BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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2. Page 1

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5. Title

Drift Wall Thermal Response to Loss of Ventilation

6. Group

Thermal Structural Analysis

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See Section 5	

RECORD OF REVISIONS

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DISCLAIMER

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TABLES

1. PURPOSE

The objective of this calculation is to evaluate the thermal response of the repository drift wall and near-vicinity rock temperatures due to loss of ventilation during the pre-closure period. The scope of this calculation is limited to the three-dimensional (3-D) representation of the multiple waste packages emplaced in the repository drift.

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2.4 DESIGN OUTPUTS

None.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 Active Fuel Length of the 5 DHLW/DOE-Short Waste Package

The active fuel length of the 5 DHLW/DOE-Short Waste Package is assumed to be 2.28 m.

Rationale: Section 11.2.2.7 of Reference 2.2.14 indicates that the Savannah River Site canister is an expected waste form for the 5 DHLW/DOE-Short Waste Package. Table 3.3.1 of Reference 2.2.23 indicates that the fill volume (V_f) of the Savannah River Site canister is 0.626 m^3.

Figure 3.3.1 of Reference 2.2.23 gives the outer diameter (D_o) of the Savannah River Site canister as 24.00 in and the thickness (t) of the canister shell as 3/8 in. From these values, the inner radius (r_i) of the Savannah River Site canister is determined to be:

$$r_i = \frac{D_o}{2} - t = \frac{24 \text{ in}}{2} - \frac{3}{8} \text{ in} = 11\tfrac{5}{8} \text{ in} = 0.2953 \text{ m}$$

From this value, the interior, cross-sectional area (A_i) of the Savannah River Site canister is determined to be:

$$A_i = \pi r_i^2 = 3.14(0.2953 \text{ m})^2 = 0.274 \text{ m}^2$$

Using the definition of the volume of a cylinder, $V = Al = \pi r^2 l$, the active fuel length (l_{active}) can be determined by dividing the fill volume by the interior, cross-sectional area.

$$l_{active} = \frac{V_f}{A_i} = \frac{0.626 \text{ m}^3}{0.274 \text{ m}^2} = 2.28 \text{ m}$$

This is the best information currently available.

This assumption is used in Sections 3.1.2 and 6.4.

3.1.2 Active Fuel Length of the 5 DHLW/DOE-Long Waste Package

The active fuel length of the 5 DHLW/DOE-Long Waste Package is assumed to be 3.89 m.

Rationale: The inner vessel cavity length of the 5 DHLW/DOE-Short Waste Package is 3.0131 m (Reference 2.2.18). Subtracting the active length of 2.28 m (Assumption 3.1.1) from the inner vessel cavity length gives a difference of 0.733 m. The inner vessel cavity length of the 5 DHLW/DOE-Long Waste Package is 4.6196 m (Reference 2.2.17). Subtracting the above length difference (0.733 m) from the inner vessel cavity length gives an active length of 3.89 m. This is the best information currently available.

This assumption is used in Section 6.4.

3.1.3 Peaking Factor for BWR Fuel

It is assumed that the peaking factor for BWR fuel is applied to the center 2/3 of the BWR fuel assemblies.

Rationale: Page 3-26 of Reference 2.2.24 indicates that the peaking factor for PWR fuel covers approximately the center 2/3 of the PWR assembly. This value is deemed appropriate for BWR fuel, since similar information for BWR fuel is currently unavailable.

This assumption is used in Section 6.4.

3.1.4 Use of the 21-PWR Waste Package in the ANSYS Computational Model

The 21-PWR waste package, with dimensions indicated in Reference 2.2.20, is included in the ANSYS computational model.

Rationale: The current design incorporates a TAD-bearing waste package capable of holding 21 spent fuel assemblies from a PWR (Reference 2.2.37, Section 3.8.1). Hence, the thermal loading of a 21-PWR TAD-bearing waste package should be similar to the defunct 21-PWR waste package. The 21-PWR waste package and the TAD-bearing waste package have different dimensions (Reference 2.2.38 and Reference 2.2.20), but this should have a small effect on the results, as it is expected that they both have similar thermal properties. These differences would have little or no impact on drift rock temperatures (the objective of this calculation). Therefore, using the 21-PWR waste package is justified.

This assumption is used in Section 6.1.

3.1.5 Use of the 12-PWR Waste Package in the ANSYS Computational Model

The 12-PWR waste package, with dimensions indicated in Reference 2.2.19, is included in the ANSYS computational model.

Rationale: This does not reflect the current design. However, a long TAD-bearing waste package is being considered for the future, with thermal loading similar to the 12-PWR waste package. There currently is no information available for the long TAD-bearing waste package. It is expected that, when compared to a 12-PWR waste package, a long TAD-bearing waste package will have slight dimensional changes, but will have similar properties. These differences would have little or no impact on drift rock temperatures (the objective of this calculation). Therefore, using the 12-PWR waste package is justified.

This assumption is used in Section 6.1.

3.1.6 Use of the 44-BWR Waste Package in the ANSYS Computational Model

The 44-BWR waste package, with dimensions indicated in Reference 2.2.21, is included in the ANSYS computational model.

Rationale: The current design incorporates a TAD-bearing waste package capable of holding 44 spent fuel assemblies from a BWR (Reference 2.2.37, Section 3.8.1). Hence, the thermal loading of a 44-BWR TAD-bearing waste package should be similar to the defunct 44-BWR waste package. The 44-BWR waste package and the TAD-bearing waste package have different dimensions (Reference 2.2.38 and Reference 2.2.21), but this should have a small effect on the results, as it is expected that they both have similar thermal properties. These differences would have little or no impact on drift rock temperatures (the objective of this calculation). Therefore, using the 44-BWR waste package is justified.

This assumption is used in Section 6.1.

3.1.7 Dimensions of the 5 DHLW-Long Waste Package

The length of the 5 DHLW-Long waste package, minus the lid lifting feature on the outer corrosion barrier lid, is assumed to be 5.03398 m.

Rationale: While this does not reflect the current design (Reference 2.2.17), this is the design used in the ANSYS computational model taken from Case 14 of Reference 2.2.16 (see Assumption 3.1.15), which is used in this calculation. The current design includes a shield plug and omits the middle lid (both of which, do not contribute to heat generation within the waste package), resulting in an overall increase in the length of the waste package. Using the shorter length that was used in Reference 2.2.16 allows the heat-generating sections of each waste package to be placed closer together in the ANSYS computational model. This results in slightly higher peak drift rock temperatures (the objective of this calculation), and, therefore, is conservative. This is acceptable, since the temperatures the waste packages are not of interest in this calculation.

This assumption is used in Section 6.1.

3.1.8 Dimensions of the 5 DHLW-Short Waste Package

The length of the 5 DHLW-Short waste package, minus the lid lifting feature on the outer corrosion barrier lid, is assumed to be 3.42743 m.

Rationale: While this does not reflect the current design (Reference 2.2.18), this is the design used in the ANSYS computational model taken from Case 14 of Reference 2.2.16 (see Assumption 3.1.15), which is used in this calculation. The current design includes a shield plug and omits the middle lid (both of which, do not contribute to heat generation within the waste package), resulting in an overall increase in the length of the waste package. Using the shorter length that was used in Reference 2.2.16 allows the heat-generating sections of each waste package to be placed closer together in the ANSYS computational model. This results in slightly higher peak drift rock temperatures (the objective of this calculation), and, therefore, is conservative. This is acceptable, since the temperatures the waste packages are not of interest in this calculation.

This assumption is used in Section 6.1.

3.1.9 Materials and Dimensions of the Drift Invert

It is assumed that the drift invert is constructed with two layers of materials. The bottom region is composed of only ballast material (crushed tuff), and the top region is composed of W12 x 72 steel beams (A 588 CS) and ballast material occupying all spaces within the steel beams. Furthermore, the ballast material is filled to the top of the steel beams, giving the drift invert a total height of 0.8636 m (34 in.) from the bottom of the drift.

Rationale: While this does not reflect the current design (Reference 2.2.9), this is the design used in the ANSYS computational model taken from Case 14 of Reference 2.2.16 (see Assumption 3.1.15), which is used in this calculation. The current design has similar construction with an increase in total invert height of 18 in.

The surface area of the drift and invert participating in heat exchange with the waste packages in the ANSYS model is approximately 1012 m^2. By contrast, if the dimensions of the current invert design were used, the surface area of the drift and invert participating in heat exchange with the waste packages would be 985 m^2. This represents a difference of only 2.8% (see Attachment III, file: *affected drift area.xmcd* for calculation). Taking into account the fourth-power temperature difference that governs radiation heat transfer, this difference is negligible.

This assumption is used in Sections 6.1 and 6.2.2.

3.1.10 Waste Package Emplacement Heights

The waste package emplacement heights are assumed to be those given in Reference 2.2.7.

Rationale: This is the best information currently available. The information given in Reference 2.2.7 does not reflect the current design. Reference 2.2.7 does not indicate emplacement heights for TAD-bearing waste packages. The outer diameter of a TAD-bearing waste package is 1.8816 m, which is larger than the outer diameters of the 12-PWR, 21-PWR and 44-BWR waste packages (see Table 3). Consequently, a TAD-bearing waste package would sit higher on the emplacement pallet (and, therefore, further away from the invert) than the 12-PWR, 21-PWR and 44-BWR waste packages. Since the emplacement pallets are not modeled (see Assumption 3.2.5), this assumption is conservative.

This assumption is used in Section 6.1.

3.1.11 Thermal Properties of Alluvium and Crystal-Rich Tiva/Post-Tiva

The thermal conductivity of Alluvium is assumed to be the same as the thermal conductivity of Crystal-Rich Tiva/Post-Tiva. Also, the specific heat of Alluvium and Crystal-Rich Tiva/Post-Tiva are assumed to be the same as the specific heat of the Tpcp layer.

Rationale: The thermal conductivity of Alluvium and the specific heat of Alluvium and Crystal-Rich Tiva/Post-Tiva are not currently available. Since the Alluvium and Crystal-Rich Tiva/Post-Tiva layers are at the top of the rock pillar, far from the region of interest, the impact of this assumption is anticipated to be negligible.

This assumption is used in Section 6.2.1.

3.1.12 Initial Waste Package Surface Temperature

The initial temperature of each waste package shell is assumed to be 183.5 °C

Rationale: Reference 2.2.10 (Table 3, Condition 1) gives a peak surface temperature of a 21-PWR waste package in an older design of the waste package transporter of 183.5 °C. While the calculations in Reference 2.2.10 do not reflect the current design, a thermal evaluation of a waste package in the transporter has not yet been performed for the current design. The waste package surface temperature inside the transporter is dependent on waste package type, conditions in the transporter, and time spent in the transporter. However, the calculations in Reference 2.2.10 were performed under steady-state conditions, using a limiting heat load of 11.8 kW, and, therefore, should provide bounding results for waste package surface temperature. This is the best information currently available.

This assumption is used in Section 6.3.

3.1.13 Effective Thermal Conductivity and Specific Heat of the Waste Packages

It is assumed that the effective thermal conductivity and specific heat of the homogeneous internal cylinders are the same as the values listed in Table 14 and Table 15, and are the same for all waste packages considered.

Rationale: These values were calculated in Reference 2.2.16 (see Assumption 3.1.15), based on the 21-PWR waste package, which no longer reflects the current design. The current design omits the middle lid of the waste package and adds a shield plug for all commercial SNF as part of either the canister or waste package (Reference 2.2.14, Section 11.2.1.4). Because the thermal capacitance of the loaded waste packages is small compared to that of the surrounding rock mass, it is anticipated that this will have little or no effect on drift rock temperatures (the objective of this calculation). It is not the intention of this calculation to evaluate waste package internal temperatures; therefore, these approximations are acceptable.

This assumption is used in Section 6.2.3.

3.1.14 Effective Densities of Waste Packages

It is assumed that the effective densities of the waste package internal homogeneous cylinders are the same as those listed in Table 16.

Rationale: While these values may not reflect the current design, these are the values used in the ANSYS computational model taken from Case 14 of Reference 2.2.16 (see Assumption 3.1.15), which is used in this calculation. Because the thermal capacitance of the loaded waste packages is small compared to that of the surrounding rock mass, it is anticipated that this will have little or no effect on drift rock temperatures (the objective of this calculation). It is not the intention of this calculation to evaluate waste package internal temperatures; therefore, these approximations are acceptable.

This assumption is used in Section 6.2.3.

3.1.15 Use of Pre-Existing ANSYS Computational Model

The ANSYS representation used in this calculation is the same as that described in Table 46 of Reference 2.2.16 (Case 14), repeated below in Table 1 for convenience.

Table 1. 12 WP calc Case 14 Waste Package Emplacement Order, Initial Heat, and Length

Position	WP #	WP Type	Initial Heat (kW)	Length (m)
1	WP12	21-PWR (half)	5.9	2.4607
2	WP11	5 DHLW-Long	0.407	5.0340
3	WP10	44-BWR	7.38	4.9990
4	WP5	44-BWR	7.38	4.9990
5	WP4	21-PWR	11.8	4.9990
6	WP2	21-PWR	11.8	4.9990
7	WP1	21-PWR	11.8	4.9990
8	WP3	21-PWR	11.8	4.9990
9	WP6	12-PWR	9.55	5.5350
10	WP7	44-BWR	5.954	4.9990
11	WP8	5 DHLW-Short	2.93	3.4274
12	WP9	5 DHLW-Long	0.407	5.0340
13	WP13	5 DHLW-Long (half)	0.2035	2.5559

Rationale: The configuration described in Table 1 does not reflect the current design. However, the purpose of this calculation is to determine the thermal response of the drift wall and near-vicinity rock temperatures via a parametric study. To do this, the linear heat load in the drift is varied by adjusting the initial heat outputs of the individual waste packages. The configuration of Case 14 of Reference 2.2.16 is such that waste package spacing is minimized, and higher waste package heat loads are concentrated in the center of the modeled drift segment, thus providing conservative results.

Since only the drift rock temperatures are of interest in this calculation (i.e., temperatures the waste packages are not of interest in this calculation), the available model suitable for the intended purpose.

This assumption is used in Sections 3.1.7, 3.1.8, 3.1.9, 3.1.13, 3.1.14, 6.1, and 6.5.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Representation of Emplacement Drift Segment and Emplaced Waste Packages

A "pillar" representation of the emplacement drift segment and emplaced waste packages will be assumed for the thermal calculation. This approach includes the following implicit assumptions. The average heat output of the segment is assumed to represent the average heat output over the entire repository horizon. The repository horizon is assumed to be infinite such that heat losses at the sides of the repository emplacement area (edge effects) are neglected.

Rationale: It is not possible to adequately represent all waste packages in the repository; thus, only a selected section is represented with the necessary detail around the waste packages. This assumption corresponds to Section 5.3.1.1 of Reference 2.3.4.

This assumption is used in Sections 6.1 and 6.3.

3.2.2 Rock Stratigraphy

The rock stratigraphy throughout the repository is assumed to be the same as that identified at the G-1 Borehole.

Rationale: The G-1 Borehole is used, since it is located near the center of the hottest portion of the repository (Reference 2.2.6, Figure II-4). The G-1 Borehole is also one of the deepest boreholes, starting at an elevation of 1326 m (4351 ft) (Reference 2.2.31, file: */Data_Grids_Faults/data/contacts00el.dat*), and extending to a depth of 1085 m (3558 ft). DTN: MO0012MWDGFM02.002 (Reference 2.2.31) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

This assumption is used in Sections 6.1 and 6.2.1.

3.2.3 Water Movement in the Rock

The effects of water movement (fluid flow) in the rock units (layers) on temperatures at the waste package and near-field are minor, such that the system can be approximated by a representation that considers conduction, convection, and radiation heat transfer only.

Rationale: While "conduction-only" codes cannot predict water movement or humidity, they do provide conservative estimates of the peak temperatures. The differences in wet vs. dry rock properties, as well as the heat of vaporization of water in the rock, are accounted for as shown in Section 6.2.1. This corresponds to Section 5.3.1.2 of Reference 2.3.4.

This assumption is used in Sections 6.1 and 6.2.1.

3.2.4 Initial Thermal Gradient in the Rock

The initial thermal gradient in the rock (before waste emplacement) is assumed to extend to the maximum depth of the ANSYS representation (1085 m).

Rationale: Since the variation in thermal conductivity of the rock layers is small (see Table 5), and since the heat flux across layers is constant, it is reasonable to assume that this initial, thermal gradient extends to the maximum depth of the ANSYS representation (1085 m).

This assumption is used in Section 6.3.

3.2.5 Emplacement Pallets Are Neglected

Conductive heat transfer between the waste packages and the emplacement pallets, and hence through the pallets into the invert, is neglected.

Rationale: Simplifying assumptions are needed in order to represent the geometry to a reasonable amount of detail. The waste package supports have point contact with the waste package in only a few places. Therefore, conduction through the support structure will be limited and can be conservatively neglected. This corresponds to Section 5.3.1.6 of Reference 2.3.4.

This assumption is used in Section 6.1.

3.2.6 Waste Package Representations

The waste packages emplaced in the drift are simulated as homogeneous cylinders with a single-material shell, which represents the outer corrosion barrier.

Rationale: Since the waste package internal temperatures are not of interest in this calculation, smeared material properties for the homogeneous cylinder are applied in the ANSYS representations (see Section 6.2.3). In order to simulate axial heat conduction in the waste package, the single-material shell with effective material properties is added to properly distribute the heat flow along its length.

This assumption is used in Sections 6.1 and 6.2.3.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). The emplacement drifts are classified as Safety Category items (important to safety and important to waste isolation) on the *Q-list* (Reference 2.3.2, Table A-1, p. A-11). Therefore, this document is subject to the requirements of the *Quality Management Directive* (Reference 2.1.3, Sections 2.1.C.1.1.a.i and 17.E), and the approved version is designated as QA: QA.

4.2 USE OF SOFTWARE

The finite element computer code used for this calculation is ANSYS V8.0 (Reference 2.3.1), which is identified by the Software Tracking number 10364-8.0-00. Usage of ANSYS V8.0 in this calculation constitutes Level 1 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 12). ANSYS V8.0 is qualified, baselined, and listed in the current *Qualified and Controlled Software Report*, as well as the *Repository Project Management Automation Plan* (Reference 2.3.5, Table 6-1).

Calculations using the ANSYS V8.0 software were executed on the following Hewlett-Packard (HP) 9000 Series workstations running operating system HP-UX 11.00:

Central Processing Unit (CPU) Name: Milo, Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) Tag Number: 151665

CPU Name: Opus, CRWMS M&O Tag Number: 151664

CPU Name: Rosebud, CRWMS M&O Tag Number: 150689

CPU Name: Hodge, CRWMS M&O Tag Number: 150690

CPU Name: Oliver, CRWMS M&O Tag Number: 150688

The ANSYS V8.0 evaluations performed in this calculation are fully within the range of the validation performed for ANSYS V8.0 (Reference 2.3.3). Therefore, ANSYS V8.0 is appropriate for the thermal analysis as performed in this calculation. Access to, and use of, the code for this calculation was granted by Software Configuration Management in accordance with the appropriate procedures. The details of the ANSYS analyses are described in Section 6 and the results are presented in Section 7 of this calculation.

TrueGrid version 2.2.0 is used for creating the computational meshes used in the ANSYS representations. Usage of TrueGrid version 2.2.0 in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 12). TrueGrid version 2.2.0 is listed in the current *Controlled Software Report*, as well as the *Repository Project Management Automation Plan* (Reference 2.3.5, Table 6-1).

TrueGrid version 2.2.0 was executed on the following Hewlett-Packard (HP) 9000 Series workstation running operating system HP-UX 11.00:

CPU Name: Milo, CRWMS M&O Tag Number: 151665

The meshes are verified by visual inspection.

Microsoft Excel 2000 (9.0.6926 SP-3), which is a component of Microsoft Office 2000, is used for performing simple calculations and plotting results in Section 7. Usage of Microsoft Office in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 12). Microsoft Office 2000 is listed in the current *Controlled Software Report*, as well as the *Repository Project Management Automation Plan* (Reference 2.3.5, Table 6-1).

Microsoft Excel 2000 SP-3 was executed on a PC running the Microsoft Windows 2000 SP-4 operating system. The results are confirmed by visual inspection.

Mathcad version 13.0 is used for the calculation of surface areas in Attachment III. Usage of Mathcad version 13.0 in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 12). Mathcad version 13.0 is listed in the current *Controlled Software Report*, as well as the *Repository Project Management Automation Plan* (Reference 2.3.5, Table 6-1).

Mathcad version 13.0 was executed on a PC running the Microsoft Windows 2000 SP-4 operating system. The results are confirmed by visual inspection.

All inputs and outputs are located in Attachment III.

4.3 METHOD

Finite Element Analysis (FEA) numerical solutions are performed using the commercially available code ANSYS V8.0 (Reference 2.3.1). Three-dimensional (3-D) representations of the waste packages emplaced in the drift are used to determine the canister surface temperatures and drift wall temperatures. Some minor calculations are performed by hand in order to provide some of the inputs to the ANSYS representations.

5. LIST OF ATTACHMENTS

Table 2. List of Attachments

Attachment	Description	Number of Pages
I	Interoffice Memorandum No. 0205035938 Note: The secondary references listed in Interoffice Memorandum No. 0205035938 are not used in this calculation.	7
II	File Listing for Attachment III	8
III	One (1) Compact Disc (CD)	N/A
IV	Supplemental Results For Case 4c	7

6. BODY OF CALCULATION

The method used for calculating the repository near field and waste package surface temperatures includes two steps:

During the pre-closure ventilation period of 50 years (Reference 2.2.14, Section 22.2.1.8), a transient solution of the 3-D, full-pillar, repository segment representation with multiple waste packages emplaced is obtained using time-dependent waste package heat loads. Ventilation is accounted for using convective boundary conditions within the drift. Waste package end-to-end spacing is 0.1 meter (Reference 2.2.14, Section 8.2.1.7).

The following sections describe the details of the ANSYS representation development, boundary conditions, and parameters used in the calculation.

6.1 MODEL GEOMETRY

The 3-D waste package emplacement repository is represented as a pillar of rock (Assumption 3.2.1). The overall dimensions of the repository representation starts from the upper boundary of the ground surface at the G-1 Borehole, at an elevation of 1326m (4351 ft) (Reference 2.2.31, file: */Data_Grids_Faults/data/contacts00el.dat*), and extends to the lower boundary, a depth of 1085 m (3560 ft) (Assumption 3.2.2). Note that DTN: MO0012MWDGFM02.002 (Reference 2.2.31) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

The length of the pillar model is calculated based on waste package spacing and the individual waste package lengths to be emplaced in the repository. The width of the model is taken as the drift spacing, 81 meters (Reference 2.2.14, Section 8.2.1.8). The effect of water movement in the rock units is ignored, therefore only conduction is considered in the rock (Assumption 3.2.3).

