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Thermal Response of the 21-PWR Waste Package to a Fire Accident

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A CD is also part of this calculation.

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CONTENTS

CONTENTS (Continued)

Page

FIGURES

Page

TABLES

Page

1. PURPOSE

The objective of this calculation is to evaluate the thermal response of the 21-PWR WP (pressurized water reactor waste package) to the regulatory fire event. The scope of this calculation is limited to the two-dimensional waste package temperature calculations to support the waste package design. The information provided by the sketches attached to this calculation (Attachment IV) is that of the potential design of the type of waste package considered in this calculation. The procedure AP-3.12Q, *Calculations* (Reference 1), and the Development Plan (Reference 24) are used to develop this calculation.

2. METHOD

The solution method employs finite element analysis (FEA) using the commercially available ANSYS Version (V) 5.4 finite element code. Finite element representations of the waste package are developed and analyzed using the transient ANSYS V5.4 solver.

The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information* (Reference 3), were not specified in the Development Plan (Reference 24). With regard to the development of this calculation, the control of the electronic management of data was evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Information*. The evaluation (Reference 4) determined that current work processes and procedures are adequate for the control of electronic management of data for this activity.

3. ASSUMPTIONS

The following assumptions are used for the thermal modeling of the waste package during the fire accident.

3.1 FIRE ACCIDENT ASSUMPTIONS

3.1.1 The fire accident takes place in a uniform environment temperature of 37.8°C (100°F). The rationale for this value is the requirement for fire-exposure testing of transport casks exposed to the sun as given in Section 73(b) of 10 CFR 71 (Code of Federal Regulations, Reference 23). This assumption is used in Section 5.4.

3.1.2 A uniform temperature of 800°C for the waste package surroundings (i.e., flame temperature) is assumed for the fire condition. The rationale for this value is the requirement from 10 CFR 71, Section 73(c)(4) (Reference 23). This assumption is used in Section 5.4.

3.1.3 The fire exposure duration is 30 minutes. The rationale for this value is the requirement from 10 CFR 71, Section 73(c)(4) (Reference 23). This assumption is used in Section 5.1.

3.2 WASTE PACKAGE GEOMETRY ASSUMPTIONS

This section lists the assumptions that are related to the waste package geometry.

3.2.1 The 4-mm loose gap between the inner and outer shells is not considered in this calculation. That is, a perfect contact between the two shells is assumed. The rationale for this assumption is that the subsequent overall thermal resistance is decreased, which is conservative since the limiting heat source during the fire event is located outside the waste package. In addition, no credit is taken for contact thermal resistance at the shell-to-shell interface. This assumption is in Section 5.2.

3.2.2 It is assumed that a small change in basket width has a negligible impact on effective thermal conductivities. Thus, the effective thermal conductivities established in Reference 8, p. 15 for a 0.2235-m basket width remain applicable to this calculation, which uses a 0.2264-m basket width (current 21-PWR waste package design, Attachment IV). The rationale for using the Reference 8 effective thermal conductivities is that effective thermal conductivities are primarily a function of wall temperature, heat generation rate, and fill gas. This assumption is used in Section 5.5.

3.3 HEAT TRANSFER MODES ASSUMPTIONS

This section lists the assumptions that are related to the heat transfer modes within the waste package. The properties linked to radiation heat transfer (emissivity and absorptivity) are treated separately in Section 3.6.

3.3.1 The waste package is assumed to be filled with helium. The rationale for this assumption is that helium as a backfill gas is a design basis (Reference 11). This assumption is used in Section 5.5.

3.3.2 The properties of helium at atmospheric pressure are assumed to be representative of the conditions that helium will experience within the waste package. The rationale for this assumption is the fact that one-atmosphere fill pressure at ambient temperature is representative of the industry standard for storage casks. Reference 5 (page 10) indicates that the highest pressure to which storage casks are filled is approximately 1.5 atm; also, most industry vendors use substantially lower pressure in their designs. Even though the gas internal pressure of the waste package will increase due to the temperature rise, the thermal conductivity of most gases is pressure independent (Reference 6, page 255). Thus using the thermal conductivity at 1 atm is reasonable. This assumption is used in Section 5.5.

