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Thermal Management Flexibility Analysis

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10. Revision No.	11. Description of Change
REV 00	Initial Issue.
REV 01	Revised to address DOE Comments. This includes additional clarification on direct inputs, additions to assumptions in Section 5, and clarification of the overall purpose of the report. Change bars are not used in this revision because the changes were too extensive.

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ACRONYMS AND ABBREVIATIONS

AML	Areal Mass Loading
BSC	Bechtel SAIC Company
BWR	boiling water reactor
CR	condition report
CSNF	commercial spent nuclear fuel
CSTR	Continuous Stirred Tank Reactor
DDT	discrete-heat-source, drift-scale, thermal conduction, three-dimensional (submodel)
DHLW	defense high-level (radioactive) waste
GWd	gigawatt day(s)
IED	information exchange drawing
LPD	Lineal Power Density
MTU	metric ton(s) uranium
N/A	not applicable
PWR	pressurized water reactor
SCM	Software Configuration Management
SNF	spent nuclear fuel
TAD	transportation, aging, and disposal (canister)
TOOR	time out of reactor
TSPA	total system performance assessment
TWP	technical work plan
UZ	unsaturated zone
YMP	Yucca Mountain Project

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1. PURPOSE

The purpose of this report is to demonstrate that postclosure temperature limits can be met, and certain thermal characteristics of the postclosure thermal reference case can be preserved, with alternative thermal loading schemes. The analysis considers certain variations from the base case waste stream, the predicted postclosure temperatures that develop within the rock mass due to these waste stream variations, and then compares these temperatures to postclosure temperature limits. The results define a preliminary "thermal envelope" based on evaluating variations to the postclosure thermal reference case, for consideration by multiple Yucca Mountain Project (YMP) organizations in developing a thermal management strategy for the repository.

Multiscale Thermohydrologic Model (BSC 2005 [DIRS 173944]) implements the postclosure thermal reference case for total system performance assessment (TSPA), based on information provided on information exchange drawings (IEDs). This is called the "base case" and the "TSPA reference case" in this report. The postclosure temperature limits considered in this report are the maximum drift-wall temperature of 200°C, and the maximum mid-pillar temperature of 96°C (BSC 2004 [DIRS 168489]; DOE 2006 [DIRS 176937], Section 4.6.5). In addition, some of the analyses presented here evaluate whether the alternative loading schemes increase the axial variation of drift-wall temperature along the drift crown, which is used as a measure of dimensionality (i.e., two-dimensional versus three-dimensional) for the temperature field and its effects (CRWMS M&0 1999 [DIRS 107292], Section O.2.2.1).

This report describes work performed by the Near-Field Environment team within the Lead Laboratory organization. This report has been prepared in accordance with *Technical Work Plan for: Near-Field Environment Thermal Management Calculations* (BSC 2005 [DIRS 173963]) and in accordance with SCI-PRO-005, *Scientific Analyses and Calculations*. The analysis and conclusions presented in this report are quality-affecting, as determined in the technical work plan (TWP) (BSC 2005 [DIRS 173963], Section 8).

During the process of analyzing for postclosure temperatures, it was found that the heat generation rates for the first and last half-packages in the discrete-heat-source, drift-scale, thermal conduction, three-dimensional (DDT) submodel described in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) were one-half the value given in *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705], Table 1). A condition report (CR-6521) was initiated to track this error condition. Section 6.9 presents the results of the impact study and concludes that there is insignificant impact to the previously calculated postclosure temperatures.

The thermal analyses presented in this report are based on the state of knowledge of expected waste package heat output and host-rock thermal properties. Ventilation efficiency during the preclosure period is represented based on the current ventilation model as described in this report. For the current status of these inputs and models, there are no limitations on the use of this analysis.

There are two variances from the work planned in the TWP (BSC 2005 [DIRS 173963]). These are the special model run to address the heat generation rate discrepancy for the first and last one-half waste packages in the DDT submodel as noted above, and the calculation of mid-pillar temperature in addition to drift-wall temperature, using analytical line-source solutions. Note that criteria associated with these variances are addressed in Section 4.2 of this report.

The following limitation is identified in the thermal management flexibility analysis. The work described here is based on conduction-only analytical solutions (Sections 6.4 and 6.5) or the DDT thermal-only submodel of the multiscale model (Sections 6.7 and 6.8). These analyses do not include the effects of water percolation or latent heat of vaporization in the host rock. The effects of water in the host rock tend to increase thermal conductance and heat transport, thus lowering thermal gradients and decreasing peak temperatures, wherever water exists in the host rock. The net result is that conduction-only solutions tend to overestimate temperature at mid-pillar locations, and underestimate temperature at the drift wall during dryout. The conduction-only approach provides useful estimates of peak temperatures (within a few degrees centigrade for repository simulations), but greater accuracy can be obtained with thermal-hydrologic analysis, such as that documented for the multiscale model (BSC 2005 [DIRS 173944]).

Planning and preparation of this report was initiated under the Bechtel SAIC Company (BSC) Quality Assurance Program. Therefore, forms and associated documentation prepared prior to October 2, 2006, the date this work transitioned to the Lead Laboratory, were completed in accordance with BSC procedures. Forms and associated documentation executed on or after October 2, 2006, were prepared in accordance with Lead Laboratory procedures.

2. QUALITY ASSURANCE

This document was prepared in accordance with *Technical Work Plan for: Near-Field Environment Thermal Management Calculations* (BSC 2005 [DIRS 173963]). As stated in the TWP (BSC 2005 [DIRS 173963], Section 8), the Quality Assurance Program (DOE 2006 [DIRS 177092]) applies to the work described in this report.

The methods used to control the electronic management of data as required by IM-PRO-002, *Control of the Electronic Management of Information*, were accomplished in accordance with the TWP (BSC 2005 [DIRS 173963], Section 8).

As directed by the TWP (BSC 2005 [DIRS 173963]), this document was prepared in accordance with SCI-PRO-005, *Scientific Analyses and Calculations,* IM-PRO-003, *Software Management*, and SCI-PRO-004, *Managing Technical Product Inputs*, and reviewed in accordance with SCI-PRO-003, *Document Review*.

The work scope of this report involves conducting investigations or analyses of the Engineered Barrier System as defined in LS-PRO-0203, *Q-List and Classification of Structures, Systems, and Components*. The results of this report are relevant to the demonstration of compliance with the postclosure performance objectives prescribed in 10 CFR 63.113 [DIRS 173273].

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3. USE OF SOFTWARE

Both commercial off-the-shelf software and YMP-qualified (baselined) software were used in this analysis. The work was conducted using project standard desktop computers or workstations. The solutions obtained using commercial off-the-shelf software programs (Excel and MathCad) were developed using standard functions and can be readily obtained using other off-the-shelf software programs (i.e., other spreadsheet programs could be used in lieu of Excel). Thus, these software programs are exempt from qualification as stated in Section 2.0 of IM-PRO-003. Use of baselined software for this work is discussed below.

3.1 COMMERCIAL OFF-THE-SHELF SOFTWARE

The following commercial off-the-shelf software was used in ways that were exempt from qualification:

Ventilation Model Analysis:

- EXCEL 97-SR2.

Microsoft Excel is a commercial off-the-shelf software program used for this report on Windows 2000 operating systems. The computations performed using Excel use only standard functions and are documented in sufficient detail in this report to allow an independent technical reviewer to reproduce or verify the results by visual inspection or hand calculation without recourse to the originator. The formulas or algorithms used, and a listing of inputs to and outputs from the formulas or algorithms, are sufficiently documented to allow results to be reproduced using other off-the-shelf software programs. Therefore, this software is exempt according to Section 2.0 of IM-PRO-003. EXCEL 97-SR2 is appropriate for its intended use because it offers the mathematical and graphical functionality necessary to perform and document the numerical manipulations used in this report.

Heat Conduction Analysis:

- MathCad Version 11.2a and Version 13.0.

MathCad Versions 11.2a and 13.0 are commercial off-the-shelf software programs that were used with Windows 2000 to develop information presented in Appendix A and in Output DTN: MO0506SPAPRETM.000 (in MathCad file *Thermal Management Flexibility Analysis.mcd*). The computations performed with MathCad use only standard functions and are documented in detail within the MathCad files and in this document. MathCad Version 11.2a was also used for the line-source analysis presented in Output DTN: MO0509SPALINSC.000. The formulas or algorithms used, and a listing of inputs to and outputs from the formulas or algorithms, are sufficiently documented to allow results to be reproduced using other off-the-shelf software programs. Therefore, this software is exempt according to Section 2.0 of IM-PRO-003. MathCad Versions 11.2a and 13.0 are appropriate for their intended use because they offer the mathematical and graphical functionality necessary to perform and document the numerical manipulations used in this report.

3.2 MULTISCALE THERMOHYDROLOGIC ANALYSIS SOFTWARE

The following qualified software is used in this report to support the DDT submodel analyses presented in Sections 6.6 through 6.9.

3.2.1 NUFT v3.0s

NUFT v3.0s (NUFT V3.0s [DIRS 164541], STN: 10088-3.0s-02) is baselined as qualified software per IM-PRO-003 and is used to conduct the DDT submodel calculations. NUFT v3.0s was obtained from Software Configuration Management (SCM) and run on Sun workstations with the Sun OS 5.8 operating system. NUFT v3.0s was selected because it solves the governing equations of the mathematical model, is supported by a suite of post-processing software, and imposes no limitations on outputs. The use of NUFT v3.0s for the submodel calculations was within the documented validation range of the software. Therefore, the use of this software was consistent with its intended use.

3.2.2 NUFT v3.0.1s

NUFT v3.0.1s (NUFT V3.0.1s [DIRS 166636], STN: 10130-3.0.1s-01) is baselined as qualified software per IM-PRO-003, and is used to conduct all of the nested-mesh model calculations in the model validation exercises for the multiscale model (BSC 2005 [DIRS 173944]). NUFT v3.0.1s was obtained from SCM and run on Sun workstations with the Sun OS 5.8 operating system. NUFT v3.0.1s was selected because nested meshes are a feature of this newer version. Because its use was within the documented validation range of the software (see Section 3.2.1), it was consistent with its intended use.

3.2.3 RADPRO v4.0

RADPRO v4.0 (RADPRO V4.0 [DIRS 164273], STN: 10204-4.0-00) is baselined as qualified software per IM-PRO-003, and was obtained from SCM and run on a Sun workstation with a Sun OS 5.8 (Solaris 8) operating system. RADPRO v4.0 was selected because it calculates the radiative heat transfer coefficients in the emplacement drift (in accordance with BSC 2005 [DIRS 173944], Section 6.2.3.3) without limitations on its output. Its use was consistent with its intended use and within the documented validation range of the software. Because this software is only used to conduct simple arithmetic functions, it is not applicable to identify validation ranges or limitations of use.

3.2.4 XTOOL v10.1

XTOOL v10.1 (XTOOL V10.1 [DIRS 148638], STN: 10208-10.1-00) is baselined as a qualified software routine per IM-PRO-003, and was obtained from SCM and run on a Sun workstation with a Sun OS 5.6.1 operating system. XTOOL v10.1 is used to generate graphical representations of the results given in the NUFT and MSTHAC v7.0 time-history files (which are files with the suffix *.ext). XTOOL v10.1 was developed specifically for interrogating NUFT output. Because this software is only used to generate graphical displays of data, it is not applicable to identify validation ranges or limitations of use.

3.2.5 MSTHAC v7.0

MSTHAC v7.0 (MSTHAC V7.0 [DIRS 164274], STN: 10419-7.0-00) is baselined as qualified software per IM-PRO-003, and was obtained from SCM and run on a Sun workstation with a Sun OS 5.8 (Solaris 8) operating system. MSTHAC v7.0 integrates the results of NUFT submodel calculations to predict the multiscale thermal-hydrologic conditions in the emplacement drifts and adjoining host rock throughout the repository area. MSTHAC v7.0 was developed specifically for this task, which involves the abstracting of the NUFT output. Because MSTHAC integrates the results of NUFT submodel calculations, its validation range is the same as that described for NUFT v3.0s (Section 3.2.1).

3.2.6 Heatgen_ventTable_emplace v1.0

The software routine Heatgen_ventTable_emplace v1.0 (Heatgen_ventTable_emplace V1.0 [DIRS 164276], STN: 11039-1.0-00) is baselined as qualified software per IM-PRO-003, and was obtained from SCM and run on a Sun workstation with a Sun OS 5.8 (Solaris 8) operating system. The software routine Heatgen_ventTable_emplace v1.0 modifies a heat generation rate-versus-time table in two ways. First, it can "age" the heat generation table by adding a specified number of years to the time entries. Second, it can account for the heat-removal efficiency of ventilation by multiplying the heat generation rate values by a specified fraction during the specified ventilation period. The software routine Heatgen_ventTable_emplace v1.0 also can incorporate the dependence of the heat-removal efficiency table on distance (along the emplacement drift) from the ventilation inlet. The software routine Heatgen_ventTable_emplace v1.0 was developed specifically for this task, and generates information needed to run NUFT. Because this software is only used to conduct simple arithmetic functions, it is not applicable to identify validation ranges or limitations of use.

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4. INPUTS

4.1 DIRECT INPUTS

The following data were used as direct inputs to the analyses described in Section 6. Qualification status and justification for use of the direct inputs that are obtained from outside sources, as listed in Tables 4-1 through 4-6, are discussed below.

Note that the inputs listed in Table 4-7 are the same as those used in the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 4), because that model defines the base case (postclosure thermal reference case for TSPA). This report analyzes a series of perturbations on that base case. In several instances, the input sources have been superseded since the multiscale report was issued in July of 2005. In other instances, certain inputs used by the multiscale report were already superseded when the report was issued in July of 2005 because of the length of time required to complete the multiscale model and report (the use of such superseded inputs is justified in Section 4 of BSC 2005 [DIRS 173944]).

All uses of superseded sources by the analyses documented in this report are identified and justified in Section 4.1.12. In all cases where superseded design information from an IED was used, the differences between superseded values for the base case (postclosure thermal reference case for TSPA) and current values were tabulated (Table 4-8) and found to be insignificant.

4.1.1 In-Drift Geometry and Ventilation Parameters

Table 4-1 lists various in-drift geometric and preclosure ventilation parameters for input to the analytical ventilation model and analyses described in Section 6. The analytical model does not explicitly account for thermal conduction through the invert, whereas such thermal conduction is included in the previous ANSYS model in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]). A comparison shows that the results are not sensitive to the presence of the invert because of the agreement between the ANSYS and analytical models. Accordingly, the inputs in Table 4-1 are justified for their intended use in this report.

Table 4-1. Emplacement Drift Geometries, Ventilation Flow Rate, Ventilation and Waste Duration

Parameter	Value	Source
Emplacement Drift Diameter (m)	5.5	BSC 2004 [DIRS 168489]
Emplacement Drift Spacing (m)	81	BSC 2004 [DIRS 168489]
Nominal Ventilation Airflow Rate Preclosure (m^3/s)	15	BSC 2004 [DIRS 168489]
Ventilation Duration after Final Emplacement (years)	50	BSC 2004 [DIRS 168489]
Duration of Waste Emplacement (years)	23	BSC 2004 [DIRS 168489]

4.1.2 Waste Package Dimensions and Properties

The repository design information for waste package lengths and diameters is obtained from *Waste Package Configuration [Sheet 1 of 1]* (BSC 2005 [DIRS 173501]). The emissivity of the outer surface of the waste package of Alloy 22 is 0.87 (BSC 2004 [DIRS 169862], Section 4.1.9, Table 4-15).

4.1.3 Waste Package Heat Decay for the Base Case

Waste package thermal power histories for different package types are used in Section 6 to compute average line loads and waste package temperatures. The waste package power histories were obtained from *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705]). This IED presents the waste package thermal power time histories for eight waste packages types, which are arranged for the multiscale model in a unit-cell consisting of six plus two half waste packages (BSC 2005 [DIRS 173944], Section 6.2.8). Also, the IED presents the average line load for this set of waste packages. The commercial spent nuclear fuel (CSNF) packages in this set, consisting of pressurized water reactor (PWR) and boiling water reactor (BWR) waste packages, produce the greatest power output, while the defense high-level waste (DHLW) waste packages produce the least. These waste package power histories and the unit-cell arrangement in the postclosure reference case served as the starting point for developing alternative thermal loading schemes in this report.

Table 4-2 shows the repository average lineal heat load used for the base case as a function of time since waste emplacement. This design information is used as input to the models and analyses described in Section 6.

Table 4-2. Average Waste Package Heat Decay for the Base Case

Time since Emplacement (years)	Design Basis Repository Average (kW/m)
0.000001	1.450E+00
1	1.399E+00
2	1.357E+00
3	1.321E+00
4	1.289E+00
5	1.259E+00
6	1.232E+00
7	1.206E+00
8	1.181E+00
9	1.157E+00
10	1.135E+00
11	1.110E+00
12	1.088E+00
13	1.068E+00
14	1.049E+00
15	1.033E+00
16	1.012E+00
17	9.934E-01
18	9.759E-01
19	9.595E-01
20	9.443E-01
21	9.267E-01
22	9.103E-01

Table 4-2. Average Waste Package Heat Decay for the Base Case (Continued)

Time since Emplacement (years)	Design Basis Repository Average (kW/m)
23	8.950E-01
24	8.805E-01
25	8.666E-01
26	8.525E-01
27	8.382E-01
28	8.245E-01
29	8.114E-01
30	7.992E-01
31	7.858E-01
32	7.730E-01
33	7.610E-01
34	7.493E-01
35	7.381E-01
36	7.262E-01
37	7.150E-01
38	7.042E-01
39	6.938E-01
40	6.838E-01
41	6.733E-01
42	6.632E-01
43	6.535E-01
44	6.441E-01
45	6.351E-01
46	6.258E-01
47	6.169E-01
48	6.083E-01
49	6.000E-01
50	5.920E-01

Source: BSC 2005 [DIRS 173705], Table 1.

4.1.4 Kays and Leung Parameters for Forced Convection

Table 4-3 lists Kays and Leung parameters used in the mixed convection correlation to calculate forced convection heat transfer coefficients. This information is used as input to the analytical ventilation model and analyses described in Section 6.3.

The source by Kays and Leung (1963 [DIRS 160763]) is referenced in the handbook by Rohsenow et al. (1998 [DIRS 169241], reference 111 in Chapter 5: "Forced Convection, Internal Flow in Ducts"). The information from the source is reliable and qualified for the intended use because it is a topic-specific paper published in the *International Journal of Heat and Mass Transfer* and is cited in a handbook (these types of handbooks are considered established fact per SCI-PRO-004). The extent to which this source of information addresses forced convection in annular passages is considered adequate because this topic is well known, as documented here.

Table 4-3. Kays and Leung Parameters for Forced Convection

	Annulus Radius Ratio (r)	Reynolds Number (Re)	Nusselt Number – Inner Surface Condition, Inner Surface Heated Alone (Nu_{ii})	Non-Dimensional Temperature – Inner Surface (θ_i)	Nusselt Number – Outer Surface Condition, Outer Surface Heated Alone (Nu_{oo})	Non-Dimensional Temperature – Outer Surface (θ_o)
Fluid with Prandtl Number = 0.700	0.2	1.00E+04	38.6	0.412	29.4	0.063
		3.00E+04	79.8	0.338	64.3	0.055
		1.00E+05	196	0.286	165	0.049
		3.00E+05	473	0.26	397	0.044
		1.00E+06	1,270	0.235	1,070	0.04
	0.5	1.00E+04	30.9	0.3	28.3	0.137
		3.00E+04	66	0.258	62	0.119
		1.00E+05	166	0.225	158	0.107
		3.00E+05	400	0.206	380	0.097
		1.00E+06	1,080	0.185	1,040	0.09

Source: Kays and Leung 1963 [DIRS 160763], Table 1.

4.1.5 Thermophysical Properties of the Stratigraphic Layers

Tables 4-4 and 4-5 list the thermophysical properties of the repository stratigraphic units. Except for emissivity, these properties are obtained from qualified data found in the Technical Data Management System. The thermal-property data for host rock units in Table 4-4 are from the output of *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). The specific heat data in Table 4-5 are from the output of *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]).

The emissivity values for rocks are from *Fundamentals of Heat and Mass Transfer* (Incropera and DeWitt 1996 [DIRS 108184], Table A.11 for rocks). The range of 0.88 to 0.95 is adopted from sources for hemispherical emissivity of rock at 300 K and is corroborated by handbook values (Knudsen et al. 1984 [DIRS 170057], Table 10-17, pp. 10-51 to 10-52) for normal emissivity of rough silica and rough fused quartz, ranging from 0.8 to 0.93. Therefore, the data are qualified for use as emissivity of the repository host-rock units and the invert ballast material (see Section 4.1.12) in the calculation of ventilation efficiency.

Parameter distributions are only included for the repository host-rock stratigraphic units. These parameters are used as inputs to the models and analyses described in Section 6.

Table 4-4. Thermophysical Properties of the Repository Stratigraphic Units

Unit (UZ Model Layer)	Dry Bulk Thermal Conductivity (W/m·K)		Wet Bulk Thermal Conductivity (W/m·K)		Dry Bulk Density (g/cc)		Matrix Porosity		Lithophysal Porosity	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Tptpul (tsw33)	1.1829	0.2440	1.7749	0.2474	1.8344	0.1496	0.1667	0.0412	0.1228	0.0613
Tptpmn (tsw34)	1.4189	0.2654	2.0741	0.2517	2.1483	0.0932	0.1287	0.0323	0.0254	0.0225
Tptpll (tsw35)	1.2784	0.2511	1.8895	0.2484	1.9793	0.1381	0.1486	0.0340	0.0883	0.0540
Tptpln (tsw36)	1.4900	0.2844	2.1303	0.2676	2.2114	0.0857	0.1058	0.0264	0.0302	0.0253

Unit (UZ Model Layer)	Dry Matrix Thermal Conductivity (W/m·K)		Wet Matrix Thermal Conductivity (W/m·K)		Solid Thermal Conductivity (W/m·K)		Solid Connectivity	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Tptpul (tsw33)	1.3453	0.2639	2.0201	0.2484	2.6011	0.3493	0.8517	0.1158
Tptpmn (tsw34)	1.4553	0.2690	2.1276	0.2519	2.6033	0.3518	0.8476	0.1094
Tptpll (tsw35)	1.3998	0.2640	2.0707	0.2455	2.6030	0.3413	0.8531	0.1130
Tptpln (tsw36)	1.5356	0.2908	2.1958	0.2764	2.6017	0.3505	0.8492	0.1151

Source: DTN: SN0404T0503102.011 [DIRS 169129], *ReadMe_Summary.doc*, Tables 7-10 and 7-11.

NOTE: UZ = unsaturated zone. Nomenclature correlation between stratigraphic units and UZ model layer is based on BSC 2004 [DIRS 169855], Table 6-6.

Table 4-5. Specific Heat of the Repository Stratigraphic Units

Unit	UZ Model Layer	Average Rock Grain Specific Heat (J/g·K)	
		Mean	Std. Dev.
Tptpul	tsw33	0.93	0.12
Tptpmn	tsw34	0.93	0.14
Tptpll	tsw35	0.93	0.13
Tptpln	tsw36	0.93	0.10

Source: DTN: SN0307T0510902.003 [DIRS 164196], *rock_grain_heat_capacity (edited).xls*, worksheet "C_p grain 25-325," rows 6 through 9, columns y and z.

NOTES: T = 25 to 325°C.

Nomenclature correlation between stratigraphic units and UZ model layer is based on BSC 2004 [DIRS 169855], Table 6-6.

4.1.6 Thermophysical Properties of Air

Table 4-6 lists the thermophysical properties of air at one atmosphere, which corresponds to pressure at sea level. This information is used as input to the models and analyses described in Section 6.3.

Table 4-6. Thermophysical Properties of Air

Reference Temperature (K)	Density (kg/m^3)	Specific Heat (kJ/kg·K)	Viscosity 10^7 ($N·s/m^2$)	Kinematic Viscosity 10^6 (m^2/s)	Thermal Conductivity 10^3 (W/m·K)	Thermal Diffusivity 10^6 (m^2/s)	Prandtl Number
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.995	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690

Source: Incropera and DeWitt 1996 [DIRS 108184], Table A.4.

The cited source by Incropera and DeWitt (1996 [DIRS 108184], Table A.4) is qualified for the intended use of the physical properties of air for the following reasons. The data are referenced by Incropera and DeWitt to the third edition of a handbook by Rohsenow et al. (1998 [DIRS 169241], reference number 6 in Chapter 2: "Thermophysical Properties"). The Incropera and DeWitt source cited above is the fourth edition. The information from this source is reliable and qualified for its intended use because it has been in publication through four editions, it is cited in handbooks (which are considered as established fact), it is a textbook (with exercises), and it is widely used in work on thermophysical properties and heat transfer. The extent to which this source of information addresses the thermophysical properties of air is considered adequate because it is presented in a recent textbook.

The repository is located at an elevation where the total pressure is 0.88 atmosphere (BSC 2004 [DIRS 169862], Appendix XIX). This change in total pressure from one atmosphere to 0.88 atmosphere does not affect the specific heat value shown, and does not significantly affect the viscosity or thermal conductivity. The other properties for air shown in Table 4-6 (i.e., kinematic viscosity, thermal diffusivity, and Prandtl number) are derived quantities and need no further discussion.

Because the specific heat has units of energy per unit mass per degree K, the volumetric heat capacity depends on the gas density, which can be predicted using the ideal gas law. The heat capacity of an ideal gas does not depend on pressure (Reid et al. 1977 [DIRS 130310], Section 7-1), and air behaves as an ideal gas around one atmosphere total pressure because its compressibility factor (usually denoted as Z) is close to unity, which defines an ideal gas (Reid et al. 1977 [DIRS 130310], Section 3-2). The compressibility at conditions of interest can be determined from reduced properties. Using a critical pressure of 37.2 atmospheres and a critical temperature of –140.7°C for air (Perry et al. 1984 [DIRS 125806], p. 3-111, Table 3-161), the reduced pressure at one atmosphere is $P/P_c = 1/37.2 \approx 0.027$, and the reduced temperature at 100°C is $T/T_c = 373/132.4 \approx 2.8$. According to a generalized compressibility chart for these reduced properties (Reid et al. 1977 [DIRS 130310], Figure 3-1), $Z \approx 1$ for pressures and temperatures relevant to the ventilation calculations, and thus air behaves as an ideal gas.

The viscosity of air is essentially constant with respect to small pressure changes near one atmosphere (Reid et al. 1977 [DIRS 130310], Figure 9-8). The thermal conductivity of gases at low pressure (up to 10 atmospheres) increases about 1% per atmosphere (Reid et al. 1977 [DIRS 130310], Section 10-5) so that a change of 0.12 atmosphere results in a thermal conductivity relative change of about 0.12%, which is small enough to be ignored.

Therefore, the gas-phase density is the only physical property in Table 4-6 that changes significantly as the pressure changes from one atmosphere to 0.88 atmosphere, and the gas-phase density can be calculated from the ideal gas law in the analytical ventilation model.

4.1.7 Analytical Ventilation Model

The analysis presented in Section 6.3 is based on the analytical ventilation model from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]) and is obtained from DTN: MO0307MWDAC8MV.000 [DIRS 165395] (spreadsheet *Analytical-LA-Coarse-800m.xls*). The analytical model as obtained from this source performs preclosure ventilation during the preclosure period from 1 to 50 years. As discussed in Section 6.3, this range has been extended to a maximum of 100 years.

4.1.8 Atmospheric Pressure at the Repository Horizon

The total pressure at the horizon (elevation) of the repository is estimated as follows. The minimum and maximum elevations of the repository with respect to the repository horizon are 1,039 m and 1,107 m (BSC 2005 [DIRS 176805]). The average elevation is then 1,073 m. Atmospheric pressure at this elevation can be determined from the U.S. Standard Atmosphere as given by White (1986 [DIRS 111015], Figure 2.7 and Table A.6). Since the atmospheric pressure drops off nearly linear up to a few thousand meters (as can be concluded by examining Figure 2.7 in White 1986 [DIRS 111015]), calculate the atmospheric pressure at 1,073 m by linear interpolation from the atmospheric pressures (given in Table A.6 in White 1986 [DIRS 111015]) at elevations of 1,000 and 1,500 m; the pressures are 89,889 and 84,565 Pa. Therefore, the atmospheric pressure at 1,073 m is 89,112 Pa, which is 0.879 atmospheres (use the conversions of 1 atmosphere = 101,330 N/m^2 given by Rohsenow et al. 1998 [DIRS 169241], Table 1.15; and 1 Pa = 1 Newton/m^2, as given by Rohsenow et al. 1998 [DIRS 169241], Table 2.4).

The information from White (1986 [DIRS 111015]) as used above is qualified as follows. The information used is atmospheric pressure at two elevations. This type of information is known as the standard atmosphere. This information can also be found in the work by Perry et al. (1984 [DIRS 125806], Table 3-214). The average atmospheric pressure for an elevation of 1,000 m given by White (1986 [DIRS 111015]) is 89,889 Pa, and that given by Perry et al. (1984 [DIRS 125806], Table 3-214) is 0.89876 bar. Conversion is performed by multiplying bars by 1×10^5 (Perry et al. 1984 [DIRS 125806], Table 1-6), and using 1 Pa = 1 Newton/m^2. The value given by Perry et al. converts to 89,876 Pa, which agrees reasonably well with the value of 89,889 Pa from White (1986 [DIRS 111015]). Therefore, the information referenced by White (1986 [DIRS 111015]) is considered qualified because it is corroborated in a handbook. The extent to which these data address the topic of interest is adequate because the standard atmosphere is a correct representation of average atmospheric pressure.

4.1.9 Grain Density of Solids

The calculated grain density of solids of 2,550 kg/m^3 differs from the reported grain density of solids of 2,593 kg/m^3 used in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Attachment II) for the lower lithophysal host rock unit (Tptpll). The difference is about 1.7%. The reported value is used in the analytical ventilation model ventilation analysis for consistency with other reported properties. The calculations are presented in Appendix A of this report.

4.1.10 Emissivity of Emplacement Drift Wall

The emissivity at the drift-wall surface is affected by the presence of Bernold-style surface sheets, as described in the report by Michel (1999 [DIRS 163054]), and in *Ground Control for Emplacement Drifts for LA* (BSC 2004 [DIRS 170292]) and *Longevity of Emplacement Drift Ground Support Materials for LA* (BSC 2003 [DIRS 165425]). Bernold-style sheets will be rock-bolted tightly to the drift wall to provide ground control for emplacement drifts. Because the Bernold surface sheets are in good mechanical contact with the surrounding rock, they are in reasonable thermal contact with the host rock as well. Thus, with respect to heat transfer in the drift, the influence of the Bernold sheets is limited to modification of the value of emissivity at the drift-wall surface, compared to the value for exposed rock. The Bernold-style sheets will be made from Stainless Steel Type 316, which has an emissivity range from 0.52 to 0.66, as given by McAdams (1954 [DIRS 161435]).

The referenced source by McAdams (1954 [DIRS 161435]) is cited in the handbook by Perry et al. (1984 [DIRS 125806]) in Chapter 10, "Heat Transmission," in the general references at the beginning of the chapter. Handbooks derive or present no new information and only present what has been published in the open literature, either by textbooks or journal publications. Thus, the information from the McAdams source is considered established fact (SCI-PRO-004, Attachment 1, p. 14) because it appears in the cited handbook. The extent to which this source of information addresses the emissivity of stainless steel is considered adequate because of the citation of this source by the indicated handbook, as documented here.

4.1.11 Effective Thermophysical Properties Used in Ventilation Analysis

Formulae for effective thermal-physical properties used in the analytical ventilation model are derived in Appendix B. The derivation makes extensive use of information from *Soil Physics* (Jury et al. 1991 [DIRS 102010]). The information from this work on derivation of heat capacity for geologic media and volumetric heat capacity for air is described in the fifth edition, published in 1972. The authors, W.A. Jury, W.R. Gardner, and W.H. Gardner, have published extensively on these subjects, as evidenced by their appearance in the bibliography by Hillel (1998 [DIRS 165404]), in which Jury is cited seven times, W.R. Gardner 18 times, and W.H. Gardner three times. The qualifications of the authors are therefore demonstrated to be sufficient through publication and citation history, ensuring that the information obtained from the fifth edition of their textbook is reliable for its use in this report. The extent to which this source of information addresses the topics noted here is considered adequate because the formulae resulting from these derivations are widely used in similar applications.

4.1.12 Direct Inputs to the DDT Submodel

Direct inputs to the DDT submodel of the multiscale model (BSC 2005 [DIRS 173944]) in this report are compiled in Table 4-7. The DDT submodel is used to evaluate the three-dimensional variation of drift-wall temperature. There are five major sections of the table: (1) geometry of the engineered system, (2) geometry of the natural system, (3) properties of the engineered system inside the emplacement drift, (4) properties of the natural system, and (5) boundary conditions for the natural system. These sections are further delineated to distinguish separate data, design information, and parameters.

Design information used in the DDT submodel for this report is the same as presented in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 4). It is important to use the same design information, so that the results can be compared directly to base-case DDT submodel calculations from the multiscale report. Some of this information has been superseded with small changes, typically because it was superseded at the time the multiscale report was issued in July of 2005 (see BSC 2005 [DIRS 173944], Table 4.1-2), and also because it has been superseded since then. These changes pertain to:

- Information presented in *Design and Engineering, D&E/PA/C IED Typical Waste Package Components Assembly 1 of 9* (BSC 2003 [DIRS 165406], Table 1), which is now available in *IED Waste Package Configuration* [Sheet 1 of 1] (BSC 2005 [DIRS 173501], Table 1)

- Information presented in *Interlocking Drip Shield* (BSC 2003 [DIRS 171024], Sheet 2), which is now available in *IED Interlocking Drip Shield [Sheet 1 of 1]* (BSC 2006 [DIRS 178425], Table 1)

- Information presented in *D&E / PA/C IED Emplacement Drift Configuration* (BSC 2004 [DIRS 167040], Figure 1), which has been superseded by *D&E / PA/C IED Emplacement Drift Configuration and Environment* (BSC 2004 [DIRS 168489], Figure 1).

The direct inputs listed in Table 4-7 come from current sources, with exceptions discussed in the following sections. The small differences in dimensions compared with current IED versions do not significantly affect the results of the postclosure analysis described in this report.

Table 4-7. Summary of Input Data and Information for the DDT Submodel

Model Input	Value	Source
Geometry of the Engineered System: Design Information		
Repository emplacement-drift layout (elevations and end-point coordinates for each emplacement drift)	See IED	BSC 2005 [DIRS 176805]
Drift spacing	81 m	BSC 2004 [DIRS 168489], Table 1
Waste package spacing	0.1 m	BSC 2004 [DIRS 168489], Table 1
Drift diameter	5.5 m	BSC 2004 [DIRS 168489], Table 1
Height of 21-PWR AP waste package centerline above invert	1,018 mm	BSC 2004 [DIRS 167040][a]
Invert thickness (height from bottom of drift opening)	0.806 m	BSC 2003 [DIRS 162444][a]
21-PWR AP waste package length	5.165 m	BSC 2003 [DIRS 165406], Table 1[a]
21-PWR AP waste package diameter	1.644 m	BSC 2003 [DIRS 165406], Table 1[a]
21-PWR CR waste package diameter	1.644 m	BSC 2003 [DIRS 165406], Table 1[a]
21-PWR AP waste package inner-vessel thickness	0.0508 m	BSC 2005 [DIRS 173501], Table 1
21-PWR AP waste package outer-barrier thickness	0.020 m	BSC 2005 [DIRS 173501], Table 1
Nominal quantity of 21-PWR AP waste packages in LA-design inventory	4,299	BSC 2005 [DIRS 173501], Table 13
Nominal quantity of 21-PWR CR waste packages in LA-design inventory	95	BSC 2005 [DIRS 173501], Table 13
44-BWR waste package length	5.165 m	BSC 2003 [DIRS 165406], Table 1[a]
44-BWR waste package diameter	1.674 m	BSC 2003 [DIRS 165406], Table 1[a]
44-BWR waste package inner-vessel thickness	0.0508 m	BSC 2005 [DIRS 173501], Table 1
44-BWR waste package outer-barrier thickness	0.020 m	BSC 2005 [DIRS 173501], Table 1
Nominal quantity of 44-BWR AP waste packages in LA-design inventory	2,831	BSC 2005 [DIRS 173501], Table 13
5 DHLW/DOE SNF-Long waste package length	5.217 m	BSC 2003 [DIRS 165406], Table 1[a]
5 DHLW/DOE SNF-Long waste package diameter	2.110 m	BSC 2003 [DIRS 165406], Table 1[a]
5 DHLW/DOE SNF-Long waste package inner-vessel thickness	0.0508 m	BSC 2005 [DIRS 173501], Table 1
5 DHLW/DOE SNF-Long waste package outer-barrier thickness	0.0254 m	BSC 2005 [DIRS 173501], Table 1
Nominal quantity of 5 DHLW/DOE SNF-Long waste packages in LA-design inventory	1,406	BSC 2005 [DIRS 173501] Table 13
5 DHLW/DOE SNF-Short waste package length	3.590 m	BSC 2003 [DIRS 165406], Table 1[a]
5 DHLW/DOE SNF-Short waste package diameter	2.110 m	BSC 2003 [DIRS 165406], Table 1[a]

Table 4-7. Summary of Input Data and Information for the DDT Submodel (Continued)

Model Input	Value	Source
5 DHLW/DOE SNF-Short waste package inner-vessel thickness	0.0508 m	BSC 2005 [DIRS 173501], Table 1
5 DHLW/DOE SNF-Short waste package outer-barrier thickness	0.0254 m	BSC 2005 [DIRS 173501], Table 1
Nominal quantity of 5 DHLW/DOE SNF-Short waste packages in LA-design inventory	1,147	BSC 2005 [DIRS 173501], Table 13
Drip shield length	6.105 m	BSC 2003 [DIRS 171024], Sheet 2[a]
Drip shield width	2.512 m	BSC 2003 [DIRS 171024], Sheet 2[a]
Drip shield thickness (plate-1 or plate-2)	0.015 m	BSC 2006 [DIRS 178425], Table 5
Geometry of Natural System: Parameters		
Grid of three-dimensional unsaturated zone flow and transport model: element/connection file	File: *Grid_LA_3D.mesh*	DTN: LB03023DKMGRID.001 [DIRS 162354]
Grid of three-dimensional unsaturated zone flow and transport model: vertices file	File: *grid2002.grd*	DTN: LB03023DKMGRID.001 [DIRS 162354]
Properties of the Engineered System		
Invert Thermal and Hydrologic Properties: Parameters		
Intragranular permeability (lower lithophysal unit, tswM5; tsw35 matrix continuum for mean infiltration-flux property set)	4.48×10^{-18} m^2	DTN: LB0208UZDSCPMI.002 [DIRS 161243], file: *drift-scale calibrated properties for mean infiltration2.xls*; worksheet: "Drift-scale Cal. Hydro Props."
Porosity of crushed-tuff grains (lower lithophysal unit, tswM5; tsw35 matrix continuum for mean infiltration-flux property set)	0.131	DTN: LB0208UZDSCPMI.002 [DIRS 161243], file: *drift-scale calibrated properties for mean infiltration2.xls*; worksheet: "Drift-scale Cal. Hydro Props."
Intragranular van Genuchten α (lower lithophysal unit, tswM5; tsw35 matrix continuum for mean infiltration-flux property set)	1.08×10^{-5} 1/Pa	DTN: LB0208UZDSCPMI.002 [DIRS 161243], file: *drift-scale calibrated properties for mean infiltration2.xls*; worksheet: "Drift-scale Cal. Hydro Props."
Intragranular van Genuchten m (lower lithophysal unit, tswM5; tsw35 matrix continuum for mean infiltration-flux property set)	0.216	DTN: LB0208UZDSCPMI.002 [DIRS 161243], file: *drift-scale calibrated properties for mean infiltration2.xls*; worksheet: "Drift-scale Cal. Hydro Props."
Intragranular residual saturation (lower lithophysal unit, tswM5; tsw35 matrix continuum for mean infiltration-flux property set)	0.12	DTN: LB0208UZDSCPMI.002 [DIRS 161243], file: *drift-scale calibrated properties for mean infiltration2.xls*; worksheet: "Drift-scale Cal. Hydro Props."
Invert Thermal and Hydrologic Properties: Data		
Bulk density of 4-10 crushed tuff	Table IV-8 in Appendix IV[b]	DTN: GS020183351030.001 [DIRS 163107], Table S02025_001; Rows 321 through 370
Specific heat of 4-10 crushed tuff	Table IV-9 in Appendix IV[b]	DTN: GS000483351030.003 [DIRS 152932], Table S01076_001; Rows 1 through 11

Table 4-7. Summary of Input Data and Information for the DDT Submodel (Continued)

Model Input	Value	Source
Thermal conductivity of 4-10 crushed tuff	Table IV-9 in Appendix IV[b]	DTN: GS000483351030.003 [DIRS 152932], Table S01076_001; Rows 1 through 11x
Emissivity (upper invert surface)	0.88 to 0.95	Incropera and DeWitt 1996 [DIRS 108184], Table A.11 for Rocks[a]
Waste Package Thermal Properties: Design Information		
Weight of 21-PWR AP waste package	43,000 kg	BSC 2003 [DIRS 165406], Table 1[a]
Weight of 44-BWR waste package	43,000 kg	BSC 2003 [DIRS 165406], Table 1[a]
Weight of 5 DHLW/DOE SNF-Short waste package	39,000 kg	BSC 2003 [DIRS 165406], Table 1[a]
Weight of 5 DHLW/DOE SNF-Long waste package	57,000 kg	BSC 2003 [DIRS 165406], Table 1[a]
Emissivity of Alloy 22 (at T = 650°C), which is the outer barrier of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	0.87	DTN: MO0003RIB00071.000 [DIRS 148850]
Mass density of Alloy 22, which is the outer barrier of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	8,690 kg/m^3	DTN: MO0003RIB00071.000 [DIRS 148850]
Mass density of Stainless Steel Type 316, which is the inner vessel of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	7.98 g/cm^3	ASTM G 1-90 [DIRS 103515], Table XI
Mass density of the internal cylinder of the 21-PWR AP waste package	3,495 kg/m^3	BSC 2005 [DIRS 173499], Table 2
Mass density of the internal cylinder of the 44-BWR waste package	3,342 kg/m^3	BSC 2005 [DIRS 173499], Table 2
Mass density of the internal cylinder of the 5 DHLW/DOE SNF-Short waste package	2,175 kg/m^3	BSC 2005 [DIRS 173499], Table 2
Mass density of the internal cylinder of the 5 DHLW/DOE SNF-Long waste package	2,302 kg/m^3	BSC 2005 [DIRS 173499], Table 2
Thermal conductivity of Alloy 22 (at T = 373.15 K), which is the outer barrier of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	11.1 W/m·K	DTN: MO0107TC239938.000 [DIRS 169995], p. 13
Thermal conductivity of Stainless Steel Type 316, which is the inner vessel of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	8.4 BTU/hr-ft-°F at 200°F 8.7 BTU/hr-ft-°F at 250°F	ASME 1995 [DIRS 108417], Section II-D, Table TCD, p. 606

Table 4-7. Summary of Input Data and Information for the DDT Submodel (Continued)

Model Input	Value	Source
Thermal diffusivity of Stainless Steel Type 316, which is the inner vessel of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	0.141 ft^2/hr at 200°F 0.143 ft^2/hr at 250°F	ASME 1995 [DIRS 108417], Section II-D, Table TCD, p. 606
Thermal conductivity of the internal cylinder of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	1.5 W/m·K	BSC 2005 [DIRS 173499], Table 2
Specific heat of Alloy 22 (at T = 373.15 K, or 212°F), which is the outer barrier of the following waste packages: 21-PWR AP, 44-BWR, 5 DHLW/DOE SNF-Short, 5 DHLW/DOE SNF-Long	423.0 J/kg·K	DTN: MO0107TC239938.000 [DIRS 169995], p. 13
Specific heat of the internal cylinder of the 21-PWR AP waste package	378.0 J/kg·K	BSC 2005 [DIRS 173499], Table 2
Specific heat of the internal cylinder of the 44-BWR waste package	395.0 J/kg·K	BSC 2005 [DIRS 173499], Table 2
Specific heat of the internal cylinder of the 5 DHLW/DOE SNF-Short waste package	718.0J/kg·K	BSC 2005 [DIRS 173499], Table 2
Specific heat of the internal cylinder of the 5 DHLW/DOE SNF-Long waste package	731.0 J/kg·K	BSC 2005 [DIRS 173499], Table 2
Waste Package Thermal Output		
Thermal output histories (kW per waste package) for each waste package in the DDT unit cell arrangement	See IED	BSC 2005 [DIRS 173705]
Drip Shield Thermal Properties: Design Information		
Nominal weight of drip shield (for a nominal length of 5.805 m)	5,000 kg	BSC 2006 [DIRS 178425], Table 1
Mass density of titanium	0.163 lb/in^3	ASME 1995 [DIRS 108417], Section II-D, Table NF-2, p. 620
Thermal conductivity of titanium	12.00 BTU/hr-ft-°F at 200°F; 11.85 BTU/hr-ft-°F at 250°F	ASME 1995 [DIRS 108417], Section II-D, Table TCD, p. 611
Thermal diffusivity of titanium	0.331 ft^2/hr at 200°F 0.322 ft^2/hr at 250°F	ASME 1995 [DIRS 108417], Section II-D, Table TCD, p. 611
Emissivity of titanium	0.63	Lide 1995 [DIRS 101876], p. 10-298
Drift-Wall Emissivity: Design Information		
Emissivity of rock	0.88 to 0.95	Incropera and DeWitt 1996 [DIRS 108184], Table A.11 for Rocks[a]
Properties of the Natural System		
Hydrologic Properties of All Unsaturated Zone Model Layers: Parameters		
Matrix and fracture properties of UZ model layers for mean infiltration-flux property set	Table IV-4 in Appendix IV[b]	DTN: LB0208UZDSCPMI.002 [DIRS 161243]

Table 4-7. Summary of Input Data and Information for the DDT Submodel (Continued)

Model Input	Value	Source
Fracture frequency and fracture–matrix interfacial area of UZ model layers for lower-bound, mean, and upper-bound infiltration-flux property sets	Table IV-7 in Appendix IV[b]	DTN: LB0205REVUZPRP.001 [DIRS 159525]
Fracture-contact-length factor	0.0	DTN: LB03023DKMGRID.001 [DIRS 162354], file: *mesh_3dn.dkm* (found after the heading “CONNE” for all elements beginning with “F” in columns 31 to 40)
Bulk Thermal Properties of the Unsaturated Zone Model Layers: Parameters		
Thermal conductivity and bulk density of the GFM2000 layers of the nonrepository layers	Table IV-3a in Appendix IV[b]	DTN: SN0303T0503102.008 [DIRS 162401]
Thermal conductivity and bulk density of the repository horizon GFM2000 layers	Table IV-3a in Appendix IV[b]	DTN: SN0404T0503102.011 [DIRS 169129], file: *ReadMe Summary.doc*, Table 7-10
Specific heat capacity of the mineralogic model layers	Table IV-3a in Appendix IV[b]	DTN: SN0307T0510902.003 [DIRS 164196]
Boundary Conditions of the Natural System: Parameters		
Temperatures at upper boundary (ground surface) of the three-dimensional site-scale UZ flow model	File: *INCON_thm_s32.dat*	DTN: LB991201233129.001 [DIRS 146894][a]
Gas-phase pressures at upper boundary (ground surface) of the three-dimensional site-scale UZ flow model	File: *INCON_thm_s32.dat*	DTN: LB991201233129.001 [DIRS 146894][a]
Temperatures at lower boundary (water table) of the three-dimensional site-scale UZ flow model	File: *INCON_thm_s32.dat* (pertains to an elevation of 730 m)	DTN: LB991201233129.001 [DIRS 146894][a]
Grid of the three-dimensional mountain-scale coupled processes (thermal-hydrologic) model; this grid is related to the file *INCON_thm_s32.dat*, which is used to obtain temperatures and gas-phase pressures at the boundary for the three-dimensional site-scale UZ flow model (above)	File: *MESH_rep.VF*	DTN: LB991201233129.001 [DIRS 146894][a]

[a] Indicates data or information has been superseded, is historical, or not a qualified source; justified later in text; see also Table 4-8 for IED/engineering sources only.
[b] Table/appendix in BSC 2005 [DIRS 173944].