The multiple waste package representation includes a mixture of twelve waste packages in the drift. There are actually 11 full waste packages and 2 half-waste packages modeled. The two half waste packages (WP12 and WP13) are modeled such that half of the fuel region is represented. The selection of the mixture is described in Section 6.1 of Reference 2.2.16, and the specific waste package emplacement order is the same as Case 14 of Reference 2.2.16 (Assumption 3.1.15).

The outer dimensions of the waste packages used are given in Table 3 (see Assumptions 3.1.4 through 3.1.8). Since the temperature details internal to the waste package are not required for this calculation, each waste package is assumed to be a homogeneous heat-generating cylinder, encased in a metal shell layer, which represents the outer corrosion barrier (Assumption 3.2.6). The waste package supports are not represented in the drift, so that the conduction paths through the waste package supports are neglected (Assumption 3.2.5).

Table 3 lists the relevant dimensions and vertical emplacement heights (defined as the distance between waste package center and top of the invert) (Assumption 3.1.10 and Reference 2.2.7) of the waste packages considered. Dimensions of the 21-PWR waste package are taken from

Reference 2.2.20. Dimensions of the 12-PWR waste package are taken from Reference 2.2.19. Dimensions of the 44-BWR waste package are taken from Reference 2.2.21. Dimensions of the 5-DHLW Long waste package are taken from Reference 2.2.17 and Assumption 3.1.7. Dimensions of the 5-DHLW Short waste package are taken from Reference 2.2.18 and Assumption 3.1.8.

Table 3. Modeled Waste Package Dimensions and Vertical Emplacement Locations

Waste Package Type	Diameter (m)	Length (m)	Emplacement Height (m)
21-PWR	1.637	4.9990	1.0509
12-PWR	1.3132	5.5350	0.8867
44-BWR	1.6751	4.9990	1.0728
5 DHLW-Long	2.04470	5.03398	1.2861
5 DHLW-Short	2.04470	3.42743	1.2861

The top layer of the two-layer drift invert has a depth equal to the depth of a W12 x 72 beam (Assumption 3.1.9). Page 1-28 of Reference 2.2.1 lists the depth of a W12 x 72 beam as 12.25 inches (0.3112 m). The ballast material is filled to the top of the steel beams, giving the drift invert a total height of 0.8636 m (34 in.) from the bottom of the drift (Assumption 3.1.9).

Figure 1 shows the ANSYS representation of the rock pillar. Figure 2 shows the location of the drift within the ANSYS pillar model. Figure 3 is a cutaway view of the pillar model, showing the locations of the emplaced waste packages.

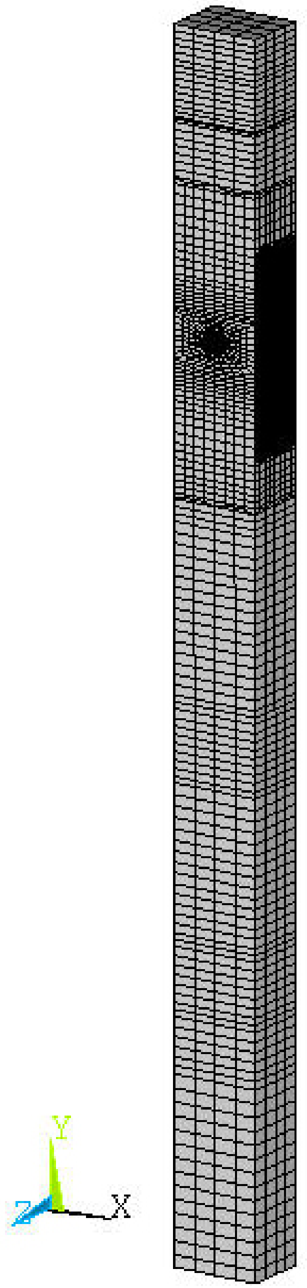

Figure 1. Rock Pillar As Modeled in ANSYS

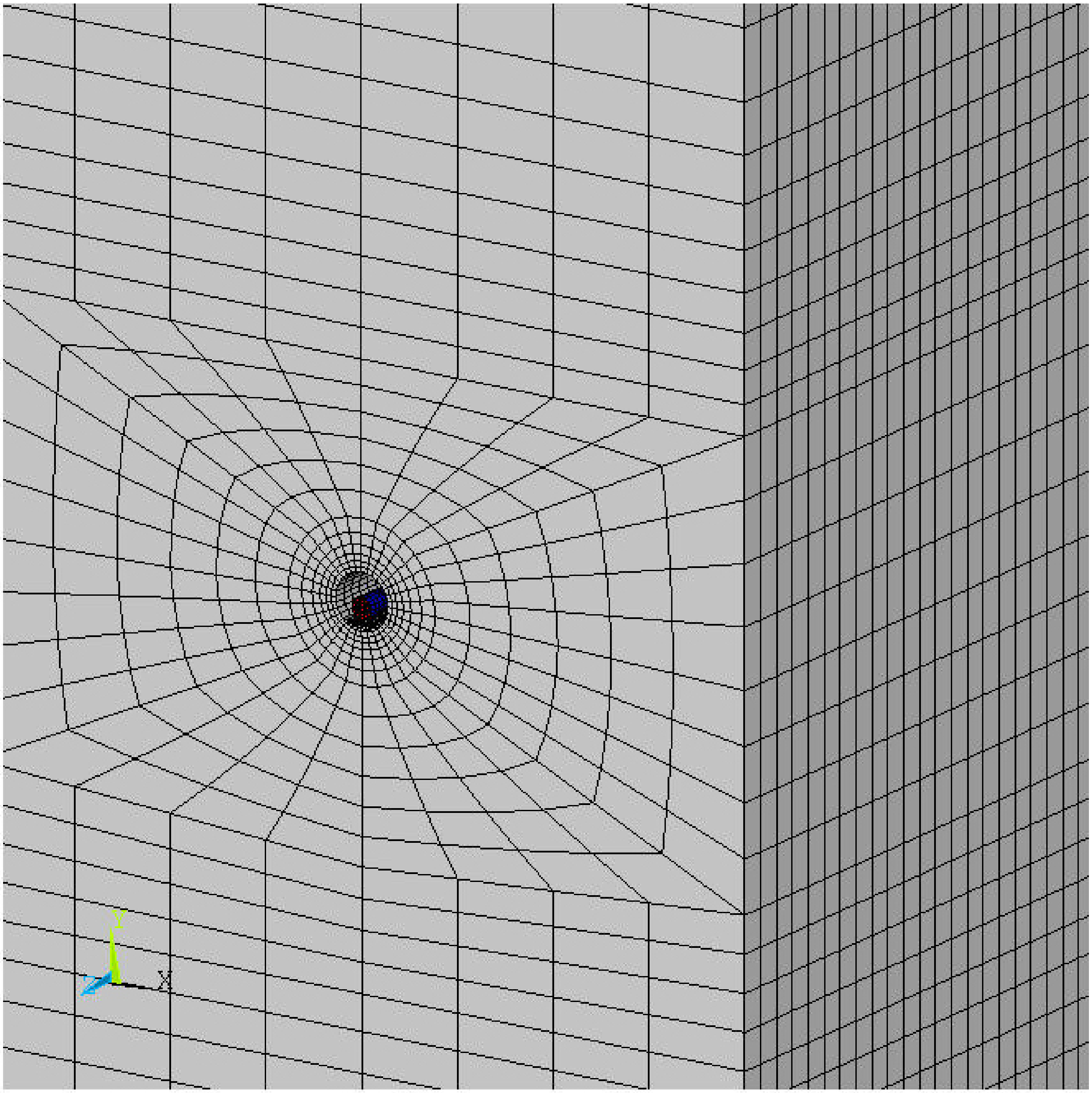

Figure 2. Location of Drift in Pillar Model

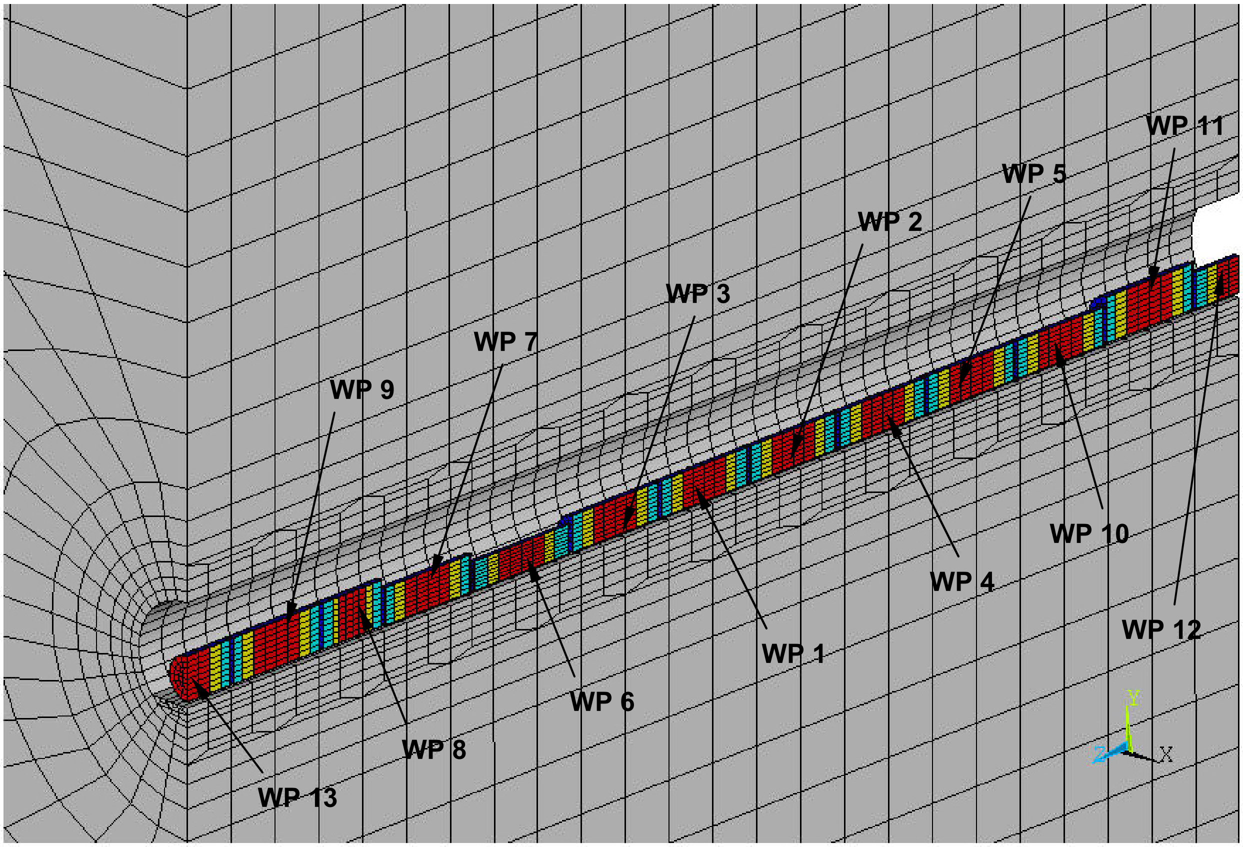

Figure 3. Cutaway View of Drift Model Showing Waste Package Emplacement Order

6.2 THERMAL PROPERTIES

6.2.1 Rock Pillar Thermal Properties

Yucca Mountain is composed of a layered rock stratigraphy. The rock units are distinguished by their physical properties noted in Table 4 through Table 6. The values in Table 4 are derived in Attachment III, file: *rock layer thicknesses.xls* and are based on G-1 Borehole data (Reference 2.2.31, file: */Data_Grids_Faults/data/ contacts00el.dat*) (Assumption 3.2.2). Note that DTN: MO0012MWDGFM02.002 (Reference 2.2.31) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation. The correlation between the abbreviations and geologic framework model unit names is given in Reference 2.2.8, Table 6-2.

Comparing Figures II-4 and III-1 of Reference 2.2.6, it can be seen that the G-1 Borehole is located closest to drift 3-15W. Page III-5 of Reference 2.2.6 gives the elevation of drift 3-15W as 1055.22 m (3462 ft).

Table 5 summarizes the density and thermal conductivity at several temperatures of the rock layers. The absence of liquid water above the boiling point is accounted for by the abrupt drop in thermal conductivity at this temperature (Assumption 3.2.3).

Values of density and thermal conductivity for the non-repository layers (non-shaded rows in Table 5) are taken from Reference 2.2.33. DTN: SN0303T0503102.008 (Reference 2.2.33) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

Values of density and thermal conductivity for the repository layers (shaded rows in Table 5) are taken from Reference 2.2.35, file: *SN0404T0503102.011ReadMe.doc*, p.1. DTN: SN0404T0503102.011 (Reference 2.2.35) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

Table 6 summarizes the specific heat of the rock layers at several temperatures. The abrupt rise and fall of specific heat around the boiling point of water accounts for the energy required by the water in the rock to change phase (Assumption 3.2.3). Values of specific heat are taken from Reference 2.2.34. DTN: SN0307T0510902.003 (Reference 2.2.34) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

An emissivity value of 0.92 is used for the drift wall in the Tptpll layer. This value is taken from Reference 2.2.28, Table A.8 (average value for rock).

Table 4. Rock Layer Thicknesses (Based on G-1 Borehole data)

Abbreviation	**Geologic Framework Model Unit**	**Thickness (ft)**	**Thickness (m)**
QaBase	Alluvium	60	18.3
Qa		0	0.0
Tmr	Crystal-Rich Tiva/Post-Tiva	0	0.0
Tpk		0	0.0
Tpc_un	Tpcp [a]	0	0.0
Tpcpv3	Tpcpv3	0	0.0
Tpcpv2	Tpcpv2	0	0.0
Tpcpv1	Tpcpv1	0	0.0
Tpbt4	Tpbt4	0	0.0
Tpy	Yucca	42	12.8
Tpbt3	Tpbt3_dc	33	10.1
Tpp	Pah	100	30.5
Tpbt2	Tpbt2	30	9.1
Tptrv3	Tptrv3	0	0.0
Tptrv2	Tptrv2	5	1.5
Tptrv1	Tptrv1	10	3.0

Tptrn	Tptrn	158	48.2
Tptrl	Tptrl	19	5.8
Tptf	Tptf	0	0.0
Tptpul	Tptpul	144	43.9
RHH	RHHtop	113	34.4
Tptpmn	Tptpmn	101	30.8
Tptpll	Tptpll	384	117.0
Tptpln	Tptpln	88	26.8
Tptpv3	Tptpv3	55	16.8
Tptpv2	Tptpv2	18	5.5
Tptpv1	Tptpv1	43	13.1
Tpbt1	Tpbt1	22	6.7
Tac	Calico	311	94.8
Tacbt	Calicobt	63	19.2
Tcpuv	Prowuv	64	19.5
Tcpuc	Prowuc	58	17.7
Tcpm	Prowmd	40	12.2
Tcplc	Prowlc	26	7.9
Tcplv	Prowlv	169	51.5
Tcpbt	Prowbt	18	5.5
Tcbuv	Bullfroguv	164	50.0
Tcbuc	Bullfroguc	124	37.8
Tcbm	Bullfrogmd	86	26.2
Tcblc	Bullfroglc	0	0.0
Tcblv	Bullfroglv	55	16.8
Tcbbt	Bullfrogbt	38	11.6
Tctuv	Tramuv	161	49.1
Tctuc	Tramuc	40	12.2
Tctm	Trammd	116	35.4
Tctlc	Tramlc	49	14.9
Tctlv	Tramlv	517	157.6
Tctbt	Trambt	36	11.0

(a) Reference 2.2.31, indicates that the Tpc_un layer lies above the Tpcpv3 layer, either within the Tpcp layer or the Crystal-Rich Tiva/Post-Tiva layer, which have the same thermal properties (See Assumption 3.1.11). DTN: MO0012MWDGFM02.002 (Reference 2.2.31) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

Table 5. Density and Thermal Conductivity of the Rock Layers

Abbreviation	Geologic Framework Model Unit	Dry Bulk Density (kg/m^3)	Dry Matrix Thermal Conductivity (T < 95 °C) (W/m·K)	Wet Matrix Thermal Conductivity (T ≥ 95 °C) (W/m·K)
QaBase [a]	Alluvium	2190	1.81	1.30
Qa [a]		2190	1.81	1.30
Tmr	Crystal-Rich Tiva/Post-Tiva	2190	1.81	1.30
Tpk		2190	1.81	1.30
Tpc_un	Tpcp	2190	1.81	1.30
Tpcpv3	Tpcpv3	2310	0.80	0.69
Tpcpv2	Tpcpv2	1460	1.06	0.49
Tpcpv1	Tpcpv1	1460	1.06	0.49
Tpbt4	Tpbt4	1460	1.06	0.49
Tpy	Yucca	1460	1.06	0.49
Tpbt3	Tpbt3_dc	1460	1.06	0.49
Tpp	Pah	1460	1.06	0.49
Tpbt2	Tpbt2	1460	1.06	0.49
Tptrv3	Tptrv3	1460	1.06	0.49
Tptrv2	Tptrv2	1460	1.06	0.49
Tptrv1	Tptrv1	2310	0.80	0.69
Tptrn	Tptrn	2190	1.81	1.30
Tptrl	Tptrl	2190	1.81	1.30
Tptf	Tptf	2190	1.81	1.30
Tptpul	Tptpul	1834	1.77	1.18
RHH	RHHtop	1834	1.77	1.18
Tptpmn	Tptpmn	2148	2.07	1.42
Tptpll	Tptpll	1979	1.89	1.28
Tptpln	Tptpln	2211	2.13	1.49
Tptpv3	Tptpv3	2310	0.80	0.69
Tptpv2	Tptpv2	1460	1.06	0.49
Tptpv1	Tptpv1	1460	1.06	0.49
Tpbt1	Tpbt1	1460	1.06	0.49
Tac	Calico	1670	1.26	0.60
Tacbt	Calicobt	1670	1.26	0.60
Tcpuv	Prowuv	1790	1.13	0.57
Tcpuc	Prowuc	1790	1.13	0.57
Tcpm	Prowmd	2070	1.63	1.06
Tcplc	Prowlc	1790	1.13	0.57
Tcplv	Prowlv	1790	1.13	0.57
Tcpbt	Prowbt	1790	1.13	0.57
Tcbuv	Bullfroguv	1880	1.19	0.66
Tcbuc	Bullfroguc	1880	1.19	0.66
Tcbm	Bullfrogmd	2260	1.81	1.30
Tcblc	Bullfroglc	1880	1.19	0.66

Tcblv	Bullfroglv	1880	1.19	0.66
Tcbbt	Bullfrogbt	1880	1.19	0.66
Tctuv	Tramuv	1760	1.10	0.54
Tctuc	Tramuc	1760	1.10	0.54
Tctm	Trammd	2140	1.63	1.06
Tctlc	Tramlc	1760	1.10	0.54
Tctlv	Tramlv	1760	1.10	0.54
Tctbt	Trambt	1760	1.10	0.54

(a) See Assumption 3.1.11.

Table 6. Specific Heat of the Rock Layers

Abbreviation	**Geologic Framework Model Unit**	**Specific Heat (J/kg·K)**		
		T < 95 °C	**95 °C ≤ T ≤ 114 °C**	**T > 114 °C**
QaBase [a]	Alluvium	913	2958	990
Qa [a]		913	2958	990
Tmr [a]	Crystal-Rich Tiva/Post-Tiva	913	2958	990
Tpk [a]		913	2958	990
Tpc_un	Tpcp	913	2958	990
Tpcpv3	Tpcpv3	1245	8393	1000
Tpcpv2	Tpcpv2	1245	8393	1000
Tpcpv1	Tpcpv1	1291	9116	1000
Tpbt4	Tpbt4	1291	9116	1000
Tpy	Yucca	1291	9116	1000
Tpbt3	Tpbt3_dc	1291	9116	1000
Tpp	Pah	1291	9116	1000
Tpbt2	Tpbt2	1291	9116	1000
Tptrv3	Tptrv3	1291	9116	1000
Tptrv2	Tptrv2	1291	9116	1000
Tptrv1	Tptrv1	894	1815	990
Tptrn	Tptrn	891	2740	990
Tptrl	Tptrl	891	2740	990
Tptf	Tptf	891	2740	990
Tptpul	Tptpul	938	3566	990
RHH	RHHtop	938	3566	990
Tptpmn	Tptpmn	908	3043	990
Tptpll	Tptpll	926	3343	990
Tptpln	Tptpln	896	2825	990
Tptpv3	Tptpv3	907	1736	1020
Tptpv2	Tptpv2	1095	5082	1020
Tptpv1	Tptpv1	1245	6438	1120
Tpbt1	Tpbt1	1245	6438	1120
Tac [b]	Calico	1403	9804	1120

Tacbt	Calicobt	1247	7622	1070
Tcpuv	Prowuv	1367	9670	1090
Tcpuc	Prowuc	1043	5423	990
Tcpm	Prowmd	1043	5423	990
Tcplc	Prowlc	1043	5423	990
Tcplv	Prowlv	1293	7208	1150
Tcpbt	Prowbt	1293	7208	1150
Tcbuv	Bullfroguv	1293	7208	1150
Tcbuc	Bullfroguc	946	3703	990
Tcbm	Bullfrogmd	946	3703	990
Tcblc	Bullfroglc	946	3703	990
Tcblv	Bullfroglv	1234	7059	1100
Tcbbt	Bullfrogbt	1234	7059	1100
Tctuv	Tramuv	1234	7059	1100
Tctuc	Tramuc	1328	10830	990
Tctm	Trammd	1328	10830	990
Tctlc	Tramlc	1328	10830	990
Tctlv	Tramlv	1190	8151	990
Tctbt	Trambt	1190	8151	990

(a) See Assumption 3.1.11.
(b) Values are average of Tac1, Tac2, Tac3, and Tac4.

6.2.2 Invert Thermal Properties

The design of the drift invert requires using two layers of materials. The bottom region is composed of only ballast material (crushed tuff). The top region is composed of steel beams (A 588 CS) and ballast material occupying all spaces within the steel beams (Assumption 3.1.9). The material properties for the two-layered invert are listed in Table 7 through Table 10.

Table 7 lists the thermal properties of invert bottom layer. The density and specific heat are taken from Reference 2.2.13, Table 5-4. The thermal conductivity is taken from Reference 2.2.25 (average thermal conductivity for 4-10 crushed tuff). DTN: GS000483351030.003 (Reference 2.2.25) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

Table 8 lists the effective density and emissivity of the invert top layer. The density is taken from Reference 2.2.13, Table 5-7. The emissivity is taken from Reference 2.2.28, Table A.8 (value for sand).

Table 9 lists the effective lateral, vertical, and axial thermal conductivity of the invert top layer taken from Reference 2.2.3, Tables 6-16, 6-8, and 6-24, respectively. The values are interpolated at a thermal conductivity of 0.164 W/m-K (see Table 7). It should be noted that the values given in Reference 2.2.3, Tables 6-16, 6-8, and 6-24, are determined using A 516 CS beams, while Assumption 3.1.9 indicates that the beams are A 588 CS. However, the thermal properties of A

516 CS are identical to A 588 CS (Reference 2.2.2, Section II, Part D, Table TCD (p.662, Material Group B)); therefore, the values in Table 9 are appropriate for this calculation.

