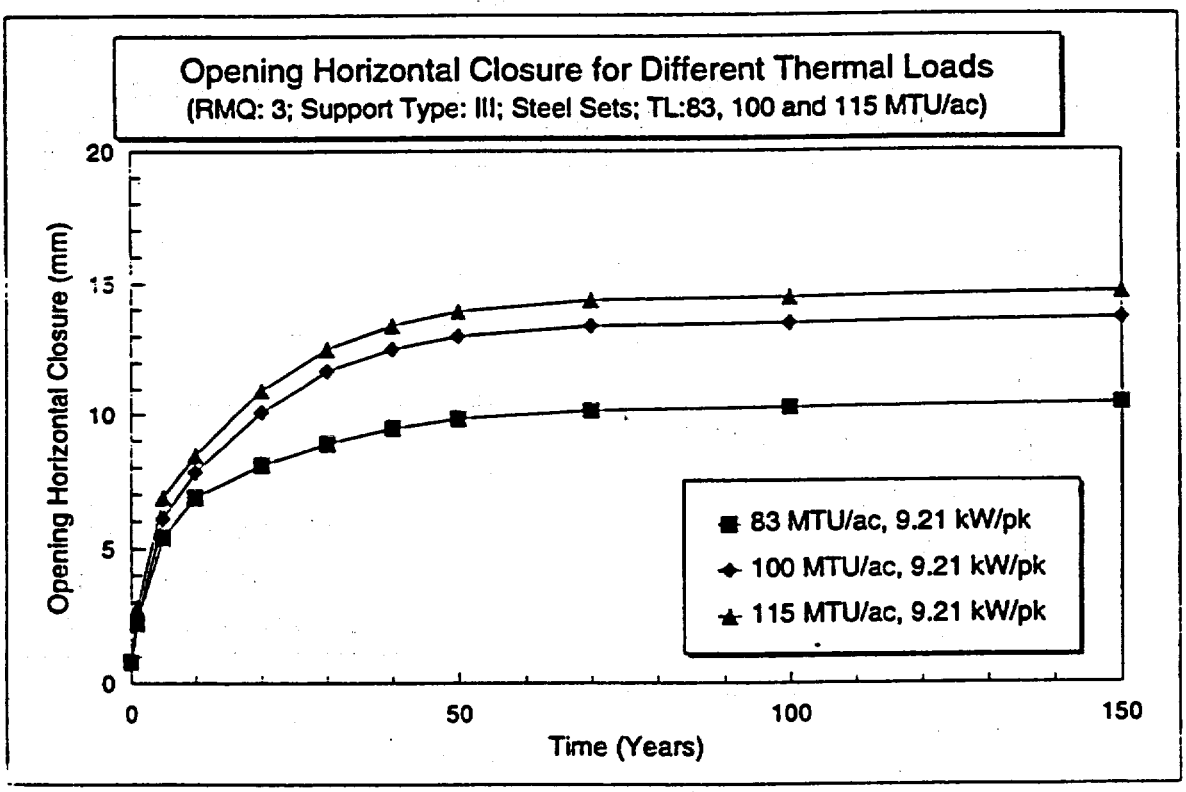
As can be seen from these results, horizontal closures for the 9.21 kW/package case are about 60 to 76 percent of those for the 14.2 kW/package case, while vertical closures for the 9.21 kW/package case are about 55 to 67 percent of those for the 14.2 kW/package case.

Rock Mass Yield

Time histories of major and minor principal stresses at the drift crown are shown in Figures C-6 a through d for the thermal loads of 83, 100 and 115 MTU/acre, the initial heat outputs of 9.21 and 14.2 kW/package, steel sets ground support for RMQ=3. When the maximum rock temperatures are below 200°C for the case of 9.21 kW/package, the major principal compressive stresses (tangential to the crown) at 150 years following waste emplacement are close to their maximum values of -32, -35 and -36 MPa (RMQ=3) for the thermal loads of 83, 100, and 115 MTU/acre, respectively. The minor principal stresses are close to their maximum values of -3 MPa for all thermal loads.

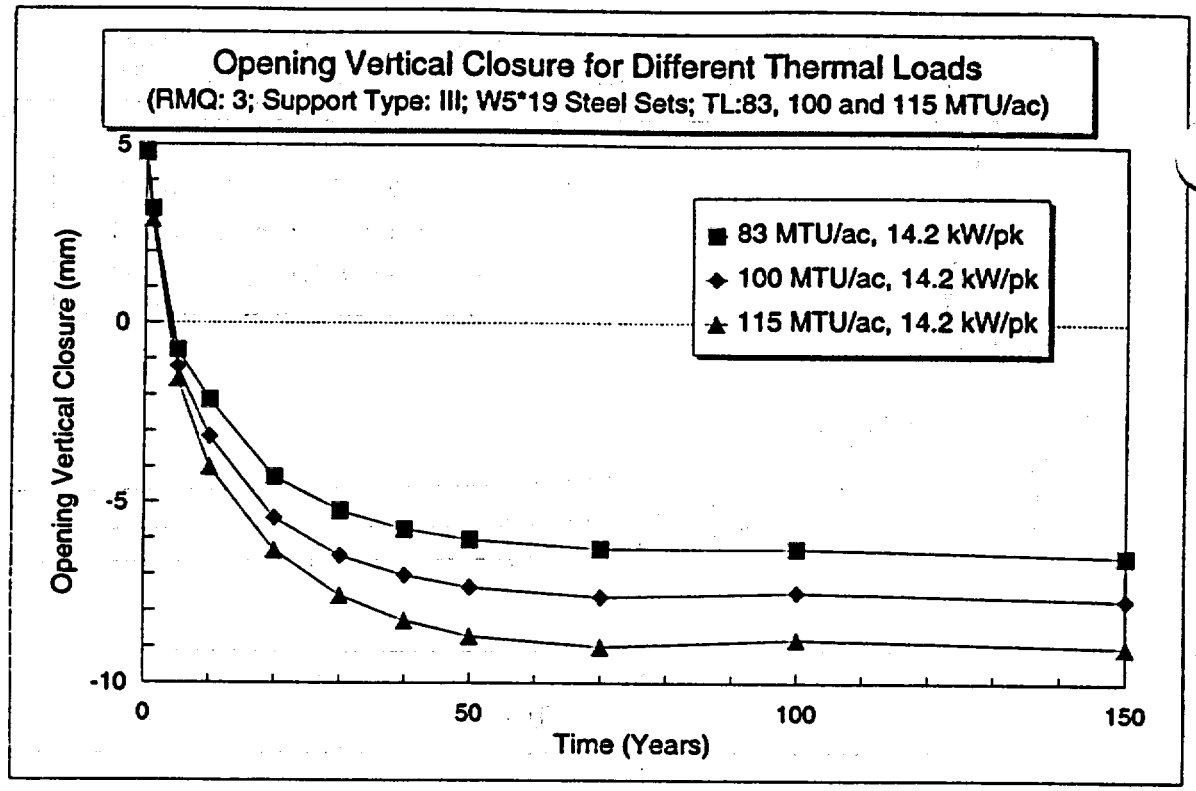


(a)

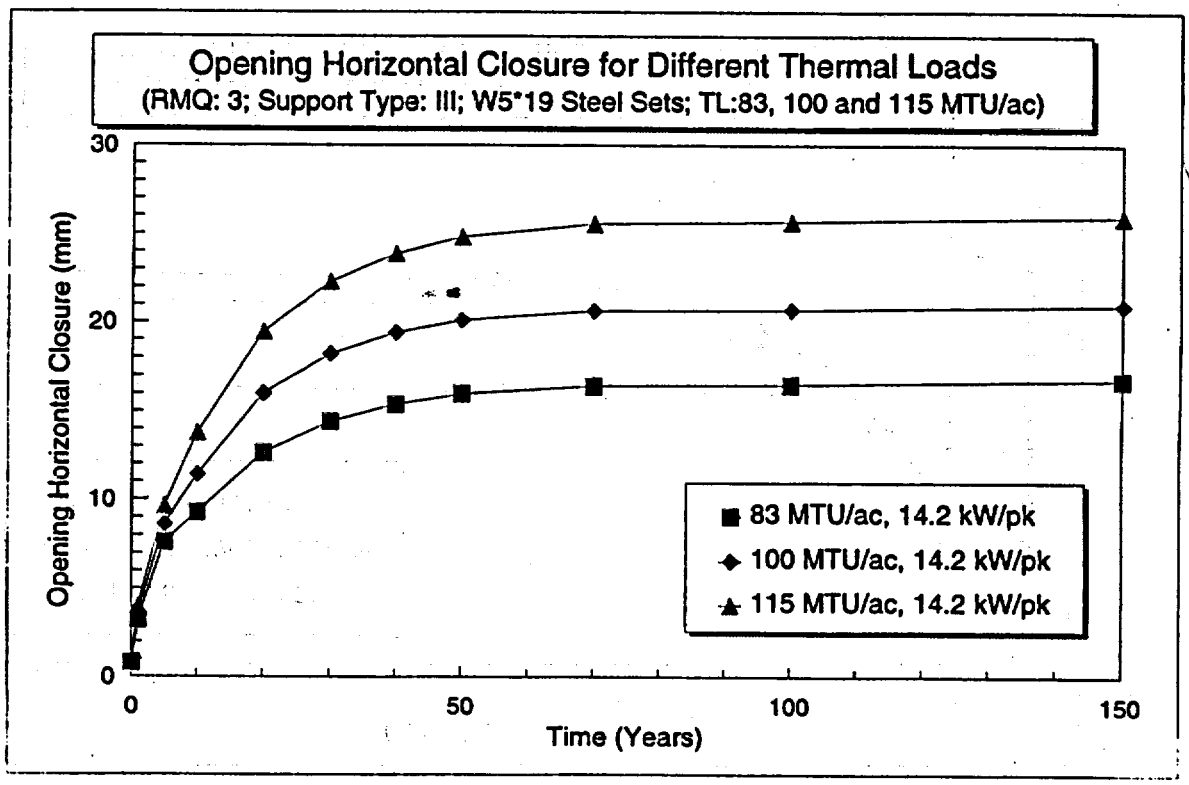


(b)

Figure C-5. Time Histories of Opening Closures for 83, 100, and 115 MTU/acre and RMQ=3: (a) Vertical Closures for 9.21 kW/package; (b) Horizontal Closures for 9.21 kW/package; (c) Vertical Closures for 14.2 kW/package; (d) Horizontal Closures for 14.2 kW/package



(c)



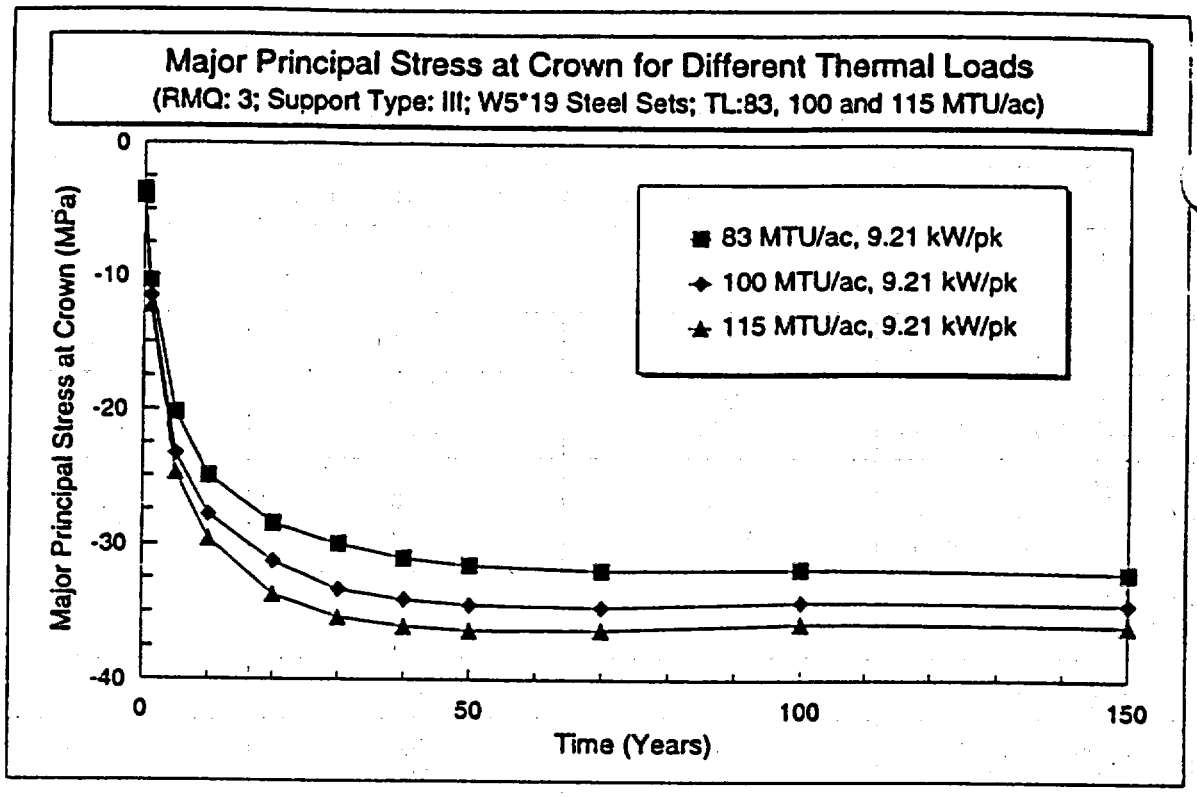
(d)

Figure C-5. Time Histories of Opening Closures for 83, 100, and 115 MTU/acre and RMQ=3: (a) Vertical Closures for 9.21 kW/package; (b) Horizontal Closures for 9.21 kW/package; (c) Vertical Closures for 14.2 kW/package; (d) Horizontal Closures for 14.2 kW/package (continued)

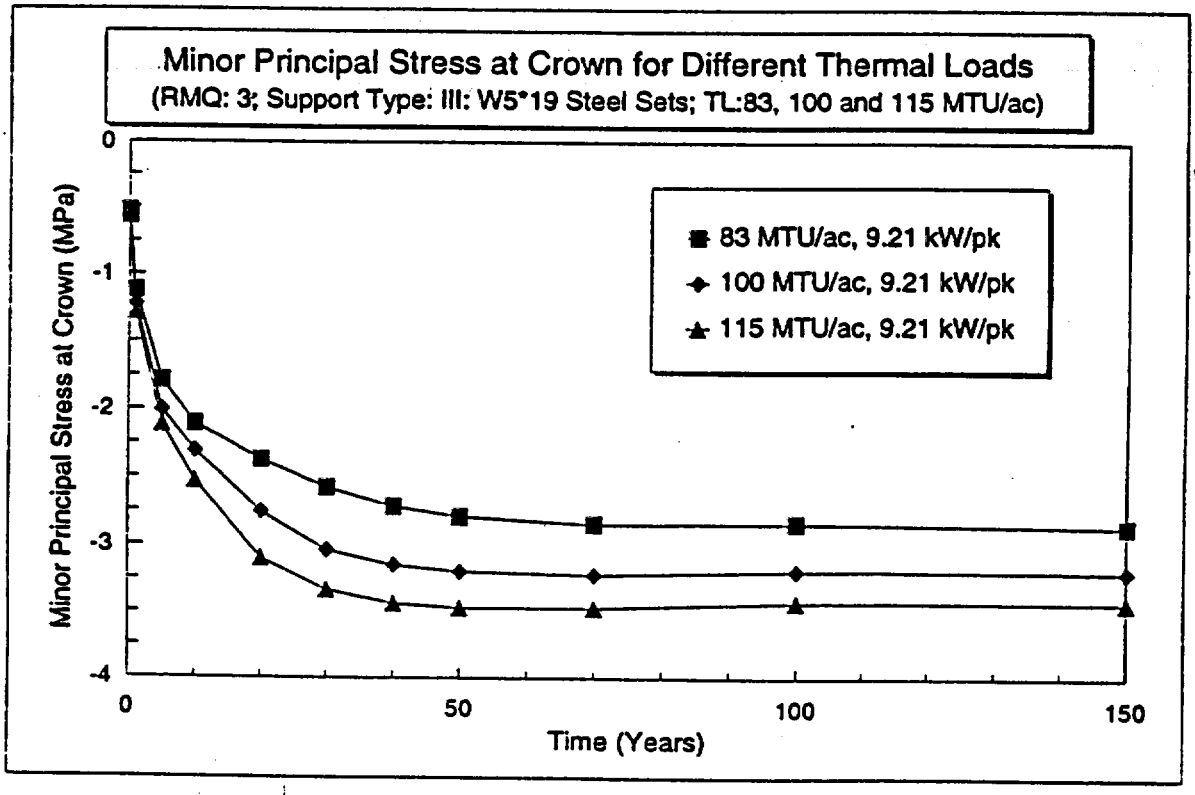
Table C-10. Results from FLAC Models for Concrete Liner Ground Support

Ground Support: 200 mm Thick Concrete Liner			
Heat Output (kW/package)	9.21		
Thermal Load (MTU/acre)	83	100	115
Max. Compressive Axial Stress in Shotcrete (MPa)	-30.5 (150)[1]	-35.4 (150)[1]	-39.7 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	1.1 (150)[1]	1.0 (150)[1]	0.9 (150)[1]
Heat Output (kW/package)	14.2		
Thermal Load (MTU/acre)	83	100	115
Max. Compressive Axial Stress in Shotcrete (MPa)	-44.2 (150)[1]	-53.4 (150)[1]	-64.1 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	0.8 (150)[1]	0.6 (150)[1]	0.5 (150)[1]

[1] Time in years after emplacement to reach a maximum value during preclosure.

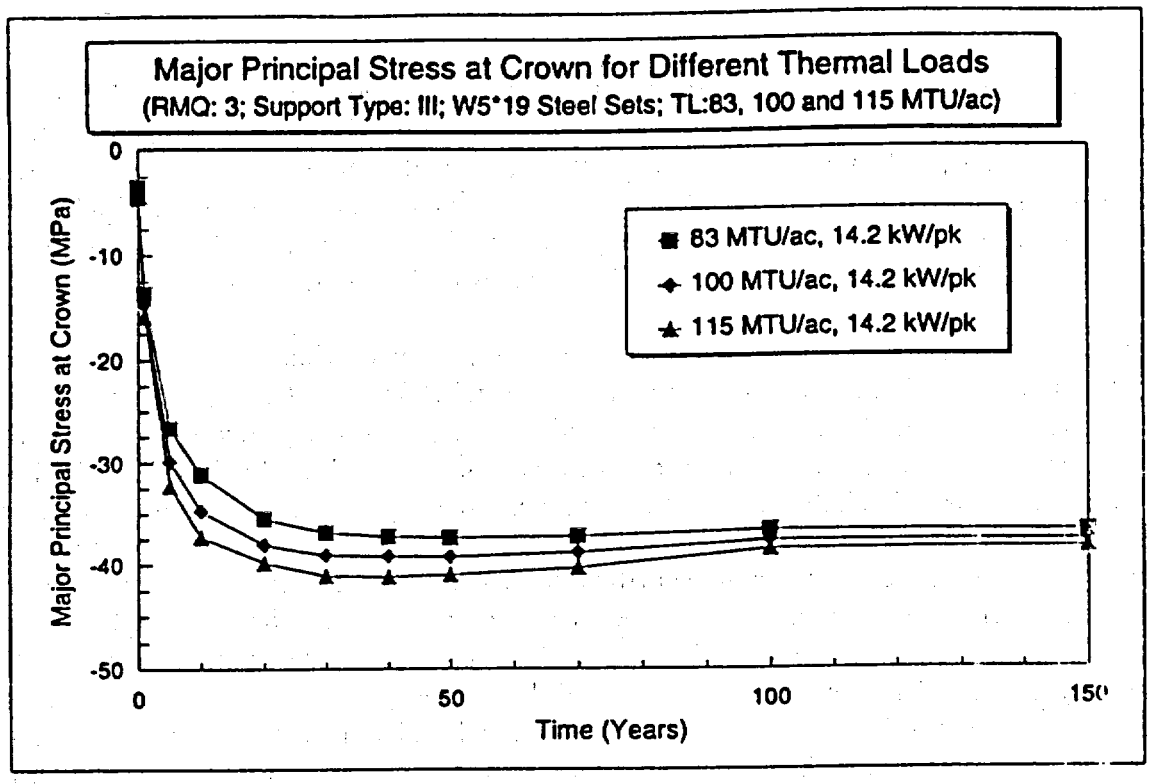


(a)

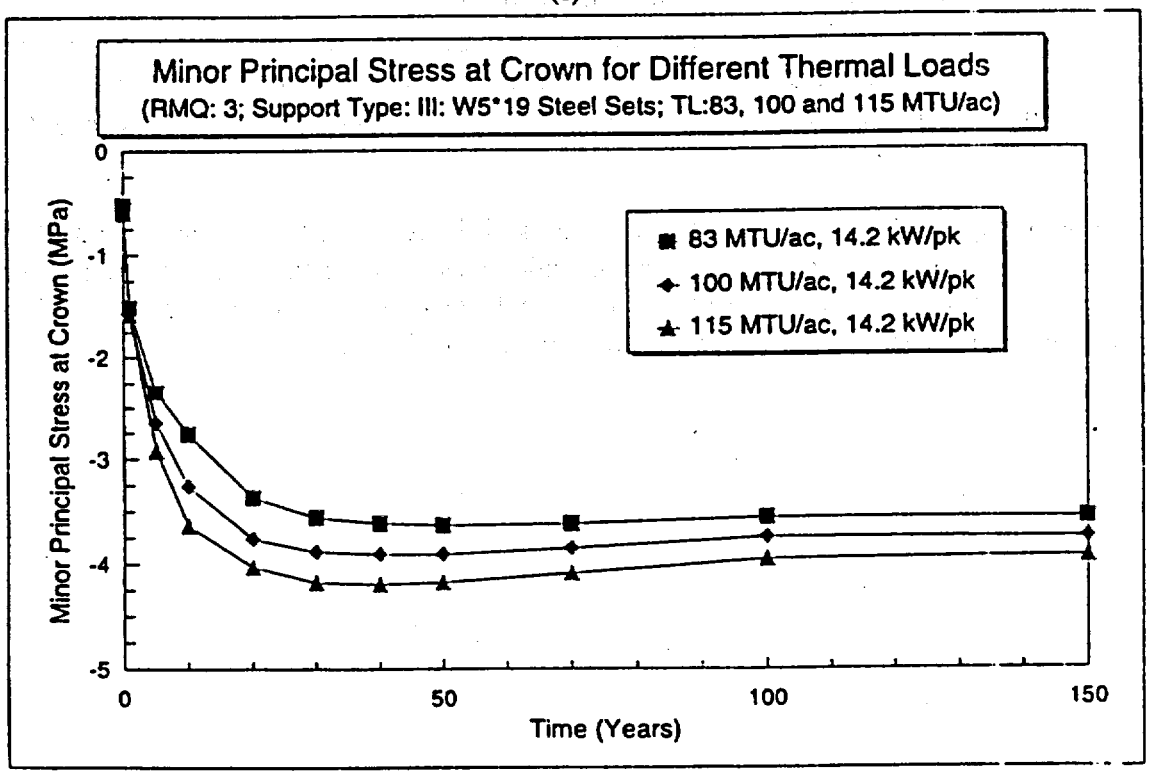


(b)

Figure C-6. Time Histories of Principal Stresses at Crown for 83, 100, and 115 MTU/acre and RMQ=3: (a) Major Principal Stress for 9.21 kW/package; (b) Minor Principal Stress for 9.21 kW/package; (c) Major Principal Stress for 14.2 kW/package; (d) Minor Principal Stress for 14.2 kW/package



(c)



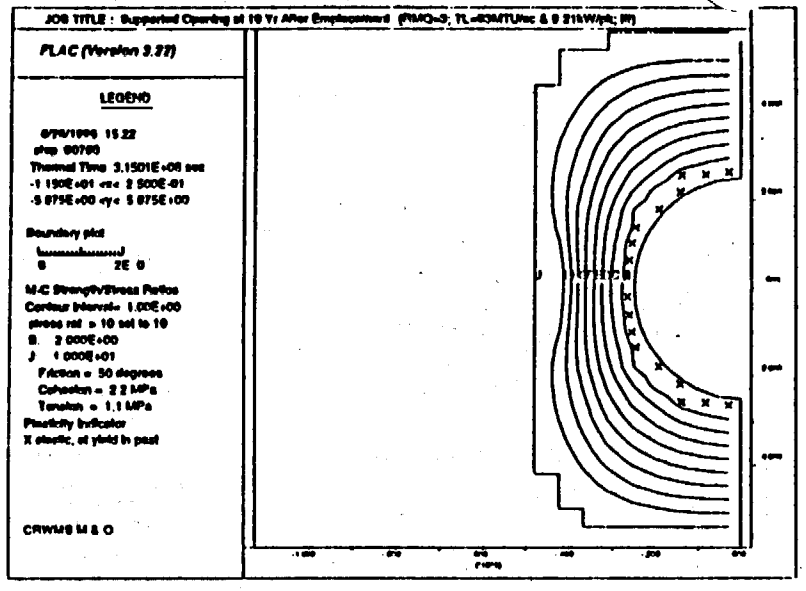
(d)

Figure C-6. Time Histories of Principal Stresses at Crown for 83, 100, and 115 MTU/acre and RMQ=3: (a) Major Principal Stress for 9.21 kW/package; (b) Minor Principal Stress for 9.21 kW/package; (c) Major Principal Stress for 14.2 kW/package; (d) Minor Principal Stress for 14.2 kW/package (continued)

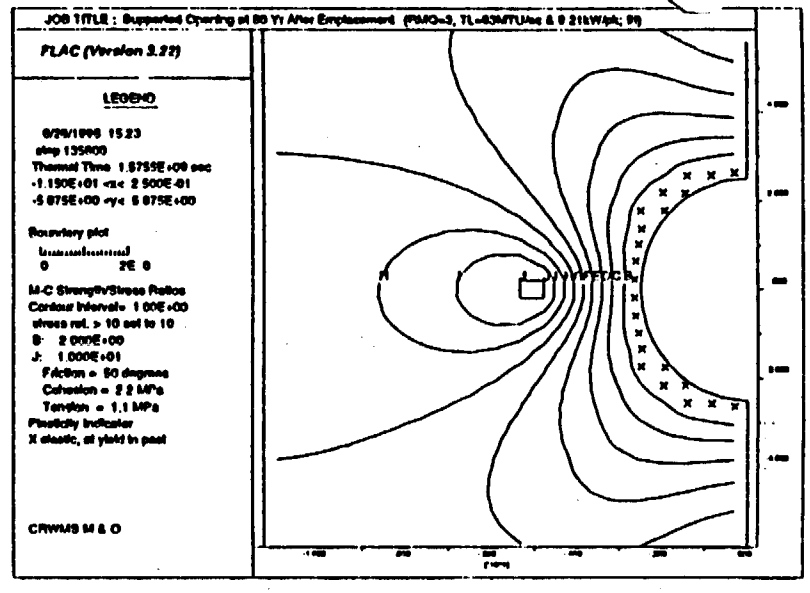
When the maximum rock temperatures are at or above 200°C for the case of 14.2 kW/package, the major principal compressive stresses at 150 years are about -37, -39, and -41 MPa for the thermal loads of 83, 100, and 115 MTU/acre, respectively, while the minor principal stresses are about -4 MPa for all thermal loads. It is indicated that the increases in the major principal compressive stresses are not significant, about 13 to 16%, even with a more than 50% increase in the waste package initial heat output (from 9.21 kW/package to 14.2 kW/package).

Potential rock mass yield is indicated by Figures C-7a, b, and c, which give strength-to-stress-ratio contour plots and failure surface envelopes at 10, 50 and 100 years after emplacement (thermal load of 83 MTU/acre, initial heat output of 9.21 kW/package, steel sets ground support and RMQ= 3). Note that the peak rock temperature for this case is about 146°C, well below 200°C. The plots of strength-to-stress ratios indicate potential rock yield to a depth of about 60 cm from the periphery of the drift (Figures C-7a through c). In addition, Figures C-7b and c show an increasing strength-to-stress ratio into the rock away from the drift wall, then a decrease, then a constant value as the line of symmetry (i.e., the center of the pillar) between the drifts is approached. Strength also decreases as the confining stress in the pillar decreases. Beyond 50 years, the strength-to-stress ratio in the majority of the pillar is at or above a value of 4.0. When the rock temperature exceeds 225°C (thermal load of 100 MTU/acre, initial heat output of 14.2 kW/package, steel sets ground support for RMQ=3), potential rock mass yield is indicated in Figures C-8a through c, which illustrate strength-to-stress-ratio contour plots and failure surface envelopes at 10, 50, and 100 years after waste emplacement. At 50 years, the potential rock mass yield, as shown in Figure C-8b, may occur to a depth of about 2 meters from the periphery of the drift. The overall patterns of strength-to-stress-ratio contours are similar to those for the case with the maximum rock temperature below 200°C.

Maximum major and minor principal stresses at the drift crown for 83, 100, and 115 MTU/acre and ground support Types II are about the same magnitude as those for the steel sets ground support for the RMQ category of 3, which means that the strength-to-stress ratios of rock mass with the concrete ground support are similar to those with the steel sets, as illustrated in Figures C-7a through C-8c.



(a)



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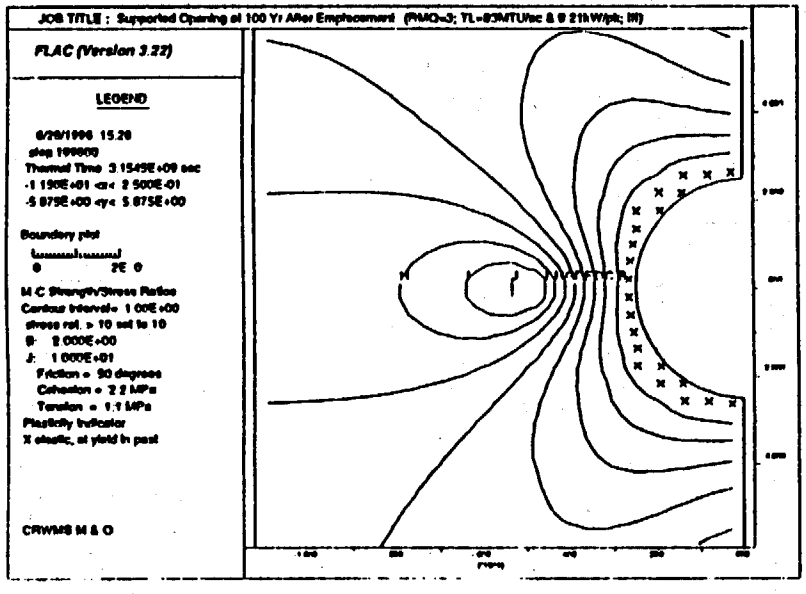
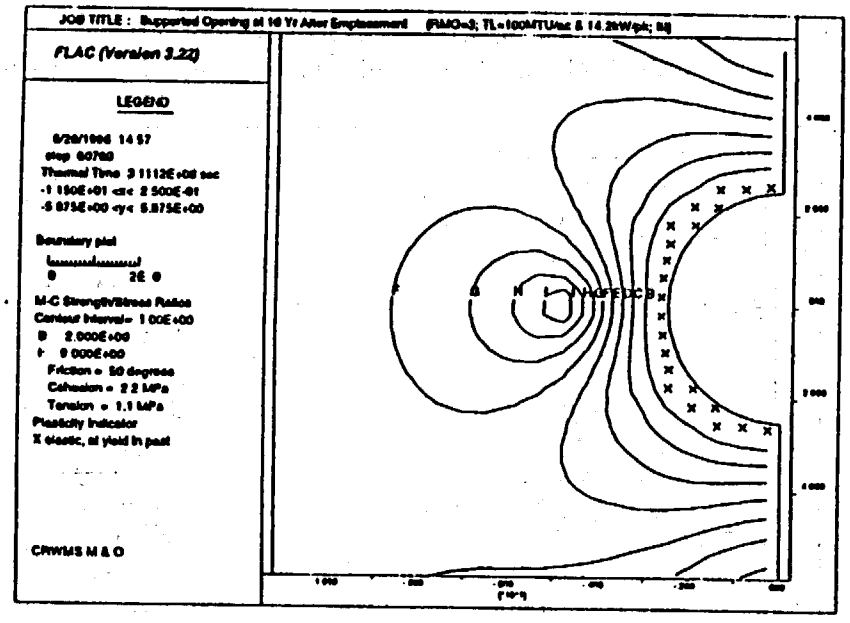
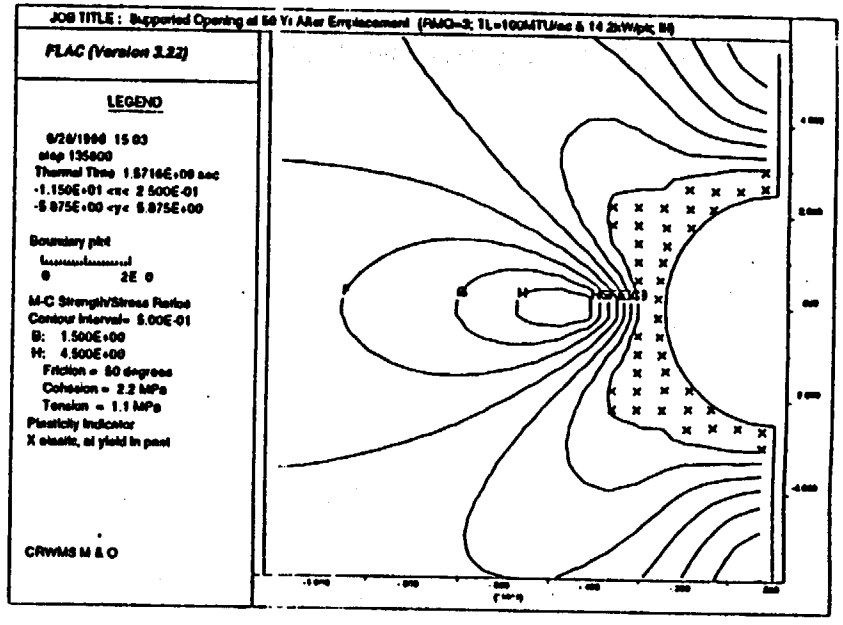


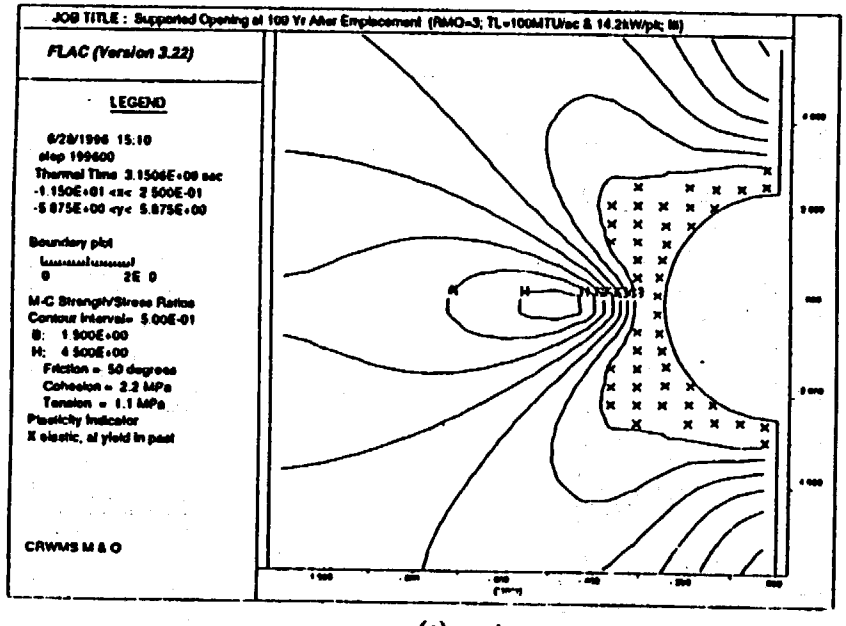
Figure C-7. Factors of Safety Contours and Plasticity Indicators around Opening with Steel Sets Ground Support for RMQ=3, 83 MTU/acre and 9.21 kW/package: (a)10 Years after Emplacement; (b) 50 Years after Emplacement; (c)100 Years after Emplacement



(a)



(b)



(c)

Figure C-8. Factors of Safety Contours and Plasticity Indicators [illegible] nd Opening with Steel Sets Ground Support for RMQ=3, 100 MT[illegible] and 14.2 kW/package : (a) 10 Years after Emplace[illegible], (b) 50 Years after Emplacement; (c) 100 Years after Emplacement

C.4.3 GROUND SUPPORT LOADS

Results of the analysis of loads induced in ground support components by thermal stress are given in the following:

Concrete Liner

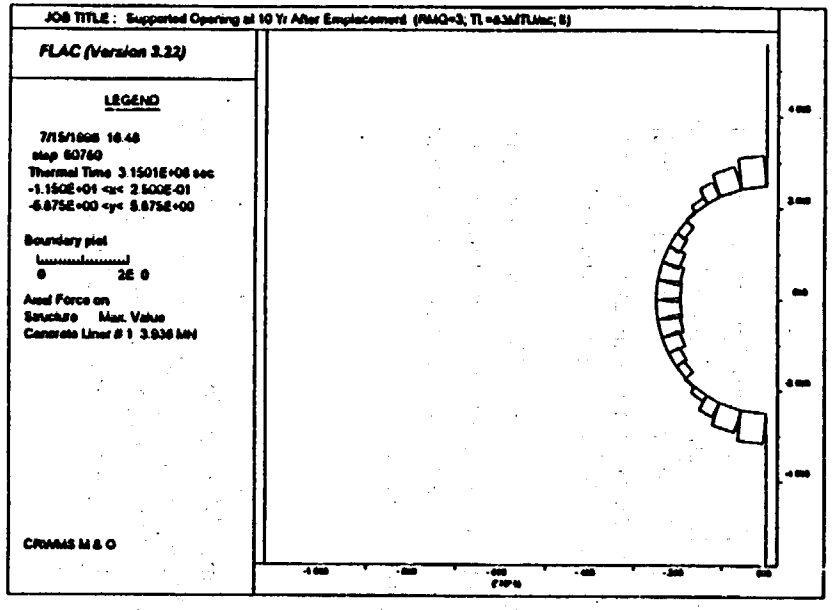
Axial forces (axial refers to the axis of a circular member, that is, it is circumferential in the drift coordinate system) in 200-mm thick concrete liner, for 83 MTU/acre and 9.21 kW/package, at 10, 50 and 100 years after waste emplacement, are presented in Figures C-9a through C-9c for concrete liner ground support for RMQ=3. Axial forces increase with time; depending on location concrete liner may be in tension or compression. All concrete liner begins in compression, but the portion along the sidewalls quickly changes to tension and remains in tension. Figures C-10a and b show time histories of maximum concrete liner compressive axial stresses for the RMQ category of 3 and the initial heat output of 9.21 and 14.2 kW/package, respectively. It is indicated that at 83 MTU/acre and 9.21 kW/package, the stresses in concrete liner increase with time, and remain below the compressive strength of 34.5 MPa during the preclosure period. The maximum compressive axial stress for 83 MTU/acre and 9.21 kW/package occurs, as shown in Table C-10, at about 150 years after emplacement and is about 88% of the compressive strength of 34.5 MPa. As illustrated in Figures C-10a and C-10b, axial stresses in the concrete liner for the RMQ category of 3 exceed the compressive strength of 34.5 MPa at about 70 years for 100 MTU/acre and 9.21 kW/package, about 30 years for 115 MTU/acre and 9.21 kW/package, about 20 years for 83 MTU/acre and 14.2 kW/package, about 15 years for 100 MTU/acre and 14.2 kW/package, and about 10 years for 115 MTU/acre and 14.2 kW/package.

Both tensile and compressive stresses are developed in concrete liner at thermal loads of 83, 100, and 115 MTU/acre. Though compressive stresses are below the strength of 34.5 MPa for 83 MTU/acre and 9.21 kW/package, tensile stresses for all cases considered are of a similar magnitude and may result in tensile failures. For steel, the tensile and compressive strengths are similar, but for concrete, the tensile strength is usually between zero and 10% of its compressive strength.

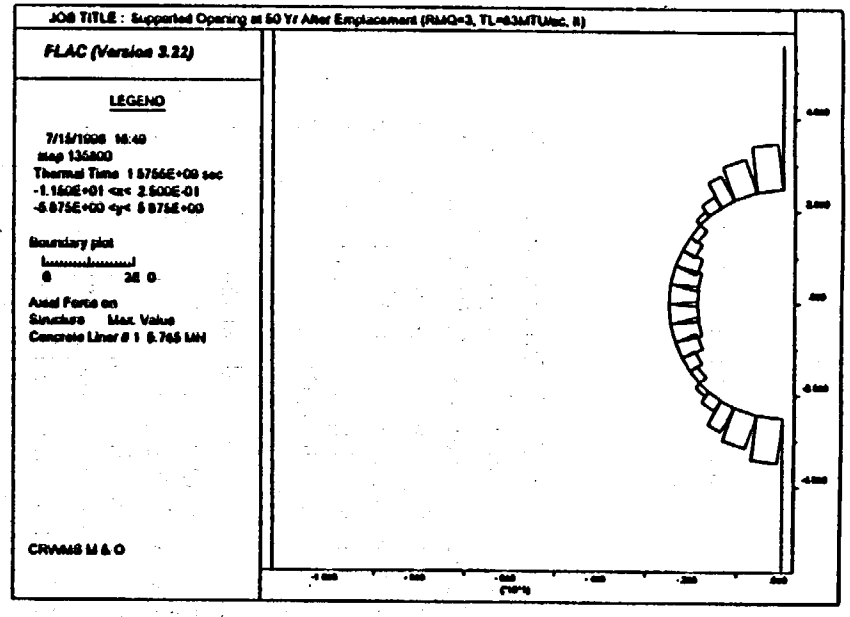
It is noted that if a concrete liner with a high compressive strength, for example 50 MPa, is used, its maximum compressive axial stress may remain below the yield limit as long as the rock temperature stays below 200°C. If the rock temperature exceeds 200°C, however, the concrete liner may experience overstress even with the high compressive strength of 50 MPa.

Steel Sets

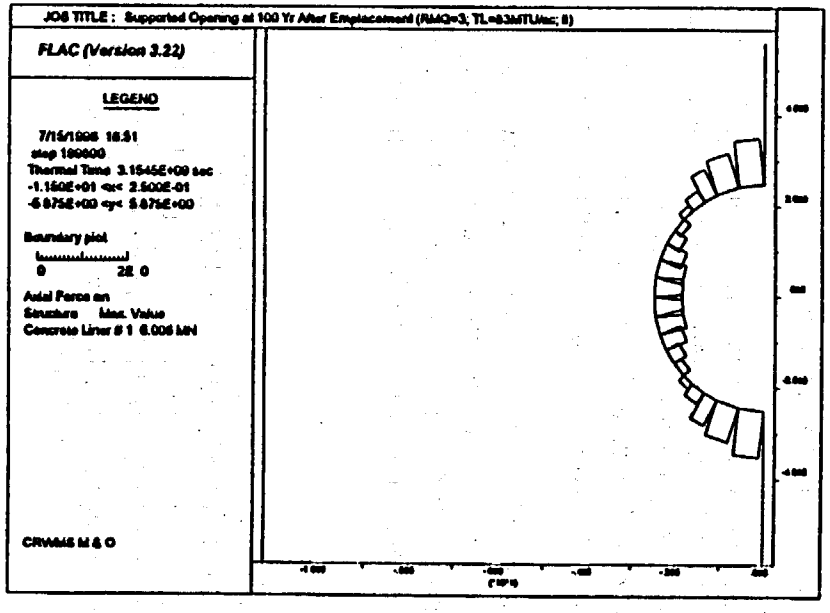
Time histories of axial stresses in steel sets (W5×19) are illustrated in Figure C-11a and C-11b for thermal loads of 83, 100, and 115 MTU/acre and 9.21 and 14.2 kW/package. Maximum compressive axial stresses, as shown in Table C-11, are 309 MPa, 387 MPa and 465 MPa for 9.21 kW/package and 83, 100, 115 MTU/acre, respectively, and are 535 MPa, 708 MPa and 915 MPa for 14.2 kW/package and 83, 100, and 115 MTU/acre, respectively, exceeding the yield limit of 248 MPa for all cases considered.



(a)

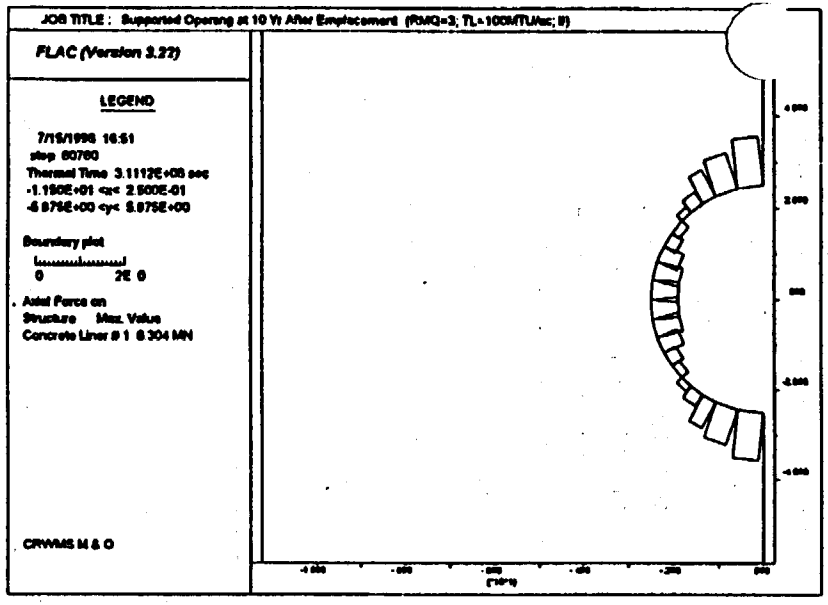


(b)



(c)

Figure C-9. Axial Forces in Concrete Liner Ground Support for R[illegible]3, 83 MTU/acre and 9.21 kW/package: (a)10 Years after Emplac[illegible] (b) 50 Years after Emplacement; (c)100 Years after [illegible]acement



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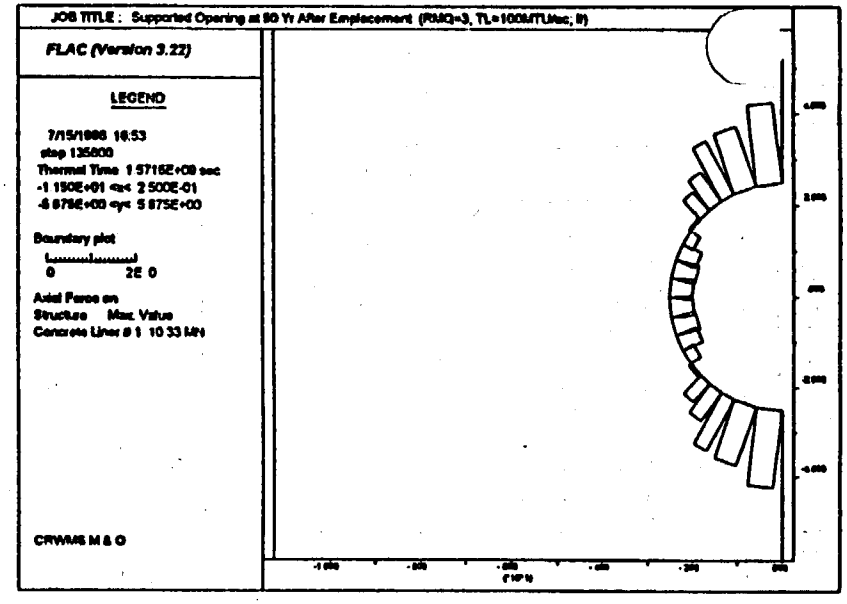

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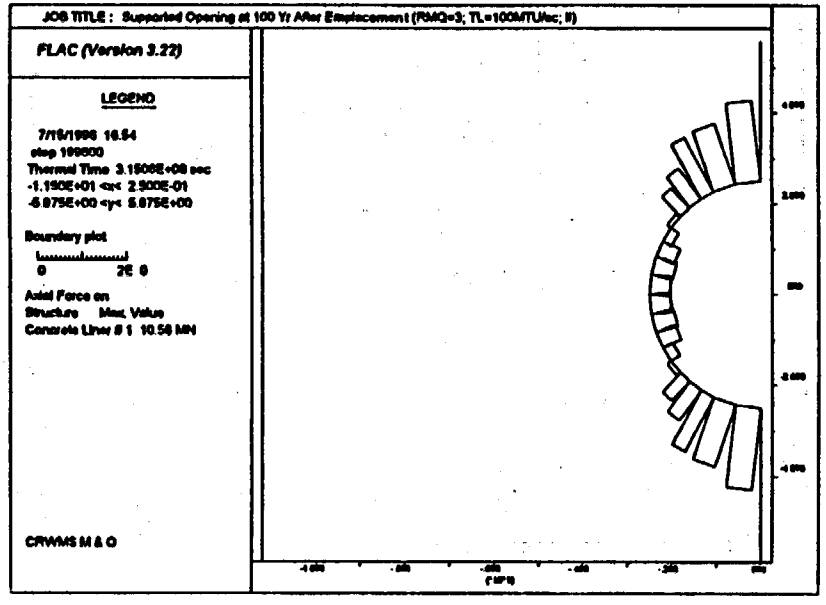
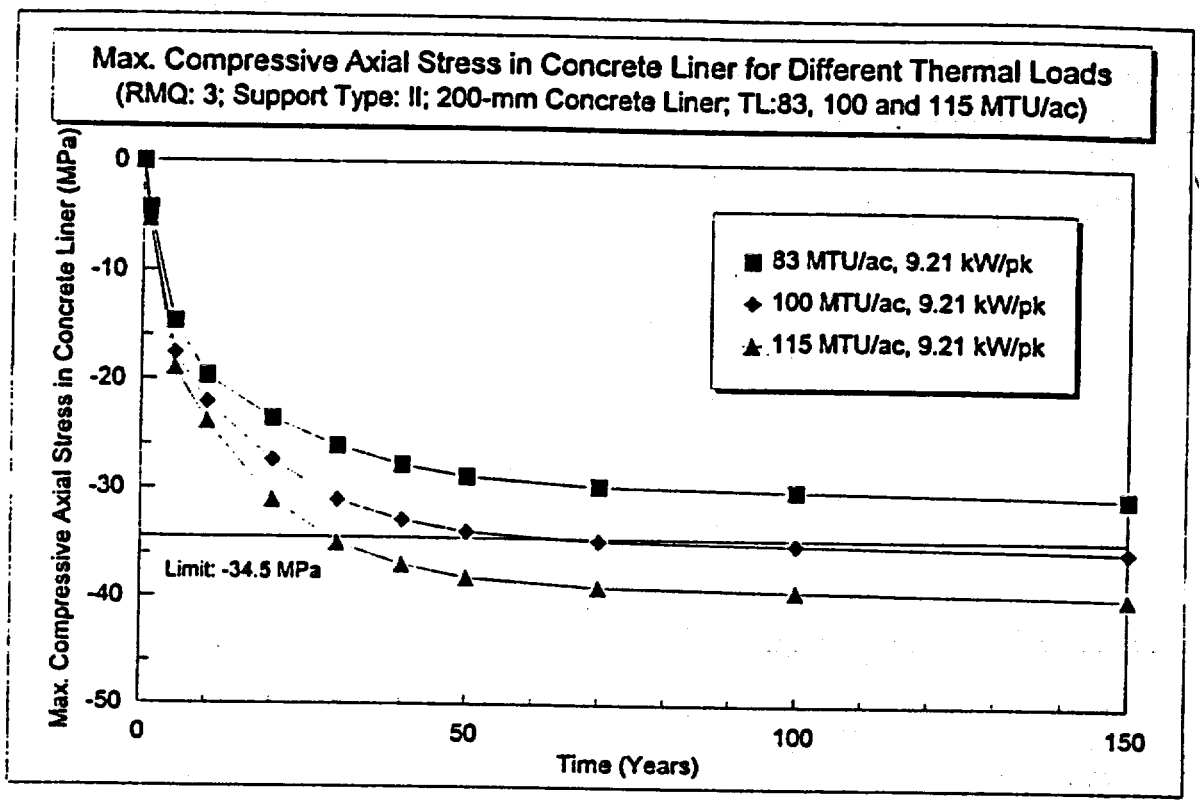
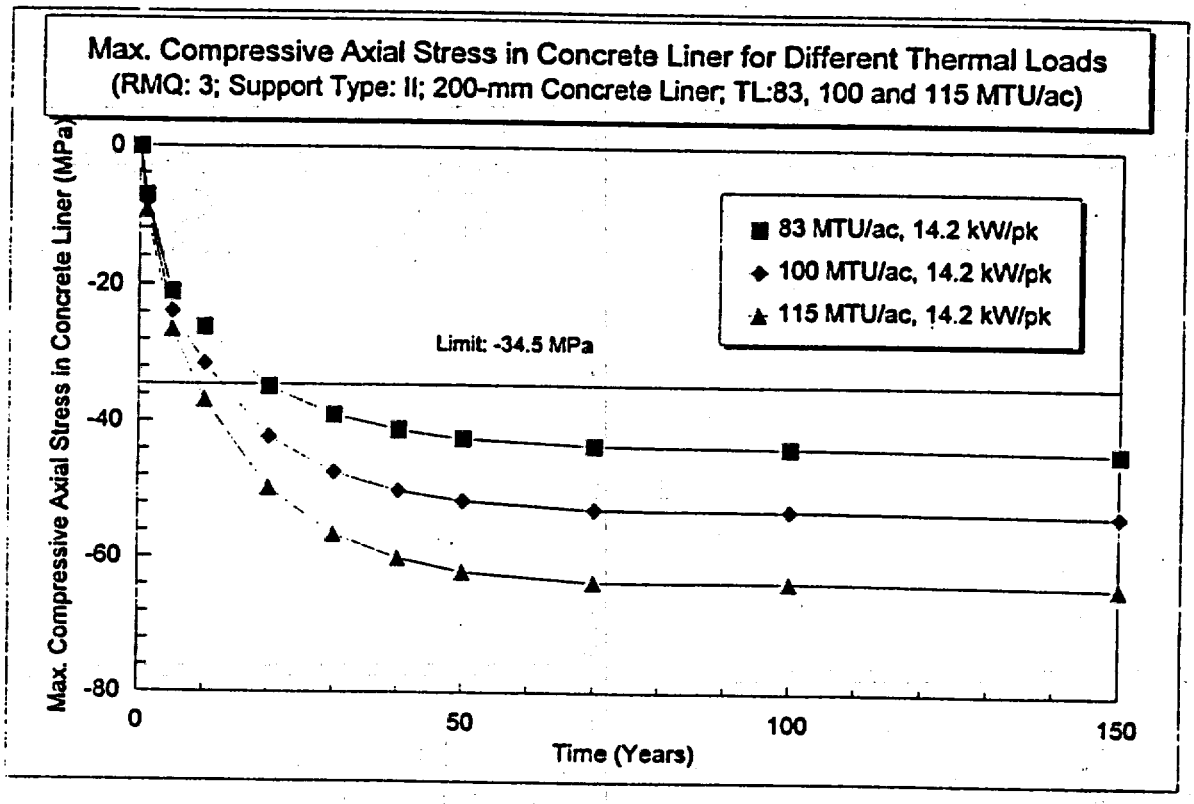