3.3.3 It is assumed that a two-dimensional (2-D) finite element representation of a cross section at the midsection of the waste package will be representative of the hottest portion of the waste package. Inherent to this assumption is that no heat transfer is accounted for in the axial direction (adiabatic conditions). The rationale for this conservative assumption is that one maximizes the peak cladding temperature since axial heat transfer occurs in reality and reduces the peak cladding temperature. This assumption is used in Section 5.2.

3.3.4 It is assumed that the heat transfer mode between the WP outer surface and the surroundings, or environment, is radiation, except during exposure to fire when free convection heat transfer of the waste package is included. The rationale for this conservative assumption is that one maximizes the peak cladding temperature. This assumption in used in Section 5.1 and Section 5.4.

3.3.5 Natural convection within the waste package is neglected. The rationale for this conservative assumption is that the dimensions of the cavities within the waste package are such that natural convection is not significant compared to the other modes of heat transfer (conduction and radiation). This assumption is used in Section 5.1 and Section 5.4.

3.3.6 This calculation utilizes the 14×14 SNF (Spent Nuclear Fuel) effective thermal conductivities. The rationale for this assumption is that the 14×14 SNF effective thermal conductivities are recommended by Reference 8. This assumption is used in Section 5.5.7, thoughout the whole fire accident.

3.4 HEAT LOADS ASSUMPTIONS

This section lists all the assumptions that are related to the heat loads. Those related to radiation heat transfer are discussed separately in Section 3.6.

3.4.1 The maximum heat generation rate within a 21-PWR waste package is 11.8 kW. The rationale for this value is the design basis from Reference 25, Section 1.2.4.2. This assumption is used in Section 5.1.

3.4.2 A constant rate of solar energy incident on the outer surface of the waste package equal to 400 cal/cm^2 per 12-hour period is assumed. The rationale for this value is the requirement from 10 CFR 71 (Reference 23) Section 71(c)(1) for the energy incident on the curved surface of a transport cask. The rate of solar energy incidence is maintained during all phases of the accident, that is, from pre-fire condition through post-fire cooling. This assumption is used in Section 5.1.

3.4.3 An axial power peaking factor of 1.25 is applied uniformly to the PWR SNF heat generation rate. The rationale for this value is that PWR reactor cores are designed such that axial peaking factors larger than 1.25 is undesirable for the full duration of a reactor operating cycle for both technical and economic reasons. The reference for the 1.25 value is Reference 26. This assumption is used in Section 5.4 for the calculation of the volumetric heat generation rate.

3.5 BOUNDARY CONDITIONS

This section lists the basis and assumptions that are related to the boundary conditions, other than the heat loads.

3.5.1 The gas that flows around the waste package during the fire accident (pre-fire conditions through post-fire conditions) is taken as air. The rationale for this assumption is that the air composition change resulting from the combustion that takes place around the waste package is ultimately not very significant, since gaseous nitrogen (N_2), the air main component, traditionally reacts in negligible quantities during combustion processes. Thus, oxygen (O_2) depletion is never complete, as adverse transport phenomena (buoyancy, turbulent flow around the waste package, mass diffusion) prevent the oxygen present in the vicinity of the fire from reaching the chemical reaction zone and disappearing from the boundary layer that governs free convection around the waste package ("Chemical reaction zone" is defined as the place where O_2 and fuel are physically transformed into CO_2 and H_2O). This assumption is used in Section 5.1.