Table 10 lists the effective specific heat of the invert top layer, taken from Reference 2.2.13, Table 5-9.

Table 7. Thermal Properties of Invert Bottom Layer

Density (kg/m^3)	Specific Heat (J/kg·K)	Thermal Conductivity (W/m·K)
1750	531.42	0.164

Table 8. Effective Density and Emissivity of the Invert Top Layer

Density (kg/m^3)	Emissivity
1890	0.90

Table 9. Effective Thermal Conductivity of the Invert Top Layer

Temperature (°C)	Thermal Conductivity (W/m·K)		
	Lateral	Vertical	Axial
50	1.701	7.041	1.166
100	1.686	7.126	1.171
150	1.665	7.133	1.169
200	1.639	7.074	1.160
250	1.609	6.964	1.146
300	1.574	6.815	1.127
350	1.537	6.641	1.104

Table 10. Effective Specific Heat of the Invert Top Layer

Temperature		Specific Heat (J/kg·K)
(°F)	(°C)	
70	21.11	523.09
100	37.78	524.65
150	65.56	526.07
200	93.33	526.99
250	121.11	528.52
300	148.89	529.63
350	176.67	530.71
400	204.44	531.54
450	232.22	532.59
500	260.00	533.72
550	287.78	534.38
600	315.56	535.16
650	343.33	536.14
700	371.11	537.20
750	398.89	538.35
800	426.67	539.61
850	454.44	541.04
900	482.22	542.55
950	510.00	543.90
1000	537.78	545.71
1050	565.56	547.73
1100	593.33	549.05

6.2.3 Waste Package Thermal Properties

To simplify the finite element representation, each waste package is modeled as a homogeneous heat-generating cylinder encased in a shell representing the outer corrosion barrier (Assumption 3.2.6). The outer corrosion barrier is composed of Alloy 22 (Reference 2.2.14, Section 11.2.2.10).

Table 11 lists the density and emissivity of Alloy 22. The density is taken from Reference 2.2.2, Section II, Part B, SB-575, Section 7.1. The emissivity is taken from Reference 2.2.29, p. 10-297. Table 12 lists the thermal conductivity of Alloy 22. Table 13 lists the specific heat of Alloy 22. The values of thermal conductivity and specific heat are taken from Reference 2.2.27, p. 13. The information cited in Reference 2.2.27 is data from the vendor of Alloy 22, and, therefore, is suitable for use in this calculation.

Table 11. Density and Emissivity of Alloy 22

Density (kg/m^3)	Emissivity
8690	0.87

Table 12. Thermal Conductivity of Alloy 22

Temperature (°C)	Thermal Conductivity (W/m·K)
48	10.1
100	11.1
200	13.4
300	15.5
400	17.5
500	19.5
600	21.3

Table 13. Specific Heat of Alloy 22

Temperature (°C)	Specific Heat (J/kg·K)
52	414
100	423
200	444
300	460
400	476
500	485
600	514

Table 14 lists the effective thermal conductivity for the waste package internal homogeneous cylinders (Assumption 3.1.13), taken from Reference 2.2.16, Table 26.

Table 14. Effective Thermal Conductivity of Internal Homogeneous Cylinders

Axial Thermal Conductivity (W/m-K)	Radial Thermal Conductivity (W/m-K)
1.4	1.5

Table 15 lists the effective specific heat of the waste package homogeneous inner cylinders (Assumption 3.1.13), taken from Reference 2.2.16, Table 28.

Table 15. Effective Specific Heat of Waste Package Homogeneous Inner Cylinders

Specific Heat (J/kg·K)
438

The effective density of each waste package internal homogeneous cylinder is listed in Table 16 (see Assumption 3.1.14). The effective densities are taken from Reference 2.2.16, Table 29.

Table 16. Effective Density of Internal Homogeneous Cylinders

Waste Package Type	**Effective Density (kg/m^3)**
21-PWR	3655
12-PWR	3599
44-BWR	3511
5 DHLW-LONG	2983
5 DHLW-SHORT	2830

6.3 BOUNDARY CONDITIONS

The 3-D pillar repository segment is represented with planes of symmetry represented by two adiabatic boundaries halfway between the drifts and at the two ends of the segment perpendicular to the drift axis (Assumption 3.2.1).

The thermal representation of the waste package emplacement interfaces with the environment at the top and bottom planes. Constant temperature boundary conditions are applied at the top and bottom to represent the ground surface and the underlying rock as heat sinks. At a depth of 1085 m, the lower boundary is far enough from the heat source and areas of concern, that a constant temperature boundary condition at this location will not significantly affect the repository temperature calculation.

DTN: LL030808623122.036 (Reference 2.2.30, file: */MSTHM_submodel_files / INPUT / main_runs / LDTH / mi / LDTH55 / P2WR5C10-LDTH55-1Dds_mc-mi-01.in*) gives the ground surface temperature as 17°C. DTN: LL030808623122.036 (Reference 2.2.30) is cited in *IED Geotechnical and Thermal Parameters* (Reference 2.2.12), and, therefore, is approved and appropriate for the intended use in this calculation.

Based on the values of rock temperature and depth for the USW SD-12 borehole given in DTN: GS031208312232.003 (Reference 2.2.26, file: *TEMPERATURE.txt*), the initial thermal gradient in the rock (before waste emplacement) is determined to be 0.02 °C/m (see Attachment III, file: *GS031208312232_003_SD-12.xls* for calculation). DTN: GS031208312232.003 (Reference 2.2.26) is cited in *IED Geotechnical and Thermal Parameters II* (Reference 2.2.22), and, therefore, is approved and appropriate for the intended use in this calculation. Based on this gradient and the surface temperature, the rock temperature at the lower boundary of the ANSYS representation (1085 m) is determined to be 39°C (see Assumption 3.2.4). To be conservative, a value of 40°C is used at the lower boundary of the ANSYS representation.

The initial temperature of the waste package shell is set to 183.5°C (see Assumption 3.1.12). This is an initial condition, applied only at the initial time step.

Ventilation during the pre-closure period is simulated via a convective boundary condition applied to the surfaces of the waste packages, drift wall, and invert surface. The convective boundary condition is removed to simulate a loss of ventilation in the drift. Table 2 of Reference 2.2.36 gives the ventilation airflow rate in the drift as 15 m^3/s (Note: the information in Reference 2.2.36 is the best information currently available, and it is attached as Attachment I.). Table 17 lists the heat transfer coefficients used in this calculation, taken from Table 6-5 of Reference 2.2.5, at a volumetric flow rate of 15 m^3/s. The air temperature used is 50°C (122°F) (Reference 2.2.15, Section 4.2.13.5.7).

Table 17. Heat Transfer Coefficients

Surface	**h (W/m^2-K)**
Waste Packages	2.7
Drift Wall	4.4
Invert Surface	1.9

6.4 WASTE PACKAGE HEAT OUTPUT

Table 18 lists the average waste package initial heat outputs. Heat outputs for all waste packages are taken from Table 7 and Table 9 of Reference 2.2.11. The heat output of each 21-PWR waste package (the hottest waste package) is scaled up to achieve an initial maximum value of 11.8 kW (Reference 2.2.14, Section 8.2.1.6).

Table 18. Initial Heats of Modeled Waste Packages

WP Type	Initial Heat (kW)
21-PWR	11.8
12-PWR	9.55
44-BWR	7.38
5 DHLW-Long	0.407
5 DHLW-Short	2.93

For each case considered, the linear heat load in the emplacement drift is determined based on the initial heat loads and lengths of the waste packages modeled. Equation 6 and Figure 4 show an example of linear heat load calculation based on a given waste package emplacement representation.

$$LinearHeatLoad = \frac{\left(\sum_{n=1}^{11} Q_n\right) + \frac{Q_{12}}{2} + \frac{Q_{13}}{2}}{\left(\sum_{n=1}^{11} L_n\right) + \frac{L_{12}}{2} + \frac{L_{13}}{2} + 12 \cdot S} \quad \text{(Equation 6)}$$

where:

Q_n ≡ Heat output of the waste packages (W)
L_n ≡ waste package length (m)
S ≡ waste package end-to-end spacing = 0.1 m (Reference 2.2.14, Section 8.2.1.7)

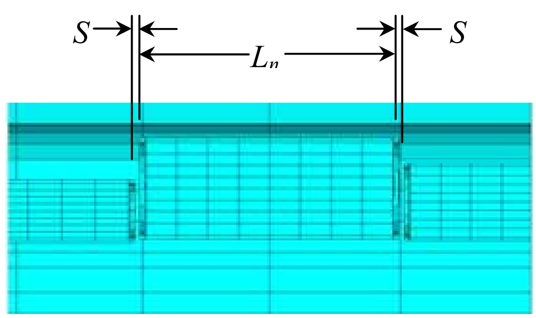

Figure 4. Linear Heat Load Parameters

In each waste package modeled, the homogeneous inner cylinder is divided axially into an active fuel region centered between two non-fuel regions. The heat generation is applied only to the active fuel region. Table 19 lists the active fuel lengths of modeled waste packages.

The active fuel length of the 21-PWR Waste Package is 3.66 m. This is based on the active length of a WE 17 x 17 fuel assembly, given in Reference 2.2.32, p. 64. The active fuel length of the 12-PWR Waste Package is 3.81 m. This is based on the active length of a CE 16 x 16 fuel assembly, given in Reference 2.2.32, p. 67. The active fuel length of the 44-BWR Waste Package is 3.81 m. This is based on the active length of a GE BWR 4-6 fuel assembly, given in Reference 2.2.32, p. 44. The active fuel length of the 5 DHLW/DOE-Short Waste Package is assumed to be 2.28 m (Assumption 3.1.1). The active fuel length of the 5 DHLW/DOE-Long Waste Package is assumed to be 3.89 m (Assumption 3.1.2).

Table 19. Active Fuel Lengths of Modeled Waste Packages

Waste Package Type	**Active Fuel Length (m)**
21-PWR	3.66
12-PWR	3.81
44-BWR	3.81
5 DHLW-Long	3.89
5 DHLW-Short	2.28

The active length section is further divided into three sections, to which, appropriate axial peaking factors (APFs) are applied to the heat load. Page 3-26 of Reference 2.2.24 gives the axial peaking factor of a PWR fuel assembly as 1.25. Page 3-26 of Reference 2.2.24 also indicates that the peaking factor covers approximately the center 2/3 of the PWR assembly. Page 48 of Reference 2.2.4 gives the axial peaking factor of a BWR fuel assembly as 1.4. It is assumed that this peaking is applied to the center 2/3 of the BWR fuel (Assumption 3.1.3). There is no axial peaking factor applied to DHLW.

In order to conserve the total heat load across the active fuel length, the axial peaking factors for the ends (comprising a total of 1/3 of the active fuel length) are determined using the Equation 7, and the results are listed in Table 20:

$$\frac{2}{3}\left(APF_{CENTER}\right)+\frac{1}{3}\left(APF_{ENDS}\right)=1 \qquad \text{(Equation 7)}$$

In Equation 7, APF_{CENTER} is the axial peaking factor in the center section of the fuel assembly, and APF_{ENDS} is the axial peaking factor on the ends of the fuel assembly.

Table 20. Application of Peaking Factors

Waste Package Type	Active Fuel Length (L)		
	0 < L < 1/6	1/6 ≤ L ≤ 5/6	5/6 < L < 1
21-PWR	0.5	1.25	0.5
12-PWR	0.5	1.25	0.5
44-BWR	0.2	1.4	0.2
5 DHLW-Long	1.0	1.0	1.0
5 DHLW-Short	1.0	1.0	1.0

6.5 CALCULATION CASES

The configuration used in all cases of this calculation is the same as Case 14 of Reference 2.2.16 (Assumption 3.1.15). All cases have axial peaking factors indicated in Table 20.

The variables in each case are the linear heat load in the drift, the peak waste package heat output, and the time at loss of ventilation. There are four cases, each having different thermal parameters. Each of those four cases is subdivided into three sub-cases, with each sub-case having a different specified time when loss of ventilation occurs. The cases considered in this calculation are summarized in Table 21.

Table 21. Calculation Cases

Case		Description		
		Linear Heat Load (kW/m)	**Peak Waste Package Heat Output (kW)**	**Time at Loss of Ventilation (years)**
1	A	1.45	11.8	0.1
	B	1.45	11.8	0.5
	C	1.45	11.8	1
2	A	1.25	11.8	0.1
	B	1.25	11.8	0.5
	C	1.25	11.8	1
3	A	1.75	14	0.1
	B	1.75	14	0.5
	C	1.75	14	1
4	A	2	18	0.1
	B	2	18	0.5
	C	2	18	1

Table 22 through Table 25 provide the waste package emplacement order, initial heat outputs, and lengths modeled. The calculations of linear heat loads can be found in Attachment III, file: *calculation_cases.xls*.

The linear heat load for each case is determined by evaluating Equation 6 with the values listed in Table 22 through Table 25. In each case, the values of initial waste package heat output for all waste packages are adjusted as necessary to give the center waste package (WP1) the peak value listed in Table 21, while maintaining the linear heat load given in Table 21.

Table 22. Case 1 Waste Package Emplacement Order and Initial Heat

Position	WP #	WP Type	Initial Heat (kW)
1	WP12	21-PWR (half)	5.9
2	WP11	5 DHLW-Long	0.407
3	WP10	44-BWR	7.38
4	WP5	44-BWR	7.38
5	WP4	21-PWR	11.8
6	WP2	21-PWR	11.8
7	WP1	21-PWR	11.8
8	WP3	21-PWR	11.8
9	WP6	12-PWR	9.55
10	WP7	44-BWR	5.954
11	WP8	5 DHLW-Short	2.93
12	WP9	5 DHLW-Long	0.407
13	WP13	5 DHLW-Long (half)	0.2035

Table 23. Case 2 Waste Package Emplacement Order and Initial Heat

Position	WP #	WP Type	Initial Heat (kW)
1	WP12	21-PWR (half)	5.9
2	WP11	5 DHLW-Long	0.407
3	WP10	44-BWR	5.2398
4	WP5	44-BWR	5.2398
5	WP4	21-PWR	8.378
6	WP2	21-PWR	11.8
7	WP1	21-PWR	11.8
8	WP3	21-PWR	11.8
9	WP6	12-PWR	6.7805
10	WP7	44-BWR	5.2398
11	WP8	5 DHLW-Short	2.0803
12	WP9	5 DHLW-Long	0.407
13	WP13	5 DHLW-Long (half)	0.2035

Table 24. Case 3 Waste Package Emplacement Order and Initial Heat

Position	WP #	WP Type	Initial Heat (kW)
1	WP12	21-PWR (half)	5.9
2	WP11	5 DHLW-Long	0.407
3	WP10	44-BWR	9.06264
4	WP5	44-BWR	9.06264
5	WP4	21-PWR	14.0
6	WP2	21-PWR	14.0
7	WP1	21-PWR	14.0
8	WP3	21-PWR	14.0
9	WP6	12-PWR	11.7274
10	WP7	44-BWR	9.06264
11	WP8	5 DHLW-Short	3.59804
12	WP9	5 DHLW-Long	0.407
13	WP13	5 DHLW-Long (half)	0.2035

Table 25. Case 4 Waste Package Emplacement Order and Initial Heat

Position	WP #	WP Type	Initial Heat (kW)
1	WP12	21-PWR (half)	5.9
2	WP11	5 DHLW-Long	0.407
3	WP10	44-BWR	9.4833
4	WP5	44-BWR	9.4833
5	WP4	21-PWR	15.163
6	WP2	21-PWR	18
7	WP1	21-PWR	18
8	WP3	21-PWR	18
9	WP6	12-PWR	12.27175
10	WP7	44-BWR	9.4833
11	WP8	5 DHLW-Short	3.76505
12	WP9	5 DHLW-Long	0.407
13	WP13	5 DHLW-Long (half)	0.2035

7. RESULTS AND CONCLUSIONS

The outputs of this calculation are reasonable compared to the inputs, and the results are suitable for the intended use.

While uncertainties have not been quantified, this calculation provides appropriate bounding thermal results for design guidance at this time. Limiting heat loads have been used together with nominal conservative assumptions. Future work may quantify the inherent safety margin.

7.1 CASE 1 RESULTS

Case 1 was run with a linear heat load of 1.45 kW/m and a peak, initial waste package heat output of 11.8 kW. The time at loss of ventilation was 0.1 year, 0.5 year, and 1.0 year for sub-cases A, B, and C, respectively.

Table 26 through Table 28 list the time it takes to reach 177 ºC and 200 ºC on the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface, after a loss of pre-closure ventilation.

Table 26. Case 1 Times to Reach Specified Temperatures on Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 1A	0.1	101	178
Case 1B	0.5	88	163
Case 1C	1.0	86	159

Table 27. Case 1 Times to Reach Specified Temperatures 0.5 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 1A	0.1	225	383
Case 1B	0.5	225	394
Case 1C	1.0	202	342

Table 28. Case 1 Times to Reach Specified Temperatures 1.0 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 1A	0.1	451	659
Case 1B	0.5	443	688
Case 1C	1.0	406	734

Figure 5 and Figure 6 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 1A. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface. Figure 7 shows the thermal gradient through the rock out from the drift wall at times when the drift wall temperature is 177 ºC and 200 ºC for Case 1A.

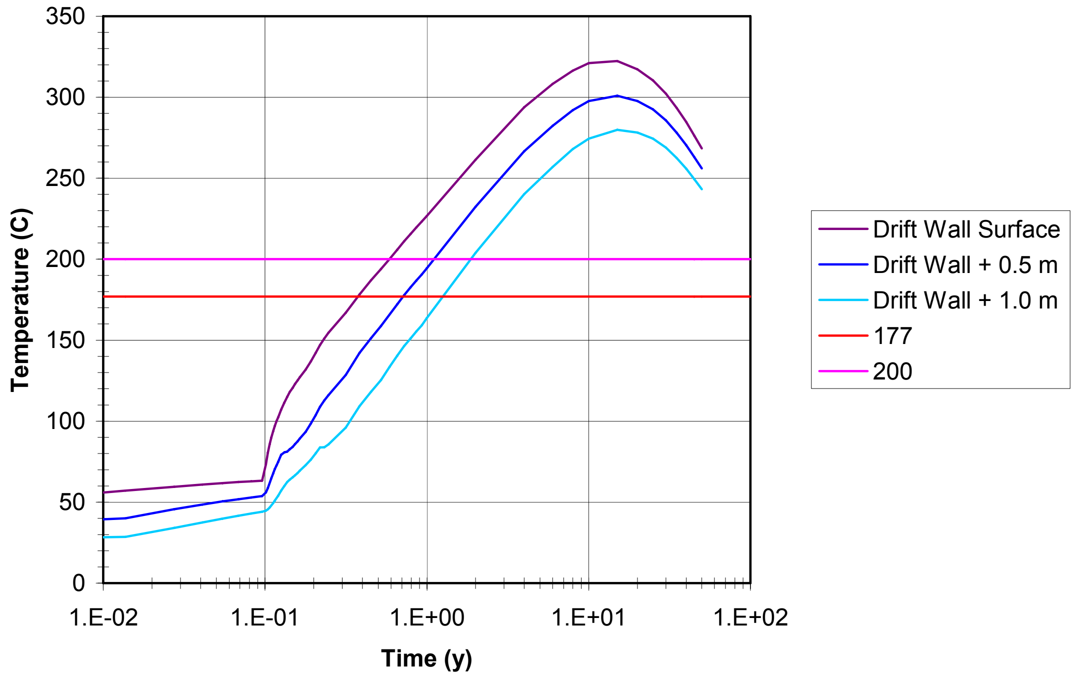

Figure 5. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1A)

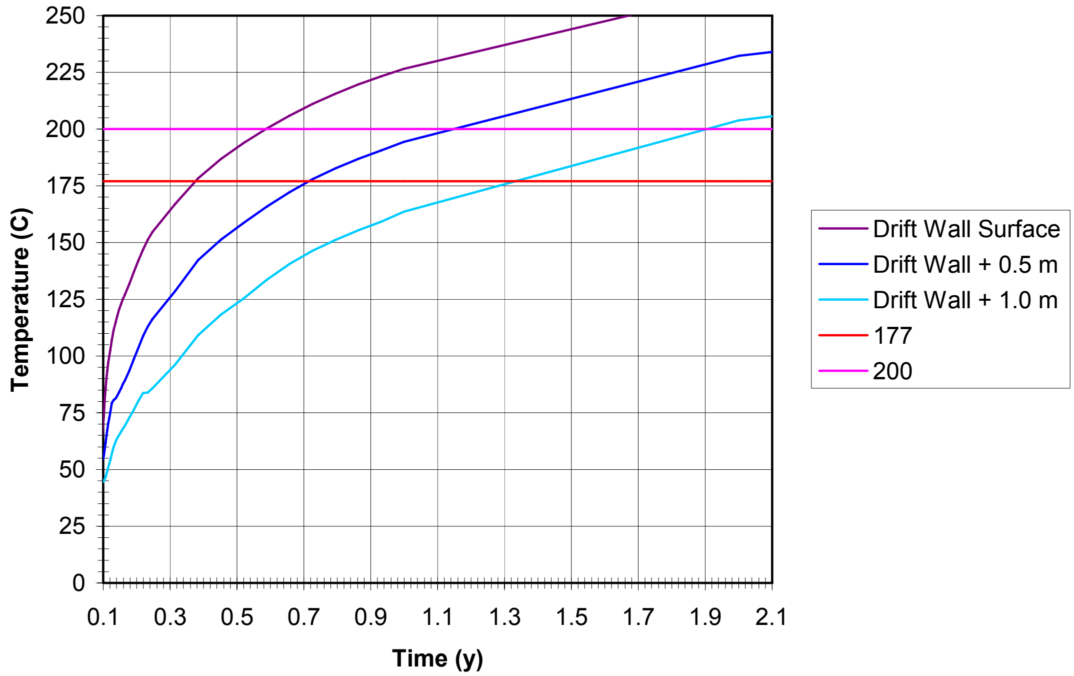

Figure 6. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1A, Close-up)

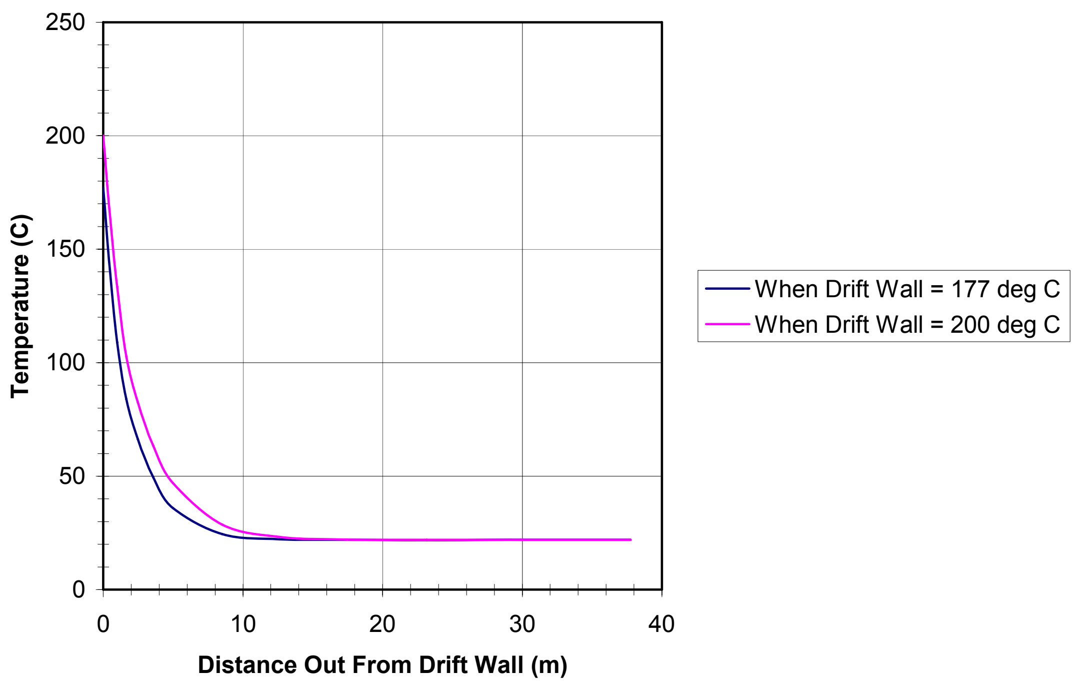

Figure 7. Thermal Gradient Through Rock Out From Drift Wall (Case 1A)

Figure 8 and Figure 9 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 1B. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface. Figure 10 shows the thermal gradient through the rock out from the drift wall at times when the drift wall temperature is 177 ºC and 200 ºC for Case 1B.