(f)

Figure C-9. Axial Forces in Concrete Liner Ground Support for RMQ=3, 100 MTU/acre and 14.2 kW/package: (a)10 Years after Emplacement; (b) 50 Years after Emplacement; (c)100 Years after Emplacement (continued)

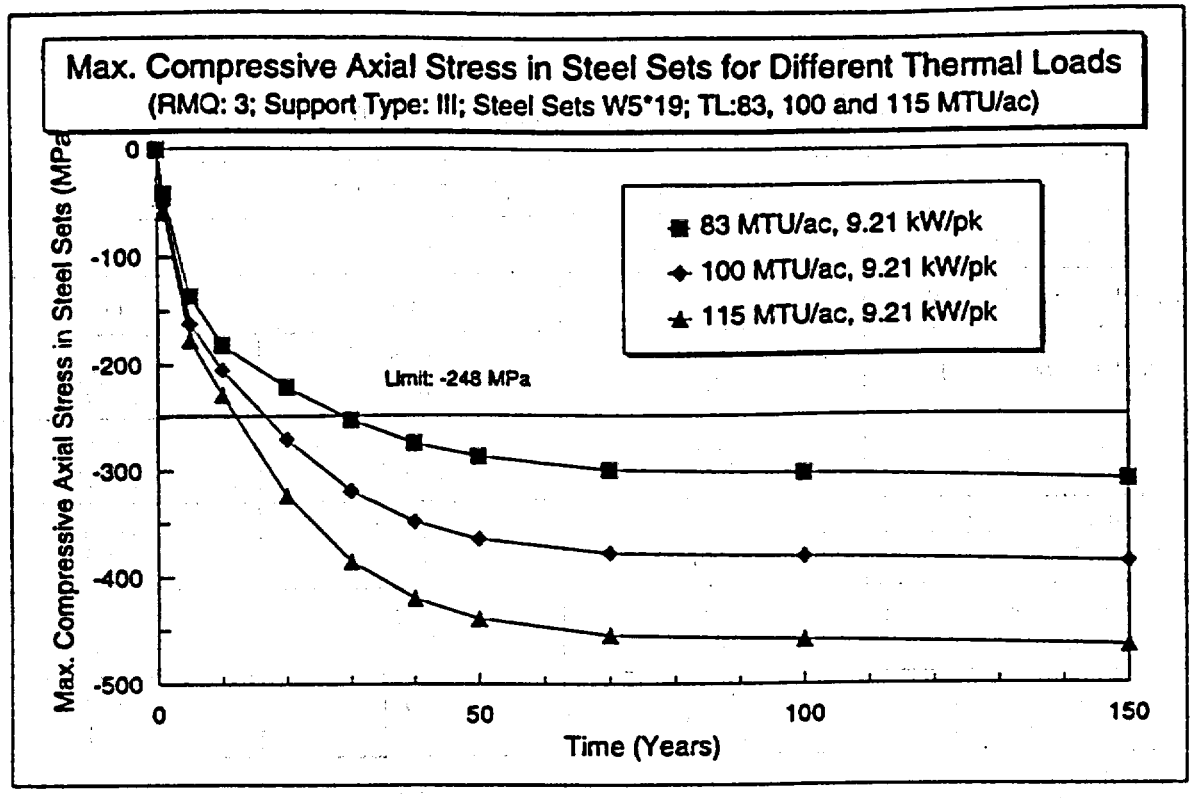


(a)

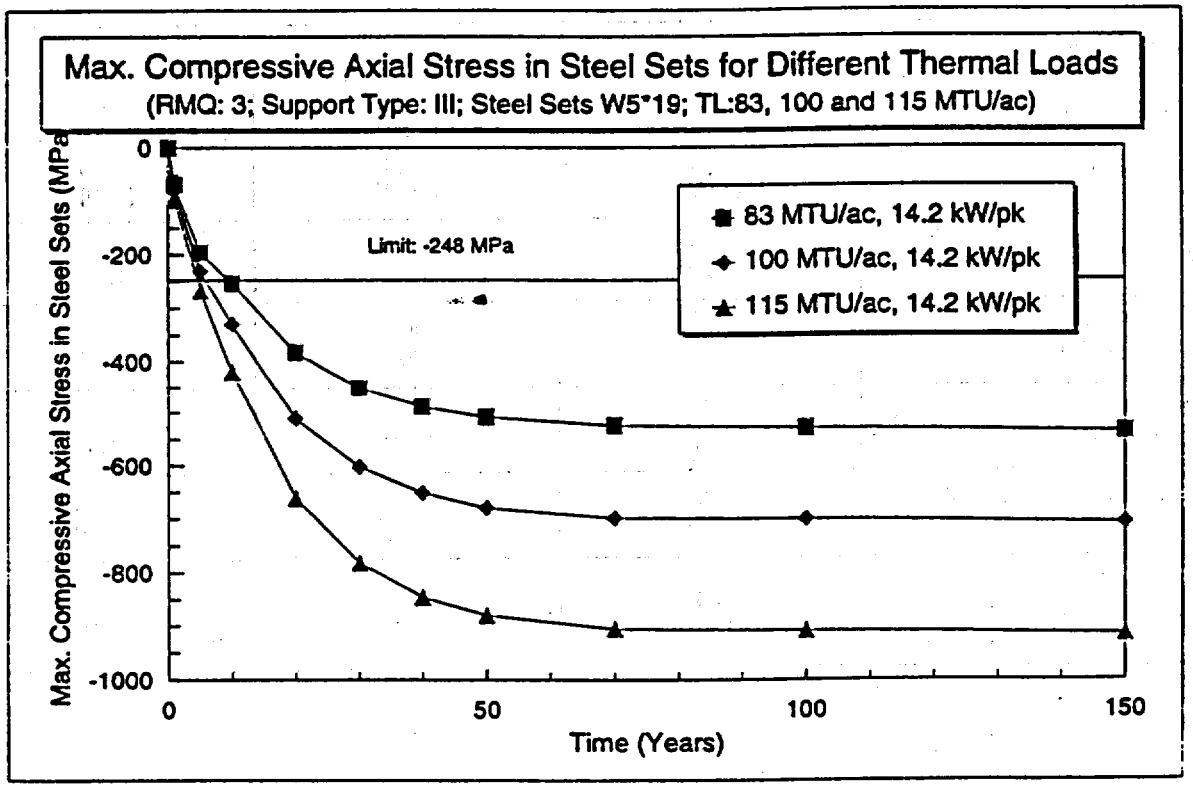


(b)

Figure C-10. Time Histories of Max. Compressive Axial Stress in Concrete Liner for Ground Support for RMQ=3, and 83, 100, and 115 MTU/acre: (a) 9.21 kW/package; (b) 14.2 kW/package



(a)



(b)

Figure C-11. Time Histories of Max. Compressive Axial Stress in Steel Sets for Ground Support for RMQ=3, and 83, 100, and 115 MTU/acre: (a) 9.21 kW/package; (b) 14.2 kW/package

Table C-11. Results from FLAC Models for Steel Sets Ground Support

Ground Support: 1.2 m Spacing W5x19 Steel Sets			
Heat Output (kW/package)	9.21		
Thermal Load (MTU/acre)	83	100	115
Horizontal Closure (mm)	10.41 (150)[1]	13.7 (150)[1]	14.7 (150)[1]
Vertical Closure (mm)	-3.9 (150)[1]	-4.9 (150)[1]	-5.8 (150)[1]
Max. Major Principal Stress at Crown (MPa)	-32.1 (150)[1]	-34.6 (70)[1]	-36.4 (50)[1]
Max. Minor Principal Stress at Crown (MPa)	-2.9 (150)[1]	-3.2 (70)[1]	-3.5 (50)[1]
Max. Compressive Axial Stress in Steel Sets (MPa)	-309.0 (150)[1]	-387.1 (150)[1]	-465.0 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	0.8 (150)[1]	0.6 (150)[1]	0.5 (150)[1]
Heat Output (kW/package)	14.2		
Thermal Load (MTU/acre)	83	100	115
Horizontal Closure (mm)	16.7 (150)[1]	20.9 (150)[1]	25.9 (150)[1]
Vertical Closure (mm)	-6.5 (150)[1]	-7.7 (150)[1]	-9.0 (150)[1]
Max. Major Principal Stress at Crown (MPa)	-37.4 (50)[1]	-39.3 (50)[1]	-41.2 (40)[1]
Max. Minor Principal Stress at Crown (MPa)	-3.6 (50)[1]	-3.9 (50)[1]	-4.2 (40)[1]
Max. Compressive Axial Stress in Steel Sets (MPa)	-535.3 (150)[1]	-707.8 (150)[1]	-915.1 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	0.5 (150)[1]	0.4 (150)[1]	0.3 (150)[1]

[1] Time in years after emplacement to reach a maximum value during preclosure.

It is noted that overstress in steel sets may be caused by the way with which steel sets are modeled in the FLAC program. FLAC simulates steel sets by assuming that they are bounded with rock perfectly, and no relative sliding or normal displacement occurs between steel sets and rock surface. This assumption is conservative when compared to reality. However, the analysis presented here for steel sets with FLAC is still useful in that it shows the relationship of potential stresses among the different scenarios (different thermal loads and waste package heat outputs) even if the magnitude of the stresses is overstated. An effort is currently being made by using the ANSYS program to model the interaction between steel sets and rock mass such that the relative sliding or normal displacement is allowed with the use of interface or gap elements, which connect the steel sets elements to those of rock but allow them to move relatively in both normal and tangential directions. Preliminary results with this approach indicate that decrease of stresses in steel sets is substantial, but it is too early to draw any definitive conclusion on this matter.

C.5 SUMMARY

Uniformly-spaced emplacement 5-meter-diameter drifts have been analyzed using both ANSYS and FLAC codes under combinations of static and thermal loading conditions. Only one set of material properties for average rock mass state (RMQ=3) was considered. Concrete liner and steel sets were incorporated in numerical models as candidate ground support for the drift. The main objective of the analysis is to examine the response of emplacement drifts to the elevated temperature, especially above 200°C, under long-term thermal loading, so that the drift stability can be assessed.

Input data to numerical analyses reflect the best documented information currently available on elastic properties, strength parameters, thermal properties, in situ stresses, and thermal loads. These properties and their time dependent behavior, if any, have been considered in modeling as realistically as possible. Careful attention was also given to mesh refinement and boundary conditions in order to minimize the effect of mesh dimensions on numerical output.

Under the thermal loads of 83, 100, and 115 MTU/acre, the drift experiences higher horizontal closure than vertical closure. In fact, the drift will elongate vertically. The maximum horizontal closure detected is 14.7 mm for the rock temperature below 200°C and 25.9 mm for the rock temperature above 250°C, while the maximum vertical elongation is 5.8 mm for the rock temperature below 200°C and 9.0 mm for the rock temperature above 250°C. Potential rock mass yield at temperature below 200°C may occur to a depth of about 60 cm from the periphery of the drift. At temperature above 225°C, the potential rock mass yield may occur to as deep as about two meters, but is by no means substantial. These values indicate that though the normal components of the stress state have increased significantly, rock mass behaves essentially elastically even with the rock temperature exceeding 200°C.

Overstress in concrete liner and steel sets at elevated temperatures both below and above 200°C due to long-term thermal loads is substantial. Maximum compressive axial stresses in 200-mm thick concrete liner exceed its compressive strength for all cases except for the 83 MTU/acre and 9.21 kW/package case in which the peak rock temperature is about 146°C. Regardless whether the temperature is below or above 200°C under thermal loads, tensile load in concrete liner is high enough for tensile cracks to develop, eventually reducing the effectiveness of the concrete liner. Light steel sets are also shown to exceed their yield strength in tension and in compression. In this

respect, high thermal loads indicate the need for structurally flexible support systems such as a pre-cast concrete liner.

In conclusion, it is shown that substantial rock mass yield may not occur even at the rock temperature above 200°C. However, the increase in the coefficient of thermal expansion of the TSw2 tuff when the rock temperature exceeds 200°C may trigger rock deformation, which may, in turn, produces high stresses in ground support elements such as concrete liner or steel sets unless the ground support systems are structurally flexible to be capable of adjusting to the thermally-induced rock deformation.

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APPENDIX D

COUPLED VENTILATION AND HYDROTHERMAL EVALUATIONS

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COUPLED VENTILATION AND HYDROTHERMAL EVALUATIONS

Realistic calculations of the psychrometric environment in a potential repository require an understanding of the amount of heat and moisture that are removed from the emplacement drifts and the near-field rock by ventilation. To achieve this, a coupled simulation procedure was developed using the Lawrence Livermore National Laboratory Nonisothermal Unsaturated-Saturated Flow and Transport code for the hydrothermal calculations in the near field (Nitao 1995) and the Mackay Thermal Enhancement and Climate Simulation model (Danko 1992; Danko and Mousset-Jones 1992; Danko and Mousset-Jones 1993; and Danko 1994) for the heat and mass transport calculations in the air. The coupled codes, using projected site properties, produce three-dimensional calculations of the hydrothermal behavior of the near-field rock-air interface, and the dilution of water vapor in the drift air flow and subsequent transport out of the system.

Ventilation calculations were done for anticipated repository conditions to examine the amount of heat and moisture removal that could be achieved with varying degrees of ventilation. An advanced conceptual design like scenario was examined to evaluate the heat and moisture removal. In a more realistic scenario, multiple waste packages, each with different heat outputs, were simulated to evaluate the potential for ventilation to remove the temperature variations that variable heat output packages would produce. Additionally, other passive thermal management techniques as thermal rock bolts and axial heat pipes were evaluated.

Coupled calculations can take a significant amount of computing time because of the numerous iterations between the various models which must be done. Because of this, a thermohydrologic simulator was developed based on numerous runs from the Nonisothermal Unsaturated-Saturated Flow and Transport code. This simulator is put in terms of a matrix solution which can be entered with various conditions of wall temperature and air vapor pressure to solve for the rock conditions. This simulator runs significantly faster and has been checked a for a number of cases using the full coupled model. Most of the runs shown in this appendix were done with the simulator code coupled with the ventilation model. Additional discussions of the model development can be found in Danko, et. al. (1996 and 1995).

Ventilation Evaluations. In the first set of evaluations advanced conceptual design conditions were evaluated. In these calculations the waste packages were large, 21 pressurized-water reactor (PWR) sized packages. A weighted average PWR and BWR (oldest-fuel-first spent nuclear fuel (SNF) was assumed) was used so that with a waste package spacing of 16 m and a drift spacing of 22.5 m the air input temperature at drift entrance was 26°C with a relative humidity of 30 percent. Most of the calculations were done for emplacement drift lengths of 1152 m and the results plotted as a function of drift length so that comparisons can be made with other model predictions at the respective drift location.

The first set of calculations were done with a high ventilation rate of 10 m^3/s. The results of these calculations are shown in Figures D-1 through D-13. Parameters such as air temperature, drift wall temperature, partial pressure of water in air (labeled air pressure), partial pressure of water at the wall (labeled wall pressure), moisture mass flux per meter of wall, heat flux, integrated moisture mass flux over a meter length of drift, and integrated wall heat flux are plotted as a function of time. In some cases two-dimensional plots of these parameters are included.

Next, similar calculations are done at a modest ventilation rate of 1 m^3/s which is potentially what might occur with natural ventilation. Figures D-14 through D-21 depict the appropriate parameters. Calculations were also done with a very low air flow of 0.1 m^3/s which simulates a very low natural ventilation. Figures D-22 through D-27 provide the results of these calculations.

Evaluations of Multiple Heat Waste Packages. A number of evaluations were also done with several different waste package heats. These calculations simulate the effects of emplacing waste packages with varying heat outputs. The thermal loading for these cases was 20.6 kgU/m^2 (83 MTU/acre). Two sizes of waste packages [a large (21 PWR) and a small (12 PWR)] plus a defense high-level waste package were considered in the calculations. The various waste packages were the following:

d1: Defense high-level waste; 2.15 MTU; heat output about 1.6 kW

h1: 21 PWR; 26 year old SNF; 8.83 MTU; heat output about 9 kW

h2: 12 PWR; 40 year old SNF; 4.67 MTU; heat output about 3 kW

h3: 40 boiling-water reactor (BWR); 26 year old SNF; 7.07 MTU; heat output about 6 kW

d2: Defense high-level waste; 2.15 MTU; heat output about 2.6 kW

h4: 21 PWR; 10 year old SNF; 8.83 MTU; heat output about 17.5 kW

The spacing on these waste packages is either close spaced with 0.1 m between packages and 53.8 m drift spacing or an advanced conceptual design spacing with 22.5 m spacing between drifts. In the advanced conceptual design-like case, d1 is centered in an emplacement length of 5.18 m, h1 is next and is centered in a 19.12 m space which starts where the d1 emplacement length ends, next is h2 which is centered in an emplacement length of 10.12 m, h3 is centered in 15.32 m, d2 is centered in a 5.18 m space, and h4 is centered in a 19.12 m space. The waste package emplacement scheme is then sequentially repeated as one continues downstream in the drift.

Six cases were evaluated. These cases were the following:

Case 1: No ventilation, no cooling enhancement

Case 2: Natural ventilation (0.1 m^3/s), no cooling enhancement

Case 3: Natural ventilation (1 m^3/s), no cooling enhancement

Case 4: Forced ventilation in a looped ventilation system (two drifts tied together with recirculated air, no fresh inlet air), 10 m^3/s for 30 years the 0.1 m^3/s for remainder of time, no cooling enhancement

Case 5: No ventilation, axial heat pipes between containers (thermal resistance 0.00133 W/°C/m, active heat pipe diameter 0.5 m and outside coated diameter 0.2 m)

Case 6: No ventilation, thermal rock bolts in the wall (thermal resistance of 0.0133 W/°C/m) on a 1.5 x 1.5 m pattern. (Danko 1994, pp 890-898).

Figures D-28 to D-31 show Case 1. Figures D-32 to D-35 depict Case 2. Case 4 is shown in Figures D-36 to D-39. Case 5 is shown in Figures D-40 to D-43. Two dimensional temporal plots of drift wall temperature, air temperature, drift wall heat flux, and drift wall moisture flux are presented.

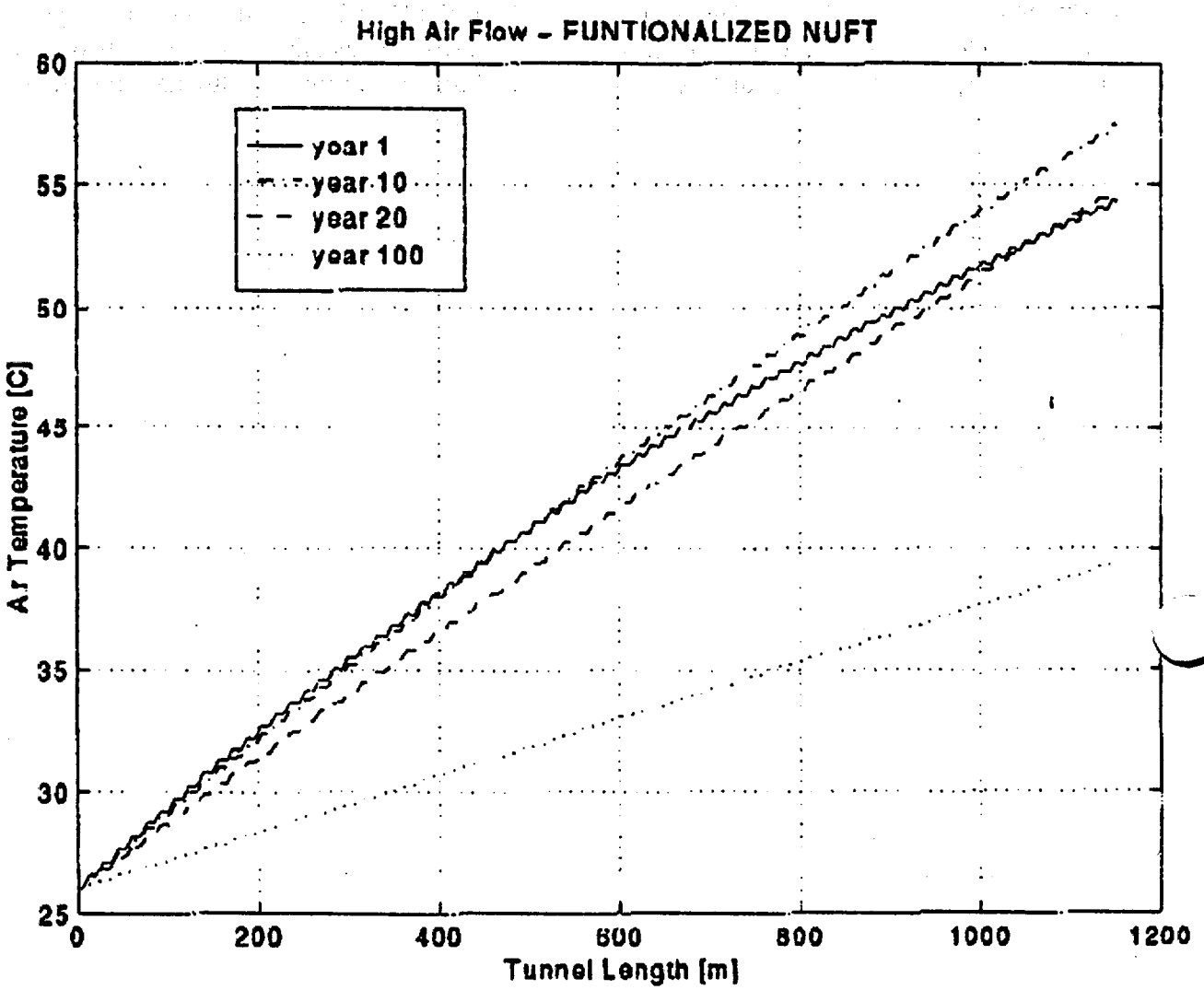

Figure D-1. Air Temperature for High Flow (10 m^3/s) Ventilation

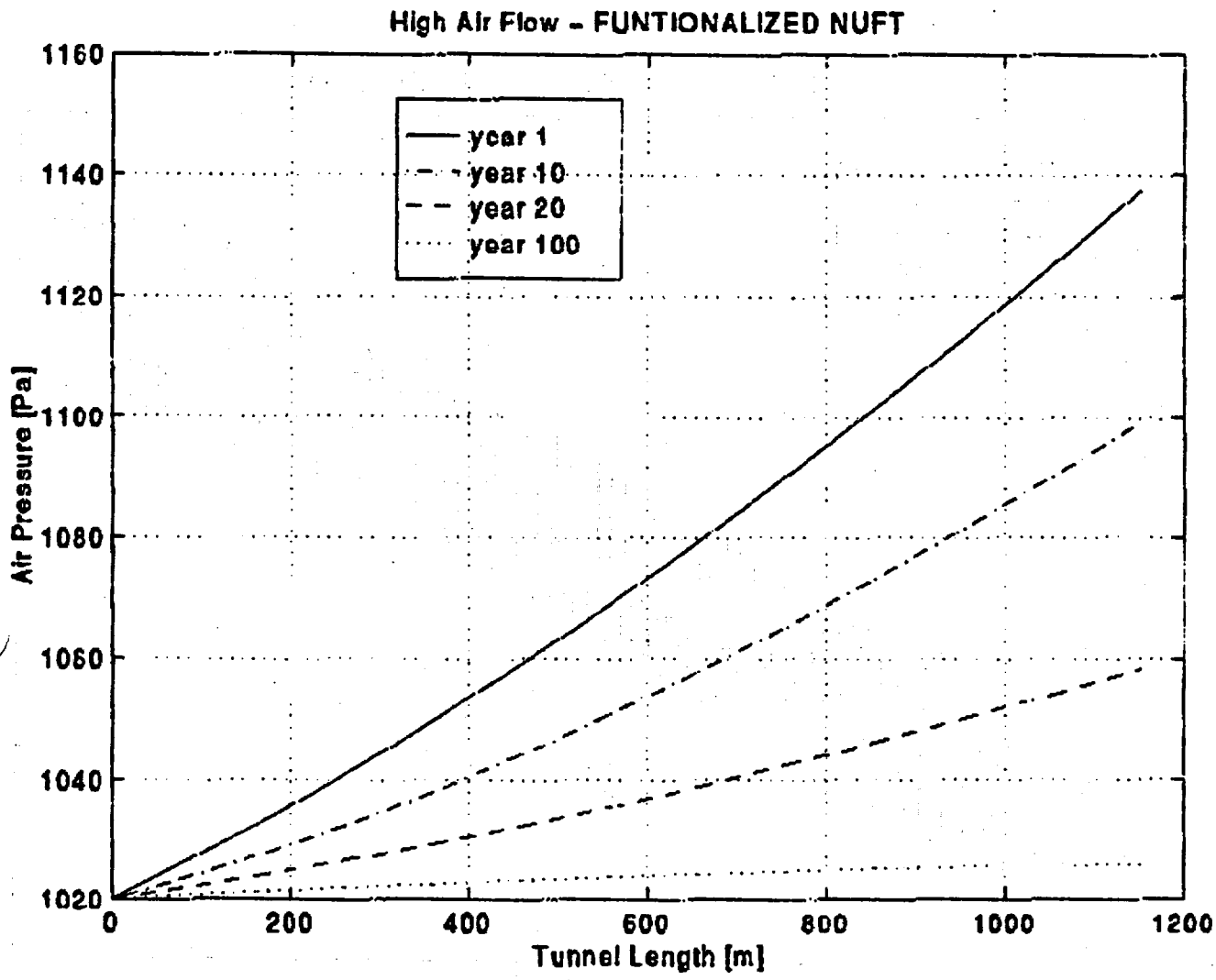

Figure D-2. Air Pressure for High Flow (10 m^3/s) Ventilation

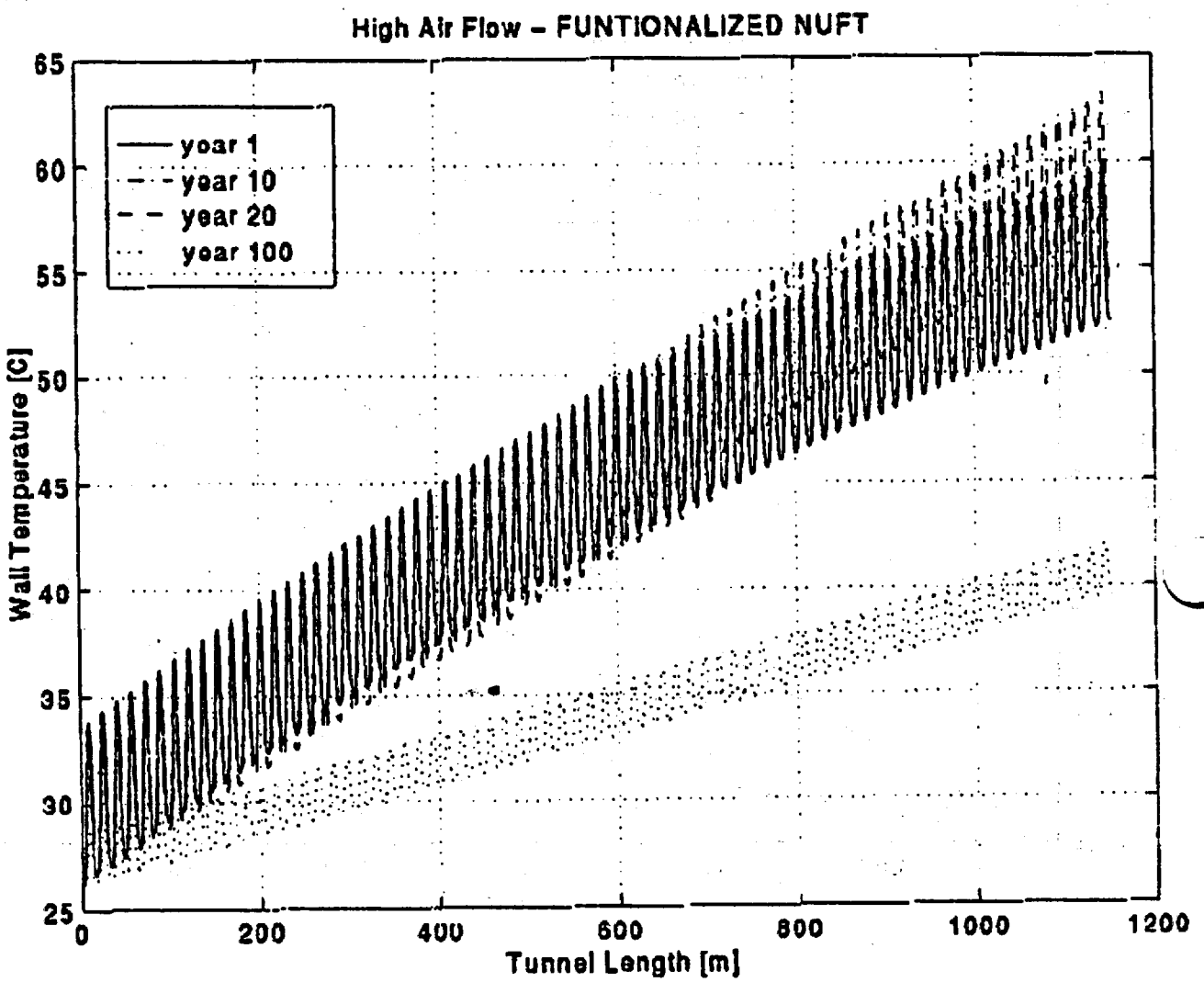

Figure D-3. Wall Temperature for High Flow (10 m^3/s) Ventilation

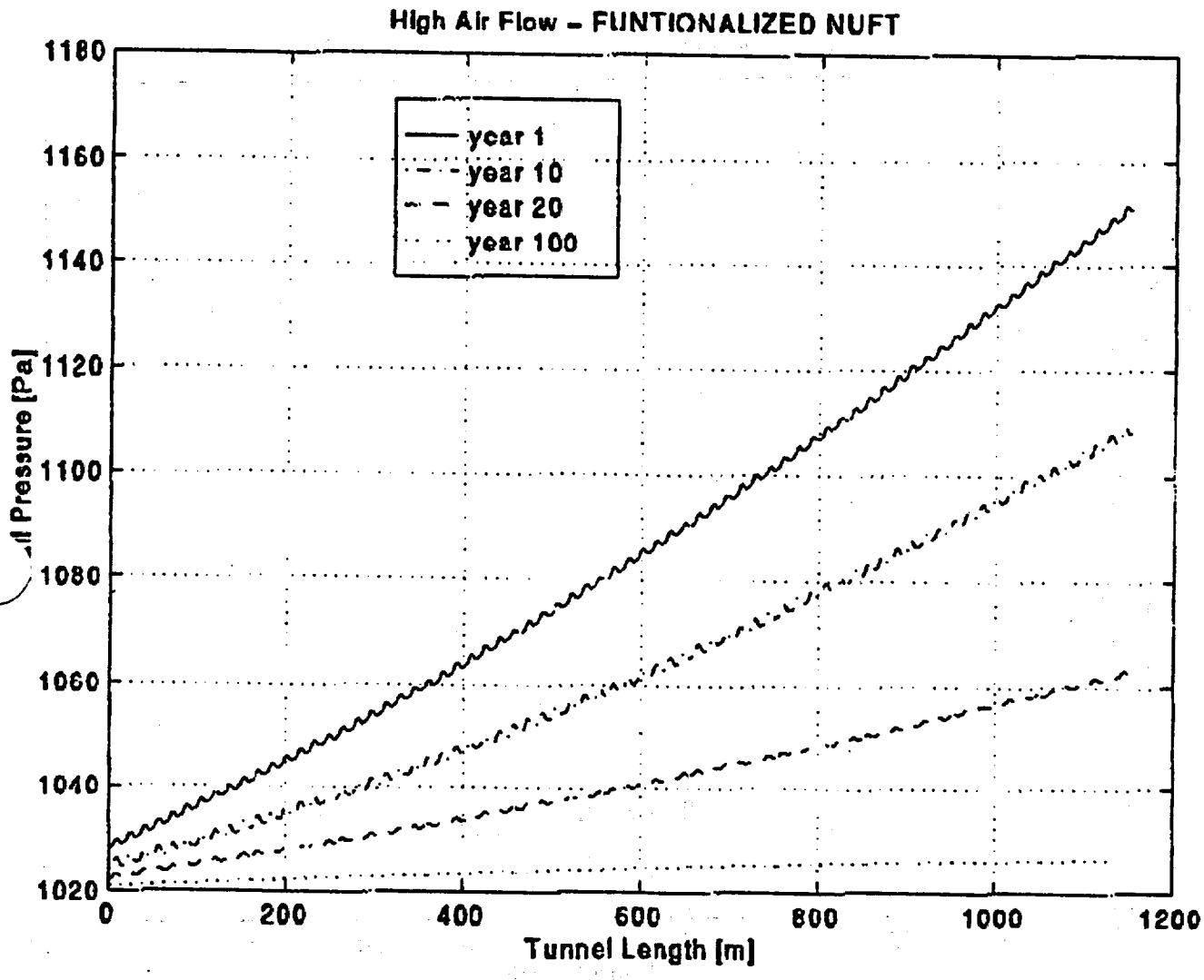

Figure D-4. Wall Pressure for High Flow (10 m^3/s) Ventilation

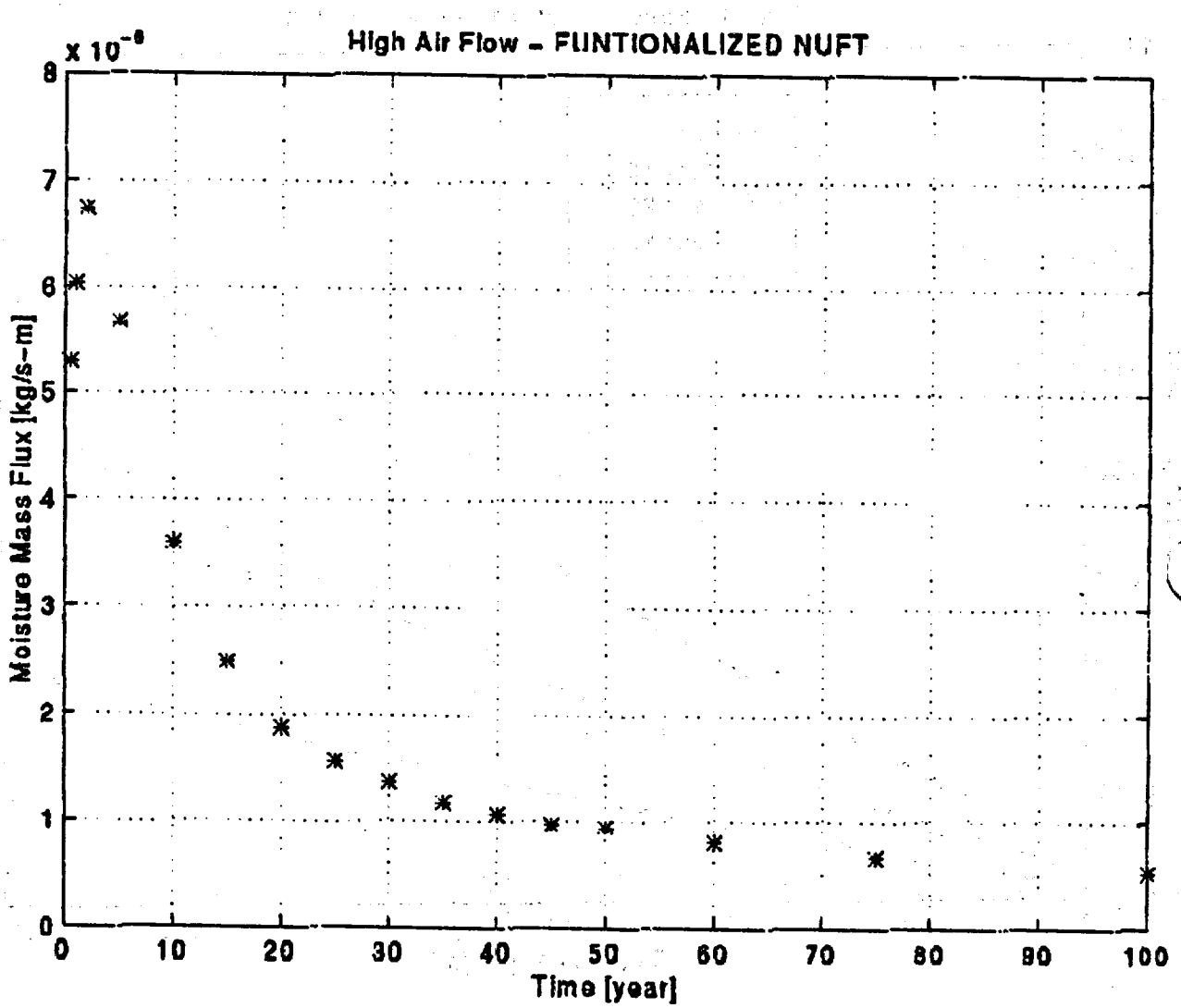

Figure D-5. Moisture Flux for High Flow (10 m^3/s) Ventilation

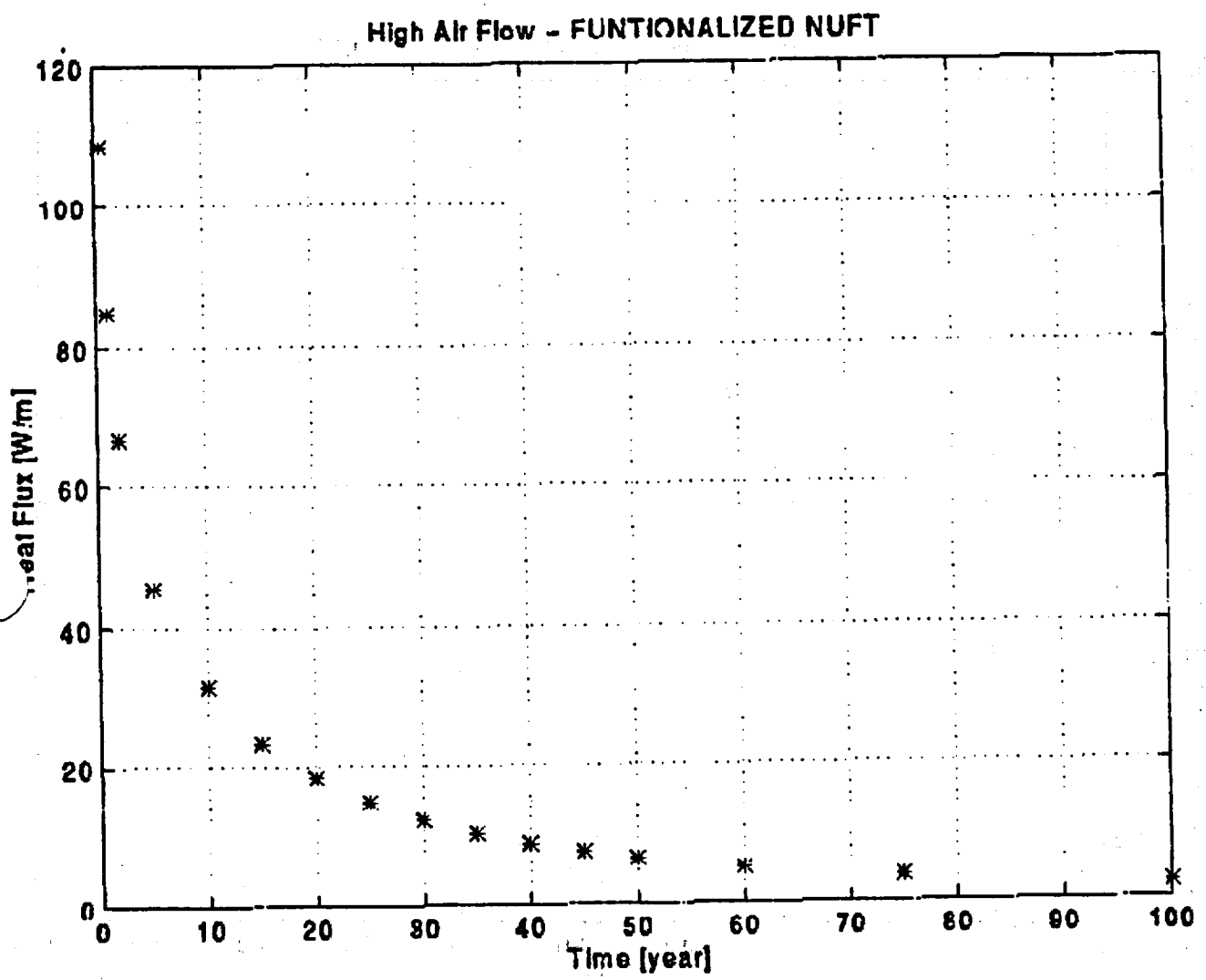

Figure D-6. Heat Flux for High Flow (10 m^3/s) Ventilation

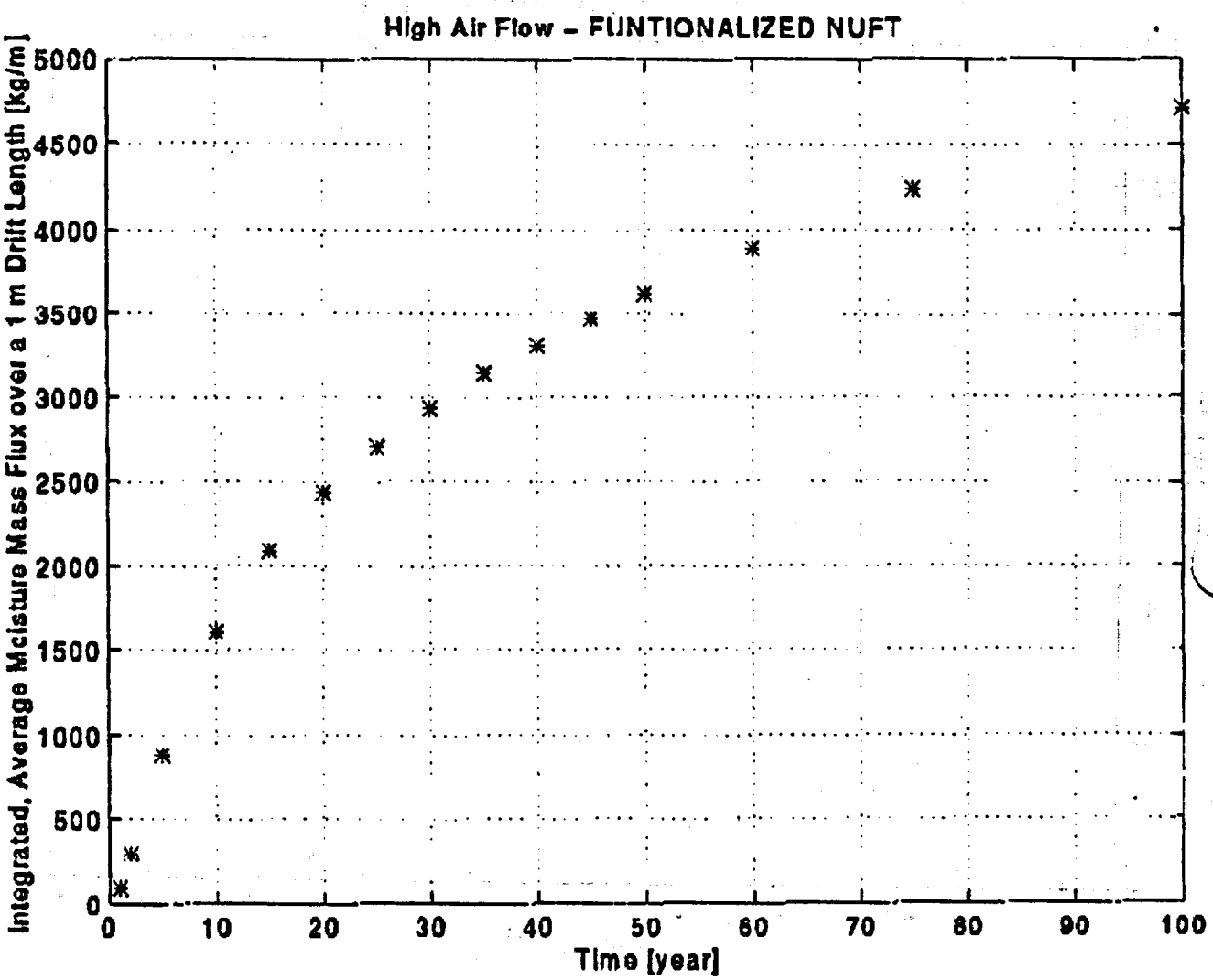

Figure D-7. Integrated Moisture Flux for High Flow (10 m^3/s) Ventilation

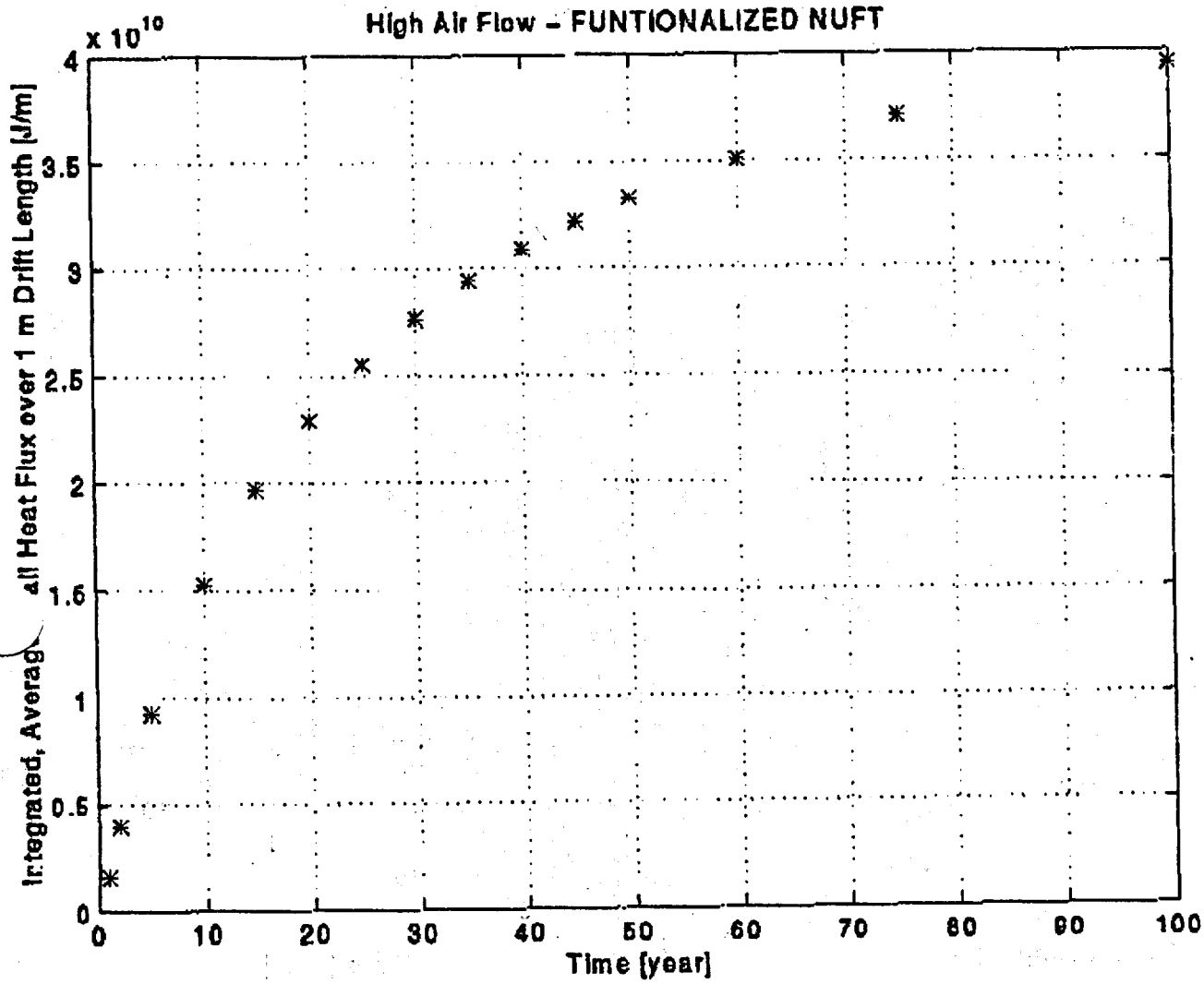

Figure D-8. Integrated Wall Heat Flux for High Flow (10 m^3/s) Ventilation

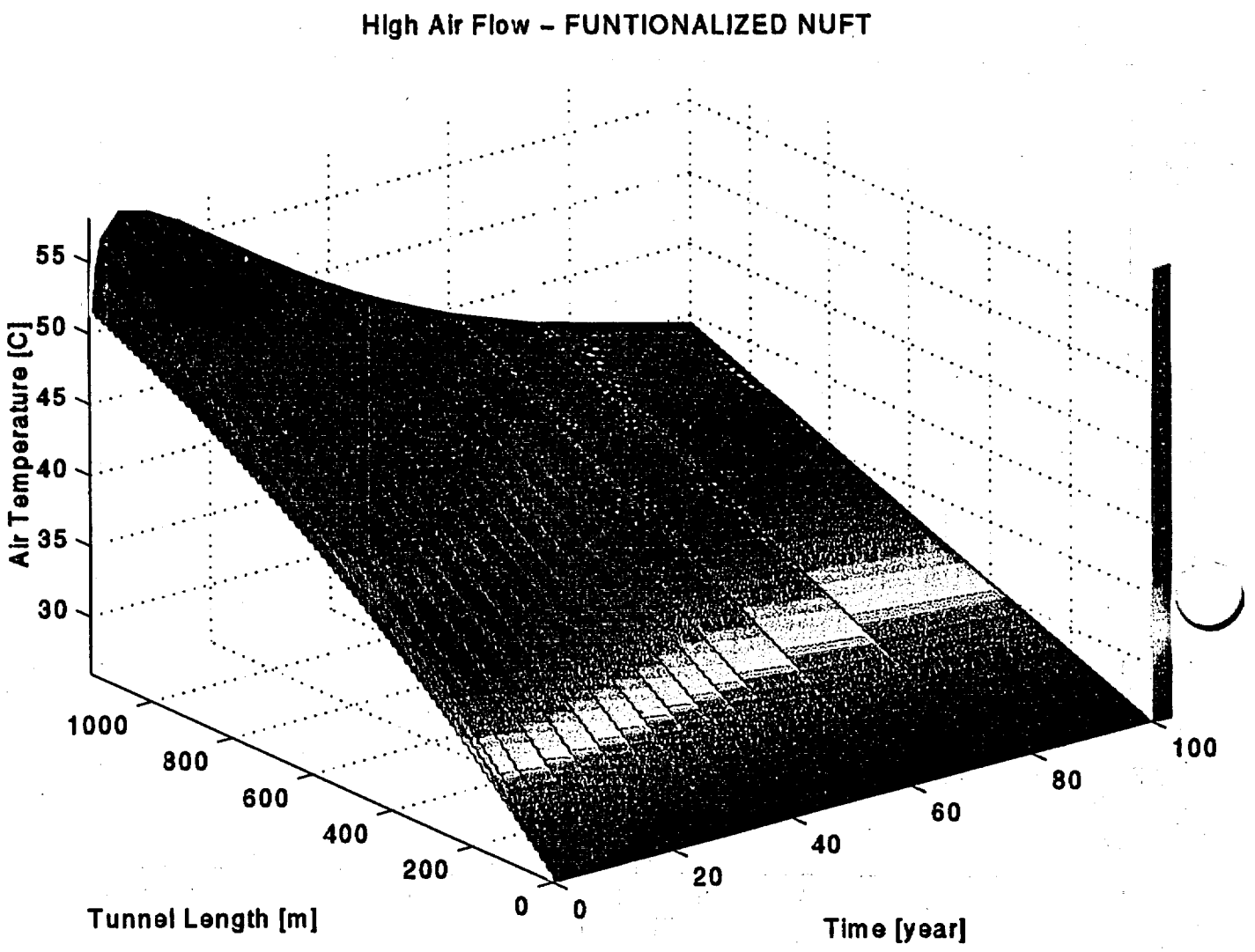

Figure D-9. Air Temperature Temporal Profiles for High Flow (10 m^3/s) Ventilation

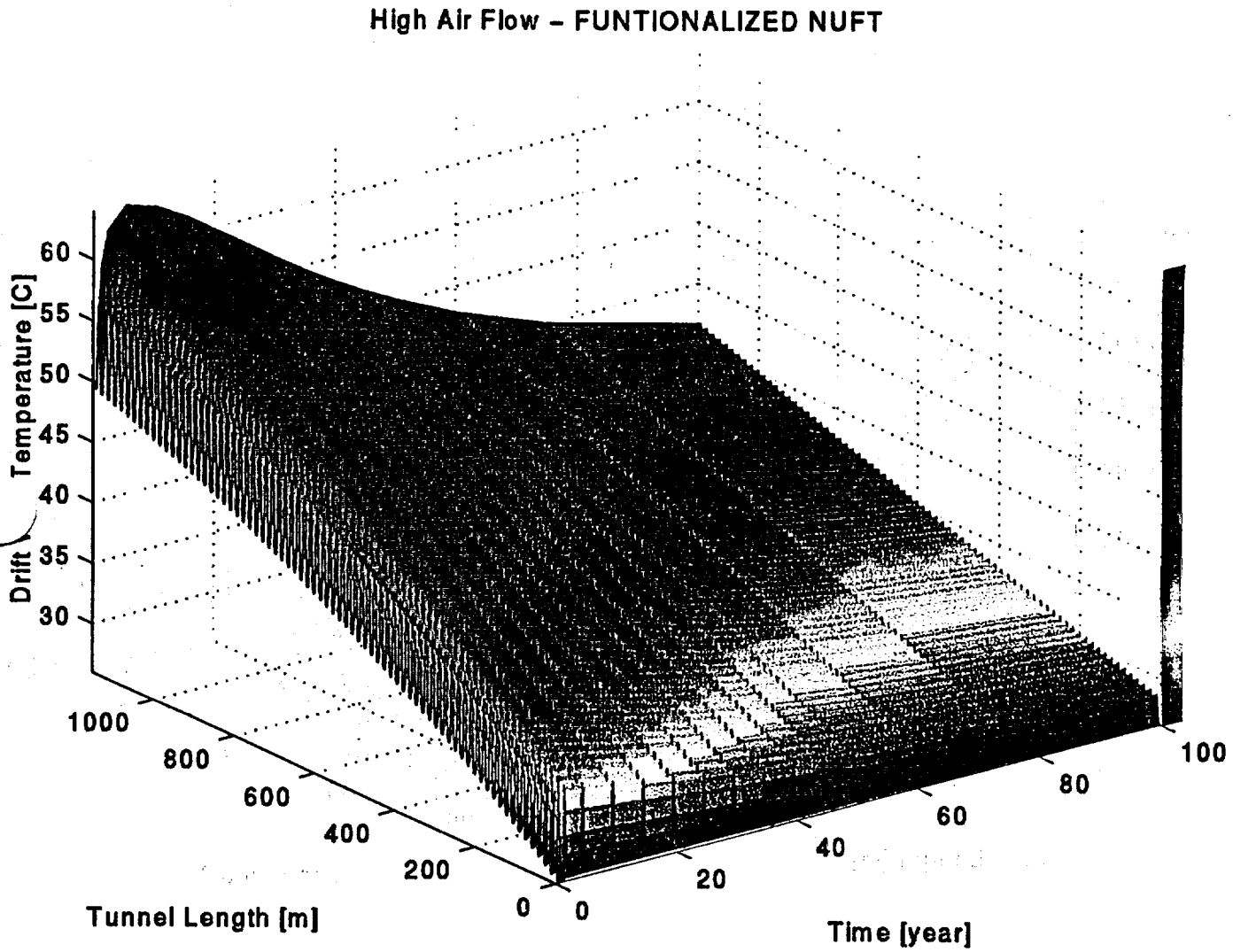

Figure D-10. Drift Wall Temperature Temporal Profiles for High Flow (10 m^3/s) Ventilation