3.5.2 Free convection heat transfer at the waste package outer surface is taken into account only during heating of the waste package by the fire (see also assumption 3.3.4). Free convection is assumed to vary based on the correlation for air at normal temperatures and atmospheric pressure per the following equation (Reference 17, converting from engineering units to SI units):

$$h_{conv} = 1.312 \cdot \Delta T^{1/3} \ (\mathrm{W/m^2 \cdot K})$$

(Equation 3.5-1)

where h is the natural convection coefficient, and ΔT is the temperature difference between the outer shell outer surface and the flame temperature, in ^{0}C or K. The rationale for this assumption is that Equation 3.5-1 gives conservatively high values of the heat transfer coefficient for the waste package heating phase. Note the above equation corresponds to the generic free convection coefficient relationship for horizontal cylinders, also found in Reference 17, applied to air. As most free convection correlations, this relationship depends upon the Grashof number (ratio of the buoyancy force to the viscous force), β (volumetric thermal expansion coefficient), thermal conductivity, and thermal diffusivity. This assumption is used in Section 5.1 and Section 5.4.

3.6 RADIATION HEAT TRANSFER ASSUMPTIONS

This section lists the assumptions related to radiation heat transfer.

3.6.1 A value of 1.0 for the emissivity of the waste package surroundings for the pre- and post-fire conditions is assumed. The rationale for this conservative assumption is that one maximizes the calculated radiative energy incident on the waste package outer surface, and, therefore, the waste package temperatures calculated for both the pre-fire condition and the post-fire cooldown. This assumption is used in Section 5.1.

3.6.2 A value of 1.0 for the emissivity of the flame for the fire condition is assumed. The rationale for this conservative assumption is that one maximizes the heating of the waste package. This value exceeds the minimum value of 0.9 specified in Section of 73(c)(4) of 10 CFR 71 (Reference 23). This assumption is used in Section 5.1.

3.6.3 A value of 1.0 for the solar absorptivity of the waste package outer surface is assumed. The rationale for this conservative assumption is that one maximizes the amount of heat received on the waste package outer surface. This assumption is used in Sections 5.1 and 5.4.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

The finite element analysis computer code used for this calculation is ANSYS V5.4. The ANSYS V5.4 software installed on the HP9000/C200 is denoted as ANSYS V5.4L2. ANSYS is a commercially available finite element code and is appropriate for performing thermal analysis of waste packages as utilized in this calculation. The computer platform used for ANSYS was the Hewlett-Packard Model 9000 Series 200 workstation (HP9000/C200), designated as 'gr0', with FCF (Framatome Cogema Fuels) tag number 2002611431 (Reference 7, p. 1), located in Lynchburg, Virginia. The HP Model 9000 Series 200 ANSYS V5.4L2 is identified with Software Tracking Number (STN) 10027-5.4L2-00. The STN was obtained from Software Configuration Management in accordance with appropriate procedures. The ANSYS V5.4L2 evaluations performed in this calculation are fully within the range of validation performed for ANSYS V5.4L2.

Software qualification of ANSYS V5.4L2 is summarized in Reference 7. Inputs to the ANSYS software are included as attachments and are described in the following documentation.

The ANSYS V5.4L2 input and output files of the cases analyzed in this calculation are located in Attachment VI.

4.2 SOFTWARE ROUTINES

None used.

4.3 MODELS

None used.

5. CALCULATION

5.1 FIRE ACCIDENT SCENARIO

This calculation determines the thermal response of the 21-PWR waste package to a fire accident. In addition to the base case, additional runs are performed to demonstrate sensitivity of the PWR fuel assemblies peak cladding temperature.

The conditions defined for the fire accident in Section 73(c)(4) of 10 CFR 71 are as follows:

> The waste package shall be considered totally immersed in a flame temperature equal to at least 800°C, for a period of 30 minutes.
>
> The effective emissivity for gases in the flame shall be at least 0.9.
>
> The waste package outer surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the flame temperature specified, or 0.8, or whichever greater. Heat input from hot gases to the waste package will include the free-convection heat transfer mode in addition to thermal radiation.
>
> No credit shall be taken for artificial cooling of the waste package after termination of exposure to the flame.