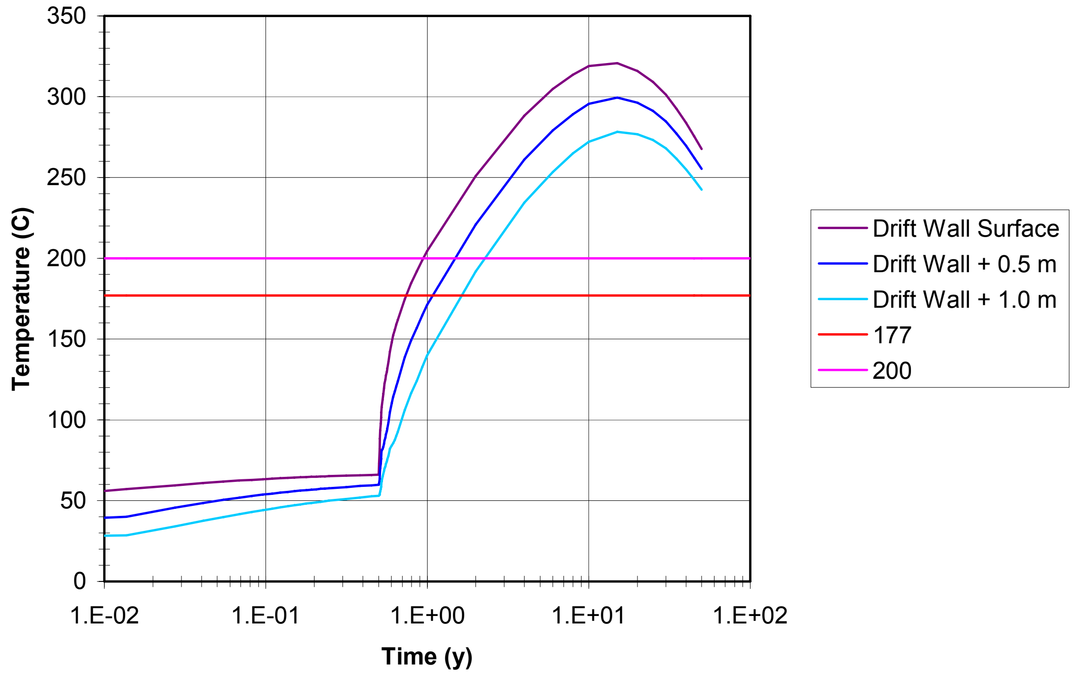

Figure 8. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1B)

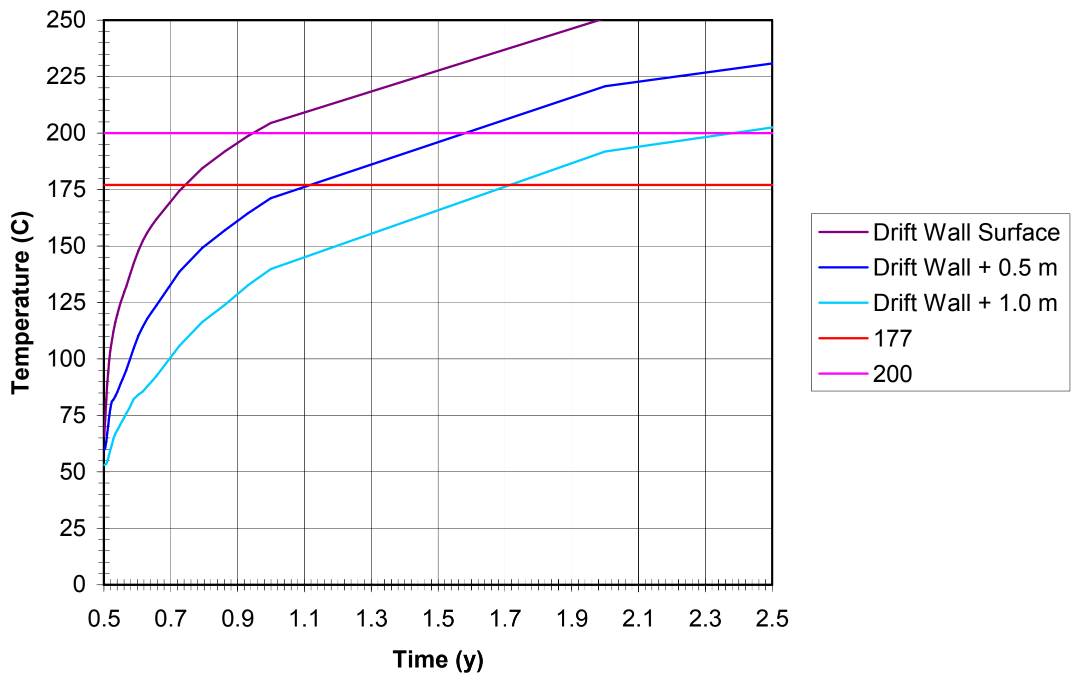

Figure 9. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1B, Close-up)

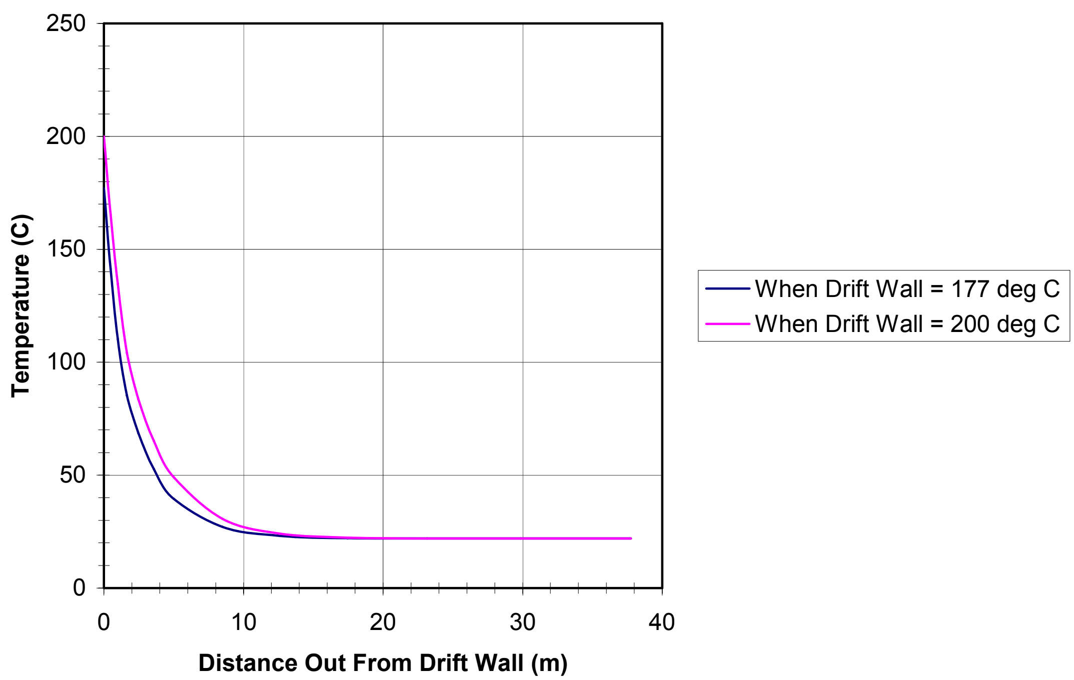

Figure 10. Thermal Gradient Through Rock Out From Drift Wall (Case 1B)

Figure 11 and Figure 12 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 1C. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface. Figure 13 shows the thermal gradient through the rock out from the drift wall at times when the drift wall temperature is 177 ºC and 200 ºC for Case 1C.

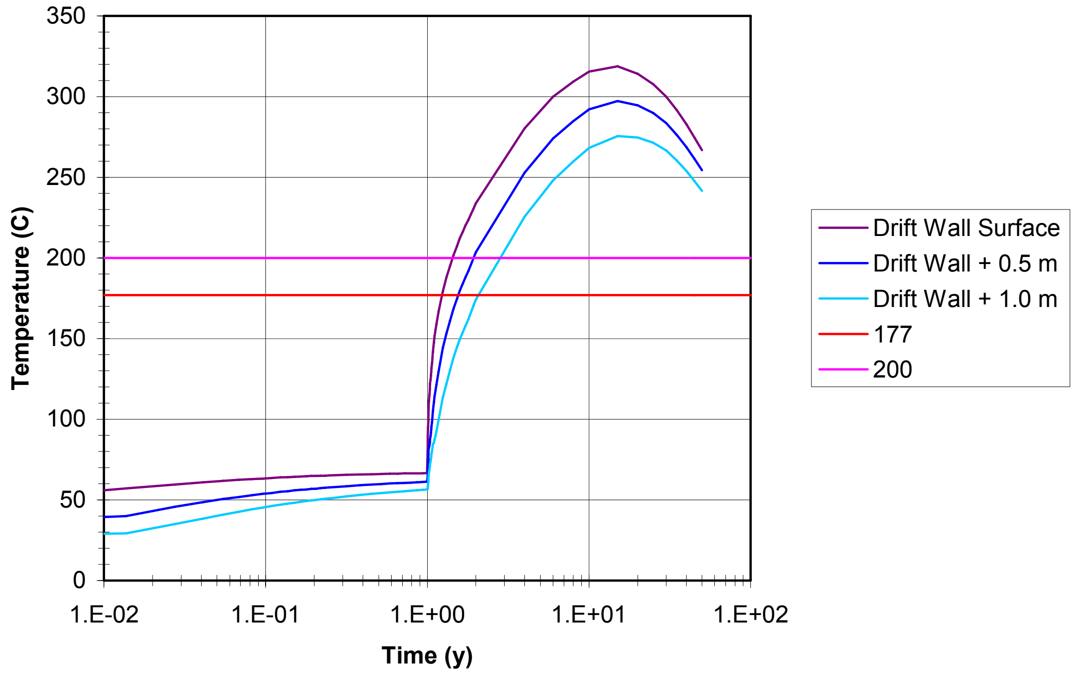

Figure 11. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1C)

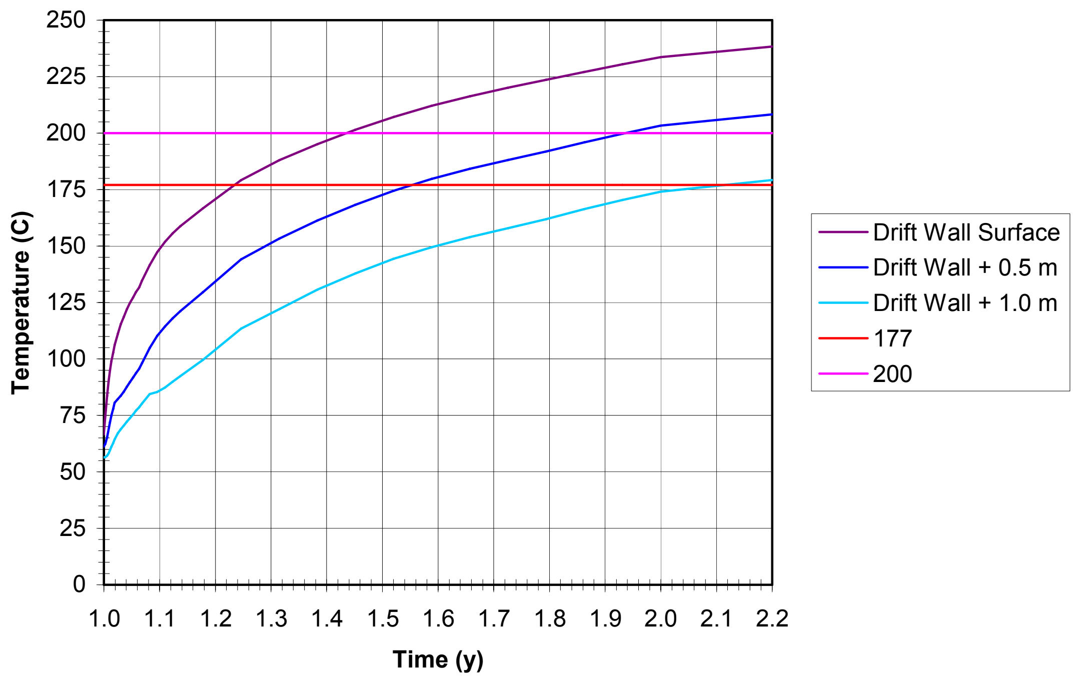

Figure 12. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 1C, Close-up)

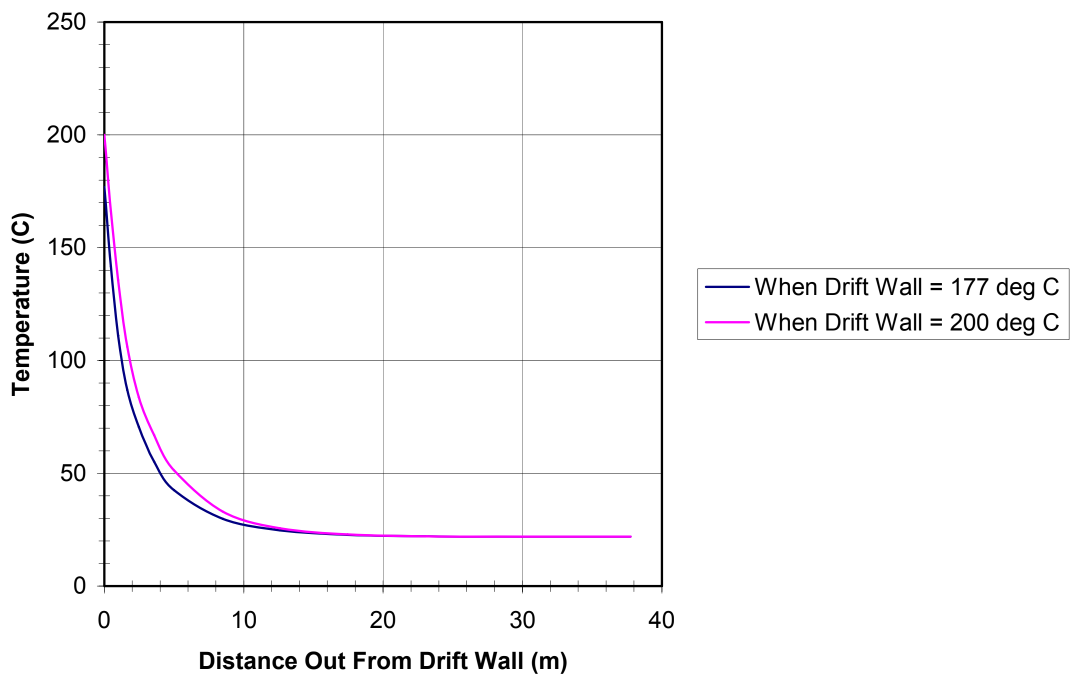

Figure 13. Thermal Gradient Through Rock Out From Drift Wall (Case 1C)

7.2 CASE 2 RESULTS

Case 2 was run with a linear heat load of 1.25 kW/m and a peak, initial waste package heat output of 11.8 kW. The time at loss of ventilation was 0.1 year, 0.5 year, and 1.0 year for sub-cases A, B, and C, respectively.

Table 29 through Table 31 list the time it takes to reach 177 ºC and 200 ºC on the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface, after a loss of pre-closure ventilation.

Table 29. Case 2 Times to Reach Specified Temperatures on Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 2A	0.1	147	277
Case 2B	0.5	130	298
Case 2C	1.0	126	254

Table 30. Case 2 Times to Reach Specified Temperatures 0.5 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 2A	0.1	335	613
Case 2B	0.5	361	592
Case 2C	1.0	307	664

Table 31. Case 2 Times to Reach Specified Temperatures 1.0 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 2A	0.1	652	1164
Case 2B	0.5	654	1146
Case 2C	1.0	710	1092

Figure 14 and Figure 15 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 2A. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

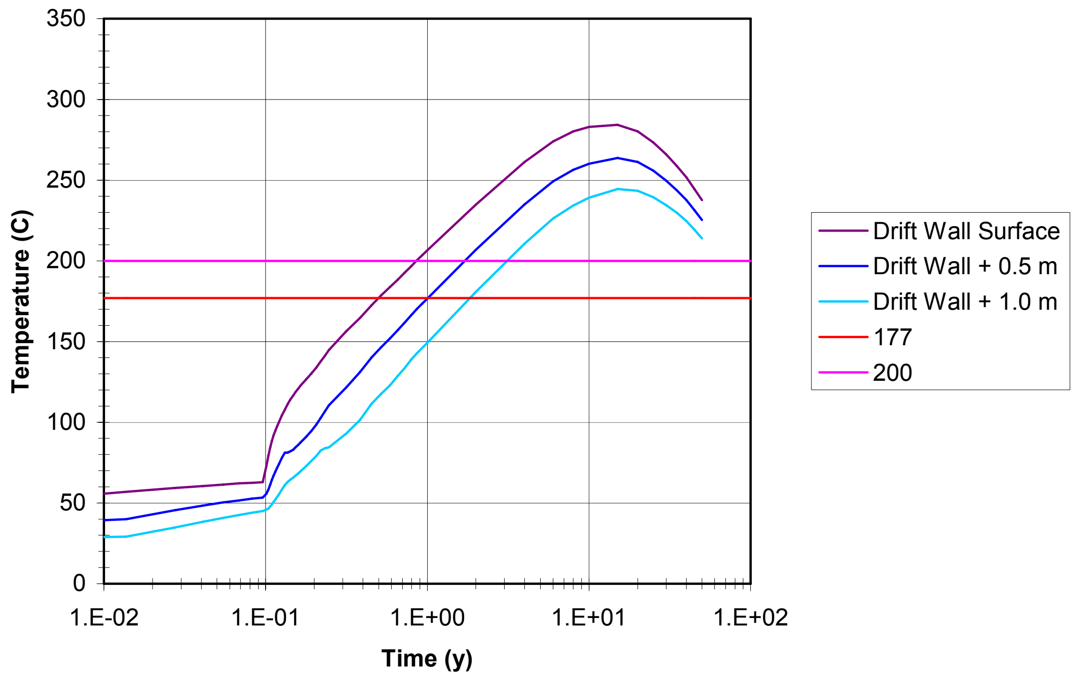

Figure 14. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2A)

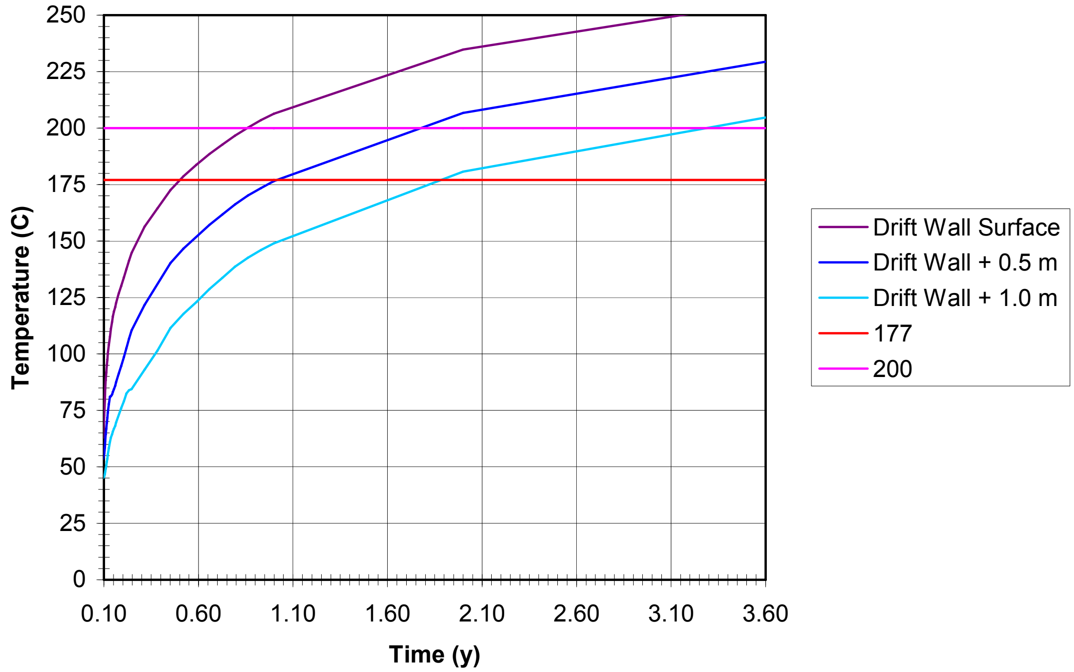

Figure 15. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2A, Close-up)

Figure 16 and Figure 17 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 2B. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