4.1.12.1 Waste Package Lengths

The IED identified in Table 4-7 for waste package lengths is *Design and Engineering, D&E/PA/C IED Typical Waste Package Components Assembly 1 of 9* (BSC 2003 [DIRS 165406]); this is the source used in the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This IED has been superseded by *IED Waste Package Configuration [Sheet 1 of 1]* (BSC 2005 [DIRS 173501]). The impacts of the changes are not significant, as summarized in Table 4-8 and described in Section 4.1.2.1 of the multiscale model report (BSC 2005 [DIRS 173944]).

The differences in waste package lengths between those used in this report and those listed in the current IED (BSC 2005 [DIRS 173501]) are small, ranging from −2.7 to −3.8%. The DDT submodel is used for (1) calculating the temperature difference between the waste package and drip shield, and (2) calculating the longitudinal temperature variations along the drift axis. The slightly shorter waste package lengths given in the current IED (BSC 2005 [DIRS 173501]) would produce slightly less variation of drift-wall temperature along the drift axis. Such a small reduction in axial variability is insignificant compared to the range of temperature variation associated with uncertainty and variability in thermal conductivity of the host rock, and response to alternative thermal loading schemes, as discussed in Section 6.7. The waste package lengths from the superseded IED are therefore justified for use in the DDT submodel, for the sensitivity analyses in this report.

4.1.12.2 Waste Package Diameters

The IED identified in Table 4-7 for waste package diameters is *Design and Engineering, D&E/PA/C IED Typical Waste Package Components Assembly 1 of 9* (BSC 2003 [DIRS 165406]); this is the source used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This IED has been superseded by *IED Waste Package Configuration [Sheet 1 of 1]* (BSC 2005 [DIRS 173501]). The impacts of the changes are not significant, as summarized in Table 4-8 and described in Section 4.1.2.2 of the multiscale model report (BSC 2005 [DIRS 173944]).

As summarized in Table 4.1-2, the differences in waste package diameters between those used in this report, which are obtained from the superseded IED (BSC 2003 [DIRS 165406]), and those listed in the current IED (BSC 2005 [DIRS 173501]) are small, ranging from +0.8 to +4.9%. The slightly larger waste package diameters given in the current IED (BSC 2005 [DIRS 173501]) would have the effect of slightly increasing radiative coupling between the waste package and drip shield, and between the ends of adjacent waste packages. These effects would very slightly decrease the longitudinal temperature variability, and the magnitude would be insignificant compared to the range of temperature variation associated with uncertainty and variability in thermal conductivity of the host rock. The waste package diameters from the superseded IED are therefore justified for use in the DDT submodel, for the sensitivity analyses in this report.

4.1.12.3 Waste Package Weights

The IED identified in Table 4-7 for waste package weights is *Design and Engineering, D&E/PA/C IED Typical Waste Package Components Assembly 1 of 9* (BSC 2003 [DIRS 165406]); this is the source used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This IED has been superseded by *IED Waste Package Configuration [Sheet 1 of 1]* (BSC 2005 [DIRS 173501]), and the impacts of the changes are considered small, as shown in Table 4-8 and also described in Section 4.1.2.3 of the multiscale model report (BSC 2005 [DIRS 173944]).

As summarized in Table 4.1-2 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), the differences in waste package weights between those used in this report, which are obtained from the superseded IED (BSC 2003 [DIRS 165406]), and those listed in the current IED (BSC 2005 [DIRS 173501]) are small, ranging from –3.0 to –7.4%.

The volumetric heat capacity of the waste package is equal to the product of the weight and the specific heat capacity of the waste package. The only manner in which the waste package heat capacity affects the multiscale model results is by influencing the time required for heat transfer from the waste packages to the drift wall to reach a quasi-steady-state condition. Because this quasi-steady-state condition is established much earlier than when peak waste package, drip-shield, and drift-wall temperatures occur, it has an insignificant effect on peak temperatures. If the slightly lower waste package weights given in the current IED (BSC 2005 [DIRS 173501]) were employed in the multiscale model calculations for this report, they would only result in allowing heat transfer from the waste package to the drift wall to reach the quasi-steady-state condition slightly earlier. Furthermore, because the weight of the waste package is much less than that of the surrounding host rock, the waste package heat capacity per unit length of drift is much less than that of the surrounding host rock. As discussed in Section 6.3.2 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), parametric uncertainty of the host-rock heat capacity has an insignificant influence on multiscale model predictions of temperature and relative humidity. Therefore, the waste package weights from the superseded IED are suitable for use in the multiscale model calculations presented in Section 6.7 of this report.

4.1.12.4 Drip Shield Length

The IED identified in Table 4-7 for the drip-shield length is *Interlocking Drip Shield* (BSC 2003 [DIRS 171024]); this is the source used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This IED has been superseded by *IED Interlocking Drip Shield [Sheet 1 of 1]* (BSC 2006 [DIRS 178425], Table 1) and the impacts of the changes are negligible, as summarized in Table 4-8 and also described in Section 4.1.2.4 of the multiscale model report (BSC 2005 [DIRS 173944]).

The drip shield length is used for the DDT submodel to calculate the weight per unit length for the drip shield, which is then used to calculate drip shield total heat capacity. The drip shield weighs much less than the waste packages (Table 4-7), so the effect of a length change on the order of 5% (Table 4-8) is much less than the effect of differences in waste package weight discussed above.

4.1.12.5 Drip Shield Width

The IED identified in Table 4-7 for the drip shield width is *Interlocking Drip Shield* (BSC 2003 [DIRS 171024]); this is the source used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This IED has been superseded by *IED Interlocking Drip Shield [Sheet 1 of 1]* (BSC 2006 [DIRS 178425], Table 1). The change is not significant, as summarized in Table 4-8 and described in Section 4.1.2.5 of the multiscale model report (BSC 2005 [DIRS 173944]).

The drip shield width is used for the DDT submodel to calculate surface area for radiative heat transfer. This mode of heat transfer is so efficient that a difference on the order of 1% (Table 4-8) does not produce significant temperature differences, compared with the effects from uncertainty and variability in host-rock thermal conductivity.

4.1.12.6 Invert Thickness

The IED identified in Table 4-7 for the invert thickness, or height from the bottom of the drift opening, has been cancelled; this is the source for the value of 0.806 m used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The current source for this information is *Repository Subsurface Emplacement Drifts Steel Invert Structure Plan & Elevation* (BSC 2004 [DIRS 169503]), which gives an invert height of 2 feet, 10 inches. This dimension converts to 0.8636 m (using 0.3048 ft/m from Perry et al. [DIRS 125806], Table 1-6). Using an invert height of 0.806 m is justified because it replicates the dimensions used in the published multiscale model report (BSC 2005 [DIRS 173944]), and because the small difference (approximately 6 cm) has little effect on heat transfer through the invert. Thermal conductivity of the invert ballast is low (0.2 W/m·K; see BSC 2005 [DIRS 173944], Table IV-9) compared to the host rock (BSC 2005 [DIRS 173944], Table IV-3a), so relatively little heat moves through the invert, and a small change in the invert thickness does not significantly affect local temperatures.

4.1.12.7 Height of 21-PWR AP Waste Package Centerline above the Invert

The IED identified in Table 4-7 for the location of the 21-PWR AP waste package centerline above the invert is *D&E / PA/C IED Emplacement Drift Configuration* (BSC 2004 [DIRS 167040]), which has been superseded by *D&E / PA/C IED Emplacement Drift Configuration and Environment* (BSC 2004 [DIRS 168489]). The impacts of the change are negligible, as summarized in Table 4-8 and described in Section 4.1.2.7 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Table 4-8. Changes to the Waste Package and Drip Shield Design Information

Model Input	Superseded IED		Current IED		Relative Change in Value
	Value	Source	Value	Source	
21-PWR AP waste package length	5.165 m	BSC 2003 [DIRS 165406], Table 1	5.024 m	BSC 2005 [DIRS 173501], Table 1	−2.7%
21-PWR AP waste package diameter	1.644 m	BSC 2003 [DIRS 165406], Table 1	1.718 m	BSC 2005 [DIRS 173501], Table 1	+4.5%
21-PWR CR waste package diameter	1.644 m	BSC 2003 [DIRS 165406], Table 1	1.718 m	BSC 2005 [DIRS 173501], Table 1	+4.5%
Weight of 21-PWR AP waste package	43,000 kg	BSC 2003 [DIRS 165406], Table 1	41,100 kg	BSC 2005 [DIRS 173501], Table 1	−4.4%
44-BWR waste package length	5.165 m	BSC 2003 [DIRS 165406], Table 1	5.024 m	BSC 2005 [DIRS 173501], Table 1	−2.7%
44-BWR waste package diameter	1.674 m	BSC 2003 [DIRS 165406], Table 1	1.756 m	BSC 2005 [DIRS 173501], Table 1	+4.9%
Weight of 44-BWR waste package	43,000 kg	BSC 2003 [DIRS 165406], Table 1	41,700 kg	BSC 2005 [DIRS 173501], Table 1	−3.0%
5 DHLW/DOE SNF-LONG waste package length	5.217 m	BSC 2003 [DIRS 165406], Table 1	5.059 m	BSC 2005 [DIRS 173501], Table 1	−3.0%
5 DHLW/DOE SNF-LONG waste package diameter	2.110 m	BSC 2003 [DIRS 165406], Table 1	2.126 m	BSC 2005 [DIRS 173501], Table 1	+0.8%
Weight of 5 DHLW/DOE SNF-LONG waste package	57,000 kg	BSC 2003 [DIRS 165406], Table 1	53,100 kg	BSC 2005 [DIRS 173501], Table 1	−6.8%
5 DHLW/DOE SNF-SHORT waste package length	3.590 m	BSC 2003 [DIRS 165406], Table 1	3.453 m	BSC 2005 [DIRS 173501], Table 1	−3.8%
5 DHLW/DOE SNF-SHORT waste package diameter	2.110 m	BSC 2003 [DIRS 165406], Table 1	2.126 m	BSC 2005 [DIRS 173501], Table 1	+0.8%
Weight of 5 DHLW/DOE SNF-SHORT waste package	39,000 kg	BSC 2003 [DIRS 165406], Table 1	36,100 kg	BSC 2005 [DIRS 173501], Table 1	−7.4%
Drip-shield length	6.105 m	BSC 2003 [DIRS 171024], Sheet 2	5.805 m	BSC 2006 [DIRS 178425], Table 1	−4.9%
Drip-shield width	2.512 m	BSC 2003 [DIRS 171024], Sheet 2	2.533 m	BSC 2006 [DIRS 178425], Table 1	+0.8%
Height of 21-PWR AP waste package centerline above invert	1018 mm	BSC 2004 [DIRS 167040], Figure 1	1050.9 mm	BSC 2004 [DIRS 168489], Figure 1	+3.2%

The difference between the value used in the DDT submodel and the current IED is small, approximately 33 mm (+3.2%). This dimension determines the position of the waste package above the invert in the DDT submodel. The only effect of the difference is on radiative heat transfer between the waste package and drip shield, and thus on the temperature difference between the waste package and drip shield. This small difference is insignificant with respect to the geometric approximation of the waste package and drip shield in the DDT submodel (BSC 2005 [DIRS 173944], Section 6.2.8), and compared with the axial variation of waste package and drift-wall temperatures, as discussed in Section 6.7. The height information from the superseded IED is therefore justified for use in the DDT submodel, for the sensitivity analyses in this report.

4.1.13 Direct Inputs to the Thermal Conduction-Only Analyses Using Analytical Solutions

Direct inputs for use of thermal conduction-only analytical solutions are: the average thermal line-load; thermal conductivity, heat capacity, and bulk density of the host rock; the end-point coordinates for all emplacement drifts; and physical properties of liquid water.

4.1.13.1 Waste Package Heat Decay for the Base Case

The average thermal line-load used in conduction-only analysis is obtained from *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705]). This line load is tabulated in Table 4-2 for up to 50 years; additional values beyond 50 years are obtained from the IED.

4.1.13.2 Thermal Conductivity of the Repository Layers

Values for thermal conductivity of the lithophysal host-rock units (Tptpul and Tptpll) are used to evaluate the sensitivity of the mid-pillar peak temperature to thermal conductivity (Table 4-4). This information is obtained from DTN: SN0404T0503102.011 [DIRS 169129] (file: *ReadMe_Summary.doc*, Tables 7-10 and 7-11).

4.1.13.3 Coordinates for the Emplacement Drifts

Coordinates for all the emplacement drifts are used to determine mid-pillar locations for analysis. The repository emplacement drift layout (elevations and end-point coordinates for each emplacement drift) is presented in *IED Subsurface Facilities Layout Geographical Data [Sheet 1 of 1]* (BSC 2005 [DIRS 176805]).

4.1.13.4 Density and Specific Heat Capacity of Liquid Water

The density and specific heat capacity of liquid water are used to calculate the volumetric heat capacity (heat capacitance) for the matrix pore-water fraction of the bulk host rock, using the formulae in Appendix B, for use in the preclosure ventilation analysis (Section 6.3). The value used for the density is 982.3 kg/m^3, and the specific heat capacity used is 4,186 J/(kg·K). These values are interpolated linearly at 62°C, within ranges given by Incropera and DeWitt (2002 [DIRS 163337], Table A.6). The basis for using 62°C as an effective temperature for heat storage by liquid water in the host rock is discussed in Section 6.3, and used in the preclosure ventilation and analytical line-source analyses (Sections 6.3 and 6.4). The interpolated values are corroborated by *Perry's Chemical Engineers' Handbook* (Perry et. al. 1984 [DIRS 125806], Table 3-28 for density of water and Table 3-195 for specific heat of solutions containing no solute). The density of water interpolated from Perry et al. at 62°C is 982.160 kg/m^3, which is within 0.02% of the value given above. The specific heat interpolated from Perry et al. at 62°C is 1.0063 cal/g °C, converted to 4,213.2 J/kg °C (conversion factors from Perry et al. 1984 [DIRS 125806], Table 1-6), which is within 1% of the value given above. Therefore, the values interpolated from Incropera and DeWitt (2002 [DIRS 163337], Table A.6) are corroborated by established-fact values. This information adequately represents the heat storage properties of liquid water, subject to small uncertainties associated with interpolation and different data sources.

4.1.13.5 Host-Rock Specific Heat Capacity

The specific heat capacity of the repository horizons used in the volumetric heat capacity calculations is obtained from DTN: SN0307T0510902.003 [DIRS 164196] (file: *rock_grain_heat_capacity.xls*, worksheet "Cp grain 25-325," rows 8 to 11, columns y and z).

4.1.14 Boundary Conditions of the Natural System

DTN: LB991201233129.001 [DIRS 146894] was used in the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), for temperatures at lower and upper boundaries and gas phase pressures at the upper boundary of the three-dimensional site-scale UZ flow model. Also, DTN: LB991201233129.001 [DIRS 146894] contains the grid of the three-dimensional mountain-scale coupled processes (thermal-hydrologic) model; this grid is related to the file *INCON_thm_s32.dat*, which is used to obtain temperatures and gas-phase pressures at the boundary for the three-dimensional site-scale UZ flow model. DTN: LB991201233129.001 [DIRS 146894] is from a superseded report: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000 [DIRS 144454]). These data have not been updated and are the most up-to-date information. The DDT submodel is not sensitive to the temperature and pressure values used, and thus any variations have no impact.

4.2 CRITERIA

The performance criteria evaluated by the work described in this report are the peak postclosure drift-wall temperature (200°C) and the peak postclosure mid-pillar temperature (96°C), set forth in *Yucca Mountain Project Conceptual Design Report* (DOE 2006 [DIRS 176937], Section 4.6.5). In addition, another criterion evaluated is the package-to-package variability of temperature at the drift wall, in the direction along the drift axis, which is reported as 14°C in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Table 6.3-14).

The conduction-only analyses described in this report provide the accuracy, precision, and representativeness needed to identify alternative thermal loading schemes that meet these performance criteria. The solutions are accurate because they implement mathematical models that have been separately derived and validated for this use (principally BSC 2004 [DIRS 169862] for the ventilation model, BSC 2004 [DIRS 164327] for analytical solutions, and BSC 2005 [DIRS 173944] for the DDT submodel). The precision of analyses performed here is limited by the precision of property values used as input, which are generally the same values used for the models supporting TSPA. For the DDT submodel, precision is also impacted by numerical consistency, which is the same as for the multiscale model.

The DDT submodel is used in this report specifically to evaluate axial package-to-package variation of drift-wall temperature, and is used in the multiscale model for exactly the same purpose, providing the only information on axial variability of in-drift temperatures. Package-to-package temperature differences from the DDT submodel are applied in the multiscale model as additive corrections. Accordingly, the DDT submodel is equally representative as the multiscale model for this application, and DDT submodel variations for alternative thermal loading schemes can be compared directly to the base case.

Representativeness of the conduction-only solutions described in this report is limited because the effects of water in the host rock are not included, as discussed in Section 1. The alternative thermal loading schemes identified here as meeting the performance criteria can be evaluated with more detailed (and computationally intensive) methods to provide mid-pillar and drift-wall temperature predictions that take into account hydrologic or other coupled responses, as appropriate. Heat transfer in the host rock is dominated by thermal conduction, so conduction-only analyses provide good approximations for both near-field and far-field temperature responses.

4.2.1 Yucca Mountain Review Plan Criteria

Multiscale Thermohydrologic Model (BSC 2005 [DIRS 173944]) produces information that directly or indirectly pertains to quantity of water contacting engineered barriers and waste forms. This product evaluates whether certain changes to the postclosure reference case, as implemented in the multiscale model, comply with postclosure temperature criteria. Accordingly, the following acceptance criteria from *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.3.3.3) are applicable to this technical product. As discussed in Section 7.1, some of the criteria applicable to the multiscale model are not included here because they do not apply (BSC 2005 [DIRS 173944]).

Acceptance Criterion 1 – System Description and Model Integration Are Adequate

(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the quantity and chemistry of water contacting engineered barriers and waste forms abstraction process.

(3) Important design features, such as waste package design and material selection, backfill, drip shield, ground support, thermal loading strategy, and degradation processes, are adequate to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting engineered barriers and waste forms.

(6) The expected ranges of environmental conditions within the waste package emplacement drifts, inside the breached waste packages, and contacting the waste forms and their evolution with time are identified. These ranges may be developed to include: (i) the effects of the drip shield and backfill on the quantity and chemistry of

waster (e.g., the potential for condensate formation and dripping from the underside of the shield); (ii) conditions that promote corrosion of engineered barriers and degradation of waste forms; (iii) irregular wet and dry cycles; (iv) gamma-radiolysis; and (v) size and distribution of penetrations of engineered barriers.

(7) The model abstraction for quantity and chemistry of water contacting engineered barriers and waste forms is consistent with the detailed information on engineered barrier design and other engineered features. For example, consistency is demonstrated for: (i) dimensionality of the abstractions; (ii) various design features and site characteristics; and (iii) alternative conceptual approaches. Analyses are adequate to demonstrate that no deleterious effects are caused by design or site features that the U.S. Department of Energy does not take into account in this abstraction.

(12) Guidance in NUREG–1297 (Altman et al. 1988 [DIRS 103597]) and NUREG–1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches, is followed.

Acceptance Criterion 2 – Data Are Sufficient for Model Justification

(1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

Acceptance Criterion 3 – Data Uncertainty Is Characterized and Propagated through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

(2) Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.

(4) Adequate representation of uncertainties in the characteristics of the natural system and engineered materials is provided in parameter development for conceptual models, process-level models, and alternative conceptual models. DOE may constrain these uncertainties using sensitivity analyses or conservative limits. For example, DOE demonstrates how parameters used to describe flow through the EBS bound the effects of backfill and excavation-induced changes.

Acceptance Criterion 4 – Model Uncertainty Is Characterized and Propagated through the Model Abstraction

(1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.

4.3 CODES, STANDARDS, AND REGULATIONS

This analysis provides indirect support for postclosure performance assessment activities being conducted to demonstrate compliance with 10 CFR Part 63 [DIRS 173273], the U.S. Nuclear Regulatory Commission rule on high-level radioactive waste.

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5. ASSUMPTIONS

The following assumptions are used in Sections 6.3, 6.4, and 6.6 as noted below. These assumptions include those applicable from *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]), and *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327]). None of these assumptions requires further confirmation because they are all supported by direct confirming data or evidence.

5.1 REPRESENTATIVE LOCATION WITHIN THE REPOSITORY FOOTPRINT

The location at Northing 234913, Easting 170730 (State Plane Coordinates, meters) within the repository layout is selected to represent host rock stratigraphy and initial conditions for the ventilation analyses (Section 6.3) because it is representative of rock properties, in situ temperature, and stratigraphy information. This location lies within the lower lithophysal unit (Tptpll), which predominates in the repository horizon. In addition, this location is representative because it does not lie on an edge or corner of the repository footprint, and it experiences typical infiltration rates.

5.2 REPRESENTATIVE THERMAL PROPERTIES CORRESPONDING TO A 21-PWR WASTE PACKAGE

The thermal properties for a 21-PWR waste package are used as representative properties for all waste packages emplaced in the repository, for preclosure ventilation modeling (Section 6.3). The rationale is that the PWR and BWR waste package types have similar properties (Table 4-7), and that the PWR and BWR types together will constitute the majority of waste packages in the repository (Table 5-1). Note that in the future the PWR and BWR waste packages will be replaced with the transportation, aging, and disposal (TAD) canister waste package design.

5.3 LIQUID WATER SATURATION OF HOST-ROCK UNITS

The initial water saturation of the stratigraphic layers is assumed to be approximately 90.5%, for the purpose of calculating host-rock specific heat and thermal conductivity (Sections 6.3 and 6.4). The rationale is that this value is typical for the range of data from the densely welded host-rock units, and is evaluated in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]), Sections 6.9 and 6.11). The saturation of 90.5% is corroborated by *Characterization of Hydrogeologic Units Using Matrix Properties* (Flint 1998 [DIRS 100033], Figure 4).

Lithophysal pores are assumed to be 100% air-filled. This is consistent with the treatment in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 5.4), which is the basis for host-rock thermal conductivity values used in the multiscale and ventilation models. The rationale is that large voids do not retain liquid water in situ. This assumption is used in Sections 6.3, 6.4, and 6.6.

5.4 INVERT BALLAST MATERIAL

D&E / PA/C IED Emplacement Drift Configuration and Environment (BSC 2004 [DIRS 168489]) describes the invert ballast material as crushed tuff, referencing the material description in *Estimation of Mechanical Properties of Crushed Tuff for Use as Ballast Material in Emplacement Drifts* (BSC 2004 [DIRS 168138], Sections 8.2 and 8.3, and Figure 9). The multiscale model (BSC 2005 [DIRS 173944]) and the ventilation model (BSC 2004 [DIRS 169862]) assume properties corresponding to measured data for a "4-10 crushed tuff" material. The discrepancy for thermal and hydrologic properties of these two material descriptions was identified in CR-5154.

For the ventilation model, the presence of the invert (and its thermal properties) was shown to be insignificant (BSC 2004 [DIRS 169862], Sections 5.5, 6.5.3, and 6.6.2), so the original values for "4-10 crushed tuff" are acceptable for use in this report.

For the DDT submodel, the invert thermal conductivity value used (0.2 W/m·K) is nearly the same as the value recently estimated in response to CR-5154 (0.21 W/m·K) (BSC 2006 [DIRS 177403], Section 6.2). The difference is well within the uncertainty on this parameter, hence the invert thermal conductivity values used in this report are justified.

5.5 TEMPERATURE OF THE VENTILATION AIR AT THE INLET

The average temperature of the ventilation air at the inlet to the drift is assumed, for ventilation efficiency calculations in Section 6.3, to be equal to the ambient temperature of the host rock at the repository horizon. There are several justifications for this: (1) the ambient temperature of the host-rock repository horizon is within a few degrees of the average annual surface temperature, which ranges between approximately 15°C and 20°C (DTN: LB991201233129.001 [DIRS 146894], *INCON_thm_s32.dat*; BSC 2004 [DIRS 169862], Section 6.5.5); (2) incoming ventilation air will exchange heat with the host rock before it enters the emplacement drifts; and (3) because of a high ventilation efficiency, the ventilation efficiency does not significantly vary with the value of the inlet air temperature. In *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Section 6.11), an analysis of the uncertainty in ventilation efficiency with various input parameters was presented using the Delta method. As described in that report (BSC 2004 [DIRS 169862], Section 6.11), the contribution to variance for the system output (ventilation efficiency) is the product of two factors: (1) the sensitivity of the ventilation efficiency to an input parameter (as represented by the partial derivative to the input parameter), and (2) the variance of the input parameter. Though the uncertainty analysis using the Delta method showed that inlet air temperature was a major contributor to system variance, the overall system variance was several percent, and is considered small. This is because preclosure ventilation for the given preclosure ventilation flow rate, the given geometry of the emplacement drifts, and the given rock properties extract nearly 90% of the heat. If one percent of the heat were extracted, the contribution to system variance under these conditions would be negligible.

Selection of the inlet air temperature equal to the initial rock temperature is also a modeling simplification that prevents heat exchange from the air to the rock during early time immediately after emplacement. If the inlet air is initially warmer or cooler than the rock, the ventilation efficiency is skewed because efficiency is calculated from the temperature difference for the inlet versus the outlet, multiplied by the volumetric heat capacity of the air. Note that this same assumption is used in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Section 5.7).

For the spatial coordinates chosen for preclosure ventilation analysis, the calculated average ambient host-rock temperature for the repository horizon is 22.8°C, calculated using ANSYS between a surface temperature of 17°C and a water table temperature of 28°C (rounded) (BSC 2004 [DIRS 169862], Section 6.5.6).

5.6 WATER TABLE RISE

Climate change to colder, wetter conditions may cause the water table at Yucca Mountain to rise (BSC 2005 [DIRS 174012], Section 5). Water table rise changes the liquid saturation in the rock and thus the thermal properties (conductivity, specific heat) used in the ventilation model (Section 6.3), the thermal conduction-only analytical solutions (Section 6.4), and the DDT submodel (Section 6.6). Water table rise may also increase the importance of convective heat transfer at or below the water table. The analyses presented in this report assume that the effect of water table rise on the evaluations against temperature performance criteria (Section 4.2) is insignificant. This is justified because the potential rock thermal property changes are limited, since the rock units already have appreciable water saturation in their ambient condition (Section 5.3). Also, water table rise is unlikely to occur during the first few hundred years after repository closure. The temperature performance measures used in this report occur during the first few hundred years after closure, prior to projected water table rise. Note that this assumption is justified on other grounds for use in the multiscale model (BSC 2005 [DIRS 173944], Section 5.1.5).

5.7 CONDUCTION-DOMINATED HEAT TRANSFER IN THE HOST ROCK

The analyses presented in this report (Sections 6.3, 6.4, and 6.6) are based on the assumption that thermal conduction dominates other heat transfer mechanisms (i.e., convection in fractures and lithophysae, and latent-heat transfer) in the host rock. Conduction-dominated temperature response has been demonstrated by observation and modeling of the Drift Scale Test (Birkholzer and Tsang 2000 [DIRS 154608], p. 1439). Far-field response is also conduction-dominated because evaporation and transport of moisture is insignificant (BSC 2005 [DIRS 174101], Section 5.1). This assumption is subject to the accuracy limitations described in Section 4.2, and is justified given the purpose of this report.

5.8 WASTE PACKAGE EMPLACEMENT

In evaluating thermal loading arrangements in this report, an assumption is made that all emplacement drifts in the repository are emplaced at the same time, while all drifts receive forced ventilation for 50 years. This is justified because: (1) simultaneous emplacement bounds the temperature at any point, by maximizing the contributions from multiple drifts, and is therefore conservative with respect to meeting postclosure temperature limits; (2) some emplacement drifts will be ventilated for longer than 50 years, thus removing more heat; (3) the time-frame for peak mid-pillar temperature is a few hundred years, which is much longer than the preclosure duration of waste emplacement activities; and (4) the peak drift-wall temperature occurs approximately 20 years after closure but is much more sensitive to local conditions, i.e., the nearest waste package. This assumption is also justified for the multiscale model (BSC 2005 [DIRS 173944], Section 5.2.3). This assumption is used in Sections 6.3, 6.4, and 6.6.

5.9 AVERAGE WASTE PACKAGE DIAMETER

In the ventilation model, the conduction-only model, and the DDT submodel (Sections 6.3, 6.4, and 6.6), the outer diameter for all waste packages is assumed to be 1.644 m, which is the diameter of the 21-PWR AP waste package (Table 4-7). The 21-PWR AP and 44-BWR AP waste packages comprise the majority of waste packages with an appreciable heat output (Table 5-1), and have diameters of 1.644 and 1.674 m, respectively (Table 4), which are well represented by the value of 1.644 m in the DDT submodel. Note that in the future the PWR and BWR waste packages will be replaced with the TAD canister waste package designs. Waste packages that deviate substantially from a diameter of 1.644 m, such as the co-disposal waste packages (Table 4-7), generate much less heat and also comprise a relatively small portion of the overall waste package inventory (Table 5-1). Accordingly, the assumption that all waste packages have 1.644-m diameter is justified for use in the ventilation model, the conduction-only model, and the DDT submodel.

5.10 WASTE PACKAGE SEQUENCE ALONG DRIFTS

Multiscale Thermohydrologic Model (BSC 2005 [DIRS 173944], Figure 6.2-2) presents the so-called “unit-cell” waste package sequence and applies it to all emplacement drifts. The unit-cell arrangement is a repeating array of six plus two half waste packages of different types that captures much of the anticipated waste stream, and is a key part of the postclosure thermal reference case. (The half-packages are situated at the ends of the array, and form full waste packages when implemented using the symmetry conditions of the DDT submodel.) The postclosure reference case is considered to be representative of waste package-to-waste package heat output variability throughout the entire repository. Table 5-1 compares the waste package types in the unit cell with those for the anticipated repository inventory. The unit-cell sequence covers 86.7% of the total inventory, and the percentages of the waste package types are similar to the anticipated inventory. Therefore, the waste package sequence, or unit-cell, is a reasonable representation of the total inventory of waste packages in the repository.

One important detail of the unit-cell arrangement is that DHLW waste packages, which are cooler than CSNF waste packages, are not grouped together but are always placed adjacent to CSNF waste packages. Variations in this detail are explored in the alternative thermal loading schemes evaluated in this report (Section 6.2).

Table 5-1. Summary of Waste Package Types in the Repository Inventory and in the Multiscale Model

Waste Package Type	Nominal Number in Inventory [a]	Nominal Percentage of Inventory	Number Represented in Multiscale[b]	Percentage of Waste Packages Represented in Multiscale
21-PWR AP	4,299	38.4	2.5	35.7
44-BWR AP	2,831	25.4	2.5	35.7
5 DHLW/DOE SNF-Long	1,406	12.6	1	14.3
5 DHLW/DOE SNF-Short	1,147	10.3	1	14.3
Total Number of 21-PWR AP, 44-BWR AP, 5 DHLW/DOE SNF-Long, 5 DHLW/DOE SNF-Short	9,683	86.7	7	100
Total Inventory	11,184	100	7	100

[a] BSC 2005 [DIRS 173501], Table 13.
[b] BSC 2005 [DIRS 173944], Figure 6.2-2 and Table 6.3-13.

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6. SCIENTIFIC ANALYSIS DISCUSSION

Sections 6.1 and 6.2 develop a set of alternative thermal loading schemes differing with respect to waste thermal output, spent-fuel decay age, and makeup of the unit-cell arrangement. These alternatives are selected based on experience with thermal attributes of the postclosure system. They are intended to produce peak temperatures and temperature variation that meet but do not exceed the criteria given in Section 4.2 (i.e., peak drift-wall temperature, peak mid-pillar temperature, and magnitude of package-to-package axial variation of drift-wall temperature). The ensemble of alternatives that meet the criteria defines the limits of a thermal loading envelope derived from the postclosure reference case. The cases defining this envelope will then be available for further analysis with respect to operational constraints, and with respect to the postclosure geomechanical, geochemical, and geohydrologic responses.

6.1 DEVELOPMENT OF ALTERNATIVE THERMAL LOADING SCHEMES FOR ANALYSIS

The postclosure reference case waste package powers and package types are documented in *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705]), which presents the thermal power histories for the six plus two half waste packages in the unit cell. The IED also presents the average line load for this series of waste packages. The CSNF packages (PWR and BWR waste packages) produce the highest power output while the DHLW waste packages produce the least. Note that in the future the PWR and BWR waste packages will be replaced with the TAD canister waste package design. The reference-case thermal power histories and the unit-cell sequence are the starting point for developing alternative thermal loading schemes.

6.1.1 Calculation of the Average Line Load

The waste package dimensions are obtained from *IED Waste Package Configuration [Sheet 1 of 1]* (BSC 2005 [DIRS 173501]) and from *Design and Engineering, D&E/PA/C IED Typical Waste Package Components Assembly 1 of 9* (BSC 2003 [DIRS 165406]). The waste package spacing is obtained from *D&E / PA/C IED Emplacement Drift Configuration and Environment* (BSC 2004 [DIRS 168489]).

In performing this calculation, the initial average waste power heat loading for the unit-cell arrangement (Section 5.10) containing six plus two half waste packages was evaluated. The results of this calculation are presented in Output DTN: MO0506SPAPRETM.000 (file: *Thermal Management Flexibility Analysis.mcd*).

The calculation for the average line load at a specified time for the six-plus-two-halves waste package sequence is given by:

$$P_{Average} = \frac{Half\_PWR + HLW_{5\_Long} + PWR_{Hot} + BWR + BWR_{Adjusted} + HLW_{Short} + PWR + Half\_BWR}{\frac{L_{PWR}}{2} + L_{DHLWL} + L_{PWR} + 2 \cdot L_{BWR} + L_{DHLWS} + L_{PWR} + \frac{L_{BWR}}{2} + 7 \cdot \delta_{space}}$$

(Eq. 6-1)

where

$P_{Average}$	=	Average line load for sequence of waste packages (W/m)
$Half\_PWR$	=	Power of one half of a PWR (W)
HLW_{5_Long}	=	Power of a DHLW long package (W)
PWR_{Hot}	=	Power of a hot PWR (W)
BWR	=	Power of a BWR (W)
$BWR_{Adjusted}$	=	Power of an adjusted BWR (W)
HLW_{Short}	=	Power of a DHLW short package (W)
PWR	=	Power of a PWR (W)
$Half\_BWR$	=	Power of one half of a PWR (W)
L_{PWR}	=	Length of a PWR (5.0244 m)
L_{DHLWL}	=	Length of a DHLW long package (5.0594 m)
L_{BWR}	=	Length of a BWR (5.0244 m)
L_{DHLWS}	=	Length of a DHLW short package (3.4528 m)
δ_{space}	=	Spacing between the waste packages (10 cm).

The results of this calculation show that the average initial line-load, calculated on the basis of revised waste package lengths, is 1.497 kW/m instead of 1.45 kW/m (Table 4-2). This difference reflects small differences in the waste package dimensions. The revised line-load is used for the analyses in this report.

6.1.2 Methodology for Developing Other Waste Package Powers

The methodology for developing alternative thermal loading schemes, as described in the TWP (BSC 2005 [DIRS 173963], Section 2.1.2), is to shift the average line-load decay curve (from the IED) to an earlier age and then multiply this shifted power by a scale factor so that either (1) the power or (2) the slope at 50 years (relative time based on the IED time reference) matches as illustrated in Figures 6-1 and 6-2. The reason for matching at 50 years is because 50 years is the ventilation duration used in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Table 4.1-1). The shift-and-multiply operations facilitate generation of alternative thermal loading schemes that:

(1) Produce peak drift-wall temperatures that approach but do not exceed 200°C (scaling the unit-cell arrangement is a simple way to do this)

(2) Preserve the same ratios of thermal power output for adjacent waste packages as the postclosure reference case, to examine thermal flexibility within the constraint of the unit-cell arrangement but with greater thermal output, i.e., younger age

(3) Preserve the package-to-package axial variation of drift-wall temperature, by scaling up the output of the entire unit-cell array.

This scaling is not expected to preserve exactly the axial variation of drift-wall temperature, because radiant heat transfer (from waste package to drip shield to drift wall) is not linear with respect to temperature. However, radiative heat transfer is nearly linear if temperature changes and differences are small.

Other waste package sequences to be considered may include the unit-cell from the reference case, but with the DHLW packages replaced by either PWR or BWR packages. Such an arrangement could expand the envelope of waste package powers that can be emplaced and maintain the drift-wall temperature-variation criterion.

The shift in time of waste package powers described above suggests the use of an invariant time scale, the time out of reactor (TOOR). The age of spent nuclear fuel (SNF) can thus be expressed as TOOR or time of emplacement. The TOOR can be used as a convenient descriptor of both thermal output and decay characteristics for a spent-fuel waste package.

In *Repository Subsurface Waste Emplacement and Thermal Management Strategy* (CRWMS M&O 1998 [DIRS 105230], Section 4.3.2), the average SNF assembly ages are considered. The average assembly ages for CSNF characteristics upon receipt at the repository are:

- 25.9 years TOOR with 39.56 GWd/MTU burnup and 3.69% enrichment for PWR spent fuel assemblies

- 27.2 years TOOR with 32.24 GWd/MTU burnup and 3.00% enrichment for BWR spent fuel assemblies.

Note that the average TOOR can be calculated on the basis of length or initial waste package power for the four waste packages in the unit-cell waste package sequence. The weighting based on length is:

$$Spent\_Fuel\_Age = \frac{\sum_{i=1}^{4} PWR_i \cdot L_i}{\sum_{i=1}^{4} L_i} \qquad \text{(Eq. 6-2)}$$

and the weighting expressed based on power is:

$$Spent\_Fuel\_Age = \frac{\sum_{i=1}^{4} PWR_i \cdot Q_i}{\sum_{i=1}^{4} Q_i} \qquad \text{(Eq. 6-3)}$$

where

Spent_Fuel_Age	=	Average age of the spent fuel
PWR_i	=	Age of the *i*th waste package
L_i	=	Length of the *i*th waste package
Q_i	=	Initial waste package power of the *i*th waste package.

For the average line-load from the postclosure reference case, the average TOOR of the spent fuel can be determined by weighting on the basis of length for the four PWR and BWR waste packages (note that in the future the PWR and BWR waste packages will be replaced with the TAD canister waste package design):

$$Spent\_Fuel\_Age = \frac{(2.5122 + 2 \cdot 5.0244) \cdot 25.9 + (2 \cdot 5.0244 + 2.5122) \cdot 27.2}{2.5122 + 2 \cdot 5.0244 + 2 \cdot 5.0244 + 2.5122} = 26.55\, years$$

(Eq. 6-4)

The average TOOR of the spent fuel can also be determined by weighting on the basis of initial waste package power for the four PWR and BWR waste packages, which is justified because the waste package lengths are nearly identical:

$$Spent\_Fuel\_Age = \frac{(5.76 + 11.80 + 11.5) \cdot 25.9 + (7.38 + 7.10 + 3.69) \cdot 27.2}{5.76 + 11.80 + 11.5 + 7.38 + 7.10 + 3.69} = 26.40\, years$$

(Eq. 6-5)

Note that an averaging on the basis of initial line load that accounts for the small differences in the spent fuel (PWR versus BWR) length yields a value of about 26.4 years. For purposes of analysis, this value is rounded to 26 years.

Consider that the average TOOR of SNF in the postclosure reference case is 26 years. Ventilating for 50 years from the end of emplacement then yields an TOOR of 76 years. The postclosure reference case is based on instantaneous emplacement of the waste inventory, whereas waste packages emplaced at the beginning of the emplacement period add 23 years for a total ventilation duration of 73 years. Extended ventilation periods of 73 and 100 years are considered below in addition to 50 years ventilation from the reference case.

Now consider when the thermal output for the postclosure reference case (BSC 2005 [DIRS 173705]) is shifted to an earlier age. The following discussion illustrates this shift and multiplication by a scalar, to represent hotter SNF including fuel with younger TOOR.

Sections 6.1.3 and 6.1.4 develop perturbations of the average thermal line-load for the postclosure reference case to represent CSNF with different characteristics (age and burnup). All heat-generating isotopes exhibit radioactive decay, and the overall heat output of spent fuel can be exactly specified as a sum of exponential decay functions weighted according to energy per decay, and relative isotopic inventory. The postclosure thermal reference case is based on this type of decay and inventory information (note that the reference case corresponds to the 55-MTU/acre DDT submodel of the multiscale model (BSC 2005 [DIRS 173944], Section 6.2.8)) and is thus appropriate as a starting point for the analyses in this report.

The governing equation for radioactive decay of any particular isotope or radionuclide is:

$$P(t) \approx a \cdot \exp(-\lambda \cdot t) \qquad \text{(Eq. 6-6)}$$

where a represents thermal output at zero time (TOOR), λ is the decay constant, and t is time. The sum of exponentials for all isotopes in repository waste forms can be represented using fewer terms as shown in Equation 6-7 . The terms of this equation represent isotopes or groups of isotopes with similar decay constants.

To represent younger spent fuel (e.g., 10 years TOOR) with burnup characteristics similar to the postclosure reference case, the exponentials in Equation 6-7 are shifted to earlier time (replace t by $t+\Delta t$ in every term), and rescaled (replace the coefficients a_i by $C_{power} \cdot a_i$ in each term), to match the reference-case thermal output at closure (Section 6.1.3). Matching the power at closure is selected as a means to ensure that postclosure thermal limits will be met, and the result is tested for three ventilation periods (50, 73, and 100 years).

To represent younger spent fuel (e.g., 10 years TOOR) with greater burnup, the exponential terms are again shifted to earlier time (replace t by $t+\Delta t$ in every term of Equation 6-7), and rescaled (replace the coefficients a_i by $C_{slope} \cdot a_i$ in each term), to match the reference-case decay slope at closure. The constant C_{slope} is determined from rescaling Equation 6-7 and matching the time-derivative (i.e., slope) to that of the reference case at closure (Section 6.1.4). This representation is appropriate because the initial thermal output of high-burnup spent fuel at emplacement is strongly influenced by decay of relatively short-lived fission products that are insignificant at the time of closure.

6.1.3 Shifting Then Matching Power Output

The reference-case average line-load (Figure 6-1) (BSC 2005 [DIRS 173705]) can be shifted by 16 years to represent younger TOOR for the commercial SNF. The resulting curve is scaled to match the reference case at 76 years TOOR (50 years after emplacement), yielding a maximum average linear power of 1,844 W/m beginning at 10 years TOOR. The reason for shifting by 16 years is that CSNF is typically shipped as early as 10 years TOOR. Fuel elements must spend the first five years out-of-reactor cooling in spent-fuel pools, and allowing a five-year window for handling and transportation gives 10 years TOOR at the repository. The 16-year shift is a reasonable representation of younger fuel shipped to the repository, and other shifts may be considered if needed. Scaling to match power output at closure (representing the TOOR of 10 years plus a ventilation period of 50, 73, or 100 years) with the reference case at 76 years TOOR represents the behavior of younger SNF with burnup characteristics similar to the reference case.

6.1.4 Shifting Then Matching Power Decay Slope

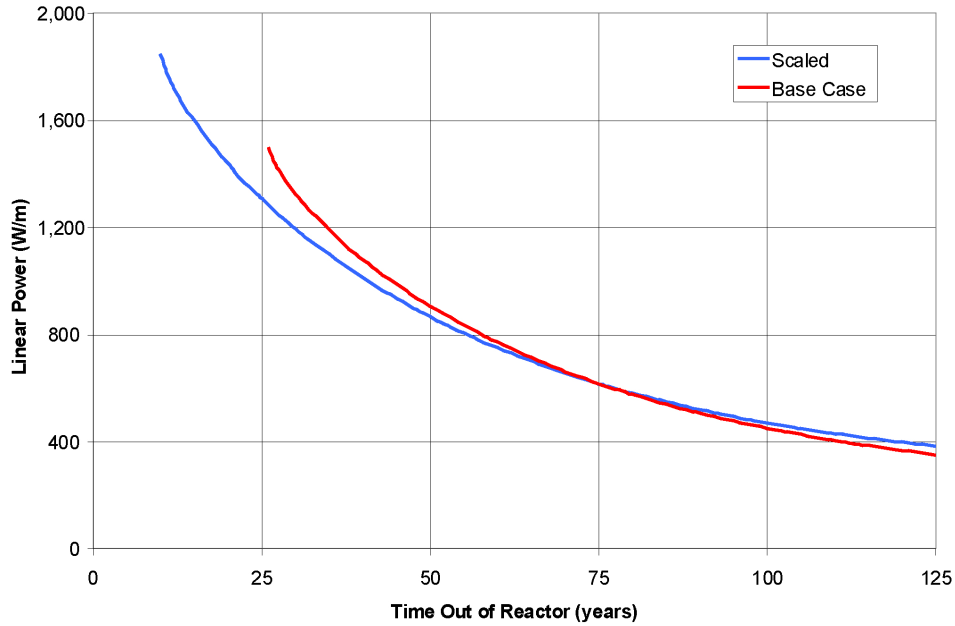
The reference-case average line-load, shifted by 16 years, is matched to the slope of the reference case at 76 years TOOR. This yields a maximum average linear power of approximately 2,100 W/m beginning at 10 years TOOR (Figure 6-2). Scaling to match the rate of decay at closure (representing the TOOR of 10 years plus a ventilation period of 50, 73, or 100 years) with the reference case at 76 years TOOR represents the behavior of younger SNF with greater burnup (greater initial output and greater rate of decay) than matching the power output.

In matching the slope at that time, it was found that the slope of the average line-load curve for the reference case is not exactly smooth when analyzed on one-year increments (Figure 6-3). This does not affect calculation of postclosure temperatures, which are time-integrated measures.