For transport package testing, Section 73(b) of 10 CFR 71 (Reference 23) specifies a maximum temperature of 37.8°C (100°F) for the temperature of ambient air before and after the specified 30-minute duration of the fire. Section 71 of 10 CFR 71, for normal conditions of transport, lists the total solar energy incident on the curved surface of a transport cask over a 12-hour period as 400 cal/cm^2.

Based on the above requirements, the fire accident evaluated with the WP at the surface facility is described as follows:

> The waste package is loaded, sealed, and in a horizontal position. The waste package is at steady thermal conditions with radiation heat transfer to the surroundings balancing the sum of volumetric heat generation rates in the fuel rods and uniform solar radiation incident on the waste package outer surface.
>
> The waste package outer surface is instantaneously subjected to the thermal conditions specified for the regulatory fire as described above, producing uniform heating by both radiation and free convection heat transfer modes. Exposure of the waste package to the fire is terminated after 30 minutes.

After termination of the fire, the surrounding air and surfaces return instantly to the temperature conditions existing prior to the accident. Cooling of the WP occurs by radiation to the immediate surroundings only.

Table 5-1 summarizes the heat loads and the boundary conditions used in this calculation for the base case analyzed in Section 6.2.

Table 5-1. 21-PWR Waste Package Evaluations

ITEM	ACCIDENT CONDITION Initial / Fire / Post-Fire	DESCRIPTION
Thermal Load per Fuel Assembly (W)	561.9 / 561.9 / 561.9	Design value (Assumption 3.4.1).
Axial Peaking Factor	1.25 / 1.25 / 1.25	Design value (Assumption 3.4.3).
Temperature of Surroundings (°C)	37.8 / 800 / 37.8	Initial and post-fire value of 37.8°C is from Section 73(b) of 10 CFR 71 (Assumption 3.1.1). For the fire condition, the value of 800°C is from Section 73(c)(4) of 10 CFR 71 (Assumption 3.1.2).
Emissivity of Surroundings	1.0 / 1.0 / 1.0	Initial and post-fire values of 1.0 are used since the surroundings emit radiation at the ambient temperature (Assumption 3.6.1). For the fire condition, the value of 1.0 is conservative relative to the minimum value of 0.9 specified for the flame in Section 73(c)(4) of 10 CFR 71 (Assumption 3.6.2).
Emissivity of WP Outer Surface	0.87 / 0.87 / 0.87	Initial and post-fire values of 0.87 are used based on the value stated in Section 5.5.
Solar Heat Flux	400 cal/cm^2 per 12 hours (constant with time)	The rate of 400 cal/cm^2 per 12-hour period is based on the value stated in Section 71 of 10 CFR 71 for energy incident on the curved surface of a transport cask (Assumption 3.4.2). Setting the absorption rate equal to the rate of incidence is equivalent to value of 1.0 for solar absorptivity, which is conservative (Assumption 3.6.3).
Convection Coefficient	$1.312 \cdot \Delta T^{1/3}$ $W/m^2 \cdot K$	*Free convection relationship for horizontal cylinder in air* (Assumption 3.5.2).

5.2 ANSYS REPRESENTATION GEOMETRY AND INPUT FILES

This section briefly describes the ANSYS V5.4L2 input file format used to develop the ANSYS cases. Each ANSYS V5.4L2 input file is provided as part of the ANSYS output files on the compact disk (CD) associated with this document.

To investigate the thermal response of the 21-PWR waste package to a fire accident, a half symmetry of the 2-D waste package cross section is represented in ANSYS V5.4L2 to capture the temperature distribution in the waste package. The representation includes the waste package inner and outer shells, and a detailed waste package internal structure (tubes, neutron absorber plates, thermal shunts, support guides, among others). Solid connections are assumed between the inner shell and the fuel basket. The 4-mm loose fit between the inner and outer shells is not represented (Assumption 3.2.1). Helium is assumed as the waste package internal fill gas (Assumption 3.3.1). Natural convection is not accounted for within the waste package (Assumption 3.3.5), that is, only conduction and radiation heat transfer apply. The spent nuclear fuel (SNF) assemblies located inside the tubes are represented as homogeneous materials using effective thermal conductivities to estimate the SNF cladding temperatures. The methodology of calculating and using SNF effective thermal conductivities is described in Reference 8 and is summarized in Section 5.3.