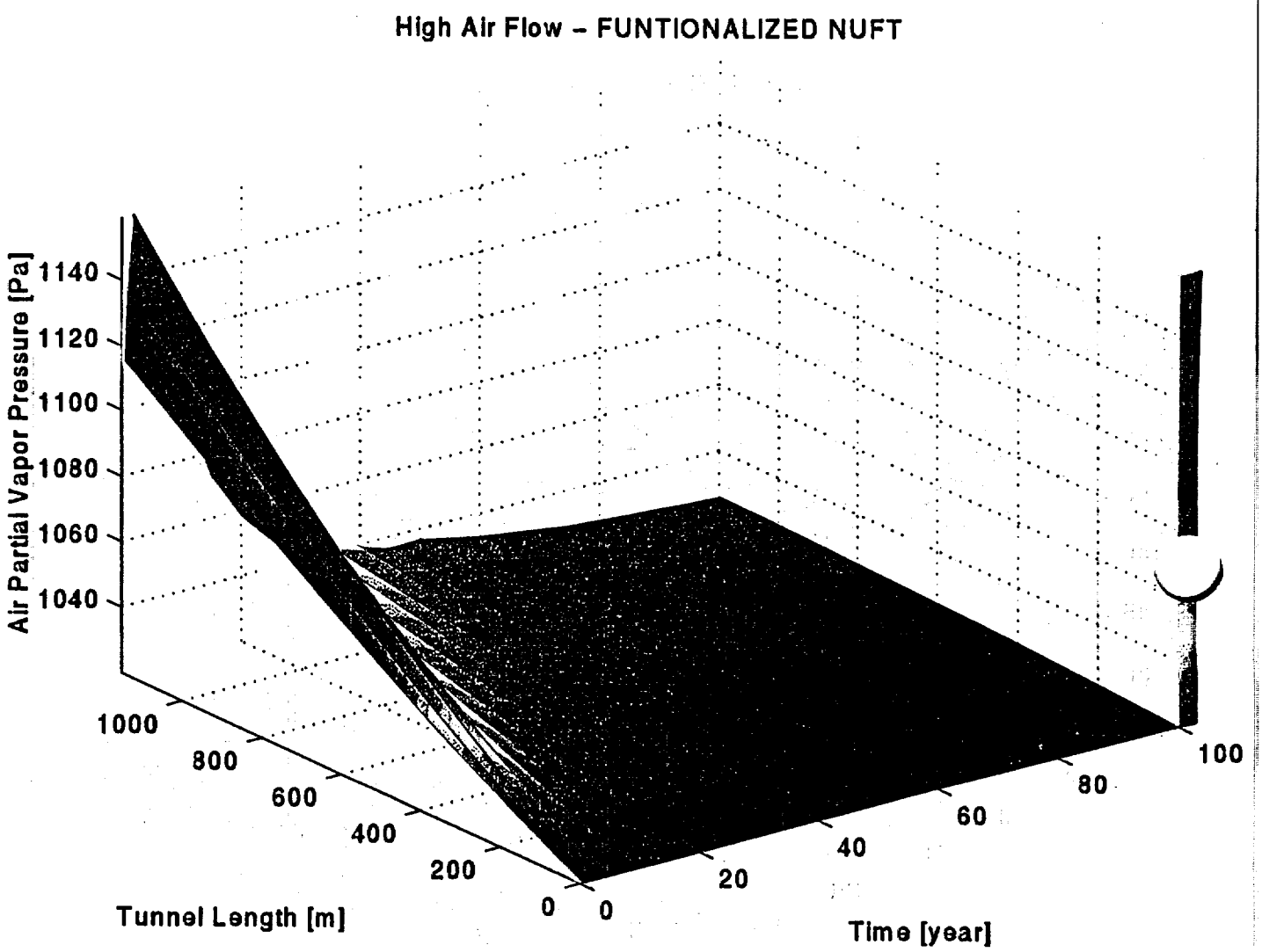

Figure D-11. Air Vapor Pressure Temporal Profiles for High Flow (10 m^3/s) Ventilation