The following procedure was performed to obtain the scale factor that matched the slopes. A series of points from TOOR year 70 to TOOR year 81 were written to an Excel component (not a separate file) in the MathCad file *Thermal Management Flexibility Analysis.mcd* in Output DTN: MO0506SPAPRETM.000. The Excel Solver was used to fit a three-component exponential decay function to thermal output versus time. The three-component exponential function is written as:

$$\text{Heat} = a_1 \exp(-\lambda_1 t) + a_2 \exp(-\lambda_2 t) + a_3 \exp(-\lambda_3 t) \qquad \text{(Eq. 6-7)}$$

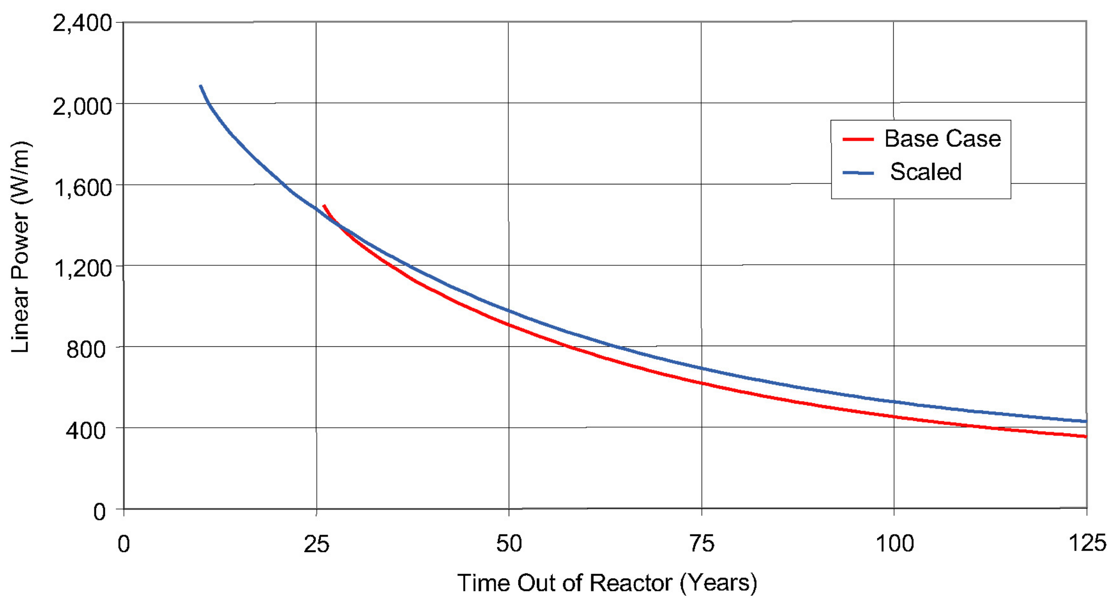
This functional form allows mathematical operations such as time shifting and differentiation. A three-component exponential fit was derived for the reference case average line load. This function can be readily shifted and matched to the reference-case decay curve, or to the slope of the reference-case decay curve, at closure. The results of these operations are summarized in Section 6.2.



Source: Output DTN: MO0506SPAPRETM.000, *Case1.xls*, Chart 1.

NOTE: Figure illustrates shifting the reference-case average line-load (begins at 26 years TOOR) by 16 years, then matching the power to the reference case at 76 years TOOR. Shifted emplacement power is 1,845 W/m at 10 years TOOR.

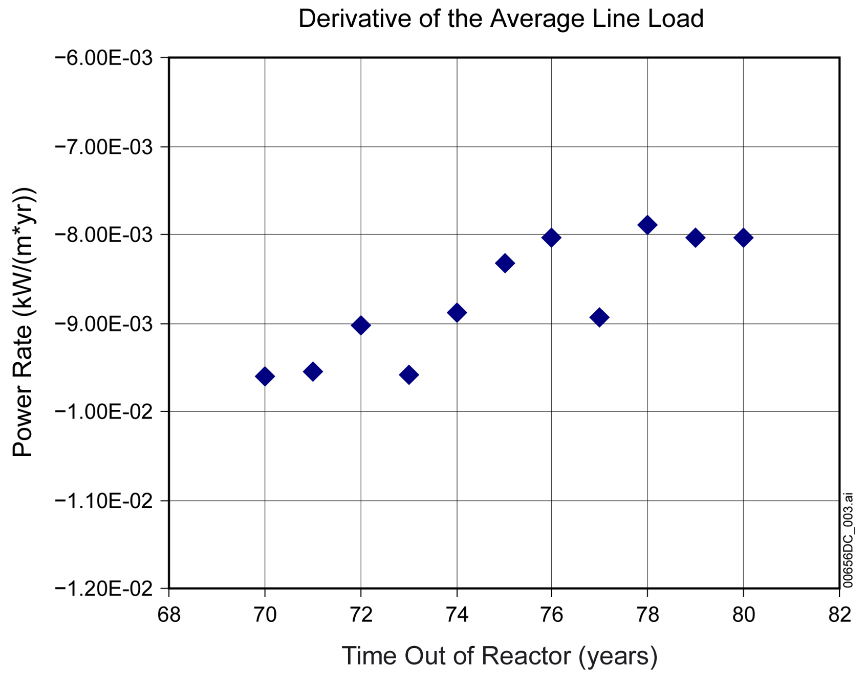
Figure 6-1. Scaling Line Load on a Power Basis



Source: Output DTN: MO0506SPAPRETM.000, *Case4.xls*, Chart 1.

NOTE: Figure illustrates shifting the reference-case average line-load (begins at 26 years TOOR) by 16 years, then matching the slope at 76 years TOOR. Shifted emplacement power is 2,101 W/m at 10 years TOOR.

Figure 6-2. Scaling the Average Line Load on a Slope Basis



Source: Output DTN: MO0506SPAPRETM.000, *Thermal Management Flexibility Analysis.mcd*.

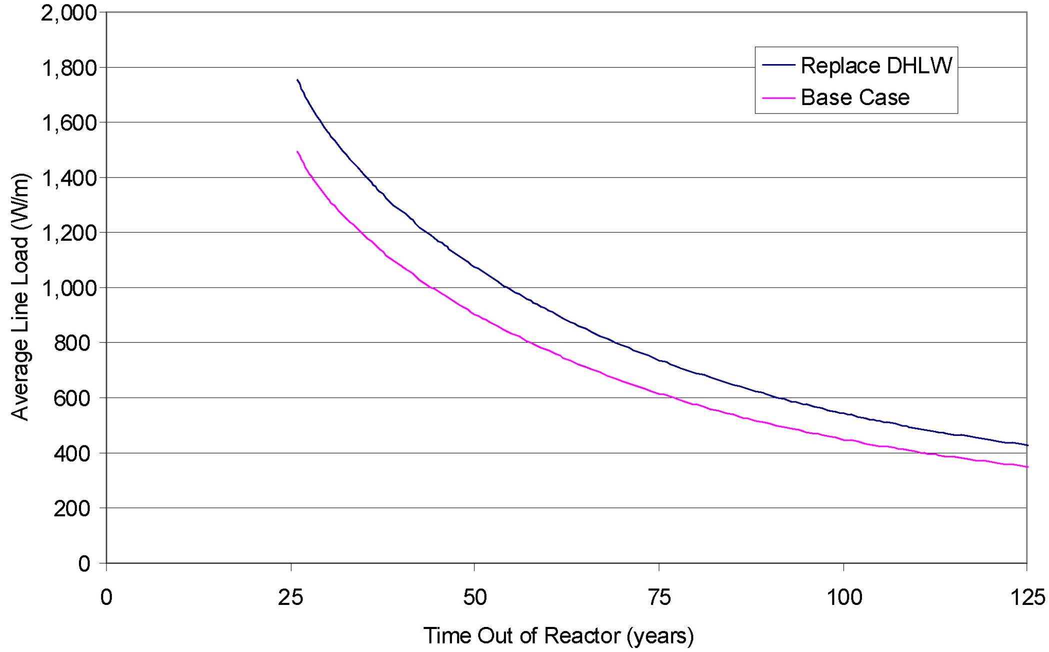
Figure 6-3. Power Decay Rate as a Function of TOOR Based on One-Year Increments

6.1.5 Replacement of DHLW Packages with the Average Line Load

For this case, the DHLW waste packages in the unit-cell arrangement for the reference case are replaced with hypothetical spent-fuel packages having line-loading characteristics equal to the reference case line load. Whereas the reference case line load is a composite of six CSNF packages and two DHLW packages, the contribution of the DHLW packages is relatively small. Thus, using the reference case average line load is similar to scaling the average of the six CSNF packages, and is a convenient estimate for thermal characteristics of typical SNF. The resulting new average line load is presented in Figure 6-4 along with the reference-case line load, illustrating the relative increase. Note that, subsequently, limited analyses are presented to evaluate the average drift-wall temperature, the mid-pillar temperature, and in the case of the multiscale DDT results presented in Section 6.7, the difference in temperatures between the hottest and coldest waste packages for this case. The replacement of DHLW waste packages with spent fuel would result in less waste package-to-waste package variability in this report than in the multiscale model.

6.1.6 Comparison of Average Line Loads for the Several Cases

The results of the development process for alternative thermal loading schemes are compared in Figure 6-5. These analyses are presented numerically in Appendix C. Identification of alternative thermal cases for analysis is presented in Table 6-1. The nine cases use the mean rock mass thermal conductivity from *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Table 4.1-1), and then are repeated with the lower value for rock mass thermal conductivity from the same source, giving a total of 18 cases.



Source: Output DTN: MO0506SPAPRETM.000, *Case7.xls*, Chart 1.

Figure 6-4. Replacement of the DHLW Packages with Hypothetical Packages Having Average Output

Source: Output DTN: MO0506SPAPRETM.000, *Case1.xls*, *Case4.xls*, and *Case7.xls*.

Figure 6-5. Comparison of Average Line Loads for Alternative Thermal Loading Cases with the Reference Case

6.2 SUMMARY OF ANALYSES FOR THERMAL MANAGEMENT CALCULATIONS

The average line load for the postclosure reference case was evaluated by summing contributions from individual packages, and found to be 1.497 kW/m at emplacement, similar to the IED value of 1.45 kW/m from *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705]). The former value is used for the line-load analyses in this report.

The methodology described in Section 6.1 was used to develop nine alternative thermal loading cases represented by average line-load curves that are modified from the postclosure reference case by: (1) shifting 16 years and scaling to match power after 50 years ventilation; (2) shifting 16 years and scaling to match the power decay slope after 50 years ventilation; and (3) substituting hypothetical waste packages with average thermal output for the two DHLW packages in the unit-cell arrangement. Methods (1) and (2) produce thermal loading curves that represent younger SNF that is hotter than the reference case. Method (3) allows for a different type of flexibility in which emplacement of SNF is decoupled from availability of DHLW. Each of the three cases is repeated with 50, 73, and 100 years of ventilation. Each of the nine resulting cases is repeated for mean and lower-bound values of the thermal conductivity, resulting in 18 cases overall (Table 6-1).

Table 6-1. Summary of Analyses for Thermal Management Calculations

Case #	Description	Hypothesis to Be Tested by Thermal Analysis
1	Shift to younger age by 16 years, **match power** at closure with reference case at 76 years TOOR, ventilate for 50 years	Matching power at closure with the reference case at 76 years TOOR and ventilating for 50 years is expected to yield slightly higher peak drift-wall and mid-pillar temperatures than the reference case, with similar drift-wall temperature axial variation.
2	Shift to younger age by 16 years**,** **match power** at closure with reference case at 76 years TOOR, ventilate for 73 years	Matching power at closure with the reference case at 76 years TOOR and ventilating for 73 years is expected to yield slightly higher peak drift-wall and mid-pillar temperatures than the reference case, but less than Case 1, and similar drift-wall temperature axial variation.
3	Shift to younger age by 16 years, **match power** at closure with reference case at 76 years TOOR, ventilate for 100 years	Matching power at closure with the reference case at 76 years TOOR and ventilating for 100 years is expected to yield slightly lower peak drift-wall and mid-pillar temperatures than the preceding case, with similar drift-wall temperature axial variation.
4	Shift to younger age by 16 years, **match slope** at closure with reference case at 76 years TOOR, ventilate for 50 years	Matching slope at closure with the reference case at 76 years TOOR and ventilating for 50 years is expected to yield slightly higher peak drift-wall and mid-pillar temperatures than the reference case, with similar drift-wall temperature axial variation.
5	Shift to younger age by 16 years, **match slope** at closure with TOOR, ventilate for 73 years	Matching slope at closure with the reference case at 76 years TOOR and ventilating for 73 years is expected to yield slightly higher peak drift-wall and mid-pillar temperatures than the reference case, but less than Case 4, and similar drift-wall temperature axial variation.
6	Shift to younger age by 16 years, **match slope** at closure with reference case at 76 years TOOR, ventilate for 100 years	Matching slope at closure with the reference case at 76 years TOOR and ventilating for 100 years is expected to yield slightly lower peak drift-wall and mid-pillar temperatures than the preceding case, with similar drift-wall temperature axial variation.

Table 6-1. Summary of Analyses for Thermal Management Calculations (Continued)

Case #	Description	Hypothesis to Be Tested by Thermal Analysis
7	**Replace** DHLW packages with line average powers, ventilate for 50 years	Replacing DHLW packages is expected to decrease drift-wall temperature variation, with slightly higher peak drift-wall and mid-pillar temperatures than the reference case.
8	**Replace** DHLW packages with line average powers, ventilate for 73 years	Replacing DHLW packages is expected to decrease drift-wall temperature variation, with slightly higher peak drift-wall and mid-pillar temperatures than the reference case, but less than Case 7.
9	**Replace** DHLW packages with line average powers, ventilate for 100 years	Replacing DHLW packages is expected to decrease drift-wall temperature variation, with slightly lower peak drift-wall and mid-pillar temperatures than the preceding case.

NOTES: Analyses 10 through 18 are the same as analyses 1 through 9 except that a lower host-rock thermal conductivity is used. These cases are expected to have higher peak drift-wall temperatures than the corresponding cases.

The times of closure for SNF emplaced at 10 years TOOR and ventilation periods of 50, 73, and 100 years, are respectively 60, 83, and 110 years TOOR. Scaling was performed so that values for power or slope at these closure times were matched to the values for the reference case at 76 years TOOR

6.3 PRECLOSURE VENTILATION MODEL ANALYSIS

The analytical ventilation model is obtained from DTN: MO0307MWDAC8MV.000 [DIRS 165395], particularly the *Analytical-LA-coarse-800m.xls* spreadsheet. The mathematical basis for the ventilation model is given by *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Section 6.4.2). The output includes ventilation efficiencies; drift-wall heat transfer rates; and waste-package, drift-wall, and drift-air temperatures during the preclosure period for a drift of up to 800 m length. The analytical ventilation model consists of a calculation of the thermal "pulse response" for an instantaneous heat source in a homogeneous medium, which is convolved with the heat loss history for segments of a repository drift, and integrated with a network model that represents heat and convective mass transfer within the drift.

These spreadsheet calculations are configured for a ventilation period of 50 years, and they were modified so that the ventilation duration can be specified up to 100 years. The justification for the use of DTN: MO0307MWDAC8MV.000 [DIRS 165395] for ventilation durations up to 100 years is that ventilation duration does not change any of the physical or mathematical bases of the model, including the thermal pulse response calculation (BSC 2004 [DIRS 169862], Section 6.4.2.4).

Other modifications for this report include implementing the alternative thermal loading schemes, different host rock properties, changing the atmospheric pressure and waste package diameter, and changing the drift-wall emissivity to represent the effect of stainless steel Bernold plates as discussed below.

6.3.1 Selection of Thermal Properties for Use in the Thermal Management Flexibility Preclosure Analysis

The rock mass thermal conductivity for the first set of nine analyses is set to the in situ value for the Tptpll using mean porosities on the following basis:

- The rock matrix thermal properties of the Tptpll are $k_{matrixdry} = 1.40 \pm 0.26$ W/(m·K) and $k_{matrixwet} = 2.07 \pm 0.25$ (Table 4-4). The matrix saturation is assumed to be 90.5% (Section 5.3).

- The matrix and lithophysal porosities of the Tptpll are 0.149 ± 0.034 and 0.0883 ± 0.054, respectively (Table 4-4). The matrix porosity is used in the volumetric heat capacity calculation presented in the spreadsheet *Thermal Model of the Workbook Analytical-LA-Coarse-800m REV01.xls* (as modified from DTN: MO0307MWDAC8MV.000 [DIRS 165395]).

- The rock matrix thermal conductivity for the Tptpll unit is modified for in situ liquid saturation as $1.40 + (2.07 - 1.40) \times 0.905 = 2.01$ W/(m·K) using linear interpolation between wet and dry values (the same as implemented in multiscale model).

- Using volume averaging, the in situ rock mass thermal conductivity is calculated as $2.01 \times (1 - 0.088) + 0.028 \times 0.088 = 1.83$ W/(m·K), where 0.028 W/(m·K) is the thermal conductivity of air for temperatures between 300 and 350 K (BSC 2004 [DIRS 169862], Table 4-17). This calculation uses linear scaling as implemented in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). The result is similar to the mean value for bulk, saturated thermal conductivity of 1.89 W/(m·K) for the tsw35 (Tptpll) unit in the multiscale model (BSC 2005 [DIRS 173944], Table IV-3b).

These values are consistent with the values used in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]) and in DTN: MO0307MWDAC8MV.000 [DIRS 165395]. The rock mass value for bulk wet thermal conductivity of the lower lithophysal (Tptpll) host rock unit is 1.83 W/(m·K), as determined in *Thermal Model of the Workbook Analytical-LA-Coarse-800m REV01.xls* (as modified from DTN: MO0307MWDAC8MV.000 [DIRS 165395]).

Engineered Barrier System: Physical and Chemical Environment (BSC 2005 [DIRS 175083], Figure 6.2-2) presents the rock moisture content as a function of temperature as measured from neutron logging of borehole 79. The figure shows that when preclosure drift-wall temperatures in the rock mass are maintained below 96.8°C, then saturations are predicted to remain high due to the fine pore structure and high retention characteristics of welded tuff.

The values for the lower rock mass thermal conductivity are selected on the basis of higher porosities that might be encountered in underground emplacement drifts. The lower rock mass thermal conductivity (k_{rock}) is selected on the following basis for the Tptpul unit (note that a portion of the repository is in the Tptpul unit):

- The $k_{matrixdry}$ and $k_{matrixwet}$ are selected for the Tptpul unit as the average value minus one standard deviation or 1.345 – 0.26 and 2.02 – 0.25 W/(m·K), respectively, or 1.08 and 1.77, from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 4-6) (Table 4-4).

- The matrix and lithophysal porosities are selected as the average value plus one standard deviation or 0.167 + 0.041 and 0.123 + 0.061, respectively, or 0.208 and 0.184, respectively (Table 4-4).

- Using a linear saturation relationship, the rock matrix thermal conductivity is modified for in situ liquid saturation as 1.08 + 0.905 × (1.77 – 1.08) = 1.70 W/(m·K) using linear interpolation between wet and dry values (the same as implemented in the multiscale model).

- Using volume averaging, the bulk rock mass thermal conductivity becomes 1.70 × (1 – 0.184) + 0.184 × 0.028 = 1.39 W/(m·K). This calculation uses linear scaling as implemented in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). The result is similar to the low value for bulk, saturated thermal conductivity of 1.54 W/(m·K) for the tsw33 (Tptpul) unit in the multiscale model (BSC 2005 [DIRS 173944], Table 6.3-23).

The value of 1.39 W/(m·K) for in situ thermal conductivity of the Tptpul unit is a lower bound because it is not up-scaled to represent mainly vertical heat transfer at the scale of the repository. In addition, the variability behaviors of $k_{matrixdry}$, $k_{matrixwet}$, matrix porosity, and lithophysal porosity are statistically independent, and therefore the combined result from the above procedure is very unlikely (i.e., the estimate is a bound).

The specific heat and grain density for the solids fraction of the rock are 930 J/(m·K) and 2,550 kg/m^3, respectively.

The volumetric heat capacity of liquid water (used in the formulae of Appendix B for estimating the effective bulk heat capacity of the host rock) was estimated at 62°C and used over the range from 25°C to 100°C, over which the preclosure ventilation analysis (this section) and the analytical line-source analysis (Section 6.4) represent far-field behavior. These properties change little with temperature, and use of a constant value is a simplification that preserves the linearity of the analytical solutions. Note that including liquid water in the estimation of host rock heat capacity is appropriate for describing far-field temperature, where the host rock does not dry out. It is also useful for describing near-field temperature because the region of dryout is spatially limited, and the repository heat output is large, so that any calculated storage of sensible heat in the region of dryout is not significant. Also, any sensible heat stored in pore water in the near-field during heating is far exceeded by the removal of latent heat by vaporization and transport during dryout (which is not included in the analytical solutions). The approximation at 62°C is accurate to within a few percent for liquid water, and heat storage by water is a small fraction (on the order of 20%) of that stored in the bulk host rock in a wet condition.

The analytical ventilation model was exercised with these property values to produce a thermal pulse response for calculating preclosure ventilation heat-removal efficiency. The thermal conduction-only line-source analytical solution (Section 6.4) was also exercised using these property values.

Additional YMP data for lithophysal porosity of the host rock are available for the upper and lower lithophysal units (Tptpul and Tptpll). Information on lithophysal porosity was compiled for both units in *Drift Degradation Analysis* (BSC 2004 [DIRS 166107], Table E-9) for assessing mechanical properties of lithophysal tuff from large-diameter samples, and for assessing the rock mass unconfined compressive strength. The estimates are similar; for example, the estimated mean lithophysal porosity for the Tptpul unit on the basis of 23 measurements is 0.188, which approximately equals the value of 0.184 for the Tptpul unit used in this analysis.

6.3.2 Preclosure Ventilation Analysis Results

The thermal pulses are documented in Output DTN: MO0506SPAPRETM.000 in the Excel workbooks entitled *Preclosure Thermal Management Flexibility Analysis* and dated June 28, 2005. The listing of these files is presented Table 6-2.

Table 6-2. Files Used in the Preclosure Ventilation Results

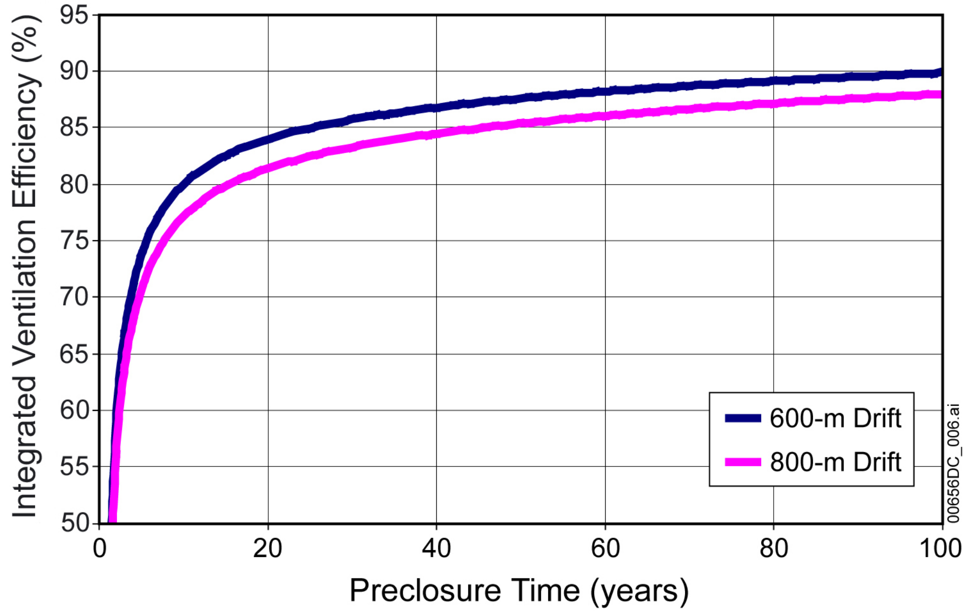
Case Number	Waste Package Power File	Ventilation Analysis File
Tptpll Repository Horizon		
Cases 1 through 3	*Case1.xls*	*Cases13 Ventilation Analysis.xls*
Cases 4 through 6	*Case4.xls*	*Cases46 Ventilation Analysis.xls*
Cases 7 through 9	*Case7.xls*	*Cases79 Ventilation Analysis.xls*
Tptpul Repository Horizon		
Cases 10 through 12	*Case1.xls*	*Cases 1012 Ventilation Analysis.xls*
Cases 13 through 15	*Case4.xls*	*Cases1315 Ventilation Analysis.xls*
Cases 16 through 18	*Case7.xls*	*Cases1618 Ventilation Analysis.xls*

Source: Output DTN: MO0506SPAPRETM.000.

The integrated ventilation efficiencies for the Tptpll and Tptpul repository horizon units are presented in Figures 6-6 and 6-7, respectively. The analysis shows that with increased preclosure ventilation time, the ventilation efficiencies increase to values that are close to 90% after 100 years. The analysis shows that, with the reduced thermal conductivity in the Tptpul unit, the ventilation efficiency is slightly increased. The analysis reflects the fact that when ventilation efficiencies are high during the preclosure period, variations in rock mass thermal conductivity result in integrated ventilation efficiency of several percent. These results are consistent with previous ventilation parametric studies as presented in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Section 6.11). The analysis shows that for the first nine cases, the integrated ventilation efficiencies during the preclosure period are very similar.

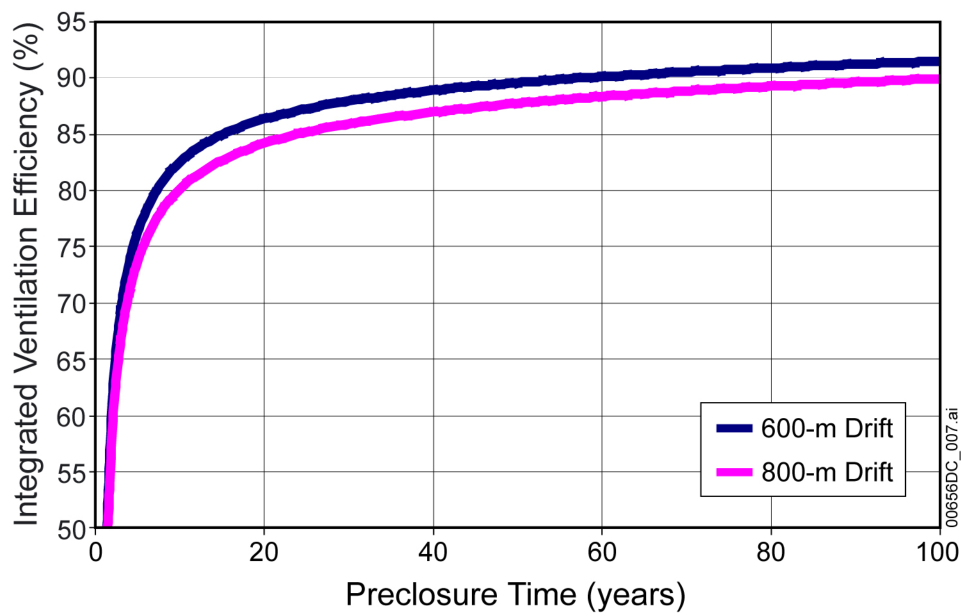
The preclosure temperatures of the waste package, the drift wall, and the ventilation air are presented in Figures 6-8 through 6-10 for the Tptpll repository location for the first nine cases. The temperature results are reported for Continuous Stirred Tank Reactor (CSTR) 04 (see BSC 2004 [DIRS 169862], Section 6.4.2.1, for the description of a CSTR) or approximately 350 m from the inlet drift. This CSTR is near the center of the repository. The temperatures are all below 100°C during the preclosure period. For the Tptpul repository location, the temperatures are presented for CSTR02 since the emplacement drift in this repository horizon is shorter, and CSTR02 would correspond to the center of the emplacement drift. The temperatures scale to line load, i.e., a higher line load results in higher temperatures. In all cases evaluated, the predicted preclosure drift-wall temperature is less than 96°C.

The preclosure temperatures of the waste package, the drift wall, and the ventilation air are presented in Figures 6-11 through 6-13 for the Tptpul repository location for the second nine cases. The temperature results are reported for CSTR02 at an approximate distance of 150 m from the inlet drift. As discussed subsequently, the postclosure temperatures are calculated at a location near the center of the repository for an 800-m drift in the Tptpll unit, and near the edge of the repository for the Tptpul unit. In the latter case, the drift is approximately 400 m long, and the center of the drift corresponds to about 200 m. Again, for all cases evaluated the predicted preclosure drift-wall temperature is less than 96°C.



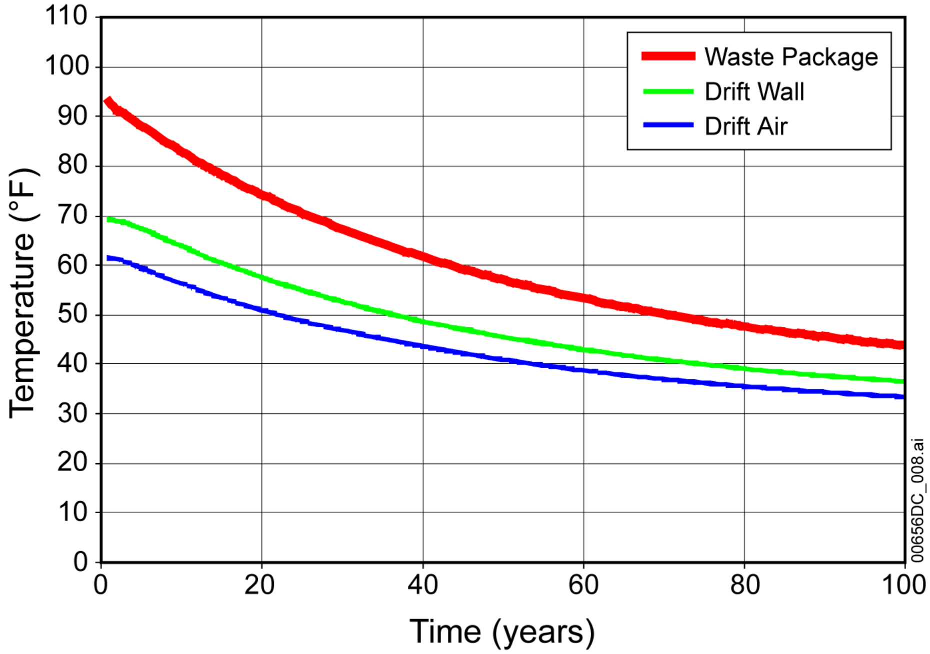
Source: Output DTN: MO0506SPAPRETM.000, *Cases13 Ventilation Analysis.xls*.

Figure 6-6. Integrated Ventilation Efficiency for Cases 1 through 3 in the Tptpll Unit



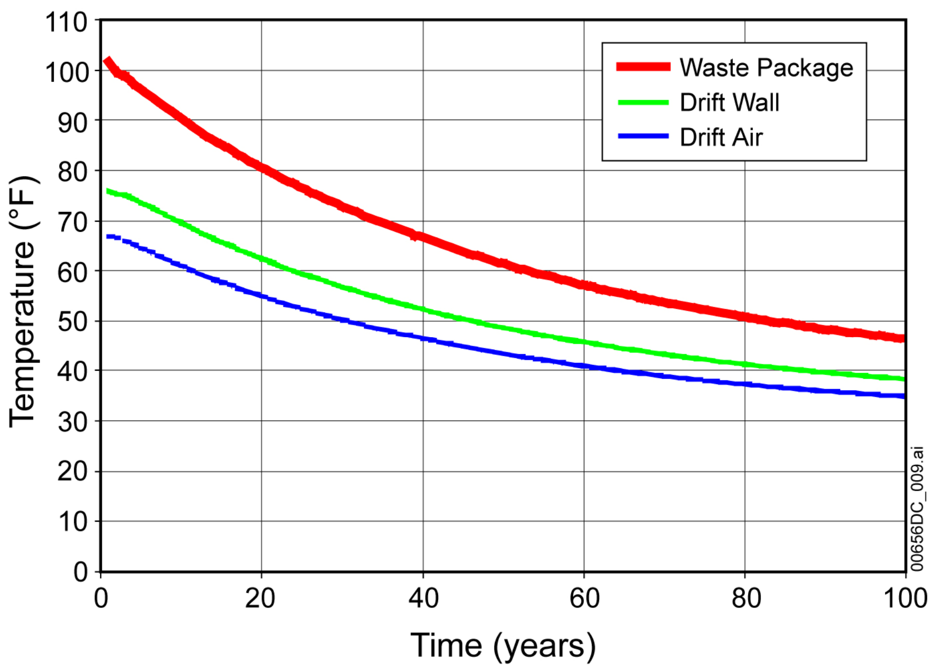
Source: Output DTN: MO0506SPAPRETM.000, *Cases 1012 Ventilation Analysis.xls*.

Figure 6-7. Integrated Ventilation Efficiency for Cases 10 through 12 for the Tptpul Repository Horizon Unit



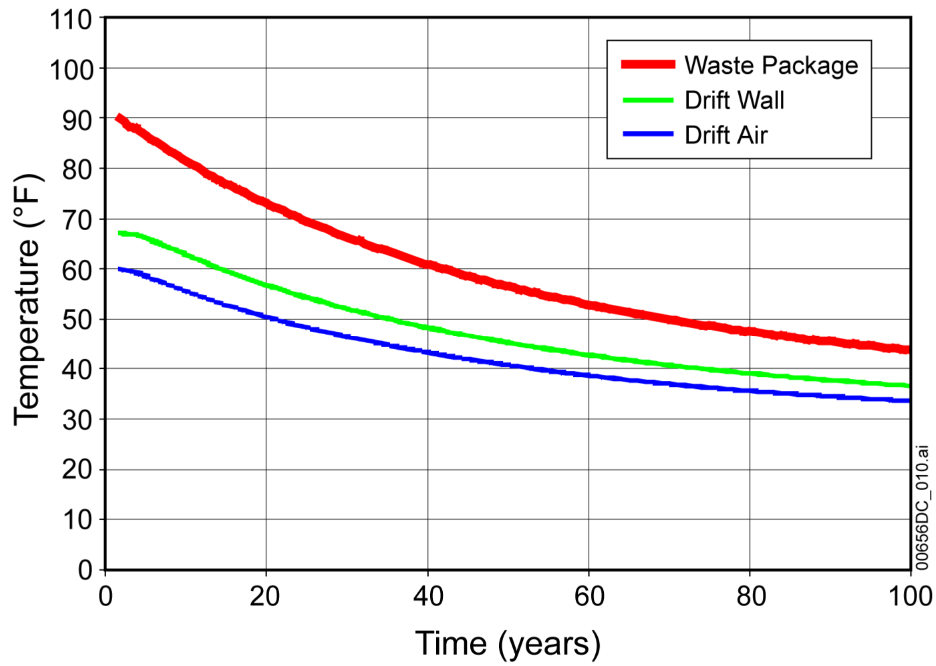
Source: Output DTN: MO0506SPAPRETM.000, *Cases 13 Ventilation Analysis.xls*.

Figure 6-8. Temperatures for CSTR04 during the Preclosure Period for Cases 1 through 3



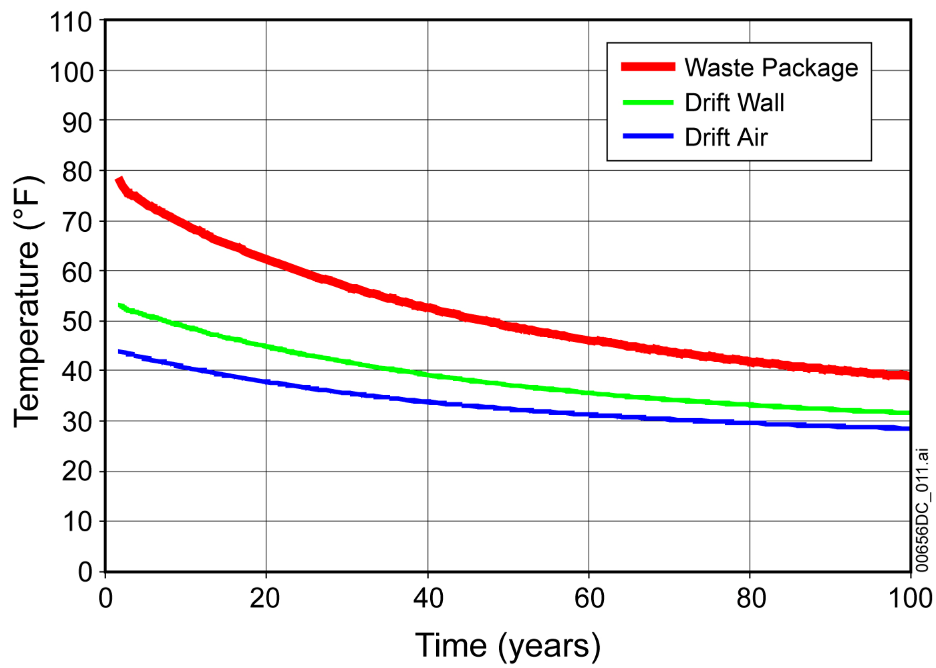
Source: Output DTN: MO0506SPAPRETM.000, *Cases 46 Ventilation Analysis.xls*.

Figure 6-9. Temperatures for CSTR04 during the Preclosure Period for Cases 4 through 6



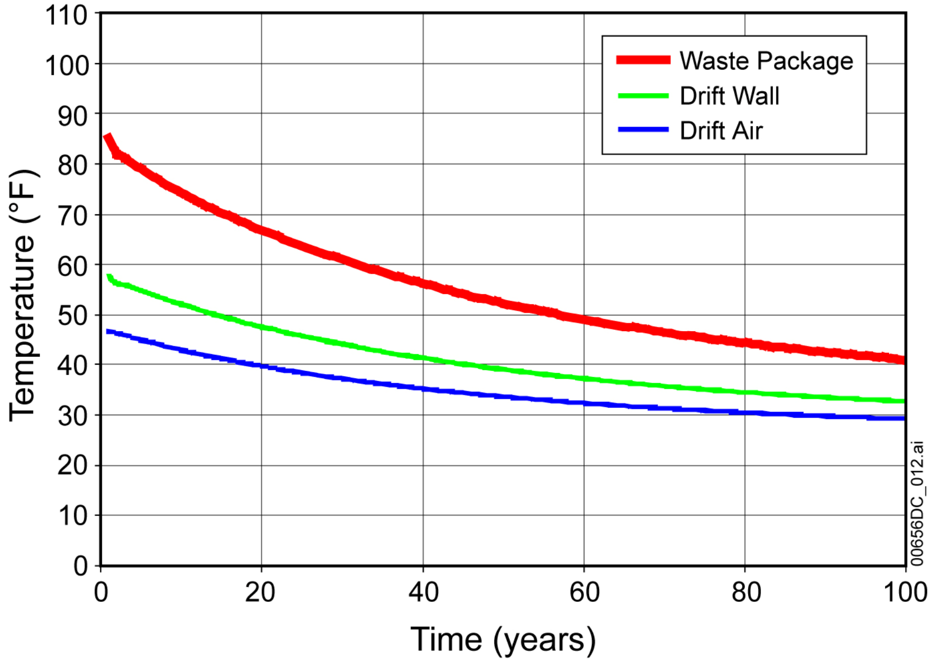
Source: Output DTN: MO0506SPAPRETM.000, *Cases 79 Ventilation Analysis.xls*.

Figure 6-10. Temperatures for CSTR04 during the Preclosure Period for Cases 7 through 9



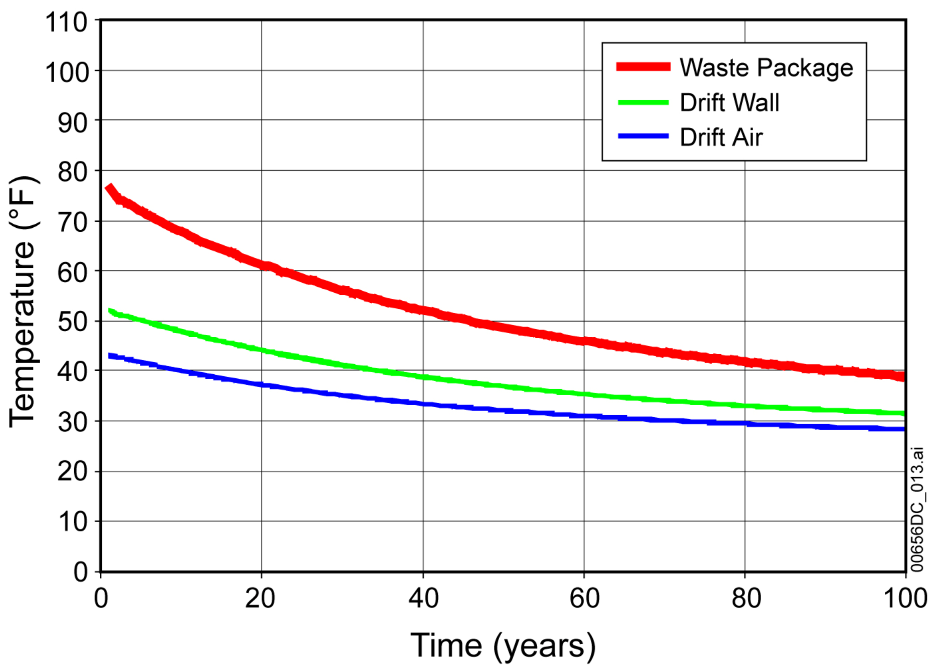
Source: Output DTN: MO0506SPAPRETM.000, *Cases 1012 Ventilation Analysis.xls*.

Figure 6-11. Temperatures for CSTR02 during the Preclosure Period for Cases 10 through 12



Source: Output DTN: MO0506SPAPRETM.000, *Cases 1315 Ventilation Analysis.xls*.

Figure 6-12. Temperatures for CSTR02 during the Preclosure Period for Cases 13 through 15



Source: Output DTN: MO0506SPAPRETM.000, *Cases 1618 Ventilation Analysis.xls*.

Figure 6-13. Temperatures for CSTR02 during the Preclosure Period for Cases 16 through 18

As discussed previously, the base case analysis with modified waste package lengths resulted in an initial line load of 1.49 kW/m. The ventilation analyses presented above incorporated a number of changes to ventilation input parameters such as drift-wall emissivity. The base case ventilation analysis was calculated using the initial line load of 1.45 kW/m for future thermal analyses and is presented in Output DTN: MO0701VENTCALC.000.

6.4 LINE-SOURCE CONDUCTION-ONLY ANALYSIS METHODS

This section presents the line-source calculation method for estimating the drift-wall temperature. This method was developed in *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327], Section 6.3.5.1.1). The line source solution is derived from the transient solution for a continuous point source with heat liberated at a rate q(t) in an infinite medium (Carslaw and Jaeger 1959 [DIRS 100968], p. 261):

$$T_{point}(t,r) = \frac{1}{8 \cdot \rho C_p \cdot (\pi \cdot \alpha)^{3/2}} \cdot \int_0^t \frac{q(t')}{(t-t')^{3/2}} \cdot e^{\frac{-r2}{4 \cdot \alpha \cdot (t-t')}} dt' \qquad \text{(Eq. 6-8)}$$

where

T_{point} = Temperature rise at the point due to a point source *r* distant at time *t*

C_p = Specific heat capacity J/(kg·K)

α = Thermal diffusivity (m^2/sec)

t = Time

t' = Integration variable

r = Radius to a point.

The radial distance from the point source is *r* (Figure 6-14). The initial temperature equals the ambient temperature at the depth of the repository. The distance from the point source to the point at which the temperatures are evaluated is given in *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327], Equation 6.3-5):

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} \qquad \text{(Eq. 6-9)}$$

where

x_0, y_0, z_0 = Source location

x,y,z = Point in space at which the temperature is evaluated.

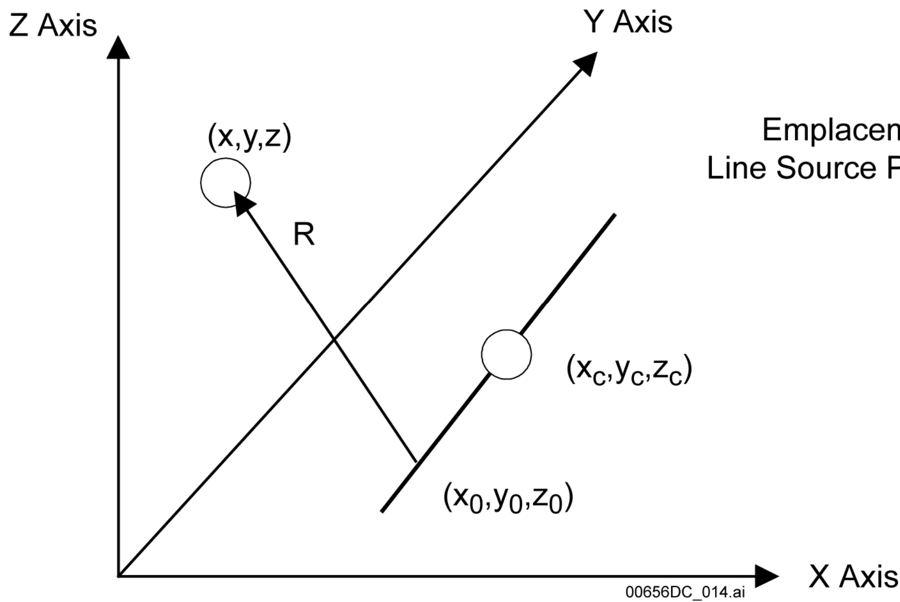


Figure 6-14. Geometry of the Line-Source Calculation in an Infinite Medium

The line source equation is obtained by integrating the point source equation over the length of the emplacement drift (BSC 2004 [DIRS 164327], Equation 6.3-7):

$$T_{line}(t,x,y,z) = \frac{1}{8 \cdot \rho \cdot C_p \cdot (\pi \cdot \alpha)^{3/2}} \cdot \int_0^t \frac{qL(t')}{(t-t')^{3/2}} \cdot e^{\frac{-((x-x_C)^2+(z-z_C)^2)}{4\alpha \cdot (t-t')}} \cdot \int_{y_C-L/2}^{y_C+L/2} e^{\frac{(y-y_0)^2}{4\alpha \cdot (t-t')}} \cdot dy_0 \cdot dt'$$

(Eq. 6-10)

where $qL(t')$ is the line load.

The analytical solution for an infinite domain is extended to the case of a semi-infinite domain by the method of images. A sink of strength equal to the source is reflected across the isothermal plane at $z = z_G$ (ground surface) as shown in Figure 6-15. The solution is the sum of source and sink fields (superposition).