ANSYS input files normally include the following:

1) File description, problem evaluated, and additional files needed to run the input file (material property files and heat load files), etc.
2) Parameters and dimensions which are repeatedly used in the representation.
3) Element types.
4) Geometry and mesh.
5) Radiation surfaces and creation of a radiation mesh matrix.
6) Heat sources and boundary conditions.
7) Solution of the problem.
8) Temperature print-out at the desired locations.

The material properties are discussed in Section 5.5. The key parameters used to create the waste package geometry are shown in Table 5-2. The heat loads and the boundary conditions are discussed in Section 5.4.

The mesh of the finite element representation is appropriately generated according to standard engineering practice. Thus, the accuracy and representativeness of the results of this temperature prediction calculation is deemed acceptable. The mesh used for this calculation is shown in Figure 5-1.

Table 5-2. Key Dimensions Used in the Calculation

Outer Diameter	1.564 m (Attachment IV)
Outer Shell Thickness	0.02 m (Attachment IV)
Inner Shell Thickness	0.05 m (Attachment IV)
Tube Thickness	0.005 m (Attachment IV)
Thermal Shunt Thickness	0.005 m (Attachment IV)
Neutron Absorber Plate Thickness	0.007 m (Attachment IV)
Corner and Side Guide Thickness	0.01 m (Attachment IV)
Active Fuel Assembly Length	3.6017 m (Ref. 9, p. 2A-7)
Basket Cell Width	0.2264 m (Attachment IV)

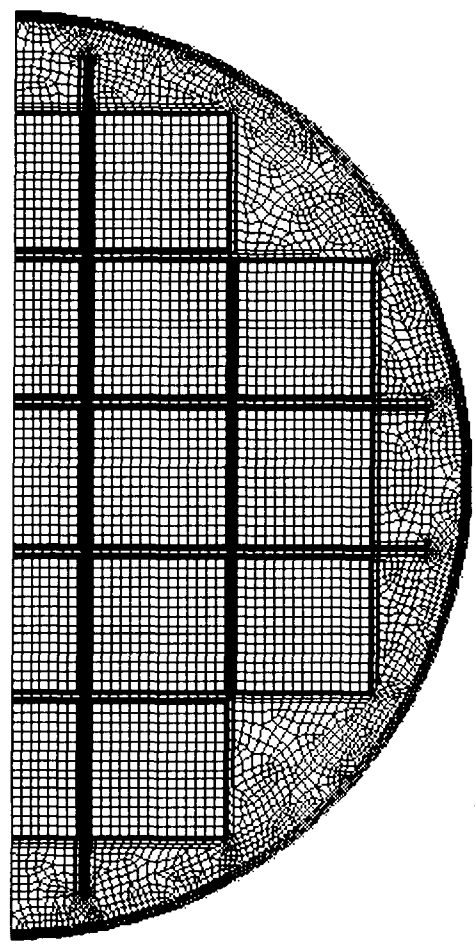

Figure 5-1. 21-PWR Waste Package Mesh

5.3 EFFECTIVE THERMAL CONDUCTIVITY METHODOLOGY

This section describes briefly the effective thermal conductivity methodology, which is paramount to this calculation. This methodology is extensively discussed in Reference 8, which serves as the basis to this section.

The effective thermal conductivity methodology was developed as a way to reduce the computer time necessary for performing waste package thermal calculations. This methodology consists in lumping the individual fuel rods and the surrounding gas present in a waste package basket into a homogeneous medium in order to establish effective (or equivalent) thermal conductivities for peak cladding temperatures predictions. These effective thermal conductivities are specific to the peak cladding temperature, that is, new sets of effective thermal conductivities have to be developed for predicting, for example, maximum fuel pellet temperatures.