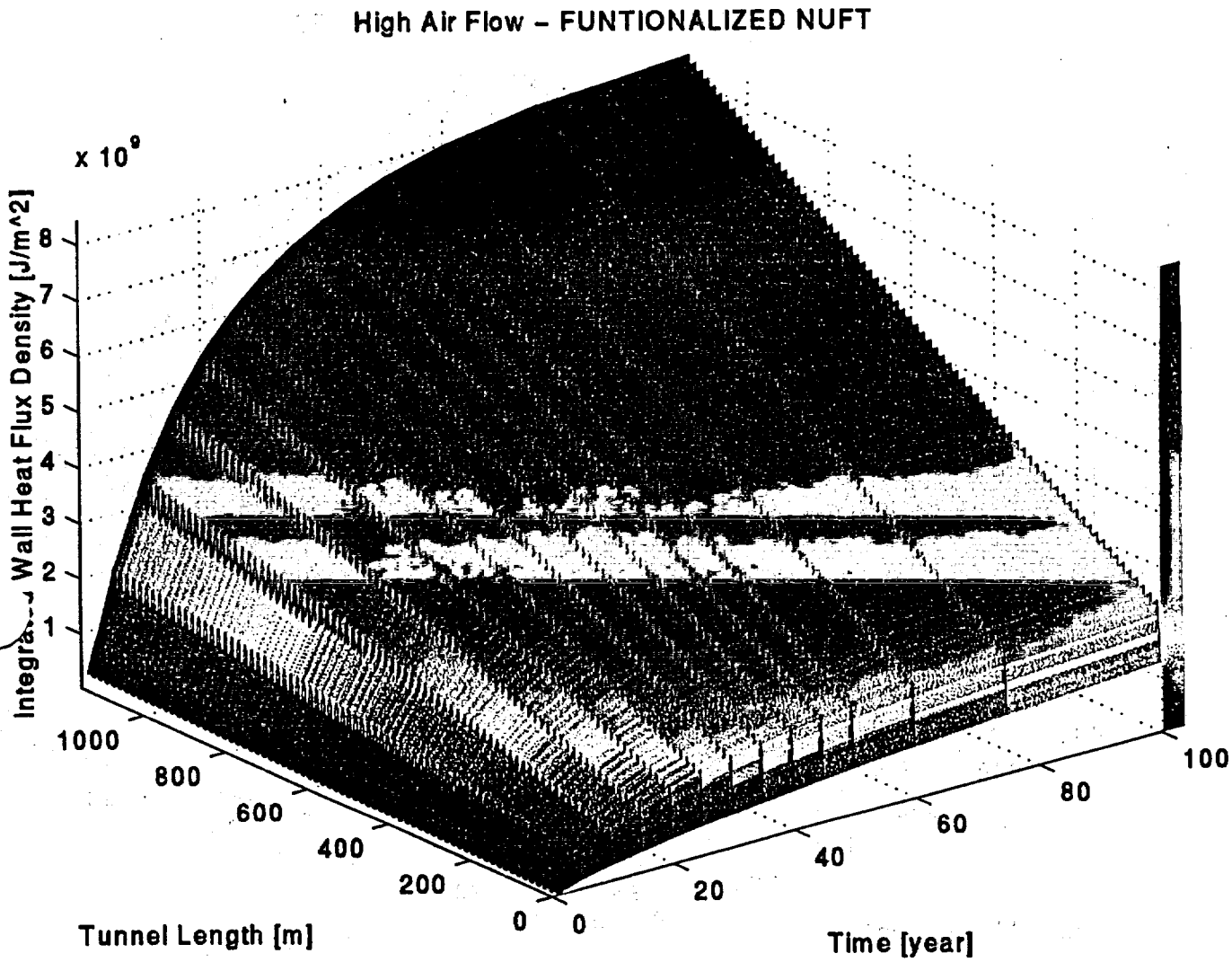

Figure D-12. Integrated Wall Heat Flux for High Flow (10 m^3/s) Ventilation

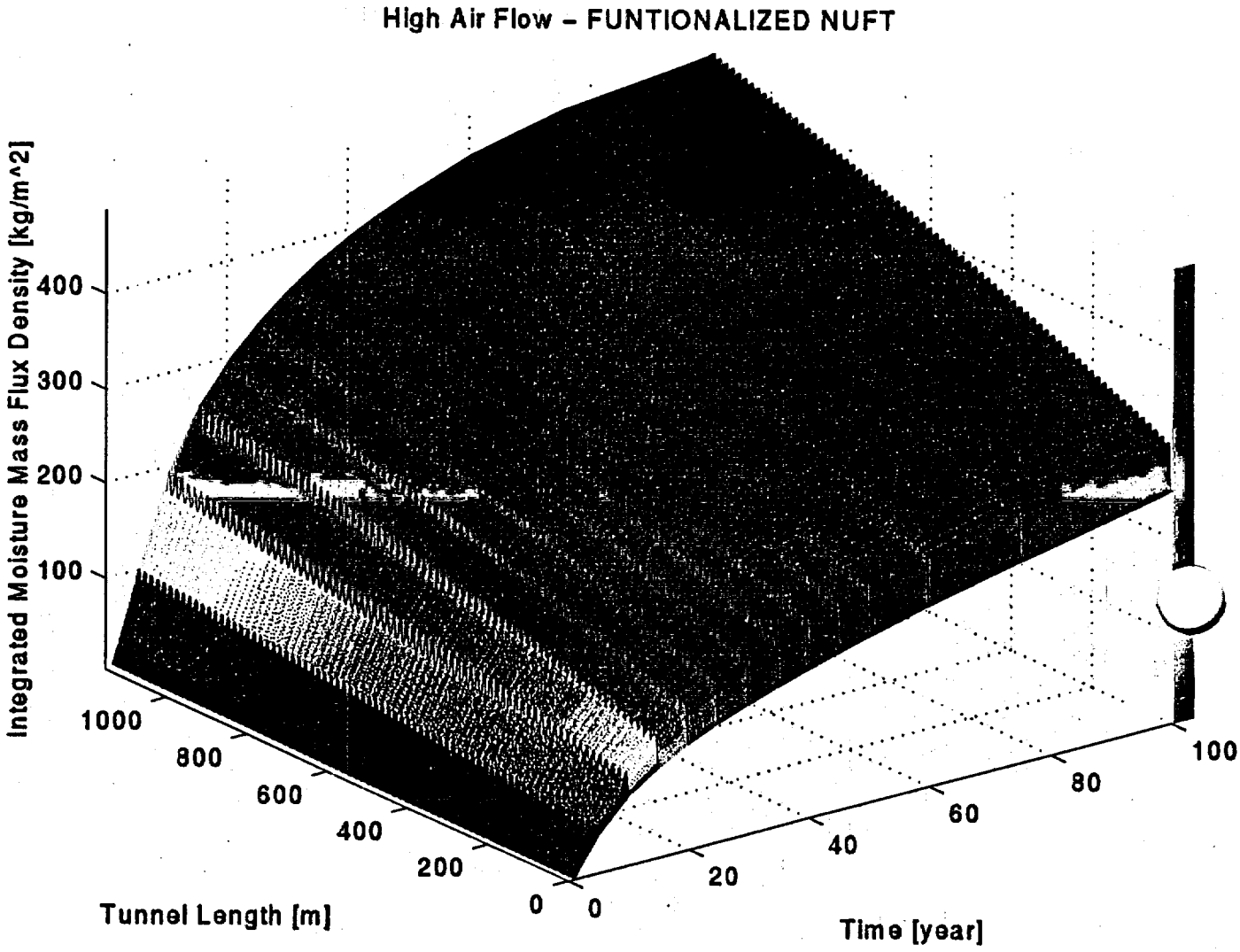

Figure D-13. Integrated Moisture Flux for High Flow (10 m^3/s) Ventilation

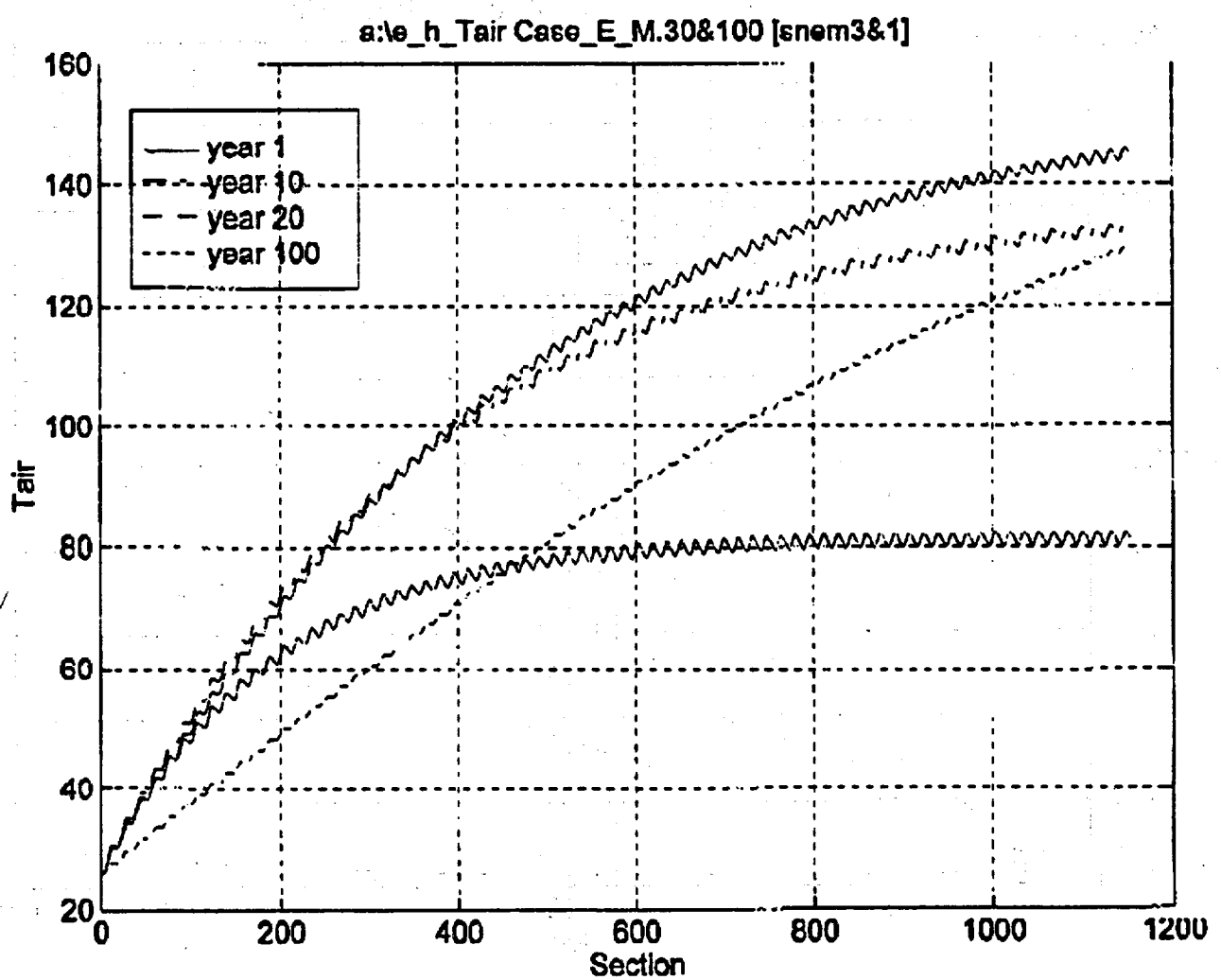

Figure D-14. Air Temperature for Medium Flow (1 m^3/s) Ventilation

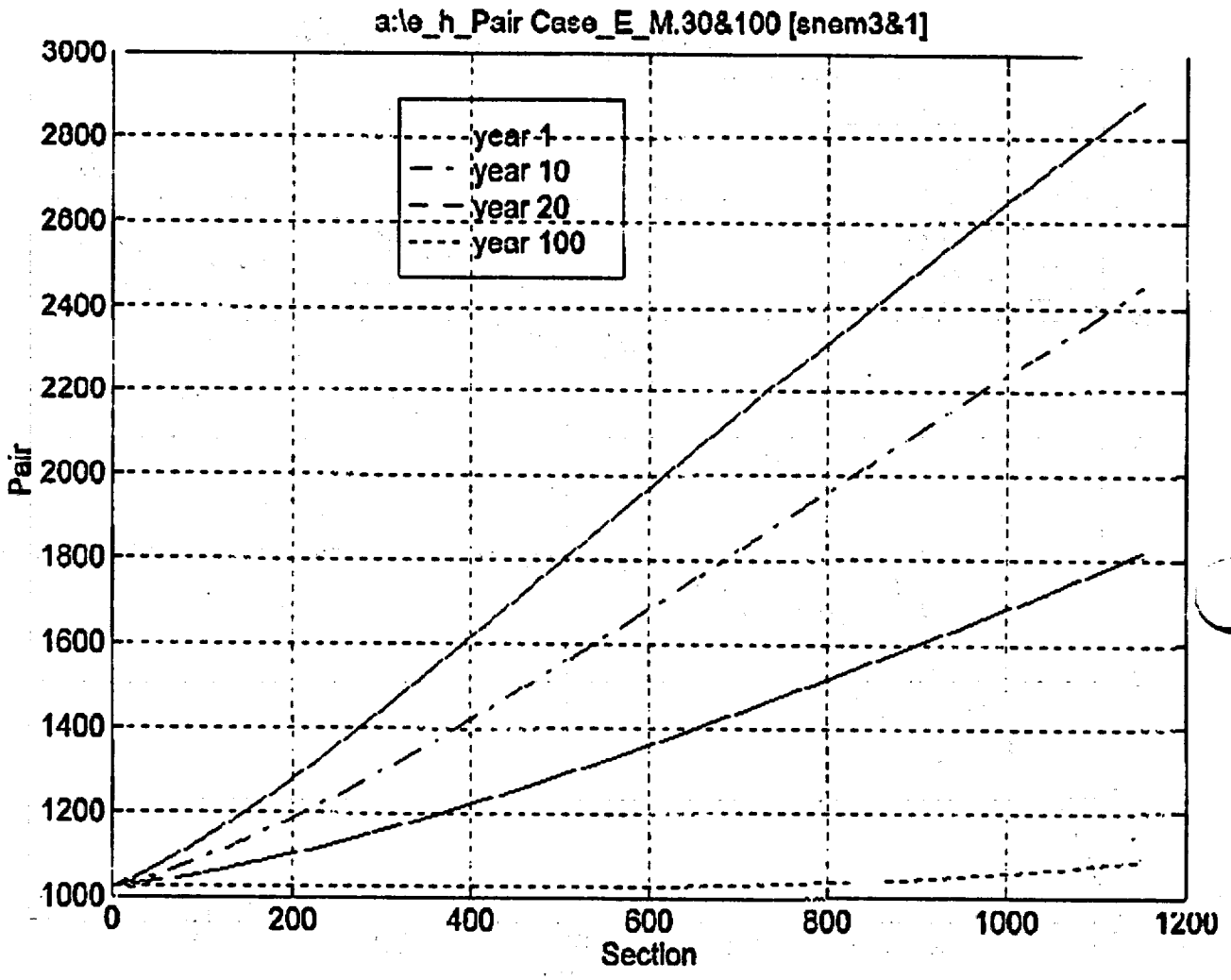

Figure D-15. Air Temperature for Medium Flow (1 m^3/s) Ventilation

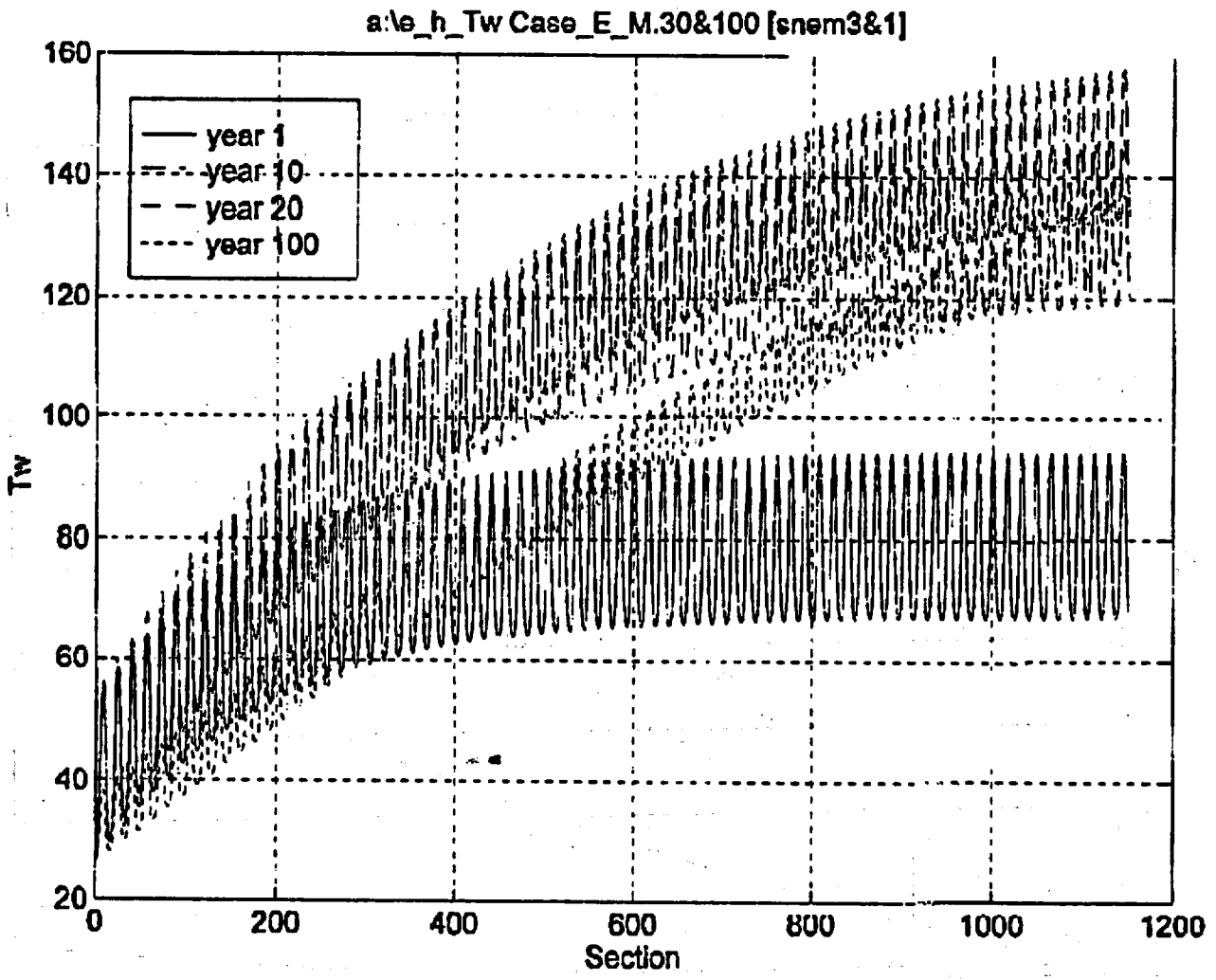

Figure D-16. Wall Temperature for Medium Flow (1 m^3/s) Ventilation

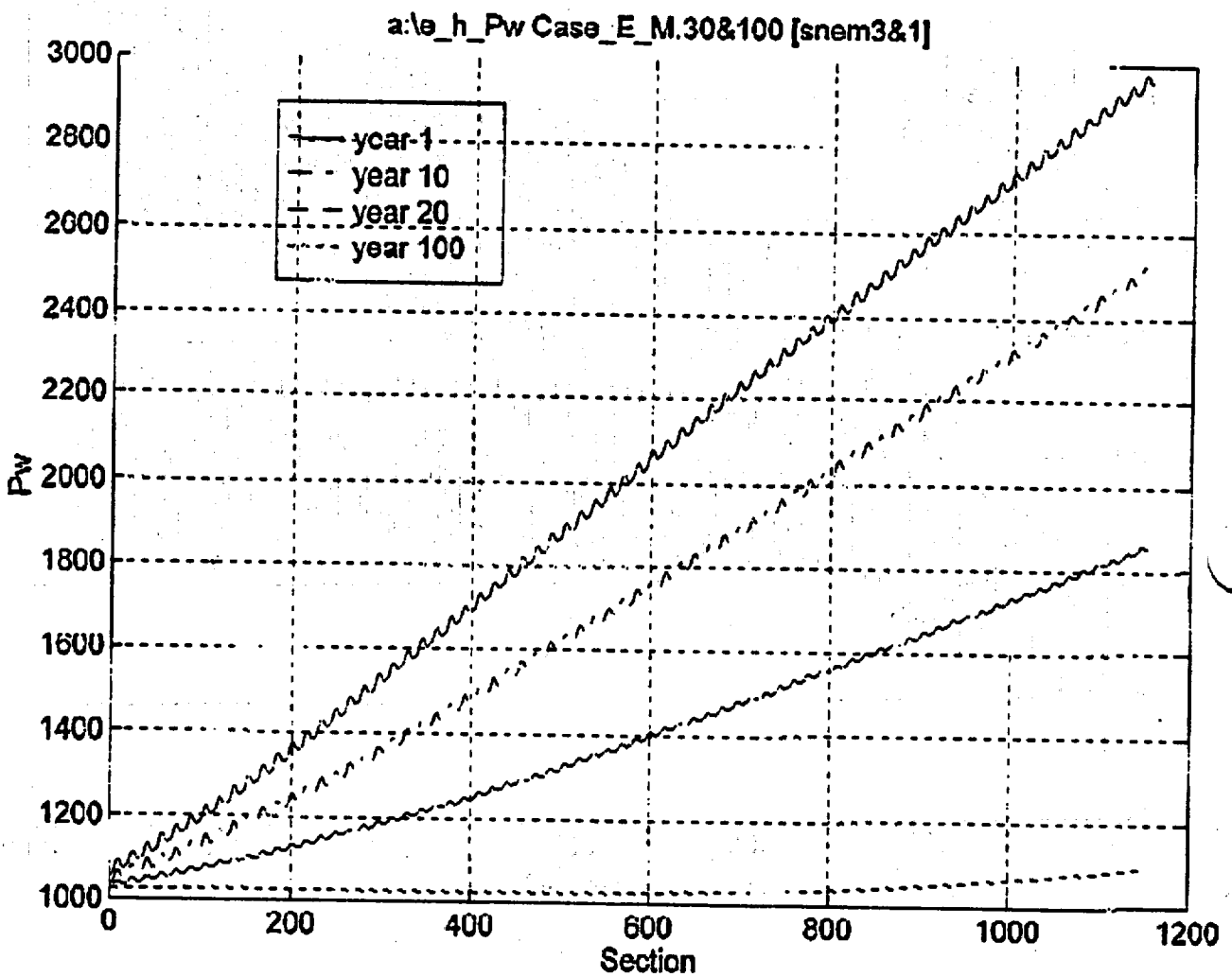

Figure D-17. Wall Pressure for Medium Flow (1 m^3/s) Ventilation

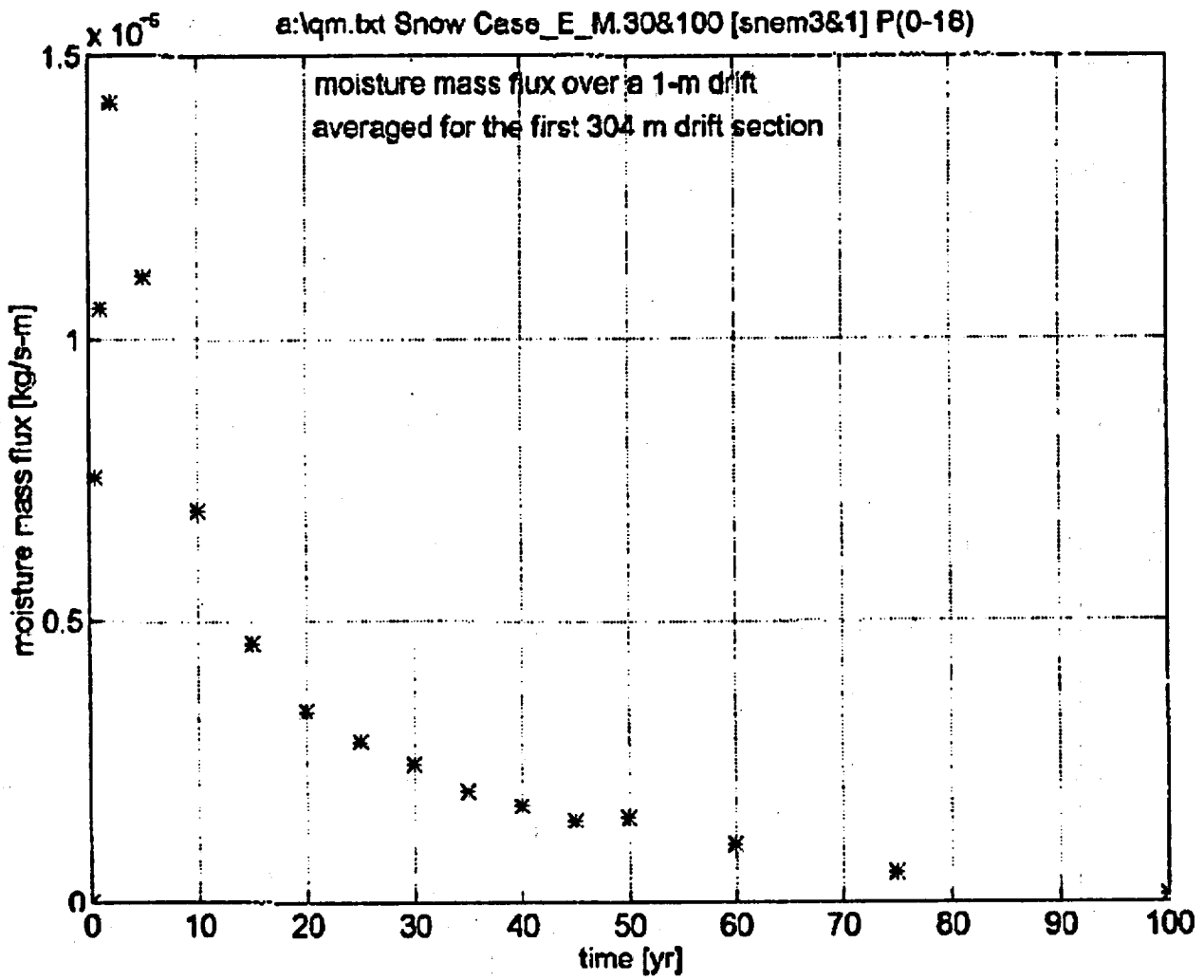

Figure D-18. Moisture Flux for Medium Flow (1 m^3/s) Ventilation

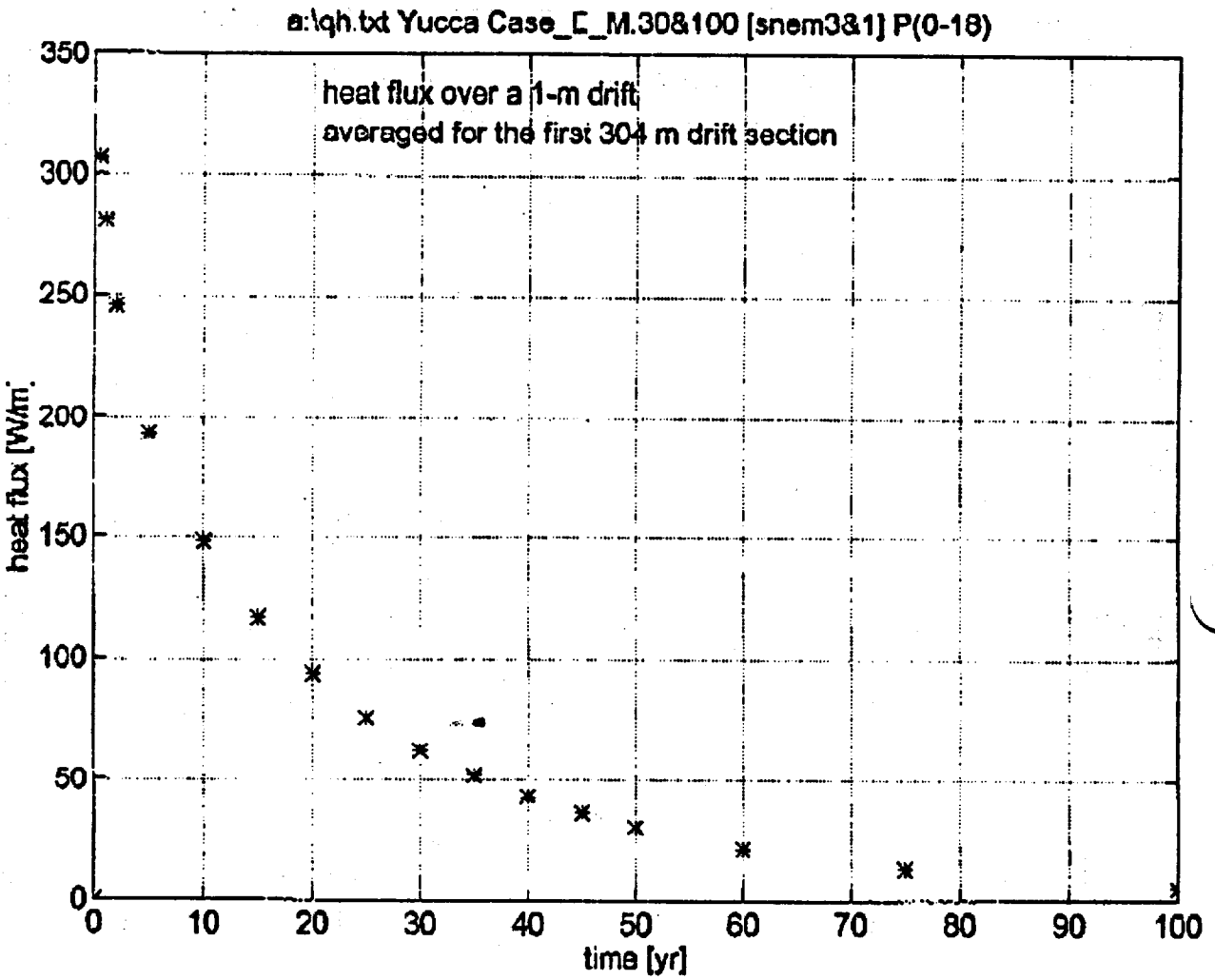

Figure D-19. Heat Flux for Medium Flow (1 m^3/s) Ventilation

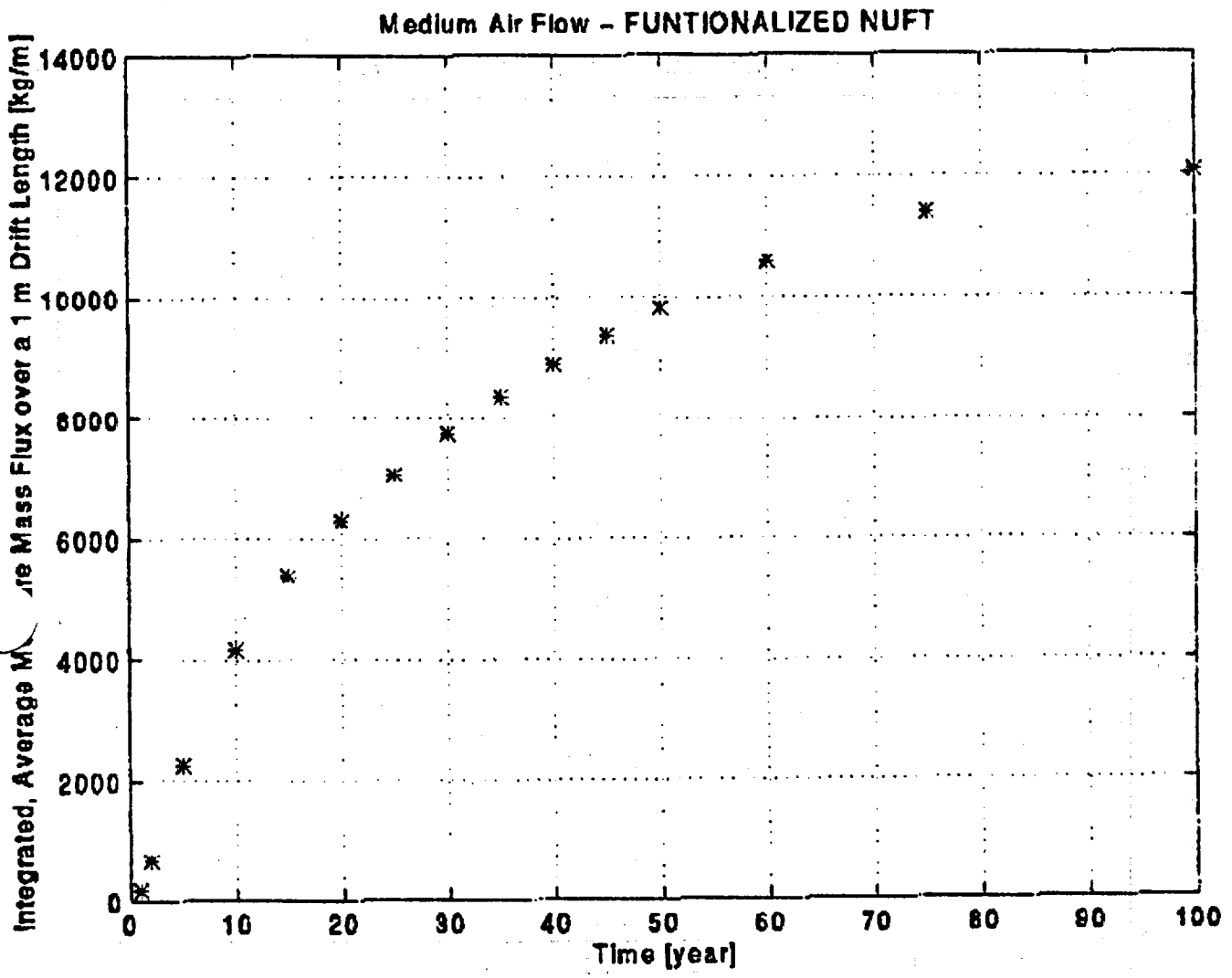

Figure D-20. Integrated Moisture Flux for Medium Flow (1 m^3/s) Ventilation

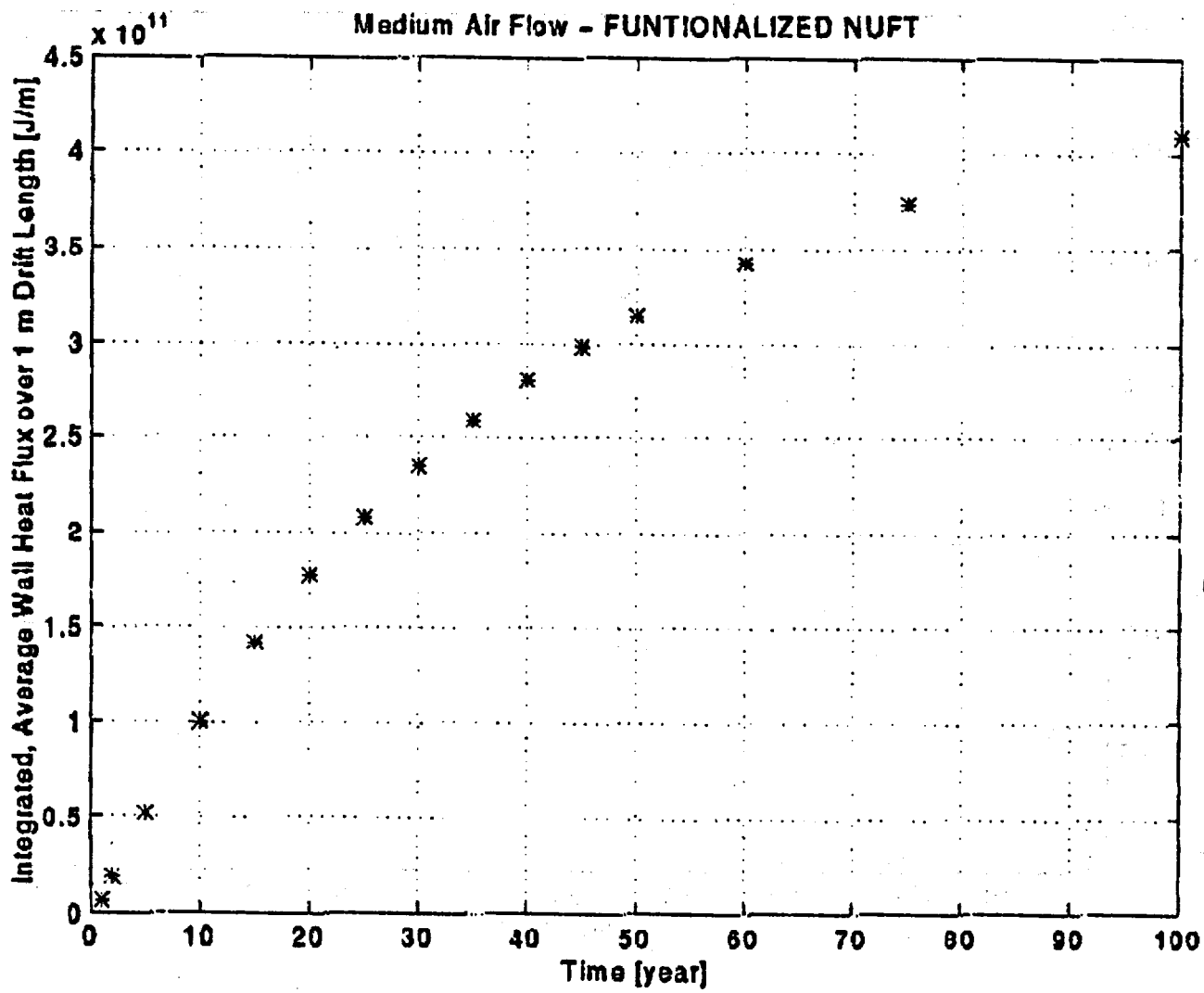

Figure D-21. Integrated Wall Heat Flux for Medium Flow (1 m^3/s) Ventilation

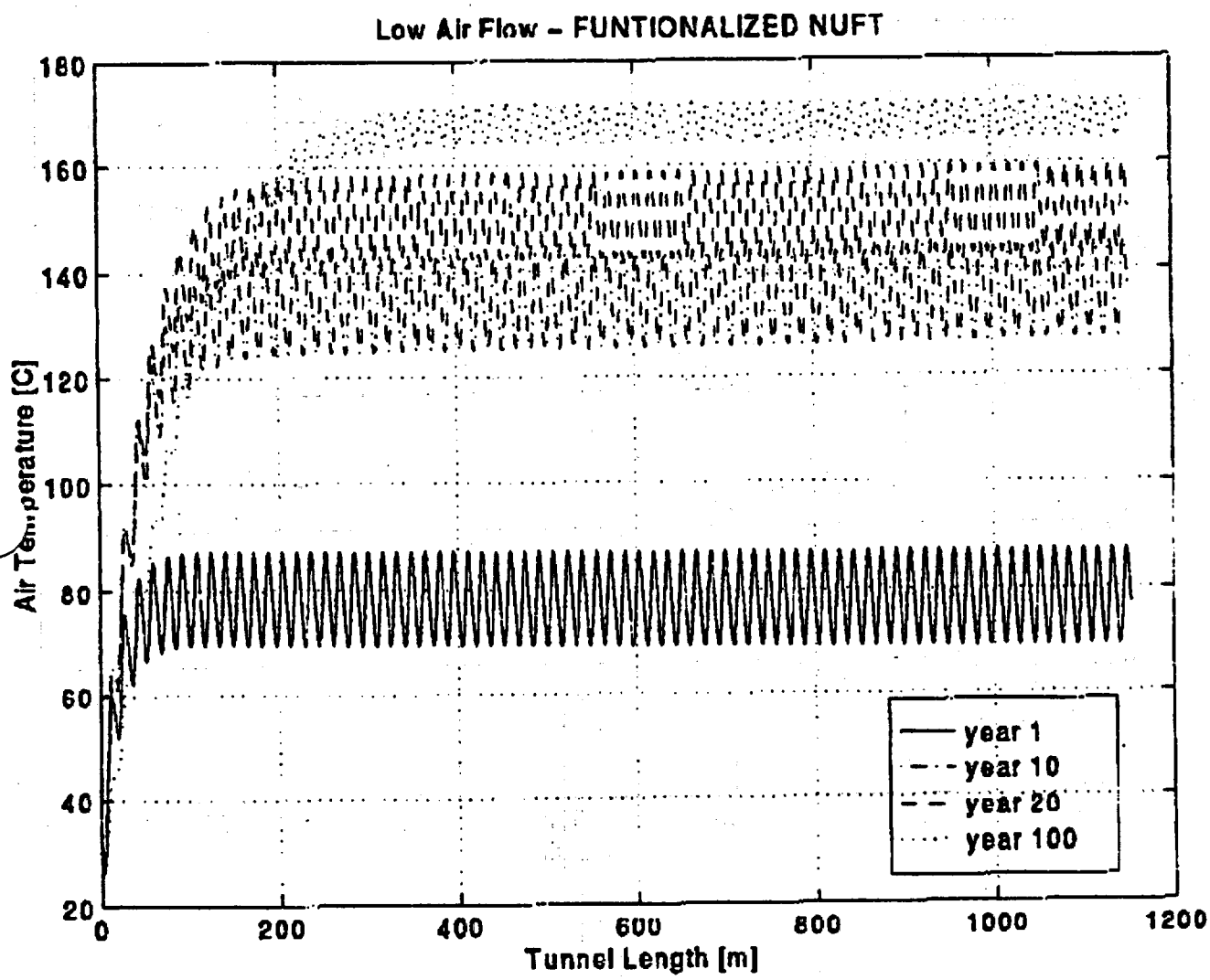

Figure D-22. Air Temperature for Low Flow (0.1 m^3/s) Ventilation

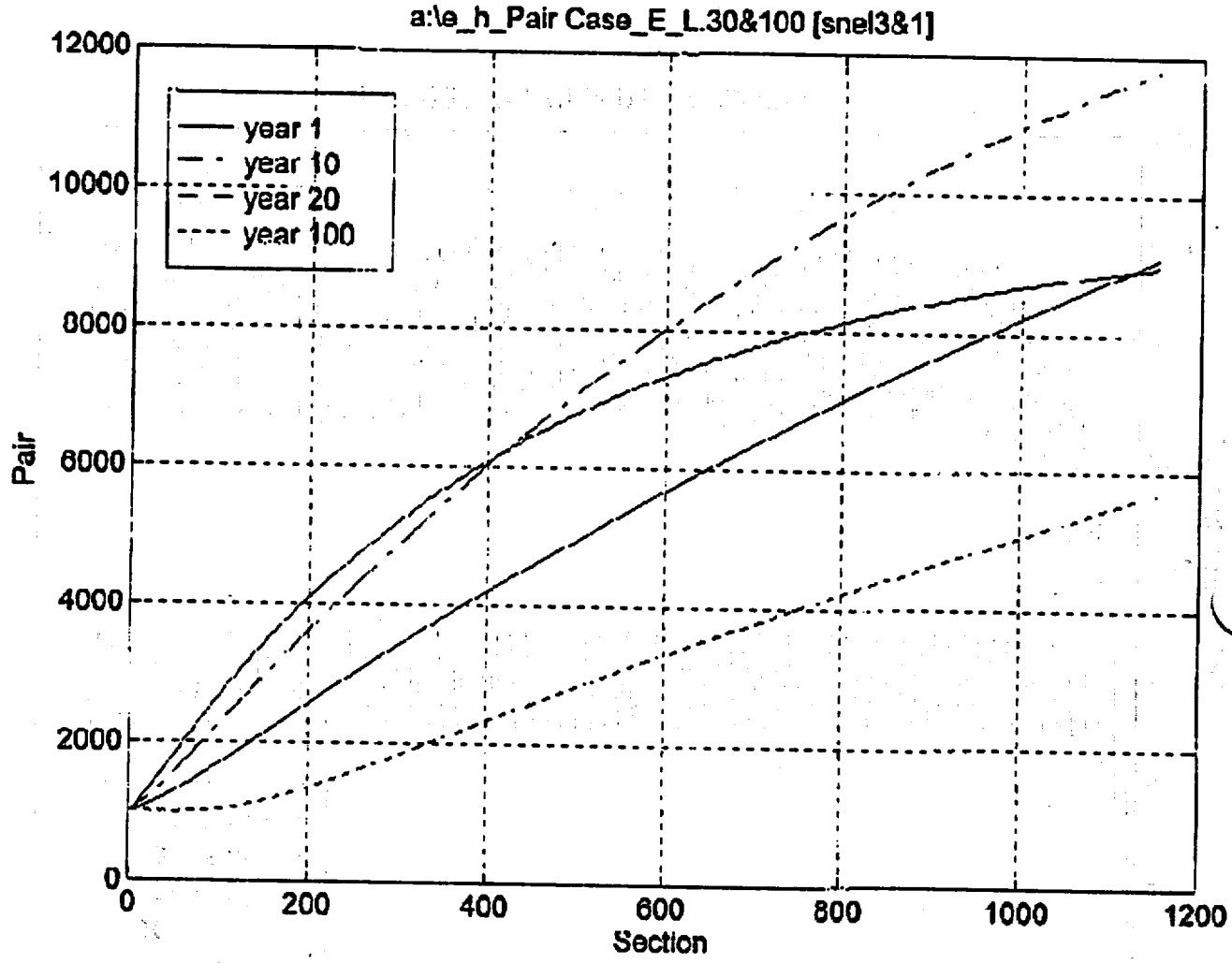

Figure D-23. Air Pressure for Low Flow (0.1 m^3/s) Ventilation

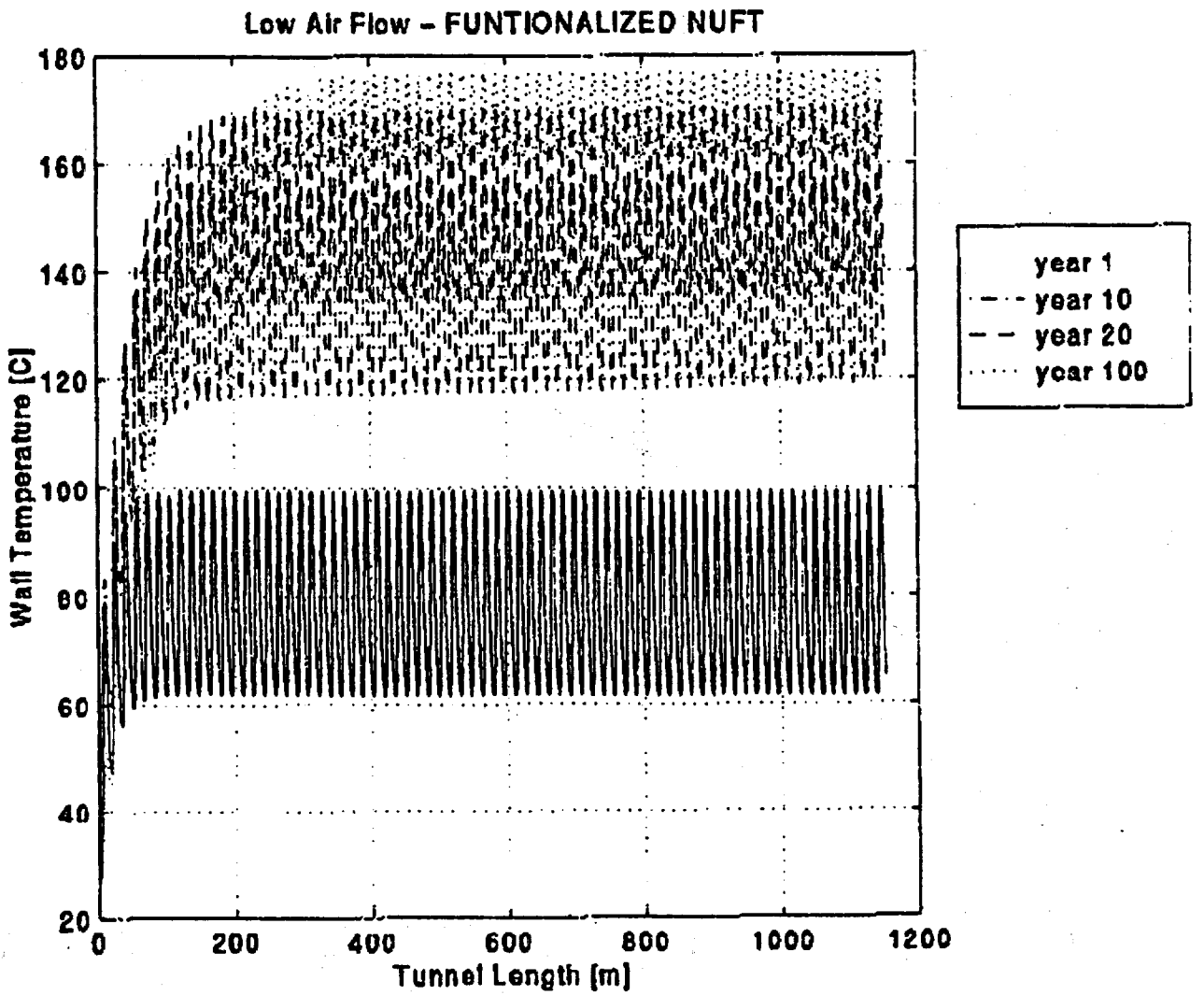

Figure D-24. Wall Temperature for Low Flow (0.1 m^3/s) Ventilation

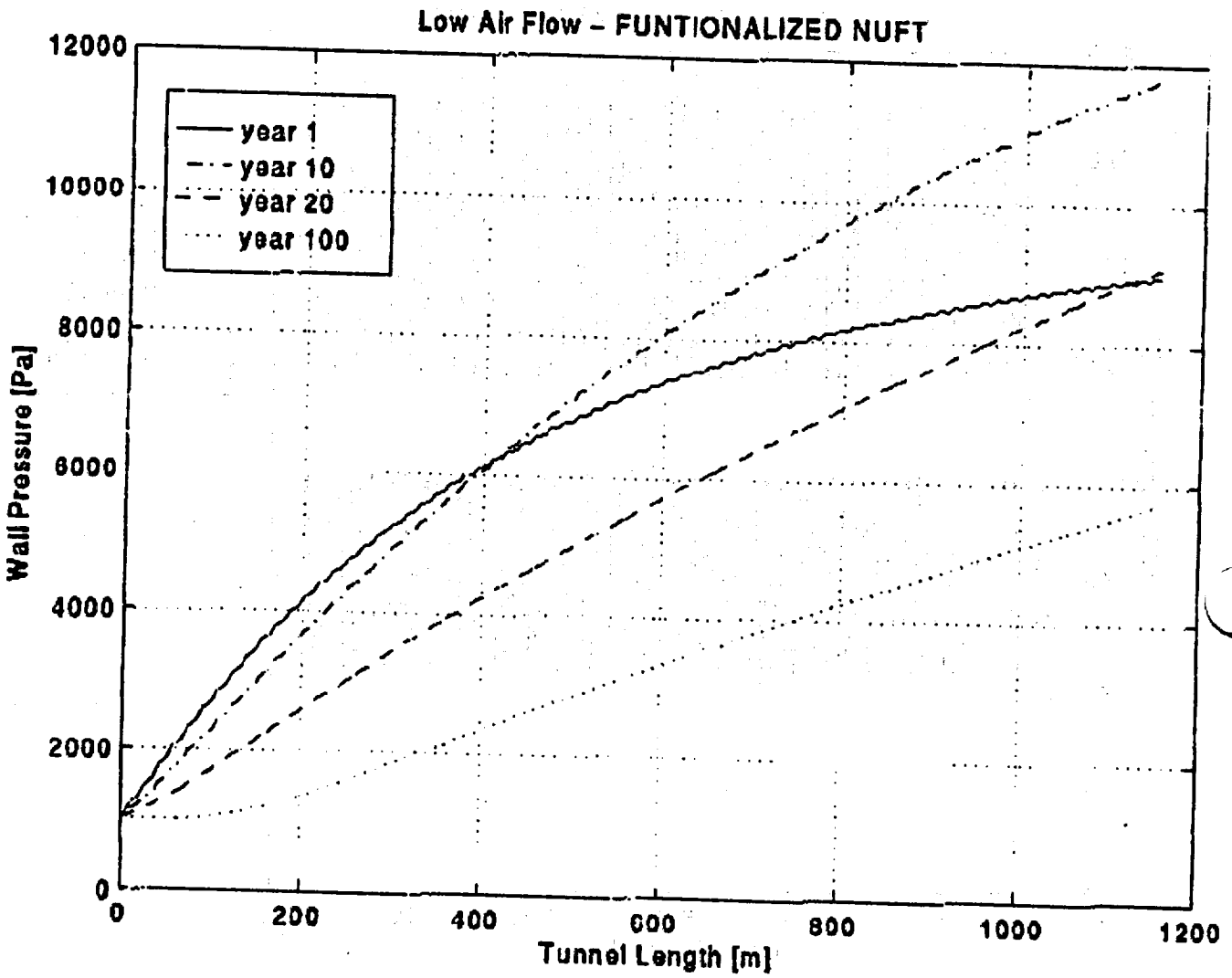

Figure D-25. Wall Pressure for Low Flow (0.1 m^3/s) Ventilation

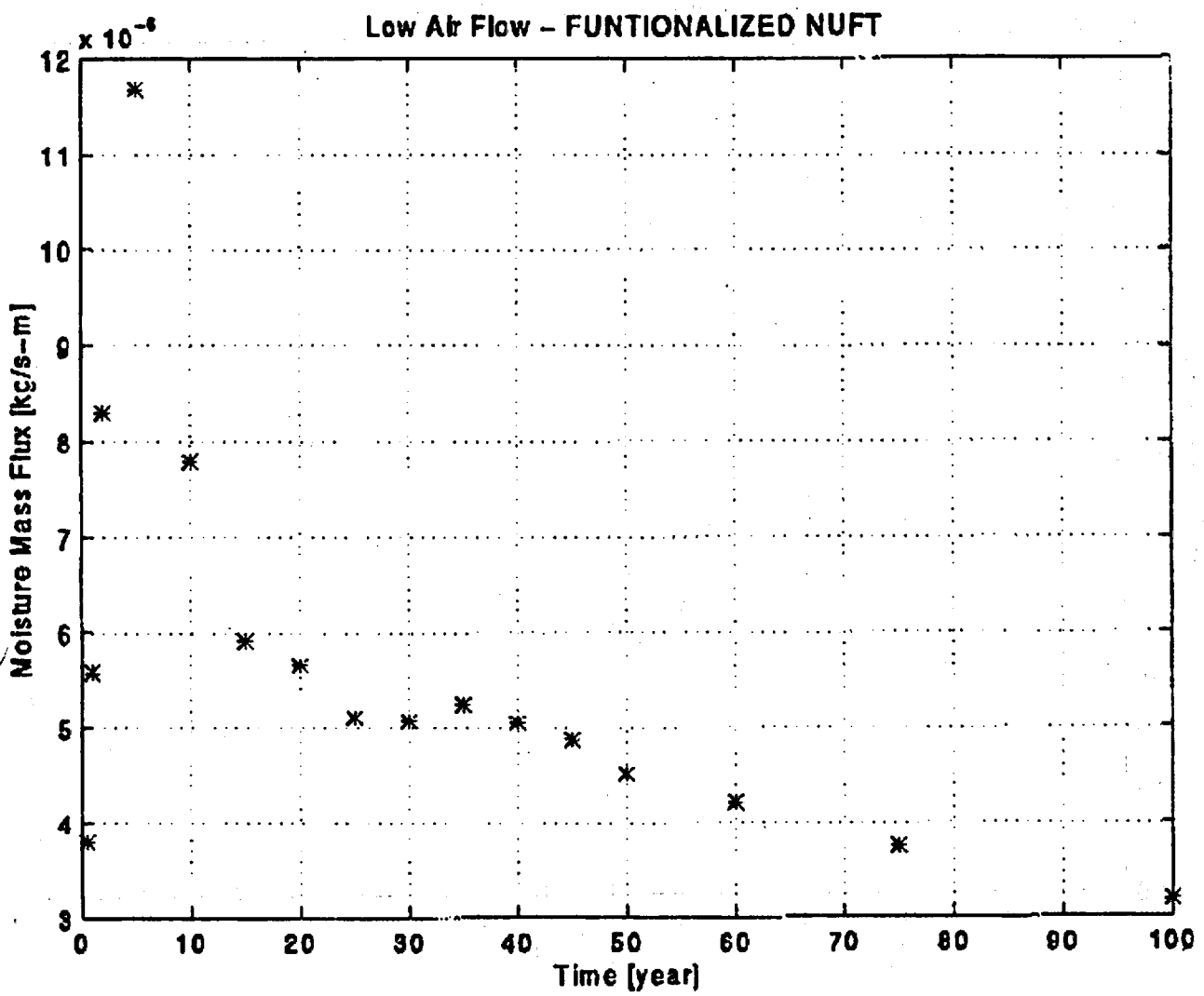

Figure D-26. Moisture Flux for Low Flow (0.1 m^3/s) Ventilation

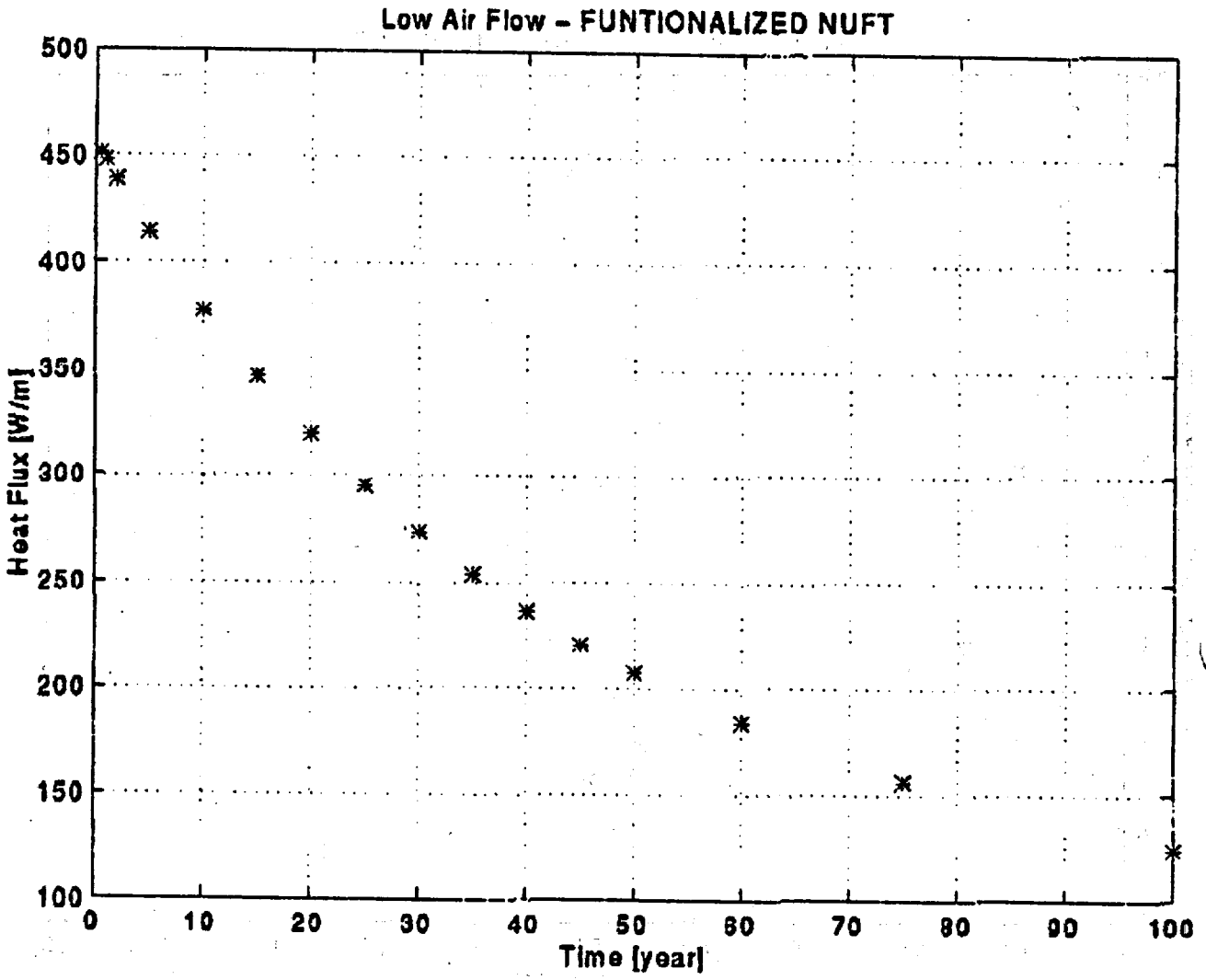

Figure D-27. Heat Flux for Low Flow (0.1 m^3/s) Ventilation

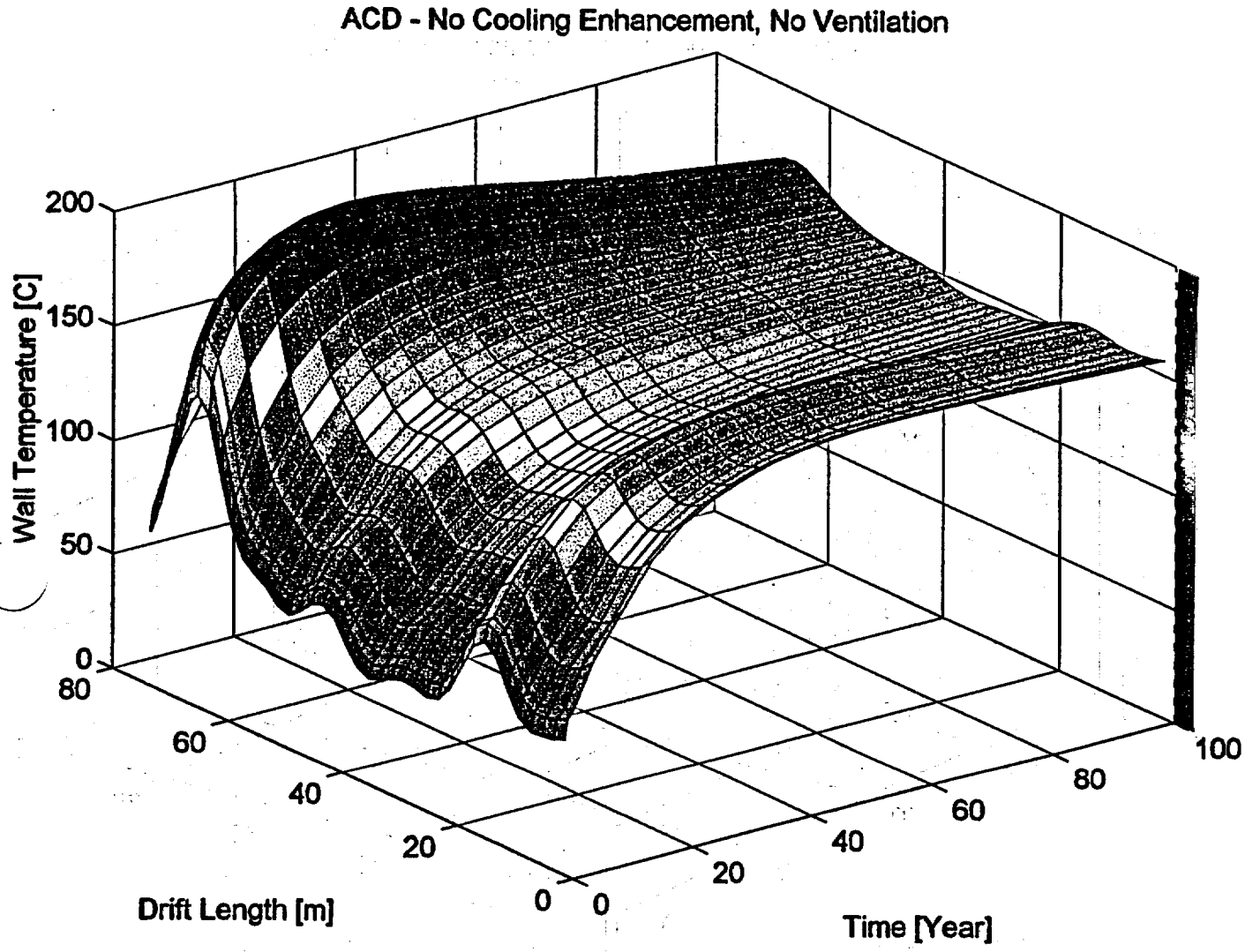

Figure D-28. Drift Wall Temperature for Multiple Waste Package Heats and No Ventilation

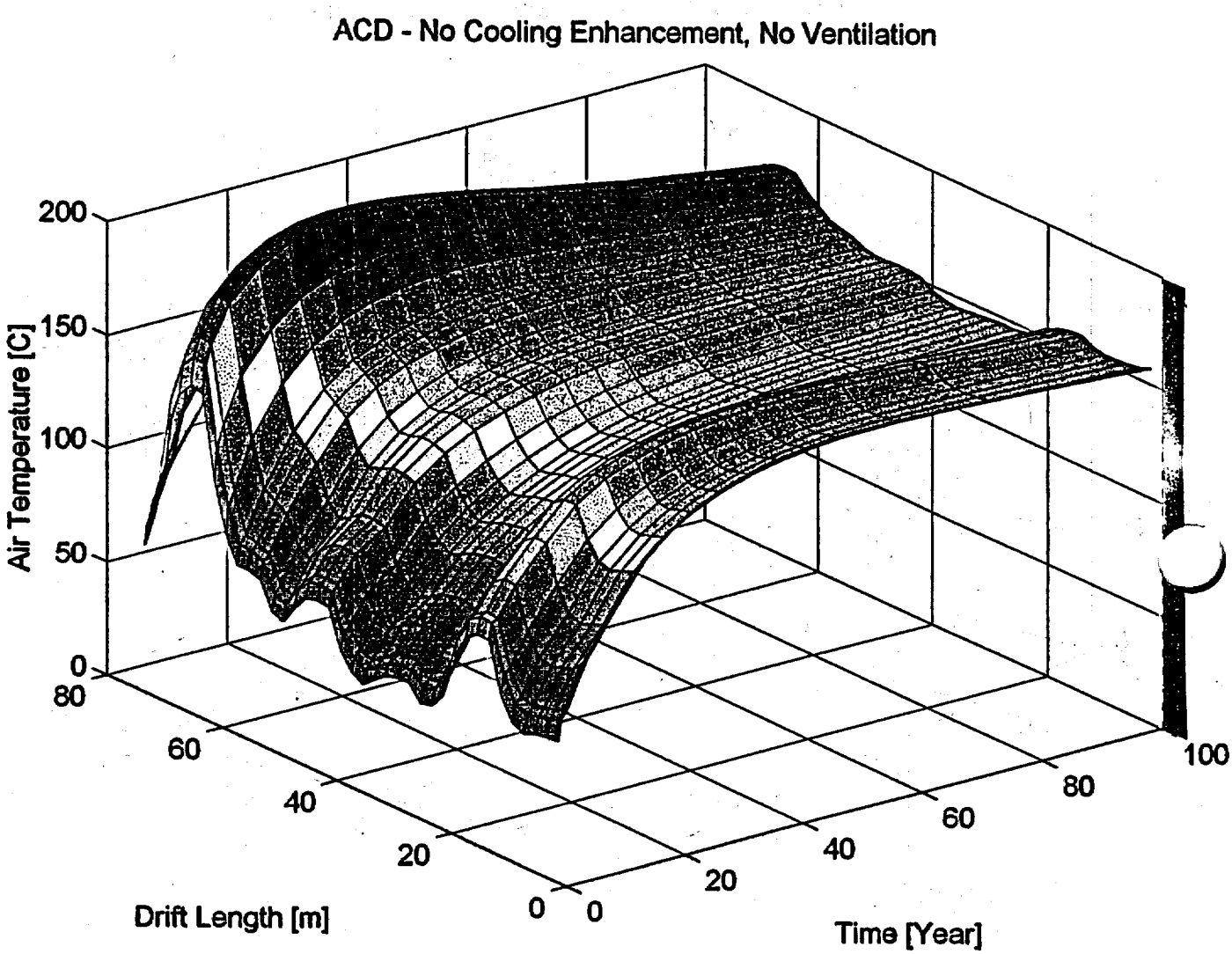

Figure D-29. Air Temperature for Multiple Waste Package Heats and No Ventilation

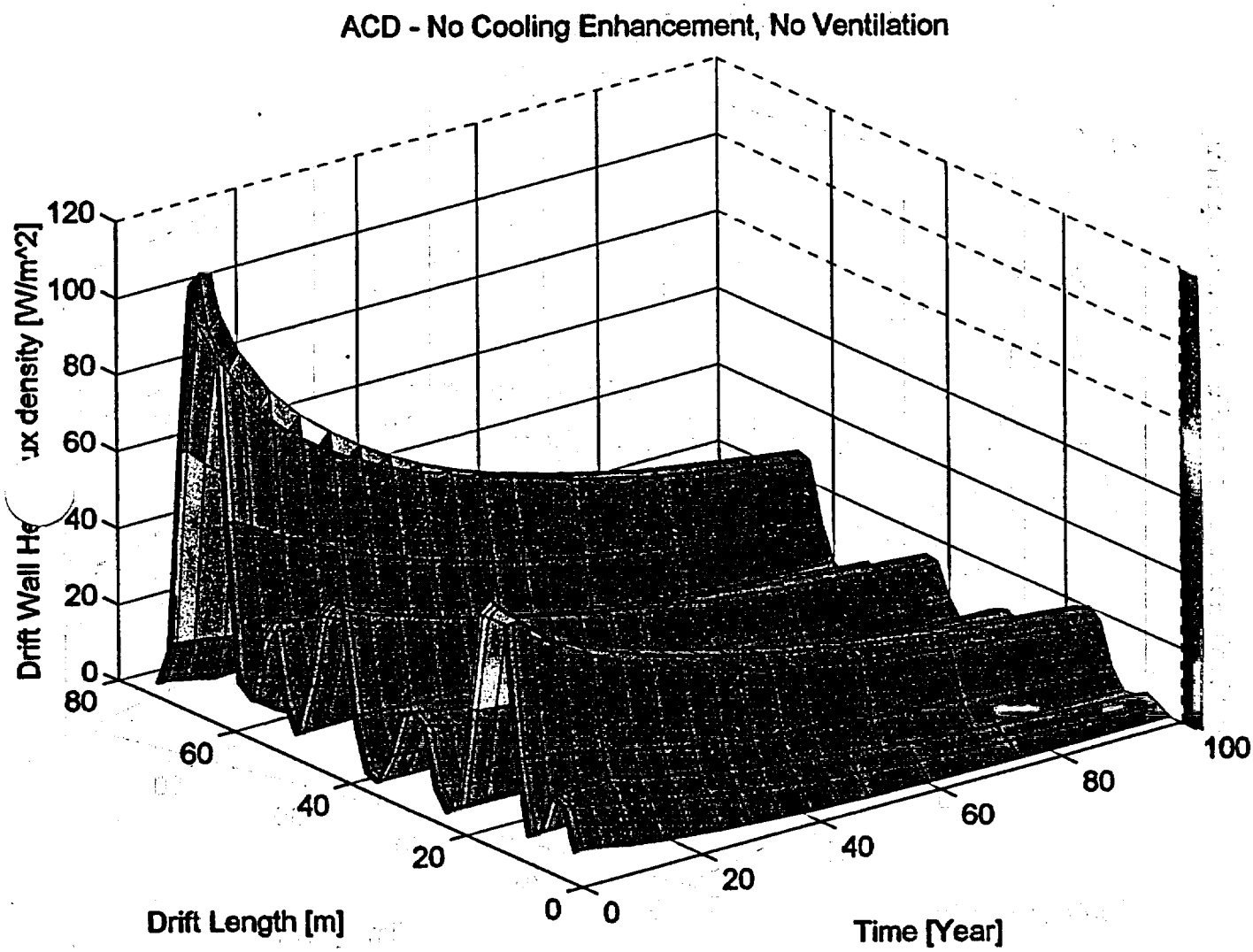

Figure D-30. Wall Heat Flux for Multiple Waste Package Heats and No Ventilation

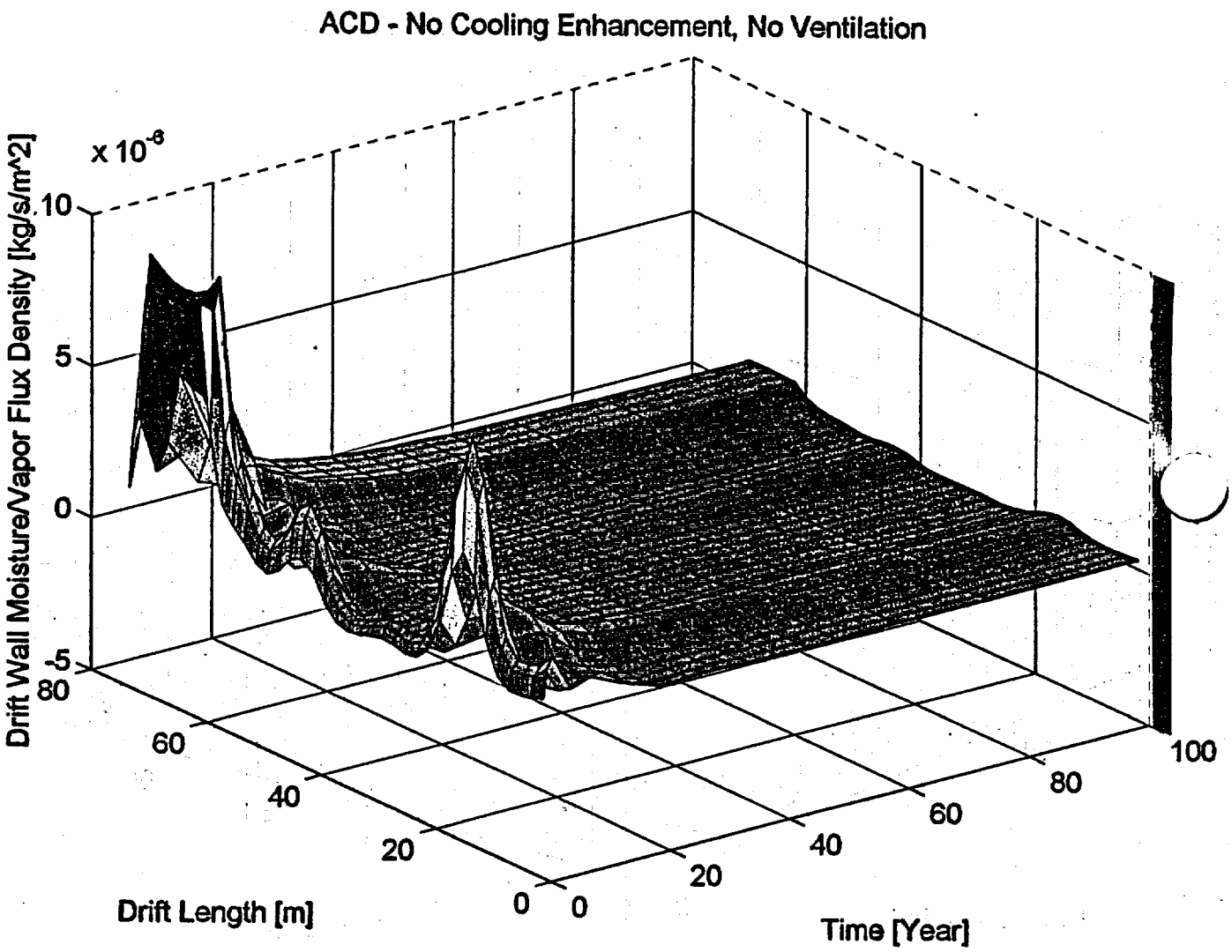

Figure D-31. Drift Wall Moisture Flux for Multiple Waste Package Heats and No Ventilation

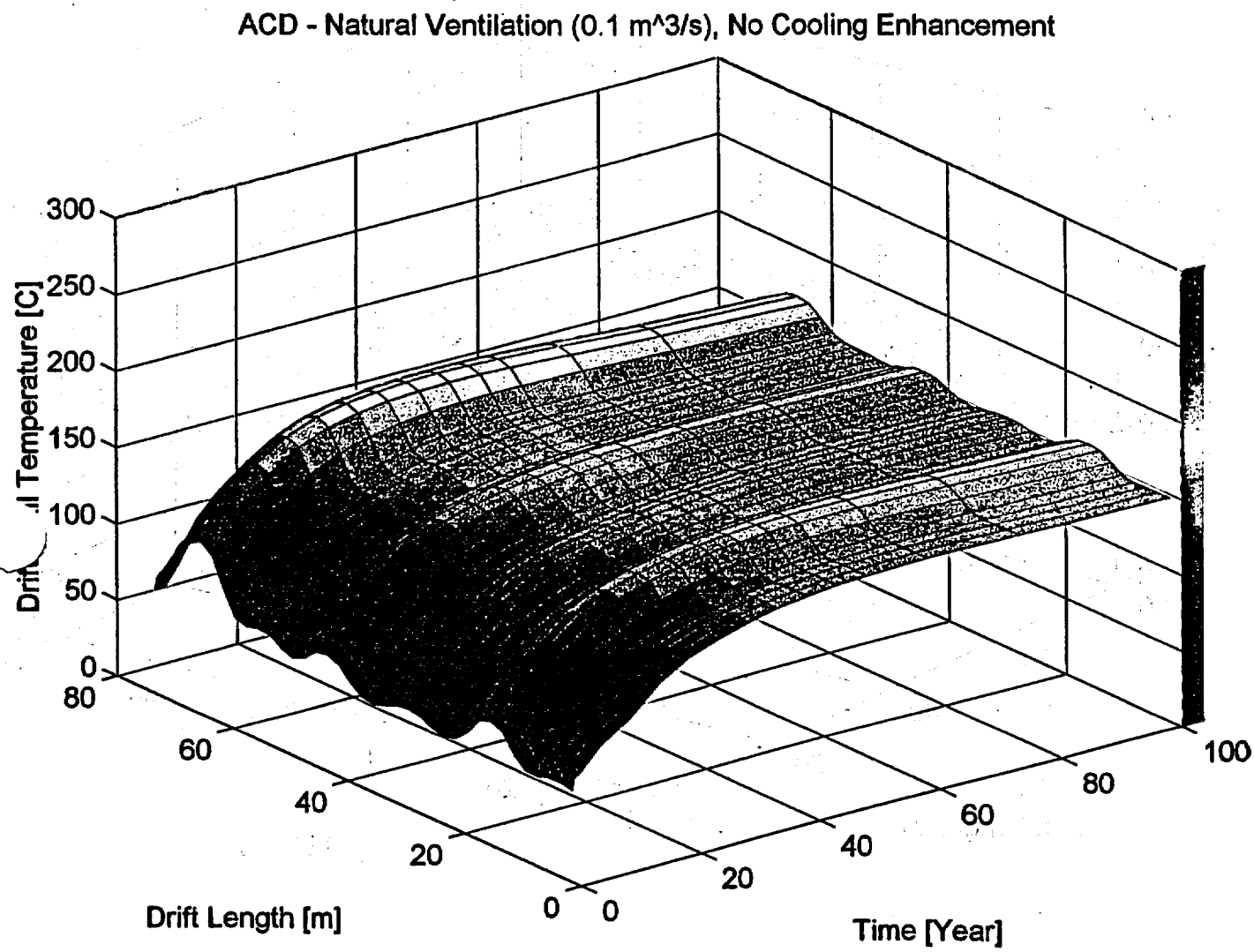

Figure D-32. Drift Wall Temperature for Multiple Waste Package Heats and Natural Ventilation (0.1 m^3/s)

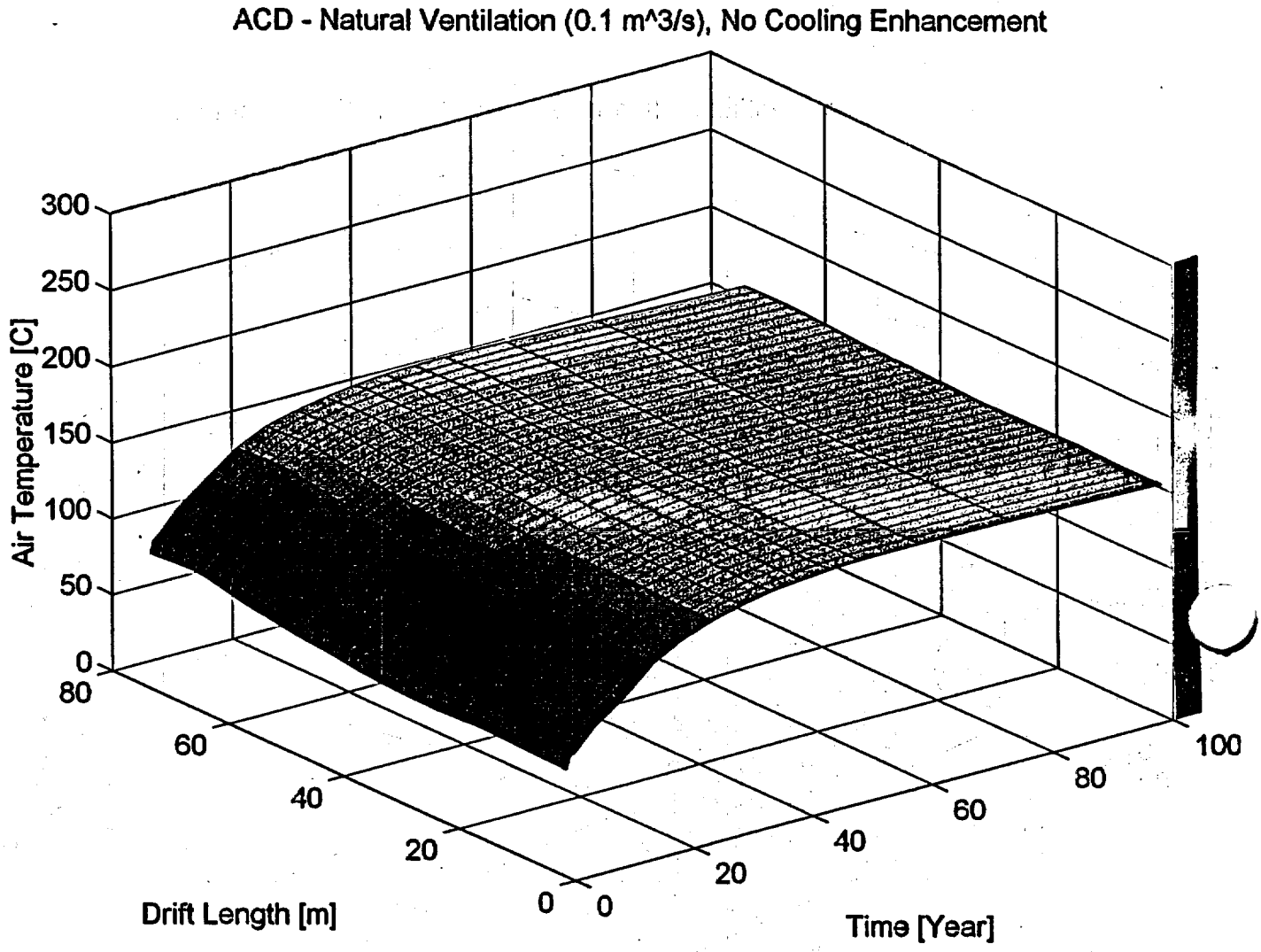

Figure D-33. Air Temperature for Multiple Waste Package Heats and Natural Ventilation (0.1 m^3/s)

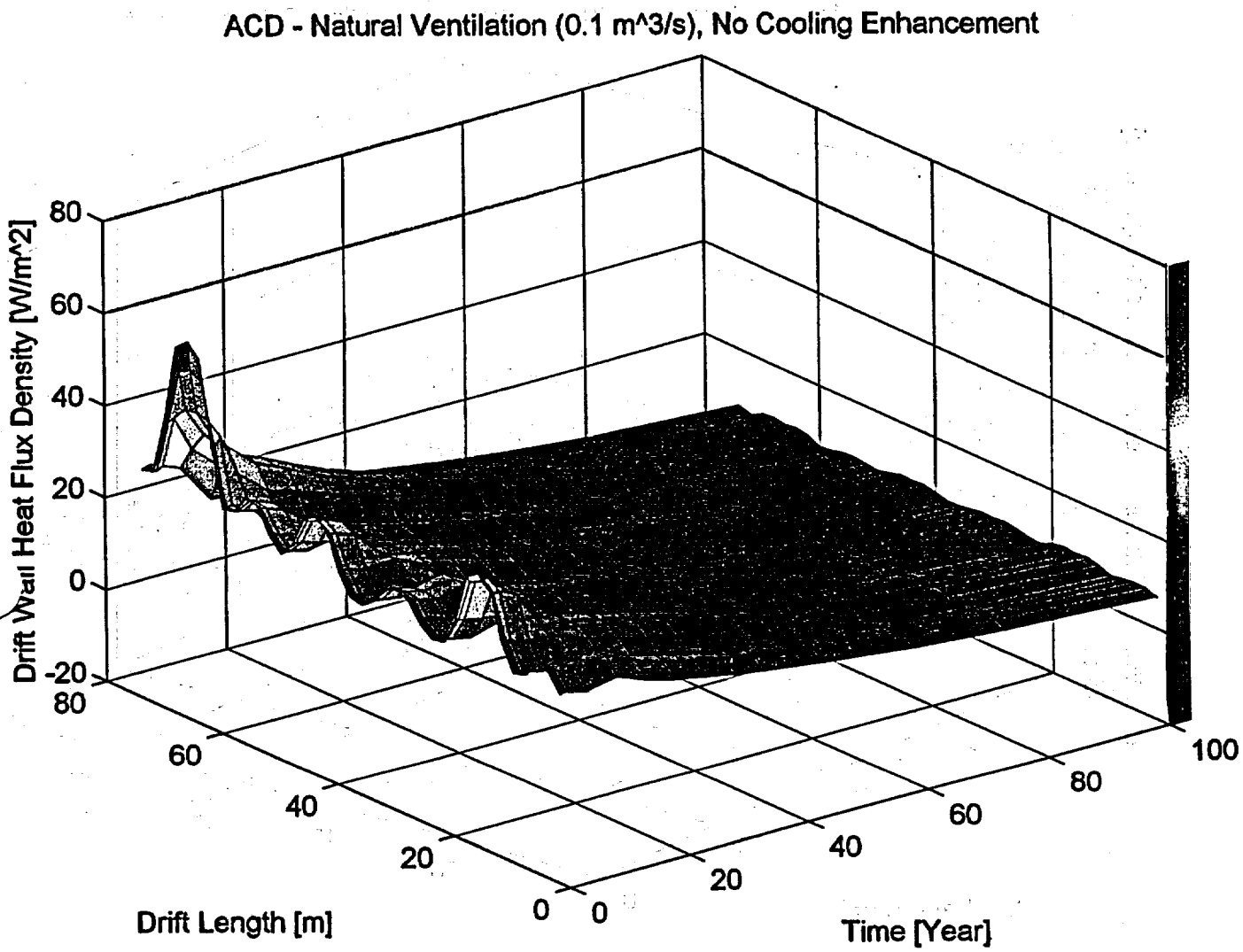

Figure D-34. Wall Heat Flux for Multiple Waste Package Heats and Natural Ventilation (0.1 m^3/s)

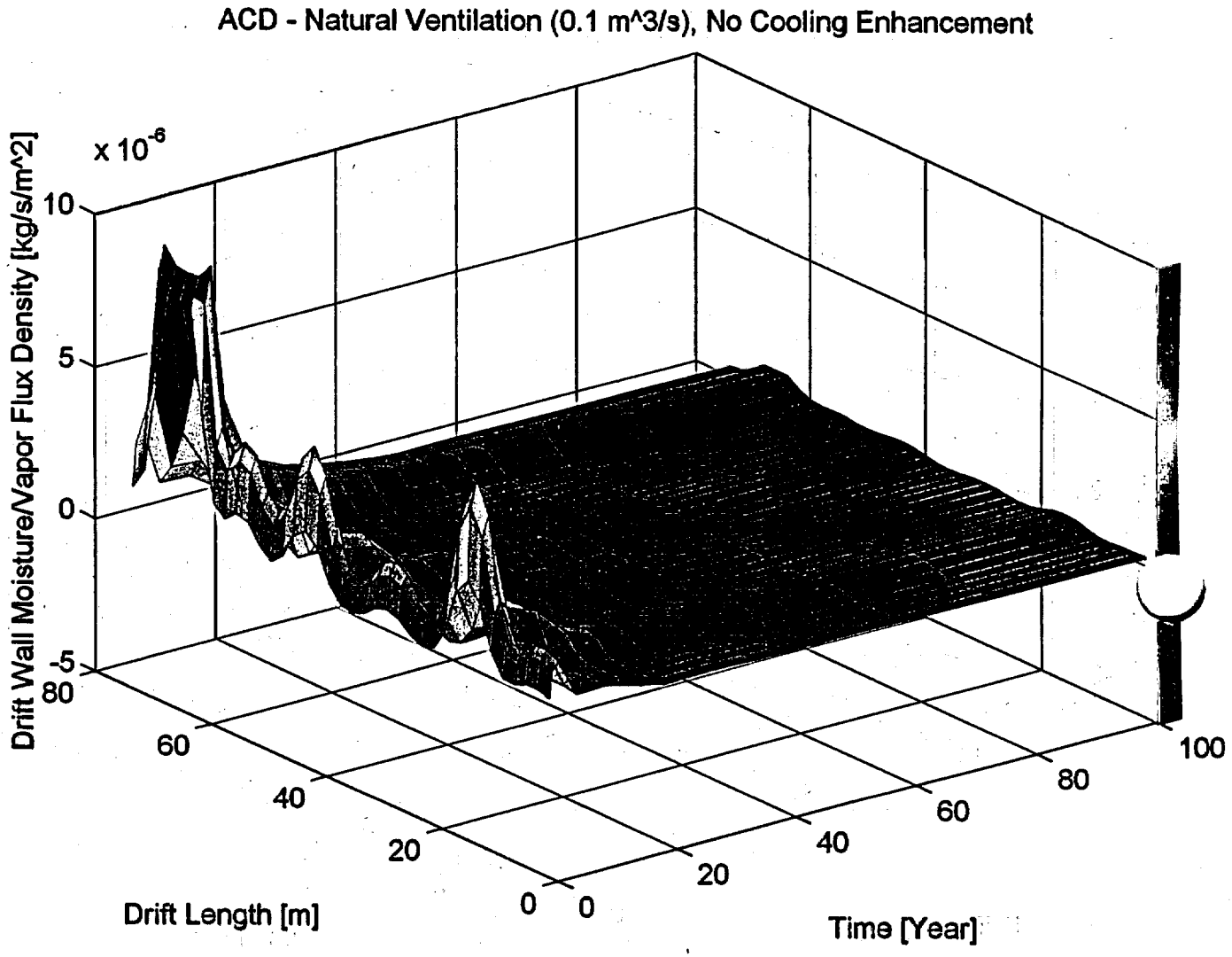

Figure D-35. Wall Moisture Flux for Multiple Waste Package Heats and Natural Ventilation (0.1 m^3/s)

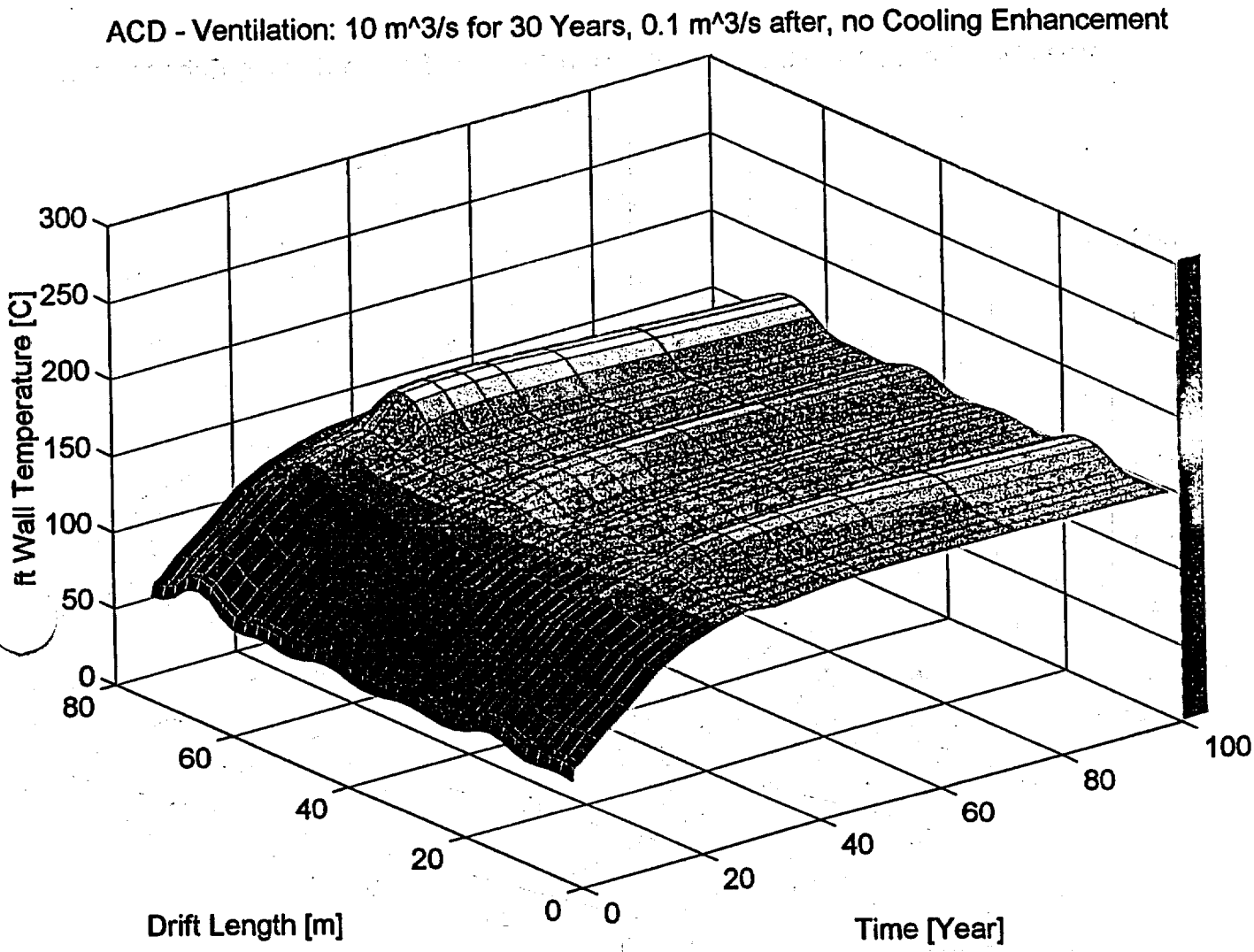

Figure D-36. Wall Temperature for Multiple Waste Package Heats and Looped Ventilation for 30 Years

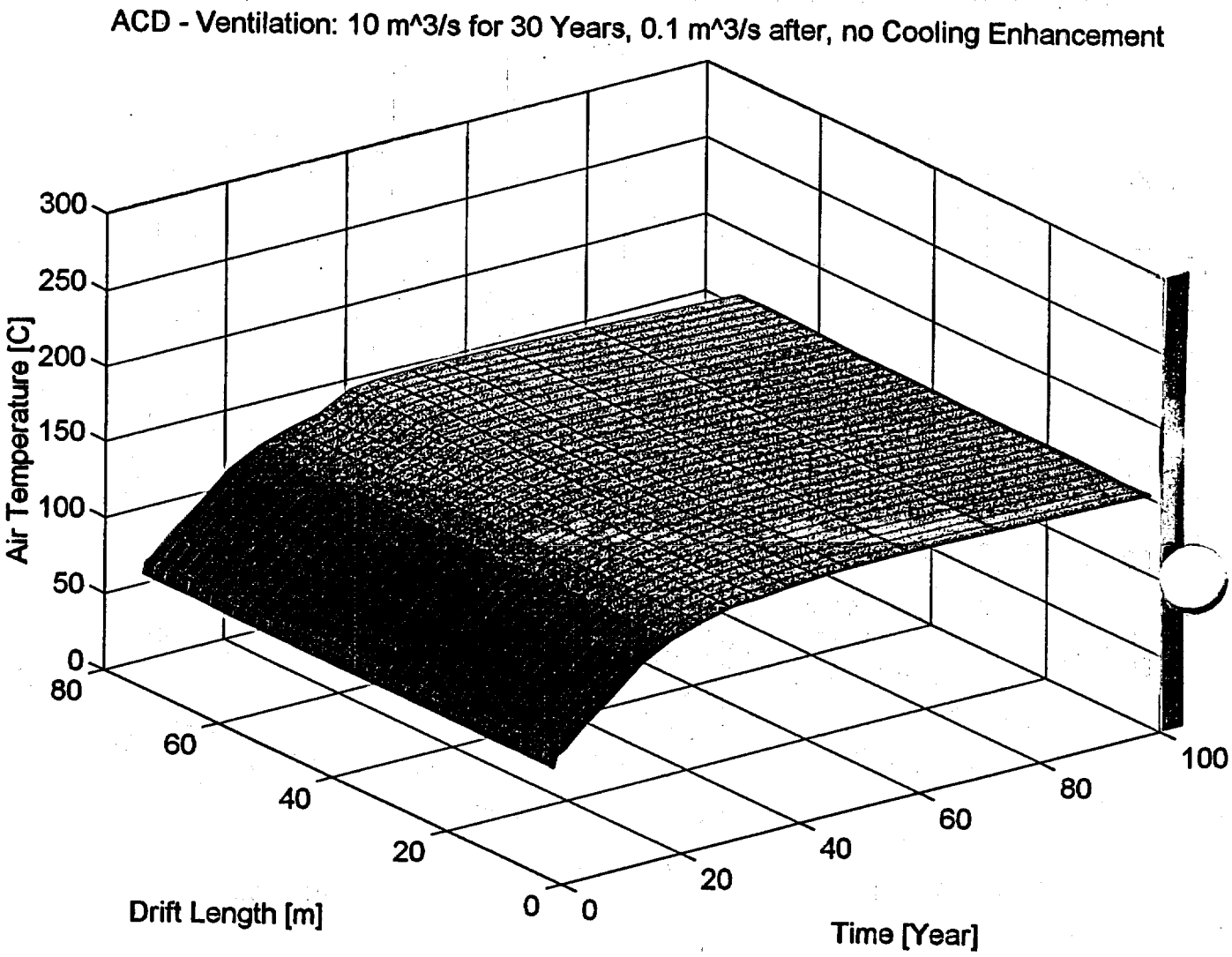

Figure D-37. Air Temperature for Multiple Waste Package Heats and Looped Ventilation for 30 Years

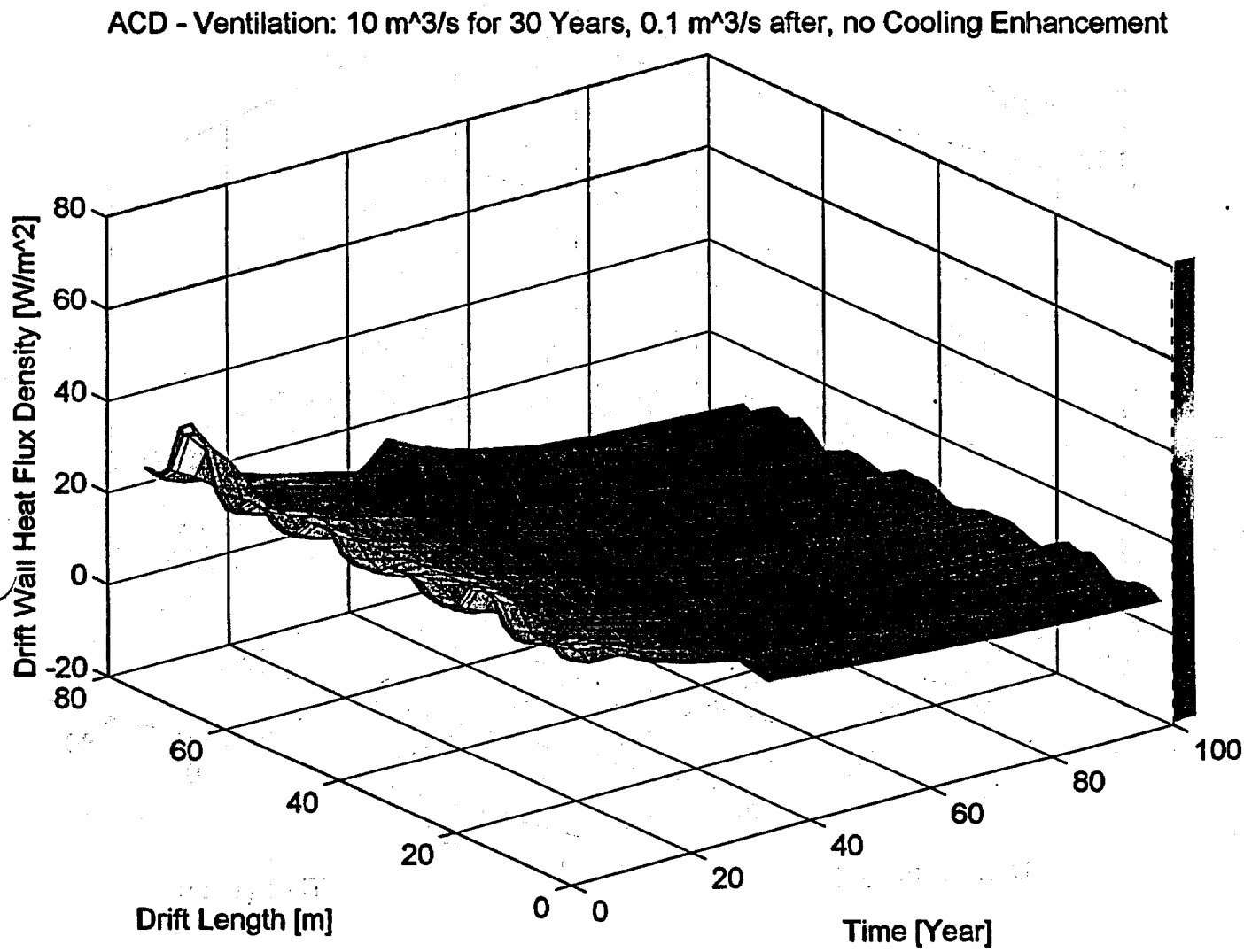

Figure D-38. Wall Heat Flux for Multiple Waste Package Heats and Looped Ventilation for 30 Years

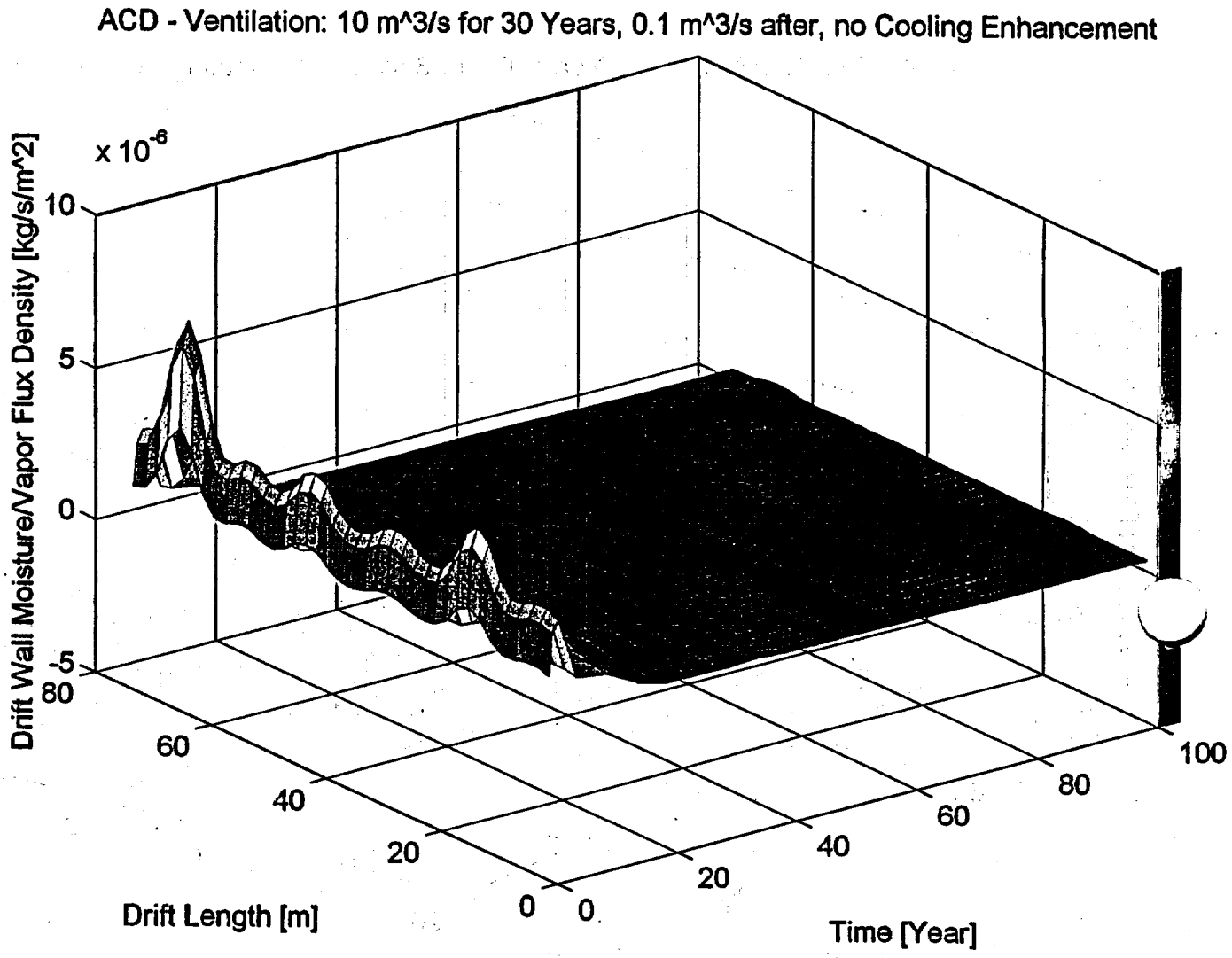

Figure D-39. Wall Moisture Flux for Multiple Waste Package Heats and Looped Ventilation for 30 Years