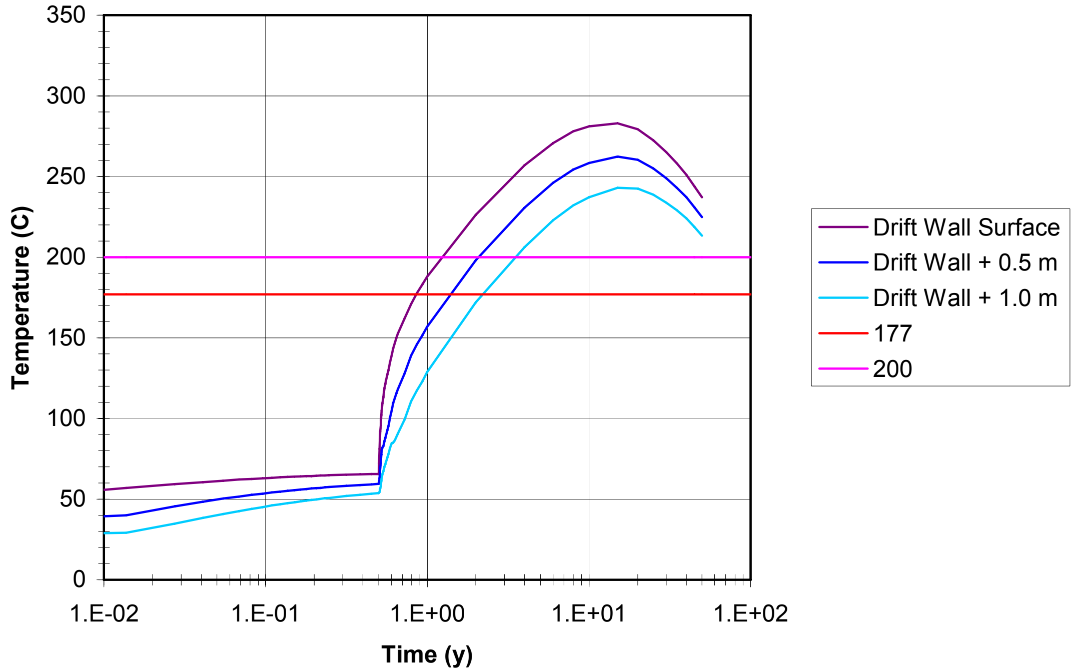

Figure 16. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2B)

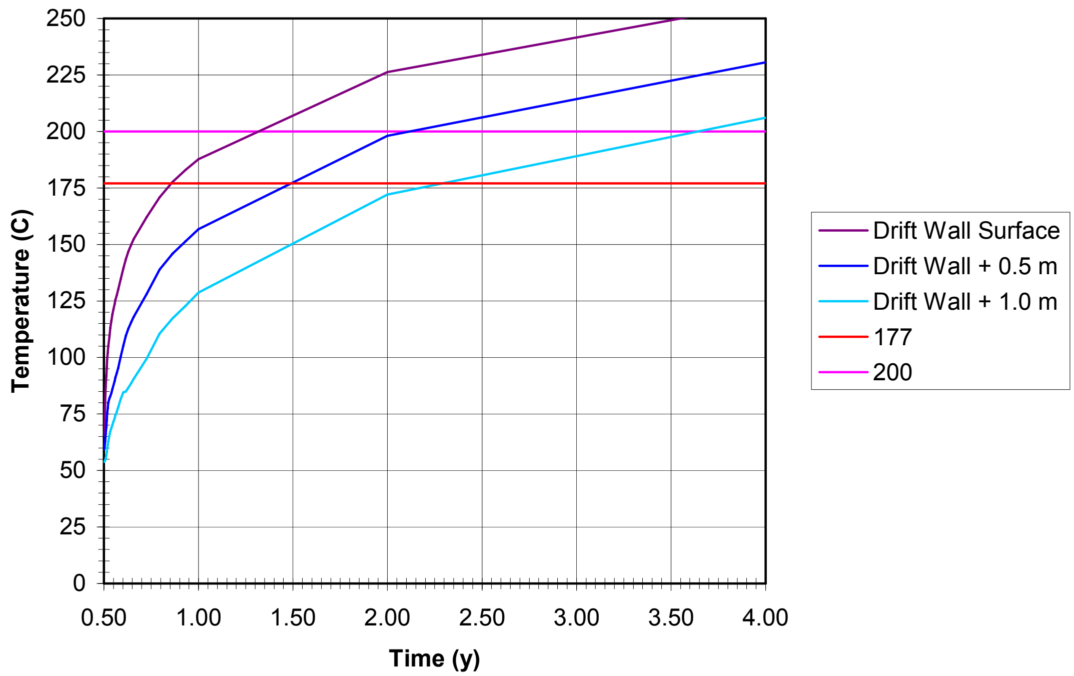

Figure 17. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2B, Close-up)

Figure 18 and Figure 19 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 2C. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

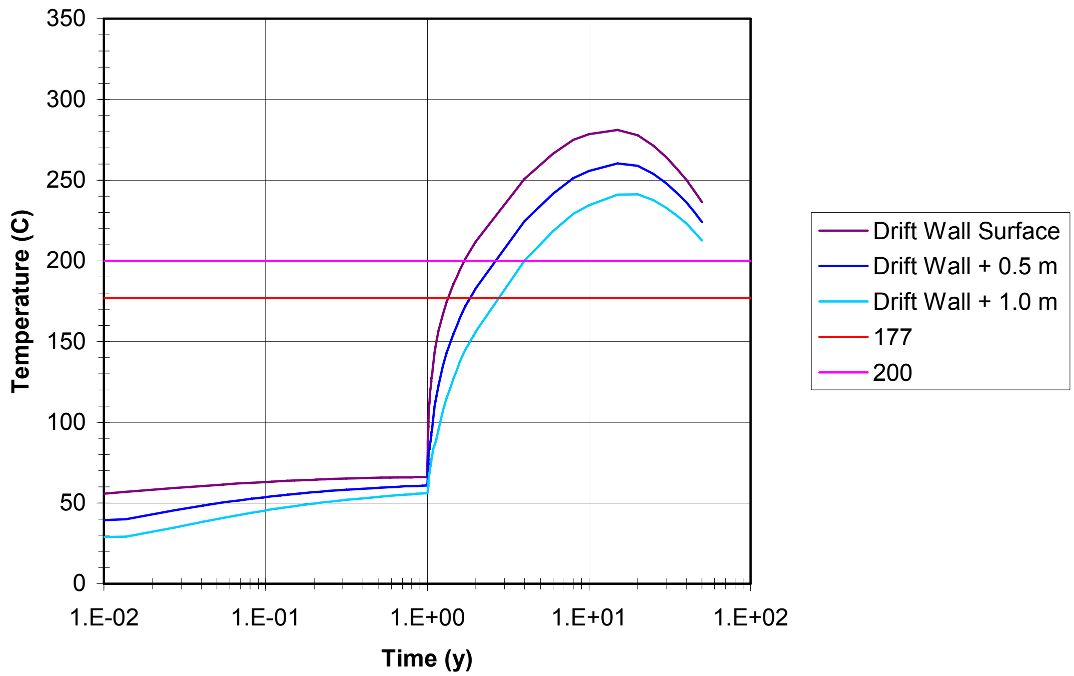

Figure 18. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2C)

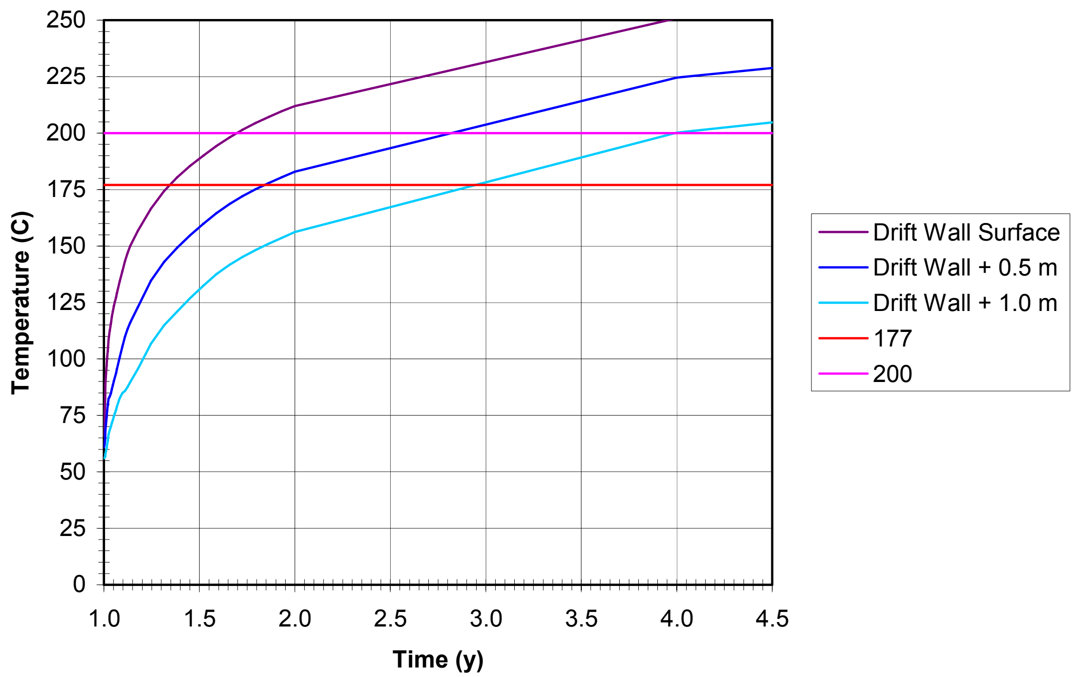

Figure 19. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 2C, Close-up)

7.3 CASE 3 RESULTS

Case 3 was run with a linear heat load of 1.75 kW/m and a peak, initial waste package heat output of 14 kW. The time at loss of ventilation was 0.1 year, 0.5 year, and 1.0 year for sub-cases A, B, and C, respectively.

Table 32 through Table 34 list the time it takes to reach 177 ºC and 200 ºC on the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface, after a loss of pre-closure ventilation.

Table 32. Case 3 Times to Reach Specified Temperatures on Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 3A	0.1	53	89
Case 3B	0.5	46	78
Case 3C	1.0	45	77

Table 33. Case 3 Times to Reach Specified Temperatures 0.5 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 3A	0.1	131	204
Case 3B	0.5	118	193
Case 3C	1.0	114	186

Table 34. Case 3 Times to Reach Specified Temperatures 1.0 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 3A	0.1	257	387
Case 3B	0.5	268	401
Case 3C	1.0	234	354

Figure 20 and Figure 21 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 3A. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

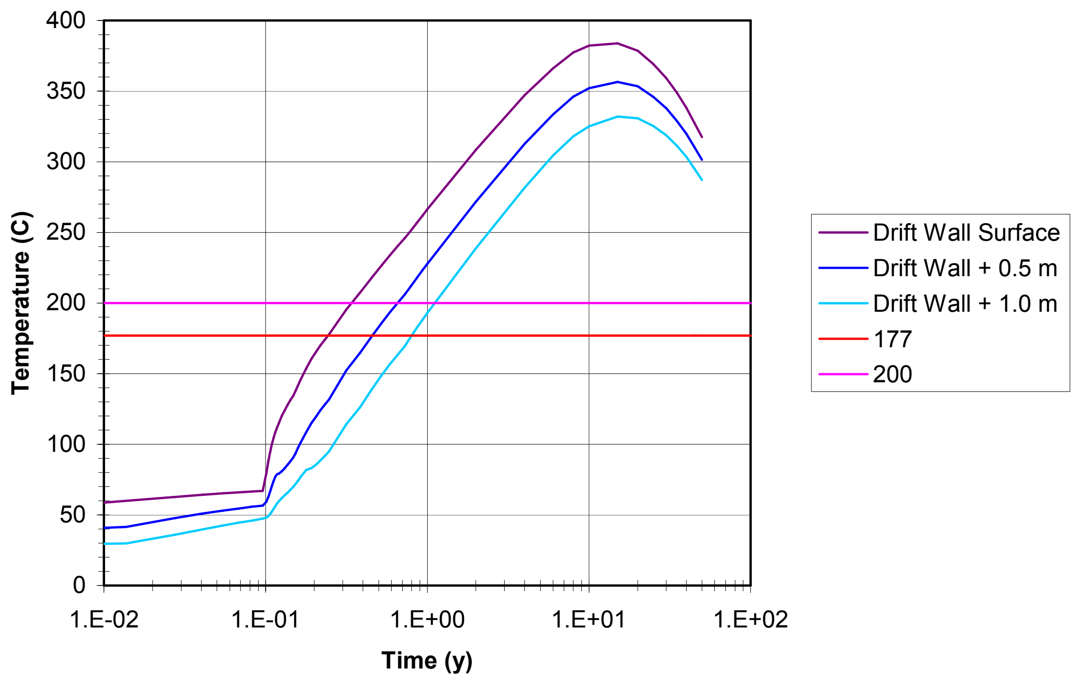

Figure 20. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3A)

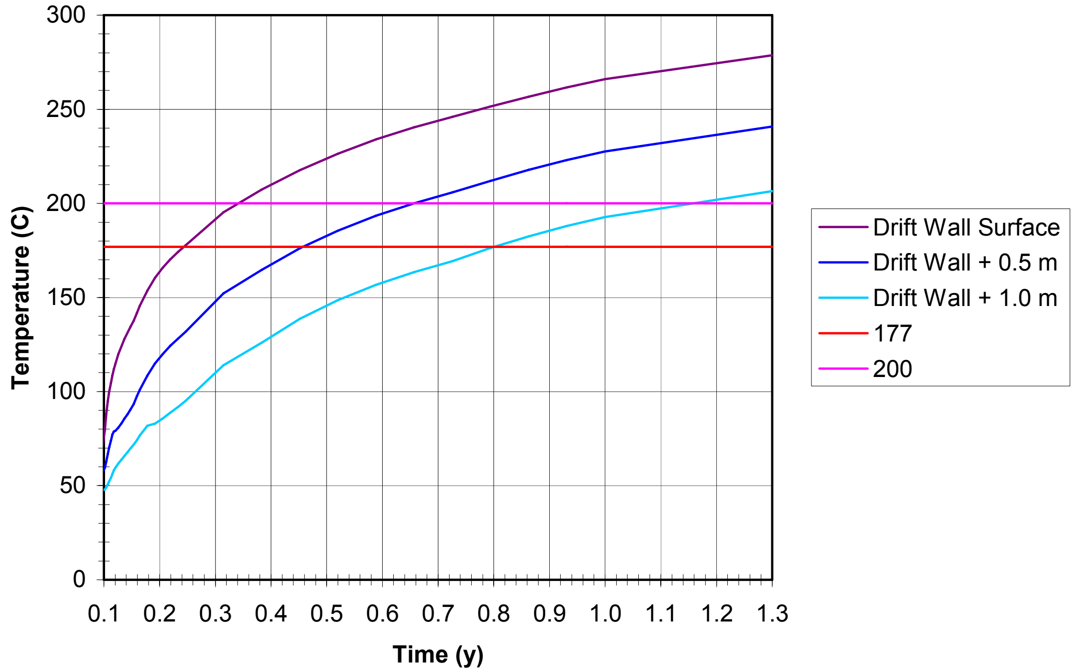

Figure 21. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3A, Close-up)

Figure 22 and Figure 23 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 3B. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

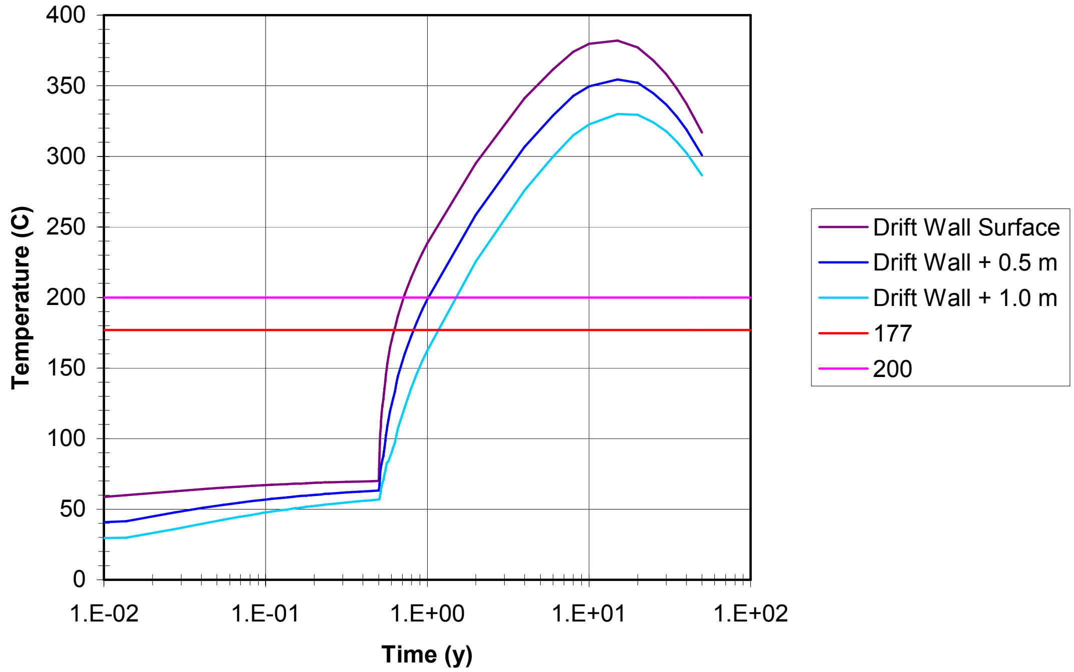

Figure 22. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3B)

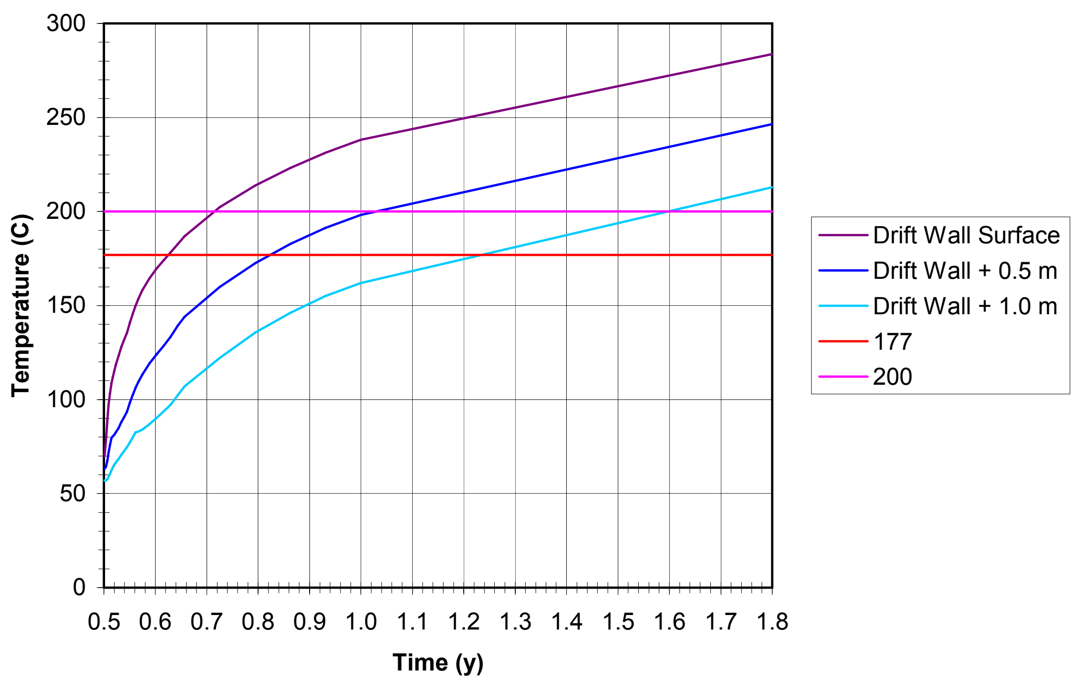

Figure 23. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3B, Close-up)

Figure 24 and Figure 25 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 3C. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

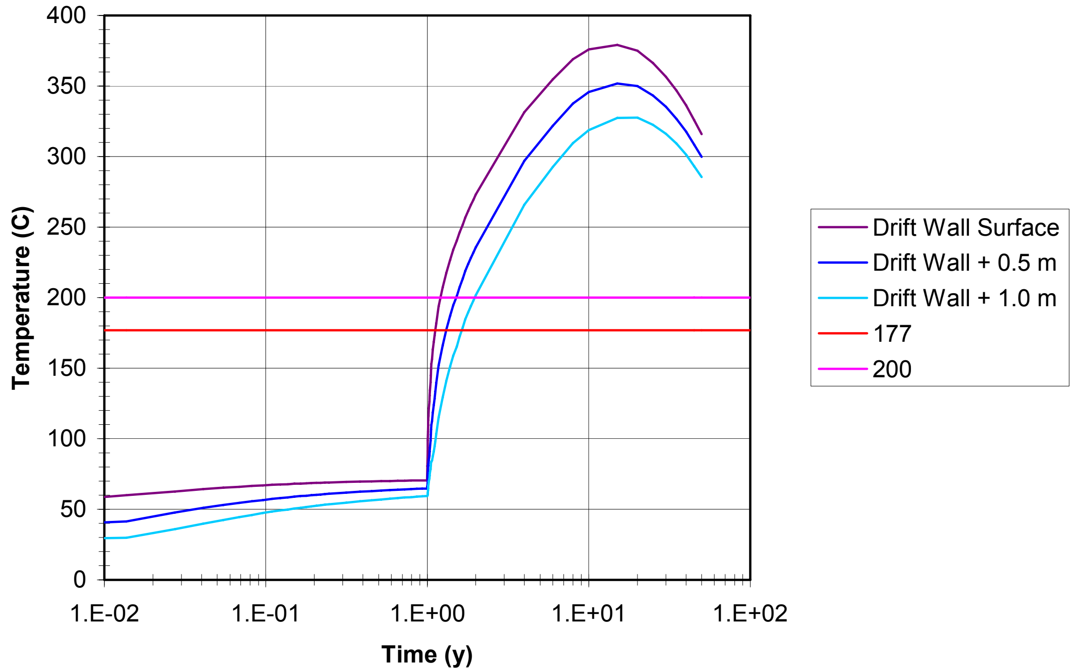

Figure 24. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3C)

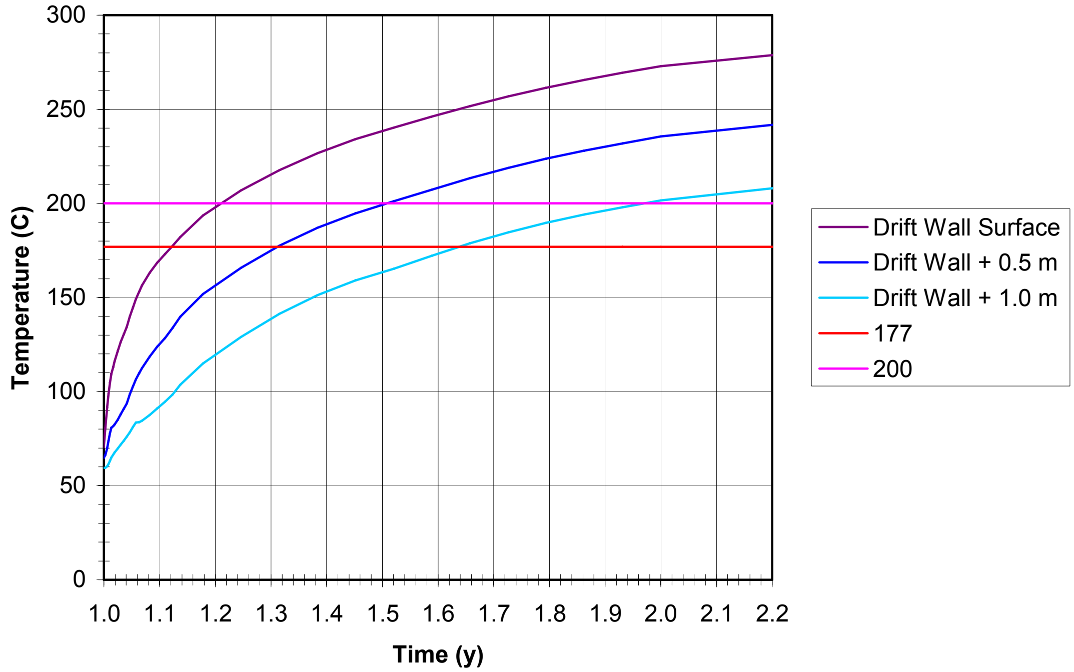

Figure 25. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 3C, Close-up)

7.4 CASE 4 RESULTS

Case 4 was run with a linear heat load of 2 kW/m and a peak, initial waste package heat output of 18 kW. The time at loss of ventilation was 0.1 year, 0.5 year, and 1.0 year for sub-cases A, B, and C, respectively.