The finite element analysis representations used for obtaining these effective thermal conductivities consist in a quarter basket. Thus, these representations represent the basket wall, the fuel rods, the instrument guide-tube and the guide-tubes, the number of which may vary depending on the fuel assembly designs, and the fill gas. The cell wall temperature is used as the boundary condition, while representative heat loads are used. Heat is transferred from fuel rod to fuel rod and then from fuel rod to basket wall through gaseous conduction and radiation heat transfer, natural convection being neglected. Note the constant cell wall temperature serves as the heat sink, the absence of which leads any heat generating system to thermal runaway.

The relationship that gives the effective thermal conductivity is derived in Reference 8, p. 80 and is as follows:

$$k_e = \frac{0.2947 \cdot Q}{4L_a(T_o - T_s)}$$

where

Q : Assembly heat generation (watts)
L_a : Active fuel length (m)
T_o : Peak cladding temperature (^oC)
T_s : Basket wall temperature (^oC)

This calculation uses the 14×14 PWR SNF effective thermal conductivities (shown on Table 5-22) that were recommended in Reference 8 (Assumption 3.3.6).

5.4 WASTE PACKAGE HEAT OUTPUT AND BOUNDARY CONDITIONS

This section discusses the bases for the boundary conditions and heat loads that are used in this calculation. These boundary conditions and heat loads follow the Code of Federal Regulations recommendations (Reference 23) and constitute the base case (Table 5-1 and Table 6-1 contain addtional information) that is discussed throughout the present section. Additional cases with additional conservatisms are analyzed (Table 6-1).

5.4.1 Heat Generation Rate

The waste package heat generation rate is calculated in a manner consistent with the effective thermal conductivities methodology used in this calculation and that was developed in Reference 8. Thus, the volumetric heat generation rate is calculated over the basket volume, by opposition to using the fuel assembly volume. The calculation of the volumetric heat generation rate is performed using the maximum 11.8 kW design basis value (Assumption 3.4.1). Using a 3.6017-m active fuel length (Table 5-2), and a 0.2264-m cell width (Table 5-2), one obtains the volumetric heat generation rate:

$$\text{Volumetric Heat Rate} = \frac{11800}{21 \times 0.2264^2 \times 3.6017} = 3043.7\ \text{W/m}^3$$

(Equation 5.4-1)

Accounting for the 1.25 axial peaking factor discussed in Section 3.4 (Assumption 3.4.3), one obtains a 3804.6 W/m^3 volumetric heat generation rate.

5.4.2 Waste Package Surface Heat Flux

The waste package is assumed exposed to the sun (Assumption 3.4.2). Thus, the value retained for the sun exposure is 400 cal/cm^2 per day (a 12-hour daily exposure duration is assumed). This value is transformed into a SI-units surface heat flux as follows:

$$\text{Surface Heat Flux} = \frac{400\ \text{cal/cm}^2 \times 4.184\ \text{J/cal} \times 10000\ \text{cm}^2/\text{m}^2}{3600\ \text{sec/hr} \times 12\text{hr}} = 387.4\ \text{W/m}^2$$

(Equation 5.4-2)

This heat flux is applied in its entirety to the waste package outer surface, i.e. a waste package 'solar' absorptivity of 1.0 is assumed (Assumption 3.6.3).

5.4.3 Natural Convection on the Waste Package Outer Shell Outside Surface

The surroundings temperature is assumed to be 37.8°C for the pre- and post-fire conditions, and 800°C during exposure to fire (Assumptions 3.1.1 and 3.1.2). The natural convection relationship used in this calculation is as follows (Assumption 3.5.2):

$$h_{conv} = 1.312 \cdot \Delta T^{1/3} \ (\text{W/m}^2\cdot\text{K})$$

(Equation 3.5-1)

For the base case, free convection heat transfer at the waste package outer surface is taken into account only during heating of the waste package by the fire (Assumption 3.5.2). This equation corresponds to the generic free convection coefficient relationship for horizontal cylinders, also found in Reference 17, applied to air.