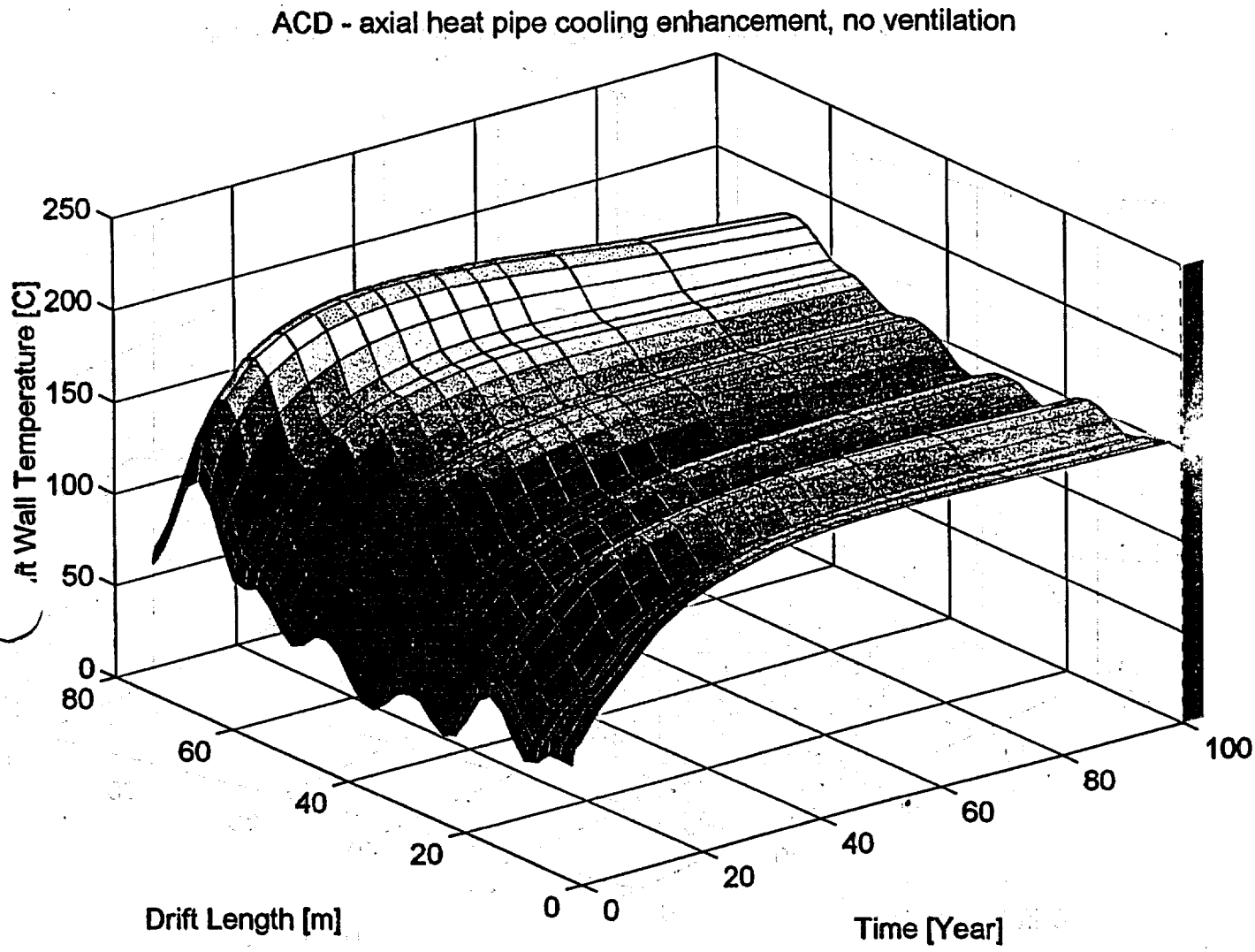

Figure D-40. Wall Temperature for Multiple Waste Package Heats and an Axial Heat Pipe

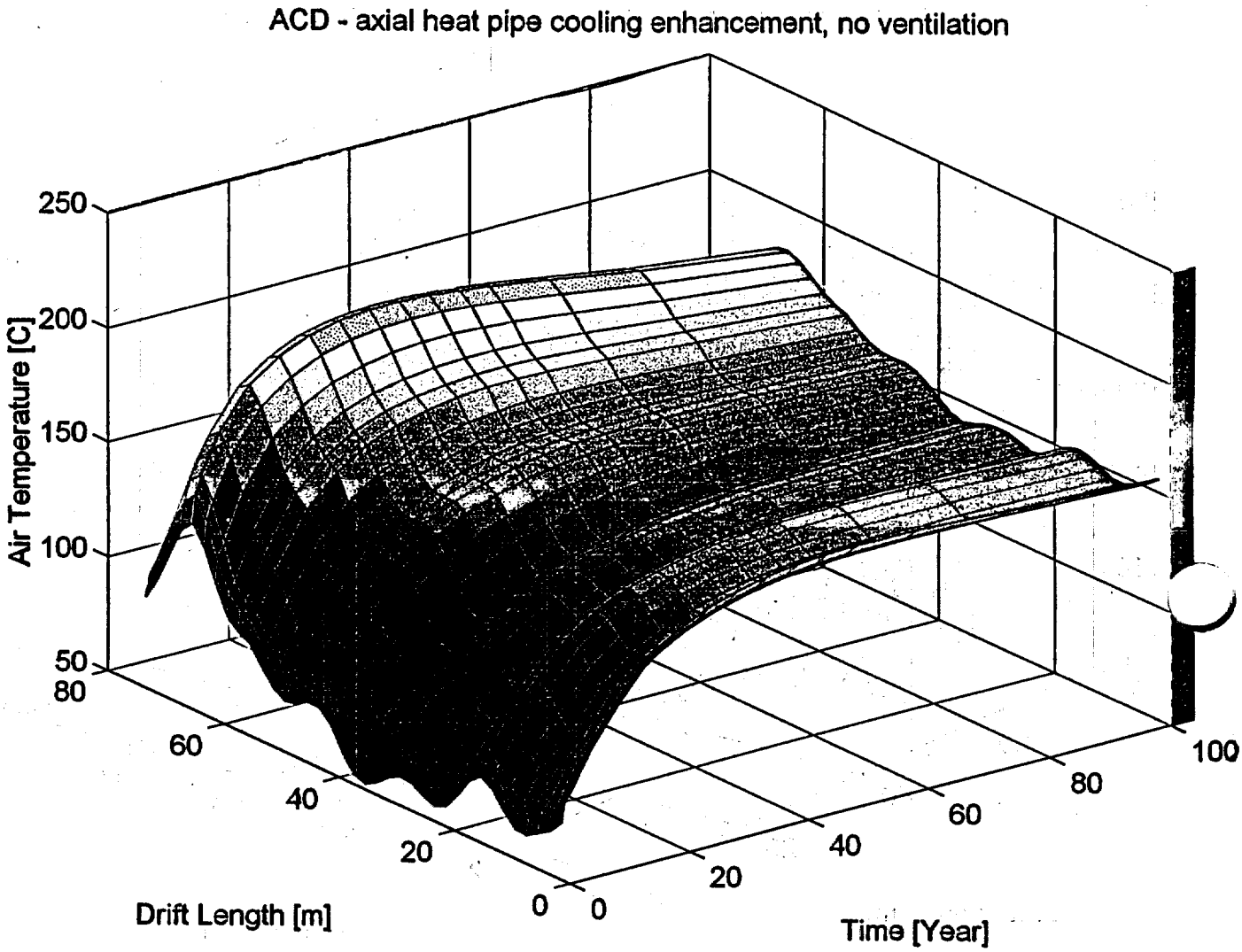

Figure D-41. Air Temperature for Multiple Waste Package Heats and an Axial Heat Pipe

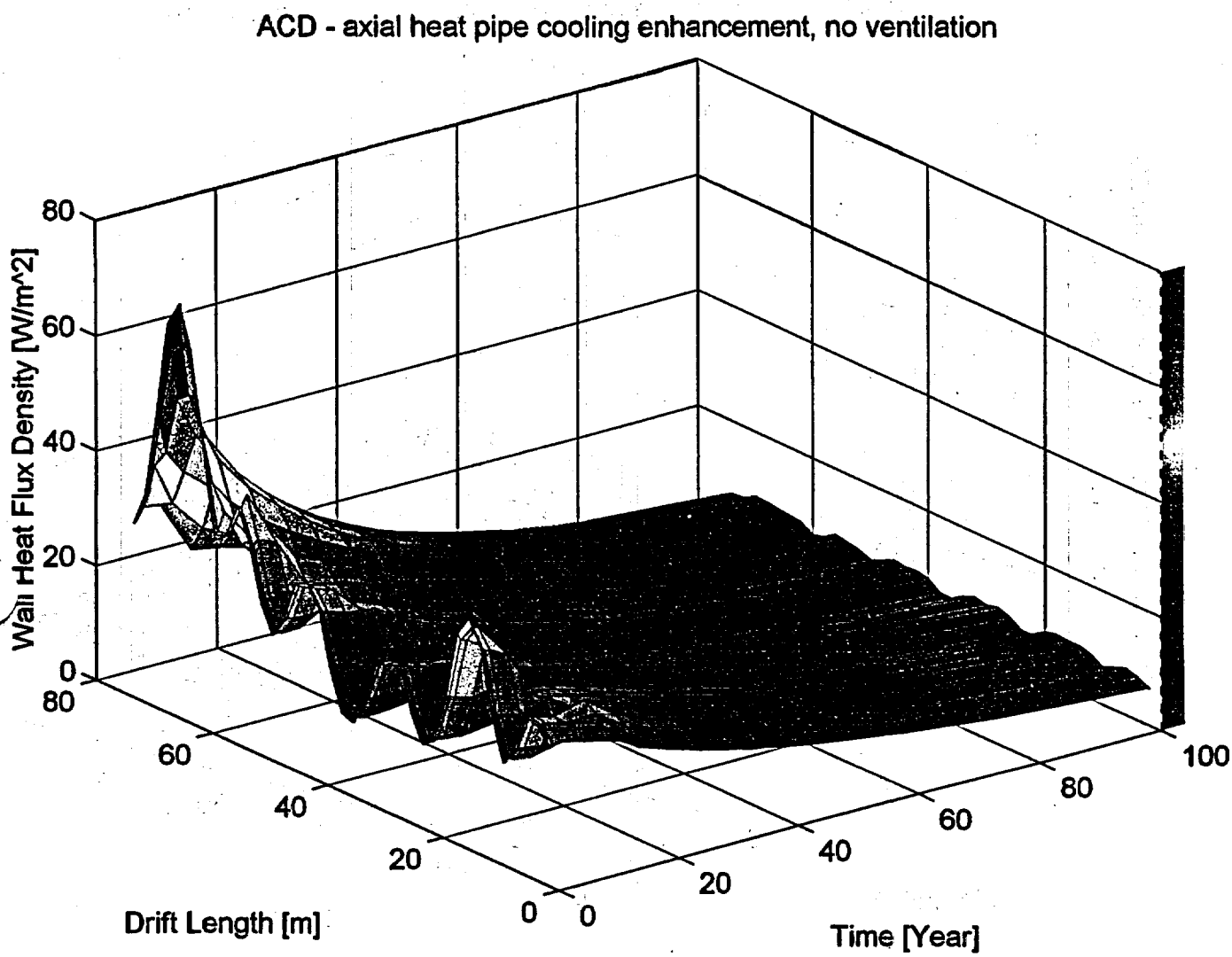

Figure D-42. Wall Heat Flux for Multiple Waste Package Heats and an Axial Heat Pipe

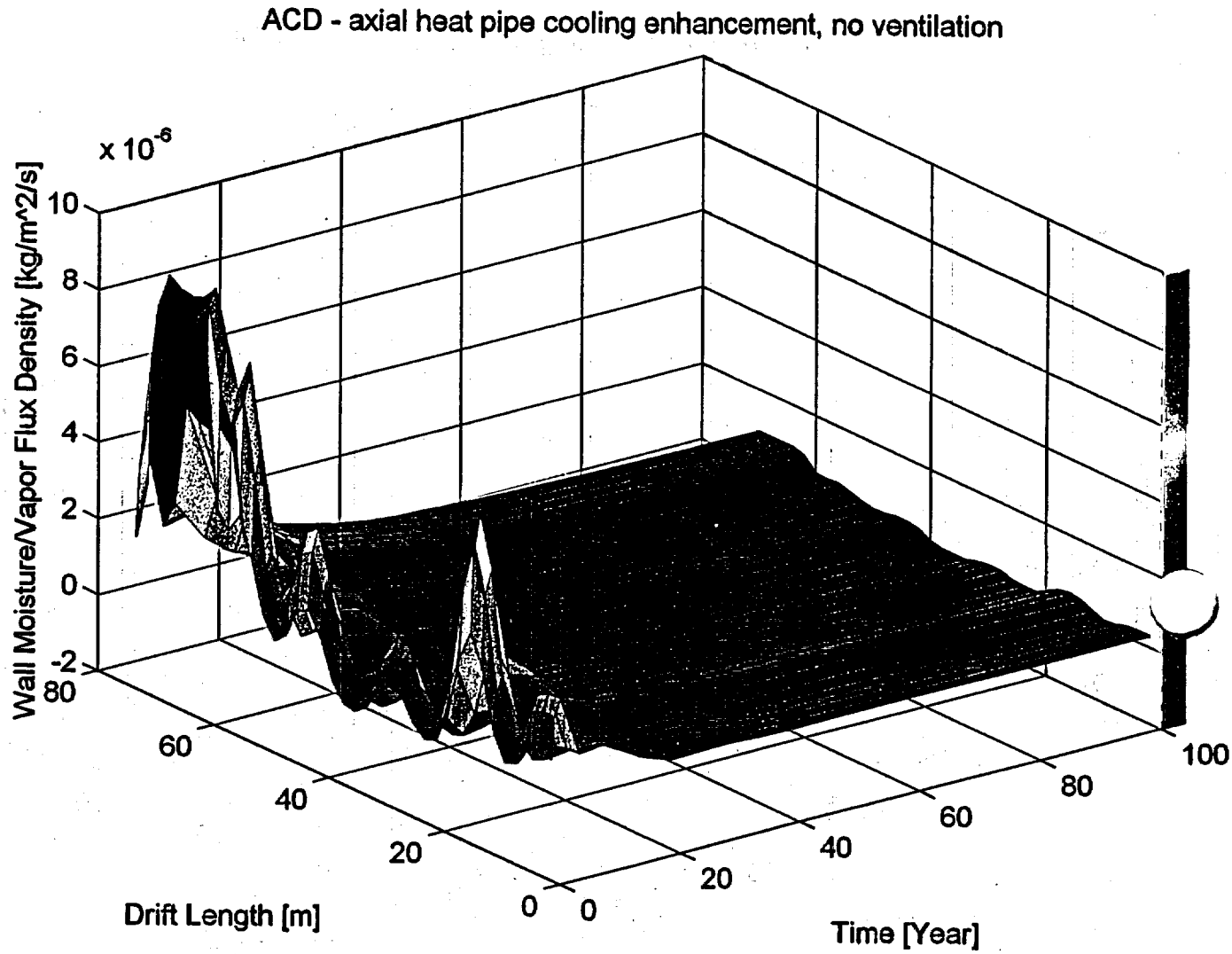

Figure D-43. Wall Moisture Flux for Multiple Waste Package Heats and an Axial Heat Pipe

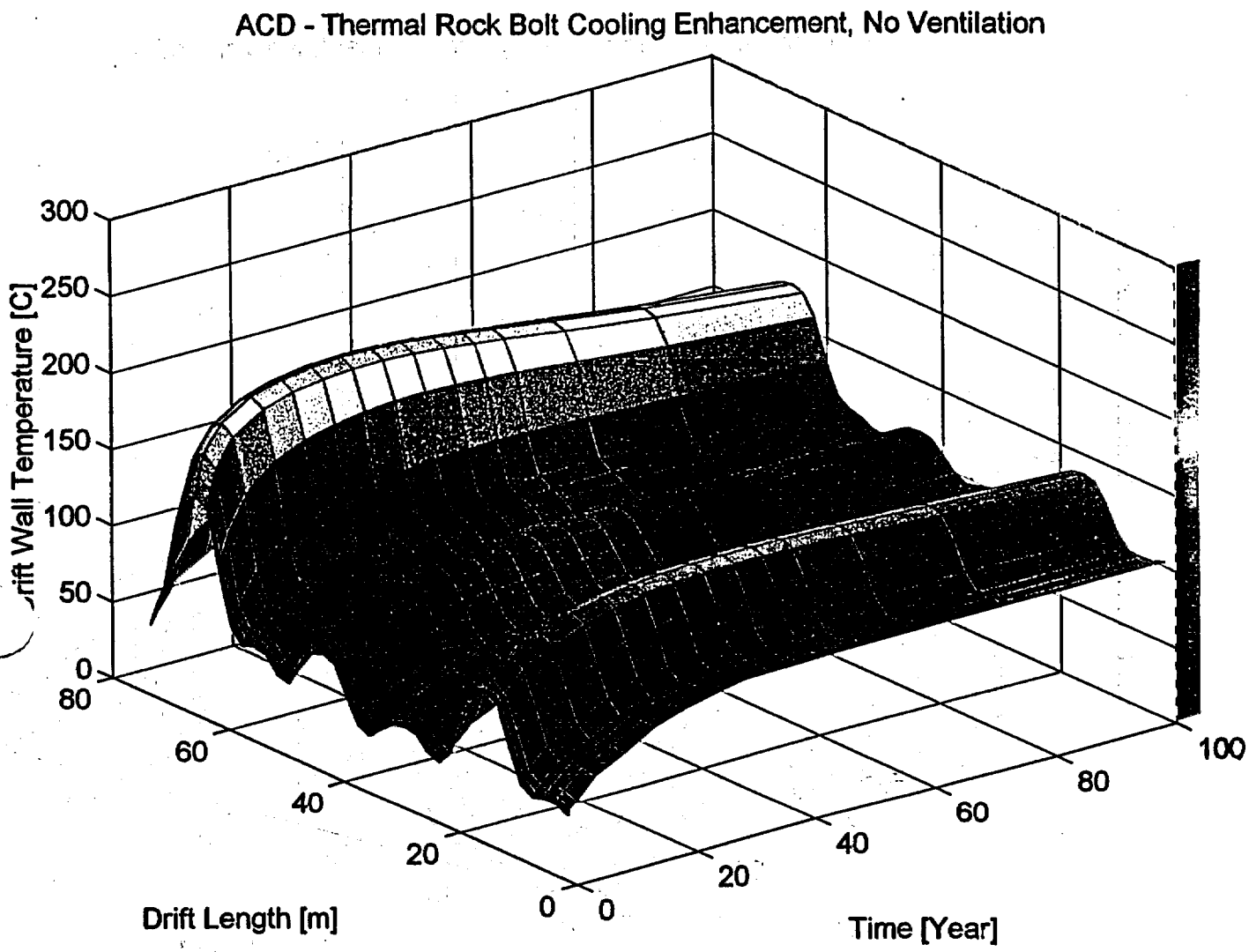

Figure D-44. Drift Wall Temperatures for Multiple Waste Package Heats for Thermal Rock Bolts

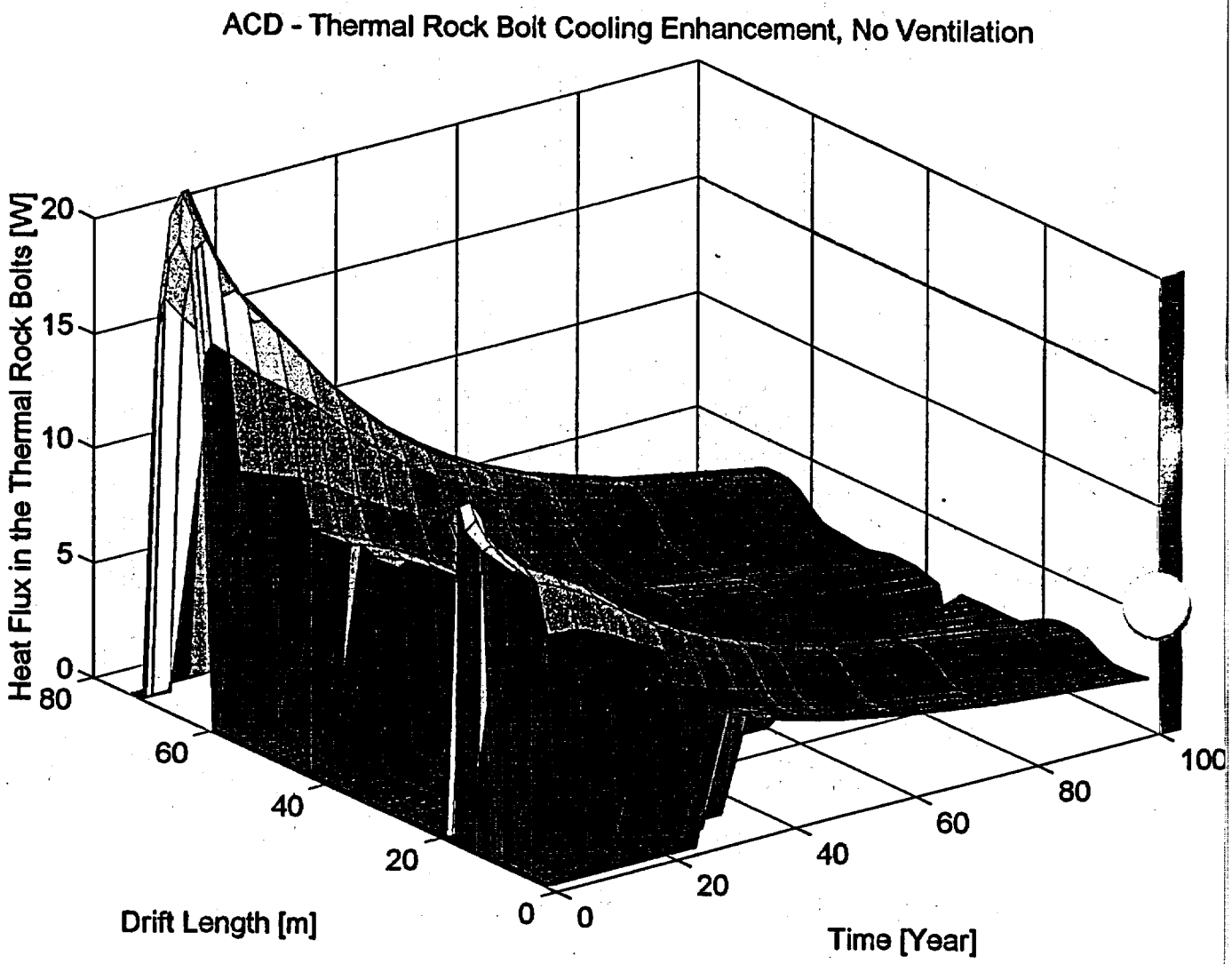

Figure D-45. Heat Flux in the Thermal Rock Bolts for Multiple Heat Packages

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APPENDIX E

HEAT FLOW AND TEMPERATURE CALCULATIONS FOR CONTINUOUSLY VENTILATED EMPLACEMENT DRIFTS

FIGURES

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HEAT FLOW AND TEMPERATURE CALCULATIONS FOR CONTINUOUSLY VENTILATED EMPLACEMENT DRIFTS

The calculations of heat flows and temperatures were performed by treating a ventilated emplacement drift as a series of finite drift segments, and dividing the entire ventilation time period of interest as a number of short time-steps. With this approach, the temperature of air traveling in a drift segment within a short time span can be reasonably represented by a constant, which is required as a boundary condition by general thermal analysis software. Thermal analysis with computer models was performed for each drift-section sequentially from the beginning (intake) to the end (exhaust) of the drift. The computer code ANSYS Revision 5.1 (thermal analysis phase) was used for modeling thermal conditions in individual drift-sections. Results obtained from each drift segment were used as inputs to the calculations for next drift segment in the flowpaths. Outputs in each time span were recorded and later used as initial conditions for modeling the next time-step.

Upon the completion of the required computational efforts for all drift-sections and time-steps, results for all individual segments and time intervals are assembled. The outcome forms a comprehensive description of the heat transfer process for the entire drift at different times after emplacement. The calculations are depicted in Figures E-1 through E-18.

General Data/Information Used:

- Mass Load: 83 MTU/Ac
- Emplacement Mode: Center-In-Drift
- Emplacement Drift Length: 600 m
- Emplacement Drift Diameter: 5 m
- Waste Package Diameter: 1.85 m
- Acceptance Strategy: Oldest Fuel First (OFF), no MRS, deferred dry storage, derated canisters, and four truck sites
- Fuel Characteristics: 26.4 years old with 39.65 Gwd/MTU burnup and 3.68 wt. percent enrichment
- Package Type: 21 PWR,
- Average Initial Heat Output: 9.21 kW/pk
- Average Package Content: 8.83 MTU/pk
- Airflow Rate: 0.1, 0.6, 1, 2, 5 and 10 m^3/s per emplacement drift
- Temperature of Air Entering Emplacement Drift: 26°C
- Initial Temperature of Rock Mass at Start of Ventilation: 26°C
- Time of Continuous Ventilation: 100 years

NOTE: The non-uniform time spans (0, 1, 4, 8.5,14,19.5,26.5, 34,5, 44, 56.5, 73, 100 yrs) of the calculations were selected for the purpose of obtaining a constant decrease in heat output within each time span, according to the thermal decay function of the spent fuel.

Estimate of Additional Cost for Continuous Ventilation

The additional ventilation airways and total additional ventilation costs needed for continuous ventilation of all emplacement drifts are estimated using the existing underground repository layout developed for the Mined Geologic Disposal System Advanced Conceptual Design. The advanced conceptual design layout contains four major openings (two shafts and two ramps) to the surface and four underground main drifts. Ventilation airflow that can be delivered through these major airways is capable of supporting the repository underground operations if *no* ventilation is required for emplacement drift cooling.

If continuous ventilation is to be provided to all emplacement drifts after completion of waste emplacement, additional shafts and/or main drifts will be needed to accommodate the increased total airflow quantity resulted from using ventilation for emplacement drift cooling. As the emplacement activities progress, the number of emplacement drifts to be ventilated and the airflow requirement will increase. When the air flow rate exceeds the capacity of the existing system, additional shafts and/or main underground drifts will be added.

The Estimate of the Ventilation Cost Was Performed Using the Following Information:

- $12 million for adding one shaft (8 m diameter)
- $71 million for adding one main underground drift (9 m diameter)
- 75 percent average fan efficiency
- $0.09 per kWh electric power cost rate
- "K" factors for ventilation air flow in:

Ventilation Shaft	0.0030 kg/m^3
Man-and Material Shaft	0176 kg/m^3
Waste Ramp	0.0056 kg/m^3
Tuff Ramp	0.0111 kg/m^3
Exhaust Mains:	0.0111 kg/m^3
West and East Mains:	0.0130 kg/m^3
TBM Launch Mains:	0.0130 kg/m^3
Emplacement Drifts:	
Without Waste Packages	0.0130 kg/m^3
With Waste Packages	0.0158 kg/m^3

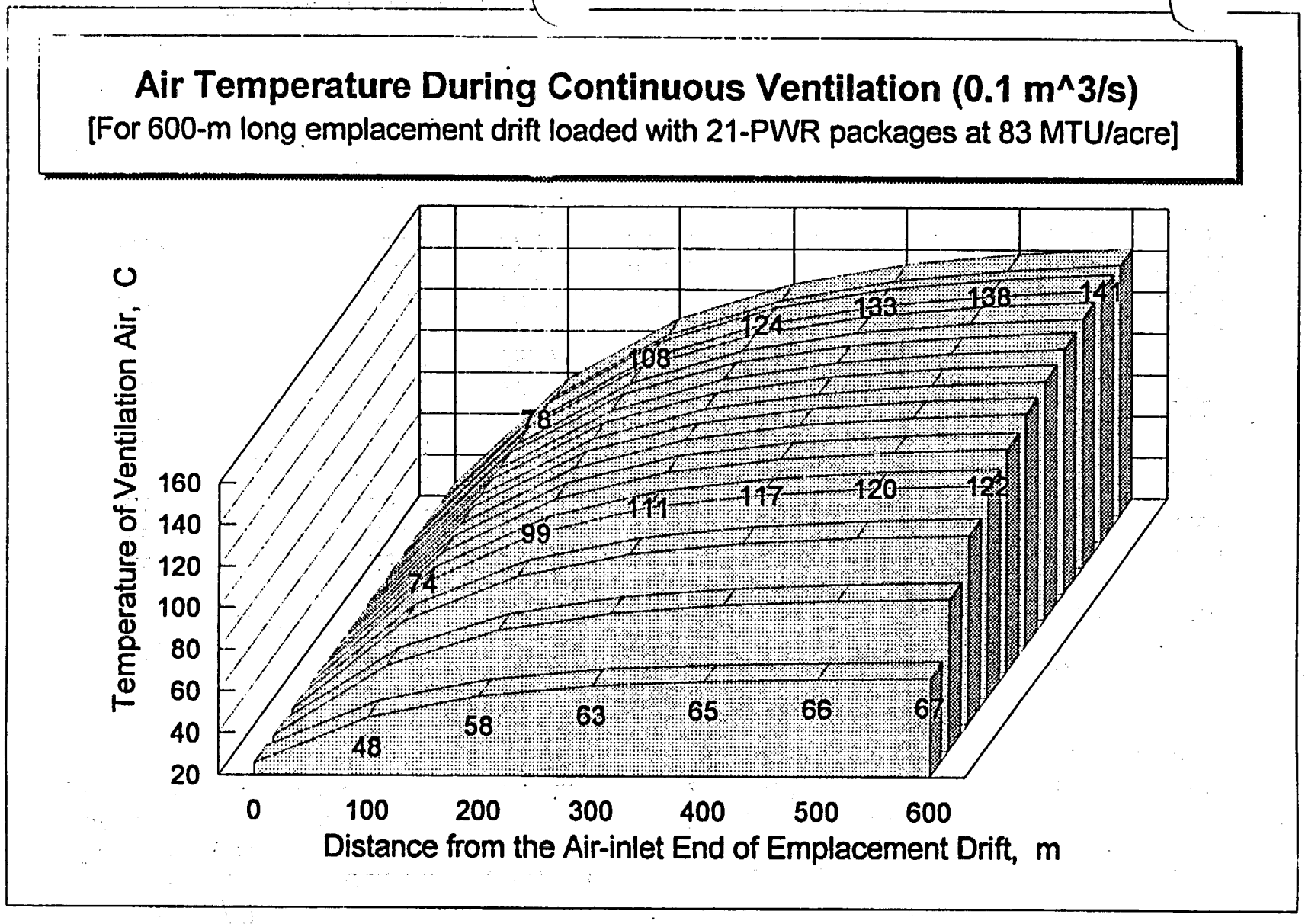

Figure E-1. Air Temperature During Continuous Ventilation (0.1 m^3/s)

0.1 m^3/s **Continuous Emplacement Drift Ventilation**

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	47.50	57.86	62.84	65.24	66.40	66.96
4.0		26.00	59.82	76.72	85.15	89.36	91.46	92.51
8.5		26.00	68.68	90.25	101.12	106.59	109.36	110.75
14.0		26.00	74.02	98.51	110.97	117.27	120.49	122.14
19.5		26.00	76.45	102.29	115.52	122.26	125.70	127.50
26.5		26.00	77.95	104.88	118.89	126.12	129.85	131.83
34.5		26.00	78.77	106.54	121.20	128.90	132.94	135.12
44.0		26.00	79.13	107.60	123.02	131.30	135.73	138.16
56.5		26.00	79.04	108.19	124.24	132.98	137.71	140.32
73.0		26.00	78.35	107.76	124.18	133.26	138.28	141.06
100.0		26.00	77.03	106.40	123.15	132.63	137.98	141.01

Figure E-1. Air Temperature During [illegible]nuous Ventilation (0.1 m^3/s) (continued)

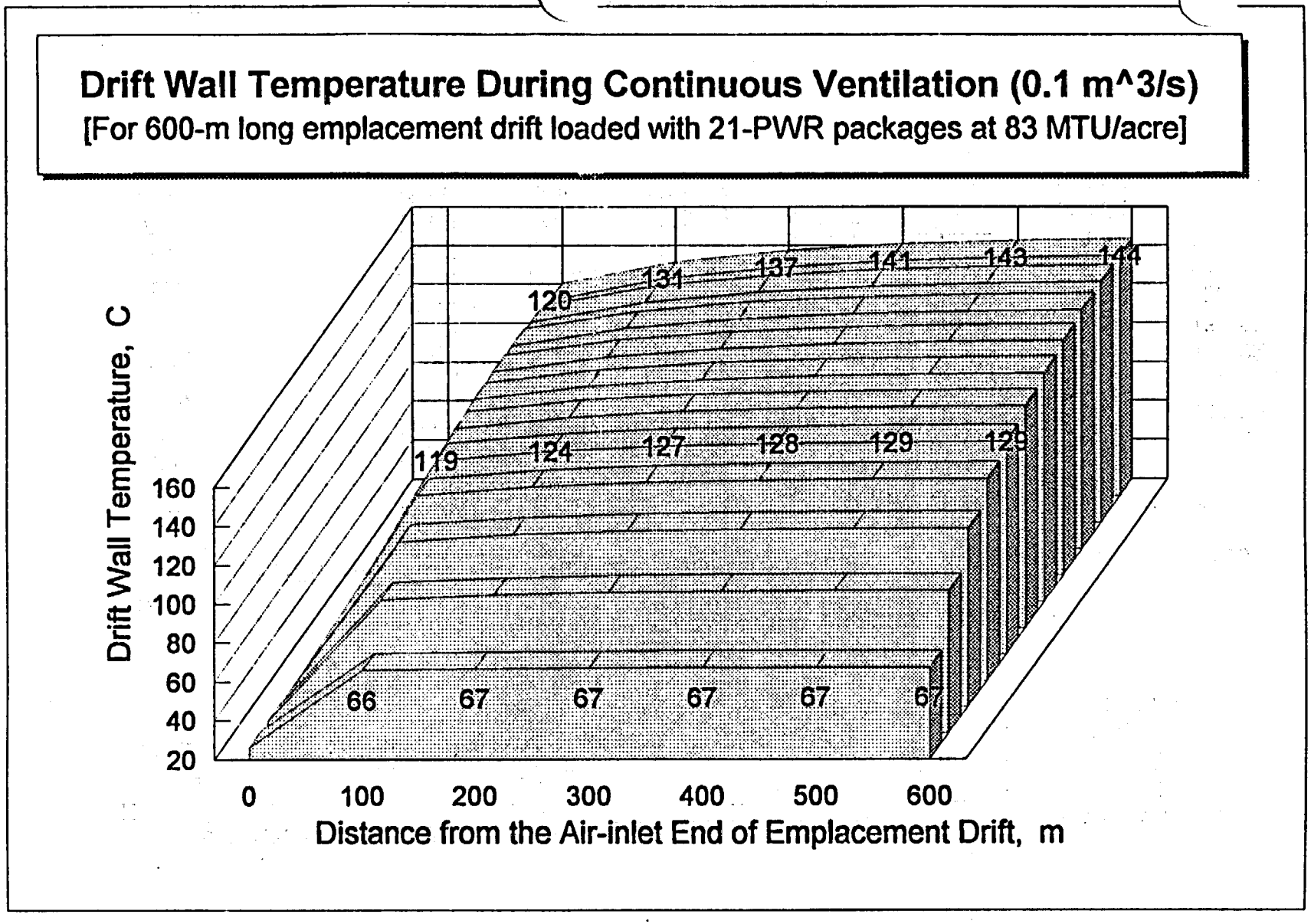

Figure E-2. Drift Wall Temperature During Continuous Ventilation (0.1 m^3/s)

0.1 m^3/s **Continuous Emplacement Drift Ventilation**

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	65.79	66.67	67.08	67.29	67.38	67.43
4.0		26.00	88.58	91.09	92.33	92.94	93.25	93.40
8.5		26.00	104.97	108.60	110.36	111.24	111.72	111.92
14.0		26.00	114.86	119.34	121.57	122.63	123.22	123.54
19.5		26.00	119.36	124.26	126.78	127.99	128.63	129.02
26.5		26.00	122.13	127.79	130.81	132.28	133.02	133.50
34.5		26.00	123.65	130.15	133.67	135.44	136.38	136.97
44.0		26.00	124.32	131.81	136.14	138.33	139.51	140.22
56.5		26.00	124.15	132.97	137.90	140.40	141.74	142.53
73.0		26.00	122.87	132.78	138.15	140.99	142.54	143.43
100.0		26.00	120.43	131.37	137.40	140.69	142.54	143.58

Figure E-2. Drift Wall Temperature Du[illegible] ntinuous Ventilation (0.1 m^3/s) (continued)

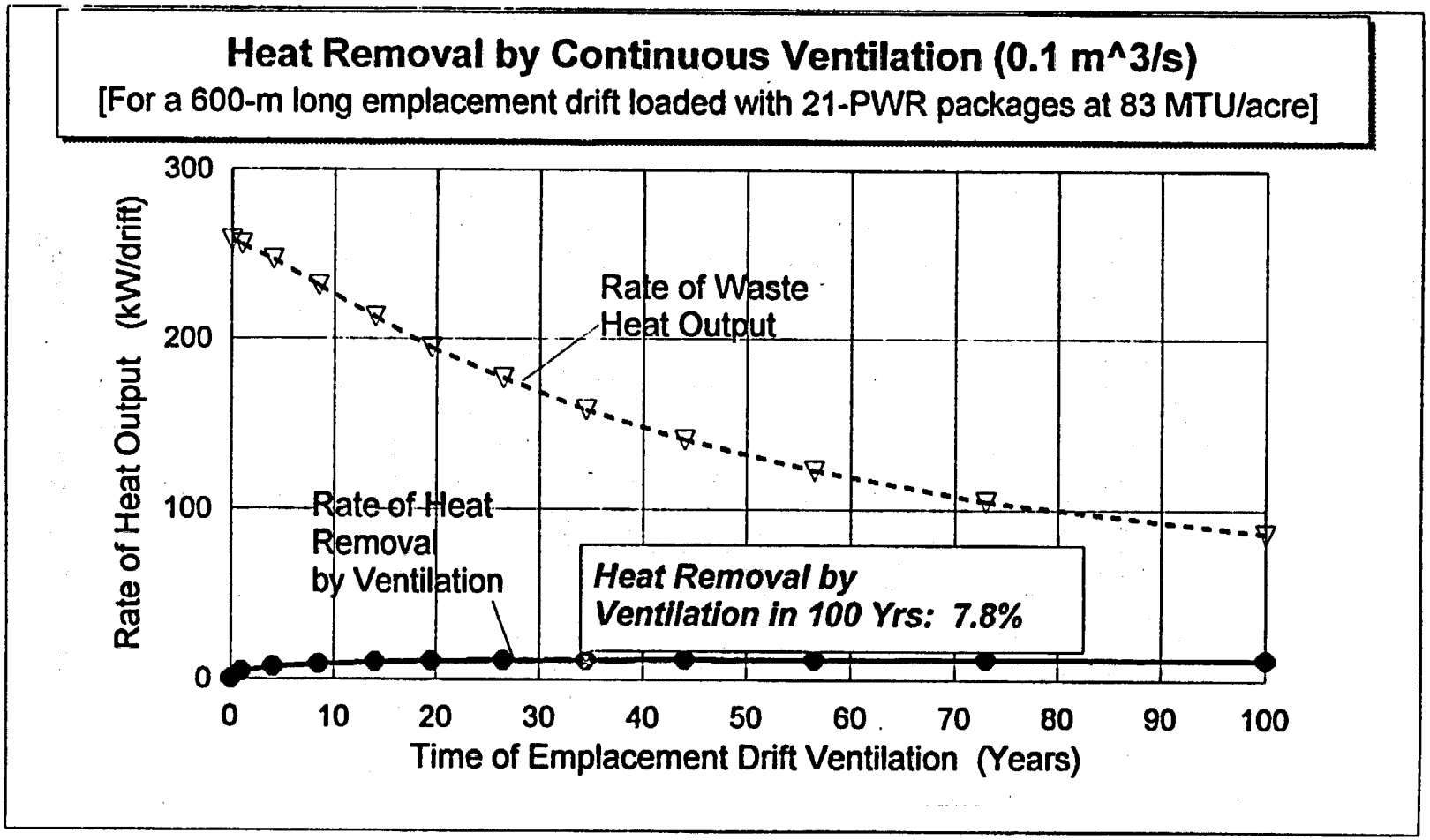

Figure E-3. Heat Removal by Continuous Ventilation (0.1 m^3/s)

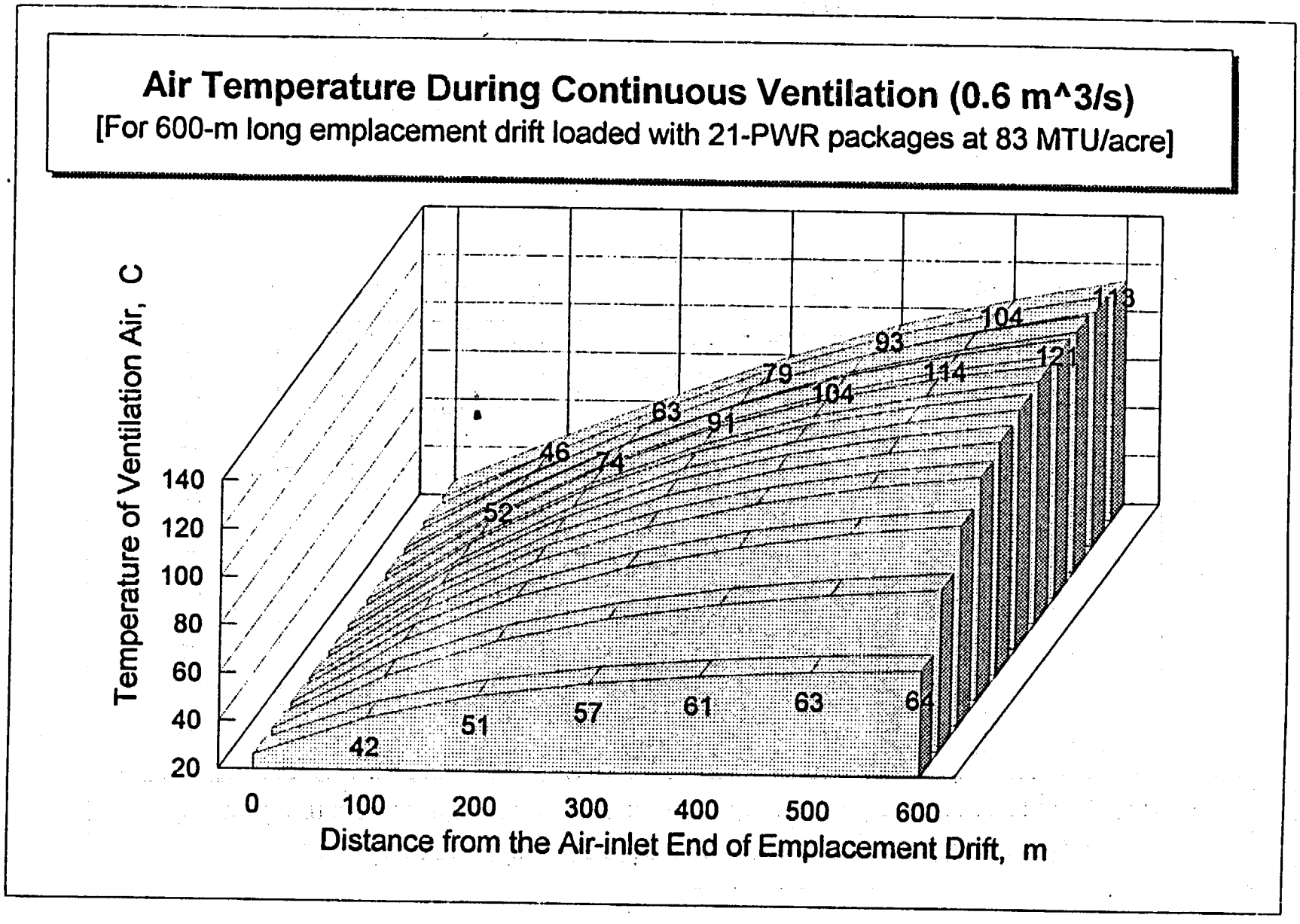

Figure E-4. Air Temperature D Continuous Ventilation (0.6 m^3/s)

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0.6 m^3/s Continuous Emplacement Drift Ventilation

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam =	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density=	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	41.76	51.35	57.18	60.72	62.87	64.18
4.0		26.00	48.41	63.37	73.33	79.93	84.30	87.18
8.5		26.00	52.36	70.99	84.03	92.93	99.03	103.13
14.0		26.00	54.23	75.00	89.90	100.37	107.65	112.64
19.5		26.00	54.64	76.37	92.29	103.57	111.43	116.69
26.5		26.00	54.40	76.63	93.17	105.02	113.44	119.39
34.5		26.00	53.52	75.73	92.60	104.96	113.98	120.49
44.0		26.00	52.22	73.98	91.09	103.94	113.51	120.58
56.5		26.00	50.46	71.29	88.51	101.82	111.94	119.62
73.0		26.00	48.24	67.71	84.77	98.38	108.98	117.21
100.0		26.00	45.51	63.09	79.31	93.09	104.20	112.97

Figure E-4. Air Temperature During Continuous Ventilation (0.6 m^3/s) (continued)

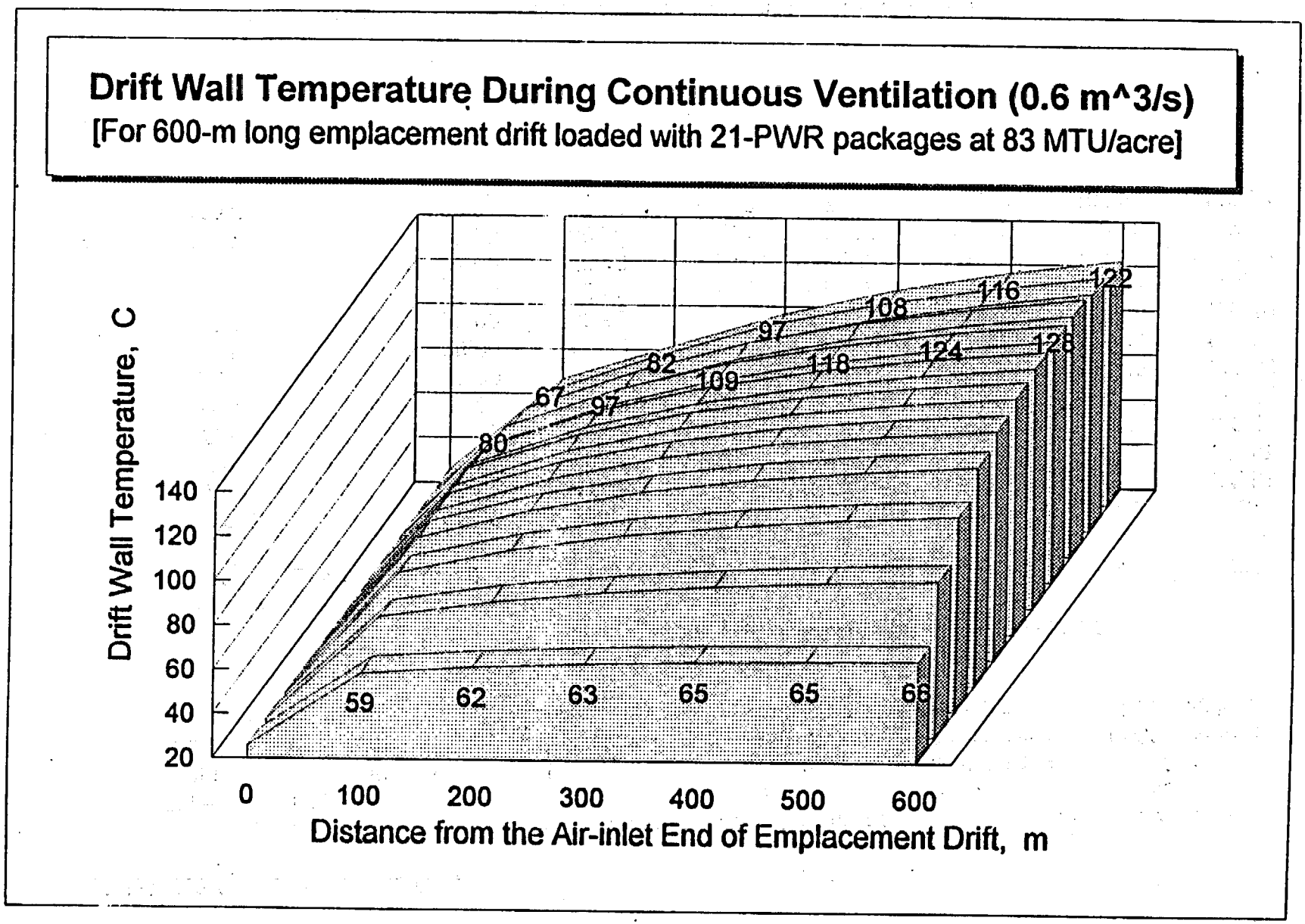

Figure E-5. Drift Wall Temperatu ing Continuous Ventilation (0.6 m^3/s)

1 m^3/s **Continuous Emplacement Drift Ventilation**

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	58.73	61.67	63.45	64.53	65.19	65.59
4.0		26.00	72.52	79.48	84.04	87.04	89.00	90.28
8.5		26.00	80.73	91.05	98.06	102.51	105.59	107.54
14.0		26.00	84.62	97.36	105.94	111.64	115.48	118.02
19.5		26.00	85.46	99.77	109.42	115.72	119.89	122.72
26.5		26.00	84.97	100.55	110.97	117.78	122.50	125.79
34.5		26.00	83.15	99.63	110.77	118.27	123.68	127.49
44.0		26.00	80.45	97.40	109.50	117.78	123.81	128.18
56.5		26.00	76.79	93.71	107.04	116.15	122.83	127.88
73.0		26.00	72.18	88.66	103.13	113.04	120.39	126.07
100.0		26.00	66.50	82.01	96.77	107.93	116.16	122.41

Figure E-5. Drift Wall Temperature During Continuous Ventilation (0.6 m^3/s) (continued)

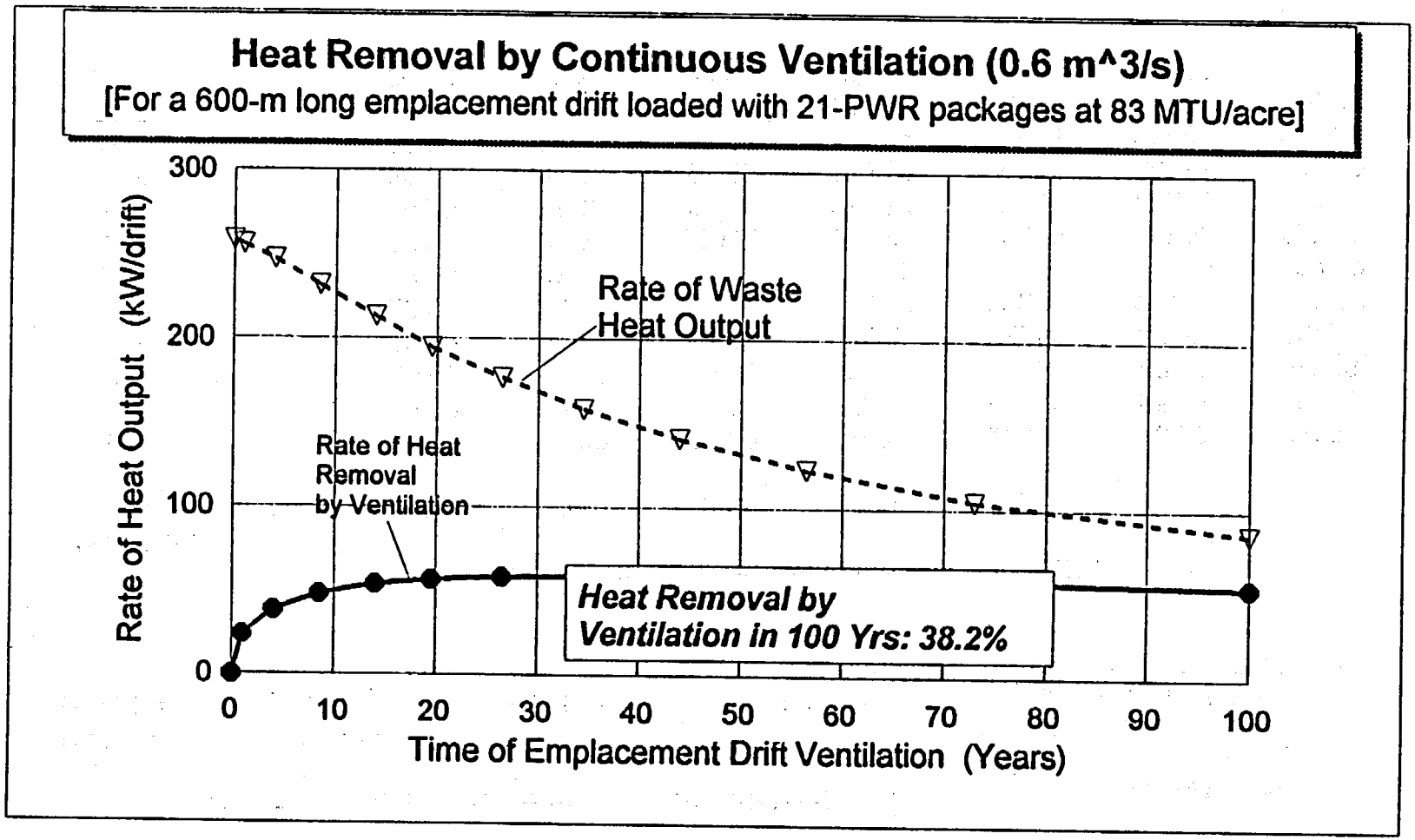

Figure E-6. Heat Removal ntinuous Ventilation (0.6 m^3/s)