Table 35 through Table 37 list the time it takes to reach 177 ºC and 200 ºC on the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface, after a loss of pre-closure ventilation.

Table 35. Case 4 Times to Reach Specified Temperatures on Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 4A	0.1	26	45
Case 4B	0.5	23	39
Case 4C	1.0	22	39

Table 36. Case 4 Times to Reach Specified Temperatures 0.5 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 4A	0.1	80	121
Case 4B	0.5	71	108
Case 4C	1.0	68	107

Table 37. Case 4 Times to Reach Specified Temperatures 1.0 m in from Drift Wall Surface

	Time at Loss of Ventilation (yr)	Time to Reach 177 °C After Loss Of Ventilation (days)	Time to Reach 200 °C After Loss Of Ventilation (days)
Case 4A	0.1	172	242
Case 4B	0.5	158	253
Case 4C	1.0	152	221

Figure 26 and Figure 27 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 4A. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

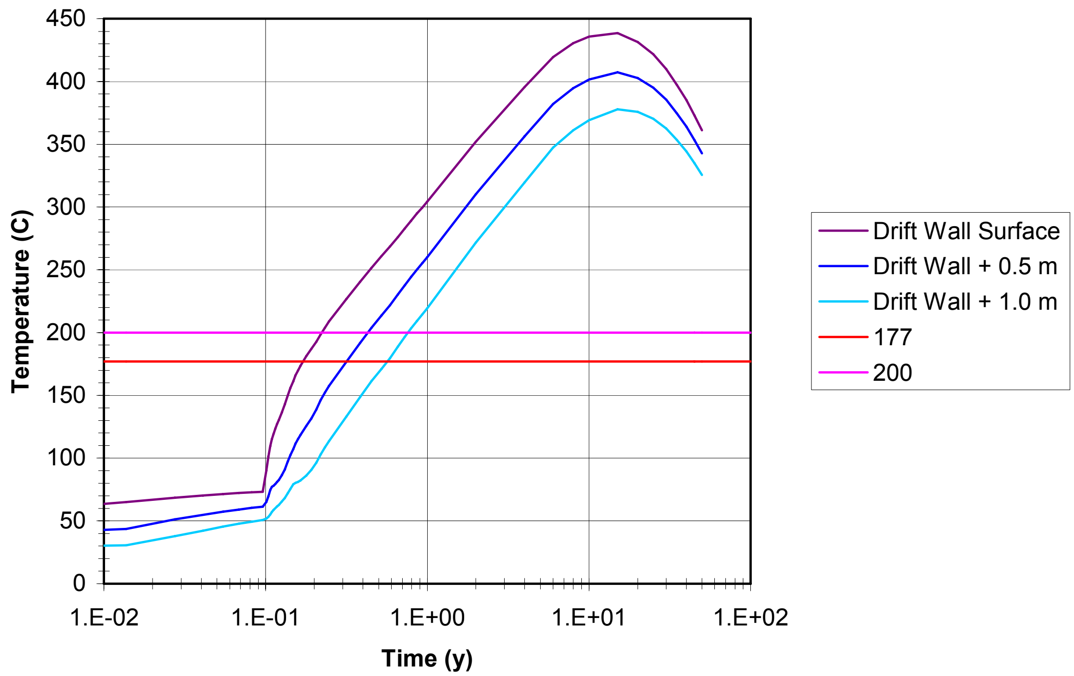

Figure 26. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4A)

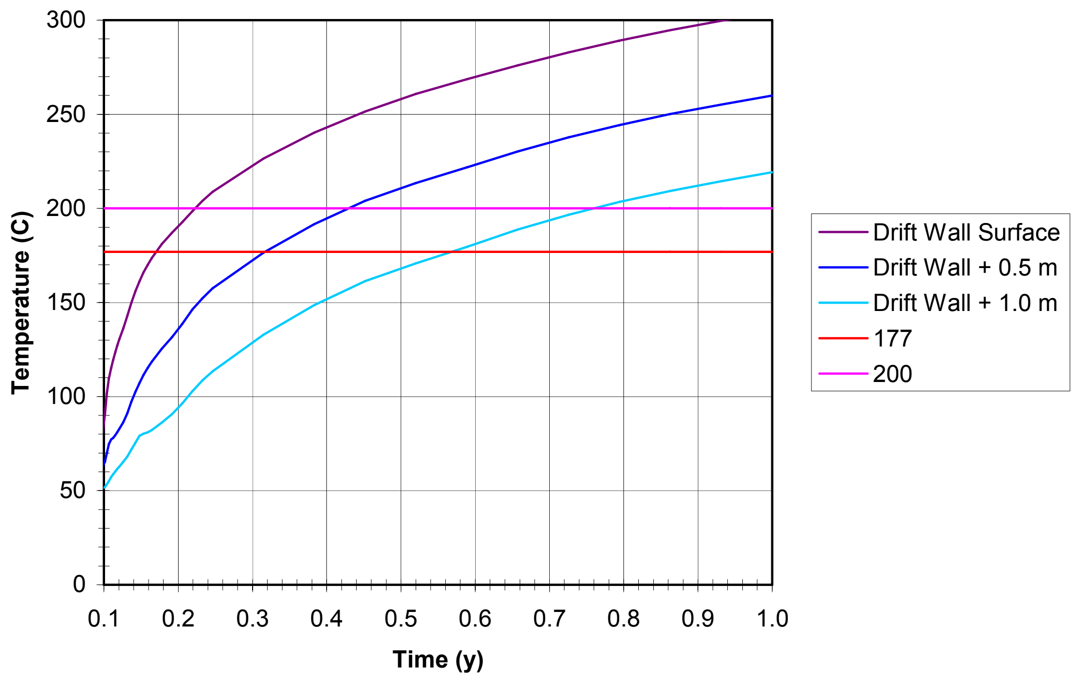

Figure 27. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4A, Close-up)

Figure 28 and Figure 29 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 4B. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

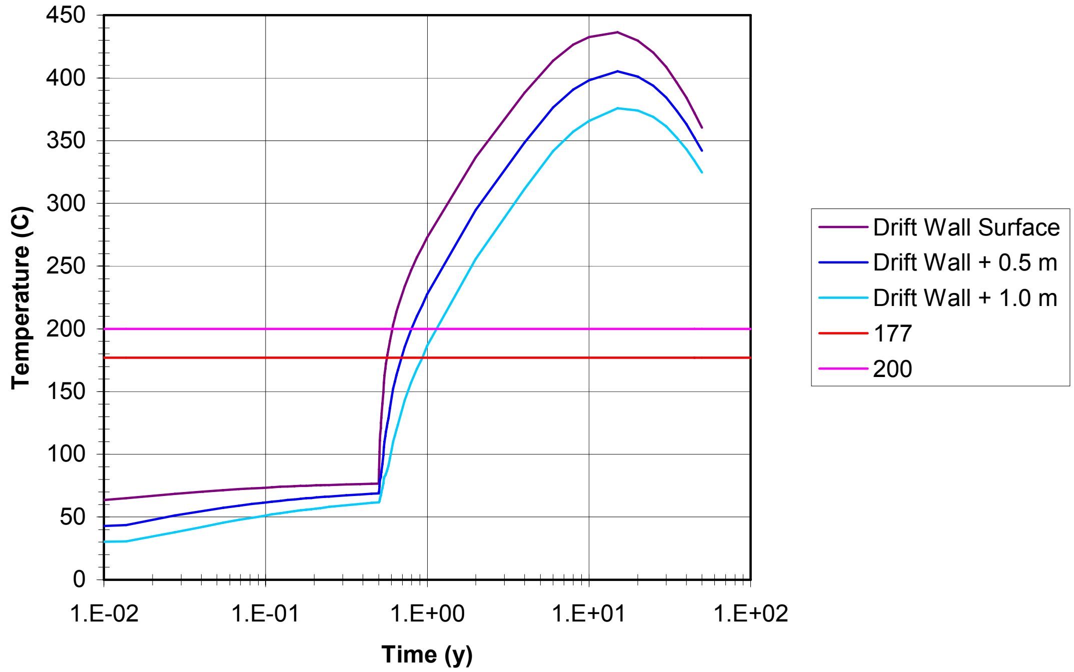

Figure 28. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4B)

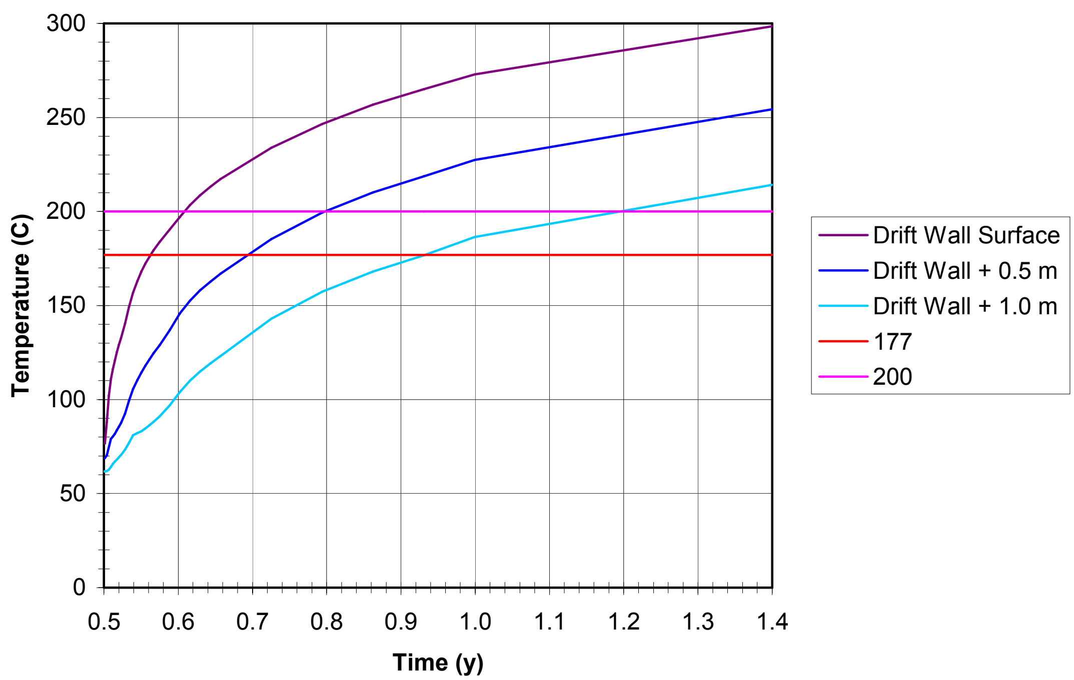

Figure 29. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4B, Close-up)

Figure 30 and Figure 31 show the peak temperature histories for the drift wall, as well as the peak near-vicinity rock temperatures 0.5 m and 1 m in from the drift wall surface for Case 4C. The temperature histories taken at a cross-sectional slice perpendicular to the *z*-plane, at nodal locations closest to the hottest point on the drift wall surface.

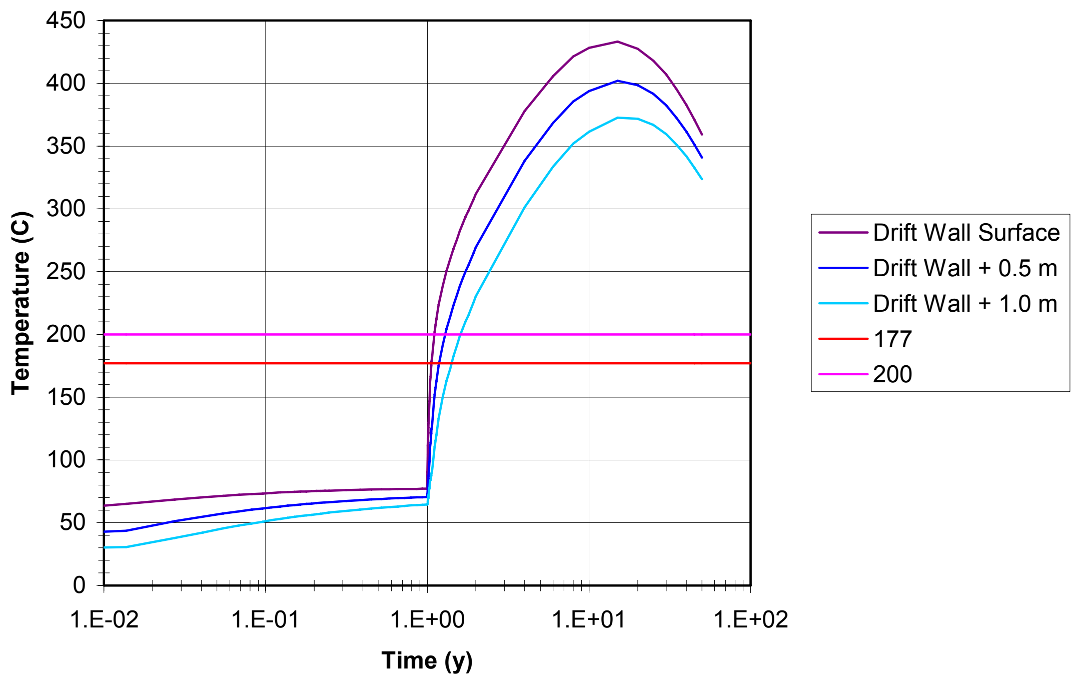

Figure 30. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4C)

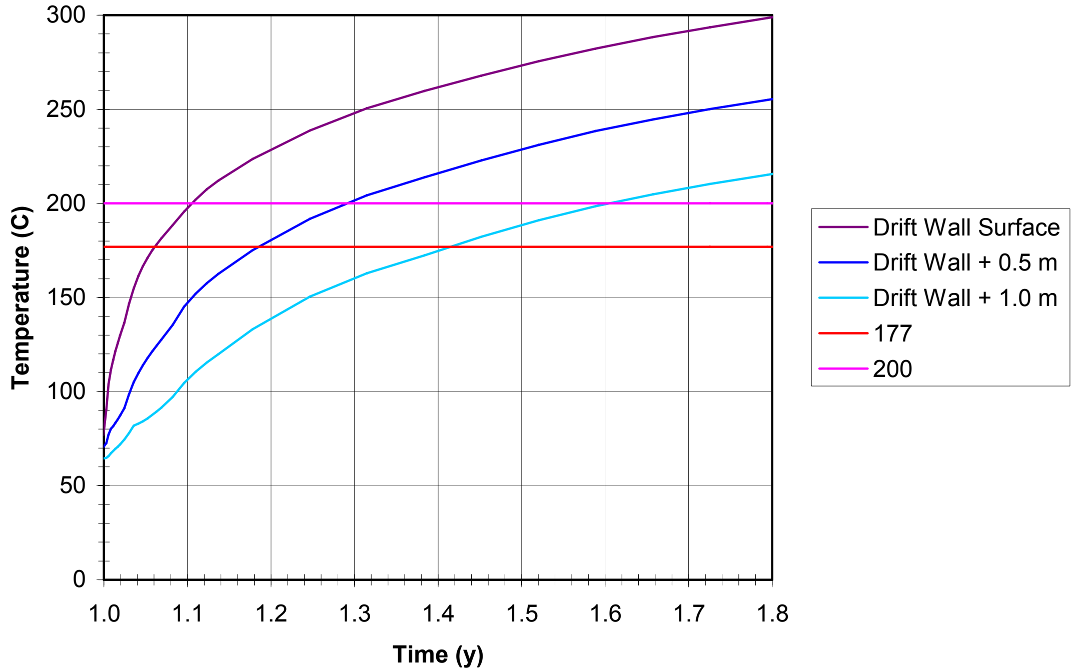

Figure 31. Peak Drift Wall and Near-Vicinity Rock Temperature Histories (Case 4C, Close-up)

7.5 SUMMARY AND CONCLUSIONS

Case 1 was run with a linear heat load of 1.45 kW/m and a peak, initial waste package heat output of 11.8 kW. When loss of ventilation occurred at 1 year after emplacement, it took the drift wall 86 days to reach a temperature of 177 ºC and 159 days to reach 200 ºC. When loss of ventilation occurred at 0.5 year after emplacement, it took the drift wall 88 days to reach a temperature of 177 ºC and 163 days to reach 200 ºC. When loss of ventilation occurred at 0.1 year after emplacement, it took the drift wall 101 days to reach a temperature of 177 ºC and 178 days to reach 200 ºC.

Case 2 was run with a linear heat load of 1.25 kW/m and a peak, initial waste package heat output of 11.8 kW. When loss of ventilation occurred at 1 year after emplacement, it took the drift wall 126 days to reach a temperature of 177 ºC and 254 days to reach 200 ºC. When loss of ventilation occurred at 0.5 year after emplacement, it took the drift wall 130 days to reach a temperature of 177 ºC and 298 days to reach 200 ºC. When loss of ventilation occurred at 0.1 year after emplacement, it took the drift wall 147 days to reach a temperature of 177 ºC and 277 days to reach 200 ºC.

Case 3 was run with a linear heat load of 1.75 kW/m and a peak, initial waste package heat output of 14 kW. When loss of ventilation occurred at 1 year after emplacement, it took the drift wall 45 days to reach a temperature of 177 ºC and 77 days to reach 200 ºC. When loss of ventilation occurred at 0.5 year after emplacement, it took the drift wall 46 days to reach a temperature of 177 ºC and 78 days to reach 200 ºC. When loss of ventilation occurred at 0.1 year after emplacement, it took the drift wall 53 days to reach a temperature of 177 ºC and 89 days to reach 200 ºC.

Case 4 was run with a linear heat load of 2 kW/m and a peak, initial waste package heat output of 18 kW. When loss of ventilation occurred at 1 year after emplacement, it took the drift wall 22 days to reach a temperature of 177 ºC and 39 days to reach 200 ºC. When loss of ventilation occurred at 0.5 year after emplacement, it took the drift wall 23 days to reach a temperature of 177 ºC and 39 days to reach 200 ºC. When loss of ventilation occurred at 0.1 year after emplacement, it took the drift wall 26 days to reach a temperature of 177 ºC and 45 days to reach 200 ºC.

As expected, the results indicate that the drift wall heats up faster as the heat load in the drift is increased.

ATTACHMENT I

INTEROFFICE MEMORANDUM NO. 0205035938

APR 0 4 2003

POSSIBLE ZAP EXPECTED

BECHTEL SAIC COMPANY, LLC

Interoffice Memorandum

MOL.20030501.0081

QA: QA

To: Distribution **No.:** 0205035938

From: Nancy H. Williams **Date:** 4-4-03

Re: Thermal Inputs for Evaluations Supporting TSPA-LA, Supplement **CC:**

This interoffice memorandum provides some key thermal inputs (goals, design features, and operational characteristics) selected for the Total System Performance Assessment-License Application evaluation and all supporting models and analyses. This memorandum restates the thermal inputs from an earlier interoffice memorandum (Williams, N. H., 2002, Tables 1 and 2) and provides some supplementary details of waste package inventory (Table 3). These thermal inputs represent a high thermal operating mode and are consistent with the inputs used in the Total System Performance Assessment-Site Recommendation. Information from the earlier interoffice memorandum has been incorporated in Information Exchange Drawings (BSC 2003). These Information Exchange Drawings should be updated to include the supplementary information from this interoffice memorandum as appropriate.

If there are any questions, please contact Thomas W. Doering (702) 295-7414.

DAT:NHW:cjp

Enclosures:
1. Table 1 *"Recommended Thermal Goals"*
2. Table 2 *"Recommended Design Features and Operational Characteristics"*
3. Table 3 "*WP Inventory Information*"

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References:

67 FR 19432, Surplus Plutonium Disposition Program. Readily available.

Board, M. P.; Linden, A.; and Zhu, M. 2002. Design Evolution Study – Underground Layout. TDR-MGR-MG-000003 REV 00. Las Vegas, Nevada: BSC. ACC: MOL.20020429.0023.

BSC 2002. *Repository/PA IED Subsurface Facilities*. 800-IED-EBS0-00403-000 REV 00B. Las Vegas, Nevada: BSC. ACC: MOL.20030109.0147.

Chestney, R. and Thomas, E. 2002. *Repository/PA IED Subsurface Facilities Plan*. DWG-MGR-MD-000003 REV A. Las Vegas, Nevada: BSC. ACC: MOL.20020601.0194.

CRWMS M&O 1999, *1999 Design Basis Waste Input Report for Commercial Spent Nuclear Fuel*, REV 01. Washington, D.C.: CRWMS M&O. ACC: MOV.19991217.0001

CRWMS M&O 2000a, *Total System Performance Assessment (TSPA) Model For Site Recommendation,* MDL-WIS-PA-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001226.0003

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DOE 2001. *Civilian Radioactive Waste Management System Requirement Document*. DOE/RW-0406 REV 05 DCN 04. Washington, D.C.: U.S. Department of Energy Office of Civilian Radioactive Waste Management. ACC: MOL.20010628.0243.

McKenzie, J. M. 2001. *Transmittal of "Thermal Data for Naval Nuclear Propulsion Program spent Nuclear Fuel Canister"*. SER 08U/01-13933. Washington, D. C.: Department of the Navy. ACC: MOL.20011029.0285

Williams, N.H. 2002, *Thermal Inputs for Evaluations Supporting TSPA-LA* 0911024159. Las Vegas, Nevada: BSC. ACC: MOL.20021008.0141.

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Table 1 Recommended Thermal Goals

Requirement	Discussion
Pillar Drainage	This goal is intended to ensure that pore water liberated from the host rock matrix and percolation flux drains through sub-boiling region of the fracture network to the water table rather than accumulate above the repository horizon.
$T_{clad}^{max} \leq 350°C$	Goal is to limit cladding temperature to less than 350°C to provide margin to failure by creep rupture.
$T_{DW}^{max}\|_{pre\text{-}closure} \leq 96°C$	Goal is to limit pre-closure drift wall temperature to 96°C or less to not preclude cool operating modes.
$T_{DW}^{max}\|_{post\text{-}closure} \leq 200°C$	Goal is to limit post-closure drift wall temperature to 200°C or less to avoid adverse mineralogical transitions.