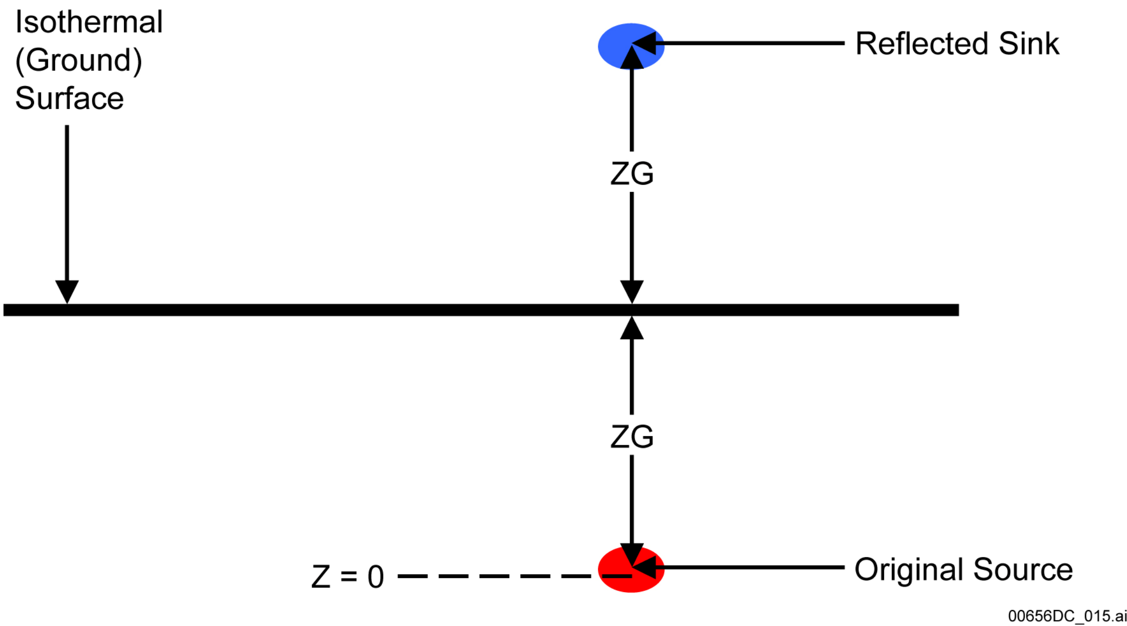


Figure 6-15. Creation of an Isothermal Surface Using the Method of Images

The technique is applicable to the entire line and plane source solutions derived above. Hence:

$$T_{line}(t,x,y,z) \approx T_{line}(t,x,y,z) - T_{line}(t,x,y,z-2\cdot z_G) \qquad \text{(Eq. 6-11)}$$

where the temperature contribution from the sink is evaluated with respect to the sink location. The temperature increase due to a single line in the presence of the isothermal surface becomes:

$$T_{line}(t,x,y,z) = \frac{1}{8\pi\cdot k}\cdot\int_0^t \frac{qL(t')}{t-t'}\cdot e^{\frac{-(x-x_c)^2}{4\cdot\alpha\cdot(t-t')}}\cdot\left(e^{\frac{-(z-z_c)^2}{4\cdot\alpha\cdot(t-t')}} - e^{\frac{-(z-2z_G-z_c)^2}{4\cdot\alpha\cdot(t-t')}}\right)\cdot\left(erf\left(\frac{(y-y_c)+\frac{L}{2}}{\sqrt{4\cdot\alpha\cdot(t-t')}}\right) - erf\left(\frac{(y-y_c)-\frac{L}{2}}{\sqrt{4\cdot\alpha\cdot(t-t')}}\right)\right)\cdot dt'$$

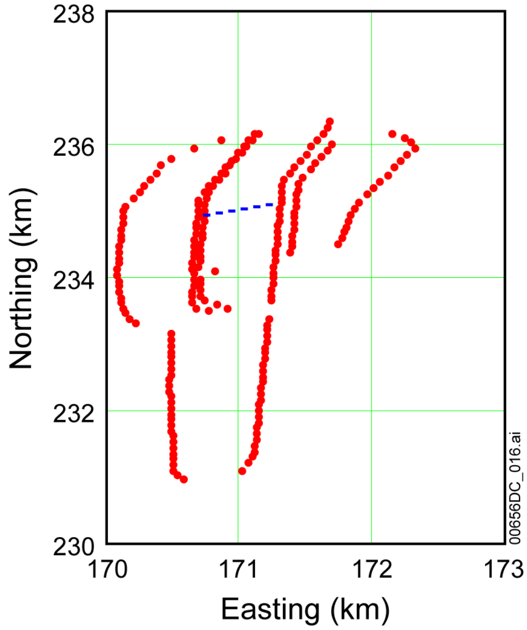
(Eq. 6-12)

where k is the medium thermal conductivity and L is the length of the drift with emplaced waste packages. Now consider the series of sources that represent the various drifts:

$$T_{line}(t,x,y,z) = \frac{1}{8\pi\cdot k}\cdot\int_0^t \sum_{n=1}^{N_{lines}} \frac{qL_n(t')}{t-t'}\cdot e^{\frac{-(x-x_{cn})^2}{4\cdot\alpha\cdot(t-t')}}\cdot\left(e^{\frac{-(z-z_{cn})^2}{4\cdot\alpha\cdot(t-t')}} - e^{\frac{-(z-2z_G-z_{cn})^2}{4\cdot\alpha\cdot(t-t')}}\right)\cdot\left(erf\left(\frac{(y-y_{cn})+\frac{L}{2}}{\sqrt{4\cdot\alpha\cdot(t-t')}}\right) - erf\left(\frac{(y-y_{cn})-\frac{L}{2}}{\sqrt{4\cdot\alpha\cdot(t-t')}}\right)\right)\cdot dt'$$

(Eq. 6-13)

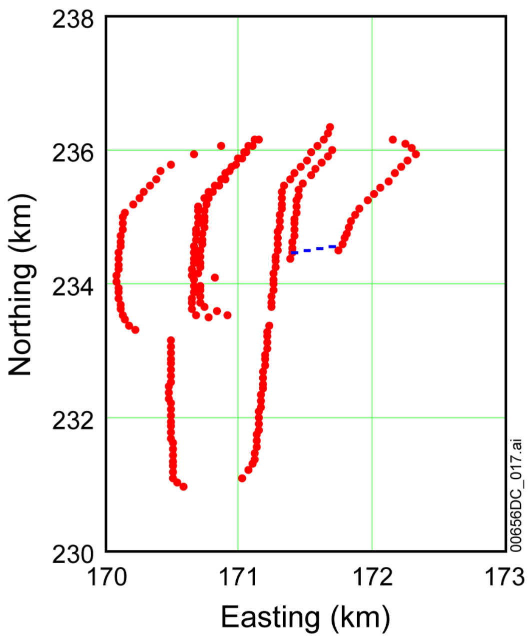
The above equation was applied to the repository for two locations in the Tptpll unit and the Tptpul unit as shown in Figures 6-16 and 6-17.



Source: Output DTN: MO0607MPDWCOAN.000, *Case1.xmcd*.

NOTE: The location of the drift corresponds approximately to location P2WR5C10 in Figure 6-25.

Figure 6-16. Location of the Drift in the Tptpll Unit for Calculations



Source: Output DTN: MO0607MPDWCOAN.000, *Case18.xmcd*.

NOTE: The location of the drift corresponds approximately to location P2ER8C6 in Figure 6-25.

Figure 6-17. Location of the Drift in the Tptpul Unit for Calculations

The mid-pillar temperature is calculated from Equation 6-13 where the "cn" subscripts are the center-of-drift coordinates (BSC 2004 [DIRS 164327], Section 6.3.5.1.1). These center-of-drift coordinates are fixed for all drifts. The z direction is the vertical direction because the ground surface is located at $z = z_G$, as previously stated following Equation 6-10. The drift axis is parallel to the y axis as shown in Figure 6-14. The contribution to the temperature at some point x is obtained by integrating a point source with respect to y between the limits $y_C - L/2$ and $y_C + L/2$ as indicated in Equation 6-10. Therefore, x and y for z = 0 identify a location in the plane of the drifts. A mid-pillar temperature along the pillar center line between drifts j and k is calculated by specifying $x = x_{Cj} + 40.5$, varying y according to $\Delta y + y_{Cn}$, and summing over all n drifts using Equation 6-13.

6.5 LINE-SOURCE CONDUCTION-ONLY RESULTS

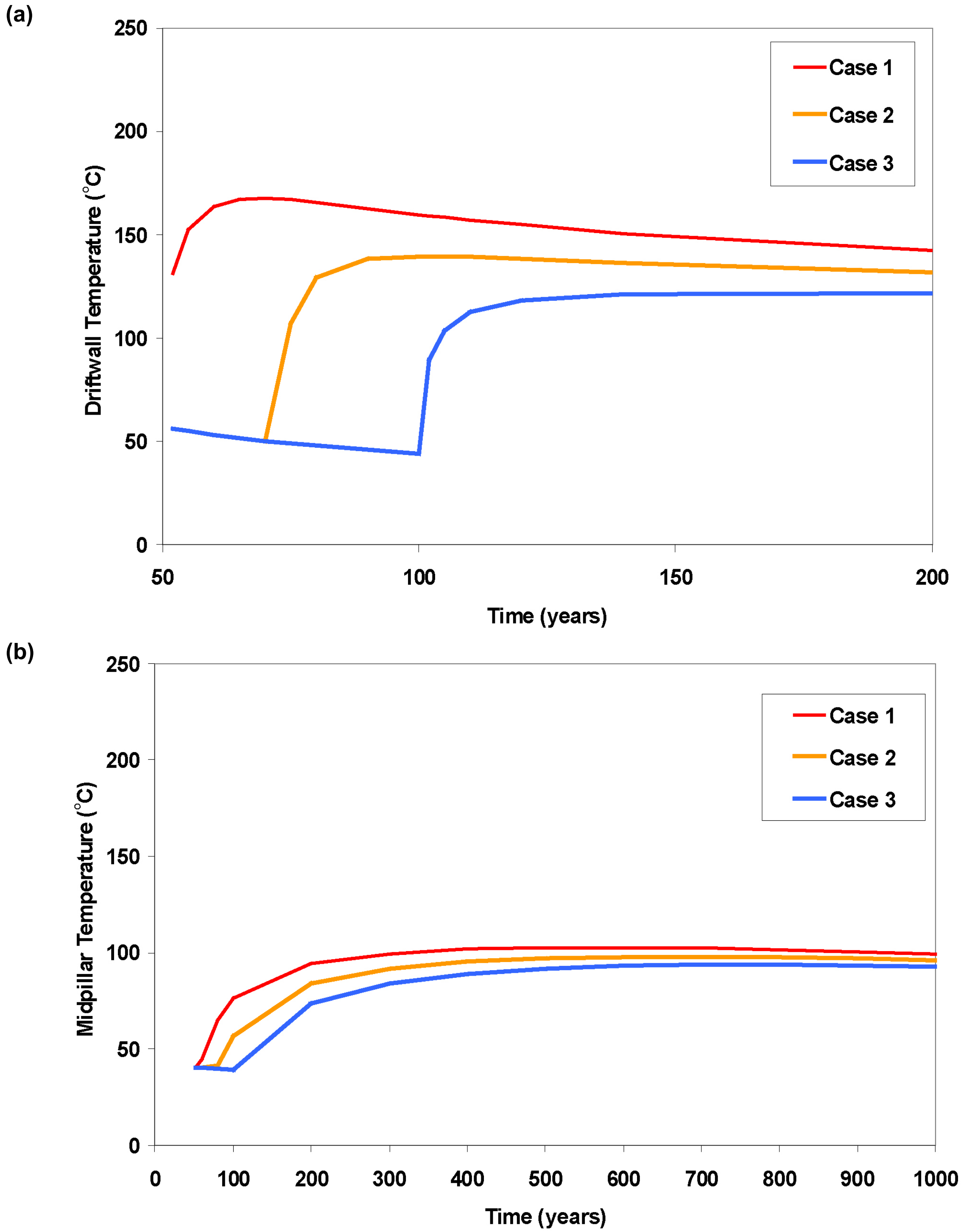
The drift-wall and mid-pillar temperature results of the line-source analysis are presented in Figures 6-18 through 6-24. As the ventilation period is increased for the same line average loading, the peak drift-wall temperature is shifted out in time, and decays more slowly with time during the period from 50 to 150 years.

When the slope is matched at repository closure, the average line loading at emplacement is higher (2.09 kW/m versus 1.84 kW/m; see Figure 6-5 for comparison), and this results in higher temperatures than for the case of matching the power at closure. For example, the line-source conduction-only model predicts an approximate peak drift-wall temperature of 182°C as shown in Figure 6-19 in comparison to a peak drift-wall temperature of 163°C as shown in Figure 6-18.

When the coolest DHLW waste packages are replaced with the average line, the average line load relationship is higher, and the peak drift-wall temperatures are higher than the base case. For example, the line-source conduction-only model predicts an approximate peak postclosure temperature of 159°C as shown in Figure 6-20 in comparison to a peak drift-wall temperature of 140°C (BSC 2005 [DIRS 173944], Figure 6.3-15).

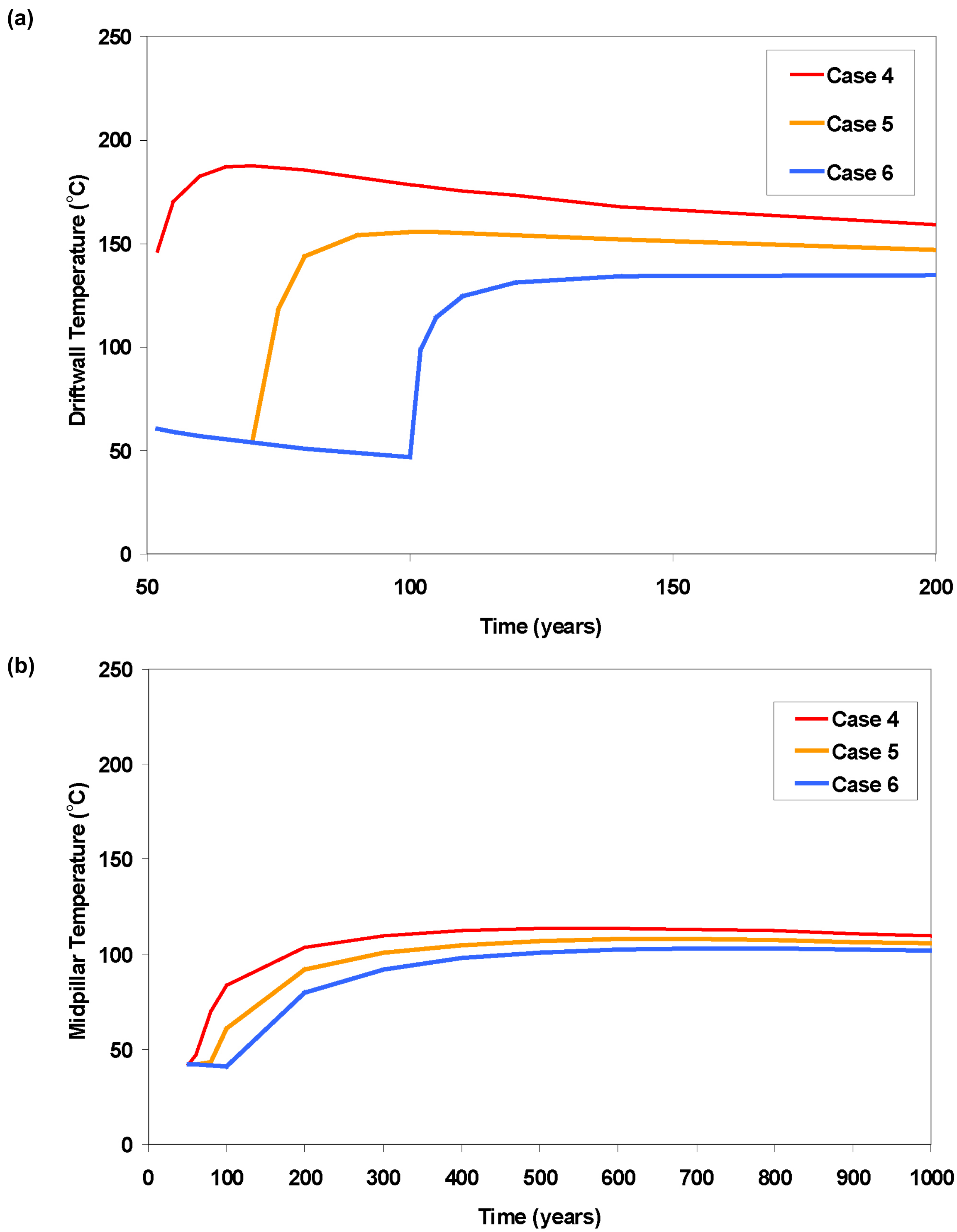
The temperature results for the reduced rock mass thermal conductivity in the Tptpul unit are higher (Figures 6-21 through 6-23) than the temperatures in the Tptpll unit (Figures 6-18 through 6-20), as would be predicted on the basis of a conduction-only model. The peak drift-wall temperatures for the case of matching the slope in the Tptpul unit would exceed the drift-wall temperature criterion of 200°C when ventilation of 50 years is considered. Note that this occurs because of the lower-bound value for the rock mass thermal conductivity of 1.72 W/(m·K) selected for the Tptpul unit (rock matrix thermal properties minus one standard deviation, and the lithophysal porosity plus one standard deviation). The results do show that if this lower bound were encountered in the repository, with an increased ventilation period out to 73 years or 100 years, then the peak drift-wall temperatures are reduced to below 200°C.

Figure 6-24 shows the relationship of the change in peak drift-wall temperature from ambient temperature (i.e., 22.8°C) for different ventilation periods to the ratio of the initial line load divided by the rock mass thermal conductivity. These relationships show a high degree of correlation, and support a method of estimation of the peak drift-wall temperature from this ratio. These results are predicted on the basis of the closed-form analytical solution for heat conduction because the energy flux divided by the thermal conductivity appears in the lead coefficient of the solution (Carslaw and Jaeger 1959 [DIRS 100968], p. 338).



Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

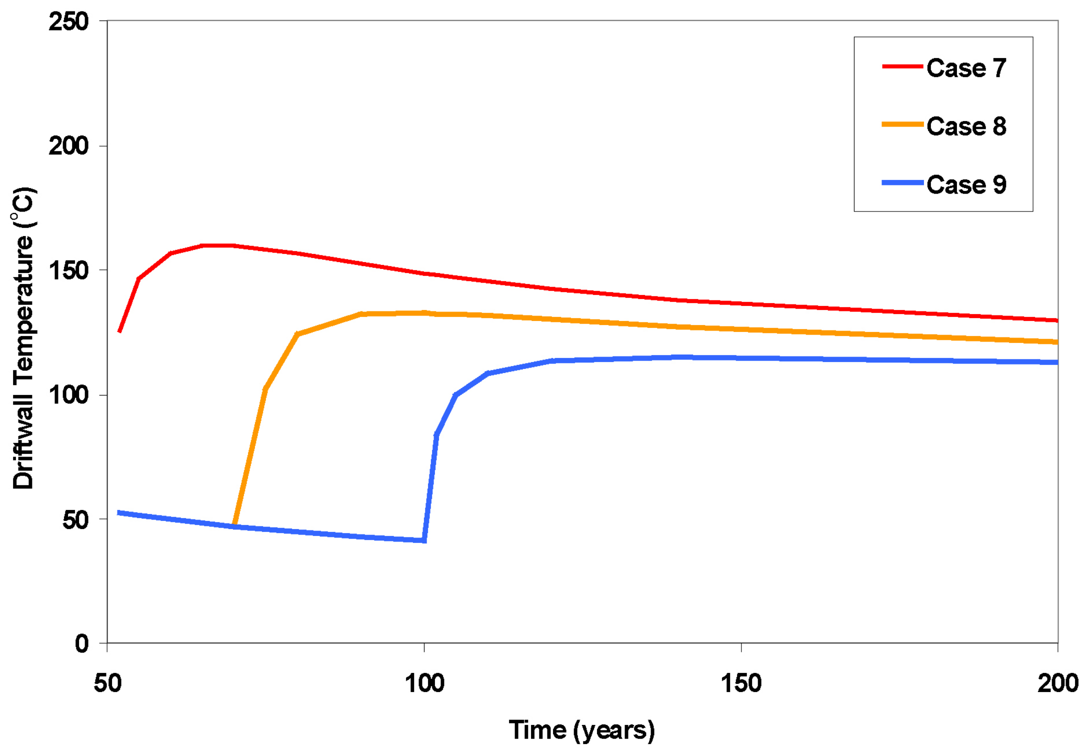
Figure 6-18. Postclosure Drift-Wall Temperature versus Time for Cases 1 through 3 for the Tptpll Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures



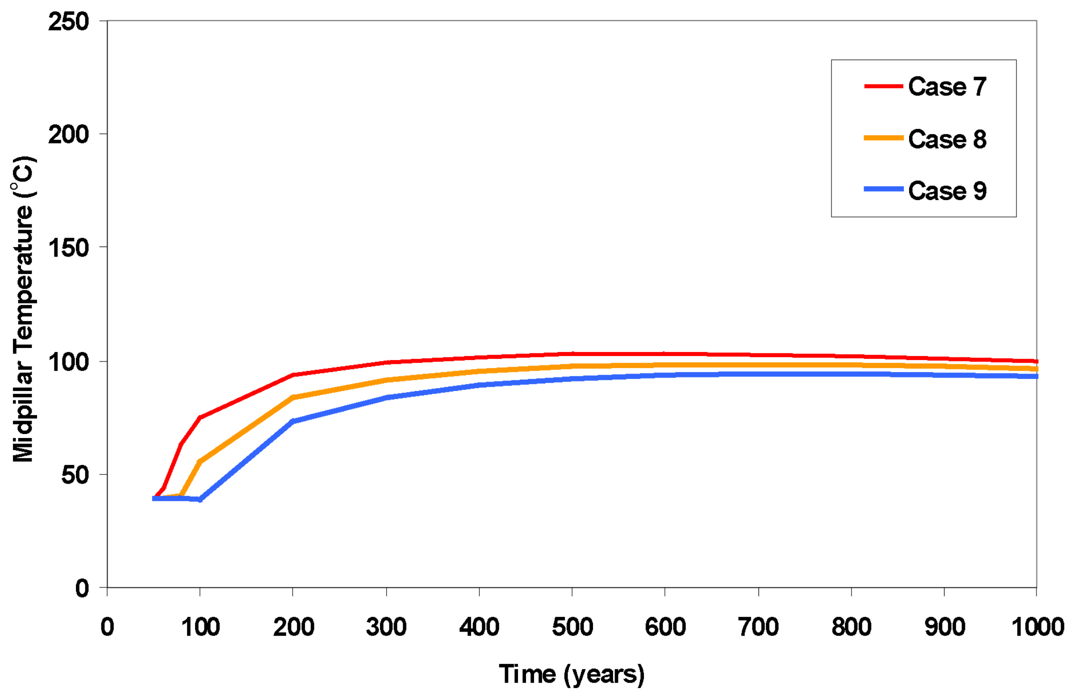
Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Figure 6-19. Postclosure Drift-Wall Temperature versus Time for Cases 4 through 6 for the Tptpll Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures

(a)

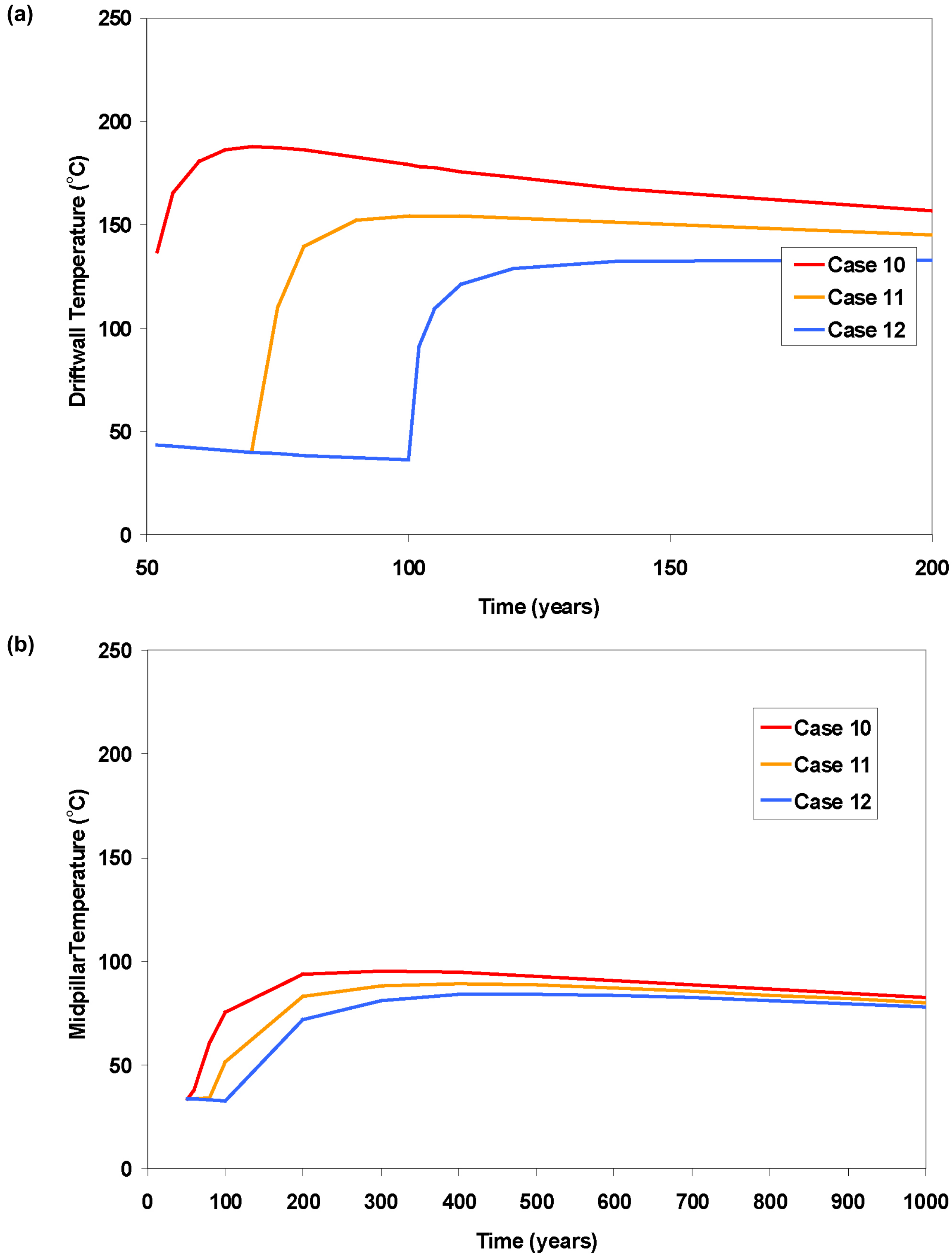


(b)



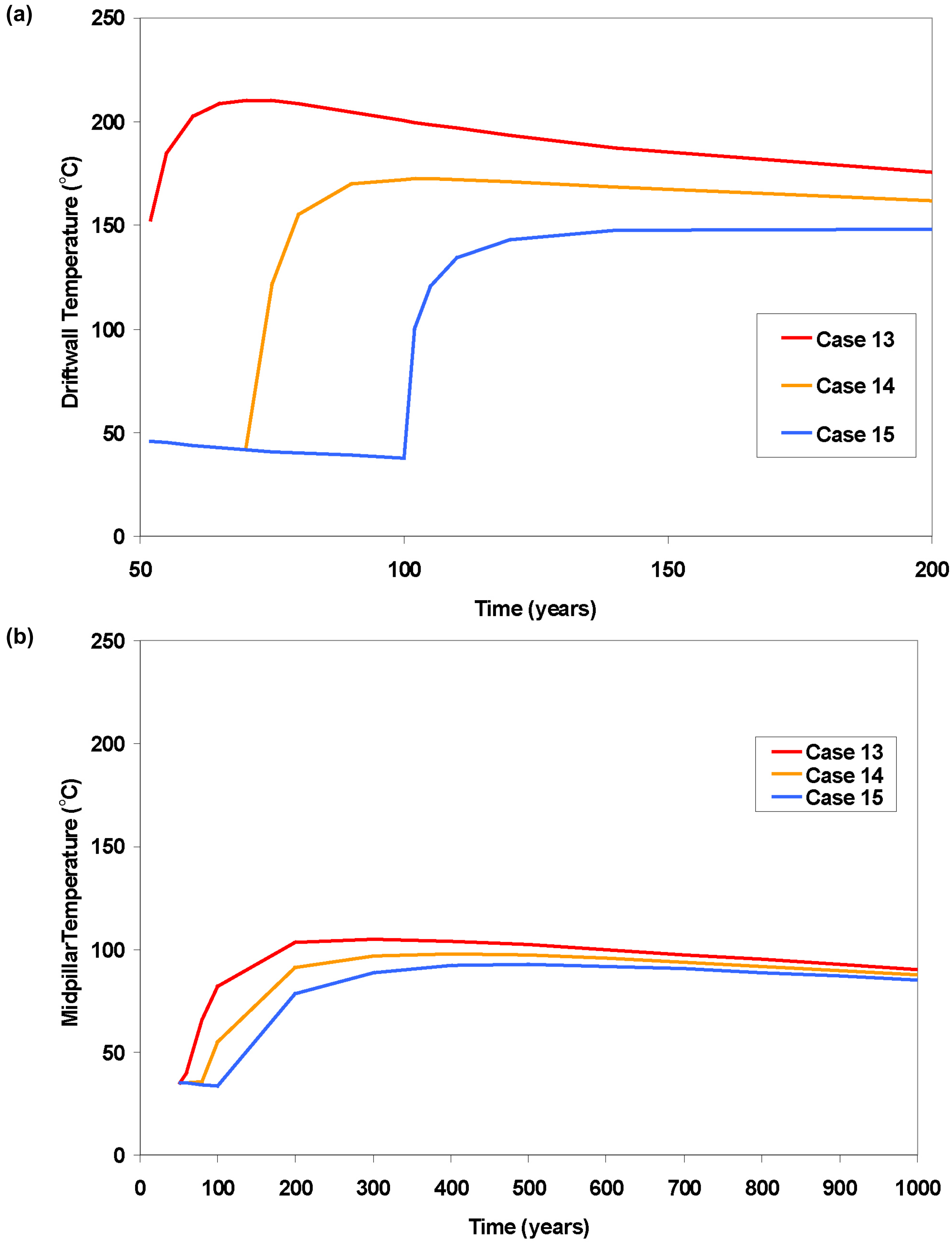
Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Figure 6-20. Postclosure Drift-Wall Temperatures versus Time for Cases 7 through 9 for the Tptpll Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures



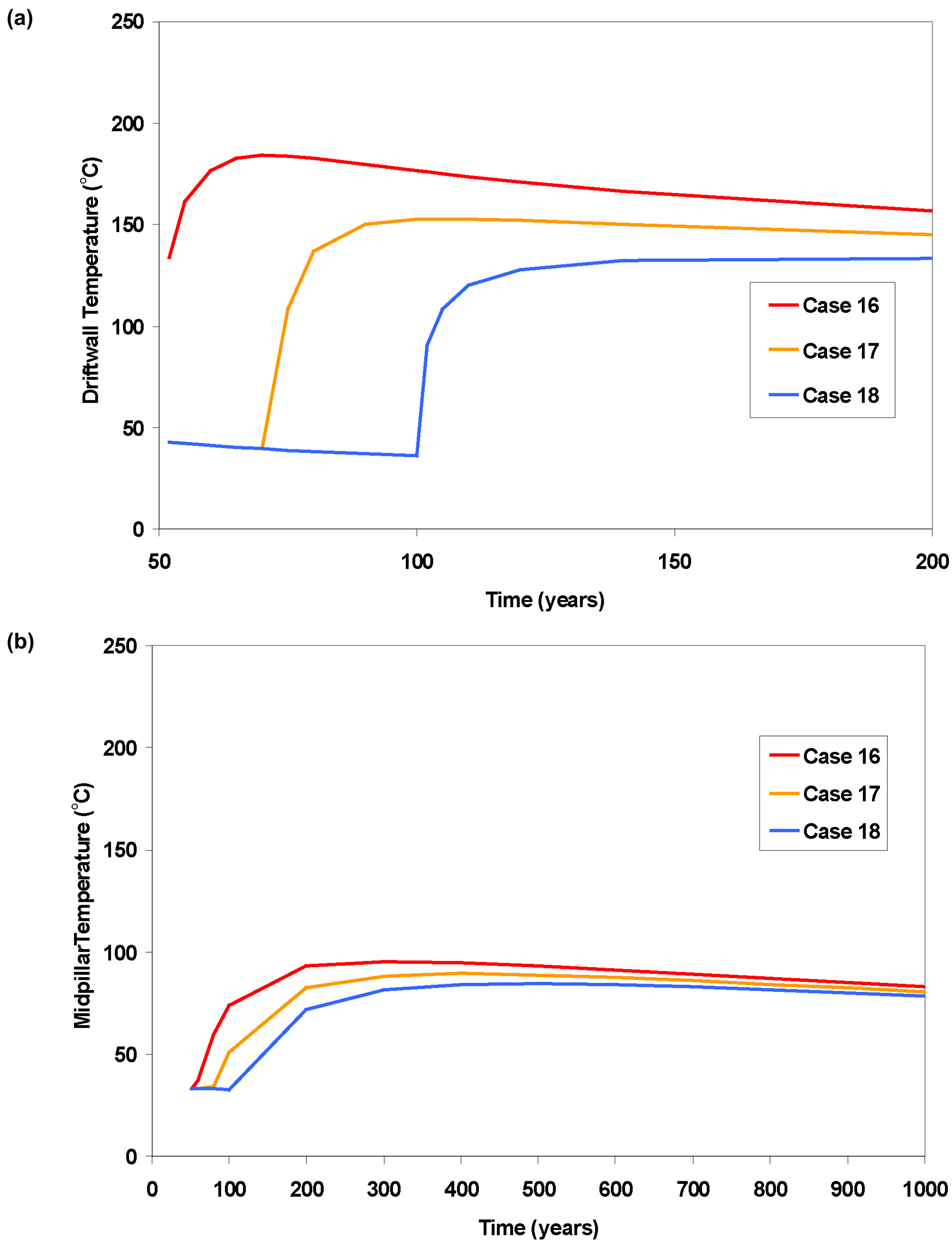
Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Figure 6-21. Postclosure Drift-Wall Temperatures versus Time for Cases 10 through 12 for the Tptpul Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures



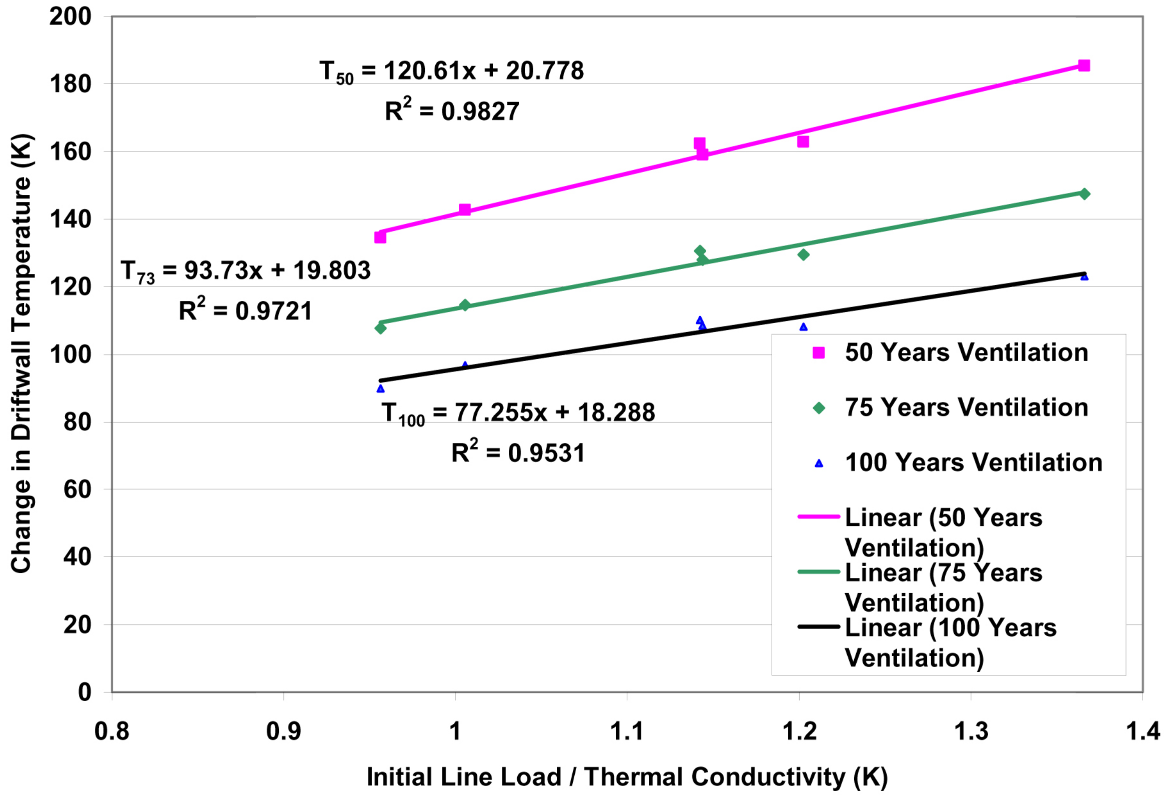
Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Figure 6-22. Postclosure Drift-Wall Temperatures versus Time for Cases 13 through 15 for the Tptpul Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures



Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Figure 6-23. Postclosure Drift-Wall Temperatures versus Time for Cases 16 through 18 for the Tptpul Unit at the P2WR5C10 Location: (a) Drift-Wall Temperatures and (b) Mid-pillar Temperatures



Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

Note: The base case is 50 years ventilation.

Figure 6-24. Relationship of the Change in Peak Drift-Wall Temperature (relative to initial temperature) to the Ratio of Line Load to Rock Mass Thermal Conductivity

The calculation of the peak mid-pillar temperatures using Equation 6-13 for all cases identified in Table 6-1 yields the following results presented in Table 6-3. The time histories of the mid-pillar temperature for the various cases show that mid-pillar peak temperatures are lower than peak drift-wall temperatures, and the times at which peak temperatures occur are shifted out in time to periods between approximately 300 and 800 years. The analysis predicts that the mid-pillar temperature exceeds 96°C for Cases 1, 2, 4, 5, 6, 7, 8, 13, and 14. These are most of the cases representing younger fuel and higher burnup, and only extended ventilation can limit mid-pillar temperature to 96°C. Substitution of the DHLW packages with packages representing average SNF also requires extended ventilation. For the comparable cases in the Tptpul location (Cases 9 through 18), the mid-pillar temperatures are lower because this location is influenced by repository edge cooling effects. The mathematical form of Equation 6-13 generally produces greater mid-pillar temperature with smaller values of thermal conductivity. Only Cases 13 and 14, representing higher burnup SNF, exceed 96°C at this location.

Comparison of predicted peak drift-wall temperature (Figures 6-18 through 6-23) with peak mid-pillar temperatures (Table 6-19) shows that mid-pillar temperature is a greater constraint on thermal loading. Only Case 13 exceeded the drift-wall temperature criterion of 200°C, while many more cases exceeded the mid-pillar criterion.

Table 6-3. Calculated Peak Mid-pillar Temperature Using Line Sources

Case Identification	Emplacement Line Load (W/m)	Peak Mid-pillar Temperature (°C)
Case1	1,837	102.9
Case2	1,837	97.9
Case3	1,837	93.7
Case4	2,092	113.7
Case5	2,092	108.1
Case6	2,092	103.2
Case7	1,754	103.2
Case8	1,754	98.5
Case9	1,754	94.3
Case10	1,837	95.5
Case11	1,837	89.2
Case12	1,837	84.4
Case13	2,092	105.2
Case14	2,092	98.1
Case15	2,092	92.6
Case16	1,754	95.4
Case17	1,754	89.5
Case18	1,754	84.9

Source: Output DTN: MO0607MPDWCOAN.000, *Drift Wall Results Rev02.xls*.

NOTE: The case identification corresponds to the cases identified in Table 6-1, where the number identifies the ventilation duration in years. Temperatures are based in an initial temperature of 25°C. To obtain the temperature for a different initial temperature, subtract 25 and add the new initial temperature. The peak temperatures were read from the corresponding MathCad file using the "trace" function.

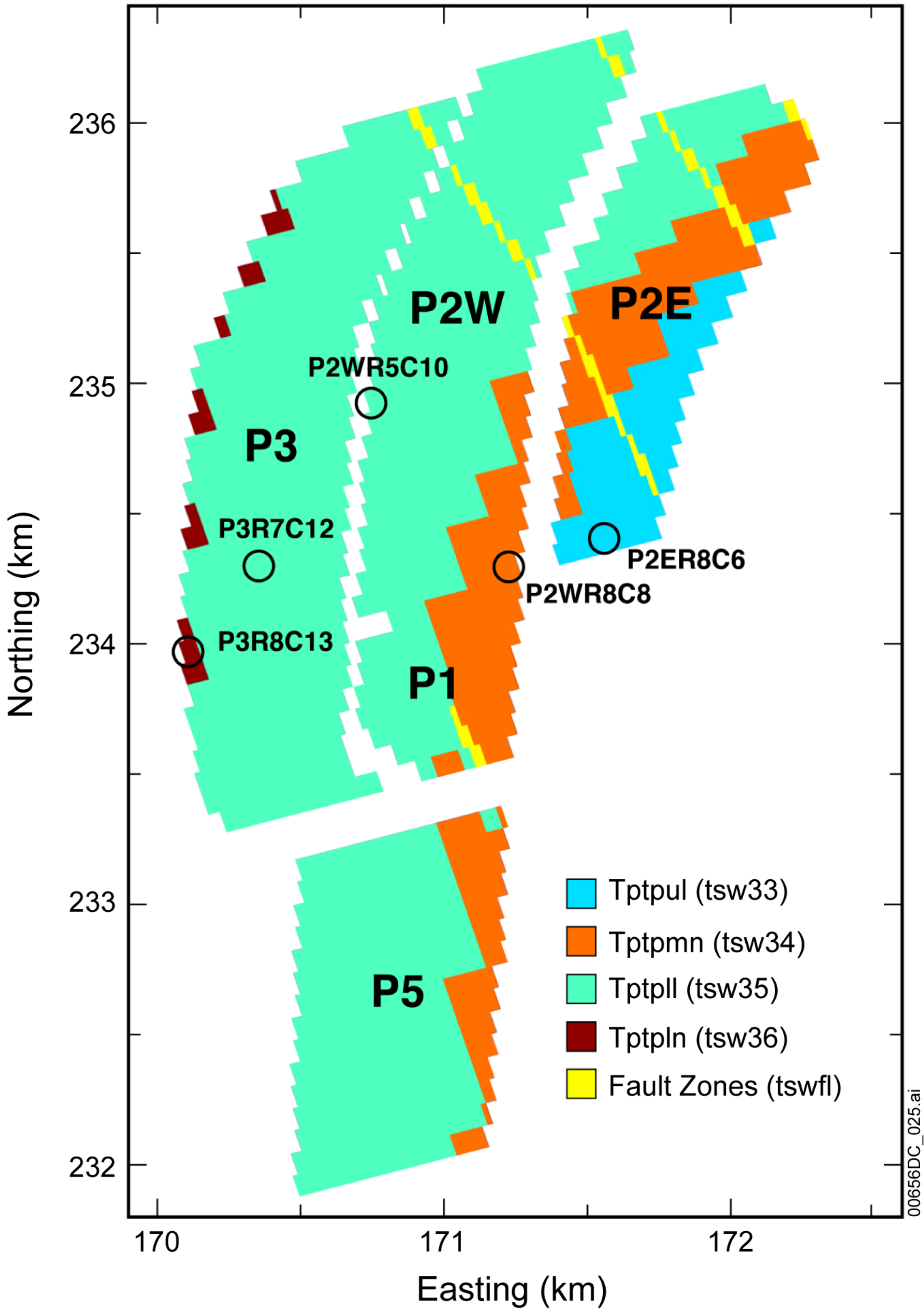
Note that all the mid-pillar temperature calculations were performed using a nearly saturated or wet thermal conductivity (90.5% saturation; Section 5.3) regardless of the final mid-pillar temperature. It is clear that when the calculated mid-pillar temperature exceeds approximately 96°C, the rock may dry out from the drift wall to the mid-pillar location, depending on the percolation flux. If dryout is extensive, thermal-hydrologic analysis using both dry and wet thermal conductivities with saturation dependence would yield more representative mid-pillar temperatures. However, the conduction-only analysis in this report is intended to evaluate whether the mid-pillar temperature of 96°C is likely to be exceeded, and thus it was not necessary to recalculate mid-pillar temperatures when above 96°C using a dry thermal conductivity and accounting for latent heat of vaporization effects.

6.6 POSTCLOSURE THERMAL ANALYSIS

Postclosure thermal calculations were conducted using the DDT submodel, which is described in Section 6.2.8 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The DDT submodel used in this study is the same as that described in Section 6.2.8 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), with the exception of the heat generation tables used (Table 6-4; Appendix C, Tables C-1 to C-3) and slightly revised waste package lengths (Table 6-6). The small differences in waste package lengths are seen by comparing those in Tables 6-6 through 6-8 with those in Table 6-9, which is taken from Table 6.3-13 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). Table 6-4 summarizes the 27 postclosure thermal management cases run for this study, plus the base case described in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.1), also referred to herein as the reference case, which corresponds to the 55-MTU/acre DDT submodel of the multiscale model (BSC 2005 [DIRS 173944], Section 6.2.8). As described in Section 6.2.8.6 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), the 55-MTU/acre DDT submodel was run, along with the 14-, 27-, and 66-MTU/acre DDT submodels, to generate all multiscale results. As indicated in Table 6-4, the 27 thermal management cases arise from a $3 \times 3 \times 3$ matrix of cases, corresponding to three heat generation cases, three preclosure ventilation periods, and two locations within the repository footprint (Figure 6-25), with one of the locations (P2ER8C6) having two host-rock thermal conductivity cases. All input files for these cases, including the base case, are found in Output DTN: LL051001723122.065.

The thermal properties for the cases in the upper lithophysal zone of the Topopah Spring unit (Tptpul) or for Cases 10 through 18 (Section 6.3.1) were intended to produce a lower bound to the rock mass thermal conductivity, and represent a consistent set of properties in that the lower rock mass thermal conductivity is associated with higher matrix and lithophysal porosities. In particular, the air-filled lithophysal porosity would exhibit a low rock mass thermal conductivity because the ratio of the solids thermal conductivity to air conductivity is lower by approximately two orders of magnitude. For the low host-rock thermal conductivity cases presented in Table 6-4, the rock mass thermal conductivity was selected for the saturated case as 1.5405 W/(m·K). This represents the mean value minus one standard deviation value of wet thermal conductivity for the upper host-rock unit (Tptpul) using values listed in Table 6.3-23 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This value is higher than the rock mass thermal conductivity of 1.40 W/(m·K) used in the preclosure ventilation analysis as presented in Section 6.3.1.