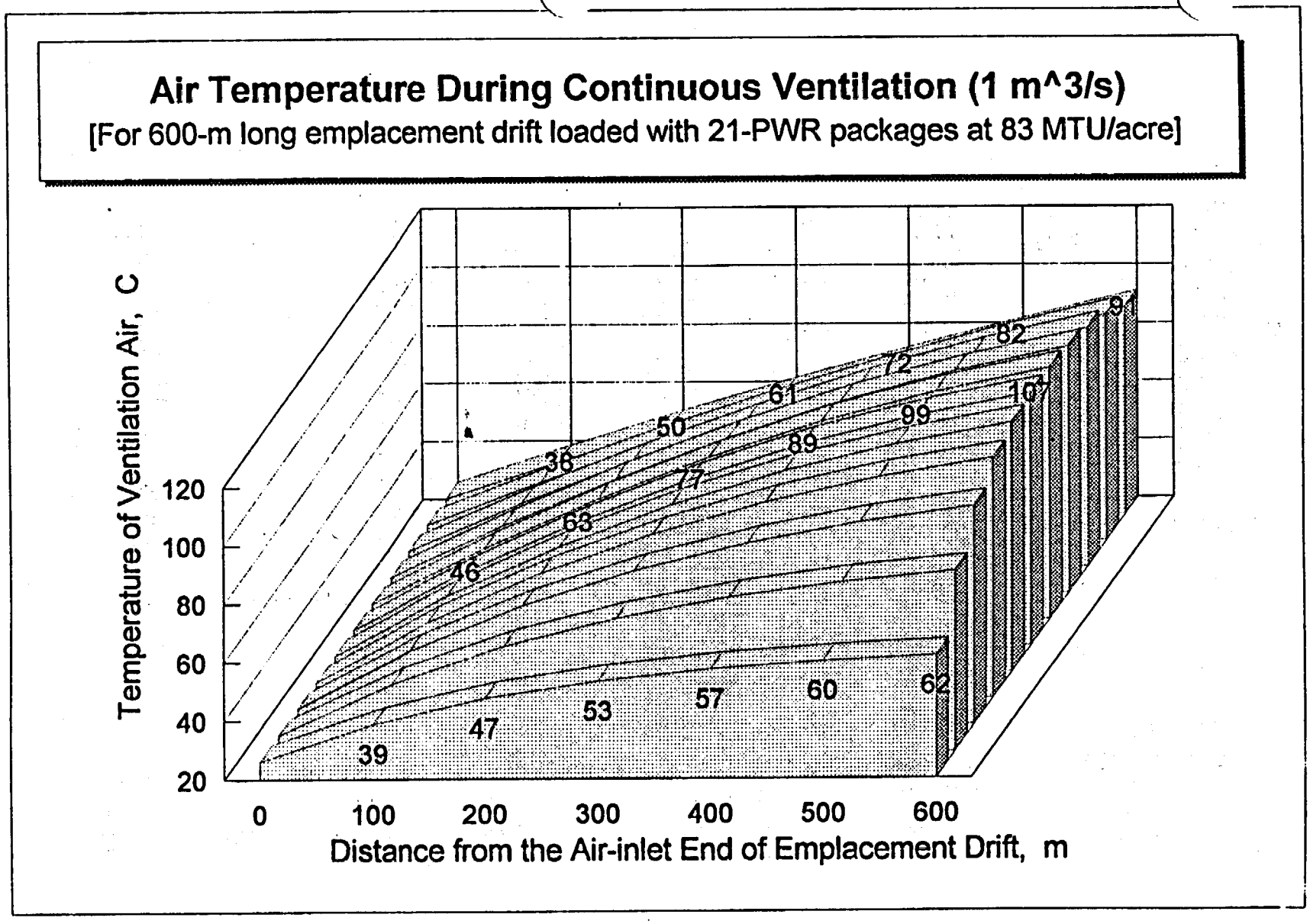

Figure E-7. Air Temperature During Continuous Ventilation (1 m^3/s)

1 m^3/s Continuous Emplacement Drift Ventilation

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	38.67	47.29	53.15	57.13	59.84	61.68
4.0		26.00	43.23	56.08	65.62	72.68	77.90	81.74
8.5		26.00	45.63	61.02	73.05	82.41	89.53	94.95
14.0		26.00	46.48	63.16	76.67	87.42	95.84	102.37
19.5		26.00	46.37	63.41	77.56	89.09	98.26	105.41
26.5		26.00	45.83	62.82	77.27	89.32	98.98	106.59
34.5		26.00	44.89	61.41	75.79	88.10	98.12	106.16
44.0		26.00	43.71	59.49	73.51	85.87	96.19	104.66
56.5		26.00	42.24	57.00	70.36	82.50	93.05	101.92
73.0		26.00	40.50	53.95	66.35	77.77	88.43	97.62
100.0		26.00	38.48	50.28	61.38	71.80	81.80	91.15

Figure E-7. Air Temperature Durin inuous Ventilation (1 m^3/s) (continued)

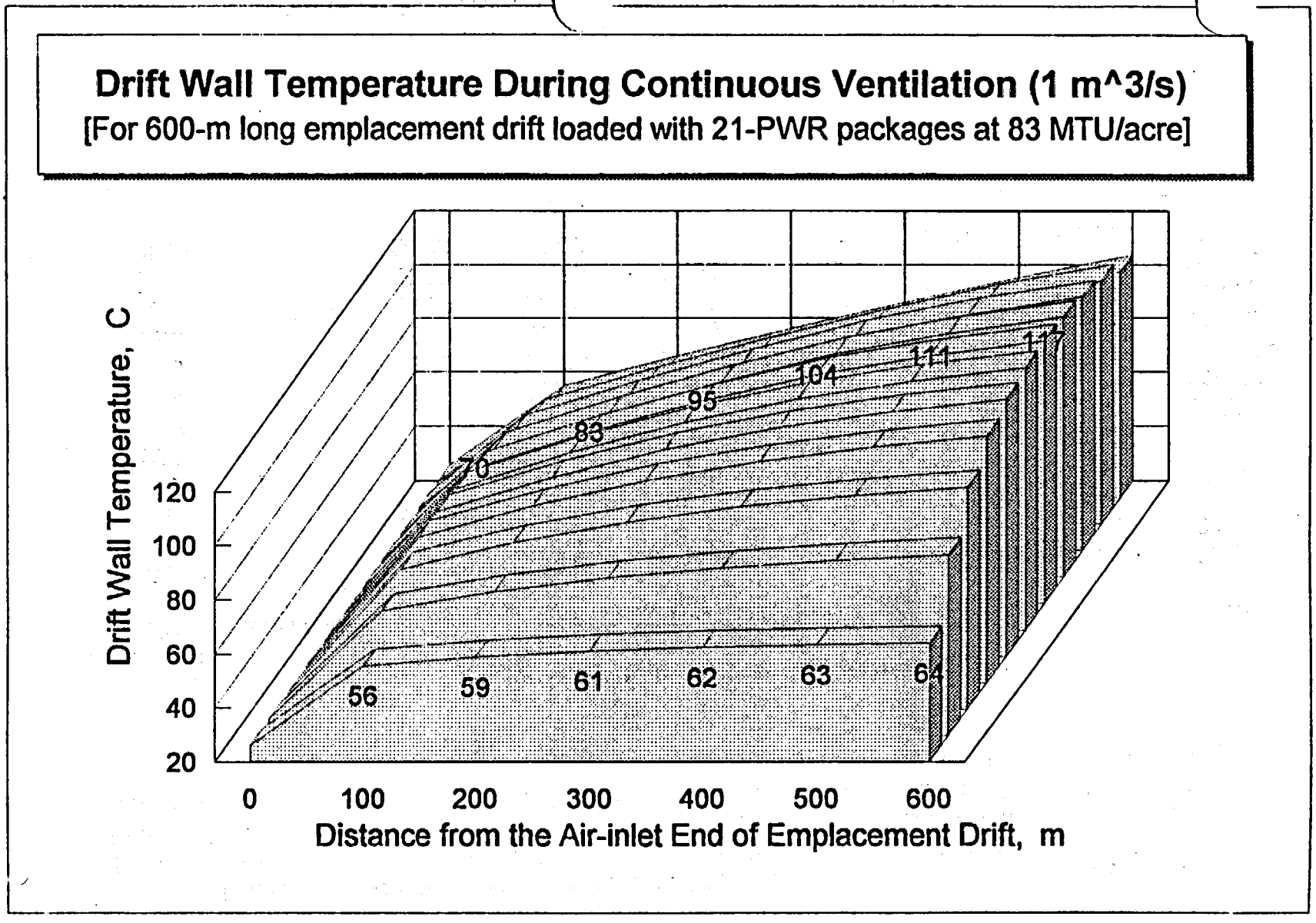

Figure E-8. Drift Wall Temperature During Continuous Ventilation (1 m^3/s)

1 m^3/s Continuous Emplacement Drift Ventilation

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	55.52	58.74	60.93	62.43	63.44	64.13
4.0		26.00	66.14	73.16	78.30	82.07	84.83	86.84
8.5		26.00	71.72	81.49	89.04	94.84	99.01	102.14
14.0		26.00	73.71	85.33	94.62	101.72	107.04	111.04
19.5		26.00	73.46	86.05	96.37	104.42	110.44	114.92
26.5		26.00	72.20	85.39	96.49	105.34	111.81	116.72
34.5		26.00	70.00	83.38	94.91	104.47	111.44	116.85
44.0		26.00	67.24	80.48	92.13	102.31	109.91	115.92
56.5		26.00	63.82	76.62	88.12	98.63	107.09	113.70
73.0		26.00	59.79	71.82	82.85	92.94	102.60	109.83
100.0		26.00	55.07	65.96	76.15	85.65	95.09	103.59

Figure E-8. Drift Wall Temperature D[illegible] Continuous Ventilation (1 m^3/s) (continued)

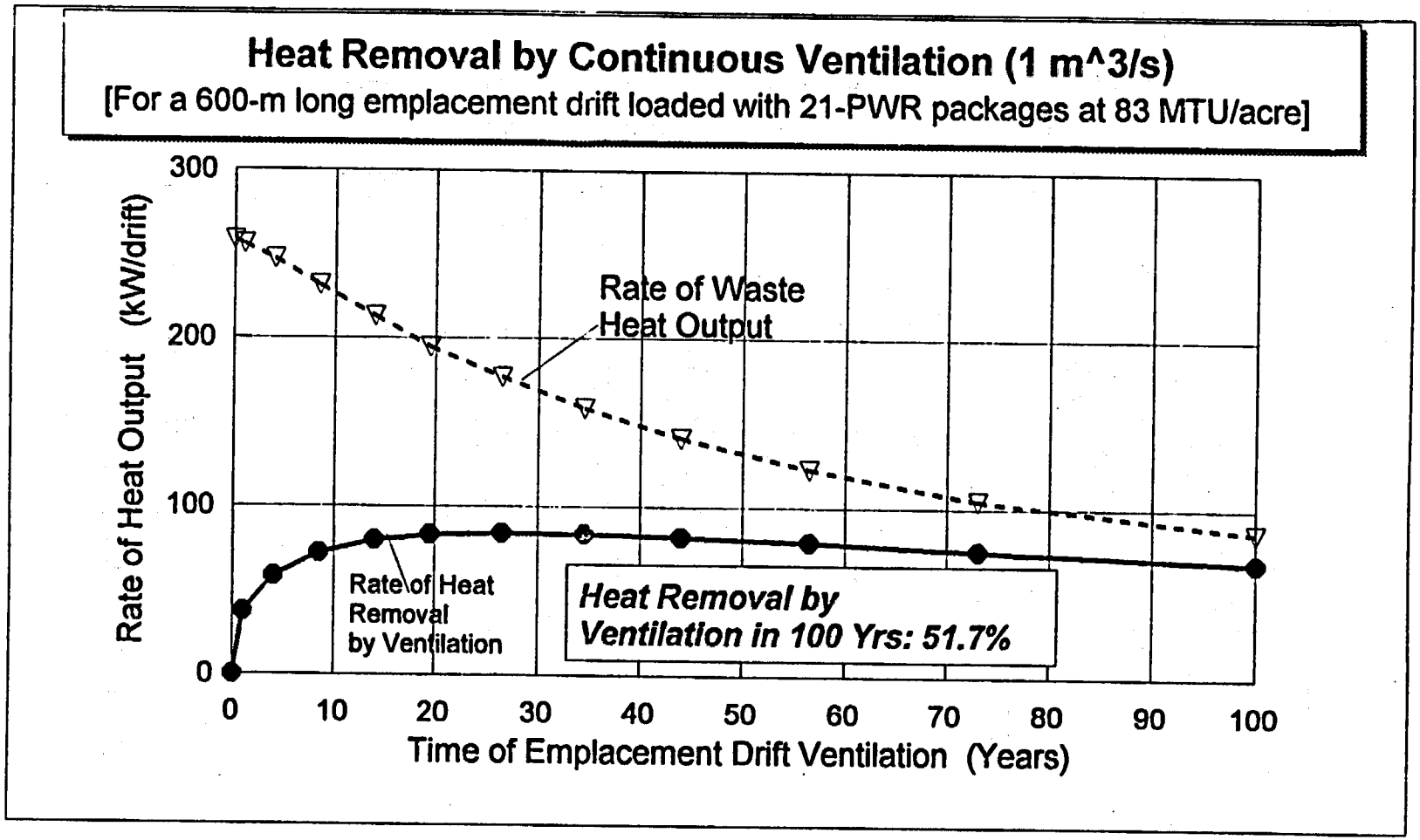

Figure E-9. Heat Removal by Continuous Ventilation (1 m^3/s)

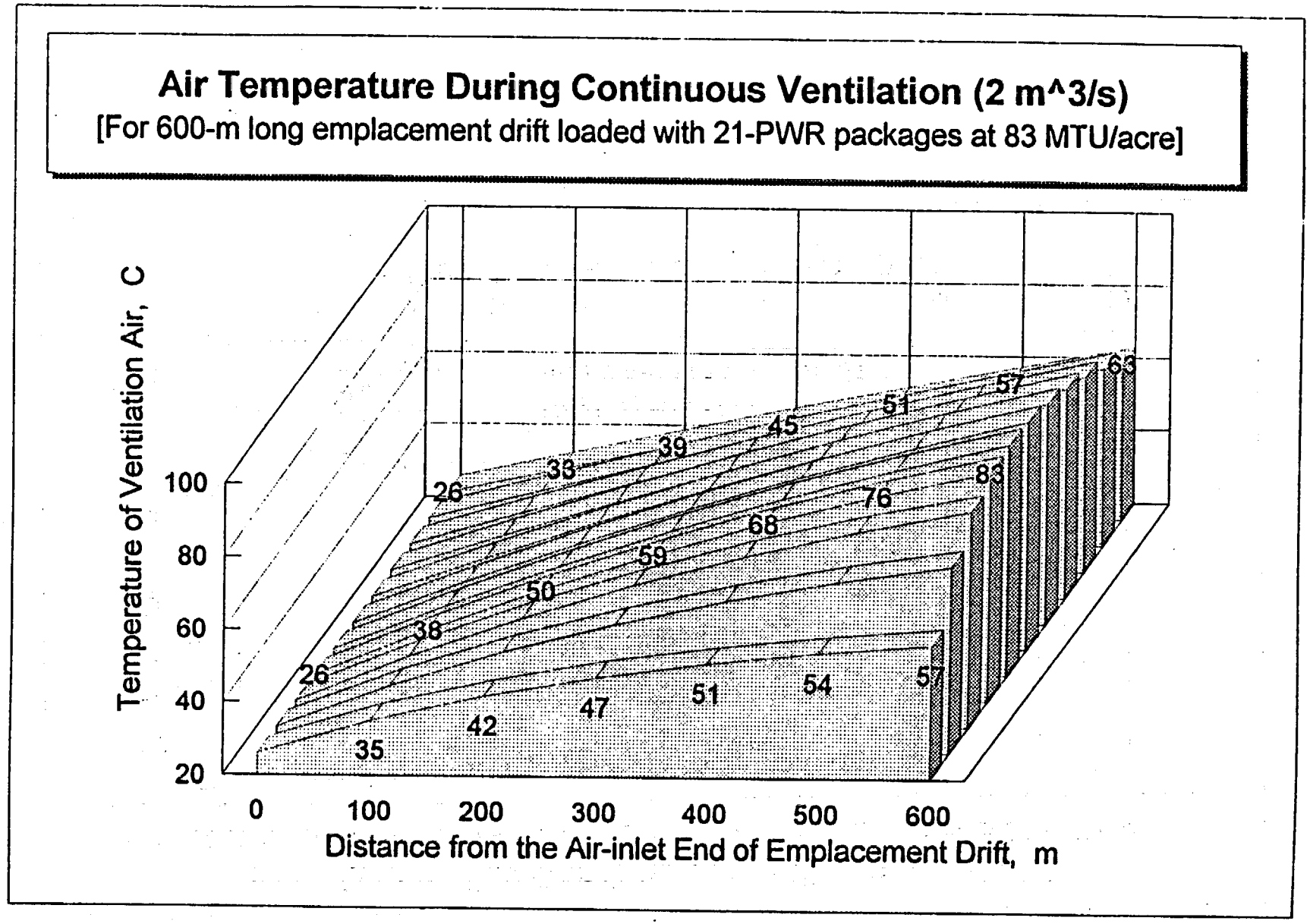

Figure E-10. Air Temperatur ng Continuous Ventilation (2 m^3/s)

2 m^3/s **Continuous Emplacement Drift Ventilation** Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density=	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	35.03	41.94	47.22	51.27	54.36	56.73
4.0		26.00	37.41	46.92	54.83	61.37	66.78	71.24
8.5		26.00	38.36	49.10	58.40	66.43	73.34	79.27
14.0		26.00	38.43	49.53	59.42	68.19	75.94	82.78
19.5		26.00	38.04	49.00	58.94	67.91	76.00	83.27
26.5		26.00	37.44	48.02	57.77	66.72	74.92	82.40
34.5		26.00	36.66	46.66	56.00	64.69	72.76	80.23
44.0		26.00	35.80	45.10	53.89	62.17	69.95	77.24
56.5		26.00	34.82	43.28	51.36	59.07	66.40	73.34
73.0		26.00	33.72	41.21	48.46	55.44	62.15	68.69
100.0		26.00	32.52	38.91	45.15	51.23	57.14	62.88

Figure E-10. Air Temperature During Continuous Ventilation (2 m^3/s) (continued)

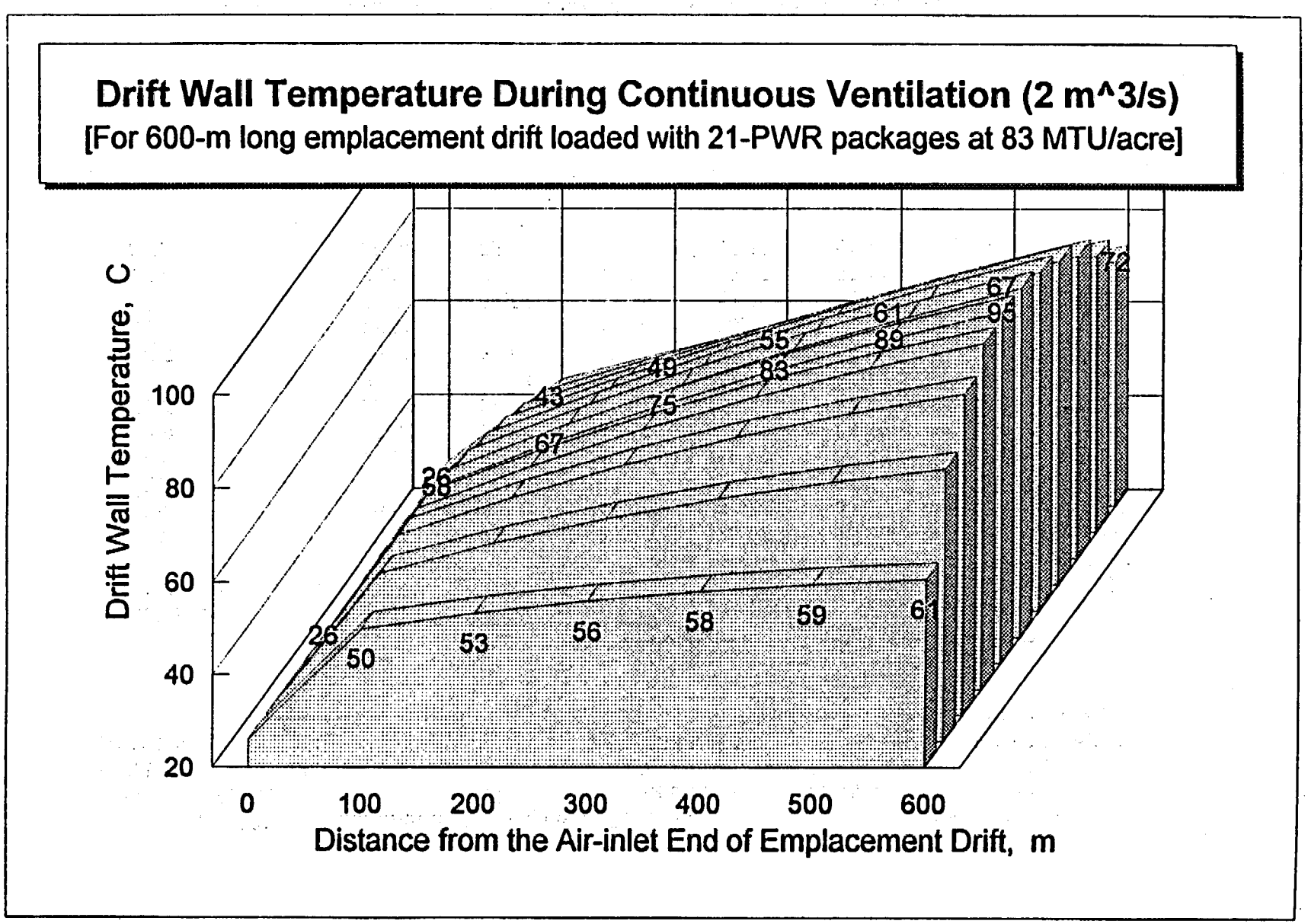

Figure E-11. Drift Wall Tempera[illegible]uring Continuous Ventilation (2 m^3/s)

2 m^3/s **Continuous Emplacement Drift Ventilation** Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density=	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	49.91	53.33	55.94	57.93	59.46	60.63
4.0		26.00	56.23	62.61	67.86	72.16	75.70	78.59
8.5		26.00	58.75	66.81	73.74	79.66	84.73	89.05
14.0		26.00	58.93	67.84	75.71	82.64	88.73	94.06
19.5		26.00	57.90	67.07	75.32	82.72	89.34	95.25
26.5		26.00	56.31	65.47	73.84	81.48	88.43	94.74
34.5		26.00	54.25	63.14	71.39	79.02	86.06	92.55
44.0		26.00	51.97	60.43	68.38	75.82	82.77	89.26
56.5		26.00	49.36	57.22	64.69	71.78	78.47	84.80
73.0		26.00	46.46	53.57	60.40	66.95	73.21	79.20
100.0		26.00	43.27	49.44	55.44	61.26	66.89	72.34

Figure E-11. Drift Wall Temperature During Continuous Ventilation (2 m^3/s) (continued)

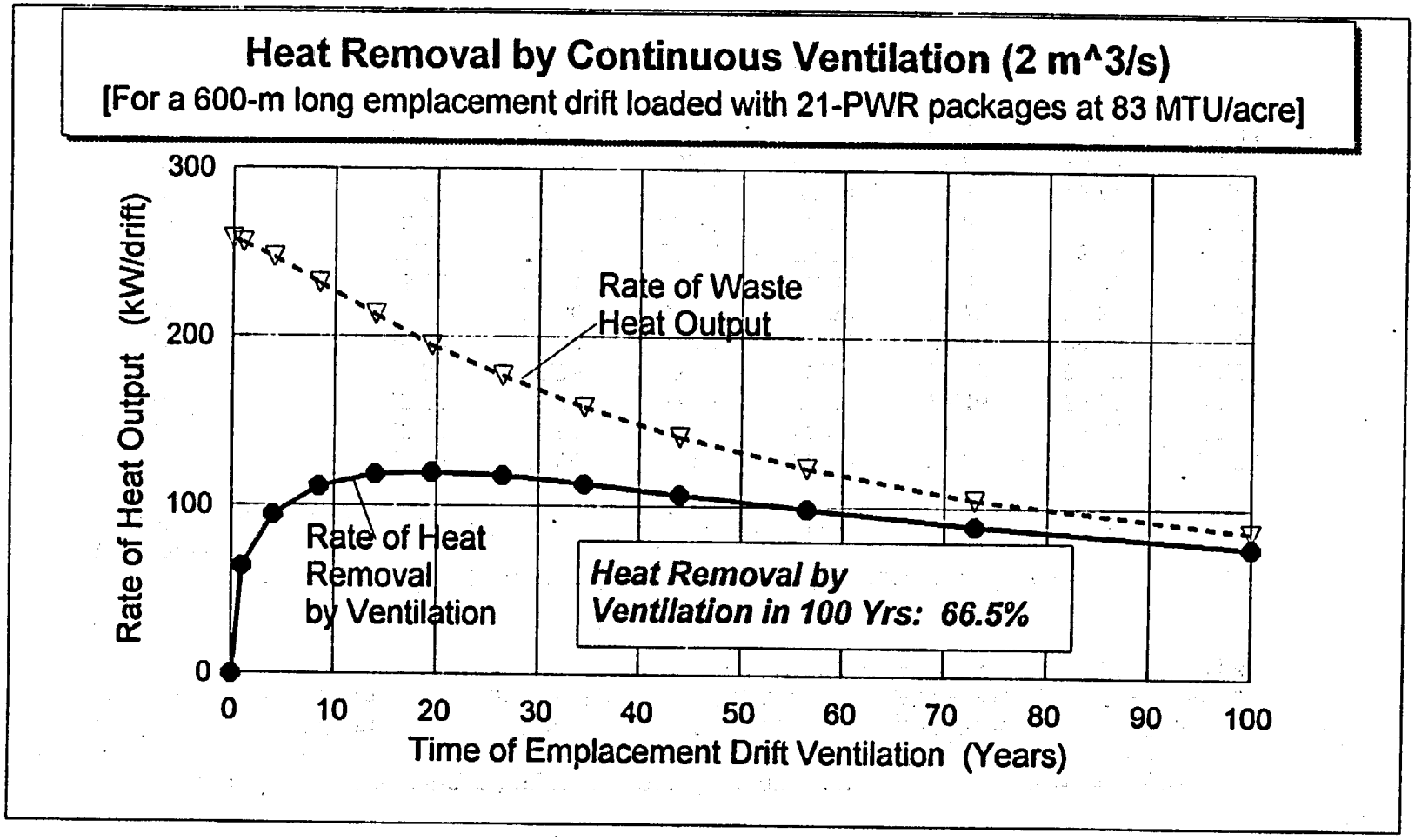

Figure E-12. Heat Remov[illegible] Continuous Ventilation (2 m^3/s)

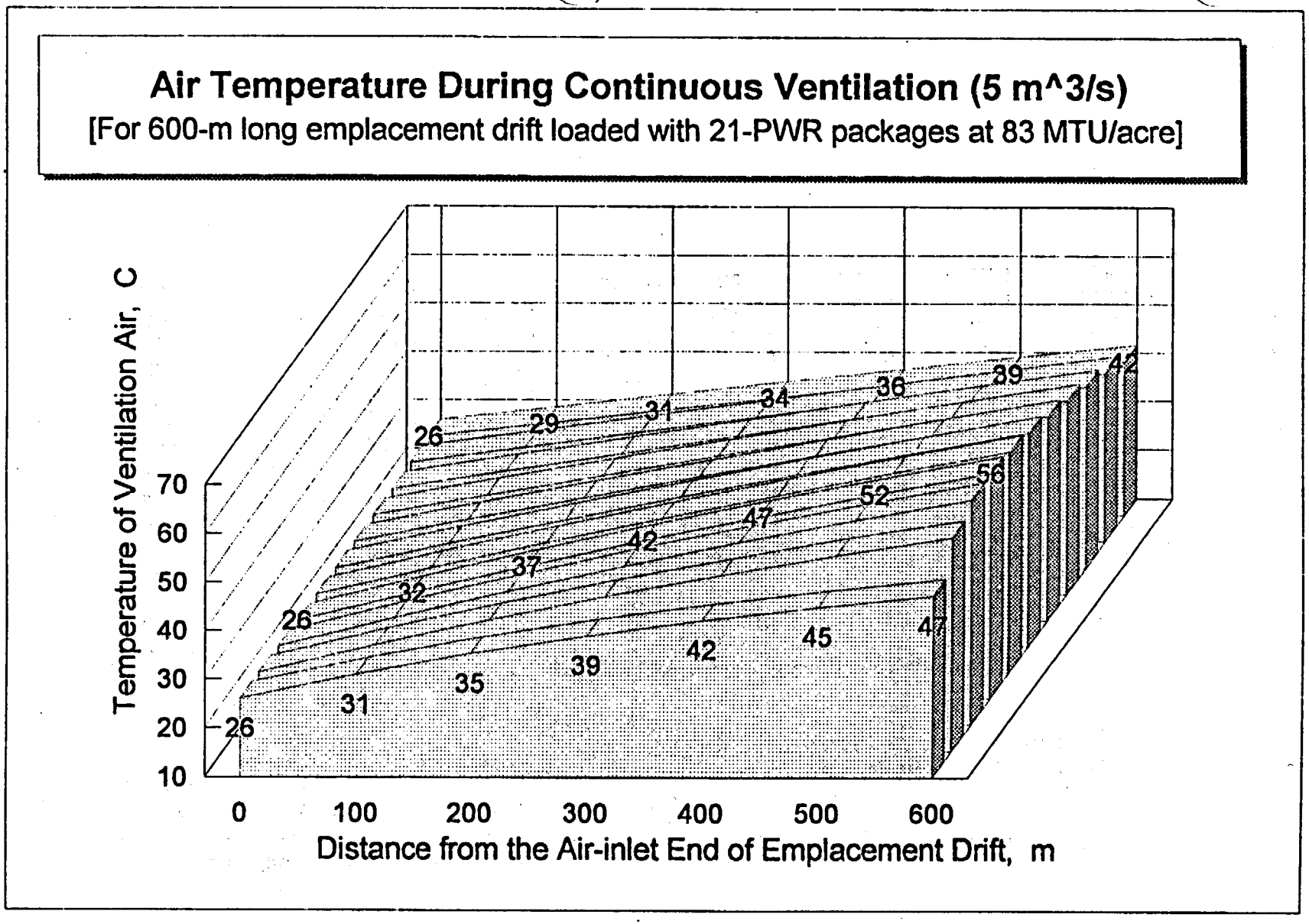

Figure E-13. Air Temperature During Continuous Ventilation (5 m^3/s)

5 m^3/s Continuous Emplacement Drift Ventilation

Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density=	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	30.96	35.25	38.96	42.17	44.95	47.34
4.0		26.00	31.73	36.88	41.72	46.15	50.20	53.90
8.5		26.00	31.87	37.39	42.58	47.45	52.02	56.30
14.0		26.00	31.68	37.11	42.29	47.23	51.92	56.39
19.5		26.00	31.37	36.55	41.53	46.33	50.93	55.36
26.5		26.00	30.99	35.85	40.55	45.11	49.53	53.81
34.5		26.00	30.57	35.04	39.40	43.65	47.80	51.83
44.0		26.00	30.14	34.20	38.18	42.09	45.93	49.68
56.5		26.00	29.66	33.28	36.85	40.42	43.87	47.28
73.0		26.00	29.16	32.30	35.41	38.48	41.53	44.54
100.0		26.00	28.64	31.26	33.87	36.46	39.04	41.60

Figure E-13. Air Temperature Duri[illegible]ntinuous Ventilation (5 m^3/s) (continued)

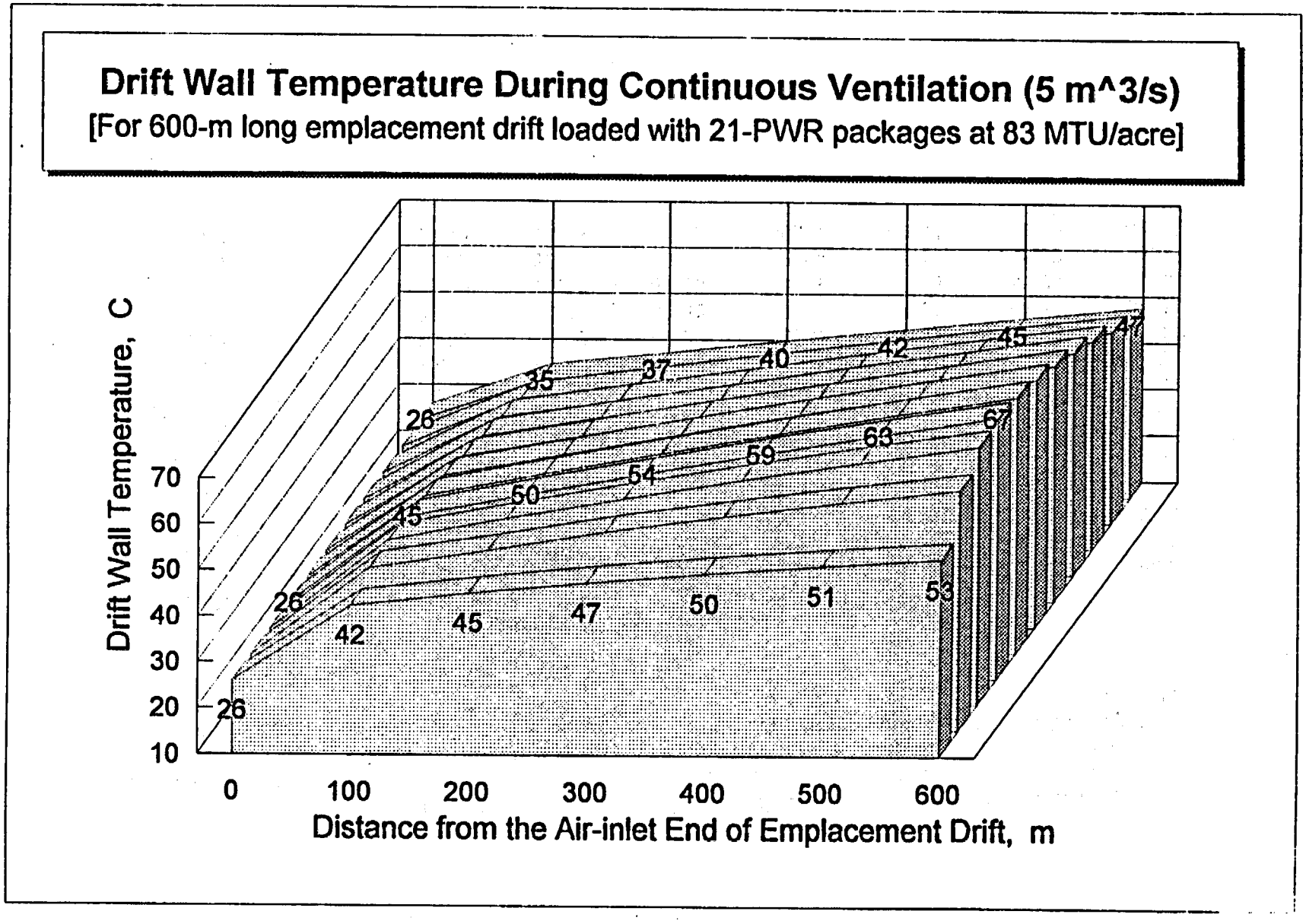

Figure E-14. Drift Wall Temperature During Continuous Ventilation (5 m^3/s)

5 m^3/s **Continuous Emplacement Drift Ventilation** Hang Yang & Yiming Sun

Tin =	(Varies)	D.S =	22.5 m	MTU/ac =	83
Drift L =	600 m	P.S. =	19.14 m	Drift Diam	5 m
Delta L =	100 m	Init. Heat =	258 kW/drift	Air density=	1.0393 kg/m^3
		or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	42.35	45.10	47.48	49.53	51.31	52.84
4.0		26.00	44.87	48.72	52.82	56.31	59.49	62.39
8.5		26.00	45.33	50.07	54.49	58.63	62.50	66.12
14.0		26.00	44.73	49.57	54.17	58.55	62.70	66.64
19.5		26.00	43.69	48.42	52.97	57.33	61.51	65.51
26.5		26.00	42.46	46.98	51.35	55.58	59.67	63.62
34.5		26.00	41.06	45.28	49.40	53.41	57.31	61.10
44.0		26.00	39.62	43.52	47.33	51.07	54.72	58.28
56.5		26.00	38.07	41.58	45.03	48.61	51.81	55.08
73.0		26.00	36.42	39.49	42.54	45.54	48.52	51.45
100.0		26.00	34.68	37.28	39.85	42.41	44.95	47.47

Figure E-14. Drift Wall Temperature D[illegible] Continuous Ventilation (5 m^3/s) (continued)

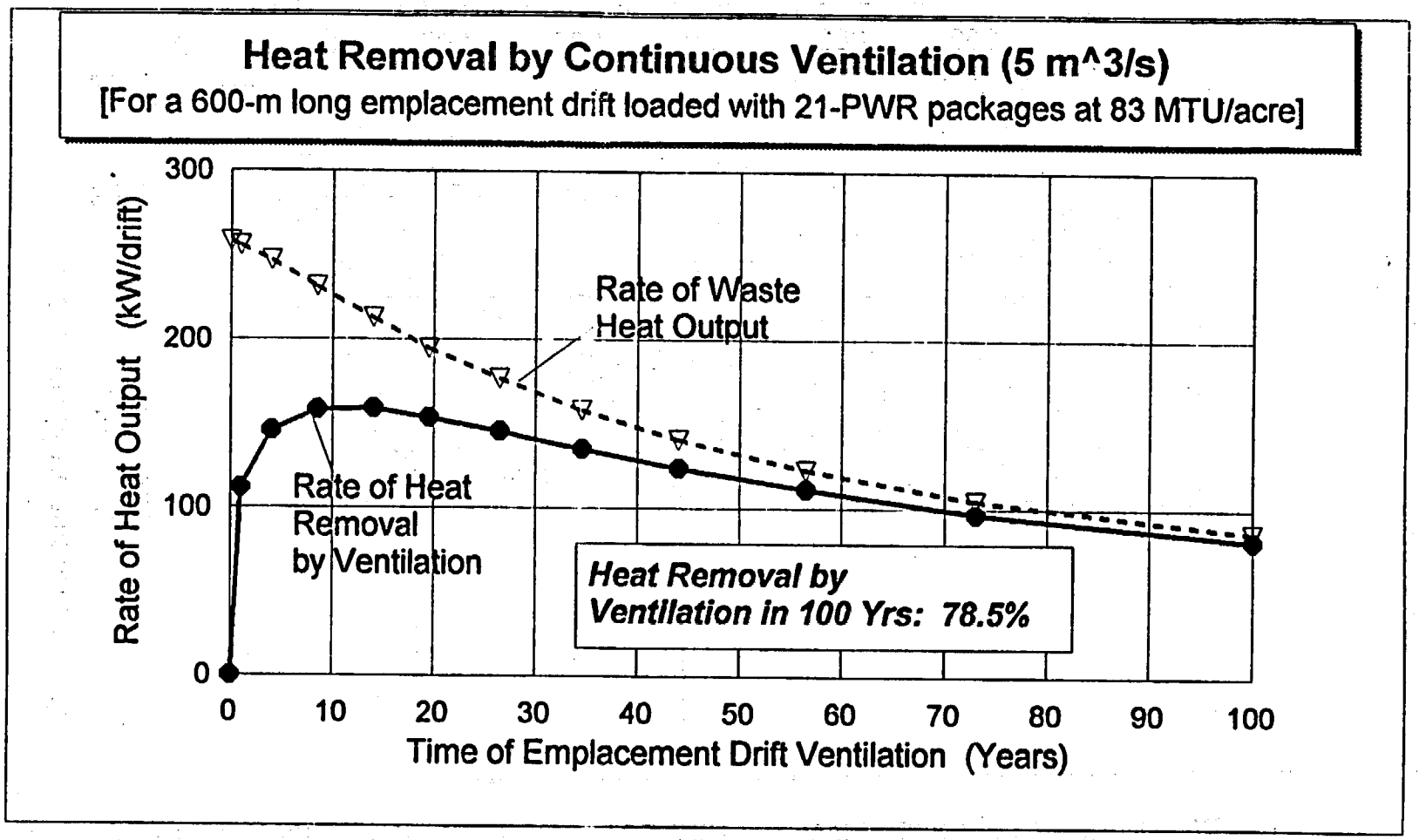

Figure E-15. Heat Removal by Continuous Ventilation (5 m^3/s)

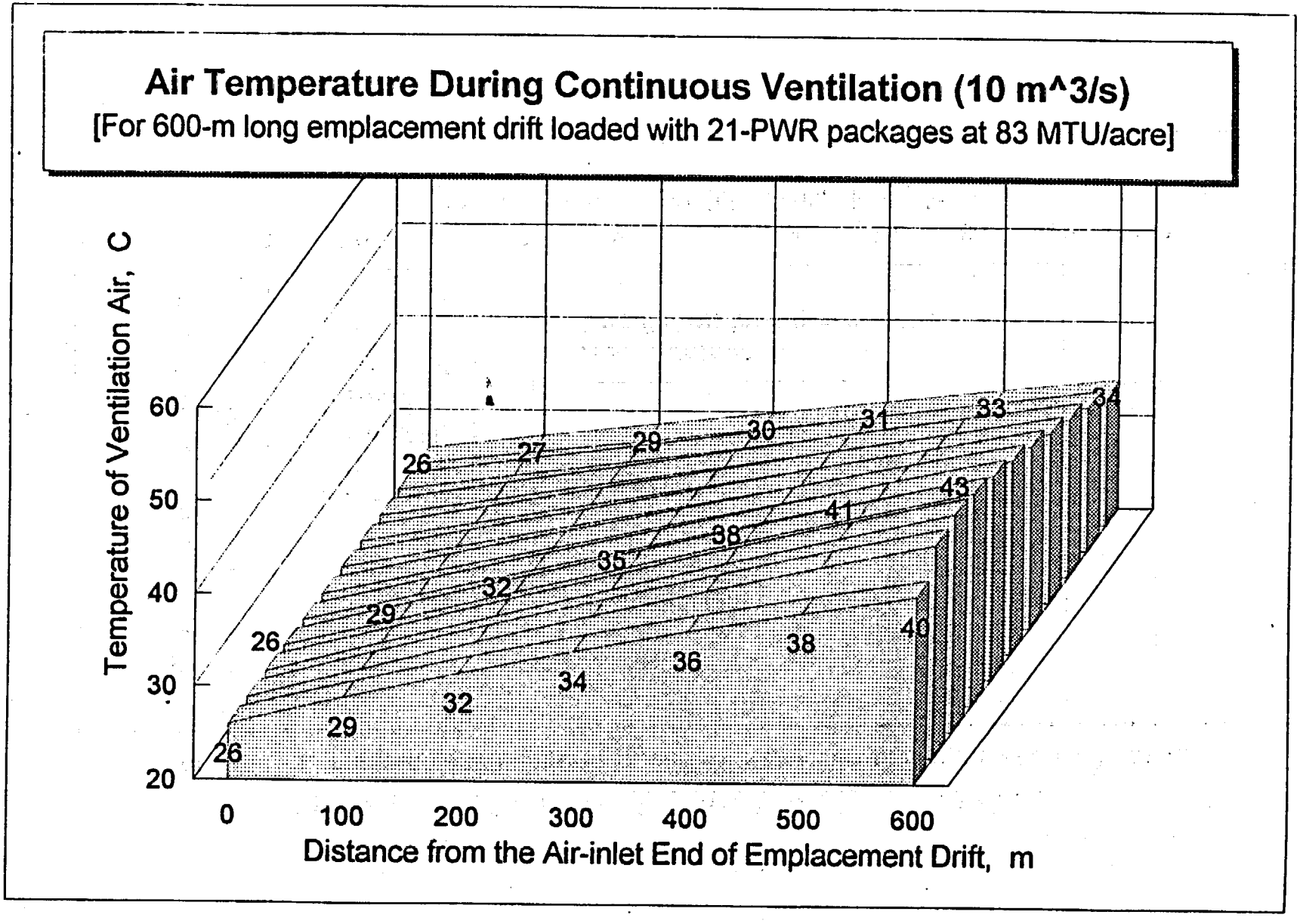

Figure E-16. Air Temperature During Continuous Ventilation (10 m^3/s)

10 m^3/s **Continuous Emplacement Drift Ventilation** Hang Yang & Yiming Sun

Tin =	(Varies)		D.S =	22.5	m	MTU/ac =	83
Drift L =	600	m	P.S. =	19.14	m	Drift Diam =	5 m
Delta L =	100	m	Init. Heat =	258	kW/drift	Air density=	1.0393 kg/m^3
			or	43	kW/100m	Air Cp =	1.007 kJ/kg K

Air Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	28.88	31.53	33.96	36.19	38.24	40.12
4.0		26.00	29.15	32.15	35.03	37.78	40.40	42.90
8.5		26.00	29.13	32.16	35.10	37.95	40.71	43.39
14.0		26.00	28.97	31.88	34.72	37.50	40.21	42.86
19.5		26.00	28.77	31.50	34.18	36.81	39.39	41.93
26.5		26.00	28.56	31.08	33.57	36.02	38.44	40.82
34.5		26.00	28.32	30.62	32.89	35.13	37.36	39.55
44.0		26.00	28.09	30.15	32.21	34.24	36.08	38.13
56.5		26.00	27.84	29.66	31.48	33.29	35.08	36.86
73.0		26.00	27.58	29.15	30.71	32.27	33.83	35.37
100.0		26.00	27.31	28.61	29.91	31.22	32.51	33.81

Figure E-16. Air Temperature During Continuous Ventilation (10 m^3/s) (continued)

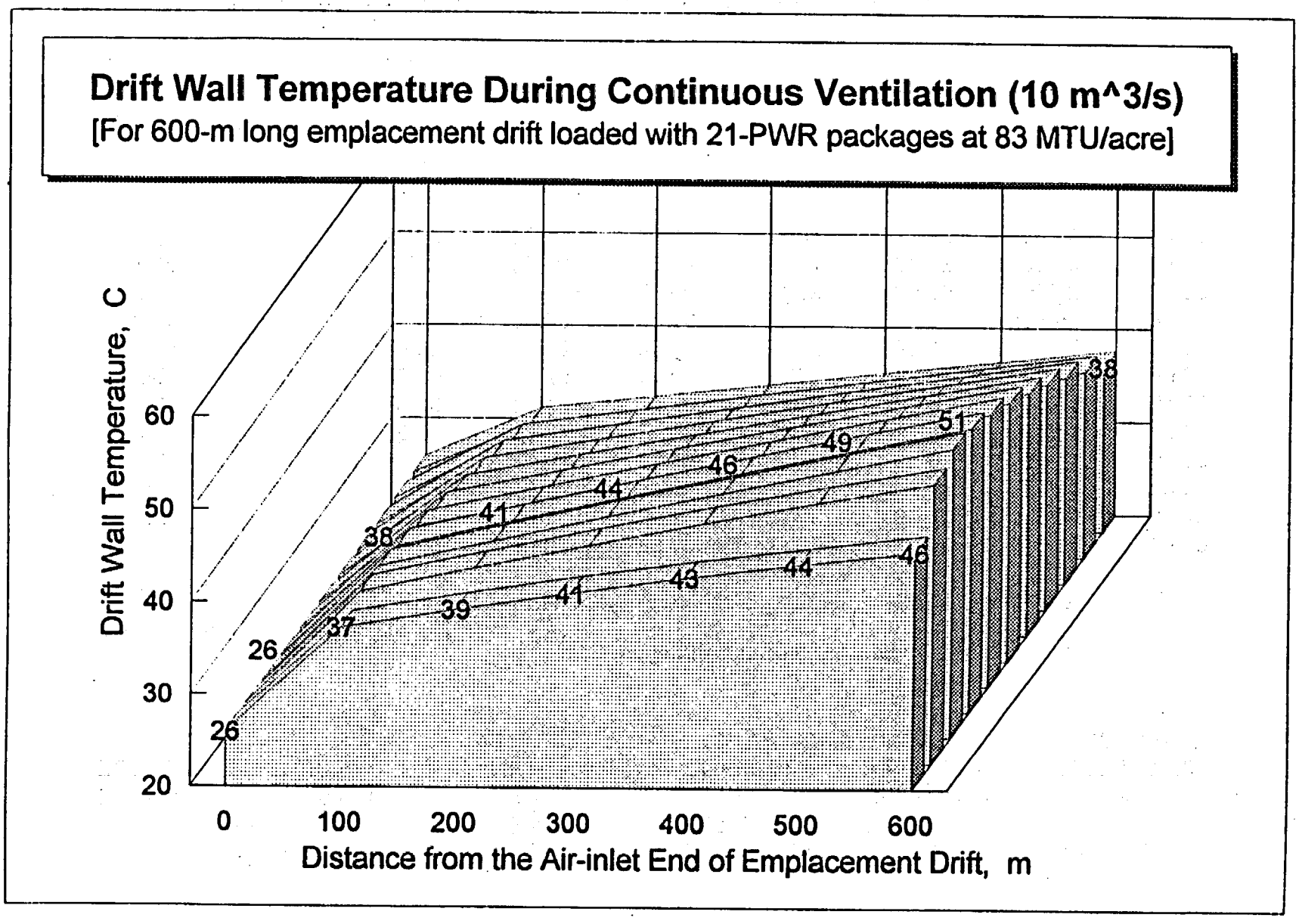

Figure E-17. Drift Wall Temperature During Continuous Ventilation (10 m^3/s)

Continuous Emplacement Drift Ventilation

Hang Yang & Yiming Sun

	10 m^3/s	D.S =	22.5 m	MTU/ac =	83
Tin =	(Varies)	P.S. =	19.14 m	Drift Diam	5 m
Drift L =	600 m	Init. Heat =	258 kW/drift	Air density	1.0393 kg/m^3
Delta L =	100 m	or	43 kW/100m	Air Cp =	1.007 kJ/kg K

Drift Wall Temperatures in Emplacement Drift, C

Vent Time (Yr)	*DRIFT L, m ->*	*0*	*100*	*200*	*300*	*400*	*500*	*600*
0.0		26.00	26.00	26.00	26.00	26.00	26.00	26.00
1.0		26.00	37.35	39.30	41.10	42.74	44.26	45.65
4.0		26.00	38.39	40.99	43.48	45.84	48.09	50.24
8.5		26.00	38.31	41.07	43.74	46.32	48.82	51.24
14.0		26.00	37.70	40.42	43.07	45.65	48.18	50.64
19.5		26.00	36.93	39.51	42.05	44.54	46.98	49.37
26.5		26.00	36.07	38.49	40.87	43.22	45.54	47.81
34.5		26.00	35.13	37.36	39.56	41.74	43.88	46.01
44.0		26.00	34.21	36.23	38.24	40.22	42.19	44.14
56.5		26.00	33.23	35.03	36.82	38.59	40.35	42.10
73.0		26.00	32.20	33.76	35.31	36.85	38.39	39.92
100.0		26.00	31.15	32.45	33.74	35.03	36.32	37.61

Figure E-17. Drift Wall Temperature During Continuous Ventilation (10 m^3/s) (continued)

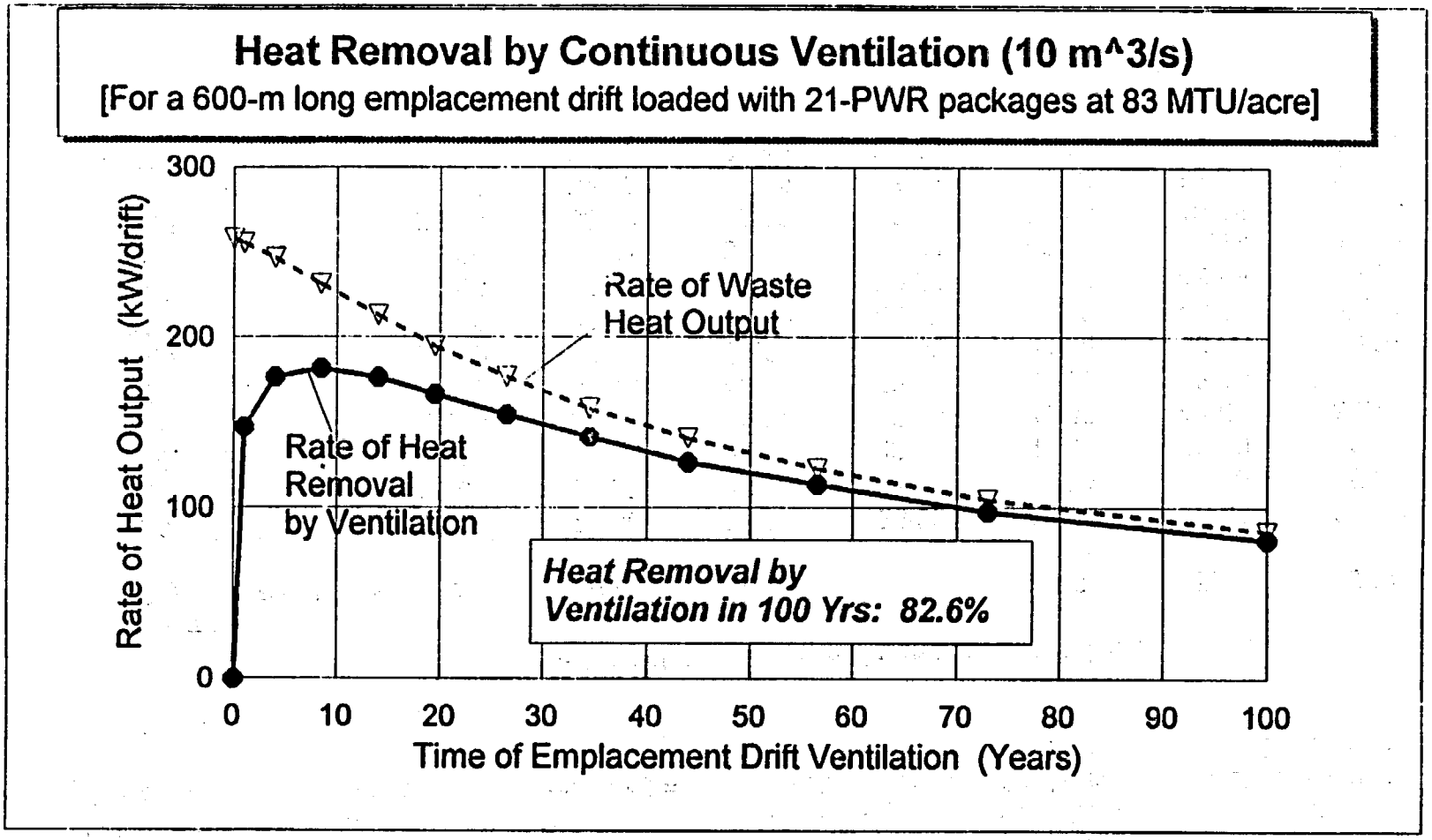

Figure E-18. Heat Remov[illegible] Continuous Ventilation (10 m^3/s)

APPENDIX F

THERMAL MANAGEMENT USING AGING AND/OR WASTE PACKAGE SELECTION

FIGURES

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F-2. Thermal Loading Study Cases F-8
F-3. Surface Repository Life Cycle Cost F-10
F-4. Surface Repository Cost Delta to Base F-11

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THERMAL MANAGEMENT USING AGING AND/OR WASTE PACKAGE SELECTION

General Discussion

The following discussion describes the anticipated operation of the Mined Geologic Disposal System (MGDS) Surface Facilities and discusses the impacts that will occur as a result of employing various schemes that might be used to accommodate the optimization of thermal loading of the high-level waste as it is placed in the repository. The first section, details the operation of the Surface Facilities as given in the Advanced Conceptual Design (ACD). This operational concept serves as the baseline for evaluating various scenarios which allow flexibility in the selection of wastes based upon their heat content.