Table 2 Recommended Design Features and Operational Characteristics

Description/Value	Comments/Reference
Design Features	
Waste Package Suite/ 44-BWR 24-BWR 12-PWR Naval-Long Naval-Short 5 DHLW/DOE SNF-Short 5 DHLW/DOE SNF Long 2 MCO/2-DHLW 21-PWR w/ Absorber Plates 21-PWR w/ Control Rods	The same as TSPA-SR (CRWMS 2000a)
Number of Waste Packages/ (See Table 3)	The same as TSPA-SR (CRWMS 2000a, p.228)
Drift Diameter/5.5 m	The same as TSPA-SR (CRWMS 2000a)
Drift Pitch/81 m	The same as TSPA-SR (CRWMS 2000a)
Subsurface Layout	Layout from Design Evolution Study (Board, et al. 2002) formally documented in the Information Exchange Drawing (Chestney, R. and Thomas, E. 2002)
Operational Characteristics	
Waste Stream/ 1999 Design Basis Waste Stream Case A Legal-Limit Scenario	The same as TSPA-SR (CRWMS 1999 and CRWMS 2000b)
Average waste package skirt-to-skirt spacing/0.1 m	The same as TSPA-SR (CRWMS 2000a)
Average thermal line load/1.45 kW/m	The same as TSPA-SR (CRWMS 2000a)

Table 2 Recommended Design Features and Operational Characteristics (continued)

Average waste package thermal power at time of emplacement/This value is about 7.54 kW for the recommended waste stream	This value is dependent on the waste stream selected, and, thus, is the same as the SR baseline.
Maximum waste package power at emplacement/11.8 kW	The same as TSPA-SR (CRWMS 2000a)
Average length of all waste packages within inventory/This value is about 5.1 m for the recommended waste stream	This value is dependent on the waste stream selected, and, thus, is the same as the SR baseline.
Ventilation Volumetric Flow Rate/15 m^3/s	Will provide acceptable performance.
Duration of Ventilation/50 Years after final emplacement	The same as TSPA-SR (CRWMS 2000a)
Duration of waste emplacement/23 years	Value from the CRD (DOE 2001)
CSNF Waste Emplacement Rate By Year/ 2010 400 MT 2011 600 MT 2012 1200 MT 2013 2000 MT 2014 to 2032+ 3000 MT 2033 1800 MT	Value from the CRD (DOE 2001)
Naval Canister Emplacement Rate By Year/ 2010 3 2011 3 2012 6 2013 6 2014 12 2015 to 2029 14 2030 to 2033 15	McKenzie 2001

Table 3 WP Inventory Information

Waste Package Configuration	Nominal Quantity for SR[a]	Nominal Quantity for LA[b]	Not to Exceed Quantity[c]
21 PWR AP	4299[d]	4299[d]	4500
21 PWR CR	95[d]	95[d]	100
12 PWR AP Long	163[d]	163[d]	170
44 BWR AP	2831[d]	2831[d]	3000
24 BWR AP	84[d]	84[d]	90
5 IPWF	95	0	1200[e]
5 HLW Short/1 DOE SNF Short	1052	1147	
5 HLW Long/1 DOE SNF Long	1406	1406	1500
2 MCO/2 HLW	149	149	160
5 HLW Long/1 DOE SNF Short	126	31	730[f]
5 HLW Long Only	584	679	
Naval Short	200	144[g]	300[g]
Naval Long	100	156[g]	
Total	11184	11184	-

[a] Nominal quantities for Site Recommendation are from the Project Description Document (PDD) (Curry 2001) and represent the potential number of each waste package (WP) configuration to accommodate the legal limit of 70,000 MTHM, including IPWF packages.
[b] Nominal quantities for LA are those for SR and represent the potential number of each WP configuration to accommodate the legal limit of 70,000 MTHM, except that IPWF packages are no longer considered (67 FR 19432) and the Navy has revised its estimate of WPs (McKenzie 2001). The HLW short canisters that would have contained the Plutonium have been redistributed among the co-disposal WPs in a manner consistent with the expected number of short DOE SNF canisters. This results in fewer short DOE SNF canisters to co-dispose with long HLW canisters.
[c] The "not to exceed quantities" are for each WP configuration separately. The total of this column would clearly make the repository exceed 70,000 MTHM. If the quantity of one configuration increases above the nominal value, the quantity for another configuration must decrease to maintain the maximum legal limit of 70,000 MTHM.
[d] The nominal number of WPs for CSNF (CRWMS 2000b) are for the Case A Legal Limit scenario from the 1999 Design Basis Waste Input Report, as used for Site Recommendation.
[e] Since the IPWF configuration is no longer being considered, the "not to exceed" quantities from the PDD for the "IPWF" and "5 HLW Short/1 DOE SNF Short" configurations are combined for LA.
[f] Since the IPWF configuration is no longer being considered, the necessary redistribution of the short DOE SNF canisters among different co-disposal WPs results in more "5 HLW Long Only" WPs than in the PDD. Therefore, the "not to exceed" quantities for the "5 HLW Long/1 DOE SNF Short" and "5 HLW Long Only" WPs are combined for LA.
[g] Because of the revised Navy WP estimates, the "not to exceed" values for "Naval Short" and "Naval Long" configurations from the PDD are combined for LA. It should be noted that the estimated thermal sources for Naval WPs do not distinguish between short and long WPs.

ATTACHMENT II

FILE LISTING FOR ATTACHMENT III

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 Volume Serial Number is A83E-239D

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01/14/2007  10:28a         1,699,840 GS031208312232_003_SD-12.xls
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07/10/2006  01:03p            15,872 upper invert effective k.xls
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01/15/2007  06:37a             5,537 5-Short_heat_gen.dat
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02/22/2007  10:28a           102,666 get_50m_bc_temps.out
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02/22/2007  10:30a      <DIR>          ..
01/15/2007  06:41a               5,475 12-PWR_heat_gen.dat
01/15/2007  06:41a             130,933 12wp-model-case14r.tg
01/15/2007  06:41a               5,475 21-PWR_heat_gen.dat
01/15/2007  06:41a               5,475 44-BWR_heat_gen.dat
01/15/2007  06:41a               5,475 5-Long_heat_gen.dat
01/15/2007  06:41a               5,537 5-Short_heat_gen.dat
01/15/2007  06:41a              84,316 case_01c.inp
01/15/2007  06:41a           8,432,477 case_01c.out
02/22/2007  10:30a                 206 center_ref_node_4_50m_bc.txt
01/15/2007  06:41a              17,903 dimensions-case14.inp
02/22/2007  10:30a               3,973 get_50m_bc_temps.inp
02/22/2007  10:30a             126,998 get_50m_bc_temps.out
01/15/2007  10:12a               3,879 get_drift_temps_halfmeterin.inp
01/15/2007  10:12a              86,104 get_drift_temps_halfmeterin.out
01/15/2007  06:41a              29,001 matprops-case14.dat
02/22/2007  10:30a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  02:09p               1,074 ordered_therm_grad_nodes.txt
```

```
01/22/2007  01:47p                 996 therm_grad.inp
01/22/2007  01:47p              34,948 therm_grad.out
01/15/2007  06:41a           4,870,628 trugrdo-case14.inp
              20 File(s)     13,855,307 bytes

 Directory of D:\ANSYS_RUNS\CASE_02A

02/22/2007  10:30a    <DIR>          .
02/22/2007  10:30a    <DIR>          ..
01/22/2007  09:23a               5,475 12-PWR_heat_gen.dat
01/22/2007  09:23a             130,933 12wp-model-case14r.tg
01/22/2007  09:23a               5,475 21-PWR_heat_gen.dat
01/22/2007  09:23a               5,475 44-BWR_heat_gen.dat
01/22/2007  09:23a               5,475 5-Long_heat_gen.dat
01/22/2007  09:23a               5,537 5-Short_heat_gen.dat
01/22/2007  09:23a              84,910 case_02a.inp
01/22/2007  09:23a           8,209,794 case_02a.out
02/22/2007  10:30a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  09:23a              17,903 dimensions-case14.inp
02/22/2007  10:30a               3,973 get_50m_bc_temps.inp
02/22/2007  10:30a             102,667 get_50m_bc_temps.out
01/22/2007  09:23a              29,001 matprops-case14.dat
02/22/2007  10:30a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  09:23a           4,870,628 trugrdo-case14.inp
01/22/2007  09:23a             129,008 tsave-case14
              16 File(s)     13,610,894 bytes

 Directory of D:\ANSYS_RUNS\CASE_02B

02/22/2007  10:32a    <DIR>          .
02/22/2007  10:32a    <DIR>          ..
01/22/2007  09:29a               5,475 12-PWR_heat_gen.dat
01/22/2007  09:29a             130,933 12wp-model-case14r.tg
01/22/2007  09:29a               5,475 21-PWR_heat_gen.dat
01/22/2007  09:29a               5,475 44-BWR_heat_gen.dat
01/22/2007  09:29a               5,475 5-Long_heat_gen.dat
01/22/2007  09:29a               5,537 5-Short_heat_gen.dat
01/22/2007  09:29a              90,590 case_02b.inp
01/22/2007  09:29a           8,404,024 case_02b.out
02/22/2007  10:32a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  09:29a              17,903 dimensions-case14.inp
02/22/2007  10:32a               3,973 get_50m_bc_temps.inp
02/22/2007  10:32a             113,728 get_50m_bc_temps.out
01/22/2007  09:29a              29,001 matprops-case14.dat
02/22/2007  10:32a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  09:29a           4,870,628 trugrdo-case14.inp
              15 File(s)     13,692,857 bytes

 Directory of D:\ANSYS_RUNS\CASE_02C

02/22/2007  10:33a    <DIR>          .
02/22/2007  10:33a    <DIR>          ..
01/22/2007  09:30a               5,475 12-PWR_heat_gen.dat
01/22/2007  09:30a             130,933 12wp-model-case14r.tg
01/22/2007  09:30a               5,475 21-PWR_heat_gen.dat
01/22/2007  09:30a               5,475 44-BWR_heat_gen.dat
01/22/2007  09:30a               5,475 5-Long_heat_gen.dat
```

```
01/22/2007  09:30a               5,537 5-Short_heat_gen.dat
01/22/2007  09:30a              87,902 case_02c.inp
01/22/2007  09:30a           8,499,075 case_02c.out
02/22/2007  10:33a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  09:30a              17,903 dimensions-case14.inp
02/22/2007  10:33a               3,973 get_50m_bc_temps.inp
02/22/2007  10:33a             127,000 get_50m_bc_temps.out
01/22/2007  09:30a              29,001 matprops-case14.dat
02/22/2007  10:33a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  09:30a           4,870,628 trugrdo-case14.inp
              15 File(s)     13,798,492 bytes

 Directory of D:\ANSYS_RUNS\CASE_03A

02/22/2007  10:31a      <DIR>          .
02/22/2007  10:31a      <DIR>          ..
01/22/2007  09:25a               5,475 12-PWR_heat_gen.dat
01/22/2007  09:25a             130,933 12wp-model-case14r.tg
01/22/2007  09:25a               5,475 21-PWR_heat_gen.dat
01/22/2007  09:25a               5,475 44-BWR_heat_gen.dat
01/22/2007  09:25a               5,475 5-Long_heat_gen.dat
01/22/2007  09:25a               5,537 5-Short_heat_gen.dat
01/22/2007  09:25a              84,899 case_03a.inp
01/22/2007  09:25a           8,253,189 case_03a.out
02/22/2007  10:31a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  09:25a              17,903 dimensions-case14.inp
02/22/2007  10:31a               3,973 get_50m_bc_temps.inp
02/22/2007  10:31a             102,667 get_50m_bc_temps.out
01/22/2007  09:25a              29,001 matprops-case14.dat
02/22/2007  10:31a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  09:25a           4,870,628 trugrdo-case14.inp
01/22/2007  09:25a             129,008 tsave-case14
              16 File(s)     13,654,278 bytes

 Directory of D:\ANSYS_RUNS\CASE_03B

02/22/2007  10:35a      <DIR>          .
02/22/2007  10:35a      <DIR>          ..
01/22/2007  09:33a               5,475 12-PWR_heat_gen.dat
01/22/2007  09:33a             130,933 12wp-model-case14r.tg
01/22/2007  09:33a               5,475 21-PWR_heat_gen.dat
01/22/2007  09:33a               5,475 44-BWR_heat_gen.dat
01/22/2007  09:33a               5,475 5-Long_heat_gen.dat
01/22/2007  09:33a               5,537 5-Short_heat_gen.dat
01/22/2007  09:33a              90,579 case_03b.inp
01/22/2007  09:33a           8,462,954 case_03b.out
02/22/2007  10:35a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  09:33a              17,903 dimensions-case14.inp
02/22/2007  10:35a               3,973 get_50m_bc_temps.inp
02/22/2007  10:35a             113,729 get_50m_bc_temps.out
01/22/2007  09:33a              29,001 matprops-case14.dat
02/22/2007  10:35a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  09:33a           4,870,628 trugrdo-case14.inp
              15 File(s)     13,751,777 bytes

 Directory of D:\ANSYS_RUNS\CASE_03C
```

```
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02/22/2007  10:35a      <DIR>          ..
01/22/2007  03:22p               5,475 12-PWR_heat_gen.dat
01/22/2007  03:22p             130,933 12wp-model-case14r.tg
01/22/2007  03:22p               5,475 21-PWR_heat_gen.dat
01/22/2007  03:22p               5,475 44-BWR_heat_gen.dat
01/22/2007  03:22p               5,475 5-Long_heat_gen.dat
01/22/2007  03:22p               5,537 5-Short_heat_gen.dat
01/22/2007  03:22p              87,891 case_03c.inp
01/22/2007  03:22p           8,545,789 case_03c.out
02/22/2007  10:35a                 206 center_ref_node_4_50m_bc.txt
01/22/2007  03:22p              17,903 dimensions-case14.inp
02/22/2007  10:35a               3,973 get_50m_bc_temps.inp
02/22/2007  10:35a             127,001 get_50m_bc_temps.out
01/22/2007  03:22p              29,001 matprops-case14.dat
02/22/2007  10:35a               4,434 nodes_at_midline_plus-minus_50m.txt
01/22/2007  03:22p           4,870,628 trugrdo-case14.inp
              15 File(s)     13,845,196 bytes

 Directory of D:\ANSYS_RUNS\CASE_04A

02/22/2007  10:36a      <DIR>          .
02/22/2007  10:36a      <DIR>          ..
01/29/2007  02:35p               5,475 12-PWR_heat_gen.dat
01/29/2007  02:35p             130,933 12wp-model-case14r.tg
01/29/2007  02:35p               5,475 21-PWR_heat_gen.dat
01/29/2007  02:35p               5,475 44-BWR_heat_gen.dat
01/29/2007  02:35p               5,475 5-Long_heat_gen.dat
01/29/2007  02:35p               5,537 5-Short_heat_gen.dat
01/29/2007  02:35p              84,911 case_04a.inp
01/29/2007  02:35p           8,280,021 case_04a.out
02/22/2007  10:36a                 206 center_ref_node_4_50m_bc.txt
01/29/2007  02:35p              17,903 dimensions-case14.inp
02/22/2007  10:36a               3,973 get_50m_bc_temps.inp
02/22/2007  10:36a             102,669 get_50m_bc_temps.out
01/29/2007  02:35p              29,001 matprops-case14.dat
02/22/2007  10:36a               4,434 nodes_at_midline_plus-minus_50m.txt
01/29/2007  02:35p           4,870,628 trugrdo-case14.inp
              15 File(s)     13,552,116 bytes

 Directory of D:\ANSYS_RUNS\CASE_04B

02/22/2007  10:33a      <DIR>          .
02/22/2007  10:33a      <DIR>          ..
01/29/2007  02:35p               5,475 12-PWR_heat_gen.dat
01/29/2007  02:35p             130,933 12wp-model-case14r.tg
01/29/2007  02:35p               5,475 21-PWR_heat_gen.dat
01/29/2007  02:35p               5,475 44-BWR_heat_gen.dat
01/29/2007  02:35p               5,475 5-Long_heat_gen.dat
01/29/2007  02:35p               5,537 5-Short_heat_gen.dat
01/29/2007  02:35p              90,591 case_04b.inp
01/29/2007  02:35p           8,491,304 case_04b.out
02/22/2007  10:33a                 206 center_ref_node_4_50m_bc.txt
01/29/2007  02:35p              17,903 dimensions-case14.inp
02/22/2007  10:33a               3,973 get_50m_bc_temps.inp
02/22/2007  10:33a             113,728 get_50m_bc_temps.out
01/29/2007  02:35p              29,001 matprops-case14.dat
```

```
02/22/2007  10:33a               4,434 nodes_at_midline_plus-minus_50m.txt
01/29/2007  02:35p           4,870,628 trugrdo-case14.inp
              15 File(s)     13,780,138 bytes

 Directory of D:\ANSYS_RUNS\CASE_04C

02/21/2007  08:22a      <DIR>          .
02/21/2007  08:22a      <DIR>          ..
01/29/2007  02:36p               5,475 12-PWR_heat_gen.dat
01/29/2007  02:36p             130,933 12wp-model-case14r.tg
01/29/2007  02:36p               5,475 21-PWR_heat_gen.dat
01/29/2007  02:36p               5,475 44-BWR_heat_gen.dat
01/29/2007  02:36p               5,475 5-Long_heat_gen.dat
01/29/2007  02:36p               5,537 5-Short_heat_gen.dat
01/29/2007  02:36p              87,903 case_04c.inp
01/29/2007  02:36p           8,570,017 case_04c.out
02/21/2007  08:22a                 206 center_ref_node_4_50m_bc.txt
01/29/2007  02:36p              17,903 dimensions-case14.inp
02/21/2007  08:22a               3,973 get_50m_bc_temps.inp
02/21/2007  08:22a             127,000 get_50m_bc_temps.out
01/29/2007  02:36p              29,001 matprops-case14.dat
02/21/2007  08:22a               4,434 nodes_at_midline_plus-minus_50m.txt
01/29/2007  02:36p           4,870,628 trugrdo-case14.inp
              15 File(s)     13,869,435 bytes

 Directory of D:\RESULTS

02/05/2007  01:44p      <DIR>          .
02/05/2007  01:44p      <DIR>          ..
02/01/2007  01:20p      <DIR>          CASE_01A
02/01/2007  01:16p      <DIR>          CASE_01B
02/01/2007  01:34p      <DIR>          CASE_01C
01/31/2007  08:53a      <DIR>          CASE_02A
02/01/2007  02:33p      <DIR>          CASE_02B
01/31/2007  09:32a      <DIR>          CASE_02C
02/01/2007  03:08p      <DIR>          CASE_03A
01/31/2007  10:08a      <DIR>          CASE_03B
01/31/2007  10:28a      <DIR>          CASE_03C
01/30/2007  10:16a      <DIR>          CASE_04A
02/01/2007  03:22p      <DIR>          CASE_04B
02/26/2007  09:08a      <DIR>          CASE_04C
               0 File(s)              0 bytes

 Directory of D:\RESULTS\CASE_01A

02/01/2007  01:20p      <DIR>          .
02/01/2007  01:20p      <DIR>          ..
02/01/2007  01:20p             169,472 case_01A_drift_wall_temps.xls
01/31/2007  08:06a             100,864 case_01A_drift_half_meter_in_temps.xls
01/31/2007  08:06a             100,864 case_01A_drift_one_meter_in_temps.xls
               3 File(s)        371,200 bytes

 Directory of D:\RESULTS\CASE_01B

02/01/2007  01:16p      <DIR>          .
02/01/2007  01:16p      <DIR>          ..
01/31/2007  08:02a             114,176 case_01B_drift_one_meter_in_temps.xls
```

```
01/31/2007  08:02a            114,176 case_01B_drift_half_meter_in_temps.xls
02/01/2007  01:16p            188,928 case_01B_drift_wall_temps.xls
               3 File(s)        417,280 bytes

 Directory of D:\RESULTS\CASE_01C

02/01/2007  01:34p      <DIR>          .
02/01/2007  01:34p      <DIR>          ..
01/31/2007  08:30a            126,976 case_01C_drift_one_meter_in_temps.xls
01/31/2007  08:19a            126,976 case_01C_drift_half_meter_in_temps.xls
02/01/2007  01:34p            214,528 case_01C_drift_wall_temps.xls
               3 File(s)        468,480 bytes

 Directory of D:\RESULTS\CASE_02A

01/31/2007  08:53a      <DIR>          .
01/31/2007  08:53a      <DIR>          ..
01/31/2007  08:53a            100,864 case_02A_drift_half_meter_in_temps.xls
01/31/2007  08:53a            100,352 case_02A_drift_one_meter_in_temps.xls
01/31/2007  08:38a            140,288 case_02A_drift_wall_temps.xls
               3 File(s)        341,504 bytes

 Directory of D:\RESULTS\CASE_02B

02/01/2007  02:33p      <DIR>          .
02/01/2007  02:33p      <DIR>          ..
01/31/2007  09:14a            113,664 case_02B_drift_one_meter_in_temps.xls
01/31/2007  09:11a            114,176 case_02B_drift_half_meter_in_temps.xls
02/01/2007  02:33p            157,184 case_02B_drift_wall_temps.xls
               3 File(s)        385,024 bytes

 Directory of D:\RESULTS\CASE_02C

01/31/2007  09:32a      <DIR>          .
01/31/2007  09:32a      <DIR>          ..
01/31/2007  09:20a            178,176 case_02C_drift_wall_temps.xls
01/31/2007  09:29a            126,976 case_02C_drift_one_meter_in_temps.xls
01/31/2007  09:32a            126,976 case_02C_drift_half_meter_in_temps.xls
               3 File(s)        432,128 bytes

 Directory of D:\RESULTS\CASE_03A

02/01/2007  03:08p      <DIR>          .
02/01/2007  03:08p      <DIR>          ..
01/31/2007  09:47a            100,864 case_03A_drift_half_meter_in_temps.xls
01/31/2007  09:53a            100,352 case_03A_drift_one_meter_in_temps.xls
02/01/2007  03:08p            141,312 case_03A_drift_wall_temps.xls
               3 File(s)        342,528 bytes

 Directory of D:\RESULTS\CASE_03B

01/31/2007  10:08a      <DIR>          .
01/31/2007  10:08a      <DIR>          ..
01/31/2007  10:04a            114,176 case_03B_drift_one_meter_in_temps.xls
01/31/2007  09:58a            113,664 case_03B_drift_half_meter_in_temps.xls
01/31/2007  10:08a            157,696 case_03B_drift_wall_temps.xls
               3 File(s)        385,536 bytes
```