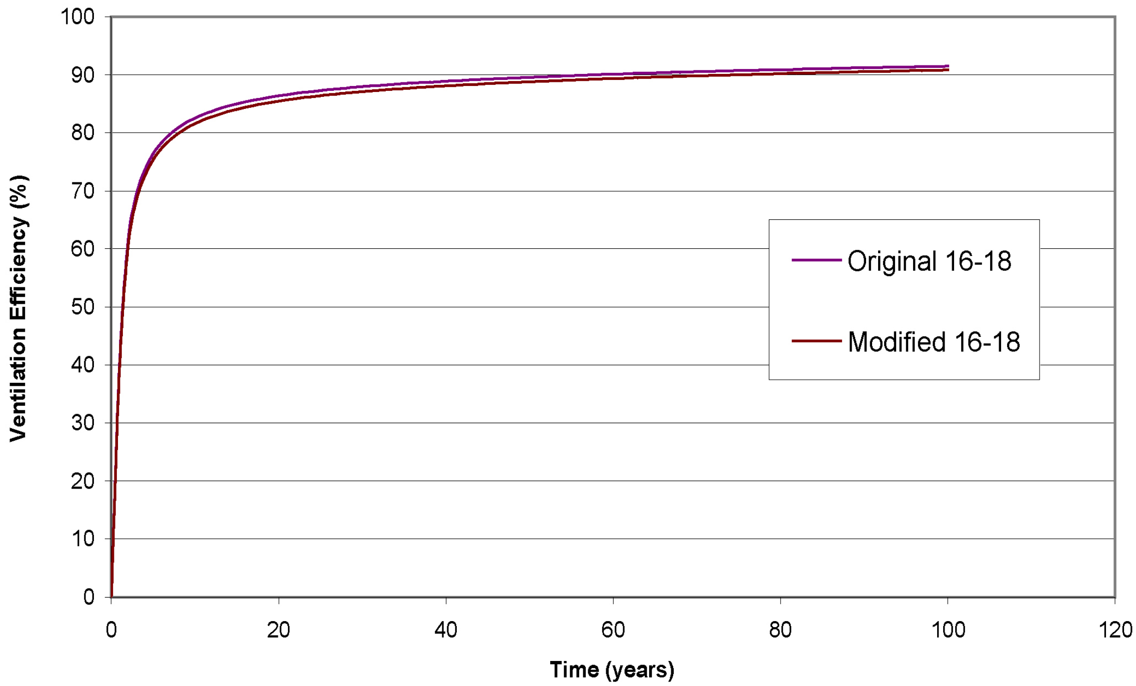
The preclosure ventilation analyses for Cases 10 through 18 were redone to investigate the effects of using inconsistent thermal properties between the preclosure ventilation and postclosure multiscale DDT analyses. These results are presented in Output DTN: MO0607MPDWCOAN.000 in the Excel workbook *Comparison of Ventilation Efficiencies Cases 10through12.xls*. The results for Cases 10 through 12 are presented in Figure 6-26, and show that after 100 years of ventilation, the ventilation efficiencies are slightly lower when using the modified thermal properties (1.54 W/m·K) for the Tptpul unit for preclosure ventilation analysis that are consistent with the properties used for the postclosure analysis. This difference is small, and reflects the fact that over the range of thermal properties considered, integrated ventilation is high, and the sensitivity of ventilation efficiency to variations in rock mass thermal properties is small.



Source: BSC 2005 [DIRS 173944], Figure 6.3-1.

NOTE: The P2WR5C10 location is in the lower lithophysal Tptpll (tsw35) host-rock unit and the P2ER8C6 location is in the upper lithophysal Tptpul (tsw33) host-rock unit.

Figure 6-25. Locations of the DDT Submodels at the Repository Center (P2WR5C10) and the Repository Edge (P2ER8C6)



Source: Output DTN: MO0607MPDWCOAN.000, *Comparison of Ventilation Efficiencies Cases 10through12.xls*.

Figure 6-26. Comparison of Ventilation Efficiencies for the Tptpul Unit for the Original and Modified Cases 10 through 12

Table 6-4. Summary of Postclosure Cases Simulated in the Thermal Management Study

Case	Case Identifier [a]	Heat Generation Case [b]	Preclosure Ventilation Period (years)	Host-Rock Unit	Location within the Repository [c]
Base	BASE-50-Tptpll	Base Case	50	Tptpll	P2WR5C10
1	A-50-Tptpll	A	50	Tptpll	P2WR5C10
2	A-73-Tptpll	A	73	Tptpll	P2WR5C10
3	A-100-Tptpll	A	100	Tptpll	P2WR5C10
4	B-50-Tptpll	B	50	Tptpll	P2WR5C10
5	B-73-Tptpll	B	73	Tptpll	P2WR5C10
6	B-100-Tptpll	B	100	Tptpll	P2WR5C10
7	C-50-Tptpll	C	50	Tptpll	P2WR5C10
8	C-73-Tptpll	C	73	Tptpll	P2WR5C10
9	C-100-Tptpll	C	100	Tptpll	P2WR5C10
1b	A-50-Tptpul	A	50	Tptpul	P2ER8C6
2b	A-73-Tptpul	A	73	Tptpul	P2ER8C6
3b	A-100-Tptpul	A	100	Tptpul	P2ER8C6
4b	B-50-Tptpul	B	50	Tptpul	P2ER8C6
5b	B-73-Tptpul	B	73	Tptpul	P2ER8C6
6b	B-100-Tptpul	B	100	Tptpul	P2ER8C6

Table 6-4. Summary of Postclosure Cases Simulated in the Thermal Management Study (Continued)

Case	Case Identifier [a]	Heat Generation Case [b]	Preclosure Ventilation Period (years)	Host-Rock Unit	Location within the Repository [c]
7b	C-50-Tptpul	C	50	Tptpul	P2ER8C6
8b	C-73-Tptpul	C	73	Tptpul	P2ER8C6
9b	C-100-Tptpul	C	100	Tptpul	P2ER8C6
10	A-50-Tptpul-LKT [d]	A	50	Tptpul	P2ER8C6
11	A-73-Tptpul-LKT [d]	A	73	Tptpul	P2ER8C6
12	A-100-Tptpul-LKT [d]	A	100	Tptpul	P2ER8C6
13	B-50-Tptpul-LKT [d]	B	50	Tptpul	P2ER8C6
14	B-73-Tptpul-LKT [d]	B	73	Tptpul	P2ER8C6
15	B-100-Tptpul-LKT [d]	B	100	Tptpul	P2ER8C6
16	C-50-Tptpul-LKT [d]	C	50	Tptpul	P2ER8C6
17	C-73-Tptpul-LKT [d]	C	73	Tptpul	P2ER8C6
18	C-100-Tptpul-LKT [d]	C	100	Tptpul	P2ER8C6

[a] This identifies the heat generation case, duration of preclosure ventilation period, and host-rock unit in which the submodel resides.

[b] The base case is similar (in rate of decay) to the heat generation case applicable to all DDT submodels in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). Case A is the scaled line load on a power basis (see Figure 6-1), Case B is the scaled line load on a slope basis (see Figure 6-2), and Case C is the line load with DHLW packages replaced with the average line load (see Figure 6-4).

[c] See Figure 6-25 for location within the repository.

[d] Low host-rock thermal conductivity case, where the mean minus one standard deviation value of wet thermal conductivity is applied to the host-rock unit (Tptpul), using values listed in Table 6.3-23 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Table 6-5. Summary of Files Used to Generate the Postclosure Heat Generation Tables

Case	Location within Repository [a]	Heat Generation Case	Unmodified Heat Generation File, Worksheet [b]	Net-Heat-Available-Fraction File, Worksheet [c]	Ventilation Duration (years)
1	P2WR5C10	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	50
2	P2WR5C10	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	73
3	P2WR5C10	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	100
4	P2WR5C10	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	50
5	P2WR5C10	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	73
6	P2WR5C10	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	100
7	P2WR5C10	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	50
8	P2WR5C10	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	73
9	P2WR5C10	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	100
1b	P2ER8C6	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	50
2b	P2ER8C6	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	73
3b	P2ER8C6	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	100
4b	P2ER8C6	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	50
5b	P2ER8C6	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	73
6b	P2ER8C6	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	100
7b	P2ER8C6	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	50
8b	P2ER8C6	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	73
9b	P2ER8C6	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	100
10	P2ER8C6 [d]	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	50
11	P2ER8C6 [d]	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	73
12	P2ER8C6 [d]	A	*Case1.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases13"	100
13	P2ER8C6 [d]	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	50
14	P2ER8C6 [d]	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	73
15	P2ER8C6 [d]	B	*Case4.xls*, "IED"	*Net Available Heat Generation.xls*, "Cases46"	100
16	P2ER8C6 [d]	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	50
17	P2ER8C6 [d]	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	73
18	P2ER8C6 [d]	C	*Case7.xls*, "IED"	*bk79fractions.xls* (entire file)	100

[a] See Figure 6-25 for location within the repository.
[b] This file gives the heat generation rate versus time for each of the waste packages without the influence of preclosure drift ventilation.
[c] This file gives the net-heat-available fraction versus time, which is applied uniformly to all waste packages (see output DTN: MO0506SPAPRETM.000).
[d] Low host-rock thermal conductivity case, where the mean minus one standard deviation value of wet thermal conductivity is applied to the four host-rock units (Tptpul, Tptpmn, Tptpll, and Tptpln), with the values listed in Table 6.3-23 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Table 6-6. Summary of Waste Packages Included in the Thermal Management Study for Cases 1 through 3 and Cases 10 through 12

Waste Package Name in Multiscale [a]	Waste Package Type [b]	Length in Model [c] (m)	Initial Heat Generation Rate [d] (kW)	Notes (based on multiscale output temperatures and heat output)
pwr1-1	21-PWR AP CSNF *½ 21-PWR AP*	2.5122	7.10 [e]	Half waste package in model; average PWR waste package in sequence with respect to heat output
dhlw-l1	5 DHLW/DOE SNF-LONG *5-HLW LONG*	5.0594	1.22	Coolest waste package in sequence with respect to heat output
pwr2-1	21-PWR AP CSNF *21-PWR AP (HOT)*	5.0244	14.54	Hottest PWR waste package in sequence with respect to heat output
bwr1-1	44-BWR CSNF *44-BWR AP*	5.0244	9.09	Average BWR waste package in sequence with respect to heat output
bwr2-1	44-BWR CSNF *44-BWR ADJUSTED*	5.0244	8.75	Coolest BWR waste package in sequence with respect to heat output
dhlw-s1	5 DHLW/DOE SNF-SHORT *5-HLW SHORT*	3.4528	3.67	Hottest DHLW waste package in sequence
pwr1-2	21-PWR AP CSNF *21-PWR AP*	5.0244	14.20	Average PWR waste package with respect to heat output
bwr1-2	44-BWR CSNF *½ 44-BWR AP*	2.5122	4.55 [e]	Half waste package in model; average BWR waste package in sequence with respect to heat output
Total	N/A	34.3342	63.12	Including 0.1-m gaps
LPD [f]	N/A	N/A	1.84 kW/m	27% higher than in base case

[a] See Table 6.3-13 of BSC 2005 [DIRS 173944].
[b] Names of waste package types as they appear in BSC 2005 [DIRS 173705] are shown in italics.
[c] File *Case1.xls*, worksheet "IED."
[d] File *Case1.xls*, worksheet "IED."
[e] These values represent the heat generation rate for a half waste package.
[f] LPD = Lineal Power Density, which is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence (including 0.1-m gaps) in the DDT submodel.

NOTE: In the future, the PWR and BWR waste packages will be replaced with the TAD canister waste package design.

Table 6-7. Summary of Waste Packages Included in the Thermal Management Study for Cases 4 through 6 and Cases 13 through 15

Waste Package Name in Multiscale [a]	**Waste Package Type** [b]	**Length in Model** [c] **(m)**	**Initial Heat Generation Rate** [d] **(kW)**	**Notes (based on multiscale output temperatures and heat output)**
pwr1-1	21-PWR AP CSNF *½ 21-PWR AP*	2.5122	8.08 [e]	Half waste package in model; average PWR waste package in sequence with respect to heat output
dhlw-l1	5 DHLW/DOE SNF-LONG *5-HLW LONG*	5.0594	1.39	Coolest waste package in sequence with respect to heat output
pwr2-1	21-PWR AP CSNF *21-PWR AP (HOT)*	5.0244	16.60	Hottest PWR waste package in sequence with respect to heat output
bwr1-1	44-BWR CSNF *44-BWR AP*	5.0244	10.40	Average BWR waste package in sequence with respect to heat output
bwr2-1	44-BWR CSNF *44-BWR ADJUSTED*	5.0244	9.96	Coolest BWR waste package in sequence with respect to heat output
dhlw-s1	5 DHLW/DOE SNF-SHORT *5-HLW SHORT*	3.4528	4.18	Hottest DHLW waste package in sequence
pwr1-2	21-PWR AP CSNF *21-PWR AP*	5.0244	16.10	Average PWR waste package with respect to heat output
bwr1-2	44-BWR CSNF *½ 44-BWR AP*	2.5122	5.18 [e]	Half waste package in model; average BWR waste package in sequence with respect to heat output
Total	N/A	34.3342	71.9	Including 0.1-m gaps
LPD [f]	N/A	N/A	2.09 kW/m	44% higher than in base case

[a] See Table 6.3-13 of BSC 2005 [DIRS 173944].
[b] Names of waste package types as they appear in BSC 2005 [DIRS 173705] are shown in italics.
[c] File *Case4.xls*, worksheet "IED."
[d] File *Case4.xls*, worksheet "IED."
[e] These values represent the heat generation rate for a half waste package.
[f] LPD is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence (including 0.1-m gaps) in the DDT submodel.

NOTE: In the future, the PWR and BWR waste packages will be replaced with the TAD canister waste package design.

Table 6-8. Summary of Waste Packages Included in the Thermal Management Study for Cases 7 through 9 and Cases 16 through 18

Waste Package Name in Multiscale [a]	Waste Package Type [b]	Length in Model [c] (m)	Initial Heat Generation Rate [d] (kW)	Notes (based on multiscale output temperatures and heat output)
pwr1-1	21-PWR AP CSNF *½ 21-PWR AP*	2.5122	5.76 [e]	Half waste package in model; average PWR waste package in sequence with respect to heat output
dhlw-l1	5 DHLW/DOE SNF-LONG *5-HLW LONG*	5.0594	7.69	Line-averaged heat output for the entire sequence is applied
pwr2-1	21-PWR AP CSNF *21-PWR AP (HOT)*	5.0244	11.80	Hottest PWR waste package in sequence with respect to heat output
bwr1-1	44-BWR CSNF *44-BWR AP*	5.0244	7.38	Average BWR waste package in sequence with respect to heat output
bwr2-1	44-BWR CSNF *44-BWR ADJUSTED*	5.0244	7.10	Coolest BWR waste package in sequence with respect to heat output
dhlw-s1	5 DHLW/DOE SNF-SHORT *5-HLW SHORT*	3.4528	5.30	Line-averaged heat output for the entire sequence is applied
pwr1-2	21-PWR AP CSNF *21-PWR AP*	5.0244	11.50	Average PWR waste package with respect to heat output
bwr1-2	44-BWR CSNF *½ 44-BWR AP*	2.5122	3.69 [e]	Half waste package in model; average BWR waste package in sequence with respect to heat output
Total	N/A	34.3342	60.22	Including 0.1-m gaps
LPD [f]	N/A	N/A	1.75 kW/m	21% higher than in base case

[a] See Table 6.3-13 of BSC 2005 [DIRS 173944].
[b] Names of waste package types as they appear in BSC 2005 [DIRS 173705] are shown in italics.
[c] File *Case7.xls*, worksheet “IED.”
[d] File *Case7.xls*, worksheet “IED.”
[e] These values represent the heat generation rate for a half waste package.
[f] LPD is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence (including 0.1-m gaps) in the DDT submodel.

NOTE: In the future, the PWR and BWR waste packages will be replaced with the TAD canister waste package design.

Table 6-9. Summary of Waste Packages Included in the Multiscale Model

Waste Package Name in Multiscale	Waste Package Type [a]	Length in Model [b] (m)	Initial Heat Generation Rate [c] (kW)	Notes (based on multiscale output temperatures and heat output)
pwr1-1	21-PWR AP CSNF *½ 21-PWR AP*	2.5825	2.88 [d]	Half waste package in model; coolest PWR waste package in sequence, but "average" PWR waste package with respect to heat output
dhlw-l1	5 DHLW/DOE SNF-LONG *5-HLW LONG*	5.217	0.99	Coolest waste package in sequence with the lowest heat output
pwr2-1	21-PWR AP CSNF *21-PWR AP (HOT)*	5.165	11.8	"Average" PWR waste package in sequence with respect to temperatures, but highest heat output in sequence
bwr1-1	44-BWR CSNF *44-BWR AP*	5.165	7.38	Hottest BWR waste package in sequence, but "average" BWR waste package with respect to heat output
bwr2-1	44-BWR CSNF *44-BWR ADJUSTED*	5.165	7.10	"Oldest" BWR waste package in sequence
dhlw-s1	5 DHLW/DOE SNF-SHORT *5-HLW SHORT*	3.59	2.98	Hottest DHLW waste package in sequence
pwr1-2	21-PWR AP CSNF *21-PWR AP*	5.165	11.5	"Hottest" waste package in sequence, but average PWR waste package with respect to heat output
bwr1-2	44-BWR CSNF *½ 44-BWR AP*	2.5825	1.85 [d]	Half waste package in model; coolest BWR waste package in sequence, but "average" BWR waste package with respect to heat output
Total	N/A	35.332	51.23	Including 0.1-m gaps
LPD [e]	N/A	N/A	1.45 kW/m	Lower than any of the thermal management cases

[a] Names of waste package types as they appear in BSC 2005 [DIRS 173705] are shown in italics.
[b] Waste package lengths are based on information from BSC 2003 [DIRS 165406], Table 1.
[c] Heat generation rates are based on information from BSC 2005 [DIRS 173705], Table 1.
[d] The DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) uses this value. For the thermal management study, the values in Table 6-10 are used.
[e] LPD is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence in the DDT submodel.

NOTE: In the future, the PWR and BWR waste packages will be replaced with the TAD canister waste package design.

Table 6-10. Summary of Waste Packages Included in the DDT Submodel Calculations

Waste Package Name in Multiscale	Waste Package Type [a]	Length in Model [b] (m)	Initial Heat Generation Rate [c] (kW)	Notes (based on multiscale output temperatures and heat output)
pwr1-1	21-PWR AP CSNF *½ 21-PWR AP*	2.5825	5.76	Half waste package in model; coolest PWR waste package in sequence, but “average” PWR waste package with respect to heat output
dhlw-l1	5 DHLW/DOE SNF-LONG *5-HLW LONG*	5.217	0.99	Coolest waste package in sequence with the lowest heat output
pwr2-1	21-PWR AP CSNF *21-PWR AP (HOT)*	5.165	11.8	“Average” PWR waste package in sequence with respect to temperatures, but highest heat output in sequence
bwr1-1	44-BWR CSNF *44-BWR AP*	5.165	7.38	Hottest BWR waste package in sequence, but “average” BWR waste package with respect to heat output
bwr2-1	44-BWR CSNF *44-BWR ADJUSTED*	5.165	7.10	“Oldest” BWR waste package in sequence
dhlw-s1	5 DHLW/DOE SNF-SHORT *5-HLW SHORT*	3.59	2.98	Hottest DHLW waste package in sequence
pwr1-2	21-PWR AP CSNF *21-PWR AP*	5.165	11.5	“Hottest” waste package in sequence, but average PWR waste package with respect to heat output
bwr1-2	44-BWR CSNF *½ 44-BWR AP*	2.5825	3.69	Half waste package in model; coolest BWR waste package in sequence, but “average” BWR waste package with respect to heat output
Total	N/A	35.332	46.51	Including 0.1-m gaps
LPD [d]	N/A	N/A	1.32 kW/m	Lower than any of the thermal management cases

[a] Names of waste package types as they appear in BSC 2005 [DIRS 173705] are shown in italics.
[b] Waste package lengths are based on information from BSC 2003 [DIRS 165406], Table 1.
[c] Heat generation rates are based on information from BSC 2005 [DIRS 173705], Table 1.
[d] LPD is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence in the DDT submodel.

NOTE: In the future, the PWR and BWR waste packages will be replaced with the TAD canister waste package design.

6.7 DDT SUBMODEL RESULTS

The DDT submodel was run with a numerical grid corresponding to an areal mass loading (AML) of 55 MTU/acre, which is the AML analyzed for the base case in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.1). The DDT submodel was repeated for a 3 × 3 × 3 matrix of cases that includes:

- Three heat generation cases (Cases A, B, and C in Tables 6-4 and 6-5).
- Three preclosure ventilation periods (50, 73, and 100 years).
- Three repository-location/host-rock thermal conductivity case combinations, including:
  - Location P2WR5C10 (see Figure 6-25) is run for the mean host-rock thermal conductivity case. This location, which is close to the repository center and is in the lower lithophysal Tptpll (tsw35) host-rock unit, is the location of the DDT submodels in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Figure 6.3-1).
  - Location P2ER8C6 (see Figure 6-25) is run for the mean host-rock thermal conductivity case. This location is at the repository edge and is in the upper lithophysal Tptpul (tsw33) host-rock unit.
  - Location P2ER8C6 (see Figure 6-25) is also run for the low host-rock thermal conductivity case, using a lower-bound estimate for thermal conductivity of the Tptpul (tsw33) unit.

The 27 DDT submodel cases are listed in Table 6-4. In addition the case used to support the multiscale base case (BSC 2005 [DIRS 173944], Section 6.2.1) is also included. The DDT submodel calculations were conducted for six and two half waste packages (total of eight) for a simulation period of 200 years (Figures 6-27 through 6-32).

Table 6-11 compares the initial heat generation rate for the eight waste packages in the sequence for the three heat generation Cases A, B, and C, and for the base case (BSC 2005 [DIRS 173944], Section 6.2.8). Table 6-12 summarizes the fractions of the overall initial heat generation rates for those cases that are assigned to each waste package type. Heat generation cases A and B, and the base case, all share similar heat generation fractions for each of the eight waste packages in the sequence. Consequently, for the 50-year preclosure ventilation cases, this causes the range in temperatures along the six-plus-two-halves waste package sequence to be similar for those respective cases, as is evident in Figures 6-27, 6-28, 6-30, and 6-31, and in Tables 6-13 and 6-14.

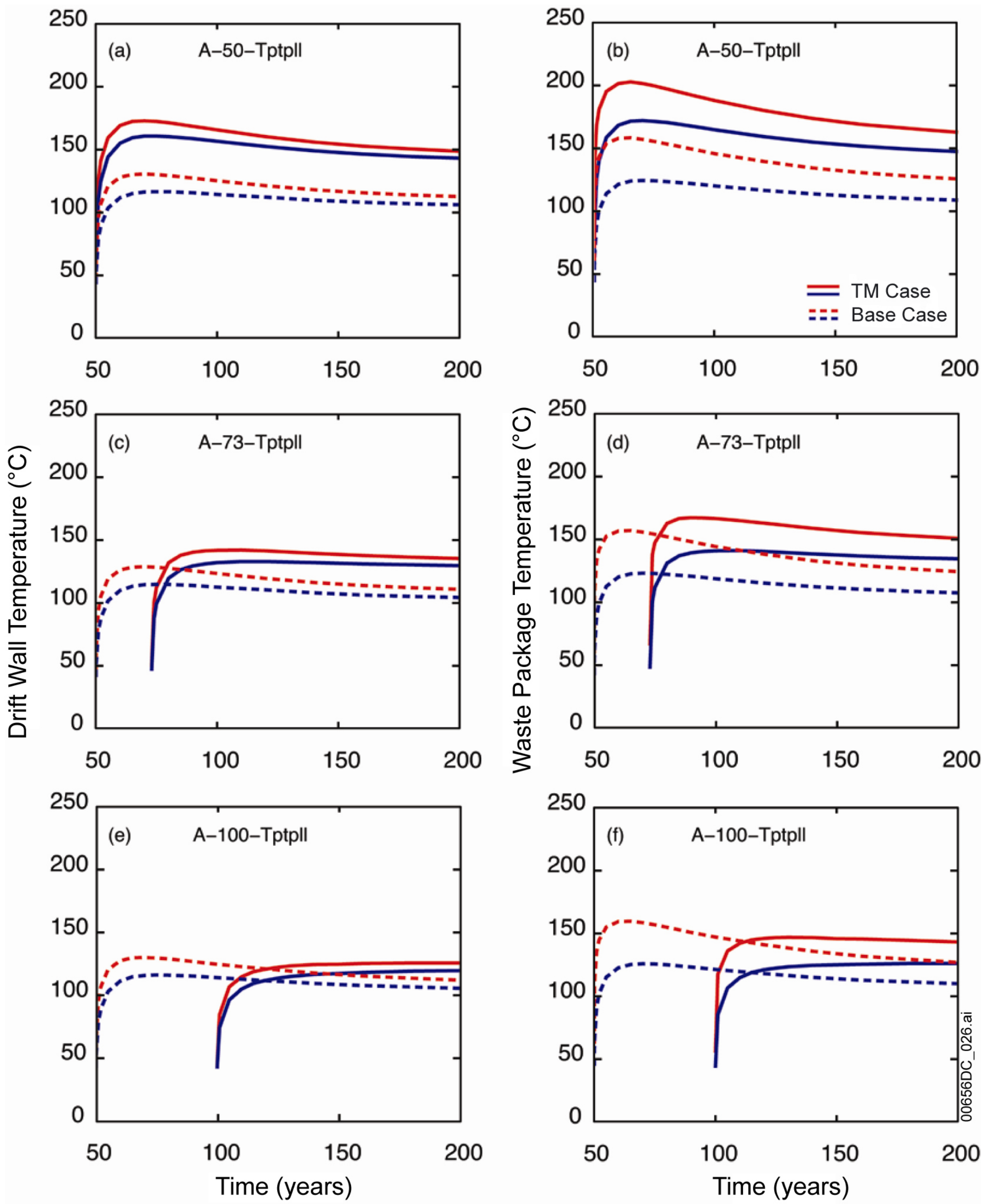
Heat generation Case C is different from the other three cases in that the heat generation tables for the two DHLW waste packages have been replaced by hypothetical waste packages with thermal output equivalent to the average line-load. Consequently, there is less waste package-to-waste package variability in heat output, resulting in a smaller range in temperatures among the respective waste packages (Tables 6-13 and 6-14). For a given thermal Case A, B, or C, maximum peak temperatures and temperature ranges are similar for the P2WR5C10 and P2ER8C6 locations and are, therefore, insensitive to repository location within the same repository horizon subunit.

A comparison of the cases using the mean host-rock thermal conductivity with the low host-rock thermal conductivity (Table 6-13) shows that the peak drift-wall temperature is greater for the low host-rock thermal conductivity case. Similarly, Table 6-14 shows that the peak waste package temperature is greater for the low host-rock thermal conductivity case. The temperature rise above ambient is roughly proportional to the reciprocal of the host-rock thermal conductivity. Tables 6-13 and 6-14 also show that the range in drift-wall and waste package temperatures among the waste packages is insensitive to host-rock thermal conductivity.

Table 6-15 lists the "deltas" in maximum peak drift-wall temperature and range of drift-wall temperature for Cases A, B, and C relative to the base case. Table 6-16 lists the deltas in maximum peak waste package temperature and range of waste package temperature for Cases A, B, and C relative to the base case. Thus, Tables 6-15 and 6-16 summarize how much hotter (or cooler) the cases are compared to the base case. Note that for a given case, the deltas are similar for the P2WR5C10 and P2ER8C6 locations and are, therefore, insensitive to repository location.

Peak temperatures and the ranges in temperatures along the six-plus-two-halves waste package sequence decrease with increasing preclosure ventilation duration (Tables 6-13 and 6-14). Tables 6-17 and 6-18 list the maximum peak drift-wall and waste package temperatures, respectively, for the cases with a 50-year preclosure ventilation period. The ratio of the temperature rise for a given Case A, B, or C divided by that of the base case is nearly the same as the ratio of the LPD for the case, divided by that for the base case. Temperature rise above ambient temperature is linearly proportional to LPD (Tables 6-17 and 6-18). Because all Cases A, B, and C all have higher values of LPD than the base case, they all result in higher peak drift-wall and waste package temperatures for a 50-year preclosure ventilation period. Longer preclosure ventilation periods (>50 years) reduce the heat load delivered to the host rock, thereby decreasing near-field temperatures relative to the base case.

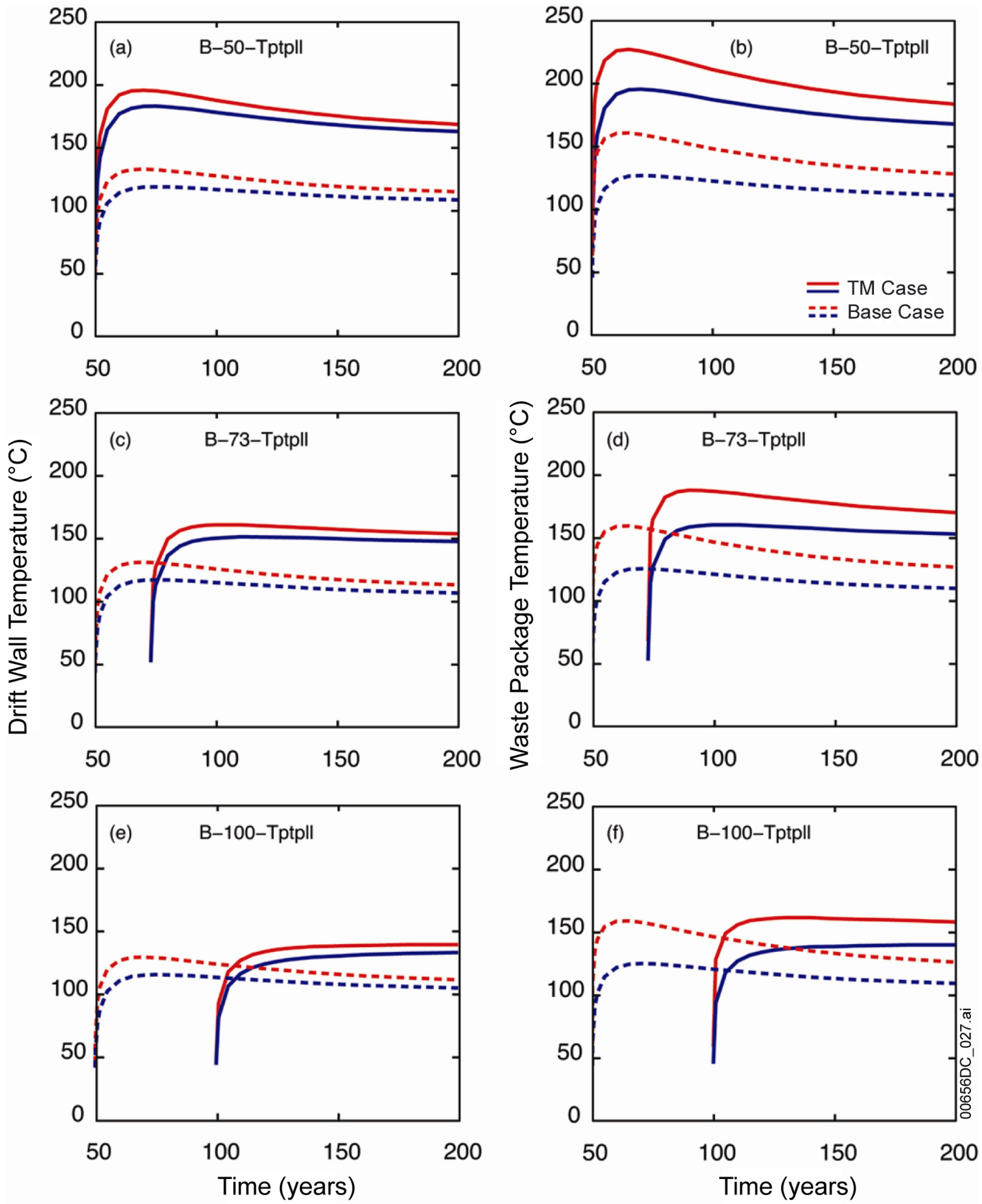
Table 6-19 presents the estimated preclosure ventilation time required to obtain the same maximum peak temperatures in Cases A, B, and C as in the base case. This ventilation time estimate is obtained by linearly interpolating or extrapolating the deltas in Tables 6-15 and 6-16 to a zero delta. Thus, the estimated preclosure ventilation period would result in the same maximum peak drift-wall or waste package temperature obtained in the base case. This additional ventilation time effectively compensates for the greater LPD. The needed ventilation times for the cases considered range from approximately 64 to 100 years.



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository center (P2WR5C10 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, "TM Case" stands for thermal management case (e.g., A-50-Tptpll case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).

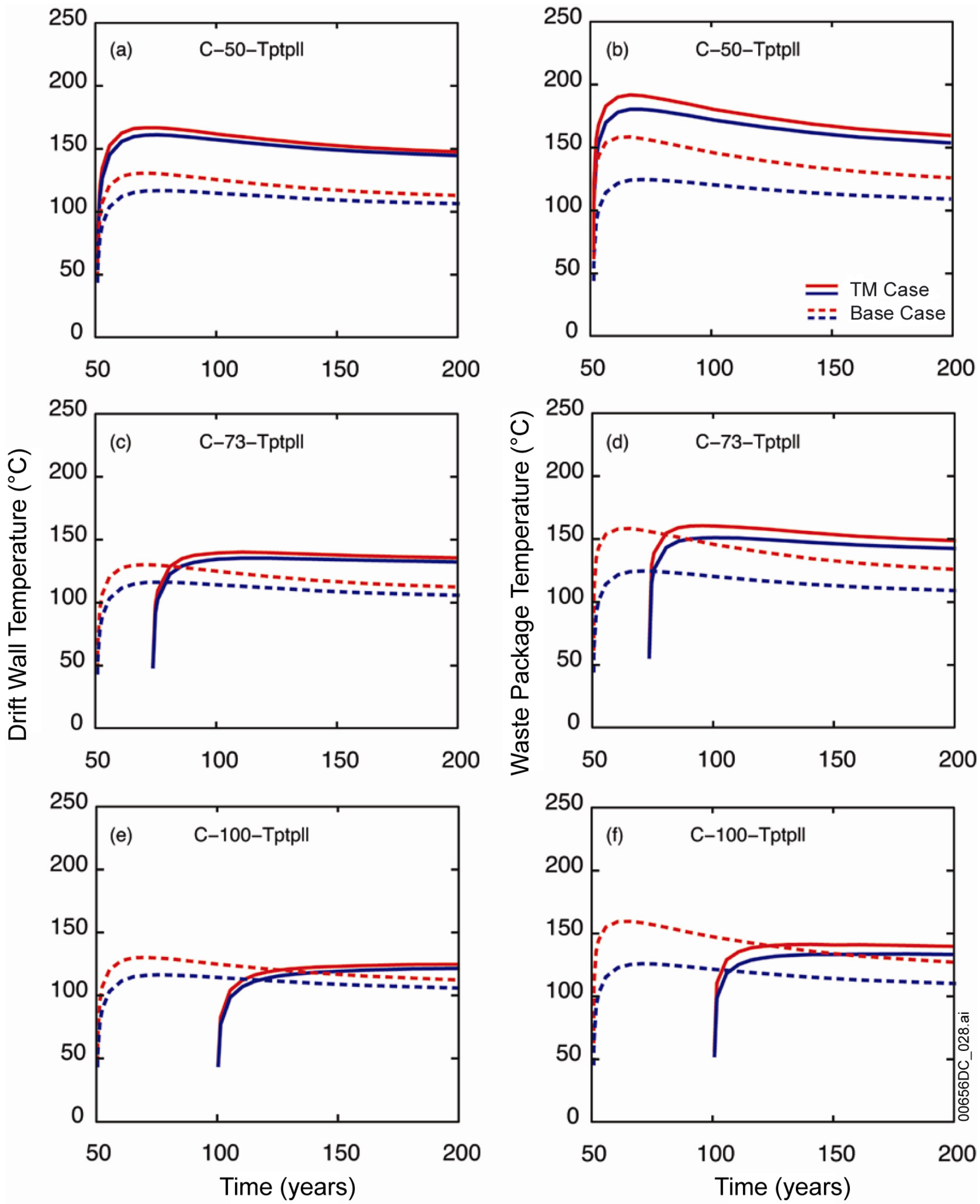
Figure 6-27. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2WR5C10 Location in the Tptpll Unit for Heat Generation Case A for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository center (P2WR5C10 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, "TM Case" stands for thermal management case (e.g., B-50-Tptpll case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).

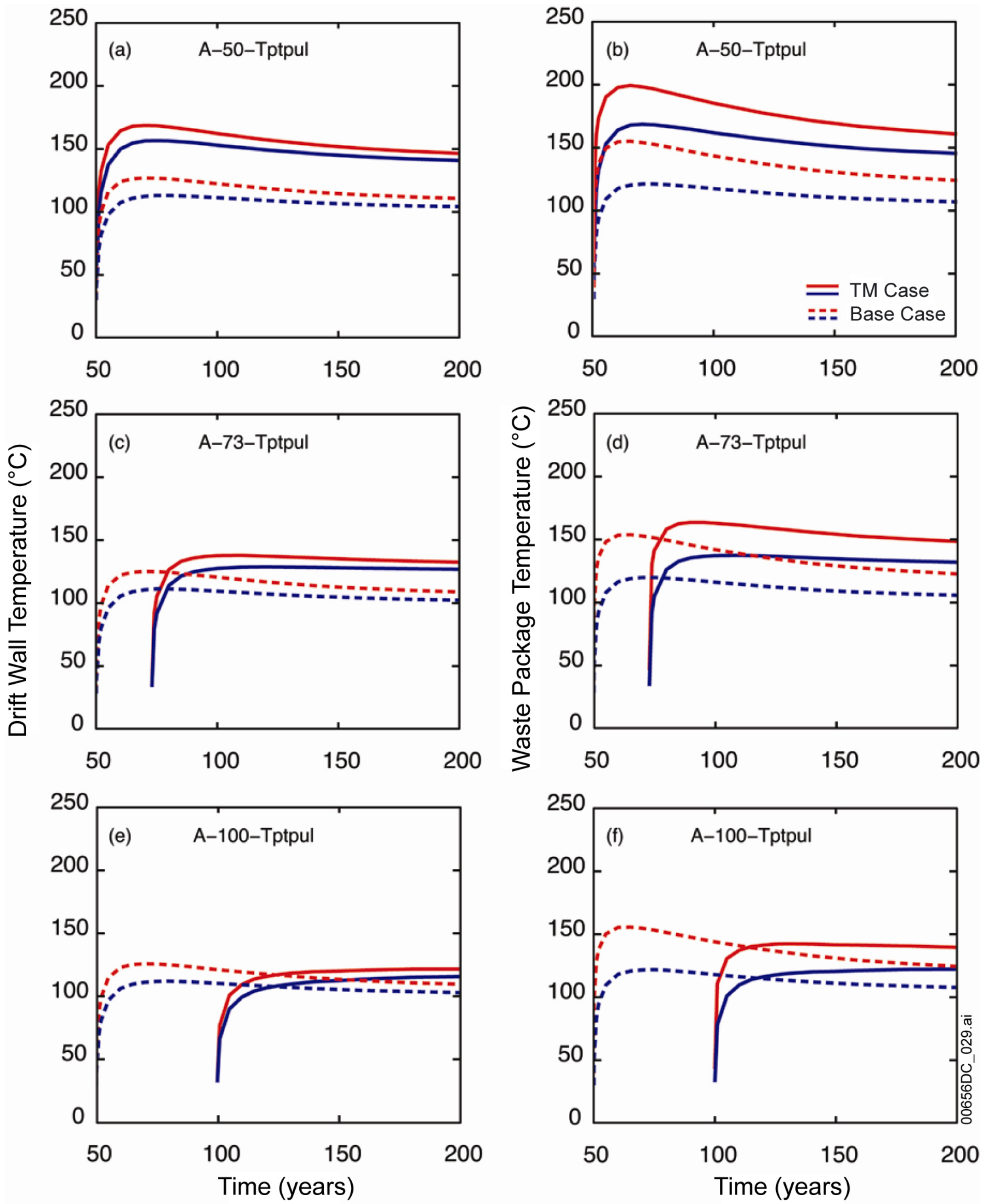
Figure 6-28. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2WR5C10 Location in the Tptpll Unit for Heat Generation Case B for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository center (P2WR5C10 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, "TM Case" stands for thermal management case (e.g., C-50-Tptpll case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).

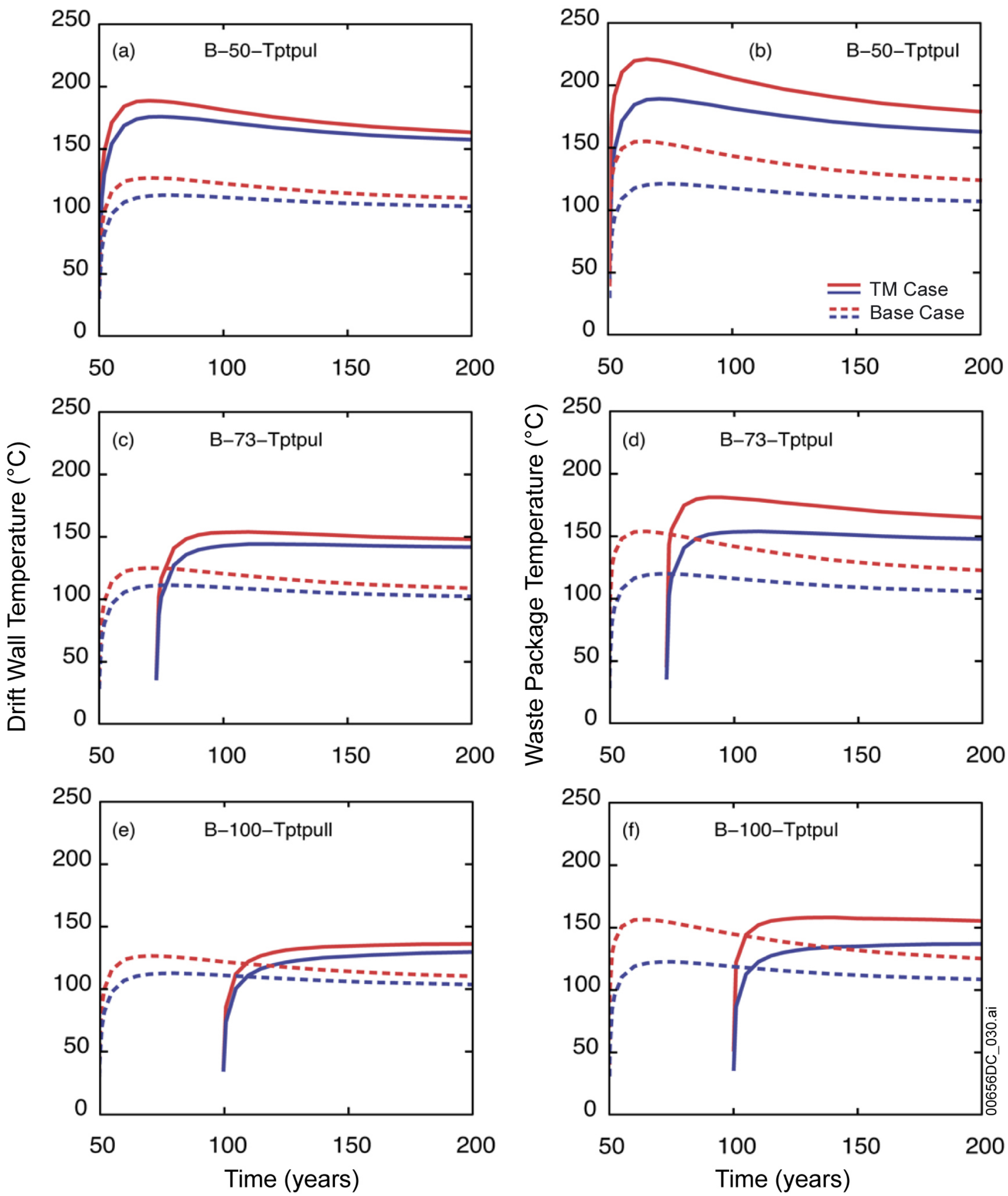
Figure 6-29. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2WR5C10 Location in the Tptpll Unit for Heat Generation Case C for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository edge (P2ER8C6 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, “TM Case” stands for thermal management case (e.g., A-50-Tptpul case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).

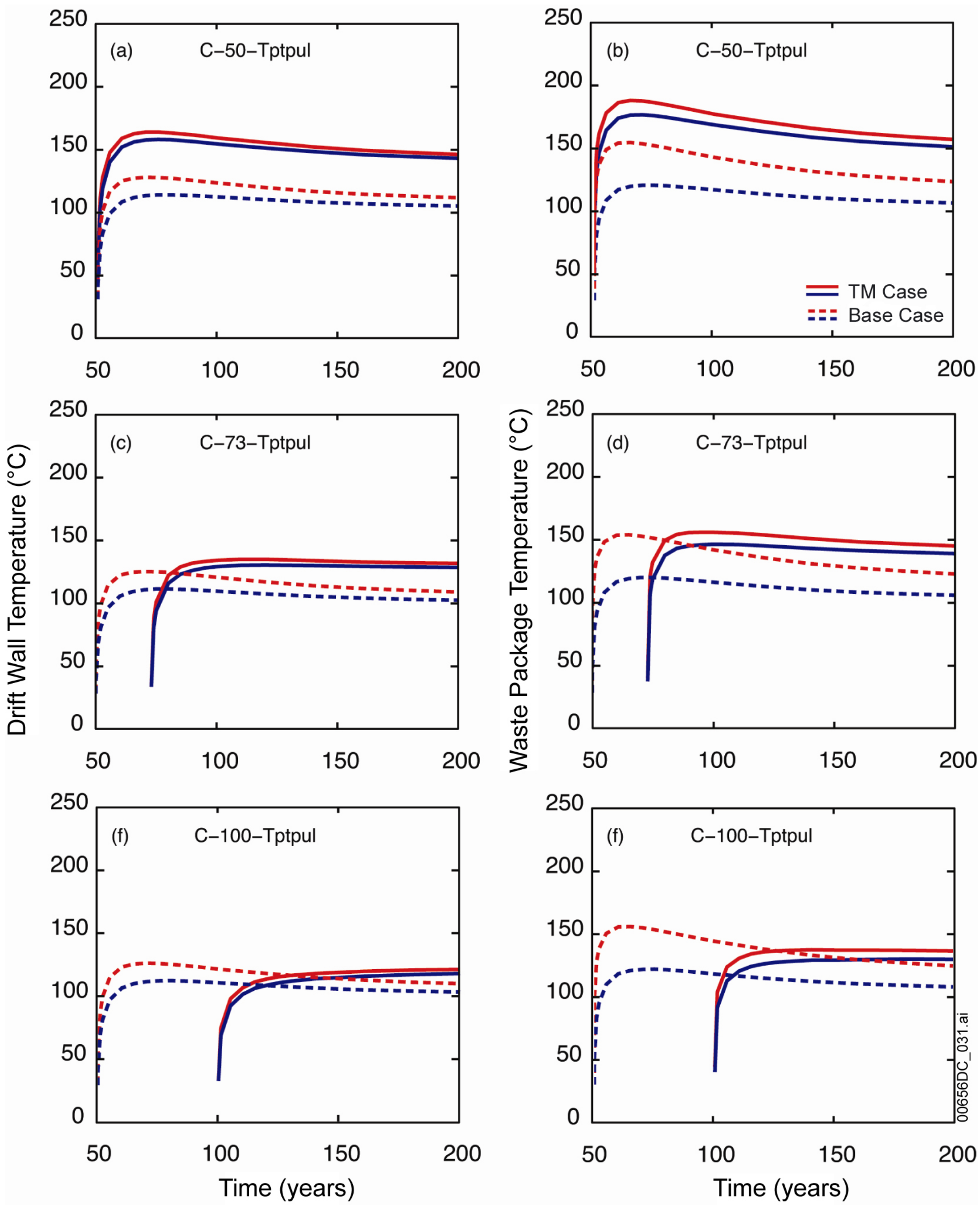
Figure 6-30. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2ER8C6 Location in the Tptpul Unit for Heat Generation Case A for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository edge (P2ER8C6 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, "TM Case" stands for thermal management case (e.g., B-50-Tptpul case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).