In the following section, the scenarios are described individually. These scenarios include the possibility of the presence of an Interim Storage Facility (ISF) which can be used as a reservoir for the selection of wastes based upon thermal loading considerations.

Assumptions

A number of assumptions were made in order to conduct this supporting study. These assumptions were made in lieu of available information and in the most part were based upon judgment.

A. No ISF cost are included. It is assumed that the cost associated with the design, construction, and operation of the ISF are totally separate and out of the scope of this effort.

B. All waste that is stored in the ISF are in Dual Purpose Canisters (DPCs).

C. The size and area of the increased space in the Waste Handling Building (WHB) that is needed for storing and handling the additional waste are based upon storing and handling the contents of five canisters which contain either 21 PWR assemblies or 40 BWR assemblies.

D. A "Calorimeter" cell was added to the WHB to permit the measurement of the thermal output of the waste forms. An area of 225 square feet was added. This size is a convenient size for a hot cell considering viewing and manipulator coverage and the dimensions of the various waste forms that could be measured.

E. The ISF is in reasonable proximity to the repository. It was assumed in several of the cases that canisters could be taken from the ISF and exchanged with others at the ISF. Long distance and/or long term travel was not considered in the study.

Surface Facility Description and Operation

The facility operations discussed below are graphically represented in Figure F-1.

Transportation casks loaded with spent nuclear fuel are delivered to the Surface Facilities on railcars or legal weight trucks. A loaded transportation cask carrier and its off-site prime mover are externally inspected for contraband and sabotage at the repository security boundary. The cask carrier is then transferred by the off-site prime mover to either the truck or rail parking area within the Radiological Controlled Area (RCA). The off-site prime mover leaves the transportation cask carrier and exits the RCA. At the parking area, the off-site prime mover may pick up a cask carrier awaiting off-site shipment. Upon receipt at the parking area, the cask and carrier will be inspected for radiological contamination.

A loaded transportation cask carrier is picked up from the parking area and delivered to the Cask Staging Shed (CSS) by the site prime mover to prepare for cask removal. Here the personnel barrier is retracted or removed, the impact limiter are separated from the cask, and the cask is reinspected for radiological surface contamination. Minor decontamination is performed as required. More substantial decontamination is done in the Cask Maintenance Facility (CMF) which is located adjacent to the WHB.

The prepared transportation cask and carrier remain in the CSS until the WHB is available for removal of the cask from the carrier. The personnel barriers and impact limiters are later reinstalled on the clean empty cask, returning form the WHB, in preparation for off-site shipment.

The site prime mover transfers the cask carrier to the WHB. IN this building the casks are removed from the carrier, waste materials are transferred from the casks to disposal containers, filler material may be added to selected spent fuel assembly (SFA) canisters, and the disposal containers are welded closed and delivered for underground transportation. These operations are described below.

A. *Cask Receiving and Preparation* - A transportation cask is unloaded from a truck or rail carrier and placed on a railcar in a vertical position using a bridge crane.

   A loaded cask requiring external decontamination or an empty cask requiring maintenance (i.e., recertification, repair or reconfiguration) is transferred on the cart to CMF. After decontamination or maintenance, the cask is returned to the WHB. If the returned cask is empty, it is loaded back on a carrier and removed from the WHB by the site prime mover.

   Loaded transportation casks are prepared for unloading, which include operations such as cleaning the top of the cask, checking the pressure of the cask cavity, analyzing the cavity gas for contamination, and introducing a small negative pressure into the cask cavity. Following cask preparation, the loaded transportation cask is unloaded as described below in paragraph B. And D.

B. *Canistered Waste Transfer* - A loaded rail transportation cask is moved on a cart to a shielded area where the lid is removed. The cask is then positioned under a cell port and the port plug is removed from above with a crane. The canister is lifted from the open cask, through the cask port, and into a hot cell. In the hot cell, the crane places the canister directly into a Disposal Container (DC). The port plug is reinstalled. Following removal of the canister, the empty transportation cask is moved to where the lid is reinstalled and

the cask is decontaminated, as necessary. The clean, empty cask is then transferred to where cask preparation and shipping operations are performed.

C. *Disposal Container Welding and Transfer* - In a hot cell, a crane moves a DC to an automated welding station, where the DC lids are installed and the welds are inspected. The closed DC (or waste package) is next moved to a device that places the container in a horizontal position. The horizontal DC, moved with a gantry, is decontaminated and placed on a subsurface waste package transporter, which is now ready to be taken underground for emplacement. A lag storage area is provided for inprocess staging of DCs before or after welding.

D. *Uncanistered Waste Transfer* - After preparation, a truck transportation cask is moved on a cart to a shielded area where the lid is removed. The case is then positioned under a cell port, the port plug is removed from above the crane, and a contamination control barrier is installed. Bare SFAs are lifted, one at a time, from the open truck cask, through the cask port and into a hot cell. In the cell, the crane place each SFA into a staging rack. When cask is empty, the contamination control barrier is decontaminated and removed, and the port plug is reinstalled. The empty transportation cask is moved to where the lid is reinstalled, and the cask is decontaminated as necessary. The clean empty cask is then transferred to where cask preparation and shipping operation are performed.

When enough SFAs have collected in the SFA staging rack to fill a DC, a DC is positioned under a transfer port. Each SFA is then lowered by crane from the SFA staging rack down through the port and into the DC. The loaded DC is moved to an area where an inner lid is seal welded in place by a laser. The sealed DC is transferred by cart to the DC welding area.

E. *Canister Filler Addition* - The addition of filler material may be required for approximately 117 SFA canisters as a moderator displacement technique to ensure long-term criticality control. This operation is performed by cutting the canister lid off, filling the voids between SFAs with carbon steel shot, and welding the canister lid back on. The operations are conducted remotely in a hot cell, and the cutting and welding are performed with a laser.

F. *Cask Preparation and Shipping* - The empty cash is transferred by cart to a preparation area after the waste has been removed. The cask arrives closed and decontaminated. Cask preparation includes visual inspections, cask closure inspections, health physics inspections, and, if necessary, purging of the cask cavity with an inert gas. These operations are safely conducted by direct contact because the casks do not contain waste materials. If the cask requires maintenance (i.e., recertification, repair, or reconfiguration), it is transferred to the CMF on a cart. Following cask maintenance, the cask is returned to the WHB. The clean empty transportation cask is lifted from the cart and loaded on a truck or rail carrier. The cash and carrier are transferred to the CSS by the site prime mover.

G. *Waste Package Underground Transfer* - The transport locomotive attaches to the loaded transporter at the WHB loading dock. The DC is loaded into the shielded part of the underground transporter in a horizontal position.

Scenario Descriptions and Discussions

The scenarios which follow describe various options that could be available to use for optimizing thermal loading strategies. They do not necessarily represent current planning; however, they all are considered feasible and could be incorporated into the designs if the benefits and costs associated with them justify their consideration. Several terminologies have been used which need explanation. *Fine Blending* means that individual assemblies are selected based on their thermal characteristics. *Coarse Blending* means that entire canisters, such as DPCs, have been selected. *Lag Storage* is storage of canisters and/or carriages containing canisters in a designated area adjacent to the WHB and acts as a "surge" point for incoming shipments. *Interim Storage* is a large area located somewhere reasonably near to the MGDS which is or can be used to store canisters for periods of time up to 100 years. This storage could be available in 2003 or 7 years prior to the startup of the MGDS Surface Facilities. The following scenarios are presented graphically in Figure F-2.

Scenario 1 - Scenario 1 is the base case and represents essentially the ACD design as described in the previous section. This scenario receives that waste as it is delivered from the utilities and processes it through the operations with no effort being made to consider thermal load concerns. The waste (high level waste and other defense waste have not been considered in this evaluation) will come in three forms. First, there will be waste arriving in canisters that can be placed directly into disposal containers. Second, there will be waste that arrives in dual purpose canisters which must be removed and repackaged into the disposal containers. Third, there will be waste arriving in standard shipping casks from which the waste will be removed and transferred into the disposal containers.

Scenario 2 - This scenario is identical to scenario 1 with the difference that Lag Storage is provided from which waste can be selected for its thermal properties. Four sizes of Lag Storage have been considered which are:

600 DPC capacity requiring 5 acres of storage area
1,200 DPC capacity requiring 10 acres of storage area
3,000 DPC capacity requiring 25 acres of storage area
4,200 DPC capacity requiring 35 acres of storage area

The impacts of this scenario are the costs associated with constructing, operating, and maintaining the lag storage yard.

Scenario 3 - This scenario assumes that an ISF, which is located in reasonable proximity to the repository, is constructed and has been in operation starting in 2003. Repository operation starts up on schedule in 2010 and handles and emplaces only the waste that it receives from the transportation system. In the last years of the repository operation, the waste that has been stored in the ISF is transferred to the WHB and processed. With this scenario, Youngest Fuel First (YFF) could be received at the ISF and allowed to age while the repository is in the first 17 years of operation. There

is no identified cost or operational impact to the repository as compared to the baseline case, scenario 1.

Scenario 4 - This case assumes that an ISF begins operation in 2003 and the repository begins its handling and emplacement activities in 2010. All waste shipped to the ISF arrives in DPCs. The waste that is shipped to the repository arrives as either bare fuel or in DPCs.

Two subcases were considered:

Case A - The repository operation has the option of selecting DPCs from the ISF based on their thermal load. There is no fine blending.

Case B - This case is the same as Case A except that fine blending of up to five DPCs (105 PWRs or 220 BWRs) is allowed in the WHB.

Impacts are that additional space must be available in the WHB for inside storage in order to permit fine blending. A space of 20 feet by 30 feet or 600 square feet must be added to the WHB cost.

Scenario 5 - This case has an ISF and is the same as Case 4a except that incoming bare fuel that is received at the repository after 2010 will be placed into DPCs. The DPCs will then be sent to the ISF (if it has a higher than acceptable thermal content). These DPCs will later be returned to the WHB toward the end of the repository operational period after they have had a chance to cool.

There is no identified cost or operation impact from this scenario with respect to the baseline case.

Scenario 6 - This case allows for fine blending in the WHB for all fuel assemblies that are received at the repository after it initiates operation in 2010. It assumes that an ISF is available which began operation in 2003 and which can act as the reservoir from which DPCs can be selected. This scenario assumes that Oldest Fuel First (OFF) is received at the repository. In this case, it will be necessary to measure the heat output of the waste forms in order to be able to know how to repackage the waste for thermal optimization.

The impacts to the repository are as follows:

- A 600 square foot storage cell is added to the WHB
- A fuel calorimetry cell of 225 square feet is added to the WHB. The operation of this cell will require 4 operators.

Scenario 7 - This is the same as the baseline Case 1 except that the YFF waste stream will be used for selection. This case offers little advantage for thermal optimization and has no identified impact as compared with the baseline case.

Scenario 8 - This is the same as Case 4a except that the DPCs that were received at the ISF are assumed to be YFF.

Scenario 9 - This is the same as Case 3 except that YFF which was received at the ISF is used for processing in the WHB in preparation for emplacement.

Scenario 10 - This is the same as Case 6 except that YFF is used for selection. Fine blending occurs in the WHB in such a way that high temperature DPCs are opened and their contents are mixed with assemblies of lower heat output to achieve DCs which have a more evenly balanced thermal output. This case will require fine blending and a measurement capability within the WHB as in Case 6.

The cost impacts that result from these different scenarios are summarized in Table F-1. The actual cost information to include surface life cycle costs and the cost differences for each scenario are depicted in Figures F-3 and F-4 respectively. All of the detailed cost information is attached for the interested reader in spreadsheet tables.

Table F-1. Cost Impacts as a Function of Scenario

Scenarios	Impacts on Costs Due to Scenario
1	This is the Base Case - No Impact
2	Lag Storage of 5, 10, 25, & 35 Acres; Construction, Operations, & Maintenance
3	No Impact
4a	Assumes that the labor force will be increased by 6 prime mover operators
4b	Add Internal Storage/Handling area of 600 ft^2
5	Assumes that the labor force will be increased by 6 prime mover operators
6	Add Internal Storage/Handling area of 600 ft^2 Add Calorimetry Cell area of 225 ft^2
7	No Impact
8	Assumes that the labor force will be increased by 6 prime mover operators
9	No Impact
10	Add Internal Storage/Handling area of 600 ft^2 Add Calorimetry Cell area of 225 ft^2

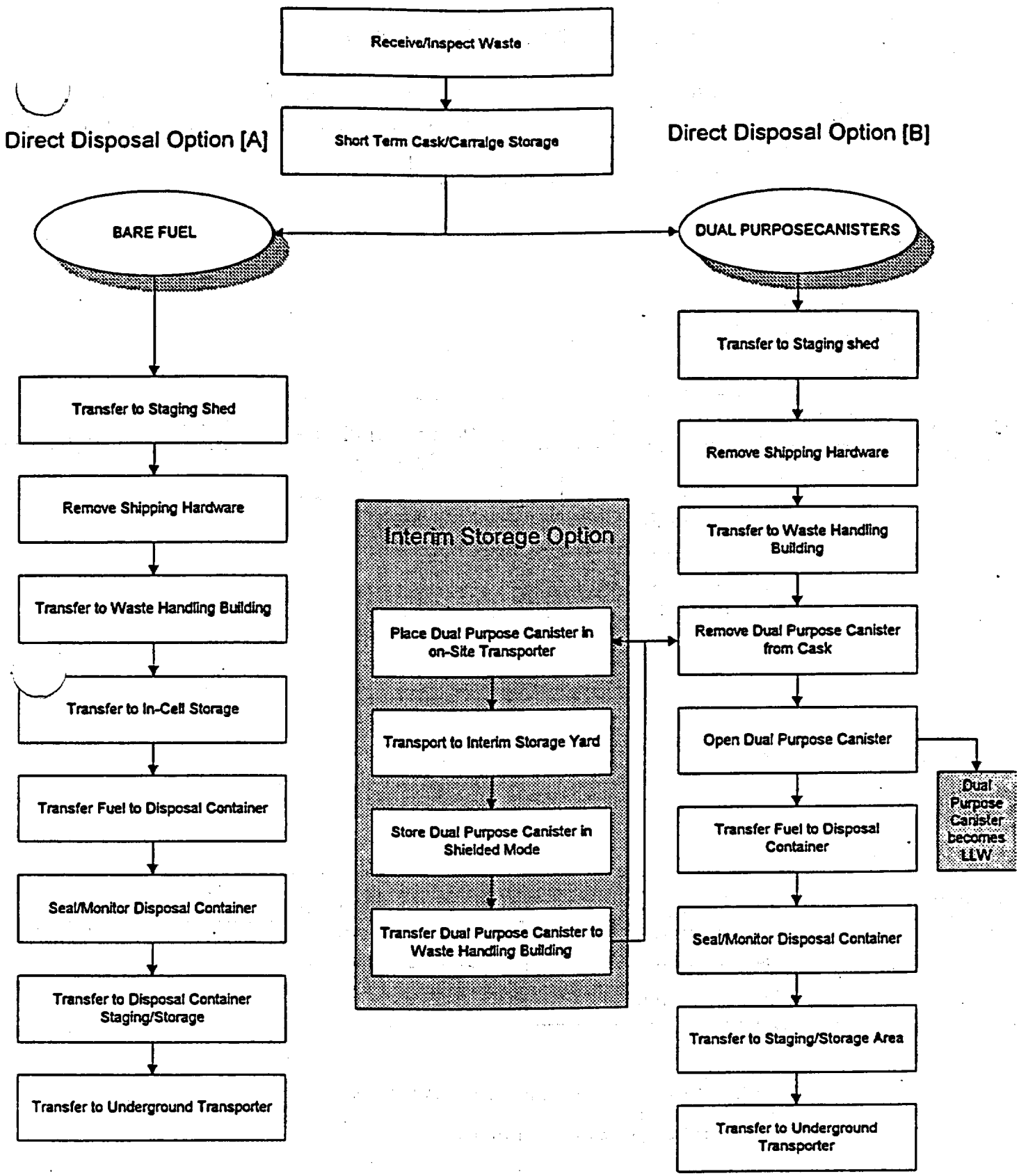
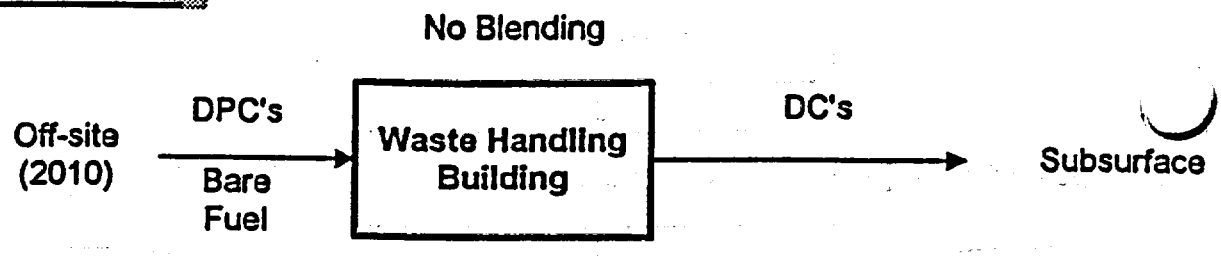
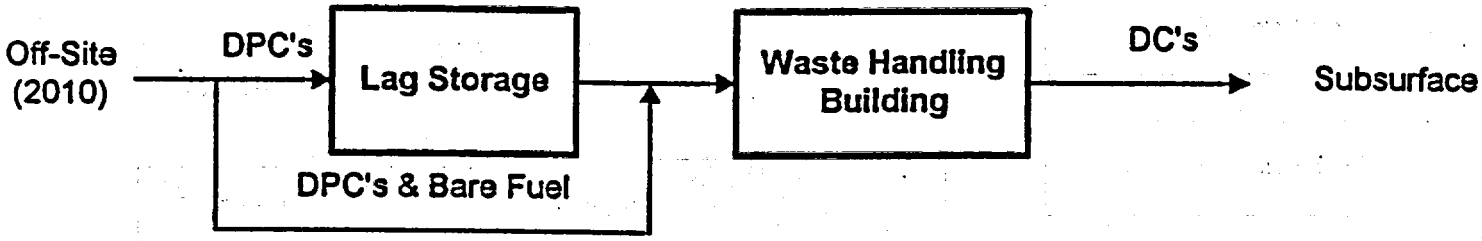


Figure F-1. Surface Facilities Handling Options for Bare Fuel and DPC Operations

Case 1 - No ISF

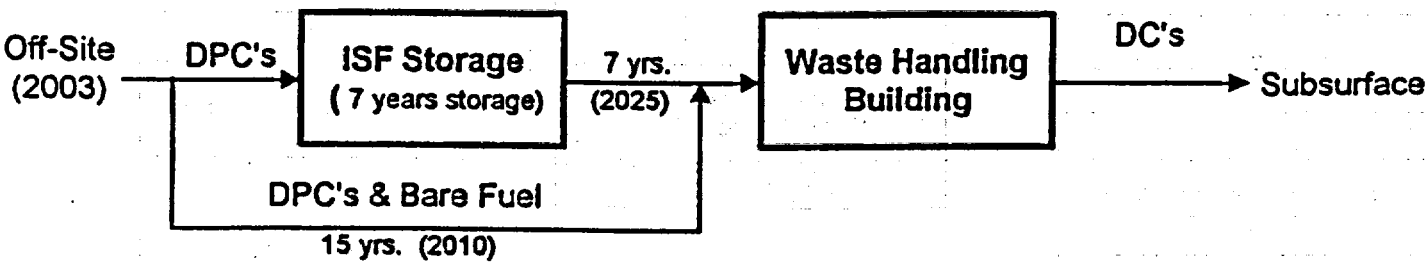


Case 2 - No ISF



Features:
Optional Canister Selection from 1 - 7 Years of Waste Receipts
Store in Transport Casks or on Concrete Pad

Case 3 - ISF

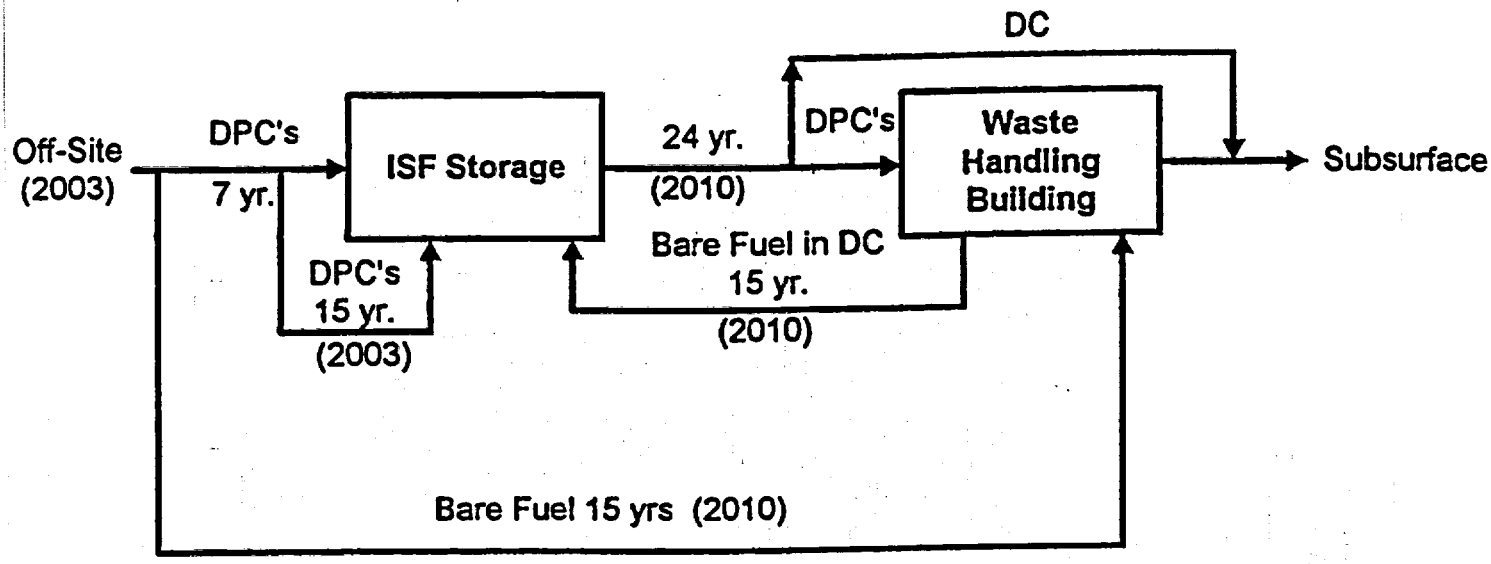


Features:
Optional Canister Selection from 1 - 7 Years Waste Receipts
ISF Stores on Concrete Pad
7 Years of Storage Available for selection

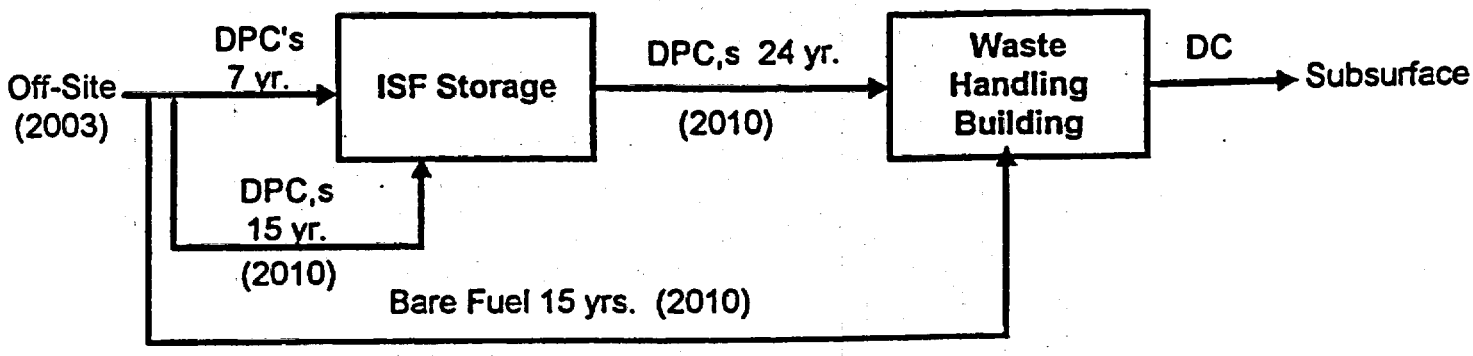
Figure F-2. Thermal Loading Study Cases

Cases 4 & 5

ISF With Bare Fuel in Storage



Without Bare Fuel in Lag Storage



Features:

Case 4 has no Fine blending
Case 5 has Fine Blending Options

Figure F-2. Thermal Loading Study Cases (continued)

Figure F-3. Surface Repository Life Cycle Cost

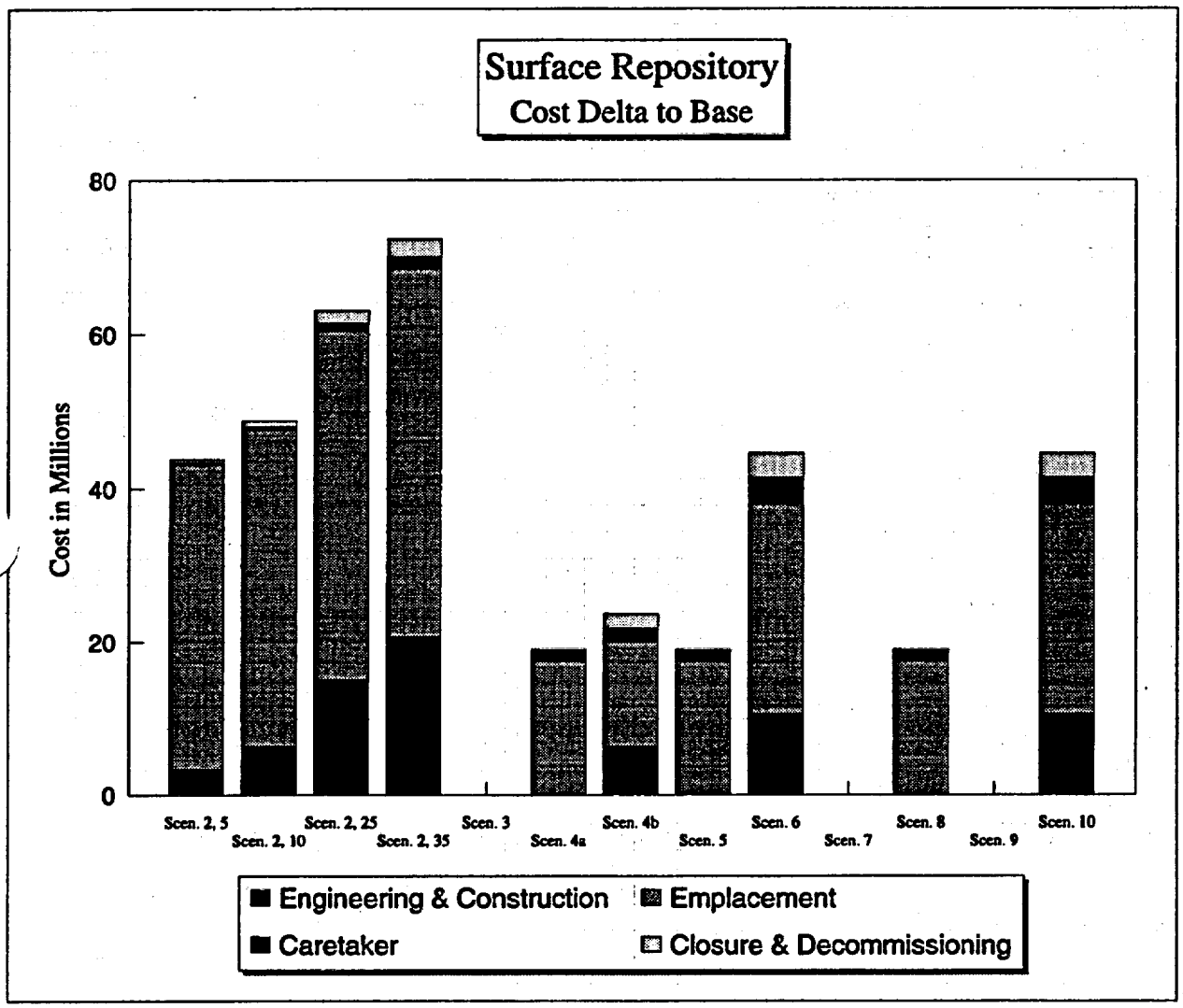


Figure F-4. Surface Repository Cost Delta to Base

Account	-Scenario 1, Base Case- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	42,638,000	28,437,000	983,000	76,195,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,230,000	33,017,000	6,821,000	178,670,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,168,485,000	160,402,000	96,100,000	1,714,498,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*690,256,000*	*111,913,000*	*74,690,000*	*1,111,703,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	-Scenario 1, Base Case- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	**BALANCE OF PLANT**	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hanc					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	**SURFACE SHAFT FACILITIES**	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,894,506,000	517,910,000	124,714,000	2,989,812,000
	TOTAL	686,355,000	1,975,736,000	550,927,000	131,535,000	3,344,553,000

Account	- -Scenario 2, 5 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,135,000				38,135,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,981,000				88,981,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,556,000				49,556,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,672,000				176,672,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,181,000	43,748,000	28,437,000	991,000	77,357,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,646,000	82,340,000	33,017,000	6,829,000	179,832,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,205,659,000	160,402,000	96,100,000	1,751,672,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*727,430,000*	*111,913,000*	*74,690,000*	*1,148,877,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	151,160,000	22,472,000	4,986,000	190,559,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	171,785,000	16,980,000	6,899,000	213,005,000
21504	Support Facilities	52,344,000	323,719,000	66,660,000	7,825,000	450,548,000

Account	- -Scenario 2, 5 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	99,766,000	727,565,000	357,762,000	13,571,000	1,198,664,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage	2,721,000	1,544,000	254,000	359,000	4,878,000
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	455,403,000	1,933,224,000	518,164,000	125,073,000	3,031,864,000
	TOTAL	689,721,000	2,015,564,000	551,181,000	131,902,000	3,388,368,000

Delta Only

Account	- -Scenario 2, 5 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	100,000				100,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	232,000				232,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	269,000				269,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO(					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	601,000				601,000
12040						
12050	EMPLOYEE TRANSPORTATION	44,000	1,110,000		8,000	1,162,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	44,000	1,110,000		8,000	1,162,000
21105						
21106	WASTE HANDLING FACILITY		37,174,000			37,174,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*37,174,000*			*37,174,000*
21300	Building/Structures					
21500	Hot Cell		12,692,000			12,692,000
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		17,889,000			17,889,000
21504	Support Facilities		6,593,000			6,593,000

Delta Only

Account	--Scenario 2, 5 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	2,721,000	1,544,000	254,000	359,000	4,878,000
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage	2,721,000	1,544,000	254,000	359,000	4,878,000
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	2,721,000	38,718,000	254,000	359,000	42,052,000
	TOTAL	3,366,000	39,828,000	254,000	367,000	43,815,000

Account	- -Scenario 2, 10 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,226,000				38,226,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	89,193,000				89,193,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,800,000				49,800,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	177,219,000				177,219,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,225,000	43,748,000	28,437,000	999,000	77,409,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,690,000	82,340,000	33,017,000	6,837,000	179,884,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,205,659,000	160,402,000	96,100,000	1,751,672,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*727,430,000*	*111,913,000*	*74,690,000*	*1,148,877,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	151,160,000	22,472,000	4,986,000	190,559,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	171,785,000	16,980,000	6,899,000	213,005,000
21504	Support Facilities	52,344,000	323,719,000	66,660,000	7,825,000	450,548,000
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					

Account	--Scenario 2, 10 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
22060	BALANCE OF PLANT	102,241,000	728,969,000	357,993,000	13,897,000	1,203,100,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,623,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage	5,196,000	2,948,000	485,000	685,000	9,314,000
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	457,878,000	1,934,628,000	618,395,000	125,399,000	3,036,300,000
	TOTAL	692,787,000	2,016,868,000	551,412,000	132,236,000	3,393,403,000

Delta Only

Account	- -Scenario 2, 10 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	191,000				191,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	444,000				444,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	513,000				513,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO(					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	1,148,000				1,148,000
12040						
12050	EMPLOYEE TRANSPORTATION	88,000	1,110,000		16,000	1,214,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	88,000	1,110,000		16,000	1,214,000
21105						
21106	WASTE HANDLING FACILITY		37,174,000			37,174,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*37,174,000*			*37,174,000*
21300	Building/Structures					
21500	Hot Cell		12,692,000			12,692,000
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		17,889,000			17,889,000
21504	Support Facilities		6,593,000			6,593,000

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ccount	- -Scenario 2, 10 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	5,196,000	2,948,000	485,000	685,000	9,314,000
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage	5,196,000	2,948,000	485,000	685,000	9,314,000
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	5,196,000	40,122,000	485,000	685,000	46,488,000
	TOTAL	6,432,000	41,232,000	485,000	701,000	48,850,000

Account	- -Scenario 2, 25 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,484,000				38,484,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	89,795,000				89,795,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	50,493,000				50,493,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	178,772,000				178,772,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,338,000	43,748,000	28,437,000	1,020,000	77,543,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,528,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,803,000	82,340,000	33,017,000	8,858,000	180,018,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,205,659,000	160,402,000	96,100,000	1,751,672,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*727,430,000*	*111,913,000*	*74,690,000*	*1,148,877,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	151,160,000	22,472,000	4,986,000	190,559,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	171,785,000	18,980,000	6,899,000	213,005,000
21504	Support Facilities	52,344,000	323,719,000	68,660,000	7,825,000	450,548,000

Account	--Scenario 2, 25 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	109,272,000	732,957,000	358,648,000	14,824,000	1,215,701,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage	12,227,000	6,936,000	1,140,000	1,612,000	21,915,000
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	464,909,000	1,938,616,000	519,050,000	126,326,000	3,048,901,000
	TOTAL	701,484,000	2,020,956,000	552,067,000	133,184,000	3,407,691,000

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Account	- -Scenario 2, 25 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	449,000				449,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	1,046,000				1,046,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	1,206,000				1,206,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	2,701,000				2,701,000
12040						
12050	EMPLOYEE TRANSPORTATION	201,000	1,110,000		37,000	1,348,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	201,000	1,110,000		37,000	1,348,000
21105						
21106	WASTE HANDLING FACILITY		37,174,000			37,174,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*37,174,000*			*37,174,000*
21300	Building/Structures					
21500	Hot Cell		12,692,000			12,692,000
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		17,889,000			17,889,000
21504	Support Facilities		6,593,000			6,593,000

Delta Only

Account	--Scenario 2, 25 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	12,227,000	6,936,000	1,140,000	1,612,000	21,915,000
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage	12,227,000	6,936,000	1,140,000	1,612,000	21,915,000
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	12,227,000	44,110,000	1,140,000	1,612,000	59,089,000
	TOTAL	15,129,000	45,220,000	1,140,000	1,649,000	63,138,000

Account	- -Scenario 2, 35 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,649,000				38,649,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	90,182,000				90,182,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	50,938,000				50,938,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	179,769,000				179,769,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,417,000	43,748,000	28,437,000	1,034,000	77,636,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,882,000	82,340,000	33,017,000	6,872,000	180,111,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,205,659,000	160,402,000	96,100,000	1,751,672,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*727,430,000*	*111,913,000*	*74,690,000*	*1,148,877,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	151,160,000	22,472,000	4,986,000	190,559,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	171,785,000	16,980,000	6,899,000	213,005,000
21504	Support Facilities	52,344,000	323,719,000	66,660,000	7,825,000	450,548,000

Account	--Scenario 2, 35 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	113,788,000	735,518,000	359,069,000	15,419,000	1,223,794,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,623,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage	16,743,000	9,497,000	1,561,000	2,207,000	30,008,000
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	469,425,000	1,941,177,000	519,471,000	126,921,000	3,056,994,000
	TOTAL	707,076,000	2,023,517,000	552,488,000	133,793,000	3,416,874,000

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Account	- -Scenario 2, 35 Acres- - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	614,000				614,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	1,433,000				1,433,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	1,651,000				1,651,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	3,698,000				3,698,000
12040						
12050	EMPLOYEE TRANSPORTATION	280,000	1,110,000		51,000	1,441,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	280,000	1,110,000		51,000	1,441,000
21105						
21106	WASTE HANDLING FACILITY		37,174,000			37,174,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*37,174,000*			*37,174,000*
21300	Building/Structures					
21500	Hot Cell		12,692,000			12,692,000
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		17,889,000			17,889,000
21504	Support Facilities		6,593,000			6,593,000

Delta Only

Account	--Scenario 2, 35 Acres-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	16,743,000	9,497,000	1,561,000	2,207,000	30,008,000
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage	16,743,000	9,497,000	1,561,000	2,207,000	30,008,000
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hanc					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	16,743,000	46,671,000	1,561,000	2,207,000	67,182,000
	TOTAL	20,721,000	47,781,000	1,561,000	2,258,000	72,321,000

Account	- - Scenario 3 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	42,638,000	28,437,000	983,000	76,195,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,230,000	33,017,000	6,821,000	178,670,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,168,485,000	160,402,000	96,100,000	1,714,498,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*690,258,000*	*111,913,000*	*74,690,000*	*1,111,703,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	- - Scenario 3 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,894,506,000	517,910,000	124,714,000	2,989,812,000
	TOTAL	686,355,000	1,975,736,000	550,927,000	131,535,000	3,344,553,000

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Account	- - Scenario 3 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION					
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION					
21105						
21106	WASTE HANDLING FACILITY					
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2					
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.					
21504	Support Facilities					

Delta Only

Account	- - Scenario 3 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES					
	TOTAL					

Account	--Scenario 4A-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	43,201,000	28,489,000	983,000	76,810,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,793,000	33,069,000	6,821,000	179,285,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,185,430,000	161,878,000	96,100,000	1,732,919,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*707,201,000*	*113,389,000*	*74,690,000*	*1,130,124,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	170,841,000	18,456,000	6,899,000	213,537,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	--Scenario 4A-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,911,451,000	519,386,000	124,714,000	3,008,233,000
	TOTAL	686,355,000	1,993,244,000	552,455,000	131,535,000	3,363,589,000

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Account	–Scenario 4A– DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION		563,000	52,000		615,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION		563,000	52,000		615,000
21105						
21106	WASTE HANDLING FACILITY		16,945,000	1,476,000		18,421,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*16,945,000*	*1,476,000*		*18,421,000*
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		16,945,000	1,476,000		18,421,000
21504	Support Facilities					

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Account	--Scenario 4A-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES		16,945,000	1,476,000		18,421,000
	TOTAL		17,508,000	1,528,000		19,036,000

Account	--Scenario 4B-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,484,000				38,484,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	89,795,000				89,795,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,718,000				49,718,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	177,997,000				177,997,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,199,000	43,013,000	28,489,000	1,002,000	76,703,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,664,000	81,605,000	33,069,000	6,840,000	179,178,000
21105						
21106	WASTE HANDLING FACILITY	293,888,000	1,181,797,000	162,130,000	97,920,000	1,735,735,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*239,221,000*	*703,568,000*	*113,641,000*	*76,510,000*	*1,132,940,000*
21300	Building/Structures	124,911,000			43,441,000	168,352,000
21500	Hot Cell	11,941,000	151,653,000	24,195,000	4,986,000	192,775,000
21501	Utilities	23,336,000	52,221,000	4,159,000	9,450,000	89,166,000
21502	HVAC	9,332,000	28,649,000	1,646,000	3,902,000	43,529,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	18,980,000	6,899,000	195,116,000
21504	Support Facilities	52,360,000	317,149,000	68,661,000	7,832,000	444,002,000

Account	–Scenario 4B– DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	457,059,000	1,907,818,000	519,638,000	126,534,000	3,011,049,000
	TOTAL	692,720,000	1,989,423,000	552,707,000	133,374,000	3,368,224,000

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Account	–Scenario 4B– DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	449,000				449,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	1,046,000				1,046,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	431,000				431,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	1,926,000				1,926,000
12040						
12050	EMPLOYEE TRANSPORTATION	62,000	375,000	52,000	19,000	508,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	62,000	375,000	52,000	19,000	508,000
21105						
21106	WASTE HANDLING FACILITY	4,377,000	13,312,000	1,728,000	1,820,000	21,237,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*4,377,000*	*13,312,000*	*1,728,000*	*1,820,000*	*21,237,000*
21300	Building/Structures	4,293,000			1,785,000	6,078,000
21500	Hot Cell		13,185,000	1,723,000		14,908,000
21501	Utilities	34,000	52,000	3,000	13,000	102,000
21502	HVAC	34,000	52,000	1,000	15,000	102,000
21503	Handling/Packaging Equip.					
21504	Support Facilities	16,000	23,000	1,000	7,000	47,000

Delta Only

ccount	--Scenario 4B-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	4,377,000	13,312,000	1,728,000	1,820,000	21,237,000
	TOTAL	6,365,000	13,687,000	1,780,000	1,839,000	23,671,000

Account	- - Scenario 5 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	43,201,000	28,489,000	983,000	76,810,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,793,000	33,069,000	6,821,000	179,285,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,185,430,000	161,878,000	96,100,000	1,732,919,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*707,201,000*	*113,389,000*	*74,690,000*	*1,130,124,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	170,841,000	18,456,000	6,899,000	213,537,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	- - Scenario 5 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,911,451,000	519,386,000	124,714,000	3,008,233,000
	TOTAL	686,355,000	1,993,244,000	552,455,000	131,535,000	3,363,589,000

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Account	- - Scenario 5 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION		563,000	52,000		615,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION		563,000	52,000		615,000
21105						
21106	WASTE HANDLING FACILITY		16,945,000	1,476,000		18,421,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*16,945,000*	*1,476,000*		*18,421,000*
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		16,945,000	1,476,000		18,421,000
21504	Support Facilities					

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ccount	- - Scenario 5 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES		16,945,000	1,476,000		18,421,000
	TOTAL		17,508,000	1,528,000		19,036,000

Account	–Scenario 6– DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,788,000				38,788,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	90,506,000				90,506,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	50,010,000				50,010,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	179,304,000				179,304,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,234,000	43,388,000	28,542,000	1,014,000	77,178,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,699,000	81,980,000	33,122,000	6,852,000	179,653,000
21105						
21106	WASTE HANDLING FACILITY	296,859,000	1,195,030,000	163,856,000	99,158,000	1,754,903,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*242,192,000*	*716,801,000*	*115,367,000*	*77,748,000*	*1,152,108,000*
21300	Building/Structures	127,850,000			44,667,000	172,517,000
21500	Hot Cell	11,941,000	164,837,000	25,918,000	4,986,000	207,682,000
21501	Utilities	23,349,000	52,241,000	4,160,000	9,455,000	89,205,000
21502	HVAC	9,345,000	28,669,000	1,647,000	3,907,000	43,568,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,366,000	317,158,000	66,662,000	7,834,000	444,020,000

Account	–Scenario 6– DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,066,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	460,030,000	1,921,051,000	521,364,000	127,772,000	3,030,217,000
	TOTAL	697,033,000	2,003,031,000	554,486,000	134,624,000	3,389,174,000

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Account	--Scenario 6-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	753,000				753,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	1,757,000				1,757,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	723,000				723,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	3,233,000				3,233,000
12040						
12050	EMPLOYEE TRANSPORTATION	97,000	750,000	105,000	31,000	983,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	97,000	750,000	105,000	31,000	983,000
21105						
21106	WASTE HANDLING FACILITY	7,348,000	26,545,000	3,454,000	3,058,000	40,405,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*7,348,000*	*26,545,000*	*3,454,000*	*3,058,000*	*40,405,000*
21300	Building/Structures	7,232,000			3,011,000	10,243,000
21500	Hot Cell		26,369,000	3,446,000		29,815,000
21501	Utilities	47,000	72,000	4,000	18,000	141,000
21502	HVAC	47,000	72,000	2,000	20,000	141,000
21503	Handling/Packaging Equip.					
21504	Support Facilities	22,000	32,000	2,000	9,000	65,000

Delta Only

ccount	--Scenario 6-- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	7,348,000	26,545,000	3,454,000	3,058,000	40,405,000
	TOTAL	10,678,000	27,295,000	3,559,000	3,089,000	44,621,000

Account	- - Scenario 7 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	42,638,000	28,437,000	983,000	76,195,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,230,000	33,017,000	6,821,000	178,670,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,168,485,000	160,402,000	96,100,000	1,714,498,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*690,256,000*	*111,913,000*	*74,690,000*	*1,111,703,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	- - Scenario 7 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,066,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,894,506,000	517,910,000	124,714,000	2,989,812,000
	TOTAL	686,355,000	1,975,736,000	550,927,000	131,535,000	3,344,553,000

Delta Only

Account	- - Scenario 7 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO(					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION					
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION					
21105						
21106	WASTE HANDLING FACILITY					
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2					
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.					
21504	Support Facilities					

Delta Only

ccount	- - Scenario 7 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES					
	TOTAL					

Account	- - Scenario 8 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	43,201,000	28,489,000	983,000	76,810,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,793,000	33,069,000	6,821,000	179,285,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,185,430,000	161,878,000	96,100,000	1,732,919,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*707,201,000*	*113,389,000*	*74,690,000*	*1,130,124,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	170,841,000	18,456,000	6,899,000	213,537,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	- - Scenario 8 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,768,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,911,451,000	519,386,000	124,714,000	3,008,233,000
	TOTAL	686,355,000	1,993,244,000	552,455,000	131,535,000	3,363,589,000

Delta Only

Account	- - Scenario 8 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO(					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION		563,000	52,000		615,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION		563,000	52,000		615,000
21105						
21106	WASTE HANDLING FACILITY		16,945,000	1,476,000		18,421,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2		*16,945,000*	*1,476,000*		*18,421,000*
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.		16,945,000	1,476,000		18,421,000
21504	Support Facilities					

Delta Only

ccount	-- Scenario 8 -- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES		16,945,000	1,476,000		18,421,000
	TOTAL		17,508,000	1,528,000		19,036,000

Account	- - Scenario 9 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,035,000				38,035,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	88,749,000				88,749,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	49,287,000				49,287,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	176,071,000				176,071,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,137,000	42,638,000	28,437,000	983,000	76,195,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,602,000	81,230,000	33,017,000	6,821,000	178,670,000
21105						
21106	WASTE HANDLING FACILITY	289,511,000	1,168,485,000	160,402,000	96,100,000	1,714,498,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*234,844,000*	*690,256,000*	*111,913,000*	*74,690,000*	*1,111,703,000*
21300	Building/Structures	120,618,000			41,656,000	162,274,000
21500	Hot Cell	11,941,000	138,468,000	22,472,000	4,986,000	177,867,000
21501	Utilities	23,302,000	52,169,000	4,156,000	9,437,000	89,064,000
21502	HVAC	9,298,000	28,597,000	1,645,000	3,887,000	43,427,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,344,000	317,126,000	66,660,000	7,825,000	443,955,000

Account	- - Scenario 9 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	452,682,000	1,894,506,000	517,910,000	124,714,000	2,989,812,000
	TOTAL	686,355,000	1,975,736,000	550,927,000	131,535,000	3,344,553,000

Delta Only

Account	- - Scenario 9 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR					
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER					
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT					
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO(					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION					
12040						
12050	EMPLOYEE TRANSPORTATION					
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION					
21105						
21106	WASTE HANDLING FACILITY					
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2					
21300	Building/Structures					
21500	Hot Cell					
21501	Utilities					
21502	HVAC					
21503	Handling/Packaging Equip.					
21504	Support Facilities					

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ccount	-- Scenario 9 -- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES					
	TOTAL					

Account	- - Scenario 10 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	38,788,000				38,788,000
01010	License Application, Support Contractor					
01020	Other					
02000	ARCHITECT ENGINEER	90,506,000				90,506,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	50,010,000				50,010,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PROG.					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	179,304,000				179,304,000
12040						
12050	EMPLOYEE TRANSPORTATION	4,234,000	43,388,000	28,542,000	1,014,000	77,178,000
12060	ON-SITE	53,465,000	38,592,000	4,580,000	5,838,000	102,475,000
12070	Roads	6,463,000			784,000	7,247,000
12080	Rail	6,048,000			731,000	6,779,000
12090	Communications	1,745,000	3,066,000	396,000	242,000	5,449,000
12100	Clearing					
13000	Grading	8,400,000				8,400,000
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities	30,809,000	35,526,000	4,184,000	4,081,000	74,600,000
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	57,699,000	81,980,000	33,122,000	6,852,000	179,653,000
21105						
21106	WASTE HANDLING FACILITY	296,859,000	1,195,030,000	163,858,000	99,158,000	1,754,903,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*242,192,000*	*716,801,000*	*115,367,000*	*77,748,000*	*1,152,108,000*
21300	Building/Structures	127,850,000			44,667,000	172,517,000
21500	Hot Cell	11,941,000	164,837,000	25,918,000	4,986,000	207,682,000
21501	Utilities	23,349,000	52,241,000	4,160,000	9,455,000	89,205,000
21502	HVAC	9,345,000	28,669,000	1,647,000	3,907,000	43,568,000
21503	Handling/Packaging Equip.	17,341,000	153,896,000	16,980,000	6,899,000	195,116,000
21504	Support Facilities	52,366,000	317,158,000	66,662,000	7,834,000	444,020,000

Account	- - Scenario 10 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility	41,086,000	340,833,000		15,960,000	397,879,000
21506	Other Facilities	*13,581,000*	*137,396,000*	*48,489,000*	*5,450,000*	*204,916,000*
21507	Site-Generated Radwaste Treat. Fac	13,581,000	137,396,000	48,489,000	5,450,000	204,916,000
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT	97,045,000	726,021,000	357,508,000	13,212,000	1,193,786,000
22070	Health/Medical Facilities	2,246,000	12,456,000	5,489,000	296,000	20,487,000
22080	Fire Protection Facilities	6,712,000	43,823,000	9,813,000	926,000	61,274,000
22090	Security Facilities	16,445,000	104,907,000	150,396,000	2,063,000	273,811,000
22100	Maintenance Facilities	11,110,000	137,765,000	61,549,000	1,410,000	211,834,000
22110	Administration/Personnel Fac.	10,476,000	167,410,000	80,014,000	1,380,000	259,280,000
22120	Training/Mockup Facility	4,209,000	27,874,000	7,549,000	580,000	40,212,000
22131	Warehouse and Receiving	1,841,000	35,665,000	14,452,000	231,000	52,189,000
22140	Visitors Center Facility	5,445,000	27,729,000	501,000	717,000	34,392,000
22141	Backup Power Generation Facility					
22142	Change Room Facility	312,000	175,000	29,000	41,000	557,000
22150	Lag Storage					
22160	Compressed Air and Steam Facility	1,707,000	68,273,000	13,906,000	246,000	84,132,000
22170	Cooling Tower	1,394,000	7,049,000	259,000	183,000	8,885,000
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hanc					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility	4,373,000	12,361,000	2,477,000	577,000	19,788,000
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility	306,000	173,000	29,000	38,000	546,000
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities	30,469,000	80,361,000	11,045,000	4,524,000	126,399,000
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES	66,126,000			15,402,000	81,528,000
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*	66,126,000			15,402,000	81,528,000
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	460,030,000	1,921,051,000	521,364,000	127,772,000	3,030,217,000
	TOTAL	697,033,000	2,003,031,000	554,486,000	134,624,000	3,389,174,000

Delta Only

Account	- - Scenario 10 - - DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
01000	SUPPORT CONTRACTOR	753,000				753,000
01010	License Application, Support Contracto					
01020	Other					
02000	ARCHITECT ENGINEER	1,757,000				1,757,000
02010	License Application, A/E					
02020						
02030						
03000						
04000	Final Procurement and Construction					
05000	Title III					
07000						
00000						
11000	CONSTRUCTION MANAGEMENT	723,000				723,000
12000	CONSULTANTS					
12010	PERFORMANCE CONFIRMATION PRO					
12020	REPOSITORY LAND ACQUISITION					
12030	MANAGEMENT AND INTEGRATION	3,233,000				3,233,000
12040						
12050	EMPLOYEE TRANSPORTATION	97,000	750,000	105,000	31,000	983,000
12060	ON-SITE					
12070	Roads					
12080	Rail					
12090	Communications					
12100	Clearing					
13000	Grading					
13010	Landscaping					
13020	Drainage Control					
13030	Fencing					
13040	Utilities					
13050	Other (Heliport)					
13060	OFF-SITE					
14000	Roads					
10000	Rail					
	Communications					
21000	Drainage					
21100	Utilities					
21102	Other Offsite Improvements					
21103	MONUMENTS					
21104	SITE PREPARATION	97,000	750,000	105,000	31,000	983,000
21105						
21106	WASTE HANDLING FACILITY	7,348,000	26,545,000	3,454,000	3,058,000	40,405,000
21107	Waste Handling Building 1					
21200	Building/Structures					
21202	Hot Cell					
21203	Utilities					
21204	HVAC					
21205	Handling/Packaging Equip.					
21206	Support Facilities					
21207	Waste Handling Building 2	*7,348,000*	*26,545,000*	*3,454,000*	*3,058,000*	*40,405,000*
21300	Building/Structures	7,232,000			3,011,000	10,243,000
21500	Hot Cell		26,369,000	3,446,000		29,815,000
21501	Utilities	47,000	72,000	4,000	18,000	141,000
21502	HVAC	47,000	72,000	2,000	20,000	141,000
21503	Handling/Packaging Equip.					
21504	Support Facilities	22,000	32,000	2,000	9,000	65,000

Delta Only

Account	-- Scenario 10 -- DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
21505	Cask Maintenance Facility					
21506	Other Facilities					
21507	Site-Generated Radwaste Treat. Fac					
21508	Vehicle Wash Facility					
22000	Decontamination Building					
22010	Performance Confirmation Bldg					
22020	Radwaste Storage					
22030	Transfer Corridors					
22040	Turntable					
22050	Waste Shaft Staging Facility					
22060	BALANCE OF PLANT					
22070	Health/Medical Facilities					
22080	Fire Protection Facilities					
22090	Security Facilities					
22100	Maintenance Facilities					
22110	Administration/Personnel Fac.					
22120	Training/Mockup Facility					
22131	Warehouse and Receiving					
22140	Visitors Center Facility					
22141	Backup Power Generation Facility					
22142	Change Room Facility					
22150	Lag Storage					
22160	Compressed Air and Steam Facility					
22170	Cooling Tower					
22180	*Exc. Material Storage and Handling*					
22190	Surface Exc. Mat. Storage and Hand					
22200	Offsite Excavated Material Disposal					
22210	Fuel Storage Facility					
22220	Chemical Storage Facility					
22230	Lab and Testing Facilities					
22240	Potable Water Facility					
23000	Sewage Treatment Facility					
23010	Backfill Facility					
23020	Packing Facility					
23030	Control and Monitoring Facilities					
23040	Standard Equipment					
23050	Other (Conventional Waste System)					
23070	SURFACE SHAFT FACILITIES					
23080	Men and Materials Facility*					
23100	Waste Facility					
23110	Excavated Material Handling Fac.					
23120	Development Intake Facility					
20000	Confinement Intake Facilities					
	Development Exhaust Facility					
	Confinement Exhaust Facilities*					
	Exploratory Shaft Facility - 1					
	Exploratory Shaft Facility - 2					
	Other					
	SURFACE FACILITIES	7,348,000	26,545,000	3,454,000	3,058,000	40,405,000
	TOTAL	10,678,000	27,295,000	3,559,000	3,089,000	44,621,000

Total Cost DESCRIPTION	ENGG CONSTR	SU_EMP OPS	CARE OPS	CLOSE DECOM	TOTAL
Scen. 1, Base Case	686.36	1975.74	550.93	131.54	3344.55
Scen. 2, 5 acre Lag Stor	689.72	2015.56	551.18	131.90	3388.37
Scen. 2, 10 acre Lag Stor	692.79	2016.97	551.41	132.24	3393.40
Scen. 2, 25 acre Lag Stor	701.48	2020.96	552.07	133.18	3407.69
Scen. 2, 35 acre Lag Stor	707.08	2023.52	552.49	133.79	3416.87
Scen. 3 No Impact	686.36	1975.74	550.93	131.54	3344.55
Scen. 4a Add 3 oper/shift	686.36	1993.24	552.46	131.54	3363.59
Scen. 4b Internal Stor	692.72	1989.42	552.71	133.37	3368.22
Scen. 5 Add 3 oper/shift	686.36	1993.24	552.46	131.54	3363.59
Scen. 6 Inter Stor & Cal Cell	697.03	2003.03	554.49	134.62	3389.17
Scen. 7 No Impact	686.36	1975.74	550.93	131.54	3344.55
Scen. 8 Add 3 oper/shift	686.36	1993.24	552.46	131.54	3363.59
Scen. 9 No Impact	686.36	1975.74	550.93	131.54	3344.55
Scen. 10 Inter Stor & Cal Cell	697.03	2003.03	554.49	134.62	3389.17
Delta DESCRIPTION	**ENGG CONSTR**	**SU_EMP OPS**	**CARE OPS**	**CLOSE DECOM**	**TOTAL**
Scen. 2, 5	3.37	39.83	0.25	0.37	43.81
Scen. 2, 10	6.43	41.23	0.48	0.70	48.85
Scen. 2, 25	15.13	45.22	1.14	1.65	63.14
Scen. 2, 35	20.72	47.78	1.56	2.26	72.32
Scen. 3	0.00	0.00	0.00	0.00	0.00
Scen. 4a	0.00	17.51	1.53	0.00	19.04
Scen. 4b	6.36	13.69	1.78	1.84	23.67
Scen. 5	0.00	17.51	1.53	0.00	19.04
Scen. 6	10.68	27.30	3.56	3.09	44.62
Scen. 7	0.00	0.00	0.00	0.00	0.00
Scen. 8	0.00	17.51	1.53	0.00	19.04
Scen. 9	0.00	0.00	0.00	0.00	0.00
Scen. 10	10.68	27.30	3.56	3.09	44.62

APPENDIX G

WASTE STREAM EVALUATIONS

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WASTE STREAM EVALUATIONS

G.1 SCENARIO OVERVIEW

This section describes all scenarios examined, except for the blending scenario, which will be described in section 3.0.