```
 Directory of D:\RESULTS\CASE_03C

01/31/2007  10:28a    <DIR>          .
01/31/2007  10:28a    <DIR>          ..
01/31/2007  10:17a           178,688 case_03C_drift_wall_temps.xls
01/31/2007  10:23a           126,976 case_03C_drift_one_meter_in_temps.xls
01/31/2007  10:28a           126,976 case_03C_drift_half_meter_in_temps.xls
               3 File(s)        432,640 bytes

 Directory of D:\RESULTS\CASE_04A

01/30/2007  10:16a    <DIR>          .
01/30/2007  10:16a    <DIR>          ..
01/30/2007  10:13a           100,352 case_04A_drift_half_meter_in_temps.xls
01/30/2007  10:15a           100,352 case_04A_drift_one_meter_in_temps.xls
01/30/2007  10:16a           140,288 case_04A_drift_wall_temps.xls
               3 File(s)        340,992 bytes

 Directory of D:\RESULTS\CASE_04B

02/01/2007  03:22p    <DIR>          .
02/01/2007  03:22p    <DIR>          ..
01/31/2007  10:53a           113,664 case_04B_drift_one_meter_in_temps.xls
01/31/2007  10:48a           113,664 case_04B_drift_half_meter_in_temps.xls
02/01/2007  03:22p           156,672 case_04B_drift_wall_temps.xls
               3 File(s)        384,000 bytes

 Directory of D:\RESULTS\CASE_04C

02/26/2007  09:08a    <DIR>          .
02/26/2007  09:08a    <DIR>          ..
02/26/2007  09:08a           179,200 case_04C_drift_wall_temps.xls
01/30/2007  01:55p           126,976 case_04C_drift_one_meter_in_temps.xls
01/30/2007  01:55p           126,976 case_04C_drift_half_meter_in_temps.xls
02/23/2007  03:27p           263,680 case_04C_bc_at_50m_temps.xls
               4 File(s)        696,832 bytes

     Total Files Listed:
             240 File(s)    171,808,175 bytes
              78 Dir(s)               0 bytes free
```

ATTACHMENT IV

SUPPLEMENTAL RESULTS FOR CASE 4C

The results provided in Section 7 indicate that Case 4C is the most limiting, thermally. This Section lists additional results for Case 4C, limited to temperatures along the vertical centerline ($z = 0$ and $x = 0$, for the purpose of this discussion) extending 50 m above and below the center of the drift (-50 m < y < 50 m, for the purpose of this discussion).

Figure 32 shows a half-symmetry view of the center plane at $z = 0$ m of the ANSYS mesh extending to $y = \pm 50$ m from the center of drift. Since the y-coordinates of the nodes do not coincide with $y = \pm 50$ m from the center of drift, temperatures are interpolated at fictitious nodes between the nodes just above and just below the desired positions. The fictitious nodes at $y = \pm 50$ m from the center of drift are shown in blue in Figure 32. The fictitious nodes located at $y = -50$ m from the center of drift are *A*, *B*, *C*, *D*, and *E*. The fictitious nodes located at $y = 50$ m from the center of drift are *A'*, *B'*, *C'*, *D'*, and *E'*.

Figure 33 shows the temperature profiles at various times at nodal locations $x = 0$ m, 0 m < y < 50 m, $z = 0$ m. Figure 34 shows the temperature profiles at various times at nodal locations $x = 0$ m, -50 m < y < 0 m, $z = 0$ m. Figure 35 shows the temperature profiles at various times at nodal locations 0 m < x < 40.5 m, $y = 50$ m, $z = 0$ m. Figure 36 shows the temperature profiles at various times at nodal locations 0 m < x < 40.5 m, $y = -50$ m, $z = 0$ m.

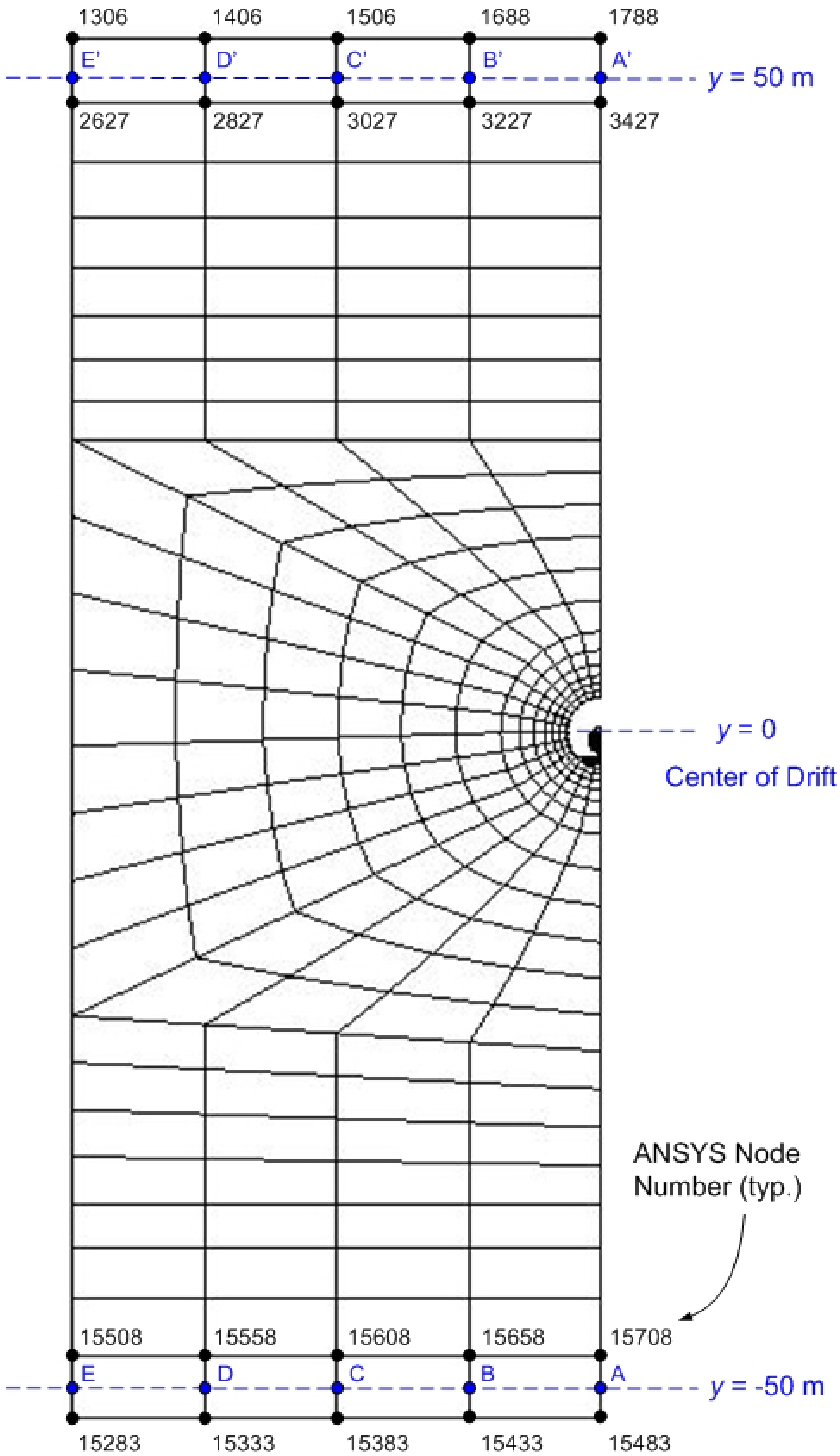

Figure 32. Half-Symmetry View of Mesh Extending to ±50 m from Center of Drift

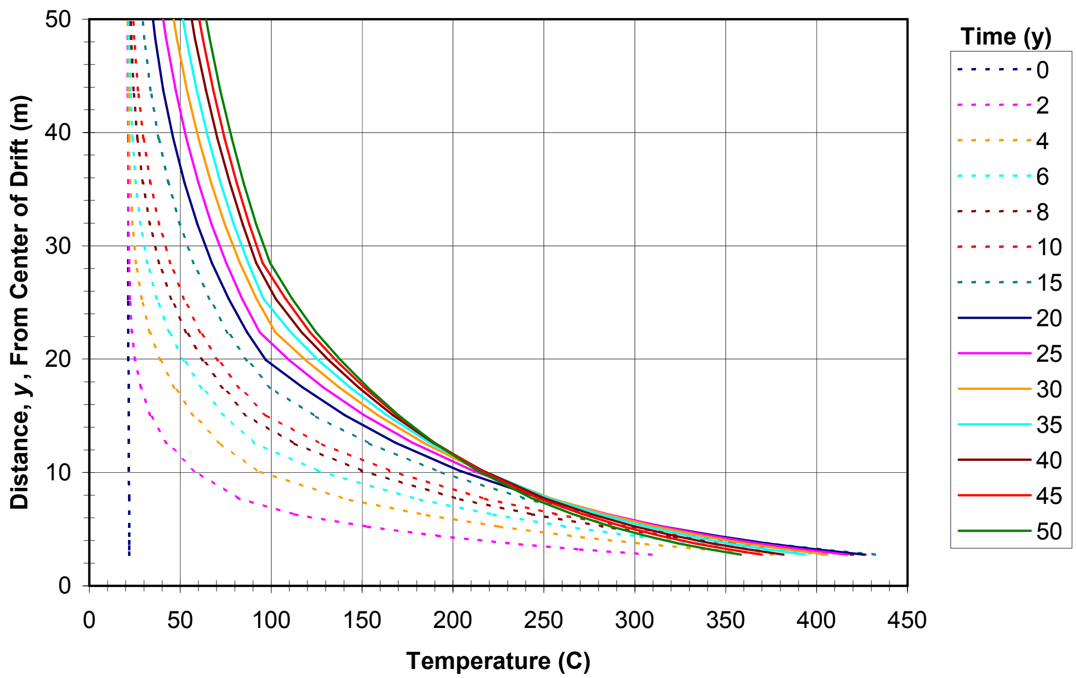

Figure 33. Case 4C Temperatures at x = 0 m, 0 m < y < 50 m, z = 0 m

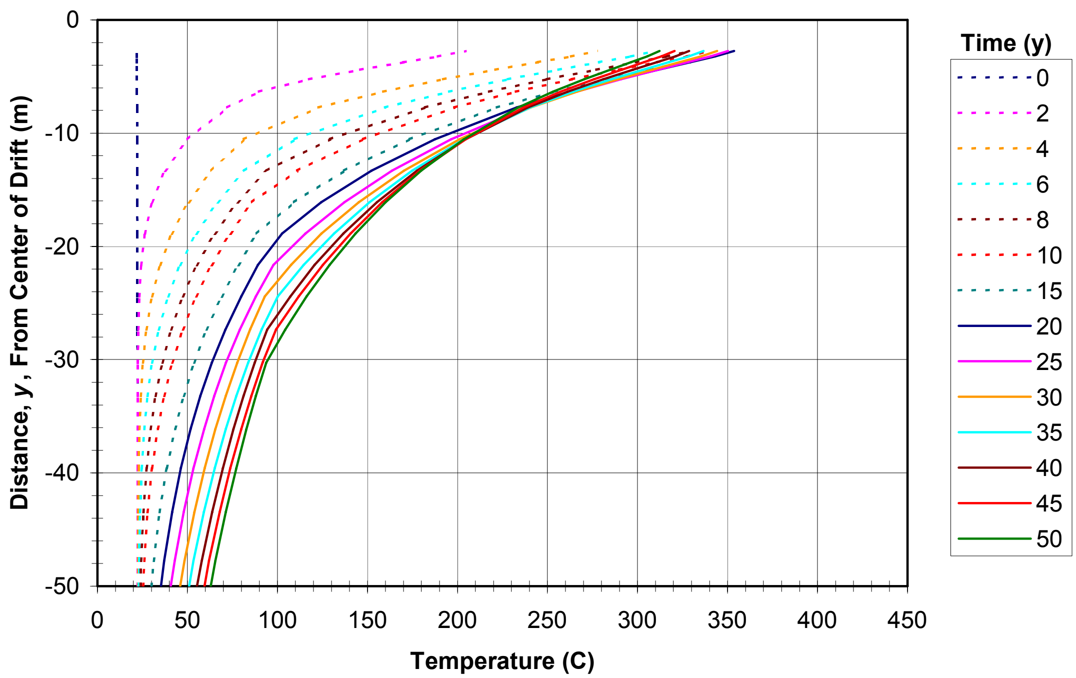

Figure 34. Case 4C Temperatures at x = 0 m, -50 m < y < 0 m, z = 0 m

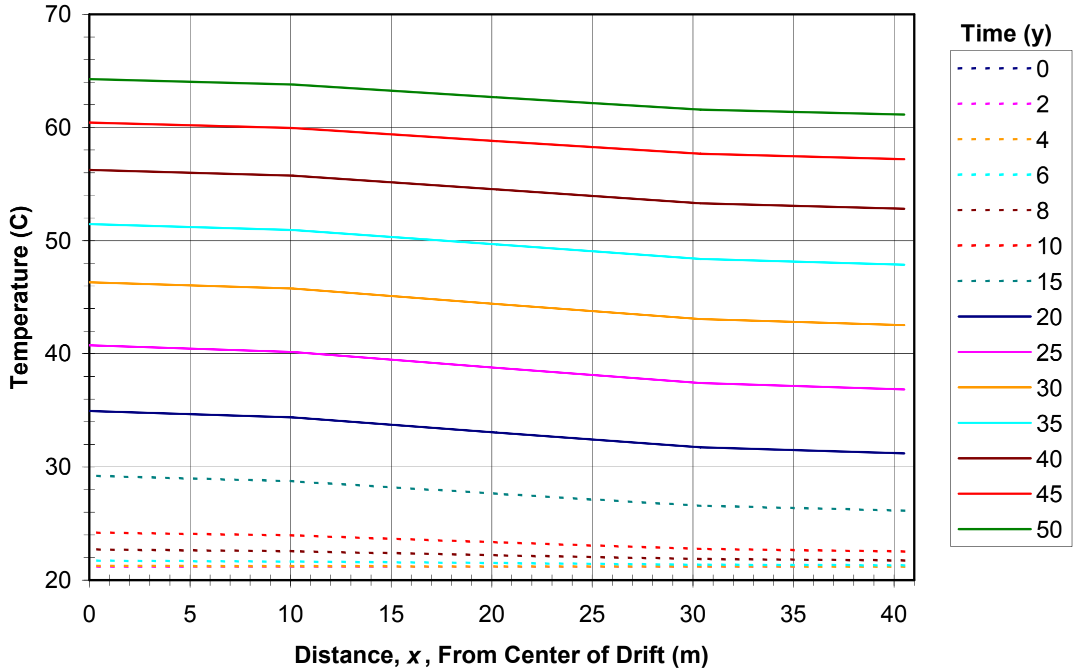

Figure 35. Case 4C Temperatures at 0 m < *x* < 40.5 m, *y* = 50 m, *z* = 0 m

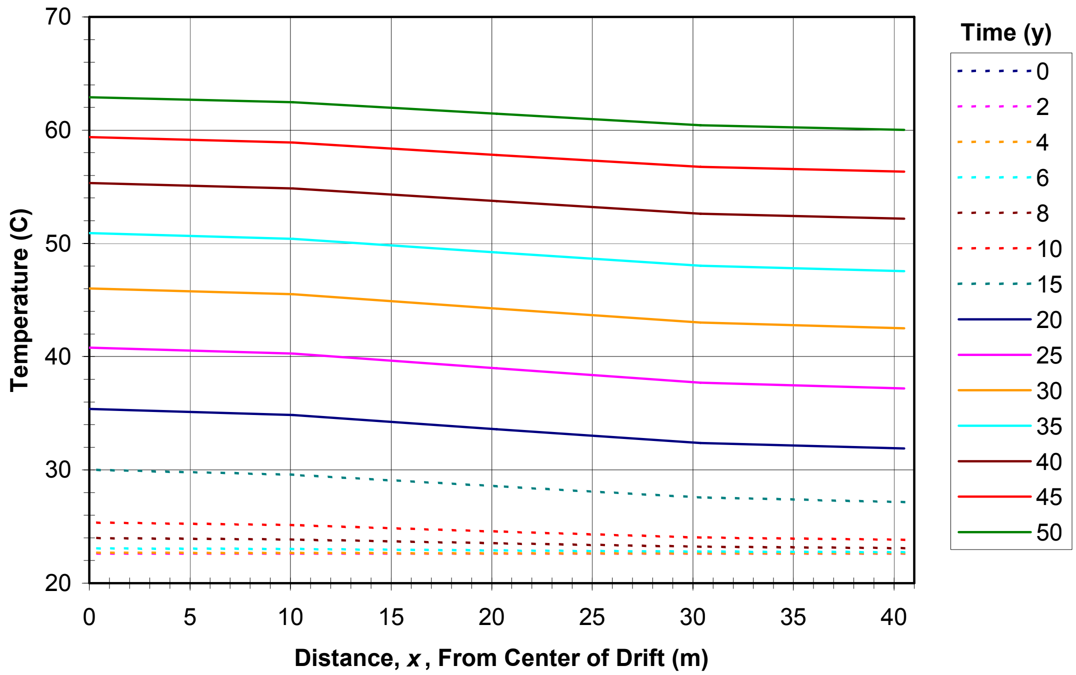

Figure 36. Case 4C Temperatures at 0 m < *x* < 40.5 m, *y* = -50 m, *z* = 0 m

Table 38 lists peak drift wall temperatures for Case 4C at selected times. See Attachment III, file: *\RESULTS\CASE_04C\case_04C_drift_wall_temps.xls* for detailed calculation.

Table 38. Case 4C Peak Drift Wall Temperatures at Selected Times

Selected Time	**Time (years)**	**Peak Temperature (°C)**
Start	0.00	21.86
Loss of Ventilation	1.00	77.06
Loss of Ventilation + 10 days	1.027	140.38
Loss of Ventilation + 22 days (drift wall = 177 °C)	1.061	177.00
Loss of Ventilation + 39 days (drift wall = 200 °C)	1.105	200.00

Table 39 lists average temperatures at 50 m above center of drift for Case 4C at selected times. See Attachment III, file: *\RESULTS\CASE_04C\case_04C_bc_at_50m_temps.xls* for detailed calculation.

Table 39. Case 4C Average Temperatures at 50 m Above Center of Drift at Selected Times

Selected Time	**Time (years)**	**Average Temperature (°C)**
Start	0.00	21.17
Loss of Ventilation	1.00	21.17
Loss of Ventilation + 10 days	1.027	21.17
Loss of Ventilation + 22 days (drift wall = 177 °C)	1.061	21.17
Loss of Ventilation + 39 days (drift wall = 200 °C)	1.105	21.17

Table 40 lists average temperatures at 50 m below center of drift for Case 4C at selected times. See Attachment III, file: *\RESULTS\CASE_04C\case_04C_bc_at_50m_temps.xls* for detailed calculation.

Table 40. Case 4C Average Temperatures at 50 m Below Center of Drift at Selected Times

Selected Time	Time (years)	Average Temperature (°C)
Start	0.00	22.60
Loss of Ventilation	1.00	22.60
Loss of Ventilation + 10 days	1.027	22.60
Loss of Ventilation + 22 days (drift wall = 177 °C)	1.061	22.60
Loss of Ventilation + 39 days (drift wall = 200 °C)	1.105	22.60

Table 41 lists temperatures at nodal locations along x = 0 m, -50 m < y < 50 m, at selected times (the same times listed in Table 38 through Table 40 above) for Case 4C. See Attachment III, file: *\RESULTS\CASE_04C\case_04C_bc_at_50m_temps.xls* for detailed calculation.

Table 41. Case 4C Temperatures at Nodes Along x = 0 m, -50 m < y < 50 m, at Selected Times

Node	*x* - coordinate	*y* - coordinate	Temperature (°C)				
			At 0.00 y	At 1.00 y	At 1.027 y	At 1.061 y	At 1.105 y
A	0.00	-50.00	22.60	22.60	22.60	22.60	22.60
15708	0.00	-47.76	22.57	22.57	22.57	22.57	22.57
15733	0.00	-43.47	22.50	22.50	22.50	22.50	22.50
15958	0.00	-39.60	22.45	22.45	22.45	22.45	22.45
15983	0.00	-36.12	22.39	22.40	22.40	22.40	22.40
16383	0.00	-33.20	22.35	22.35	22.35	22.35	22.36
16408	0.00	-30.27	22.31	22.32	22.32	22.32	22.32
16433	0.00	-27.35	22.27	22.30	22.30	22.31	22.32
16458	0.00	-24.42	22.22	22.33	22.34	22.36	22.38
16858	0.00	-21.64	22.18	22.48	22.51	22.54	22.59
16883	0.00	-18.86	22.14	22.91	22.96	23.03	23.12
16908	0.00	-16.09	22.10	23.91	24.01	24.13	24.28
16933	0.00	-13.31	22.06	26.00	26.15	26.33	26.57
16958	0.00	-10.53	22.02	30.02	30.22	30.47	30.82
12331	0.00	-7.75	21.97	37.24	37.48	37.82	38.60
12256	0.00	-6.33	21.95	43.00	43.25	44.01	46.19
12181	0.00	-5.24	21.94	48.59	48.97	51.01	55.50
11974	0.00	-4.40	21.92	53.66	54.62	58.93	65.98

7890	0.00	-3.75	21.91	57.97	60.23	67.29	76.25
7743	0.00	-3.23	21.91	61.71	66.09	75.65	86.31
7596	0.00	-2.75	21.90	65.19	72.43	84.06	95.36
5146	0.00	2.75	21.85	73.84	133.80	171.87	195.30
5342	0.00	3.23	21.84	68.10	90.52	120.11	146.24
5538	0.00	3.75	21.83	62.76	73.95	87.21	106.26
9675	0.00	4.40	21.82	57.21	61.50	70.88	81.54
9955	0.00	5.24	21.80	51.22	52.37	57.18	64.43
10055	0.00	6.33	21.78	44.93	45.25	46.87	50.57
10155	0.00	7.75	21.76	38.61	38.83	39.27	40.51
17358	0.00	10.19	21.72	31.46	31.66	31.92	32.33
17383	0.00	12.63	21.68	27.05	27.21	27.42	27.69
17408	0.00	15.07	21.65	24.43	24.55	24.70	24.90
17433	0.00	17.50	21.61	22.96	23.03	23.13	23.26
17458	0.00	19.94	21.58	22.17	22.22	22.27	22.35
3252	0.00	22.38	21.54	21.77	21.80	21.82	21.86
3277	0.00	25.33	21.50	21.57	21.58	21.59	21.61
3302	0.00	28.50	21.46	21.48	21.48	21.48	21.49
3327	0.00	31.91	21.41	21.42	21.42	21.42	21.42
3352	0.00	35.57	21.36	21.36	21.36	21.36	21.36
3377	0.00	39.50	21.31	21.31	21.31	21.31	21.31
3402	0.00	43.74	21.25	21.25	21.25	21.25	21.25
3427	0.00	48.29	21.19	21.19	21.19	21.19	21.19
A'	0.00	50.00	21.17	21.17	21.17	21.17	21.17