Figure 6-31. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2ER8C6 Location in the Tptpul Unit for Heat Generation Case B for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the DDT submodel for an AML of 55 MTU/acre for a location close to the repository edge (P2ER8C6 location shown in Figure 6.3-1 in BSC 2005 [DIRS 173944]) and for the mean host-rock thermal conductivity case. In the legend, "TM Case" stands for thermal management case (e.g., C-50-Tptpul case). Also shown is the base case (dotted curves), which corresponds to the temperatures calculated by the DDT submodel in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Figure 6-32. Drift-Wall Temperature (a, c, e) and Waste Package Temperature (b, d, f) for the Hottest and Coolest Waste Package at the P2ER8C6 Location in the Tptpul Unit for Heat Generation Case C for Preclosure Ventilation Periods of 50 Years (a, b), 73 Years (c, d), and 100 Years (e, f)

Table 6-11. Summary of Initial Heat Generation Rates for the Cases Considered in the Thermal Management Study

Waste Package Name in Multiscale	**Initial Heat Generation Rate (kW)**			
	Base Case [a]	**Heat Generation Case A (Cases 1 to 3, 10 to 12)**	**Heat Generation Case B (Cases 4 to 6, 13 to 15)**	**Heat Generation Case C (Cases 7 to 9, 16 to 18)**
pwr1-1	5.76 [b]	7.10 [b]	8.08 [b]	5.76 [b]
dhlw-l1	0.99	1.22	1.39	7.69
pwr2-1	11.80	14.54	16.60	11.80
bwr1-1	7.38	9.09	10.40	7.38
bwr2-1	7.10	8.75	9.96	7.10
dhlw-s1	2.98	3.67	4.18	5.30
pwr1-2	11.53	14.20	16.10	11.50
bwr1-2	3.69 [b]	4.55 [b]	5.18 [b]	3.69 [b]
Total	51.23	63.12	71.90	60.22
LPD [c]	1.45 kW/m	1.84 kW/m	2.09 kW/m	1.75 kW/m
LPD/LPD(base case)	1.00	1.27	1.44	1.21

[a] Corresponds to Table 6.3-13 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).
[b] These values represent the heat generation rates for a half waste package. The base case is corrected as discussed in Section 6.9.
[c] LPD is the total initial heat generation rate divided by the longitudinal length of the six-plus-two-halves waste package sequence in the DDT submodel.

Table 6-12. Summary of the Fractions of Initial Heat Generation Rates in the Sequence for the Cases Considered in the Thermal Management Study

Waste Package Name in Multiscale	**Fraction of Initial Heat Generation in Sequence**			
	Base Case [a]	**Heat Generation Case A (Cases 1 to 3, 10 to 12)**	**Heat Generation Case B (Cases 4-6, 13-15)**	**Heat Generation Case C (Cases 7-9, 16-18)**
pwr1-1	0.1124 [b]	0.1125 [b]	0.1124 [b]	0.0956 [b]
dhlw-l1	0.0193	0.0193	0.0193	0.1277
pwr2-1	0.2303	0.2304	0.2309	0.1959
bwr1-1	0.1441	0.1440	0.1447	0.1226
bwr2-1	0.1386	0.1386	0.1385	0.1179
dhlw-s1	0.0582	0.0581	0.0581	0.0880
pwr1-2	0.2251	0.2250	0.2240	0.1910
bwr1-2	0.0702 [b]	0.0721 [b]	0.0721 [b]	0.0613 [b]
Total	1.0000	1.0000	1.0000	1.0000

[a] Corresponds to Table 6.3-13 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).
[b] These values represent the heat generation rates for half waste packages. The base case is corrected as discussed in Section 6.9

Table 6-13. Summary of Range of Peak Drift-Wall Temperatures for Thermal Management Study

Location	Host-Rock Unit	Heat Generation Case	Maximum Peak Drift-Wall Temperature for Listed Preclosure Ventilation Periods [a] (°C)			Range in Peak Drift-Wall Temperature for Listed Preclosure Ventilation Periods [b] (°C)		
			50 Years	73 Years	100 Years	50 Years	73 Years	100 Years
P2WR5C10	Tptpll	Base Case [c]	141.0	N/A	N/A	10.8	N/A	N/A
P2ER8C6	Tptpul	A	168.7	139.7	123.0	12.1	9.0	6.0
P2WR5C10	Tptpll	A	172.7	143.8	126.3	12.0	8.9	5.9
P2ER8C6	Tptpul	B	188.6	155.7	136.7	12.8	9.7	6.4
P2WR5C10	Tptpll	B	193.1	160.3	140.5	12.7	9.6	6.3
P2ER8C6	Tptpul	C	162.7	136.7	122.2	5.7	4.5	3.3
P2WR5C10	Tptpll	C	166.8	140.5	125.2	5.8	4.6	3.2
P2ER8C6	Tptpul [d]	A	185.7	152.9	133.0	12.4	9.5	6.3
P2ER8C6	Tptpul [d]	B	207.6	170.7	148.1	13.0	10.0	6.8
P2ER8C6	Tptpul [d]	C	179.3	149.5	132.1	5.9	4.8	3.4

Source: Output DTN: LL051001723122.065.

[a] The maximum peak temperature pertains to the hottest waste package in the sequence.
[b] The range is the difference between the hottest and coolest waste package in the sequence.
[c] This is similar to the heat generation case applicable to all DDT submodels in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).
[d] Low host-rock thermal conductivity case, where the mean minus one standard deviation value of wet thermal conductivity is applied to the host-rock units (Tptpul, Tptpmn, Tptpll, and Tptpln), using values listed in Table 6.3-23 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Table 6-14. Summary of Range of Peak Waste Package Temperatures for Thermal Management Study

Location	Host-Rock Unit	Heat Generation Case	Maximum Peak Waste Package Temperature for Listed Preclosure Ventilation Periods [a] (°C)			Range in Peak Waste Package Temperature for Listed Preclosure Ventilation Periods [b] (°C)		
			50 Years	73 Years	100 Years	50 Years	73 Years	100 Years
P2WR5C10	Tptpll	Base Case [c]	169.3	N/A	N/A	28.9	N/A	N/A
P2ER8C6	Tptpul	A	200.1	165.8	142.8	30.6	26.1	20.0
P2WR5C10	Tptpll	A	203.5	169.5	146.5	30.5	26.1	20.7
P2ER8C6	Tptpul	B	221.7	183.3	157.6	31.6	27.2	20.9
P2WR5C10	Tptpll	B	225.3	187.5	161.8	31.3	27.2	21.6
P2ER8C6	Tptpul	C	189.3	158.2	137.8	11.3	9.6	7.4
P2WR5C10	Tptpll	C	192.7	161.6	141.0	11.2	9.5	7.7
P2ER8C6	Tptpul [d]	A	216.3	178.6	153.3	29.2	25.4	20.3
P2ER8C6	Tptpul [d]	B	239.8	198.0	169.5	29.8	26.4	21.2
P2ER8C6	Tptpul [d]	C	205.3	170.9	148.1	10.7	9.3	7.7

Source: Output DTN: LL051001723122.065.

[a] The maximum peak temperature pertains to the hottest waste package in the sequence.
[b] The range is the difference between the hottest and coolest waste package in the sequence.
[c] This is similar to the heat generation case applicable to all DDT submodels in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8).
[d] Low host-rock thermal conductivity case, where the mean minus one standard deviation value of wet thermal conductivity is applied to the host-rock units (Tptpul, Tptpmn, Tptpll, and Tptpln), using values listed in Table 6.3-23 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Table 6-15. Summary of the Deltas in the Maximum and Range of Peak Drift-Wall Temperature for the Thermal Management Cases, Relative to Those of the Base Case

Location	Host-Rock Unit	Heat Generation Case	Delta in the Maximum Peak Drift-Wall Temperature Relative to the Base Case [a] (°C) Ventilation Period 50 Years	73 Years	100 Years	Delta in the Range of Drift-Wall Temperature Relative to the Base Case [b] (°C) Ventilation Period 50 Years	73 Years	100 Years
P2ER8C6	Tptpul	A	27.7	–1.3	–18.0	1.3	–1.8	–4.8
P2WR5C10	Tptpll	A	31.7	2.8	–14.7	1.2	–1.9	–4.9
P2ER8C6	Tptpul	B	47.6	14.7	–4.3	2.0	–1.1	–4.4
P2WR5C10	Tptpll	B	52.1	19.3	–0.5	1.9	–1.2	–4.5
P2ER8C6	Tptpul	C	21.7	–4.3	–18.8	–5.1	–6.3	–7.5
P2WR5C10	Tptpll	C	25.9	–0.5	–15.7	–5.0	–6.2	–7.6

Source: Output DTN: LL051001723122.065.

[a] Determined by subtracting the maximum peak drift-wall temperature (140.0°C) for the base case from that of the thermal management cases listed in Table 6-4.

[b] Determined by subtracting the range in peak drift-wall temperature (10.8°C) for the base case from that of the thermal management cases listed in Table 6-4.

Table 6-16. Summary of the Deltas in the Maximum and Range of Peak Waste Package Temperature for the Thermal Management Cases, Relative to Those of the Base Case

Location	Host-Rock Unit	Heat Generation Case	Delta in the Maximum Peak Waste Package Temperature Relative to the Base Case [a] (°C) Ventilation Period 50 Years	73 Years	100 Years	Delta in the Range of Waste Package Temperature Relative to the Base Case [b] (°C) Ventilation Period 50 Years	73 Years	100 Years
P2ER8C6	Tptpul	A	30.8	–3.5	–26.5	1.7	–2.8	–8.9
P2WR5C10	Tptpll	A	34.2	0.2	–22.8	1.6	–2.8	–8.2
P2ER8C6	Tptpul	B	52.4	14.0	–11.7	2.7	–1.7	–8.0
P2WR5C10	Tptpll	B	56.0	18.2	–7.5	2.4	–1.7	–7.3
P2ER8C6	Tptpul	C	20.0	–11.1	–31.5	–17.6	–19.3	–21.5
P2WR5C10	Tptpll	C	23.4	–7.7	–28.3	–17.7	–19.4	–21.2

Source: Output DTN: LL051001723122.065.

[a] Determined by subtracting the maximum peak waste package temperature (169.3°C) for the base case from that of the thermal management cases listed in Table 6-4.

[b] Determined by subtracting the range in peak waste package temperature (28.9°C) for the base case from that of the thermal management cases listed in Table 6-4.

Table 6-17. Maximum Peak Drift-Wall Temperature and Temperature Rise above Ambient for Cases with a Preclosure Ventilation Period of 50 Years

Location	Heat Generation Case	LPD [a] (kW/m)	Maximum Peak T_{dw} (°C)	Initial T_{dw} (°C)	ΔT_{dw} (°C)	$\frac{\Delta T_{dw}}{\Delta T_{dw}\text{(base case)}}$	$\frac{\text{LPD}}{\text{LPD (base case)}}$
P2WR5C10	Base Case [a]	1.45	141.0	22.3	118.7	1.00	1.00
P2ER8C6	A	1.84	168.7	23.0	145.7	1.23	1.27
P2WR5C10	A	1.84	172.7	22.3	150.4	1.27	1.27
P2ER8C6	B	2.09	188.6	23.0	165.6	1.40	1.44
P2WR5C10	B	2.09	193.1	22.3	170.8	1.44	1.44
P2ER8C6	C	1.75	162.7	23.0	139.7	1.18	1.21
P2WR5C10	C	1.75	166.8	22.3	144.5	1.22	1.21

Source: Output DTN: LL051001723122.065.

[a] LPD is the sum of the initial heat generation rate divided by length of the six-plus-two-halves waste package sequence along the drift.

Table 6-18. Maximum Peak Waste Package Temperature and Temperature Rise above Ambient for Cases with a Preclosure Ventilation Period of 50 Years

Location	Heat Generation Case	LPD [a] (kW/m)	Maximum Peak T_{wp} (°C)	Initial T_{wp} (°C)	ΔT_{wp} (°C)	$\frac{\Delta T_{wp}}{\Delta T_{wp}\text{(base case)}}$	$\frac{\text{LPD}}{\text{LPD (base case)}}$
P2WR5C10	Base Case [a]	1.45	169.3	22.3	147.0	1.00	1.00
P2ER8C6	A	1.84	200.1	23.0	177.1	1.21	1.27
P2WR5C10	A	1.84	203.5	22.3	181.2	1.23	1.27
P2ER8C6	B	2.09	221.7	23.0	198.7	1.35	1.44
P2WR5C10	B	2.09	225.3	22.3	203.0	1.38	1.44
P2ER8C6	C	1.75	189.3	23.0	166.3	1.13	1.21
P2WR5C10	C	1.75	192.7	22.3	170.4	1.16	1.21

Source: Output DTN: LL051001723122.065.

[a] LPD is the sum of the initial heat generation rate divided by length of the six-plus-two-halves waste package sequence along the drift.

Table 6-19. Estimated Duration of Preclosure Ventilation Required to Achieve Same Maximum Peak Temperature of Base Case

Location	Host-Rock Unit	Heat Generation Case	Estimated Duration of Preclosure Ventilation Required to Achieve Maximum Peak Drift-Wall Temperature of Base Case [a] (years)	Estimated Duration of Preclosure Ventilation Required to Achieve Maximum Peak Waste Package Temperature of Base Case [b] (years)
P2ER8C6	Tptpul	A	72.0	70.7
P2WR5C10	Tptpll	A	77.3	73.2
P2ER8C6	Tptpul	B	93.9	87.7
P2WR5C10	Tptpll	B	99.3	92.1
P2ER8C6	Tptpul	C	69.2	64.8
P2WR5C10	Tptpll	C	72.6	67.3

Source: Output DTN: LL051001723122.065.

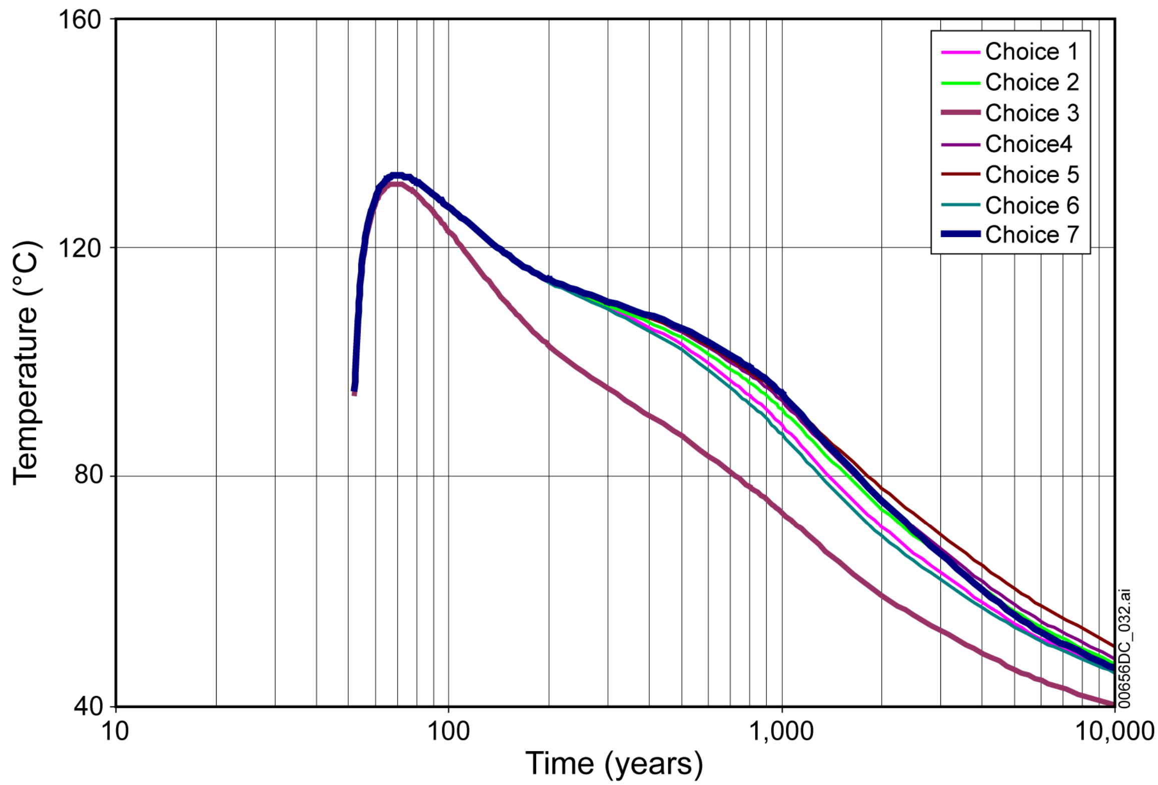
[a] Based on the deltas in maximum peak drift-wall temperature listed in Table 6.2-5 and linearly interpolating or extrapolating to a zero delta.
[b] Based on the deltas in maximum peak waste package temperature listed in Table 6.2-5 and linearly interpolating or extrapolating to a zero delta.

6.8 COMPARISON OF THE LINE-SOURCE CONDUCTION-ONLY ANALYSIS TO THE DDT SUBMODEL RESULTS

This section provides a consistency check between the line-source conduction-only analysis presented in Section 6.5 and the DDT submodel results presented in Section 6.7. Although the locations used in Section 6.4 (Figures 6-16 and 6-17) were selected to match corresponding locations in Section 6.6 (Figure 6-25), the analyses are of different types, which limits comparison. The DDT submodel is used in this report to evaluate package-to-package temperature variability, while the line-source conduction-only analysis includes the effects of finite thermal loading at the drift ends and is used to evaluate drift-wall and mid-pillar peak temperatures.

The DDT submodel units used either the wet rock mass thermal conductivity or the wet rock mass thermal conductivity minus one standard deviation (Table 6-13). For the Tptpll unit, the wet rock mass thermal conductivity value used in the DDT submodel is 1.89 W/(m·K). The value used in the line-source conduction-only analysis is also 1.89 W/(m·K) for the Tptpll unit.

Previous work with the line-source conduction-only approach presented in *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327], Figures 6.3.5-3 through 6.3.5-6) showed that repository edge effects and thermal interaction between adjacent drifts are minor until well after the time of peak drift-wall temperature, and conversely that the peak drift-wall temperature response is predominantly controlled by waste package heating in the immediate drift of interest. Therefore, these results show that the line-source conduction-only results and the DDT submodel results can be compared for peak drift-wall temperature, for the same value of rock mass thermal conductivity.



Source: BSC 2004 [DIRS 164327], Figures 6.3.5-3 through Figure 6.3.5-6.

Figure 6-33. Comparison of Peak Drift-Wall Temperature Histories for the Seven Drift Choices in the In-Drift Natural Convection and Condensation Model

A consistency check between the analyses can be applied to predicted peak drift-wall temperatures for different thermal loading conditions by comparing the ratio of the changes in temperature to the ratio of the thermal loadings. Changes in temperature are relative to the initial in situ temperature, which is approximately 23°C (Table 6-18). For comparison using the ratio of thermal loadings, the waste package thermal decay curves must scale, which is true in an average sense for the cases evaluated. This follows from the nature of the solution for time-varying flux solutions to the heat conduction problem. The initial power appears as a coefficient that multiplies a time-dependent (and position-dependent) solution (Carslaw and Jaeger 1959 [DIRS 100968], Equation 17, p. 338).

Table 6-20 presents the comparison of mean peak drift-wall temperature from the DDT submodel with peak drift-wall temperature from the line-source conduction-only analysis.

Noting that the waste package power decay with respect to time is the same for the base case, Case A (at 1.84 kW/m at emplacement) and Case B (at 2.09 kW/m at emplacement), the ratio of the peak postclosure temperature can be examined accordingly. From Table 6-20 consider the temperature for Case A (location P2ER8C6) with 50 years of ventilation. This temperature is 162.7°C, and the emplacement power is 1.84 kW/m. The relative temperature rise is 162.7 – 23 = 139.7°C. Compare this to the temperature for Case B (location P2ER8C6) with 50 years of ventilation; the temperature is 182.2°C, and the emplacement power is 2.09 kW/m. The relative temperature rise is 182.2 – 23 = 159.2°C. The ratio of these two temperatures is 1.139, and the ratio of the emplacement powers is 2.09/1.84 = 1.135. This "agreement" is to within approximately 0.3% and considered to be illustrative of the observation that these two indicated ratios provide a reasonable consistency check. Thus, for any situation where only the emplacement power is changed, the new temperatures (all of them) can be predicted by the ratio of emplacement powers as illustrated.

This relation of the ratios of temperatures and emplacement powers does not apply to the temperatures predicted for Case C relative to the other cases. The waste package power decay for Case C does not match these other cases with respect to time because the DHLW packages are replaced with the average 1.45 kW/m decay. To illustrate this situation where the waste package power decays with respect to time are not the same, consider Case C (at 1.75 kW/m at emplacement) and Case B (at 2.09 kW/m at emplacement). From Table 6-2, consider the temperatures for 73 years of ventilation at location P2ER8C6 (with the lower thermal conductivity); these temperatures are 165.7°C and 147.1°C, respectively. The temperature ratio is then (165.7 – 23)/(147.1 – 23) = 1.145, and the ratio of the emplacement powers is 2.09/1.75 = 1.194. Here the difference in the ratios is about 5%, and compared to the illustration above where the ratio difference is about 0.3%, it can be seen that when the decay with respect to time changes, the ratios do not obey the expected behavior.

Table 6-20. Comparison of Peak Drift-Wall Temperature Results for the DDT Submodel and Line-Source Conduction-Only Analysis

		Peak Drift-Wall Temperature (°C)					
		Approximate Mean DDT Submodel Results [a]			Line-Source Conduction-Only Solution		
		Ventilation Period			Ventilation Period		
Case ID	Subunit	50 years	73 years	100 years	50 years	73 years	100 years
Base Case		135.6	Not run	Not run	Not run	Not run	Not run
A	Tptpul	162.7	135.2	120.0	Not run	Not run	Not run
A	Tptpll	166.7	139.4	123.4	162.9	134.2	115.3
B	Tptpul	182.2	150.9	133.5	Not run	Not run	Not run
B	Tptpll	186.8	155.5	137.4	182.1	149.4	127.8
C	Tptpul	159.9	134.5	120.6	Not run	Not run	Not run
C	Tptpll	163.9	138.2	123.6	159.5	132.6	114.9
A	Tptpul	179.5	148.2	129.9	200.4	164.4	141.2
B	Tptpul	201.1	165.7	134.7	224.8	183.7	157.4
C	Tptpul	176.4	147.1	130.4	196.4	162.7	141.6

Source: Output DTNs: LL051001723122.065 (DDT submodel results); MO0509SPALINSC.000 (line source conduction-only results).

[a] Mean peak drift-wall temperature for the DDT submodel is obtained by subtracting one half the maximum range of drift-wall temperature axial variability from Table 6-13, from the overall peak drift-wall temperature.

Another ratio method that can be used to scale temperature is based on thermal conductivity as illustrated in Figure 6-24. Given two temperature histories that differ only in rock mass thermal conductivity, the ratio of these temperatures should approximate the inverse ratio of the thermal conductivities. This conclusion can be seen in the text by Carslaw and Jaeger (1959 [DIRS 100968], Equation 17, p. 338). However, since the rock mass thermal conductivity also appears in the thermal diffusivity, which in turn appears associated with time, the ratio method of scaling temperature with respect to thermal conductivity is only approximate. To illustrate this point, consider the Case A line source conduction-only result for Case A in the Tptpll unit from Table 6-20, compared with the result for Case A in the Tptpul unit. For 73 years of ventilation the peak postclosure drift-wall temperature from Table 6-20 is 134.2°C with a rock mass thermal conductivity of 1.89 W/m K, while at the same conditions and location but with a rock mass thermal conductivity of 1.39 W/m K the temperature is 164.4°C. The temperature ratio of interest is (164.4 – 23)/(134.2 – 23) = 1.27, and the ratio of the thermal conductivities is 1.89/1.39 = 1.35. These ratios are reasonably close, the difference being approximately 7%, and this is considered reasonable given that the thermal conductivity appears functionally elsewhere in the solution for temperature.

6.9 RESULTS OF DDT SUBMODEL IMPACT EVALUATION FOR THE MULTISCALE MODEL

As discussed in Section 6.2.8 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), the DDT submodels are used to account for waste package-specific heat generation rates and for the influence of thermal radiation between all waste package and drift surfaces to determine waste package-specific deviations (relative to line-averaged heat-source conditions) in temperatures along the drifts. During the course of conducting the DDT submodel calculations for the thermal management study, it was found that the heat generation rates for the first and last one-half waste packages in the DDT submodel (BSC 2005 [DIRS 173944], Section 6.2.8) were one-half the values given in *IED Waste Package Decay Heat Generation [Sheet 1 of 1]* (BSC 2005 [DIRS 173705], Table 1), which resulted in the values listed in Table 6-9. For the thermal analyses conducted in this report the corrected heat generation rates in Table 6-10 were used. The purpose of this section is to evaluate the impact of the reduced heat output of the first and eighth waste package of the DDT submodel on the multiscale model results.

The smaller heat generation rates of the first and last one-half waste package in Table 6-9 result in an LPD of 1.32 kW/m for the sequence, which is 9% less than that of the base case (1.45 kW/m) in the thermal management study. The impact of this 9% reduction is to reduce the temperatures of all waste packages in the sequence by about 10°C compared to the case with an LPD of 1.45 kW/m. Because all waste packages were similarly affected, the waste package deviations (compared to line-averaged conditions) are insignificantly influenced. Figure 6-34 shows the impact of the small differences in the waste package-specific temperature deviations on multiscale model calculations at the P2WR5C10 location (see Figure 6-25 for location).

Table 6-21 and Figure 6-34 show the range in drift-wall and waste package temperatures (from coolest to hottest) for the P2WR5C10 location in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.1.2), which utilized the heat generation rates in Table 6-9, and for the corrected base case, which utilizes the heat generation rates in Table 6-10. It is apparent that the reduced heat generation rates for the first and last one-half waste packages have a small influence on drift-wall and waste package temperatures.

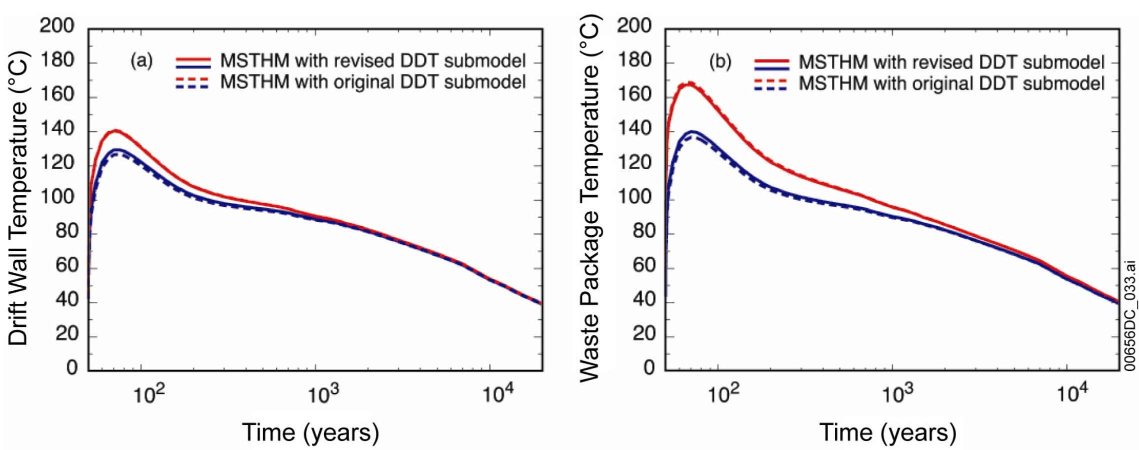
The net impact of using the DDT submodels with reduced heat output for the first and eighth waste package in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.2.8) is a slightly larger range in waste package-to-waste package variability in drift-wall temperature (14°C versus 11°C) and in waste package temperature (32.1°C versus 27.3°C) than would have occurred if the full heating rates were applied to those waste packages. Therefore, the results in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) can be considered slightly conservative with respect to waste package-to-waste package variability in thermal-hydrologic conditions. The results in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) are also slightly conservative (on the high side) for the hottest waste package in the sequence (168.1°C versus 167.3°C), and slightly conservative (on the low side) for the coolest waste package in the sequence (136.7°C versus 140.0°C). However, the degree of conservatism is insignificant compared to the impact of parametric uncertainty, which causes differences in temperature up to 60°C (BSC 2005 [DIRS 173944], Section 7.5.4), depending on the local host-rock thermal conductivity.

Table 6-21. Multiscale Model-Predicted Maximum and Range of Drift-Wall and Waste Package Temperatures at the P2WR5C10 Location for the Mean Infiltration Flux, Mean Host-Rock Thermal Conductivity Case

	Peak Drift-Wall Temperature (°C)		Peak Waste Package Temperature (°C)	
Case	**Maximum Peak**	**Range**	**Maximum Peak**	**Range**
Multiscale [a]	140.8	14.0	168.8	32.1
Multiscale [b]	140.4	11.0	167.3	27.3

Source: Output DTN: LL051001723122.065.

[a] Taken from BSC 2005 [DIRS 173944], Table 6.3-14, with the initial heat generation rates listed in Table 6-10.
[b] Similar to that in BSC 2005 [DIRS 173944], Table 6.3-14, but with revised initial heat generation rates for the first and last one-half waste packages in the sequence, listed in Table 6-9.



Source: Output DTN: LL051001723122.065.

NOTE: Postclosure temperature histories are calculated by the multiscale model for the P2WR5C10 location, the mean infiltration flux case, with mean host-rock thermal conductivity, using the *original* DDT submodels (BSC 2005 [DIRS 173944], Section 6.2.8), which use the initial heat generation rates listed Table 6.1-7, and using *revised* DDT submodels, which use the initial heat generation rates listed in Table 6.1-6.

Figure 6-34. Multiscale Model-Predicted Drift-Wall Temperature (a) and Waste Package Temperature (b) for the Hottest and Coolest Waste Package at the P2WR5C10 Location in the Tptpll Unit, Using DDT Submodels with LPD Values of 1.32 kW/m (original case) and 1.45 kW/m (revised case), Respectively

7. CONCLUSIONS

This report evaluates postclosure drift-wall and mid-pillar temperatures, and package-to-package axial variability of drift-wall temperature, for three alternative thermal loading schemes (Cases A, B, and C) and three ventilation periods (50, 73, and 100 years) (Sections 6.4 through 6.7). The predicted results were compared with postclosure temperature criteria (Section 4.2), including limits on peak postclosure drift-wall and mid-pillar temperatures from *Yucca Mountain Project Conceptual Design Report* (DOE 2006 [DIRS 176937]).

The alternative thermal loading schemes were selected to represent SNF that is younger, or younger with higher burnup, relative to the postclosure reference case (base case) (Sections 6.1 and 6.2). Various cases were repeated using low or lower-bound host-rock thermal conductivity. The methods used to perform the analyses included line-source conduction-only analytical solutions, and the DDT submodel of the multiscale model (BSC 2005 [DIRS 173944]). Note that conduction only solutions might tend to slightly overestimate rock temperatures by several degrees at midpillar when liquid advection in the vadose zone is considered in a conduction dominated system. The results of the conduction only analysis are conservative in regards to compliance with the postclosure criteria. Preclosure ventilation for the alternative loading schemes was also evaluated (Section 6.3) using the method developed previously (BSC 2004 [DIRS 169862]).

The results of the study are summarized as follows:

- Efficiency of preclosure ventilation with the alternative loading schemes is in the range 85% to 90% (Section 6.3). This represents no significant change from the reference case.

- Preclosure drift-wall temperatures during ventilation are predicted to be less than 96°C for the cases evaluated (Section 6.3).

- Peak mid-pillar temperature (criterion: 96°C) is a more important constraint on thermal loading than peak drift-wall temperature (criterion: 200°C) (Section 6.5).

- The peak mid-pillar temperature criterion is exceeded for cases representing younger SNF (Cases 1 and 2), based on line-source conduction-only analysis (Section 6.5, Table 6-3). Longer ventilation (Case 3) or repository edge loading (Cases 10, 11, and 12) maintained mid-pillar temperature less than 96°C.

- Peak mid-pillar temperature is exceeded for cases representing higher burnup SNF (Cases 4, 5, 6, 13 and 14), based on line-source conduction-only analysis (Section 6.5, Table 6-3). Longer ventilation (up to 100 years) and repository edge loading were relatively ineffective at limiting mid-pillar temperature to less than 96°C.

- Peak drift-wall temperature is controlled by the thermal output of nearby waste packages in the drift of interest, and occurs soon after closure so that thermal interference between adjacent drifts is not a factor (Section 6.7).

- Peak postclosure drift-wall temperature is inversely dependent on host-rock thermal conductivity, and may exceed the 200°C criterion for lower-bound values of conductivity (Section 6.7, Table 6-13, Case B with Tptpul lower-bound).

- Package-to-package axial variability of drift-wall temperature can be limited by extended ventilation beyond 50 years, to be within approximately 20°C of the base case (Section 6.7, Table 6-15), for all cases evaluated.

Conclusions for application to future specification of alternative thermal loading schemes:

- For the selected variations in waste package power, and spent nuclear fuel burnup, the current postclosure criteria can be met if longer ventilation times are chosen.

- Delay of emplacement will ensure that criteria for peak drift-wall temperature, and package-to-package axial variation of drift-wall temperature, are also met.

Drift-wall temperature results from the line-source conduction-only analyses (Sections 6.4 and 6.5) are in approximate agreement with the DDT submodel (Sections 6.6 and 6.7) for the Tptpll unit, and show similar trends in temperature, thus confirming the line-source conduction-only approach.

7.1 YUCCA MOUNTAIN REVIEW PLAN CRITERIA ASSESSMENT

This report evaluates the effects on postclosure peak temperatures and temperature variability, from specific changes to the postclosure thermal reference case implemented as a feed to TSPA in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The multiscale model represents temperature and humidity conditions in the emplacement drifts and adjoining host rock. This report therefore indirectly supports the TSPA, through the evaluation of repository temperature conditions corresponding to alternative thermal loading conditions. Acceptance criteria from *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.3.3.3) pertaining to the quantity and chemistry of water contacting engineered barriers and waste forms apply as discussed below.

Some aspects of the acceptance criteria (flow, seepage, chemistry, coupled hydrologic-chemical-mechanical processes) are not addressed by this report. The criteria addressed here are specific to the anticipated ranges of mid-pillar and drift-wall temperatures, the variability of drift-wall temperature, and the characterization of host-rock thermal conductivity. The following sections summarize how this report supports compliance of the postclosure risk assessment with the indicated acceptance criteria.

7.1.1 Acceptance Criterion 1 – System Description and Model Integration Are Adequate

The analyses presented in this report partially address several of the sub-criteria for system description and model integration:

(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate

assumptions throughout the quantity and chemistry of water contacting engineered barriers and waste forms abstraction process.

The design information used in this report, including waste thermal output, and design dimensions and material properties used as inputs to the DDT submodel, is in reasonable agreement with current controlled sources (Table 4-7 and Table 4-8). Section 4.1 provides justification for small differences associated with design evolution. Where possible, physical properties of engineered materials are obtained from American Society of Mechanical Engineers standards and other justified sources (Table 4-7). Simplifying assumptions about dimensions and material properties are stated and justified in Section 5. Ventilation efficiency as a function of drift location and time is input from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]). Treatment of design information in this report is consistent with *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), which provides the associated abstraction for TSPA.

Thermal properties for the host rock are obtained from, or consistent with, *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). Use of this source helps ensure consistency among the abstractions affecting the representation of the quantity and chemistry of water contacting engineered barriers and waste forms.

(3) Important design features, such as waste package design and material selection, backfill, drip shield, ground support, thermal loading strategy, and degradation processes, are adequate to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting engineered barriers and waste forms.

The DDT submodel used in this report includes important features and processes such as discrete waste packages, material properties, and thermal radiation, appropriate for calculating in-drift temperature variability. The principal contribution of this report is the evaluation of alternative thermal loading schemes, representing potential elements of a thermal loading strategy. The conclusions described in Section 7 show how postclosure temperature limits can be met, for alternative thermal loading based on perturbations to the postclosure thermal reference case. The overall conclusion that younger spent fuel or higher-burnup spent fuel can be accommodated with longer preclosure ventilation (or delayed schedule for emplacement and closure) is applicable to any thermal loading strategy that involves these waste form characteristics.

(6) The expected ranges of environmental conditions within the waste package emplacement drifts, inside the breached waste packages, and contacting the waste forms and their evolution with time are identified. These ranges may be developed to include: (i) the effects of the drip shield and backfill on the quantity and chemistry of waster (e.g., the potential for condensate formation and dripping from the underside of the shield); (ii) conditions that promote corrosion of engineered barriers and degradation of waste forms; (iii) irregular wet and dry cycles; (iv) gamma-radiolysis; and (v) size and distribution of penetrations of engineered barriers.

This report evaluates the ranges of drift-wall and waste package peak temperatures, and the axial variability of drift-wall temperature, associated with alternative thermal loading schemes. For some of the loading schemes considered, the 200°C postclosure drift-wall temperature limit was achieved, and the package-to-package variation of drift-wall temperature was comparable to the postclosure reference case (Sections 6.5 and 6.7).

(7) The model abstraction for quantity and chemistry of water contacting engineered barriers and waste forms is consistent with the detailed information on engineered barrier design and other engineered features. For example, consistency is demonstrated for: (i) dimensionality of the abstractions; (ii) various design features and site characteristics; and (iii) alternative conceptual approaches. Analyses are adequate to demonstrate that no deleterious effects are caused by design or site features that the U.S. Department of Energy does not take into account in this abstraction.

Thermal analyses in this report address both the peak in-drift and mid-pillar temperatures (Sections 6.4 through 6.7), but also the variability of in-drift temperature in the axial dimension as represented by the DDT submodel (Section 6.7). Alternative approaches are used in the analytical solutions and the DDT submodel, and are cross-checked in Section 6.8.

(12) Guidance in NUREG–1297 (Altman et al. 1988 [DIRS 103597]) and NUREG–1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches, is followed.

Inputs were selected and documented, and documents were checked and reviewed in accordance with the applicable procedures, which comply with NUREG-1297 and 1298.

7.1.2 Acceptance Criterion 2 – Data Are Sufficient for Model Justification

The analyses presented in this report partially address one of the sub-criteria for data sufficiency for model justification:

(1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

The most important parameter controlling in-drift temperature is the host-rock thermal conductivity (represented by drift-wall temperature; see BSC 2005 [DIRS 173944], Table 6.3-30). The values developed in this report to represent the range, particularly for lithophysal tuff with relative low thermal conductivity, are consistent with *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 4.1), as discussed in Section 7.1.1.

7.1.3 Acceptance Criterion 3 – Data Uncertainty Is Characterized and Propagated through the Model Abstraction

The analyses presented in this report partially address several of the sub-criteria for data uncertainty characterization and propagation through model abstraction:

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for

uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

The alternative thermal loading schemes described in this report are intended for use as limiting cases for use in defining the range of thermal loading anticipated for the repository. They are based on shifting the amplitude and time base for the average thermal line-load power curve from the postclosure thermal reference case, and thus represent a unique and technically defensible approach to developing alternatives that can be closely compared with the reference case. The results will support assessment of the sensitivity of repository performance to the anticipated range of thermal loading, and the associated uncertainty in representation of risk using the postclosure reference case.

(2) Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.

As stated in Section 7.1.2, the most important parameter controlling in-drift temperature is the host-rock thermal conductivity. The values developed in this report to represent the range, particularly for lithophysal tuff with relative low thermal conductivity, are consistent with *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 4.1). This geostatistical model for host-rock thermal conductivity is based on various forms of data from Yucca Mountain boreholes, and from laboratory testing on rock samples from Yucca Mountain. The model is validated using field measurements of in situ thermal conductivity underground, in the host-rock units at Yucca Mountain.

(4) Adequate representation of uncertainties in the characteristics of the natural system and engineered materials is provided in parameter development for conceptual models, process-level models, and alternative conceptual models. DOE may constrain these uncertainties using sensitivity analyses or conservative limits. For example, DOE demonstrates how parameters used to describe flow through the EBS bound the effects of backfill and excavation-induced changes.

Previous studies have found that uncertainty in calculated thermal-hydrologic response is most strongly affected by the uncertainty in host-rock thermal conductivity (BSC 2005 [DIRS 173944], Section 6.3.2), as discussed above and in Section 7.1.2. Uncertainty in thermal conductivity is part of the geostatistical model described in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 6.1). The values developed in this report to represent the range of thermal conductivity, particularly for lithophysal tuff with relative low thermal conductivity, are consistent with the geostatistical model.

7.1.4 Acceptance Criterion 4 – Model Uncertainty Is Characterized and Propagated through the Model Abstraction

(1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.

This report uses thermal conduction-only analytical solutions (Sections 6.4 and 6.5) and numerical implementation of thermal conduction solutions with thermal radiative coupling (Sections 6.6 and 6.7) to represent heat transfer in the host rock. Such methods are simpler alternatives to more complex coupled-process numerical models, providing insight on conduction and radiation as heat transfer processes, isolated from hydrologic, chemical, and mechanical coupled-process effects. Without mass transport, the thermal-only methods overestimate temperature increases from repository heating, since neither the sensible nor latent heat transfers associated with mass transport are represented.

The methods presented in this report are limited because they use host-rock thermal conductivity values representing in situ matrix water saturation, whereas the dryout zone that forms around repository openings has lower saturation and therefore lower thermal conductivity. Accordingly, thermal-only methods (described in Sections 6.4 and 6.6) tend to underestimate drift-wall temperature. The effect on mid-pillar temperature is small because most of the pillar does not dry out. Drift-wall temperature variation from waste package to waste package is also underestimated, because the near-field thermal rock thermal conductivity is smaller with dryout.

7.2 OUTPUT DATA TRACKING NUMBERS

The following output DTNs were developed for performing the scaling calculations presented in this report, in performing a ventilation analysis, and in calculating the mid-pillar temperatures:

- LL051001723122.065. Discrete-Heat-Source Drift-Scale Thermal (DDT) Model Output Supporting the Thermal Management Flexibility Analysis Report (ANL-EBS-MD-000075 REV 00). Submittal date: 10/18/2005

- MO0506SPAPRETM.000. Preclosure Thermal Management Flexibility Analysis. Submittal date: 06/28/2005

- MO0509SPALINSC.000. Line Source Conduction Only Postclosure Calculations for the Thermal Management Flexibility Analysis. Submittal date: 9/26/2005.

- MO0607MPDWCOAN.000. Mid-Pillar and Driftwall Conduction Only Analyses in Support of the Thermal Management Flexibility Analysis. Submittal date: 7/05/2006.

- MO0701VENTCALC.000. Analytical Ventilation Calculation for the Base Case Analysis with a 1.45 KW/Hr Initial Line Load. Submittal date: 1/23/2007.

There are no restrictions on the use of these data.

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APPENDIX A

CONSISTENCY CHECK OF GRAIN DENSITY

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A.1 PROBLEM STATEMENT

Perform a consistency check on the specific gravity of solids used in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]). The dry bulk density, matrix porosity, and lithophysal porosity are presented in Section 4 of the report. The specific gravity of solids is calculated in Appendix B. Check this calculation for consistency with the information presented in Section 4.

A.2 ANALYSIS

Consider the definitions for the matrix porosity and the lithophysal porosity. The matrix porosity is defined as the ratio of the void volume of the matrix to the total matrix volume of solids (BSC 2004 [DIRS 169862], Appendix II, Equation II-8):

$$\phi_m = \frac{V_m}{V_s + V_m}$$

(Eq. A-1)

Use the soil mechanics convention of setting the volume of solids to one. Solving for V_m in terms of the matrix porosity, and obtaining the matrix porosity from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 4-6):

$$\phi_m := 0.1486$$

$$V_m := \frac{\phi_m}{1 - \phi_m} \qquad V_m = 0.1745$$

(Eq. A-2)

The lithophysal porosity is defined as the ratio of the void volume of the lithophysae to the total volume (BSC 2004 [DIRS 169862], Table 4-6):

$$\phi_L = \frac{V_L}{V_s + V_m + V_L}$$

(Eq. A-3)

Obtain the lithophysal porosity from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 4-6):

$$\phi_L := 0.0883$$

(Eq. A-4)

Solving for the volume of the lithophysae:

$$V_L := \frac{\phi_L \cdot (1 + V_m)}{1 - \phi_L} \qquad V_L = 0.1138$$

(Eq. A-5)

Now calculate the total volume based upon the volume of the solids, the matrix, and lithophysae.

$$V_T := 1 + V_m + V_L \qquad V_T = 1.2883$$

(Eq. A-6)

Now consider the dry bulk density. The dry bulk density is given by weight of the solids divided by the total volume:

$$\rho_d = \frac{W_s}{V_T}$$

(Eq. A-7)

Obtain the lithophysal porosity from *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 4-6):

$$\rho_d := 1.9793 \cdot 1000$$

$$\rho_s := \frac{V_T \cdot \rho_d}{1} \qquad \rho_s = 2549.9$$

(Eq. A-8)

Now present the calculations in a block phase diagram and backcheck the calculations.

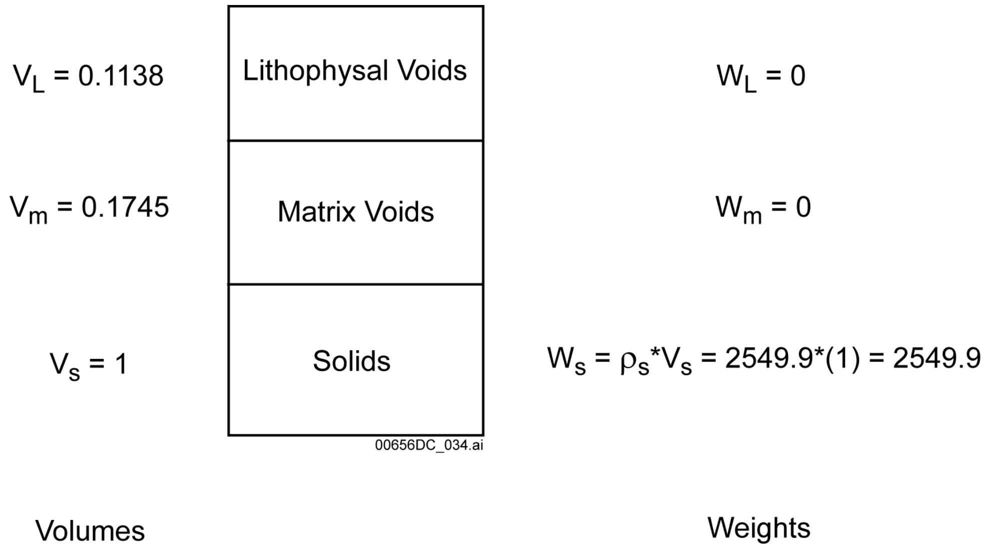

Figure A-1. Block Diagram Showing Computations for Volumes and Weights

Perform a backcheck of the calculations.

$$\phi_m := \frac{0.1745}{1 + 0.1745} \qquad \phi_m = 0.1486$$

$$\phi_L := \frac{0.1138}{1 + 0.1745 + 0.1138} \qquad \phi_L = 0.0883$$

$$\rho_s := \frac{2549.9}{(1 + 0.1745 + 0.1138)} \qquad \rho_s = 1.9793 \times 10^3$$

(Eq. A-9)

A.3 CONCLUSIONS

The calculated grain density of solids of 2,549.9 kg/m^3 differs from the reported grain density of solids of 2,593 kg/m^3. The difference is about 1.7%. The reported value is used in the analytical ventilation model, and would not result in a significant difference in ventilation efficiency.