Models

The Waste Stream Model (WSM, CRWMS M&O 1995i) was used to simulate the movement of SNF throughout the system for the scenarios examined. WSM selects fuel for transport/emplacement based on various system parameters (i.e., dry storage operations, fuel selection rules (OFF/YFFxx), allocation rights). The data from WSM is processed by the Interface Model (CRWMS M&O 1995j), which produces detailed reports (e.g., cask/assembly heats at various points in the system, fuel characteristics, logistics data), down to the assembly level.

Common Parameters

Common parameters to the scenarios are listed below:

- The 1993 RW-859 data contained in the Energy Information Administration 1995 Report (EIA 1995) for the "No New Orders" scenario was used for input to WSM
- 13 truck, 16 small rail, and 90 large rail facilities (CRWMS M&O 1995p)
- In Oldest Fuel First (OFF) acceptance scenarios, the oldest remaining fuel at a pool was selected until no more fuel >=10 years old was available, at which point fuel in dry storage was accepted.
- In Youngest Fuel First (YFF) acceptance scenarios, the youngest fuel >= 10 years old was accepted. If no fuel greater than 10 years old existed at a given pool, the next oldest fuel down to 5 years old was accepted, at which point fuel from dry storage was accepted.
- Single repository, with the emplacement limited to 63,000 MTU of commercial SNF
- No derating of waste packages (capacity=21P/44B)
- Pickup began either in 2003 or 2010 depending on whether an ISF was in the system
- SNF shipped directly to MGDS once emplacement begins (2010)
- SNF in ISF storage remains there until pickups from utilities are finished (~2025)

Table G-1 shows the receipt and emplacement rates for the scenarios not containing an ISF. Table G-2 shows the rates for the ISF scenarios.

Table G-1. Receipt Rates for No-ISF Scenarios

	Acceptance Rate	Emplacement Rate
2003	0	0
2004	0	0
2005	0	0
2006	0	0
2007	0	0
2008	0	0
2009	0	0
2010	300	300
2011	600	600
2012	1200	1200
2013	2000	2000
2014	3000	3000
2015	3000	3000
2016	3000	3000
2017	3000	3000
2018	3000	3000
2019	3000	3000
2020	3000	3000
2021	3000	3000
2022	3000	3000
2023	3000	3000
2024	3000	3000
2025	3000	3000
2026	3000	3000
2027	3000	3000
2028	3000	3000
2029	3000	3000
2030	3000	3000
2031	3000	3000
2032	3000	3000
2033	1900	1900
Total	63000	63000

Table G-2. Receipt Rates for ISF Scenarios

	Acceptance Rate	Emplacement Rate
2003	1200	0
2004	1200	0
2005	2000	0
2006	2000	0
2007	2700	0
2008	3000	0
2009	3000	0
2010	3000	300
2011	3000	600
2012	3000	1200
2013	3000	2000
2014	3000	3000
2015	3000	3000
2016	3000	3000
2017	3000	3000
2018	3000	3000
2019	3000	3000
2020	3000	3000
2021	3000	3000
2022	3000	3000
2023	3000	3000
2024	3000	3000
2025	2900	3000
2026	0	3000
2027	0	3000
2028	0	3000
2029	0	3000
2030	0	3000
2031	0	3000
2032	0	3000
2033	0	1900
Total	63000	63000

Results

The thermal load (heat) results for 4 cases are presented in the following section. These cases include:

OFF/No-ISF,
OFF/ISF,
YFF10/No-ISF and
YFF10/ISF

Tables G-3 through G-10 show, on an annual per cask basis, the minimum, average and maximum heats at emplacement, the standard deviation of the heat, and the number of casks being emplaced. There are two tables/scenario-one for BWR fuel, and one for PWR fuel. Tables G-3 and G-4 show the results for the no ISF, OFF acceptance scenario for BWR and PWR fuel, respectively. Tables G-5 and G-6 show the results for the no ISF, YFF10 acceptance scenario. Tables G-7 and G-8 are for the ISF, OFF acceptance scenario. Tables G-9 and G-10 are for the ISF, YFF10 acceptance scenario.

The average and standard deviations shown in these tables were used to create Figures G-1 through G-8.

NOTE: All figures used the minimum if it was larger than the result of (Avg-Std Dev) and use the maximum if is was smaller than the result of (Avg+Std Dev)-there were only a few points where this was necessary. The figures follow the same pattern as the tables (BWR then PWR information). The No-ISF scenarios (OFF-Figures G-1 and G-2, YFF10 Figures G-3 and G-4) are shown first, then the ISF scenarios (OFF-Figures G-5 and G-6, YFF10 Figures G-7 and G-8) are shown.

The higher heat for the OFF ISF scenario vs the OFF No-ISF (before 2025) results from the oldest 15K MTU of SNF being picked up and placed into ISF storage before emplacement begins. The lower heat the first couple of years in the No-ISF YFF10 vs the ISF, YFF10 scenario) is due to there only being "old" fuel available at many of the sites which have early acceptance rights. The discontinuity in the ISF scenarios (Tables G-7 through G-10/Figures G-5 through G-8) at ~2025 results from the switch of the pickup from the utilities to this old, cold fuel in ISF storage.

Blending Scenario

For the blending scenario fuel enters the system using an OFF criteria. All fuel is placed into storage and then individual assemblies are chosen from the pool of fuel in storage. The assemblies are chosen such that the average assembly has a heat of approximately a target heat. Assemblies arriving in a given year are not available for emplacement in that year (i.e., all fuel waits at least one year prior to emplacement).

Parameters

The main parameters for the blending scenario are listed below:

- All fuel in storage is available for emplacement
- Fuel arriving in the emplacement year is not available till the next year
- A target heat of 10kw/pkg in year of emplacement was used
- Assemblies were selected based on OFF from the utilities
- All casks were full
- BWR WP cask contains 44 assemblies
- PWR WP cask contains 21 assemblies

Table G-3. Heat characteristics (kw) at emplacement for No ISF-OFF Acceptance Scenario-BWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	0.09	1.08	4.72	1.11	27
2011	1.65	4.08	5.77	1.22	40
2012	0.30	3.77	7.98	1.38	68
2013	0.41	4.27	8.56	1.53	106
2014	1.67	4.75	9.22	1.24	156
2015	1.82	5.64	11.78	1.71	140
2016	1.54	5.92	11.96	2.74	130
2017	1.05	7.57	13.56	2.54	144
2018	0.62	8.37	13.95	2.89	121
2019	1.29	8.08	14.34	2.75	123
2020	1.27	8.07	13.58	3.22	113
2021	1.10	8.00	15.11	3.22	131
2022	2.58	8.09	12.71	3.01	114
2023	2.22	8.52	15.12	2.74	136
2024	0.63	7.88	14.51	2.85	139
2025	2.75	8.76	15.48	2.96	114
2026	0.52	8.58	14.63	3.05	122
2027	2.66	9.38	15.24	2.82	143
2028	0.66	7.61	14.98	3.35	118
2029	0.75	7.85	15.38	3.94	124
2030	0.60	7.88	16.18	3.48	134
2031	2.19	7.32	14.63	3.14	149
2032	0.59	5.89	10.65	2.71	152
2033	0.62	6.54	13.77	3.28	97

Table G-4. Heat characteristics (kw) at emplacement for No ISF-OFF Acceptance Scenario-PWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	1.24	3.35	5.00	1.09	15
2011	1.82	5.07	9.46	1.87	41
2012	0.30	7.36	17.14	4.03	83
2013	2.61	7.93	18.77	3.24	143
2014	1.63	7.97	17.41	3.39	191
2015	1.27	9.02	19.20	3.52	210
2016	2.26	8.95	20.22	3.29	223
2017	2.60	9.14	20.67	3.27	217
2018	2.00	9.55	21.01	3.39	227
2019	2.82	9.41	20.30	3.48	222
2020	0.93	9.00	19.86	3.43	233
2021	1.53	8.92	20.42	3.57	212
2022	2.42	9.83	28.06	3.79	229
2023	3.06	9.53	20.33	3.40	213
2024	2.71	10.29	20.70	3.59	209
2025	3.46	10.15	22.60	3.65	234
2026	2.39	9.92	20.09	3.51	222
2027	1.91	9.66	22.54	3.82	213
2028	3.08	10.19	19.22	3.48	224
2029	2.71	10.61	18.77	3.68	220
2030	2.62	10.20	20.35	4.18	215
2031	2.14	9.81	18.79	3.77	199
2032	2.37	10.46	19.17	4.21	196
2033	1.16	11.01	19.53	4.07	129

Table G-5. Heat characteristics (kw) at emplacement for No ISF-YFF10 Acceptance Scenario-BWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	0.15	1.87	11.25	2.81	28
2011	1.22	9.28	13.34	2.76	40
2012	1.15	8.90	13.72	3.73	68
2013	0.43	9.10	14.36	3.71	110
2014	1.68	8.64	16.16	3.39	157
2015	1.62	7.64	13.74	2.89	140
2016	1.67	8.41	15.03	3.63	136
2017	1.05	8.64	14.04	3.09	140
2018	0.83	9.52	15.07	3.44	116
2019	1.29	9.77	15.44	3.72	127
2020	1.19	8.42	14.82	3.98	112
2021	1.76	9.25	15.10	4.26	138
2022	2.02	7.55	14.02	3.72	112
2023	2.22	9.03	15.11	4.00	133
2024	0.54	7.67	16.20	4.19	131
2025	2.08	8.48	16.85	4.27	117
2026	1.80	8.06	17.16	4.24	121
2027	1.63	9.54	18.62	4.58	142
2028	0.66	7.34	15.40	4.05	120
2029	0.51	7.93	17.83	4.89	120
2030	0.75	6.69	15.86	3.83	138
2031	0.60	6.15	14.97	3.04	150
2032	0.59	4.62	10.27	2.40	148
2033	1.31	6.21	15.31	3.44	99

Table G-6. Heat characteristics (kw) at emplacement for No ISF-YFF10 Acceptance Scenario-PWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	1.51	7.23	12.48	3.15	16
2011	1.04	11.54	17.66	4.44	42
2012	0.27	12.38	19.86	4.47	88
2013	2.72	12.19	21.90	4.17	142
2014	1.76	11.85	20.83	4.48	200
2015	1.35	12.06	23.87	4.37	211
2016	2.31	13.38	28.71	4.93	222
2017	2.44	12.96	24.29	4.33	212
2018	2.00	13.27	27.16	5.13	234
2019	2.29	12.45	24.59	5.92	221
2020	1.67	12.40	25.48	5.82	230
2021	1.53	11.47	24.27	5.28	209
2022	2.42	12.01	26.39	5.87	233
2023	2.91	11.45	24.76	5.53	213
2024	2.58	11.57	26.63	5.46	216
2025	3.28	11.51	31.25	6.12	224
2026	2.79	10.39	26.69	5.41	219
2027	2.87	10.19	27.24	5.55	212
2028	3.08	10.49	35.91	5.77	222
2029	1.86	9.42	25.49	4.79	223
2030	1.87	8.90	26.70	5.13	207
2031	2.14	8.43	26.73	4.43	201
2032	2.37	8.33	26.05	4.65	197
2033	1.86	7.64	15.58	3.05	127

Table G-7. Heat characteristics (kw) at emplacement for ISF-OFF Acceptance Scenario-BWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	1.84	6.08	9.17	2.71	13
2011	5.96	8.41	9.94	1.24	21
2012	0.73	7.83	12.67	2.37	56
2013	1.81	8.20	14.42	2.63	83
2014	1.68	8.89	14.73	2.54	125
2015	0.69	9.46	14.46	2.15	141
2016	1.14	9.52	14.94	3.03	121
2017	1.98	9.44	13.01	2.20	122
2018	0.05	9.95	15.02	2.79	137
2019	0.14	9.28	14.80	3.23	132
2020	0.13	8.80	15.37	3.59	137
2021	0.52	9.87	15.99	3.06	127
2022	0.50	8.73	14.03	3.45	158
2023	0.69	9.11	15.49	3.24	117
2024	0.49	8.58	14.36	3.52	172
2025	0.46	8.51	14.62	4.17	148
2026	0.29	2.64	4.33	0.85	157
2027	0.28	3.40	4.63	0.77	155
2028	1.75	3.89	6.03	0.60	142
2029	1.53	4.00	6.67	0.87	133
2030	0.60	4.60	7.71	1.42	133
2031	1.13	4.85	8.58	1.56	140
2032	2.26	5.22	8.08	1.37	101
2033	1.25	6.12	9.15	1.19	67

Table G-8. Heat characteristics (kw) at emplacement for ISF-OFF Acceptance Scenario-PWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	6.07	8.60	11.96	1.81	22
2011	1.03	9.19	17.16	3.63	48
2012	4.43	11.14	17.15	2.90	81
2013	1.81	10.39	18.12	3.09	147
2014	3.21	11.17	18.48	2.72	222
2015	1.35	11.07	20.86	3.26	211
2016	0.67	11.54	20.24	3.48	228
2017	1.78	11.40	21.05	3.07	228
2018	1.74	12.15	20.35	3.34	212
2019	2.13	11.66	23.20	3.92	216
2020	1.24	11.66	21.36	3.96	216
2021	2.07	11.79	22.56	4.10	224
2022	2.08	12.09	21.52	4.27	197
2023	1.68	11.86	21.33	4.04	234
2024	2.25	12.29	21.51	5.18	183
2025	2.26	14.16	22.83	4.66	205
2026	0.20	4.50	9.97	1.71	203
2027	1.84	5.21	9.99	1.45	199
2028	2.34	6.00	10.94	1.69	206
2029	2.22	6.13	10.77	1.65	213
2030	2.32	6.19	10.97	1.59	220
2031	2.40	6.58	10.63	1.65	211
2032	0.66	6.38	11.33	1.76	244
2033	1.59	7.38	13.98	1.87	150

Table G-9. Heat characteristics (kw) at emplacement for ISF-YFF10 Acceptance Scenario-BWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	10.05	12.64	14.05	1.32	8
2011	2.32	9.96	14.44	3.35	24
2012	3.03	11.76	18.03	2.48	52
2013	1.78	10.86	15.77	3.28	79
2014	1.86	9.79	15.07	3.59	132
2015	1.29	10.12	20.57	3.73	128
2016	0.15	9.40	16.24	3.92	136
2017	1.95	9.55	15.62	3.74	123
2018	0.52	7.85	16.39	3.88	126
2019	0.54	9.06	16.71	4.36	133
2020	1.06	8.66	17.97	4.95	131
2021	1.10	10.28	19.45	4.24	127
2022	0.49	8.41	22.53	5.26	154
2023	0.48	9.94	22.87	4.80	116
2024	0.13	8.62	21.28	4.88	178
2025	0.10	9.24	22.82	5.46	145
2026	0.38	4.77	7.29	1.71	162
2027	0.28	5.41	9.01	1.68	153
2028	2.12	5.11	8.85	1.54	141
2029	1.73	5.12	8.85	1.66	144
2030	0.64	5.92	9.28	1.74	135
2031	2.95	6.50	9.05	1.47	128
2032	3.10	6.34	9.35	1.55	108
2033	3.20	6.92	10.03	1.41	75

Table G-10. Heat characteristics (kw) at emplacement for ISF-YFF10 Acceptance Scenario-PWR Fuel

	Min Heat	Avg Heat	Max Heat	Std Dev	Num Casks
2010	7.67	13.56	18.59	3.10	26
2011	2.29	12.02	23.40	4.39	44
2012	5.62	15.02	30.92	4.44	87
2013	1.90	13.31	28.85	5.31	151
2014	1.97	14.02	37.20	5.67	218
2015	1.36	13.00	29.55	4.97	222
2016	1.58	13.92	31.17	5.19	213
2017	1.37	12.92	34.38	5.21	225
2018	1.74	14.07	34.93	5.92	218
2019	0.77	12.21	36.99	6.57	218
2020	2.50	12.67	33.52	5.96	215
2021	2.99	12.71	34.35	6.08	222
2022	2.41	11.77	34.85	6.62	196
2023	2.57	11.19	30.66	6.31	233
2024	2.25	12.10	33.31	6.66	177
2025	2.58	12.01	26.49	6.41	209
2026	0.20	6.81	14.28	2.36	208
2027	2.07	7.52	12.05	1.80	204
2028	2.31	7.47	11.50	1.91	209
2029	2.63	7.91	14.51	1.95	208
2030	2.58	7.73	12.70	1.88	217
2031	1.79	8.27	12.61	1.79	224
2032	0.66	8.27	13.34	2.17	239
2033	1.65	7.91	13.50	2.16	147

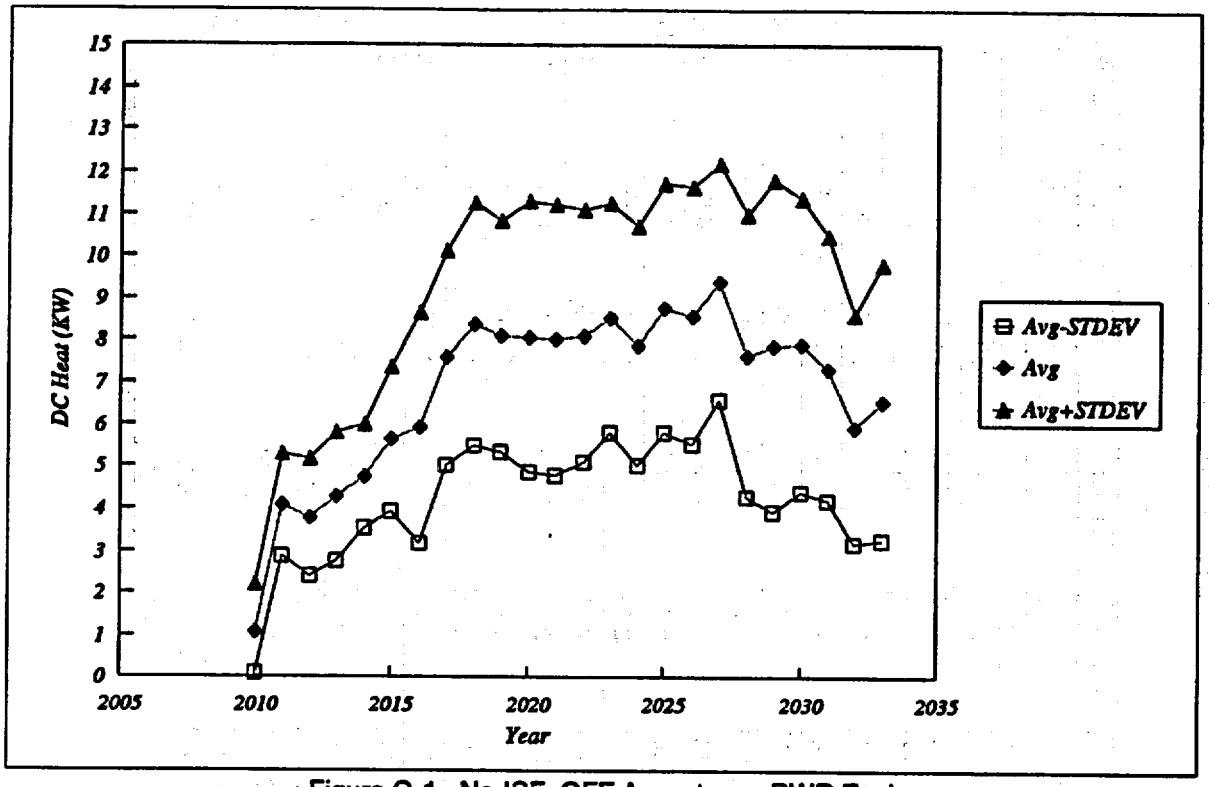

Figure G-1. No-ISF, OFF Acceptance-BWR Fuel

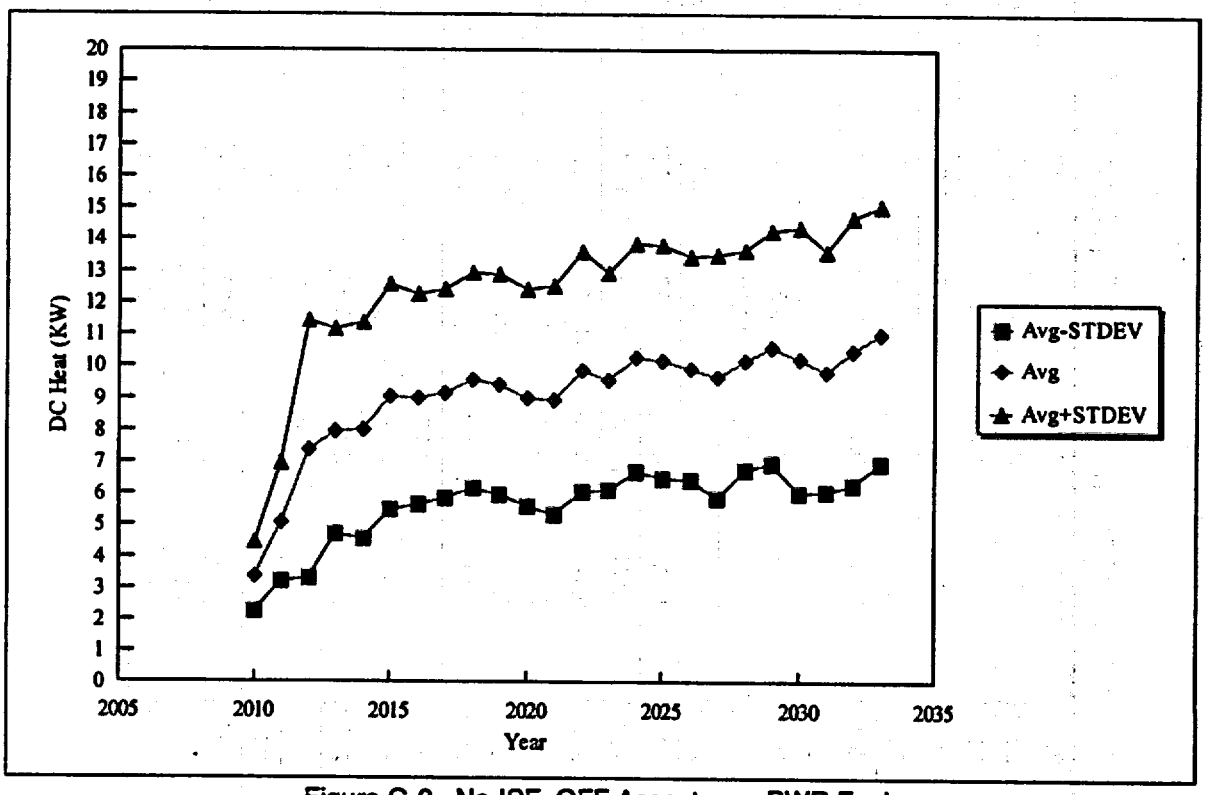

Figure G-2. No-ISF, OFF Acceptance-PWR Fuel

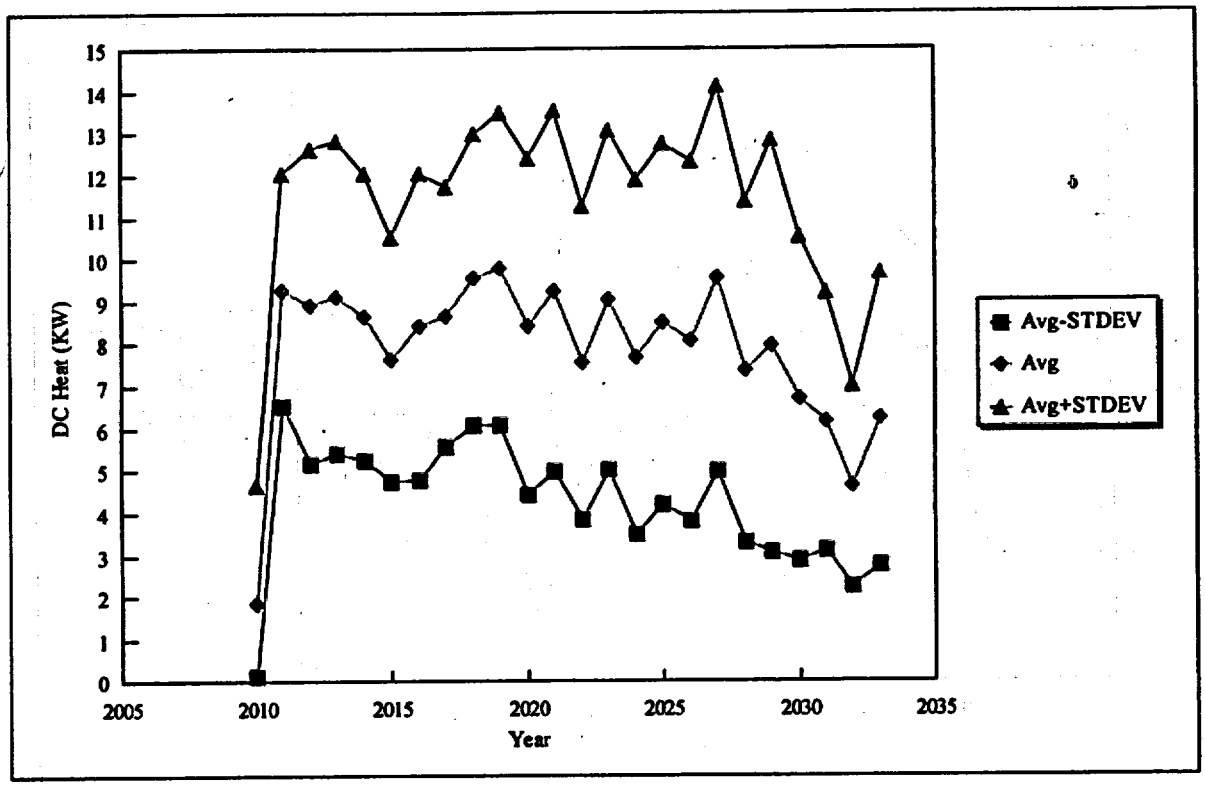

Figure G-3. No-ISF, YFF10 Acceptance-BWR Fuel

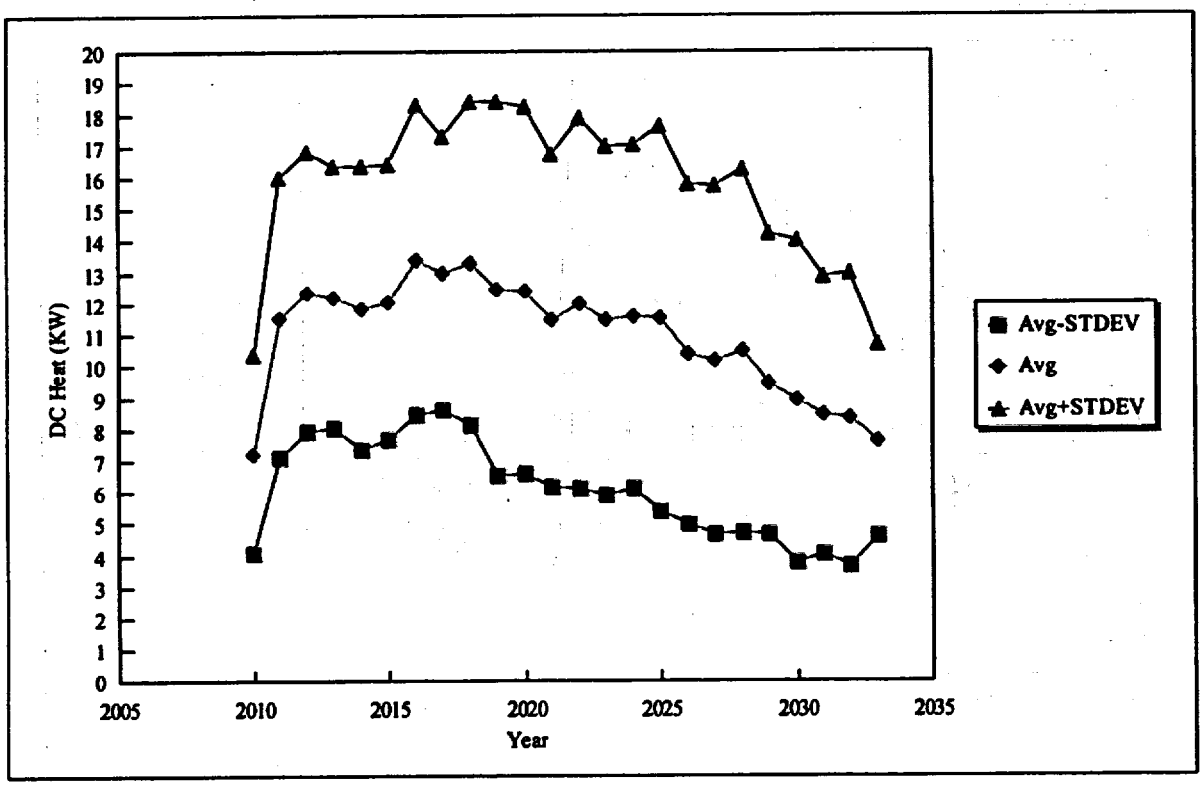

Figure G-4. No-ISF, YFF10 Acceptance-PWR Fuel

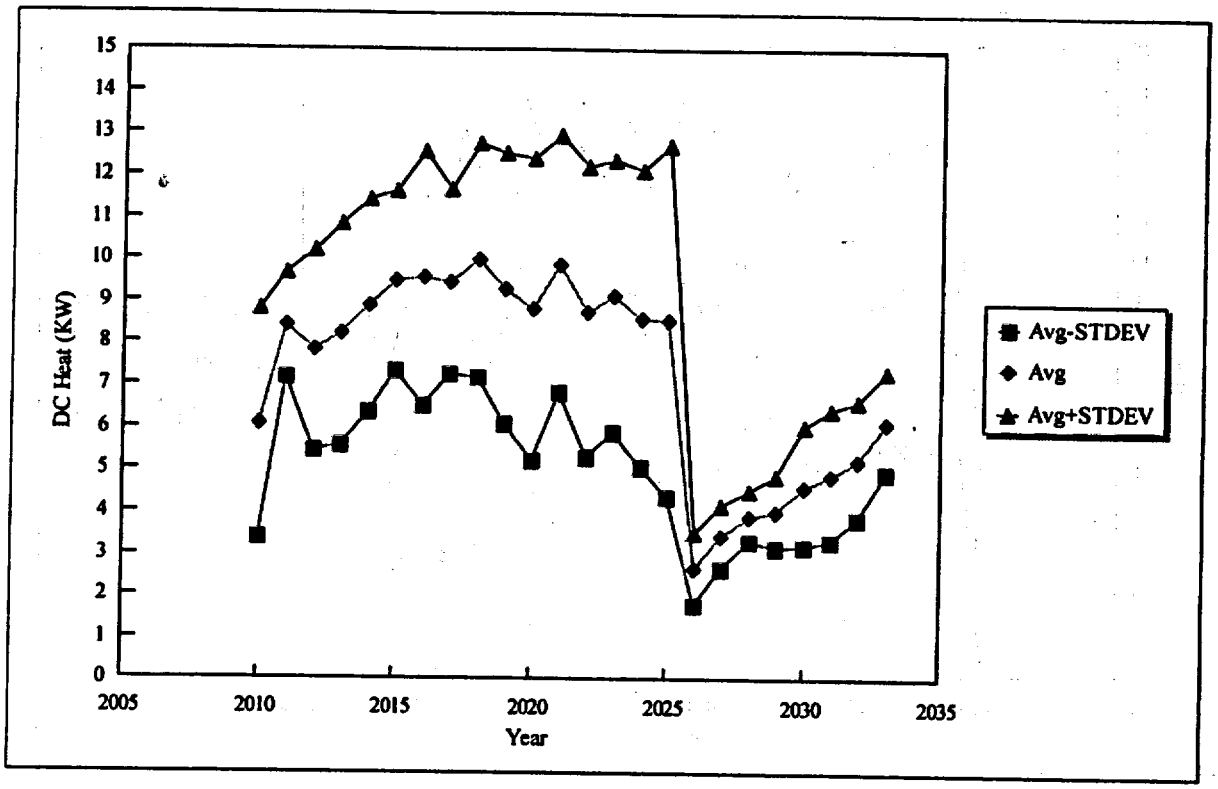

Figure G-5. ISF, OFF Acceptance-BWR Fuel

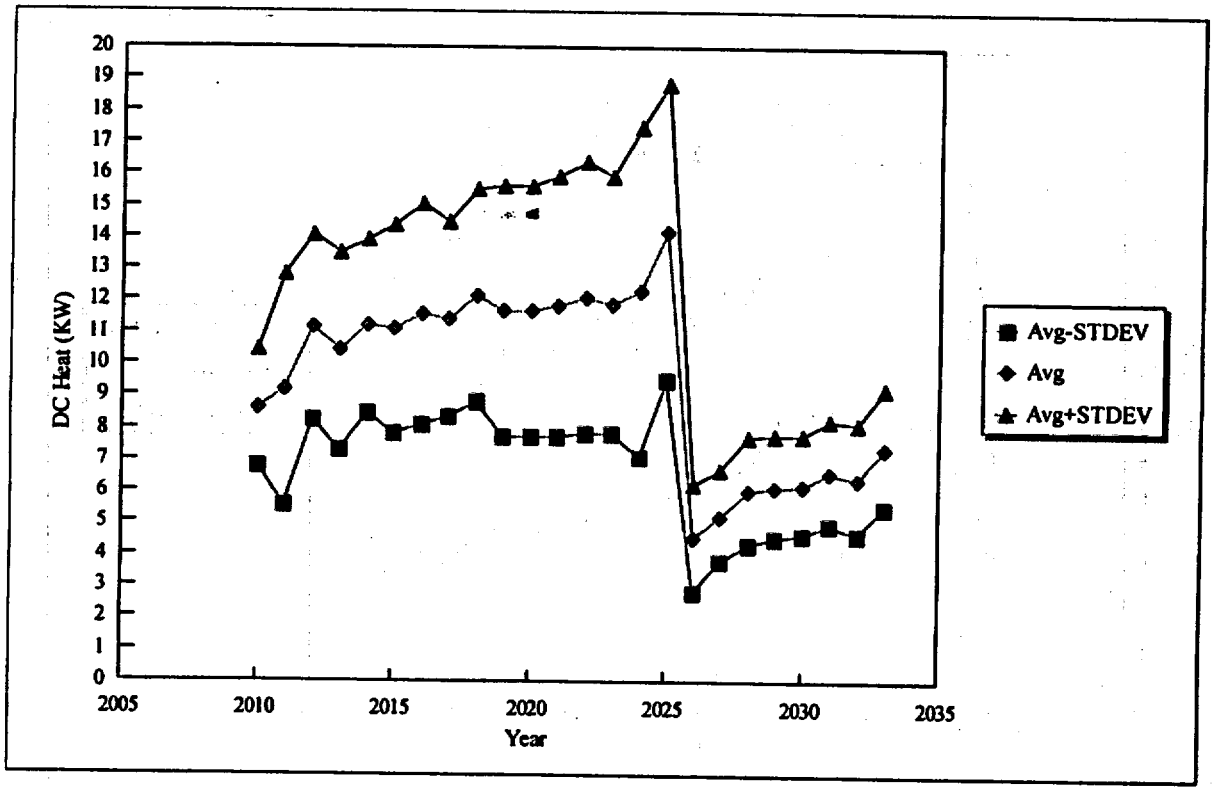

Figure G-6. ISF, OFF Acceptance-PWR Fuel

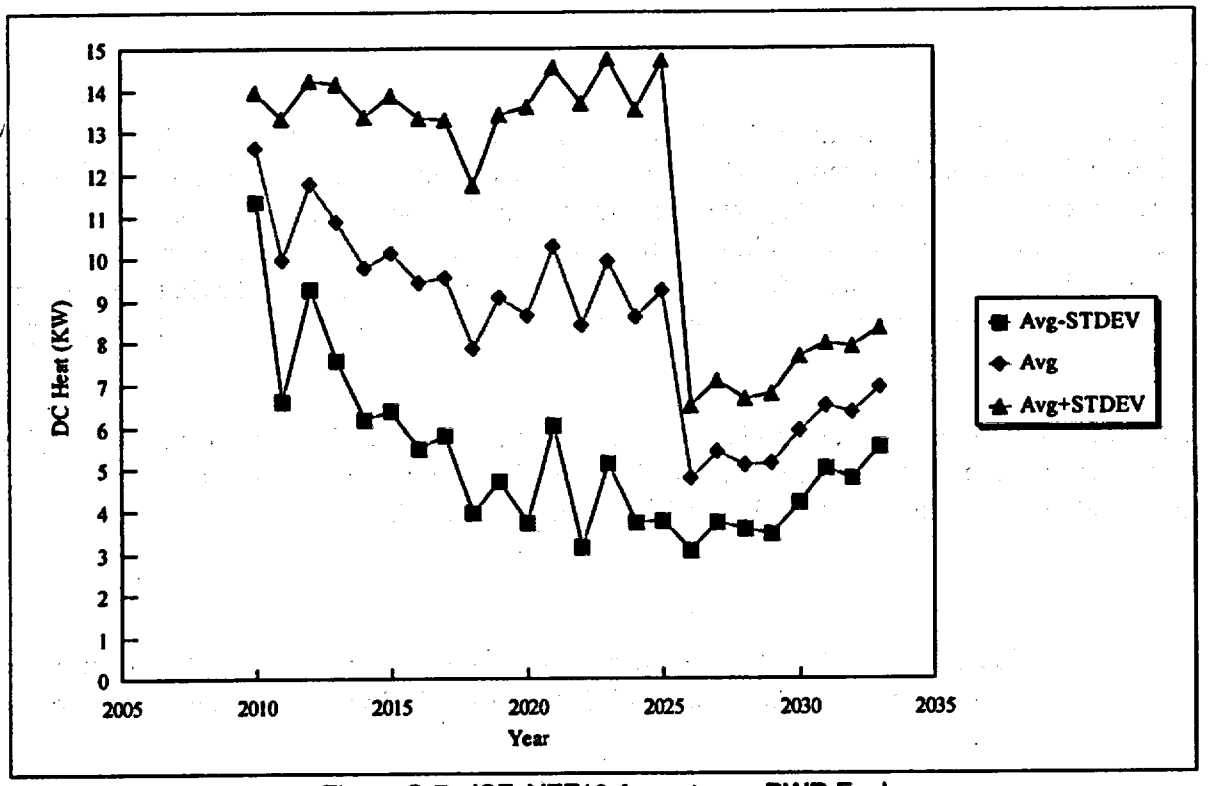

Figure G-7. ISF, YFF10 Acceptance-BWR Fuel

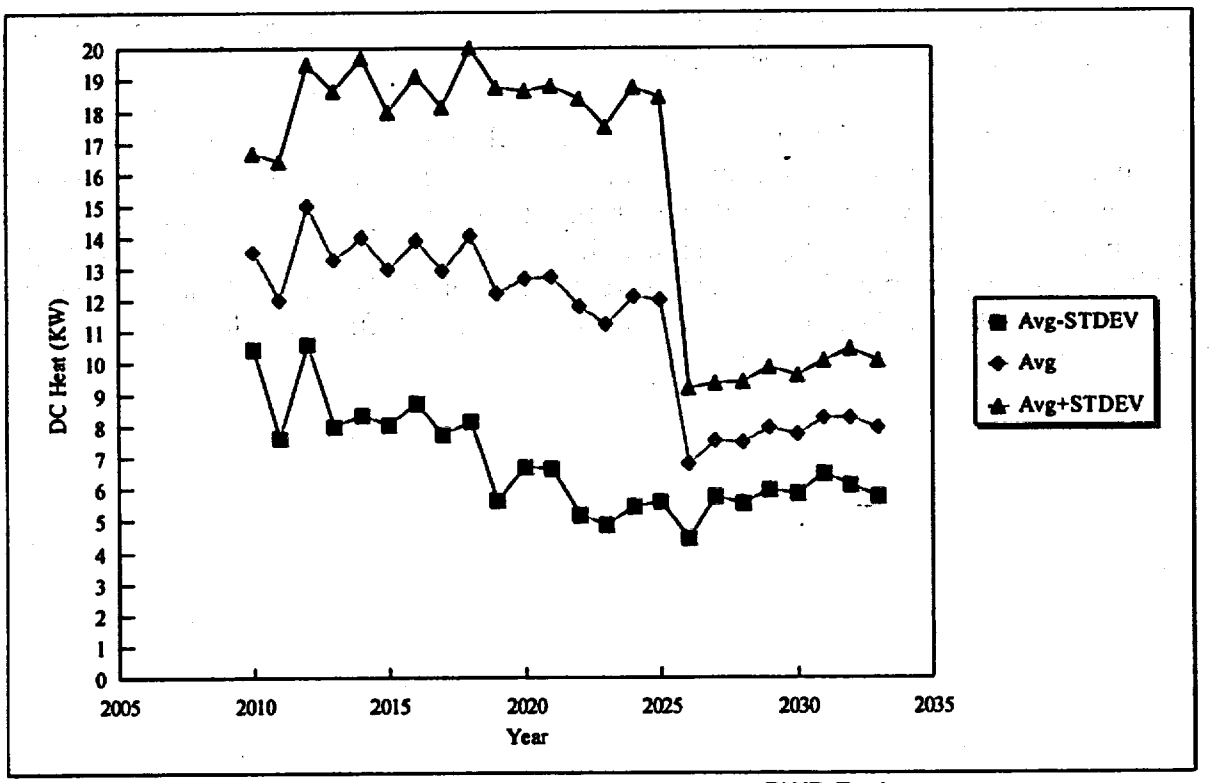

Figure G-8. ISF, YFF10 Acceptance-PWR Fuel

Results

The results are presented in two tables (G-11 and G-12) and two figures (G-9 and G-10). The tables are similar to the Tables G-3 through G-10. Each table has the emplacement year, the quantity of waste packages emplaced, the average heat (kw), and two standard deviations. There are many ways to create the WP from a pool of assemblies. In this analysis two methods were chosen. In the first method, assemblies are chosen at random from the pool of available assemblies having the average target heat. In the second method assemblies are chosen in order to create the WP with the target heat.

As can be seen from these results, overall standard deviation of the WPs is reduced substantially in any year over the results shown in Figures G-1 and G-2. The second method also produces a reduction of at least a factor of 2 over the random selection method.

Definitions

RANDOM STD DEV is the standard deviation obtained by choosing from the emplacement years pool of assemblies in a random fashion. This result is the theoretical value. The basic equation is

$$s_{pkg}=s_{assm}\sqrt{pkgsize}$$

in other words the package standard deviation is simply the square root of the package size (e.g., sqrt(21)) * the standard deviation of the assemblies.

Blended Std Dev is obtained by selecting from the pool of assemblies algorithmically. The algorithm used is to select the assemblies based on the current average heat in the package. In other words if the cask has an average assembly heat higher than the target heat the next assembly is chosen from the coldest remaining assemblies and vice-versa if the heat is colder. Note that target heat in this case is the average package heat of the assembly group or the sum of the assembly heats divided by the package size. As can be seen in the next section, the blended results achieve a much smaller standard deviation than the theoretical.

Table G-11. Blended Heat at Emplacement for BWR SNF

BWR Results				
Year	Number of Pkgs	Average Heat (kw)	Random Std dev (kw)	Blended Std dev (kw)
2010	14	6.298	0.092	0.039
2011	27	5.945	0.044	0.020
2012	53	6.019	0.076	0.015
2013	89	6.307	0.110	0.023
2014	133	6.684	0.153	0.025
2015	135	7.180	0.165	0.016
2016	134	7.927	0.176	0.019
2017	137	8.803	0.160	0.015
2018	138	8.768	0.209	0.021
2019	138	9.119	0.175	0.021
2020	138	9.322	0.179	0.018
2021	138	9.671	0.180	0.026
2022	139	9.566	0.259	0.035
2023	138	10.087	0.202	0.027
2024	137	9.334	0.299	0.044
2025	137	9.095	0.360	0.052
2026	138	9.593	0.372	0.084
2027	132	4.070	0.015	0.003
2028	132	3.700	0.012	0.002
2029	130	3.360	0.011	0.001
2030	130	2.996	0.021	0.002
2031	129	2.472	0.024	0.003
2032	134	1.666	0.038	0.006
2033	95	0.739	0.048	0.005

Table G-12. Blended Heat at Emplacement for PWR SNF

PWR Results				
Year	Number of Pkgs	Average Heat (kw)	Random Std dev (kw)	Blended Std dev (kw)
2010	21	10.004	0.120	0.052
2011	42	10.002	0.125	0.039
2012	84	10.001	0.173	0.057
2013	140	10.001	0.234	0.053
2014	210	9.786	0.286	0.080
2015	212	10.002	0.314	0.043
2016	215	9.998	0.320	0.043
2017	214	10.000	0.373	0.066
2018	216	9.999	0.368	0.047
2019	218	10.001	0.403	0.057
2020	216	9.999	0.432	0.084
2021	218	10.000	0.462	0.074
2022	216	10.001	0.502	0.117
2023	218	10.001	0.567	0.202
2024	205	10.001	1.028	0.387
2025	220	10.000	0.487	0.121
2026	218	10.001	0.684	0.193
2027	216	10.001	0.821	0.265
2028	215	10.000	0.949	0.412
2029	207	10.000	1.084	0.529
2030	205	10.002	1.279	0.448
2031	216	4.943	0.821	0.491
2032	216	3.057	0.060	0.019
2033	137	1.940	0.113	0.150

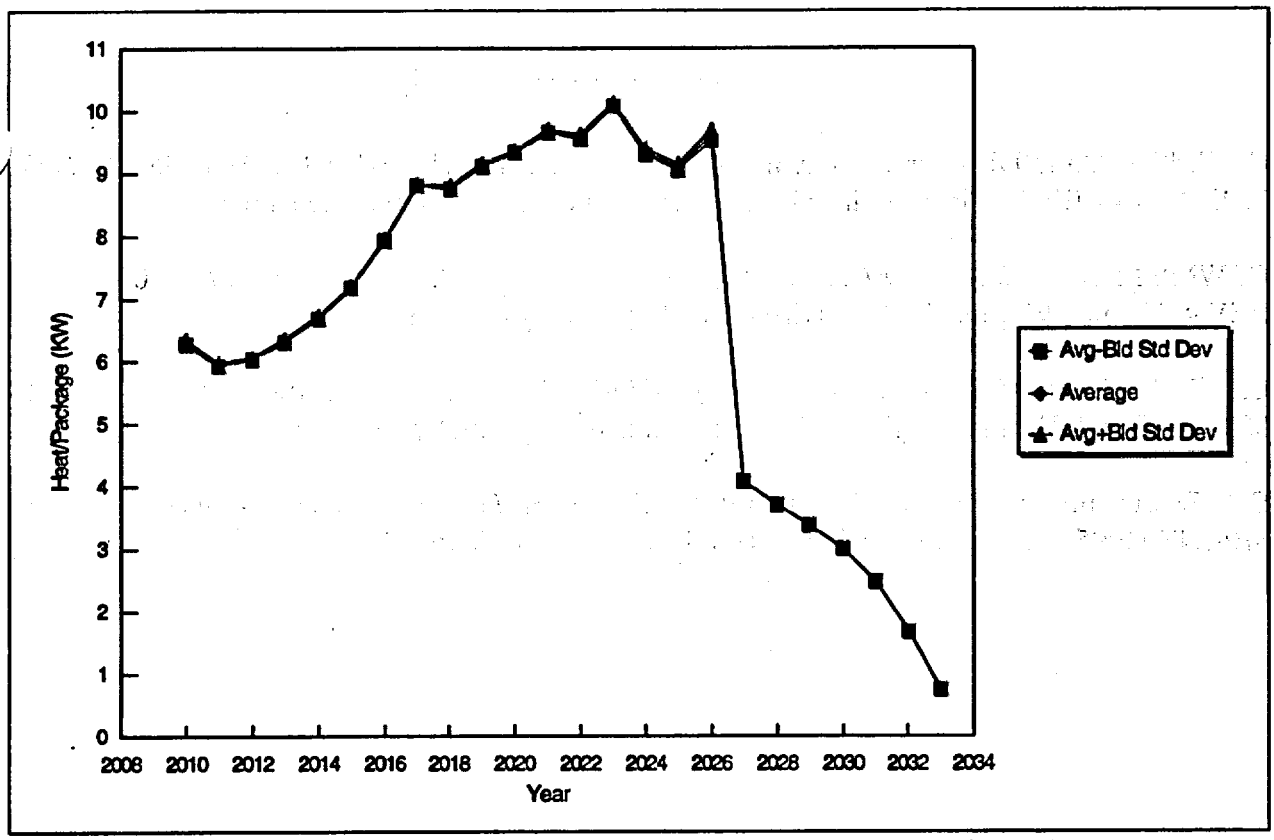

Figure G-9. BWR Waste Package Characteristics for Blending Scenario

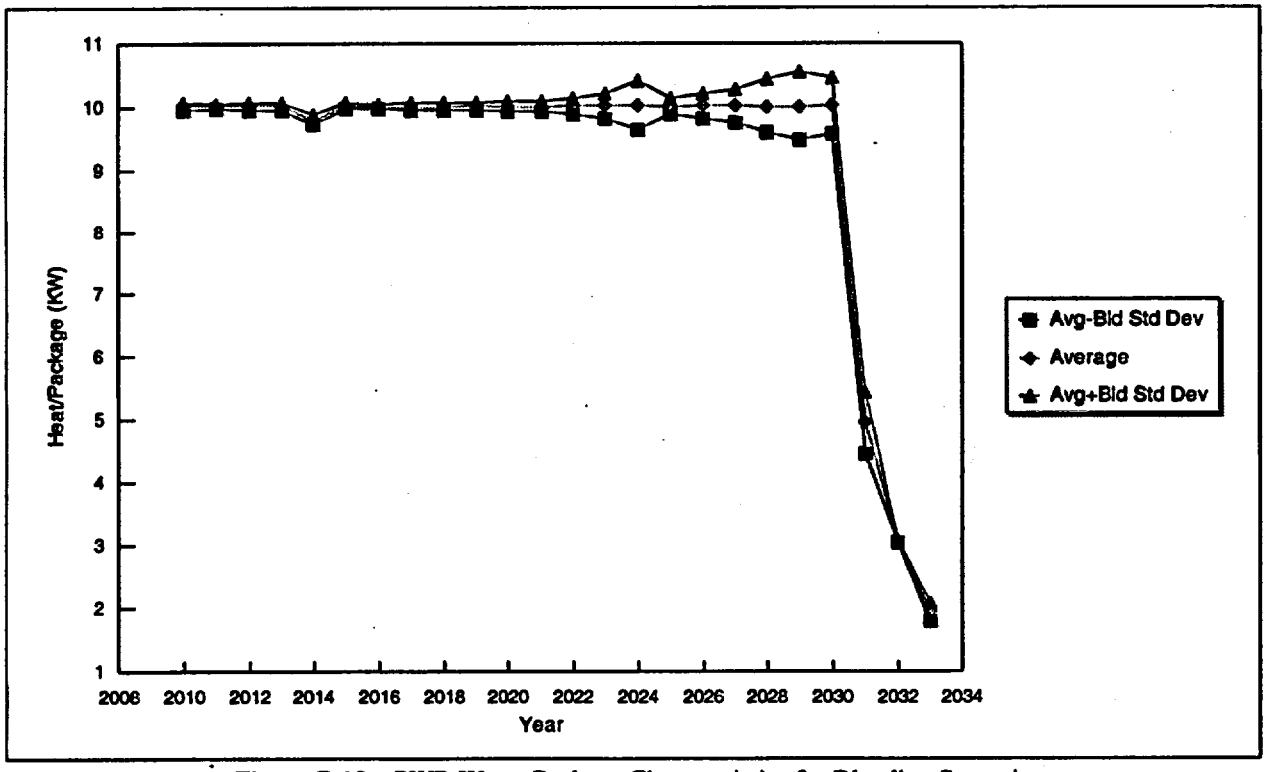

Figure G-10. PWR Waste Package Characteristics for Blending Scenario

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