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APPENDIX B

VOLUMETRIC HEAT CAPACITY CALCULATION

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This appendix documents the calculation of effective thermophysical properties used in the analytical ventilation model discussed in Section 6.3 of this report. For geologic media composed of air, water, and rock, the heat capacity per unit volume of the composite material is the sum of the heat capacities of the constituents weighted by volume fractions. Jury et al. (1991 [DIRS 102010], p. 179) express this capacity as:

$$C_{soil} = \chi_a \cdot C_a + \chi_w \cdot C_{vw} + \sum_{j=1}^{N} \chi_{sj} \cdot C_{sj} \qquad \text{(Eq. B-1)}$$

where

χ_a = Volume fraction of the air

χ_w = Volume fraction of the water

χ_{sj} = Volume fraction of *j*th component of the solids

C_a = Volumetric heat capacity of the air

C_{vw} = Volumetric heat capacity of the water

C_{sj} = Volumetric heat capacity of the *j*th component of the solids.

More specifically for the geologic units at Yucca Mountain, Equation B-1 can be written:

$$C_{rock} = \chi_{am} \cdot C_a + \chi_{al} \cdot C_a + \chi_w \cdot C_{vw} + \chi_s \cdot C_s \qquad \text{(Eq. B-2)}$$

where

χ_{am} = Volume fraction of the air in the matrix

χ_{al} = Volume fraction of the air in the lithophysae

χ_w = Volume fraction of the water in the matrix

χ_s = Volume fraction of the solids.

The various volume fractions can be written as:

$$\chi_{al} = \frac{V_{al}}{V_s + V_{wm} + V_{am} + V_{al}} \qquad \text{(Eq. B-3)}$$

$$\chi_{am} = \frac{V_{am}}{V_s + V_{wm} + V_{am} + V_{al}} \qquad \text{(Eq. B-4)}$$

$$\chi_w = \frac{V_w}{V_s + V_{wm} + V_{am} + V_{al}} \qquad \text{(Eq. B-5)}$$

$$\chi_s = \frac{V_s}{V_s + V_{wm} + V_{am} + V_{al}} \qquad \text{(Eq. B-6)}$$

Substituting these equations into Equation B-2 and using the identity that the product of the density and the specific heat of a material is the volumetric heat capacity (Incropera and DeWitt 1996 [DIRS 108184], Section 2.2.2) results in the following:

$$(V_s + V_{wm} + V_{am} + V_{al}) \cdot C_{rock} = V_{am} \cdot C_a + V_{al} \cdot C_a + V_w \cdot C_{vw} + V_s \cdot \rho_g \cdot C_p \qquad \text{(Eq. B-7)}$$

where

V_{al}	=	volume of the air in the lithophysae
V_{am}	=	volume of the air in the matrix
V_{wm}	=	volume of the water in the matrix
V_s	=	volume of the solids (which is set to 1)
C_p	=	specific heat of the solids
ρ_g	=	grain density of the solids.

Now consider the definitions for the matrix porosity and the lithophysal porosity. The matrix porosity is defined as the ratio of the void volume of the matrix to the total matrix volume (of solids):

$$\phi_m = \frac{V_m}{V_s + V_m} \qquad \text{(Eq. B-8)}$$

where $V_m = V_{am} + V_{wm}$.

Solving for the matrix void volume in terms of the matrix porosity:

$$V_m = \frac{\phi_m}{1 - \phi_m} \cdot V_s \qquad \text{(Eq. B-9)}$$

The lithophysal porosity is defined as the ratio of the volume of the lithophysae to the total volume:

$$\phi_l = \frac{V_{al}}{V_s + V_m + V_{al}} \qquad \text{(Eq. B-10)}$$

Solving for the volume of lithophysae:

$$V_{al} = \phi_l \cdot (V_s + V_m + V_{al}) \qquad \text{(Eq. B-11)}$$

Substituting Equation B-9 into Equation B-11 yields:

$$V_{al} = \frac{\phi_l}{1-\phi_l} \cdot (1 + \frac{\phi_m}{1-\phi_m}) \cdot V_s \qquad \text{(Eq. B-12)}$$

The matrix saturation (*S*) is used to estimate the volume occupied by water:

$$V_w = S \cdot \frac{\phi_m}{1-\phi_m} \cdot V_s \qquad \text{(Eq. B-13)}$$

Substituting Equation B-12 into Equation B-7, and neglecting the heat capacity of the air ($C_a << C_{vw}$) (Jury et al. 1991 [DIRS 102010], p. 180), the following equation is obtained:

$$\left(V_s + \frac{\phi_m V_s}{1-\phi_m} + \frac{\phi_l}{1-\phi_l} \cdot \left(1 + \frac{\phi_m}{1-\phi_m} \right) \cdot V_s \right) \cdot C_{rock} = S \cdot \frac{\phi_m}{1-\phi_m} C_{vw} V_s + \rho_g \cdot C_p V_s \qquad \text{(Eq. B-14)}$$

Solving for C_{rock} and canceling out the volume of the solids, V_s, the volumetric heat capacity is expressed as (with $V_s = 1$):

$$C_{rock} = \frac{S \cdot \frac{\phi_m}{1-\phi_m} C_{vw} + \rho_g \cdot C_p}{\left[1 + \frac{\phi_m}{1-\phi_m} + \frac{\phi_l}{1-\phi_l} \cdot \left(1 + \frac{\phi_m}{1-\phi_m} \right) \right]} \qquad \text{(Eq. B-15)}$$

This relationship is used in the analytical ventilation model analyses in this report.

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APPENDIX C

WASTE PACKAGE POWERS AND AVERAGE LINE LOADS FOR INCORPORATION ONTO AN INFORMATION EXCHANGE DRAWING

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This appendix presents the results of the waste package and line calculations to be incorporated onto an IED. The details of these calculations are presented in the MathCad file *Thermal Management Flexibility Analysis.mcd* of Output DTN: MO0506SPAPRETM.000 for the three line load calculations that were performed. The three line load calculations are for matching power at repository closure of 50 years for the existing line load; matching slope at repository closure of 50 years for the existing line load; and replacement of the DHLW waste packages with average line powers. Tables C-1 through C-3 present the summary analyses for these cases respectively.

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
0.1	7.10E+00	1.22E+00	1.45E+01	9.09E+00	8.75E+00	3.67E+00	1.42E+01	4.55E+00	1.84E+00
1	6.86E+00	1.19E+00	1.40E+01	8.80E+00	8.50E+00	3.34E+00	1.37E+01	4.40E+00	1.77E+00
2	6.67E+00	1.16E+00	1.37E+01	8.56E+00	8.28E+00	3.13E+00	1.33E+01	4.28E+00	1.72E+00
3	6.49E+00	1.14E+00	1.33E+01	8.34E+00	8.07E+00	2.99E+00	1.29E+01	4.18E+00	1.67E+00
4	6.33E+00	1.11E+00	1.29E+01	8.14E+00	7.87E+00	2.90E+00	1.27E+01	4.08E+00	1.63E+00
5	6.20E+00	1.08E+00	1.27E+01	7.97E+00	7.70E+00	2.81E+00	1.24E+01	3.98E+00	1.60E+00
6	6.06E+00	1.06E+00	1.24E+01	7.80E+00	7.53E+00	2.75E+00	1.21E+01	3.89E+00	1.56E+00
7	5.94E+00	1.03E+00	1.21E+01	7.64E+00	7.38E+00	2.67E+00	1.19E+01	3.82E+00	1.53E+00
8	5.82E+00	1.01E+00	1.19E+01	7.48E+00	7.23E+00	2.61E+00	1.16E+01	3.75E+00	1.50E+00
9	5.70E+00	9.84E-01	1.17E+01	7.33E+00	7.08E+00	2.55E+00	1.14E+01	3.67E+00	1.47E+00
10	5.59E+00	9.60E-01	1.14E+01	7.20E+00	6.95E+00	2.49E+00	1.12E+01	3.60E+00	1.44E+00
11	5.47E+00	9.39E-01	1.12E+01	7.04E+00	6.80E+00	2.43E+00	1.09E+01	3.51E+00	1.41E+00
12	5.36E+00	9.17E-01	1.10E+01	6.89E+00	6.67E+00	2.38E+00	1.07E+01	3.45E+00	1.38E+00
13	5.26E+00	8.96E-01	1.08E+01	6.76E+00	6.54E+00	2.33E+00	1.05E+01	3.39E+00	1.35E+00
14	5.17E+00	8.74E-01	1.06E+01	6.65E+00	6.43E+00	2.27E+00	1.03E+01	3.33E+00	1.33E+00
15	5.10E+00	8.54E-01	1.04E+01	6.54E+00	6.33E+00	2.22E+00	1.02E+01	3.28E+00	1.31E+00
16	5.00E+00	8.33E-01	1.02E+01	6.42E+00	6.21E+00	2.17E+00	9.99E+00	3.20E+00	1.28E+00
17	4.90E+00	8.13E-01	1.00E+01	6.30E+00	6.10E+00	2.12E+00	9.81E+00	3.14E+00	1.26E+00
18	4.82E+00	7.96E-01	9.87E+00	6.18E+00	6.00E+00	2.07E+00	9.65E+00	3.09E+00	1.24E+00
19	4.74E+00	7.76E-01	9.71E+00	6.09E+00	5.90E+00	2.02E+00	9.49E+00	3.04E+00	1.22E+00
20	4.67E+00	7.56E-01	9.56E+00	5.99E+00	5.82E+00	1.98E+00	9.34E+00	2.99E+00	1.20E+00
21	4.58E+00	7.39E-01	9.39E+00	5.88E+00	5.70E+00	1.93E+00	9.18E+00	2.93E+00	1.17E+00
22	4.51E+00	7.22E-01	9.23E+00	5.77E+00	5.61E+00	1.90E+00	9.02E+00	2.88E+00	1.15E+00

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
23	4.44E+00	7.05E-01	9.08E+00	5.67E+00	5.52E+00	1.85E+00	8.87E+00	2.83E+00	1.13E+00
24	4.36E+00	6.90E-01	8.93E+00	5.57E+00	5.43E+00	1.81E+00	8.74E+00	2.78E+00	1.12E+00
25	4.30E+00	6.73E-01	8.80E+00	5.48E+00	5.36E+00	1.77E+00	8.60E+00	2.75E+00	1.10E+00
26	4.23E+00	6.57E-01	8.65E+00	5.38E+00	5.25E+00	1.80E+00	8.45E+00	2.70E+00	1.08E+00
27	4.15E+00	6.42E-01	8.51E+00	5.30E+00	5.16E+00	1.76E+00	8.32E+00	2.65E+00	1.06E+00
28	4.09E+00	6.27E-01	8.38E+00	5.21E+00	5.08E+00	1.72E+00	8.18E+00	2.60E+00	1.05E+00
29	4.03E+00	6.12E-01	8.24E+00	5.13E+00	5.00E+00	1.69E+00	8.06E+00	2.56E+00	1.03E+00
30	3.97E+00	5.99E-01	8.13E+00	5.05E+00	4.94E+00	1.65E+00	7.93E+00	2.53E+00	1.01E+00
31	3.91E+00	5.84E-01	8.00E+00	4.97E+00	4.85E+00	1.61E+00	7.81E+00	2.48E+00	9.96E-01
32	3.84E+00	5.70E-01	7.87E+00	4.88E+00	4.78E+00	1.58E+00	7.69E+00	2.44E+00	9.80E-01
33	3.78E+00	5.58E-01	7.75E+00	4.81E+00	4.71E+00	1.54E+00	7.58E+00	2.40E+00	9.65E-01
34	3.73E+00	5.45E-01	7.64E+00	4.73E+00	4.64E+00	1.52E+00	7.47E+00	2.37E+00	9.51E-01
35	3.68E+00	5.32E-01	7.53E+00	4.66E+00	4.57E+00	1.48E+00	7.36E+00	2.33E+00	9.36E-01
36	3.62E+00	5.19E-01	7.42E+00	4.58E+00	4.50E+00	1.44E+00	7.24E+00	2.29E+00	9.21E-01
37	3.57E+00	5.05E-01	7.31E+00	4.51E+00	4.44E+00	1.42E+00	7.13E+00	2.25E+00	9.07E-01
38	3.51E+00	4.95E-01	7.20E+00	4.44E+00	4.37E+00	1.39E+00	7.04E+00	2.22E+00	8.93E-01
39	3.46E+00	4.84E-01	7.10E+00	4.37E+00	4.31E+00	1.36E+00	6.94E+00	2.18E+00	8.80E-01
40	3.41E+00	4.71E-01	7.00E+00	4.31E+00	4.25E+00	1.33E+00	6.84E+00	2.16E+00	8.67E-01
41	3.36E+00	4.61E-01	6.90E+00	4.24E+00	4.19E+00	1.31E+00	6.74E+00	2.12E+00	8.54E-01
42	3.31E+00	4.50E-01	6.80E+00	4.18E+00	4.13E+00	1.27E+00	6.64E+00	2.08E+00	8.41E-01
43	3.28E+00	4.41E-01	6.70E+00	4.12E+00	4.07E+00	1.24E+00	6.54E+00	2.06E+00	8.28E-01
44	3.23E+00	4.30E-01	6.60E+00	4.05E+00	4.02E+00	1.22E+00	6.46E+00	2.03E+00	8.17E-01

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								Average Line Load (kW/m)
45	3.19E+00	4.19E-01	6.52E+00	3.99E+00	3.95E+00	1.20E+00	6.37E+00	2.00E+00	8.05E-01
46	3.14E+00	4.10E-01	6.43E+00	3.94E+00	3.91E+00	1.17E+00	6.28E+00	1.97E+00	7.94E-01
47	3.09E+00	3.99E-01	6.35E+00	3.88E+00	3.86E+00	1.14E+00	6.20E+00	1.93E+00	7.82E-01
48	3.06E+00	3.91E-01	6.26E+00	3.82E+00	3.81E+00	1.12E+00	6.11E+00	1.91E+00	7.71E-01
49	3.02E+00	3.82E-01	6.17E+00	3.77E+00	3.76E+00	1.10E+00	6.04E+00	1.89E+00	7.61E-01
50	2.98E+00	3.73E-01	6.10E+00	3.72E+00	3.72E+00	1.07E+00	5.95E+00	1.86E+00	7.51E-01
51	2.93E+00	3.65E-01	6.01E+00	3.66E+00	3.67E+00	1.05E+00	5.88E+00	1.84E+00	7.40E-01
52	2.90E+00	3.56E-01	5.94E+00	3.61E+00	3.62E+00	1.03E+00	5.80E+00	1.81E+00	7.30E-01
53	2.86E+00	3.47E-01	5.86E+00	3.56E+00	3.57E+00	1.01E+00	5.73E+00	1.79E+00	7.20E-01
54	2.82E+00	3.39E-01	5.79E+00	3.51E+00	3.52E+00	9.84E-01	5.66E+00	1.76E+00	7.10E-01
55	2.80E+00	3.33E-01	5.72E+00	3.47E+00	3.49E+00	9.66E-01	5.58E+00	1.74E+00	7.02E-01
56	2.76E+00	3.24E-01	5.64E+00	3.43E+00	3.44E+00	9.49E-01	5.51E+00	1.71E+00	6.92E-01
57	2.72E+00	3.18E-01	5.57E+00	3.38E+00	3.39E+00	9.25E-01	5.45E+00	1.69E+00	6.82E-01
58	2.69E+00	3.09E-01	5.51E+00	3.33E+00	3.35E+00	9.07E-01	5.37E+00	1.66E+00	6.73E-01
59	2.66E+00	3.02E-01	5.43E+00	3.29E+00	3.31E+00	8.90E-01	5.31E+00	1.64E+00	6.65E-01
60	2.62E+00	2.96E-01	5.37E+00	3.25E+00	3.28E+00	8.71E-01	5.25E+00	1.63E+00	6.57E-01
61	2.59E+00	2.87E-01	5.31E+00	3.20E+00	3.23E+00	8.54E-01	5.19E+00	1.60E+00	6.48E-01
62	2.56E+00	2.81E-01	5.25E+00	3.17E+00	3.19E+00	8.35E-01	5.13E+00	1.58E+00	6.40E-01
63	2.54E+00	2.74E-01	5.19E+00	3.12E+00	3.15E+00	8.18E-01	5.06E+00	1.56E+00	6.32E-01
64	2.50E+00	2.67E-01	5.13E+00	3.08E+00	3.12E+00	8.00E-01	5.00E+00	1.54E+00	6.24E-01
65	2.48E+00	2.64E-01	5.06E+00	3.04E+00	3.08E+00	7.87E-01	4.95E+00	1.53E+00	6.17E-01
66	2.45E+00	2.56E-01	5.00E+00	3.01E+00	3.04E+00	7.70E-01	4.89E+00	1.50E+00	6.09E-01
67	2.41E+00	2.50E-01	4.95E+00	2.97E+00	3.01E+00	7.53E-01	4.84E+00	1.49E+00	6.02E-01

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
68	2.39E+00	2.44E-01	4.89E+00	2.93E+00	2.98E+00	7.40E-01	4.78E+00	1.47E+00	5.95E-01
69	2.37E+00	2.39E-01	4.84E+00	2.90E+00	2.94E+00	7.22E-01	4.73E+00	1.45E+00	5.88E-01
70	2.34E+00	2.33E-01	4.79E+00	2.87E+00	2.91E+00	7.11E-01	4.68E+00	1.43E+00	5.82E-01
71	2.32E+00	2.29E-01	4.73E+00	2.83E+00	2.88E+00	6.96E-01	4.63E+00	1.42E+00	5.75E-01
72	2.29E+00	2.22E-01	4.68E+00	2.80E+00	2.85E+00	6.83E-01	4.58E+00	1.40E+00	5.68E-01
73	2.27E+00	2.18E-01	4.63E+00	2.77E+00	2.82E+00	6.69E-01	4.53E+00	1.38E+00	5.62E-01
74	2.24E+00	2.13E-01	4.58E+00	2.74E+00	2.78E+00	6.55E-01	4.48E+00	1.37E+00	5.55E-01
75	2.22E+00	2.08E-01	4.53E+00	2.71E+00	2.76E+00	6.43E-01	4.44E+00	1.36E+00	5.49E-01
76	2.19E+00	2.03E-01	4.50E+00	2.67E+00	2.74E+00	6.31E-01	4.39E+00	1.34E+00	5.44E-01
77	2.17E+00	1.98E-01	4.45E+00	2.65E+00	2.70E+00	6.17E-01	4.35E+00	1.32E+00	5.37E-01
78	2.16E+00	1.93E-01	4.40E+00	2.61E+00	2.67E+00	6.06E-01	4.30E+00	1.31E+00	5.31E-01
79	2.13E+00	1.90E-01	4.36E+00	2.59E+00	2.65E+00	5.94E-01	4.26E+00	1.29E+00	5.26E-01
80	2.11E+00	1.85E-01	4.31E+00	2.56E+00	2.62E+00	5.83E-01	4.21E+00	1.28E+00	5.20E-01
81	2.08E+00	1.81E-01	4.28E+00	2.54E+00	2.60E+00	5.72E-01	4.18E+00	1.27E+00	5.15E-01
82	2.07E+00	1.76E-01	4.23E+00	2.50E+00	2.57E+00	5.61E-01	4.13E+00	1.26E+00	5.09E-01
83	2.05E+00	1.72E-01	4.19E+00	2.48E+00	2.55E+00	5.49E-01	4.09E+00	1.24E+00	5.04E-01
84	2.02E+00	1.69E-01	4.15E+00	2.45E+00	2.53E+00	5.38E-01	4.05E+00	1.23E+00	4.99E-01
85	2.01E+00	1.65E-01	4.12E+00	2.43E+00	2.50E+00	5.29E-01	4.02E+00	1.21E+00	4.94E-01
86	1.98E+00	1.61E-01	4.07E+00	2.40E+00	2.48E+00	5.19E-01	3.98E+00	1.20E+00	4.89E-01
87	1.97E+00	1.58E-01	4.03E+00	2.38E+00	2.45E+00	5.09E-01	3.94E+00	1.19E+00	4.84E-01
88	1.95E+00	1.54E-01	3.99E+00	2.35E+00	2.43E+00	4.99E-01	3.91E+00	1.18E+00	4.79E-01
89	1.93E+00	1.50E-01	3.97E+00	2.33E+00	2.40E+00	4.89E-01	3.87E+00	1.17E+00	4.75E-01
90	1.92E+00	1.47E-01	3.93E+00	2.32E+00	2.39E+00	4.81E-01	3.83E+00	1.16E+00	4.71E-01

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
91	1.90E+00	1.44E-01	3.89E+00	2.29E+00	2.37E+00	4.72E-01	3.81E+00	1.14E+00	4.66E-01
92	1.89E+00	1.40E-01	3.86E+00	2.27E+00	2.35E+00	4.62E-01	3.77E+00	1.13E+00	4.62E-01
93	1.87E+00	1.37E-01	3.82E+00	2.24E+00	2.33E+00	4.53E-01	3.73E+00	1.12E+00	4.58E-01
94	1.85E+00	1.34E-01	3.79E+00	2.23E+00	2.30E+00	4.46E-01	3.71E+00	1.11E+00	4.54E-01
95	1.84E+00	1.31E-01	3.76E+00	2.21E+00	2.29E+00	4.37E-01	3.67E+00	1.10E+00	4.49E-01
96	1.82E+00	1.28E-01	3.73E+00	2.18E+00	2.27E+00	4.29E-01	3.65E+00	1.09E+00	4.46E-01
97	1.81E+00	1.26E-01	3.70E+00	2.17E+00	2.25E+00	4.21E-01	3.61E+00	1.08E+00	4.42E-01
98	1.79E+00	1.22E-01	3.67E+00	2.14E+00	2.24E+00	4.14E-01	3.59E+00	1.07E+00	4.38E-01
99	1.77E+00	1.20E-01	3.63E+00	2.13E+00	2.22E+00	4.05E-01	3.56E+00	1.06E+00	4.34E-01
100	1.76E+00	1.17E-01	3.61E+00	2.11E+00	2.21E+00	3.98E-01	3.52E+00	1.05E+00	4.30E-01
110	1.64E+00	9.31E-02	3.36E+00	1.95E+00	2.05E+00	3.33E-01	3.28E+00	9.76E-01	3.98E-01
120	1.54E+00	7.48E-02	3.14E+00	1.81E+00	1.91E+00	2.80E-01	3.07E+00	9.08E-01	3.71E-01
130	1.44E+00	6.00E-02	2.96E+00	1.70E+00	1.80E+00	2.37E-01	2.90E+00	8.51E-01	3.48E-01
140	1.37E+00	4.84E-02	2.80E+00	1.60E+00	1.70E+00	2.02E-01	2.74E+00	8.01E-01	3.28E-01
150	1.29E+00	3.93E-02	2.65E+00	1.52E+00	1.61E+00	1.74E-01	2.59E+00	7.56E-01	3.10E-01
160	1.24E+00	3.22E-02	2.54E+00	1.45E+00	1.54E+00	1.52E-01	2.49E+00	7.24E-01	2.96E-01
170	1.19E+00	2.64E-02	2.44E+00	1.39E+00	1.48E+00	1.32E-01	2.39E+00	6.95E-01	2.84E-01
180	1.15E+00	2.18E-02	2.35E+00	1.33E+00	1.43E+00	1.16E-01	2.30E+00	6.68E-01	2.73E-01
190	1.11E+00	1.84E-02	2.27E+00	1.28E+00	1.38E+00	1.03E-01	2.22E+00	6.43E-01	2.63E-01
200	1.07E+00	1.55E-02	2.19E+00	1.24E+00	1.33E+00	9.14E-02	2.14E+00	6.21E-01	2.54E-01
250	9.43E-01	8.09E-03	1.93E+00	1.09E+00	1.17E+00	5.67E-02	1.89E+00	5.45E-01	2.22E-01
300	8.50E-01	5.72E-03	1.74E+00	9.86E-01	1.06E+00	3.92E-02	1.70E+00	4.93E-01	2.00E-01
350	7.77E-01	4.85E-03	1.59E+00	9.06E-01	9.70E-01	2.91E-02	1.55E+00	4.52E-01	1.83E-01

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
400	7.18E-01	4.47E-03	1.47E+00	8.39E-01	8.97E-01	2.27E-02	1.44E+00	4.20E-01	1.69E-01
450	6.68E-01	4.25E-03	1.37E+00	7.82E-01	8.35E-01	1.85E-02	1.33E+00	3.91E-01	1.57E-01
500	6.23E-01	4.08E-03	1.28E+00	7.33E-01	7.81E-01	1.55E-02	1.24E+00	3.66E-01	1.47E-01
550	5.84E-01	3.94E-03	1.20E+00	6.90E-01	7.33E-01	1.33E-02	1.17E+00	3.45E-01	1.38E-01
600	5.48E-01	3.81E-03	1.12E+00	6.51E-01	6.90E-01	1.18E-02	1.10E+00	3.25E-01	1.30E-01
650	5.17E-01	3.67E-03	1.06E+00	6.15E-01	6.52E-01	1.07E-02	1.03E+00	3.08E-01	1.22E-01
700	4.89E-01	3.59E-03	1.00E+00	5.83E-01	6.16E-01	9.76E-03	9.77E-01	2.92E-01	1.16E-01
750	4.62E-01	3.47E-03	9.46E-01	5.54E-01	5.84E-01	9.07E-03	9.25E-01	2.77E-01	1.10E-01
800	4.39E-01	3.39E-03	8.98E-01	5.27E-01	5.54E-01	8.50E-03	8.77E-01	2.64E-01	1.04E-01
850	4.16E-01	3.30E-03	8.53E-01	5.03E-01	5.29E-01	8.03E-03	8.33E-01	2.51E-01	9.89E-02
900	3.97E-01	3.22E-03	8.11E-01	4.79E-01	5.03E-01	7.68E-03	7.92E-01	2.40E-01	9.42E-02
950	3.77E-01	3.15E-03	7.72E-01	4.60E-01	4.81E-01	7.32E-03	7.55E-01	2.29E-01	8.98E-02
1,000	3.60E-01	3.08E-03	7.38E-01	4.39E-01	4.58E-01	7.02E-03	7.21E-01	2.19E-01	8.58E-02
1,500	2.46E-01	2.64E-03	5.03E-01	3.10E-01	3.18E-01	5.29E-03	4.92E-01	1.55E-01	5.92E-02
2,000	1.91E-01	2.39E-03	3.92E-01	2.48E-01	2.50E-01	4.48E-03	3.82E-01	1.24E-01	4.64E-02
2,500	1.64E-01	2.28E-03	3.35E-01	2.16E-01	2.16E-01	4.08E-03	3.28E-01	1.08E-01	4.00E-02
3,000	1.49E-01	2.21E-03	3.04E-01	1.98E-01	1.97E-01	3.83E-03	2.98E-01	9.89E-02	3.65E-02
3,500	1.39E-01	2.14E-03	2.86E-01	1.86E-01	1.85E-01	3.68E-03	2.78E-01	9.30E-02	3.42E-02
4,000	1.33E-01	2.11E-03	2.72E-01	1.77E-01	1.76E-01	3.56E-03	2.66E-01	8.86E-02	3.26E-02
4,500	1.28E-01	2.07E-03	2.61E-01	1.70E-01	1.69E-01	3.46E-03	2.55E-01	8.49E-02	3.13E-02
5,000	1.23E-01	2.03E-03	2.51E-01	1.63E-01	1.63E-01	3.39E-03	2.46E-01	8.16E-02	3.01E-02
5,500	1.19E-01	2.01E-03	2.43E-01	1.58E-01	1.56E-01	3.30E-03	2.38E-01	7.86E-02	2.90E-02
6,000	1.15E-01	1.97E-03	2.34E-01	1.52E-01	1.52E-01	3.23E-03	2.29E-01	7.59E-02	2.80E-02

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
6,500	1.11E-01	1.95E-03	2.27E-01	1.47E-01	1.47E-01	3.15E-03	2.22E-01	7.34E-02	2.71E-02
7,000	1.07E-01	1.91E-03	2.19E-01	1.42E-01	1.42E-01	3.08E-03	2.14E-01	7.07E-02	2.62E-02
7,500	1.04E-01	1.89E-03	2.12E-01	1.37E-01	1.37E-01	3.02E-03	2.07E-01	6.86E-02	2.53E-02
8,000	1.01E-01	1.86E-03	2.06E-01	1.32E-01	1.33E-01	2.96E-03	2.01E-01	6.62E-02	2.46E-02
8,500	9.75E-02	1.84E-03	2.00E-01	1.28E-01	1.28E-01	2.90E-03	1.95E-01	6.39E-02	2.38E-02
9,000	9.45E-02	1.81E-03	1.93E-01	1.24E-01	1.24E-01	2.83E-03	1.89E-01	6.21E-02	2.31E-02
9,500	9.15E-02	1.79E-03	1.87E-01	1.20E-01	1.21E-01	2.77E-03	1.84E-01	5.99E-02	2.24E-02
10,000	8.87E-02	1.75E-03	1.81E-01	1.16E-01	1.17E-01	2.72E-03	1.77E-01	5.80E-02	2.16E-02
15,000	6.69E-02	1.53E-03	1.37E-01	8.62E-02	8.81E-02	2.25E-03	1.34E-01	4.31E-02	1.63E-02
20,000	5.20E-02	1.36E-03	1.06E-01	6.62E-02	6.84E-02	1.92E-03	1.04E-01	3.30E-02	1.26E-02
25,000	4.18E-02	1.20E-03	8.55E-02	5.26E-02	5.49E-02	1.66E-03	8.35E-02	2.62E-02	1.01E-02
30,000	3.45E-02	1.07E-03	7.07E-02	4.29E-02	4.52E-02	1.47E-03	6.91E-02	2.14E-02	8.34E-03
35,000	2.90E-02	9.65E-04	5.93E-02	3.57E-02	3.81E-02	1.32E-03	5.79E-02	1.79E-02	6.99E-03
40,000	2.49E-02	8.72E-04	5.09E-02	3.03E-02	3.25E-02	1.19E-03	4.97E-02	1.52E-02	5.98E-03
45,000	2.14E-02	7.93E-04	4.40E-02	2.60E-02	2.81E-02	1.08E-03	4.30E-02	1.31E-02	5.17E-03
50,000	1.89E-02	7.26E-04	3.87E-02	2.28E-02	2.48E-02	9.94E-04	3.78E-02	1.14E-02	4.54E-03
55,000	1.66E-02	6.67E-04	3.41E-02	2.01E-02	2.19E-02	9.19E-04	3.34E-02	1.00E-02	4.01E-03
60,000	1.48E-02	6.14E-04	3.02E-02	1.79E-02	1.95E-02	8.61E-04	2.94E-02	8.94E-03	3.56E-03
65,000	1.32E-02	5.69E-04	2.70E-02	1.63E-02	1.76E-02	8.12E-04	2.64E-02	8.13E-03	3.20E-03
70,000	1.19E-02	5.31E-04	2.44E-02	1.47E-02	1.59E-02	7.64E-04	2.38E-02	7.32E-03	2.89E-03
75,000	1.09E-02	4.95E-04	2.23E-02	1.31E-02	1.44E-02	7.27E-04	2.17E-02	6.51E-03	2.62E-03
80,000	9.83E-03	4.67E-04	2.01E-02	1.19E-02	1.32E-02	6.97E-04	1.97E-02	5.96E-03	2.38E-03
85,000	9.06E-03	4.42E-04	1.85E-02	1.08E-02	1.21E-02	6.74E-04	1.81E-02	5.42E-03	2.19E-03

Table C-1. Waste Package Powers for Cases 1 through 3 and 10 through 12 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**IED Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
90,000	8.41E-03	4.19E-04	1.72E-02	1.03E-02	1.14E-02	6.52E-04	1.69E-02	5.15E-03	2.05E-03
95,000	7.76E-03	4.02E-04	1.59E-02	9.76E-03	1.06E-02	6.30E-04	1.55E-02	4.88E-03	1.91E-03
100,000	7.24E-03	3.83E-04	1.48E-02	8.67E-03	9.81E-03	6.14E-04	1.45E-02	4.34E-03	1.76E-03
150,000	4.92E-03	2.98E-04	1.01E-02	5.96E-03	6.85E-03	5.45E-04	9.83E-03	2.98E-03	1.21E-03
200,000	4.40E-03	2.71E-04	9.01E-03	5.42E-03	6.27E-03	5.16E-04	8.80E-03	2.71E-03	1.09E-03
250,000	4.28E-03	2.56E-04	8.74E-03	5.42E-03	6.10E-03	4.88E-04	8.54E-03	2.71E-03	1.06E-03
300,000	4.14E-03	2.48E-04	8.48E-03	5.42E-03	5.99E-03	4.52E-04	8.28E-03	2.71E-03	1.04E-03
350,000	4.14E-03	2.39E-04	8.48E-03	4.88E-03	5.72E-03	4.14E-04	8.28E-03	2.44E-03	1.01E-03
400,000	4.02E-03	2.33E-04	8.21E-03	4.88E-03	5.56E-03	3.77E-04	8.02E-03	2.44E-03	9.82E-04
450,000	3.88E-03	2.27E-04	7.95E-03	4.88E-03	5.42E-03	3.40E-04	7.76E-03	2.44E-03	9.58E-04
500,000	3.62E-03	2.23E-04	7.42E-03	4.34E-03	4.98E-03	3.07E-04	7.24E-03	2.17E-03	8.82E-04
550,000	3.50E-03	2.18E-04	7.15E-03	4.34E-03	4.85E-03	2.76E-04	6.99E-03	2.17E-03	8.59E-04
600,000	3.36E-03	2.14E-04	6.89E-03	4.34E-03	4.68E-03	2.48E-04	6.73E-03	2.17E-03	8.34E-04
650,000	3.24E-03	2.11E-04	6.62E-03	4.34E-03	4.55E-03	2.23E-04	6.47E-03	2.17E-03	8.10E-04
700,000	3.24E-03	2.08E-04	6.62E-03	3.79E-03	4.30E-03	2.01E-04	6.47E-03	1.90E-03	7.78E-04
750,000	3.10E-03	2.06E-04	6.36E-03	3.79E-03	4.18E-03	1.81E-04	6.21E-03	1.90E-03	7.55E-04
800,000	2.98E-03	2.03E-04	6.09E-03	3.79E-03	4.03E-03	1.65E-04	5.95E-03	1.90E-03	7.31E-04
850,000	2.85E-03	2.01E-04	5.83E-03	3.79E-03	3.92E-03	1.49E-04	5.69E-03	1.90E-03	7.08E-04
900,000	2.85E-03	2.00E-04	5.83E-03	3.25E-03	3.71E-03	1.37E-04	5.69E-03	1.63E-03	6.78E-04
950,000	2.72E-03	1.98E-04	5.56E-03	3.25E-03	3.60E-03	1.26E-04	5.43E-03	1.63E-03	6.56E-04

Source: DTN: MO0506SPAPRETM.00, *Case1.xls*, worksheet "IED."

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
0.1	8.08E+00	1.39E+00	1.66E+01	1.04E+01	9.96E+00	4.18E+00	1.61E+01	5.18E+00	2.09E+00
1	7.82E+00	1.36E+00	1.60E+01	1.00E+01	9.68E+00	3.80E+00	1.56E+01	5.01E+00	2.02E+00
2	7.59E+00	1.32E+00	1.56E+01	9.75E+00	9.43E+00	3.56E+00	1.52E+01	4.87E+00	1.96E+00
3	7.39E+00	1.29E+00	1.52E+01	9.50E+00	9.19E+00	3.41E+00	1.47E+01	4.76E+00	1.91E+00
4	7.21E+00	1.26E+00	1.47E+01	9.27E+00	8.97E+00	3.30E+00	1.45E+01	4.64E+00	1.86E+00
5	7.06E+00	1.23E+00	1.45E+01	9.08E+00	8.77E+00	3.20E+00	1.42E+01	4.53E+00	1.82E+00
6	6.90E+00	1.20E+00	1.42E+01	8.88E+00	8.57E+00	3.13E+00	1.38E+01	4.43E+00	1.78E+00
7	6.76E+00	1.17E+00	1.38E+01	8.70E+00	8.40E+00	3.04E+00	1.35E+01	4.35E+00	1.74E+00
8	6.62E+00	1.15E+00	1.36E+01	8.52E+00	8.24E+00	2.97E+00	1.32E+01	4.27E+00	1.71E+00
9	6.50E+00	1.12E+00	1.33E+01	8.35E+00	8.07E+00	2.90E+00	1.30E+01	4.18E+00	1.67E+00
10	6.37E+00	1.09E+00	1.30E+01	8.19E+00	7.91E+00	2.83E+00	1.27E+01	4.10E+00	1.64E+00
11	6.23E+00	1.07E+00	1.28E+01	8.01E+00	7.75E+00	2.76E+00	1.25E+01	4.00E+00	1.60E+00
12	6.10E+00	1.04E+00	1.25E+01	7.84E+00	7.59E+00	2.71E+00	1.22E+01	3.93E+00	1.57E+00
13	5.99E+00	1.02E+00	1.23E+01	7.70E+00	7.45E+00	2.65E+00	1.20E+01	3.86E+00	1.54E+00
14	5.89E+00	9.95E-01	1.21E+01	7.58E+00	7.32E+00	2.58E+00	1.18E+01	3.79E+00	1.51E+00
15	5.81E+00	9.72E-01	1.19E+01	7.45E+00	7.21E+00	2.53E+00	1.16E+01	3.73E+00	1.49E+00
16	5.70E+00	9.49E-01	1.16E+01	7.31E+00	7.07E+00	2.47E+00	1.14E+01	3.65E+00	1.46E+00
17	5.58E+00	9.26E-01	1.14E+01	7.17E+00	6.95E+00	2.41E+00	1.12E+01	3.58E+00	1.43E+00
18	5.49E+00	9.06E-01	1.12E+01	7.04E+00	6.83E+00	2.36E+00	1.10E+01	3.52E+00	1.41E+00
19	5.40E+00	8.84E-01	1.11E+01	6.93E+00	6.72E+00	2.30E+00	1.08E+01	3.47E+00	1.39E+00
20	5.32E+00	8.62E-01	1.09E+01	6.82E+00	6.62E+00	2.26E+00	1.06E+01	3.41E+00	1.36E+00
21	5.22E+00	8.42E-01	1.07E+01	6.69E+00	6.50E+00	2.20E+00	1.05E+01	3.34E+00	1.34E+00
22	5.14E+00	8.22E-01	1.05E+01	6.57E+00	6.38E+00	2.16E+00	1.03E+01	3.28E+00	1.31E+00

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
23	5.05E+00	8.03E-01	1.03E+01	6.45E+00	6.29E+00	2.10E+00	1.01E+01	3.23E+00	1.29E+00
24	4.97E+00	7.86E-01	1.02E+01	6.34E+00	6.19E+00	2.06E+00	9.95E+00	3.17E+00	1.27E+00
25	4.90E+00	7.66E-01	1.00E+01	6.24E+00	6.10E+00	2.02E+00	9.79E+00	3.13E+00	1.25E+00
26	4.81E+00	7.48E-01	9.85E+00	6.13E+00	5.98E+00	2.05E+00	9.63E+00	3.07E+00	1.23E+00
27	4.73E+00	7.31E-01	9.70E+00	6.03E+00	5.88E+00	2.01E+00	9.47E+00	3.02E+00	1.21E+00
28	4.66E+00	7.14E-01	9.54E+00	5.94E+00	5.78E+00	1.96E+00	9.32E+00	2.96E+00	1.19E+00
29	4.59E+00	6.97E-01	9.39E+00	5.84E+00	5.70E+00	1.92E+00	9.18E+00	2.92E+00	1.17E+00
30	4.52E+00	6.82E-01	9.26E+00	5.75E+00	5.63E+00	1.88E+00	9.04E+00	2.88E+00	1.15E+00
31	4.45E+00	6.65E-01	9.11E+00	5.65E+00	5.53E+00	1.84E+00	8.90E+00	2.82E+00	1.13E+00
32	4.38E+00	6.50E-01	8.97E+00	5.56E+00	5.44E+00	1.80E+00	8.76E+00	2.78E+00	1.12E+00
33	4.31E+00	6.36E-01	8.83E+00	5.47E+00	5.36E+00	1.75E+00	8.63E+00	2.74E+00	1.10E+00
34	4.25E+00	6.20E-01	8.70E+00	5.39E+00	5.29E+00	1.73E+00	8.50E+00	2.69E+00	1.08E+00
35	4.20E+00	6.06E-01	8.57E+00	5.30E+00	5.21E+00	1.68E+00	8.38E+00	2.65E+00	1.07E+00
36	4.13E+00	5.91E-01	8.45E+00	5.22E+00	5.12E+00	1.64E+00	8.25E+00	2.61E+00	1.05E+00
37	4.07E+00	5.75E-01	8.32E+00	5.14E+00	5.05E+00	1.61E+00	8.12E+00	2.57E+00	1.03E+00
38	4.00E+00	5.64E-01	8.19E+00	5.05E+00	4.98E+00	1.59E+00	8.01E+00	2.53E+00	1.02E+00
39	3.94E+00	5.51E-01	8.08E+00	4.98E+00	4.91E+00	1.54E+00	7.90E+00	2.48E+00	1.00E+00
40	3.89E+00	5.36E-01	7.97E+00	4.91E+00	4.84E+00	1.52E+00	7.79E+00	2.46E+00	9.87E-01
41	3.83E+00	5.25E-01	7.86E+00	4.83E+00	4.77E+00	1.49E+00	7.68E+00	2.41E+00	9.72E-01
42	3.77E+00	5.12E-01	7.75E+00	4.76E+00	4.70E+00	1.45E+00	7.56E+00	2.37E+00	9.57E-01
43	3.73E+00	5.02E-01	7.63E+00	4.69E+00	4.63E+00	1.42E+00	7.45E+00	2.34E+00	9.44E-01
44	3.68E+00	4.90E-01	7.52E+00	4.62E+00	4.57E+00	1.39E+00	7.35E+00	2.32E+00	9.30E-01

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
45	3.63E+00	4.77E-01	7.42E+00	4.55E+00	4.50E+00	1.36E+00	7.25E+00	2.27E+00	9.17E-01
46	3.58E+00	4.67E-01	7.32E+00	4.49E+00	4.45E+00	1.33E+00	7.16E+00	2.25E+00	9.04E-01
47	3.52E+00	4.55E-01	7.23E+00	4.42E+00	4.39E+00	1.30E+00	7.06E+00	2.20E+00	8.91E-01
48	3.48E+00	4.45E-01	7.13E+00	4.35E+00	4.34E+00	1.28E+00	6.96E+00	2.17E+00	8.78E-01
49	3.44E+00	4.35E-01	7.03E+00	4.29E+00	4.28E+00	1.25E+00	6.88E+00	2.15E+00	8.66E-01
50	3.40E+00	4.25E-01	6.95E+00	4.24E+00	4.24E+00	1.22E+00	6.78E+00	2.12E+00	8.55E-01
51	3.34E+00	4.15E-01	6.85E+00	4.17E+00	4.18E+00	1.19E+00	6.69E+00	2.09E+00	8.43E-01
52	3.30E+00	4.06E-01	6.76E+00	4.11E+00	4.13E+00	1.17E+00	6.61E+00	2.06E+00	8.31E-01
53	3.26E+00	3.96E-01	6.68E+00	4.06E+00	4.07E+00	1.15E+00	6.52E+00	2.03E+00	8.20E-01
54	3.21E+00	3.86E-01	6.59E+00	4.00E+00	4.01E+00	1.12E+00	6.44E+00	2.01E+00	8.09E-01
55	3.19E+00	3.79E-01	6.51E+00	3.96E+00	3.97E+00	1.10E+00	6.36E+00	1.98E+00	7.99E-01
56	3.14E+00	3.69E-01	6.43E+00	3.90E+00	3.91E+00	1.08E+00	6.27E+00	1.95E+00	7.88E-01
57	3.10E+00	3.62E-01	6.34E+00	3.84E+00	3.86E+00	1.05E+00	6.20E+00	1.92E+00	7.77E-01
58	3.06E+00	3.52E-01	6.27E+00	3.79E+00	3.82E+00	1.03E+00	6.12E+00	1.89E+00	7.67E-01
59	3.03E+00	3.44E-01	6.19E+00	3.75E+00	3.77E+00	1.01E+00	6.05E+00	1.87E+00	7.58E-01
60	2.99E+00	3.37E-01	6.12E+00	3.70E+00	3.73E+00	9.92E-01	5.98E+00	1.85E+00	7.49E-01
61	2.95E+00	3.27E-01	6.05E+00	3.65E+00	3.68E+00	9.72E-01	5.91E+00	1.82E+00	7.38E-01
62	2.92E+00	3.20E-01	5.98E+00	3.61E+00	3.63E+00	9.51E-01	5.84E+00	1.80E+00	7.29E-01
63	2.89E+00	3.12E-01	5.91E+00	3.55E+00	3.59E+00	9.32E-01	5.77E+00	1.78E+00	7.20E-01
64	2.85E+00	3.04E-01	5.84E+00	3.51E+00	3.55E+00	9.11E-01	5.70E+00	1.75E+00	7.11E-01
65	2.82E+00	3.00E-01	5.77E+00	3.47E+00	3.51E+00	8.97E-01	5.64E+00	1.74E+00	7.03E-01
66	2.79E+00	2.92E-01	5.70E+00	3.42E+00	3.47E+00	8.77E-01	5.57E+00	1.71E+00	6.94E-01
67	2.75E+00	2.85E-01	5.64E+00	3.38E+00	3.42E+00	8.57E-01	5.51E+00	1.70E+00	6.86E-01

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								Average Line Load (kW/m)
68	2.72E+00	2.78E-01	5.57E+00	3.34E+00	3.40E+00	8.43E-01	5.44E+00	1.67E+00	6.78E-01
69	2.69E+00	2.72E-01	5.51E+00	3.30E+00	3.35E+00	8.22E-01	5.39E+00	1.66E+00	6.70E-01
70	2.67E+00	2.65E-01	5.46E+00	3.27E+00	3.31E+00	8.10E-01	5.33E+00	1.63E+00	6.62E-01
71	2.64E+00	2.61E-01	5.39E+00	3.23E+00	3.28E+00	7.93E-01	5.28E+00	1.61E+00	6.55E-01
72	2.61E+00	2.53E-01	5.33E+00	3.19E+00	3.24E+00	7.77E-01	5.22E+00	1.60E+00	6.47E-01
73	2.58E+00	2.48E-01	5.28E+00	3.16E+00	3.21E+00	7.62E-01	5.16E+00	1.57E+00	6.40E-01
74	2.55E+00	2.43E-01	5.22E+00	3.12E+00	3.17E+00	7.46E-01	5.11E+00	1.56E+00	6.32E-01
75	2.53E+00	2.37E-01	5.16E+00	3.09E+00	3.14E+00	7.32E-01	5.05E+00	1.54E+00	6.26E-01
76	2.50E+00	2.32E-01	5.12E+00	3.04E+00	3.12E+00	7.18E-01	5.00E+00	1.53E+00	6.19E-01
77	2.47E+00	2.26E-01	5.07E+00	3.02E+00	3.07E+00	7.03E-01	4.95E+00	1.50E+00	6.12E-01
78	2.46E+00	2.20E-01	5.01E+00	2.97E+00	3.04E+00	6.90E-01	4.90E+00	1.49E+00	6.05E-01
79	2.43E+00	2.16E-01	4.97E+00	2.95E+00	3.02E+00	6.76E-01	4.85E+00	1.47E+00	5.99E-01
80	2.40E+00	2.10E-01	4.91E+00	2.92E+00	2.99E+00	6.64E-01	4.80E+00	1.46E+00	5.93E-01
81	2.37E+00	2.06E-01	4.87E+00	2.89E+00	2.96E+00	6.51E-01	4.76E+00	1.45E+00	5.87E-01
82	2.36E+00	2.01E-01	4.81E+00	2.85E+00	2.93E+00	6.38E-01	4.70E+00	1.43E+00	5.80E-01
83	2.33E+00	1.96E-01	4.77E+00	2.82E+00	2.90E+00	6.26E-01	4.66E+00	1.42E+00	5.74E-01
84	2.30E+00	1.92E-01	4.73E+00	2.79E+00	2.88E+00	6.13E-01	4.62E+00	1.40E+00	5.68E-01
85	2.29E+00	1.88E-01	4.69E+00	2.76E+00	2.85E+00	6.02E-01	4.57E+00	1.38E+00	5.63E-01
86	2.26E+00	1.84E-01	4.63E+00	2.74E+00	2.82E+00	5.91E-01	4.53E+00	1.37E+00	5.57E-01
87	2.25E+00	1.80E-01	4.59E+00	2.71E+00	2.79E+00	5.80E-01	4.49E+00	1.36E+00	5.52E-01
88	2.22E+00	1.75E-01	4.55E+00	2.68E+00	2.76E+00	5.68E-01	4.45E+00	1.34E+00	5.46E-01
89	2.20E+00	1.71E-01	4.52E+00	2.65E+00	2.74E+00	5.57E-01	4.41E+00	1.33E+00	5.41E-01
90	2.19E+00	1.67E-01	4.48E+00	2.64E+00	2.72E+00	5.47E-01	4.36E+00	1.32E+00	5.36E-01

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								Average Line Load (kW/m)
91	2.16E+00	1.64E-01	4.43E+00	2.61E+00	2.69E+00	5.37E-01	4.34E+00	1.30E+00	5.31E-01
92	2.15E+00	1.60E-01	4.39E+00	2.58E+00	2.68E+00	5.26E-01	4.29E+00	1.29E+00	5.26E-01
93	2.13E+00	1.56E-01	4.35E+00	2.55E+00	2.65E+00	5.16E-01	4.25E+00	1.28E+00	5.21E-01
94	2.10E+00	1.53E-01	4.32E+00	2.54E+00	2.62E+00	5.08E-01	4.22E+00	1.27E+00	5.17E-01
95	2.09E+00	1.49E-01	4.28E+00	2.51E+00	2.61E+00	4.98E-01	4.18E+00	1.26E+00	5.12E-01
96	2.08E+00	1.46E-01	4.25E+00	2.48E+00	2.58E+00	4.88E-01	4.15E+00	1.24E+00	5.08E-01
97	2.06E+00	1.43E-01	4.21E+00	2.47E+00	2.57E+00	4.80E-01	4.11E+00	1.23E+00	5.03E-01
98	2.03E+00	1.39E-01	4.18E+00	2.44E+00	2.55E+00	4.71E-01	4.08E+00	1.22E+00	4.99E-01
99	2.02E+00	1.36E-01	4.14E+00	2.43E+00	2.53E+00	4.62E-01	4.06E+00	1.21E+00	4.95E-01
100	2.01E+00	1.33E-01	4.11E+00	2.40E+00	2.51E+00	4.53E-01	4.01E+00	1.20E+00	4.90E-01
110	1.87E+00	1.06E-01	3.83E+00	2.22E+00	2.33E+00	3.79E-01	3.73E+00	1.11E+00	4.54E-01
120	1.75E+00	8.52E-02	3.58E+00	2.06E+00	2.17E+00	3.19E-01	3.49E+00	1.03E+00	4.22E-01
130	1.64E+00	6.83E-02	3.37E+00	1.94E+00	2.05E+00	2.69E-01	3.30E+00	9.70E-01	3.96E-01
140	1.56E+00	5.51E-02	3.19E+00	1.82E+00	1.94E+00	2.30E-01	3.12E+00	9.12E-01	3.73E-01
150	1.47E+00	4.48E-02	3.02E+00	1.73E+00	1.84E+00	1.98E-01	2.95E+00	8.62E-01	3.53E-01
160	1.42E+00	3.66E-02	2.89E+00	1.66E+00	1.75E+00	1.73E-01	2.83E+00	8.25E-01	3.37E-01
170	1.36E+00	3.00E-02	2.78E+00	1.59E+00	1.68E+00	1.50E-01	2.72E+00	7.91E-01	3.23E-01
180	1.31E+00	2.48E-02	2.68E+00	1.52E+00	1.63E+00	1.32E-01	2.62E+00	7.61E-01	3.11E-01
190	1.26E+00	2.09E-02	2.58E+00	1.46E+00	1.57E+00	1.17E-01	2.53E+00	7.32E-01	2.99E-01
200	1.22E+00	1.77E-02	2.50E+00	1.42E+00	1.52E+00	1.04E-01	2.44E+00	7.07E-01	2.89E-01
250	1.07E+00	9.22E-03	2.20E+00	1.24E+00	1.33E+00	6.45E-02	2.15E+00	6.20E-01	2.53E-01
300	9.68E-01	6.51E-03	1.98E+00	1.12E+00	1.20E+00	4.46E-02	1.94E+00	5.61E-01	2.28E-01
350	8.85E-01	5.53E-03	1.81E+00	1.03E+00	1.10E+00	3.31E-02	1.77E+00	5.15E-01	2.08E-01

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
400	8.18E-01	5.09E-03	1.67E+00	9.56E-01	1.02E+00	2.58E-02	1.64E+00	4.78E-01	1.93E-01
450	7.61E-01	4.84E-03	1.56E+00	8.91E-01	9.51E-01	2.10E-02	1.52E+00	4.45E-01	1.79E-01
500	7.10E-01	4.64E-03	1.46E+00	8.35E-01	8.90E-01	1.77E-02	1.42E+00	4.17E-01	1.67E-01
550	6.65E-01	4.49E-03	1.36E+00	7.86E-01	8.35E-01	1.52E-02	1.33E+00	3.93E-01	1.57E-01
600	6.24E-01	4.34E-03	1.28E+00	7.41E-01	7.86E-01	1.35E-02	1.25E+00	3.70E-01	1.48E-01
650	5.89E-01	4.18E-03	1.21E+00	7.00E-01	7.42E-01	1.21E-02	1.18E+00	3.51E-01	1.39E-01
700	5.57E-01	4.08E-03	1.14E+00	6.64E-01	7.02E-01	1.11E-02	1.11E+00	3.33E-01	1.32E-01
750	5.26E-01	3.96E-03	1.08E+00	6.31E-01	6.65E-01	1.03E-02	1.05E+00	3.16E-01	1.25E-01
800	5.00E-01	3.86E-03	1.02E+00	6.01E-01	6.31E-01	9.68E-03	9.99E-01	3.00E-01	1.18E-01
850	4.74E-01	3.76E-03	9.71E-01	5.72E-01	6.02E-01	9.15E-03	9.49E-01	2.86E-01	1.13E-01
900	4.52E-01	3.66E-03	9.23E-01	5.46E-01	5.72E-01	8.74E-03	9.02E-01	2.74E-01	1.07E-01
950	4.29E-01	3.59E-03	8.80E-01	5.23E-01	5.47E-01	8.33E-03	8.60E-01	2.61E-01	1.02E-01
1,000	4.10E-01	3.51E-03	8.40E-01	5.00E-01	5.22E-01	8.00E-03	8.21E-01	2.50E-01	9.77E-02
1,500	2.81E-01	3.00E-03	5.72E-01	3.54E-01	3.62E-01	6.02E-03	5.60E-01	1.77E-01	6.74E-02
2,000	2.17E-01	2.72E-03	4.46E-01	2.82E-01	2.85E-01	5.11E-03	4.35E-01	1.42E-01	5.29E-02
2,500	1.87E-01	2.60E-03	3.82E-01	2.46E-01	2.46E-01	4.64E-03	3.73E-01	1.23E-01	4.55E-02
3,000	1.70E-01	2.51E-03	3.47E-01	2.26E-01	2.25E-01	4.36E-03	3.40E-01	1.13E-01	4.15E-02
3,500	1.59E-01	2.44E-03	3.26E-01	2.12E-01	2.10E-01	4.20E-03	3.17E-01	1.06E-01	3.89E-02
4,000	1.52E-01	2.40E-03	3.10E-01	2.02E-01	2.01E-01	4.06E-03	3.03E-01	1.01E-01	3.71E-02
4,500	1.46E-01	2.36E-03	2.97E-01	1.94E-01	1.92E-01	3.94E-03	2.90E-01	9.67E-02	3.56E-02
5,000	1.40E-01	2.32E-03	2.86E-01	1.85E-01	1.85E-01	3.86E-03	2.81E-01	9.29E-02	3.43E-02
5,500	1.35E-01	2.29E-03	2.76E-01	1.80E-01	1.78E-01	3.76E-03	2.71E-01	8.95E-02	3.31E-02
6,000	1.30E-01	2.25E-03	2.67E-01	1.73E-01	1.73E-01	3.68E-03	2.61E-01	8.64E-02	3.19E-02

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
6,500	1.26E-01	2.22E-03	2.58E-01	1.67E-01	1.67E-01	3.59E-03	2.53E-01	8.36E-02	3.09E-02
7,000	1.22E-01	2.17E-03	2.50E-01	1.61E-01	1.61E-01	3.51E-03	2.44E-01	8.05E-02	2.99E-02
7,500	1.18E-01	2.15E-03	2.41E-01	1.56E-01	1.56E-01	3.44E-03	2.36E-01	7.82E-02	2.88E-02
8,000	1.14E-01	2.12E-03	2.34E-01	1.50E-01	1.52E-01	3.37E-03	2.29E-01	7.53E-02	2.80E-02
8,500	1.11E-01	2.09E-03	2.27E-01	1.46E-01	1.46E-01	3.30E-03	2.22E-01	7.28E-02	2.71E-02
9,000	1.08E-01	2.06E-03	2.20E-01	1.42E-01	1.42E-01	3.23E-03	2.15E-01	7.07E-02	2.63E-02
9,500	1.04E-01	2.03E-03	2.13E-01	1.36E-01	1.38E-01	3.16E-03	2.09E-01	6.82E-02	2.55E-02
10,000	1.01E-01	1.99E-03	2.06E-01	1.32E-01	1.33E-01	3.10E-03	2.02E-01	6.61E-02	2.46E-02
15,000	7.62E-02	1.74E-03	1.56E-01	9.82E-02	1.00E-01	2.57E-03	1.53E-01	4.91E-02	1.85E-02
20,000	5.92E-02	1.54E-03	1.21E-01	7.53E-02	7.79E-02	2.19E-03	1.18E-01	3.76E-02	1.44E-02
25,000	4.76E-02	1.37E-03	9.74E-02	5.99E-02	6.26E-02	1.89E-03	9.51E-02	2.99E-02	1.15E-02
30,000	3.93E-02	1.22E-03	8.05E-02	4.88E-02	5.15E-02	1.67E-03	7.87E-02	2.44E-02	9.50E-03
35,000	3.30E-02	1.10E-03	6.75E-02	4.07E-02	4.34E-02	1.50E-03	6.59E-02	2.03E-02	7.96E-03
40,000	2.83E-02	9.93E-04	5.80E-02	3.45E-02	3.70E-02	1.35E-03	5.65E-02	1.73E-02	6.82E-03
45,000	2.44E-02	9.04E-04	5.01E-02	2.96E-02	3.20E-02	1.23E-03	4.90E-02	1.49E-02	5.89E-03
50,000	2.15E-02	8.26E-04	4.41E-02	2.60E-02	2.82E-02	1.13E-03	4.31E-02	1.30E-02	5.18E-03
55,000	1.89E-02	7.59E-04	3.89E-02	2.29E-02	2.50E-02	1.05E-03	3.80E-02	1.14E-02	4.57E-03
60,000	1.68E-02	6.99E-04	3.44E-02	2.03E-02	2.22E-02	9.81E-04	3.35E-02	1.02E-02	4.05E-03
65,000	1.50E-02	6.48E-04	3.07E-02	1.85E-02	2.01E-02	9.25E-04	3.00E-02	9.26E-03	3.65E-03
70,000	1.36E-02	6.05E-04	2.78E-02	1.67E-02	1.81E-02	8.70E-04	2.71E-02	8.33E-03	3.29E-03
75,000	1.24E-02	5.64E-04	2.54E-02	1.49E-02	1.64E-02	8.28E-04	2.47E-02	7.41E-03	2.99E-03
80,000	1.12E-02	5.32E-04	2.29E-02	1.36E-02	1.50E-02	7.94E-04	2.25E-02	6.79E-03	2.72E-03
85,000	1.03E-02	5.04E-04	2.10E-02	1.23E-02	1.38E-02	7.68E-04	2.06E-02	6.17E-03	2.49E-03

Table C-2. Waste Package Powers for Cases 4 through 6 and 13 through 15 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
90,000	9.58E-03	4.77E-04	1.96E-02	1.17E-02	1.30E-02	7.42E-04	1.92E-02	5.87E-03	2.34E-03
95,000	8.84E-03	4.57E-04	1.81E-02	1.11E-02	1.21E-02	7.17E-04	1.77E-02	5.56E-03	2.17E-03
100,000	8.25E-03	4.36E-04	1.68E-02	9.88E-03	1.12E-02	6.99E-04	1.66E-02	4.94E-03	2.00E-03
150,000	5.60E-03	3.40E-04	1.15E-02	6.79E-03	7.80E-03	6.20E-04	1.12E-02	3.40E-03	1.37E-03
200,000	5.01E-03	3.09E-04	1.03E-02	6.17E-03	7.14E-03	5.88E-04	1.00E-02	3.09E-03	1.24E-03
250,000	4.87E-03	2.92E-04	9.95E-03	6.17E-03	6.95E-03	5.56E-04	9.72E-03	3.09E-03	1.21E-03
300,000	4.71E-03	2.82E-04	9.65E-03	6.17E-03	6.82E-03	5.15E-04	9.43E-03	3.09E-03	1.18E-03
350,000	4.71E-03	2.72E-04	9.65E-03	5.56E-03	6.51E-03	4.71E-04	9.43E-03	2.78E-03	1.15E-03
400,000	4.57E-03	2.65E-04	9.35E-03	5.56E-03	6.33E-03	4.29E-04	9.13E-03	2.78E-03	1.12E-03
450,000	4.42E-03	2.58E-04	9.05E-03	5.56E-03	6.17E-03	3.87E-04	8.84E-03	2.78E-03	1.09E-03
500,000	4.13E-03	2.54E-04	8.45E-03	4.94E-03	5.67E-03	3.49E-04	8.25E-03	2.47E-03	1.00E-03
550,000	3.98E-03	2.48E-04	8.14E-03	4.94E-03	5.53E-03	3.14E-04	7.96E-03	2.47E-03	9.78E-04
600,000	3.83E-03	2.44E-04	7.84E-03	4.94E-03	5.33E-03	2.82E-04	7.66E-03	2.47E-03	9.50E-04
650,000	3.69E-03	2.40E-04	7.53E-03	4.94E-03	5.18E-03	2.54E-04	7.37E-03	2.47E-03	9.22E-04
700,000	3.69E-03	2.37E-04	7.53E-03	4.32E-03	4.90E-03	2.29E-04	7.37E-03	2.16E-03	8.87E-04
750,000	3.54E-03	2.34E-04	7.24E-03	4.32E-03	4.76E-03	2.06E-04	7.07E-03	2.16E-03	8.60E-04
800,000	3.40E-03	2.32E-04	6.93E-03	4.32E-03	4.59E-03	1.88E-04	6.78E-03	2.16E-03	8.33E-04
850,000	3.24E-03	2.29E-04	6.64E-03	4.32E-03	4.46E-03	1.70E-04	6.48E-03	2.16E-03	8.07E-04
900,000	3.24E-03	2.27E-04	6.64E-03	3.70E-03	4.22E-03	1.56E-04	6.48E-03	1.85E-03	7.73E-04
950,000	3.10E-03	2.26E-04	6.33E-03	3.70E-03	4.10E-03	1.43E-04	6.19E-03	1.85E-03	7.47E-04

Source: Output DTN: MO0506SPAPRETM.000, *Case4.xls*, worksheet “IED.”

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
0.1	5.76E+00	7.69E+00	1.18E+01	7.38E+00	7.10E+00	5.30E+00	1.15E+01	3.69E+00	1.75E+00
1	5.57E+00	7.42E+00	1.14E+01	7.14E+00	6.90E+00	5.11E+00	1.11E+01	3.57E+00	1.70E+00
2	5.41E+00	7.20E+00	1.11E+01	6.95E+00	6.72E+00	4.96E+00	1.08E+01	3.47E+00	1.65E+00
3	5.27E+00	7.01E+00	1.08E+01	6.77E+00	6.55E+00	4.83E+00	1.05E+01	3.39E+00	1.61E+00
4	5.14E+00	6.84E+00	1.05E+01	6.61E+00	6.39E+00	4.71E+00	1.03E+01	3.31E+00	1.57E+00
5	5.03E+00	6.69E+00	1.03E+01	6.47E+00	6.25E+00	4.61E+00	1.01E+01	3.23E+00	1.53E+00
6	4.92E+00	6.54E+00	1.01E+01	6.33E+00	6.11E+00	4.51E+00	9.84E+00	3.16E+00	1.50E+00
7	4.82E+00	6.40E+00	9.86E+00	6.20E+00	5.99E+00	4.41E+00	9.63E+00	3.10E+00	1.47E+00
8	4.72E+00	6.27E+00	9.66E+00	6.07E+00	5.87E+00	4.32E+00	9.44E+00	3.04E+00	1.44E+00
9	4.63E+00	6.15E+00	9.47E+00	5.95E+00	5.75E+00	4.23E+00	9.25E+00	2.98E+00	1.41E+00
10	4.54E+00	6.03E+00	9.29E+00	5.84E+00	5.64E+00	4.15E+00	9.07E+00	2.92E+00	1.38E+00
11	4.44E+00	5.89E+00	9.09E+00	5.71E+00	5.52E+00	4.06E+00	8.88E+00	2.85E+00	1.35E+00
12	4.35E+00	5.78E+00	8.91E+00	5.59E+00	5.41E+00	3.98E+00	8.70E+00	2.80E+00	1.33E+00
13	4.27E+00	5.67E+00	8.75E+00	5.49E+00	5.31E+00	3.90E+00	8.55E+00	2.75E+00	1.30E+00
14	4.20E+00	5.57E+00	8.60E+00	5.40E+00	5.22E+00	3.84E+00	8.40E+00	2.70E+00	1.28E+00
15	4.14E+00	5.48E+00	8.47E+00	5.31E+00	5.14E+00	3.78E+00	8.27E+00	2.66E+00	1.26E+00
16	4.06E+00	5.37E+00	8.30E+00	5.21E+00	5.04E+00	3.70E+00	8.11E+00	2.60E+00	1.23E+00
17	3.98E+00	5.27E+00	8.15E+00	5.11E+00	4.95E+00	3.63E+00	7.96E+00	2.55E+00	1.21E+00
18	3.91E+00	5.18E+00	8.01E+00	5.02E+00	4.87E+00	3.57E+00	7.83E+00	2.51E+00	1.19E+00
19	3.85E+00	5.09E+00	7.88E+00	4.94E+00	4.79E+00	3.51E+00	7.70E+00	2.47E+00	1.17E+00
20	3.79E+00	5.01E+00	7.76E+00	4.86E+00	4.72E+00	3.45E+00	7.58E+00	2.43E+00	1.15E+00
21	3.72E+00	4.92E+00	7.62E+00	4.77E+00	4.63E+00	3.39E+00	7.45E+00	2.38E+00	1.13E+00
22	3.66E+00	4.83E+00	7.49E+00	4.68E+00	4.55E+00	3.33E+00	7.32E+00	2.34E+00	1.11E+00

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
23	3.60E+00	4.75E+00	7.37E+00	4.60E+00	4.48E+00	3.27E+00	7.20E+00	2.30E+00	1.09E+00
24	3.54E+00	4.67E+00	7.25E+00	4.52E+00	4.41E+00	3.22E+00	7.09E+00	2.26E+00	1.08E+00
25	3.49E+00	4.60E+00	7.14E+00	4.45E+00	4.35E+00	3.17E+00	6.98E+00	2.23E+00	1.06E+00
26	3.43E+00	4.53E+00	7.02E+00	4.37E+00	4.26E+00	3.12E+00	6.86E+00	2.19E+00	1.04E+00
27	3.37E+00	4.45E+00	6.91E+00	4.30E+00	4.19E+00	3.07E+00	6.75E+00	2.15E+00	1.02E+00
28	3.32E+00	4.38E+00	6.80E+00	4.23E+00	4.12E+00	3.01E+00	6.64E+00	2.11E+00	1.01E+00
29	3.27E+00	4.31E+00	6.69E+00	4.16E+00	4.06E+00	2.97E+00	6.54E+00	2.08E+00	9.92E-01
30	3.22E+00	4.24E+00	6.60E+00	4.10E+00	4.01E+00	2.92E+00	6.44E+00	2.05E+00	9.78E-01
31	3.17E+00	4.17E+00	6.49E+00	4.03E+00	3.94E+00	2.87E+00	6.34E+00	2.01E+00	9.62E-01
32	3.12E+00	4.10E+00	6.39E+00	3.96E+00	3.88E+00	2.83E+00	6.24E+00	1.98E+00	9.47E-01
33	3.07E+00	4.04E+00	6.29E+00	3.90E+00	3.82E+00	2.78E+00	6.15E+00	1.95E+00	9.32E-01
34	3.03E+00	3.98E+00	6.20E+00	3.84E+00	3.77E+00	2.74E+00	6.06E+00	1.92E+00	9.19E-01
35	2.99E+00	3.92E+00	6.11E+00	3.78E+00	3.71E+00	2.70E+00	5.97E+00	1.89E+00	9.05E-01
36	2.94E+00	3.86E+00	6.02E+00	3.72E+00	3.65E+00	2.66E+00	5.88E+00	1.86E+00	8.91E-01
37	2.90E+00	3.80E+00	5.93E+00	3.66E+00	3.60E+00	2.61E+00	5.79E+00	1.83E+00	8.77E-01
38	2.85E+00	3.74E+00	5.84E+00	3.60E+00	3.55E+00	2.57E+00	5.71E+00	1.80E+00	8.64E-01
39	2.81E+00	3.68E+00	5.76E+00	3.55E+00	3.50E+00	2.54E+00	5.63E+00	1.77E+00	8.52E-01
40	2.77E+00	3.63E+00	5.68E+00	3.50E+00	3.45E+00	2.50E+00	5.55E+00	1.75E+00	8.40E-01
41	2.73E+00	3.58E+00	5.60E+00	3.44E+00	3.40E+00	2.46E+00	5.47E+00	1.72E+00	8.27E-01
42	2.69E+00	3.52E+00	5.52E+00	3.39E+00	3.35E+00	2.42E+00	5.39E+00	1.69E+00	8.15E-01
43	2.66E+00	3.47E+00	5.44E+00	3.34E+00	3.30E+00	2.39E+00	5.31E+00	1.67E+00	8.03E-01
44	2.62E+00	3.42E+00	5.36E+00	3.29E+00	3.26E+00	2.35E+00	5.24E+00	1.65E+00	7.92E-01

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

	1/2 21-PWR AP	**5-HLW Long**	**21-PWR AP (Hot)**	**44-BWR AP**	**44-BWR AP (Adjusted)**	**5-HLW Short**	**21-PWR AP**	**1/2 44-BWR AP**	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
45	2.59E+00	3.37E+00	5.29E+00	3.24E+00	3.21E+00	2.32E+00	5.17E+00	1.62E+00	7.81E-01
46	2.55E+00	3.32E+00	5.22E+00	3.20E+00	3.17E+00	2.29E+00	5.10E+00	1.60E+00	7.70E-01
47	2.51E+00	3.27E+00	5.15E+00	3.15E+00	3.13E+00	2.25E+00	5.03E+00	1.57E+00	7.59E-01
48	2.48E+00	3.23E+00	5.08E+00	3.10E+00	3.09E+00	2.22E+00	4.96E+00	1.55E+00	7.49E-01
49	2.45E+00	3.19E+00	5.01E+00	3.06E+00	3.05E+00	2.19E+00	4.90E+00	1.53E+00	7.39E-01
50	2.42E+00	3.14E+00	4.95E+00	3.02E+00	3.02E+00	2.17E+00	4.83E+00	1.51E+00	7.30E-01
51	2.38E+00	3.10E+00	4.88E+00	2.97E+00	2.98E+00	2.13E+00	4.77E+00	1.49E+00	7.19E-01
52	2.35E+00	3.06E+00	4.82E+00	2.93E+00	2.94E+00	2.11E+00	4.71E+00	1.47E+00	7.10E-01
53	2.32E+00	3.02E+00	4.76E+00	2.89E+00	2.90E+00	2.08E+00	4.65E+00	1.45E+00	7.01E-01
54	2.29E+00	2.97E+00	4.70E+00	2.85E+00	2.86E+00	2.05E+00	4.59E+00	1.43E+00	6.92E-01
55	2.27E+00	2.94E+00	4.64E+00	2.82E+00	2.83E+00	2.02E+00	4.53E+00	1.41E+00	6.83E-01
56	2.24E+00	2.90E+00	4.58E+00	2.78E+00	2.79E+00	2.00E+00	4.47E+00	1.39E+00	6.74E-01
57	2.21E+00	2.86E+00	4.52E+00	2.74E+00	2.75E+00	1.97E+00	4.42E+00	1.37E+00	6.65E-01
58	2.18E+00	2.82E+00	4.47E+00	2.70E+00	2.72E+00	1.94E+00	4.36E+00	1.35E+00	6.57E-01
59	2.16E+00	2.79E+00	4.41E+00	2.67E+00	2.69E+00	1.92E+00	4.31E+00	1.33E+00	6.49E-01
60	2.13E+00	2.75E+00	4.36E+00	2.64E+00	2.66E+00	1.90E+00	4.26E+00	1.32E+00	6.41E-01
61	2.10E+00	2.71E+00	4.31E+00	2.60E+00	2.62E+00	1.87E+00	4.21E+00	1.30E+00	6.33E-01
62	2.08E+00	2.68E+00	4.26E+00	2.57E+00	2.59E+00	1.85E+00	4.16E+00	1.28E+00	6.25E-01
63	2.06E+00	2.65E+00	4.21E+00	2.53E+00	2.56E+00	1.82E+00	4.11E+00	1.27E+00	6.18E-01
64	2.03E+00	2.61E+00	4.16E+00	2.50E+00	2.53E+00	1.80E+00	4.06E+00	1.25E+00	6.10E-01
65	2.01E+00	2.59E+00	4.11E+00	2.47E+00	2.50E+00	1.78E+00	4.02E+00	1.24E+00	6.03E-01
66	1.99E+00	2.55E+00	4.06E+00	2.44E+00	2.47E+00	1.76E+00	3.97E+00	1.22E+00	5.96E-01
67	1.96E+00	2.52E+00	4.02E+00	2.41E+00	2.44E+00	1.74E+00	3.93E+00	1.21E+00	5.89E-01

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
68	1.94E+00	2.49E+00	3.97E+00	2.38E+00	2.42E+00	1.72E+00	3.88E+00	1.19E+00	5.82E-01
69	1.92E+00	2.46E+00	3.93E+00	2.35E+00	2.39E+00	1.70E+00	3.84E+00	1.18E+00	5.76E-01
70	1.90E+00	2.44E+00	3.89E+00	2.33E+00	2.36E+00	1.68E+00	3.80E+00	1.16E+00	5.69E-01
71	1.88E+00	2.41E+00	3.84E+00	2.30E+00	2.34E+00	1.66E+00	3.76E+00	1.15E+00	5.63E-01
72	1.86E+00	2.38E+00	3.80E+00	2.27E+00	2.31E+00	1.64E+00	3.72E+00	1.14E+00	5.57E-01
73	1.84E+00	2.35E+00	3.76E+00	2.25E+00	2.29E+00	1.62E+00	3.68E+00	1.12E+00	5.51E-01
74	1.82E+00	2.33E+00	3.72E+00	2.22E+00	2.26E+00	1.60E+00	3.64E+00	1.11E+00	5.45E-01
75	1.80E+00	2.30E+00	3.68E+00	2.20E+00	2.24E+00	1.58E+00	3.60E+00	1.10E+00	5.39E-01
76	1.78E+00	2.28E+00	3.65E+00	2.17E+00	2.22E+00	1.57E+00	3.56E+00	1.09E+00	5.33E-01
77	1.76E+00	2.25E+00	3.61E+00	2.15E+00	2.19E+00	1.55E+00	3.53E+00	1.07E+00	5.27E-01
78	1.75E+00	2.23E+00	3.57E+00	2.12E+00	2.17E+00	1.53E+00	3.49E+00	1.06E+00	5.22E-01
79	1.73E+00	2.20E+00	3.54E+00	2.10E+00	2.15E+00	1.52E+00	3.46E+00	1.05E+00	5.17E-01
80	1.71E+00	2.18E+00	3.50E+00	2.08E+00	2.13E+00	1.50E+00	3.42E+00	1.04E+00	5.11E-01
81	1.69E+00	2.16E+00	3.47E+00	2.06E+00	2.11E+00	1.49E+00	3.39E+00	1.03E+00	5.07E-01
82	1.68E+00	2.13E+00	3.43E+00	2.03E+00	2.09E+00	1.47E+00	3.35E+00	1.02E+00	5.01E-01
83	1.66E+00	2.11E+00	3.40E+00	2.01E+00	2.07E+00	1.45E+00	3.32E+00	1.01E+00	4.96E-01
84	1.64E+00	2.09E+00	3.37E+00	1.99E+00	2.05E+00	1.44E+00	3.29E+00	9.96E-01	4.91E-01
85	1.63E+00	2.07E+00	3.34E+00	1.97E+00	2.03E+00	1.43E+00	3.26E+00	9.86E-01	4.87E-01
86	1.61E+00	2.05E+00	3.30E+00	1.95E+00	2.01E+00	1.41E+00	3.23E+00	9.76E-01	4.82E-01
87	1.60E+00	2.03E+00	3.27E+00	1.93E+00	1.99E+00	1.40E+00	3.20E+00	9.66E-01	4.77E-01
88	1.58E+00	2.01E+00	3.24E+00	1.91E+00	1.97E+00	1.38E+00	3.17E+00	9.57E-01	4.72E-01
89	1.57E+00	1.99E+00	3.22E+00	1.89E+00	1.95E+00	1.37E+00	3.14E+00	9.47E-01	4.68E-01
90	1.56E+00	1.97E+00	3.19E+00	1.88E+00	1.94E+00	1.36E+00	3.11E+00	9.38E-01	4.65E-01

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
91	1.54E+00	1.95E+00	3.16E+00	1.86E+00	1.92E+00	1.35E+00	3.09E+00	9.29E-01	4.60E-01
92	1.53E+00	1.94E+00	3.13E+00	1.84E+00	1.91E+00	1.33E+00	3.06E+00	9.20E-01	4.56E-01
93	1.52E+00	1.92E+00	3.10E+00	1.82E+00	1.89E+00	1.32E+00	3.03E+00	9.12E-01	4.52E-01
94	1.50E+00	1.90E+00	3.08E+00	1.81E+00	1.87E+00	1.31E+00	3.01E+00	9.03E-01	4.48E-01
95	1.49E+00	1.88E+00	3.05E+00	1.79E+00	1.86E+00	1.30E+00	2.98E+00	8.95E-01	4.44E-01
96	1.48E+00	1.87E+00	3.03E+00	1.77E+00	1.84E+00	1.29E+00	2.96E+00	8.87E-01	4.40E-01
97	1.47E+00	1.85E+00	3.00E+00	1.76E+00	1.83E+00	1.27E+00	2.93E+00	8.79E-01	4.37E-01
98	1.45E+00	1.83E+00	2.98E+00	1.74E+00	1.82E+00	1.26E+00	2.91E+00	8.71E-01	4.33E-01
99	1.44E+00	1.82E+00	2.95E+00	1.73E+00	1.80E+00	1.25E+00	2.89E+00	8.64E-01	4.29E-01
100	1.43E+00	1.80E+00	2.93E+00	1.71E+00	1.79E+00	1.24E+00	2.86E+00	8.56E-01	4.26E-01
110	1.33E+00	1.67E+00	2.73E+00	1.58E+00	1.66E+00	1.15E+00	2.66E+00	7.92E-01	3.95E-01
120	1.25E+00	1.55E+00	2.55E+00	1.47E+00	1.55E+00	1.07E+00	2.49E+00	7.37E-01	3.69E-01
130	1.17E+00	1.46E+00	2.40E+00	1.38E+00	1.46E+00	1.00E+00	2.35E+00	6.91E-01	3.47E-01
140	1.11E+00	1.37E+00	2.27E+00	1.30E+00	1.38E+00	9.45E-01	2.22E+00	6.50E-01	3.28E-01
150	1.05E+00	1.30E+00	2.15E+00	1.23E+00	1.31E+00	8.93E-01	2.10E+00	6.14E-01	3.10E-01
160	1.01E+00	1.24E+00	2.06E+00	1.18E+00	1.25E+00	8.54E-01	2.02E+00	5.88E-01	2.97E-01
170	9.69E-01	1.19E+00	1.98E+00	1.13E+00	1.20E+00	8.19E-01	1.94E+00	5.64E-01	2.85E-01
180	9.33E-01	1.14E+00	1.91E+00	1.08E+00	1.16E+00	7.87E-01	1.87E+00	5.42E-01	2.75E-01
190	9.01E-01	1.10E+00	1.84E+00	1.04E+00	1.12E+00	7.58E-01	1.80E+00	5.22E-01	2.64E-01
200	8.71E-01	1.06E+00	1.78E+00	1.01E+00	1.08E+00	7.32E-01	1.74E+00	5.04E-01	2.56E-01
250	7.65E-01	9.31E-01	1.57E+00	8.85E-01	9.49E-01	6.41E-01	1.53E+00	4.42E-01	2.25E-01
300	6.90E-01	8.38E-01	1.41E+00	8.00E-01	8.58E-01	5.77E-01	1.38E+00	4.00E-01	2.02E-01
350	6.31E-01	7.66E-01	1.29E+00	7.35E-01	7.87E-01	5.27E-01	1.26E+00	3.67E-01	1.85E-01

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

Time since Emplacement (years)	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	Average Line Load (kW/m)
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
	Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)								
400	5.83E-01	7.09E-01	1.19E+00	6.81E-01	7.28E-01	4.88E-01	1.17E+00	3.41E-01	1.72E-01
450	5.42E-01	6.58E-01	1.11E+00	6.35E-01	6.78E-01	4.53E-01	1.08E+00	3.17E-01	1.59E-01
500	5.06E-01	6.16E-01	1.04E+00	5.95E-01	6.34E-01	4.24E-01	1.01E+00	2.97E-01	1.49E-01
550	4.74E-01	5.77E-01	9.70E-01	5.60E-01	5.95E-01	3.97E-01	9.48E-01	2.80E-01	1.40E-01
600	4.45E-01	5.43E-01	9.12E-01	5.28E-01	5.60E-01	3.74E-01	8.91E-01	2.64E-01	1.32E-01
650	4.20E-01	5.12E-01	8.59E-01	4.99E-01	5.29E-01	3.53E-01	8.40E-01	2.50E-01	1.24E-01
700	3.97E-01	4.84E-01	8.12E-01	4.73E-01	5.00E-01	3.33E-01	7.93E-01	2.37E-01	1.17E-01
750	3.75E-01	4.59E-01	7.68E-01	4.50E-01	4.74E-01	3.16E-01	7.51E-01	2.25E-01	1.11E-01
800	3.56E-01	4.36E-01	7.29E-01	4.28E-01	4.50E-01	3.00E-01	7.12E-01	2.14E-01	1.06E-01
850	3.38E-01	4.14E-01	6.92E-01	4.08E-01	4.29E-01	2.85E-01	6.76E-01	2.04E-01	1.00E-01
900	3.22E-01	3.94E-01	6.58E-01	3.89E-01	4.08E-01	2.72E-01	6.43E-01	1.95E-01	9.56E-02
950	3.06E-01	3.76E-01	6.27E-01	3.73E-01	3.90E-01	2.59E-01	6.13E-01	1.86E-01	9.12E-02
1,000	2.92E-01	3.59E-01	5.99E-01	3.56E-01	3.72E-01	2.47E-01	5.85E-01	1.78E-01	8.70E-02
1,500	2.00E-01	2.48E-01	4.08E-01	2.52E-01	2.58E-01	1.71E-01	3.99E-01	1.26E-01	6.00E-02
2,000	1.55E-01	1.94E-01	3.18E-01	2.01E-01	2.03E-01	1.34E-01	3.10E-01	1.01E-01	4.71E-02
2,500	1.33E-01	1.67E-01	2.72E-01	1.75E-01	1.75E-01	1.15E-01	2.66E-01	8.76E-02	4.05E-02
3,000	1.21E-01	1.53E-01	2.47E-01	1.61E-01	1.60E-01	1.05E-01	2.42E-01	8.03E-02	3.70E-02
3,500	1.13E-01	1.43E-01	2.32E-01	1.51E-01	1.50E-01	9.85E-02	2.26E-01	7.55E-02	3.46E-02
4,000	1.08E-01	1.37E-01	2.21E-01	1.44E-01	1.43E-01	9.40E-02	2.16E-01	7.19E-02	3.30E-02
4,500	1.04E-01	1.31E-01	2.12E-01	1.38E-01	1.37E-01	9.02E-02	2.07E-01	6.89E-02	3.17E-02
5,000	9.99E-02	1.26E-01	2.04E-01	1.32E-01	1.32E-01	8.68E-02	2.00E-01	6.62E-02	3.05E-02
5,500	9.64E-02	1.22E-01	1.97E-01	1.28E-01	1.27E-01	8.38E-02	1.93E-01	6.38E-02	2.94E-02
6,000	9.30E-02	1.17E-01	1.90E-01	1.23E-01	1.23E-01	8.08E-02	1.86E-01	6.16E-02	2.84E-02

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
6,500	8.99E-02	1.14E-01	1.84E-01	1.19E-01	1.19E-01	7.82E-02	1.80E-01	5.96E-02	2.75E-02
7,000	8.72E-02	1.10E-01	1.78E-01	1.15E-01	1.15E-01	7.56E-02	1.74E-01	5.74E-02	2.66E-02
7,500	8.42E-02	1.06E-01	1.72E-01	1.11E-01	1.11E-01	7.30E-02	1.68E-01	5.57E-02	2.57E-02
8,000	8.16E-02	1.03E-01	1.67E-01	1.07E-01	1.08E-01	7.08E-02	1.63E-01	5.37E-02	2.49E-02
8,500	7.91E-02	9.96E-02	1.62E-01	1.04E-01	1.04E-01	6.86E-02	1.58E-01	5.19E-02	2.41E-02
9,000	7.67E-02	9.66E-02	1.57E-01	1.01E-01	1.01E-01	6.65E-02	1.53E-01	5.04E-02	2.34E-02
9,500	7.43E-02	9.36E-02	1.52E-01	9.72E-02	9.81E-02	6.45E-02	1.49E-01	4.86E-02	2.26E-02
10,000	7.20E-02	9.06E-02	1.47E-01	9.42E-02	9.51E-02	6.24E-02	1.44E-01	4.71E-02	2.19E-02
15,000	5.43E-02	6.82E-02	1.11E-01	7.00E-02	7.15E-02	4.70E-02	1.09E-01	3.50E-02	1.65E-02
20,000	4.22E-02	5.28E-02	8.64E-02	5.37E-02	5.55E-02	3.64E-02	8.44E-02	2.68E-02	1.28E-02
25,000	3.39E-02	4.24E-02	6.94E-02	4.27E-02	4.46E-02	2.92E-02	6.78E-02	2.13E-02	1.02E-02
30,000	2.80E-02	3.49E-02	5.74E-02	3.48E-02	3.67E-02	2.41E-02	5.61E-02	1.74E-02	8.43E-03
35,000	2.35E-02	2.93E-02	4.81E-02	2.90E-02	3.09E-02	2.02E-02	4.70E-02	1.45E-02	7.06E-03
40,000	2.02E-02	2.51E-02	4.13E-02	2.46E-02	2.64E-02	1.73E-02	4.03E-02	1.23E-02	6.04E-03
45,000	1.74E-02	2.16E-02	3.57E-02	2.11E-02	2.28E-02	1.49E-02	3.49E-02	1.06E-02	5.21E-03
50,000	1.53E-02	1.90E-02	3.14E-02	1.85E-02	2.01E-02	1.31E-02	3.07E-02	9.24E-03	4.58E-03
55,000	1.35E-02	1.68E-02	2.77E-02	1.63E-02	1.78E-02	1.16E-02	2.71E-02	8.14E-03	4.05E-03
60,000	1.20E-02	1.49E-02	2.45E-02	1.45E-02	1.58E-02	1.03E-02	2.39E-02	7.26E-03	3.59E-03
65,000	1.07E-02	1.34E-02	2.19E-02	1.32E-02	1.43E-02	9.23E-03	2.14E-02	6.60E-03	3.23E-03
70,000	9.66E-03	1.21E-02	1.98E-02	1.19E-02	1.29E-02	8.34E-03	1.93E-02	5.94E-03	2.91E-03
75,000	8.82E-03	1.10E-02	1.81E-02	1.06E-02	1.17E-02	7.56E-03	1.76E-02	5.28E-03	2.64E-03
80,000	7.98E-03	9.98E-03	1.63E-02	9.68E-03	1.07E-02	6.88E-03	1.60E-02	4.84E-03	2.40E-03
85,000	7.35E-03	9.17E-03	1.50E-02	8.80E-03	9.84E-03	6.31E-03	1.47E-02	4.40E-03	2.20E-03

Table C-3. Waste Package Powers for Cases 7 through 9 and 16 through 18 (Continued)

	1/2 21-PWR AP	5-HLW Long	21-PWR AP (Hot)	44-BWR AP	44-BWR AP (Adjusted)	5-HLW Short	21-PWR AP	1/2 44-BWR AP	
	Waste Package Lengths (m)								
	2.5122	5.0594	5.0244	5.0244	5.0244	3.4528	5.0244	2.5122	
	Waste Package Lengths plus Spacings (m)								
	2.5622	5.1594	5.1244	5.1244	5.1244	3.5528	5.1244	2.5622	
Time since Emplacement (years)	**Waste Package Decay Heat Generation (kW/WP) along Seven-Package Segment (LL)**								**Average Line Load (kW/m)**
90,000	6.83E-03	8.59E-03	1.40E-02	8.36E-03	9.24E-03	5.92E-03	1.37E-02	4.18E-03	2.06E-03
95,000	6.30E-03	7.99E-03	1.29E-02	7.92E-03	8.63E-03	5.50E-03	1.26E-02	3.96E-03	1.92E-03
100,000	5.88E-03	7.36E-03	1.20E-02	7.04E-03	7.96E-03	5.07E-03	1.18E-02	3.52E-03	1.77E-03
150,000	3.99E-03	5.06E-03	8.17E-03	4.84E-03	5.56E-03	3.48E-03	7.98E-03	2.42E-03	1.21E-03
200,000	3.57E-03	4.56E-03	7.31E-03	4.40E-03	5.09E-03	3.14E-03	7.14E-03	2.20E-03	1.09E-03
250,000	3.47E-03	4.45E-03	7.09E-03	4.40E-03	4.95E-03	3.07E-03	6.93E-03	2.20E-03	1.06E-03
300,000	3.36E-03	4.36E-03	6.88E-03	4.40E-03	4.86E-03	3.00E-03	6.72E-03	2.20E-03	1.04E-03
350,000	3.36E-03	4.22E-03	6.88E-03	3.96E-03	4.64E-03	2.90E-03	6.72E-03	1.98E-03	1.01E-03
400,000	3.26E-03	4.11E-03	6.66E-03	3.96E-03	4.51E-03	2.83E-03	6.51E-03	1.98E-03	9.85E-04
450,000	3.15E-03	4.01E-03	6.45E-03	3.96E-03	4.40E-03	2.76E-03	6.30E-03	1.98E-03	9.62E-04
500,000	2.94E-03	3.70E-03	6.02E-03	3.52E-03	4.04E-03	2.54E-03	5.88E-03	1.76E-03	8.85E-04
550,000	2.84E-03	3.60E-03	5.80E-03	3.52E-03	3.94E-03	2.48E-03	5.67E-03	1.76E-03	8.62E-04
600,000	2.73E-03	3.49E-03	5.59E-03	3.52E-03	3.80E-03	2.40E-03	5.46E-03	1.76E-03	8.38E-04
650,000	2.63E-03	3.39E-03	5.37E-03	3.52E-03	3.69E-03	2.34E-03	5.25E-03	1.76E-03	8.14E-04
700,000	2.63E-03	3.26E-03	5.37E-03	3.08E-03	3.49E-03	2.24E-03	5.25E-03	1.54E-03	7.82E-04
750,000	2.52E-03	3.16E-03	5.16E-03	3.08E-03	3.39E-03	2.18E-03	5.04E-03	1.54E-03	7.59E-04
800,000	2.42E-03	3.06E-03	4.94E-03	3.08E-03	3.27E-03	2.11E-03	4.83E-03	1.54E-03	7.35E-04
850,000	2.31E-03	2.97E-03	4.73E-03	3.08E-03	3.18E-03	2.04E-03	4.62E-03	1.54E-03	7.13E-04
900,000	2.31E-03	2.84E-03	4.73E-03	2.64E-03	3.01E-03	1.96E-03	4.62E-03	1.32E-03	6.82E-04
950,000	2.21E-03	2.75E-03	4.51E-03	2.64E-03	2.92E-03	1.89E-03	4.41E-03	1.32E-03	6.60E-04

Source: Output DTN: MO0506SPAPRETM.000, *Case7.xls*, worksheet "IED."

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