5.4.4 Thermal Radiation on and from the Waste Package Outer Shell Outside Surface

It is convenient to represent the radiation heat transfer contribution from the flames or the surroundings as a convection coefficient, since this method does not necessitate the creation of ANSYS radiation elements on the waste package outer surface that are computer-time consuming. The following equations from Reference 10, p. 655, details this rationale, starting from the radiation net exchange formulation applied to two enclosed surfaces. In our situation, the first surface is the waste package outer surface (index 1), and the second surface is the surroundings surface (index 2):

$$\phi_{1\rightarrow 2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2} + \frac{1}{A_1 F_{12}}}$$

(Equation 5.4-3)

The assumptions used along this relationship are as follows: the surroundings temperature is uniform (Assumption 3.1.2), that is the surroundings components are assumed to be at the same temperature, 37.8°C before and after the fire event, and 800°C during the fire event (Assumption 3.1.1). Noticing that with $\varepsilon_2 = 1$, and that F_{12} is the view factor that represents the fraction of the waste package radiating heat flux received by the surroundings and is equal to 1.0, this equation becomes:

$$\phi_{1\rightarrow 2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1}}$$

$$= \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1 + \varepsilon_1}{\varepsilon_1 A_1}}$$

$$= A_1\varepsilon_1\sigma(T_1^4 - T_2^4)$$
$$= A_1\varepsilon_1\sigma(T_1^2 + T_2^2)(T_1^2 - T_2^2)$$
$$= A_1\varepsilon_1\sigma(T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2)$$
$$= h_{rad}A_1(T_1 - T_2)$$

(Equation 5.4-4)

where

$$h_{rad} = \varepsilon_1\sigma(T_1^2 + T_2^2)(T_1 + T_2) \quad (W/m^2\cdot K)$$

(Equation 5.4-5)

and

h_{rad} : Effective coefficient for radiation heat transfer ($W/m^2\cdot K$)
$\phi_{1\rightarrow 2}$: Heat flux exchanged between surface 1 and surface 2 (W)
A_1, A_2 : Outer shell and surroundings areas, respectively (m^2)
ε_1,ε_2 : Outer shell and surroundings emissivities, respectively
F_{12} : View factor between the waste package outer surface and the surroundings
σ : Stefan-Boltzmann constant ($5.67\cdot 10^{-8}$ $W/m^2\cdot K^4$)
T_1, T_2 : Outer shell and surroundings temperatures, respectively (K)

The surroundings emissivity is 1.0 (Assumption 3.6.1 and 3.6.2) which is conservative during exposure to fire. The 0.87 value shown on Table 5-9 is used for the waste package outer surface emissivity.

5.4.5 Equivalent Convection Coefficient on the Waste Package Outer Surface

The summation of the natural convection and the radiation heat transfer effective coefficient contributions gives the equivalent convection coefficient, as follows:

$$h_{equi} = h_{conv} + h_{rad}$$

(Equation 5.4-6)

For the base case, one obtains Table 5-3 and Table 5-4, the surroundings temperature being 37.8°C and 800°C, respectively. For Case #2 and Case #3 (described in Table 6-1), one obtains Table 5-5 through Table 5-7. Naturally, $h_{equi} = h_{rad}$ before and after the fire event since natural convection is conservatively not accounted for during these stages (Assumption 3.5.2). The equivalent convection coefficients are used in the ANSYS software through the files shown in Attachment II.

Table 5-3. Equivalent Convection Coefficient (Base Case; T_{surr} = 37. 8°C, $\varepsilon_{Outer\ Shell}$ = 0.87)

Surroundings Temperature (°C)	Surroundings Temperature (K)	Waste Package Outer Surface Temperature (°C)	Waste Package Outer Surface Temperature (K)	h_{eff} ($W/m^2 \cdot K$)
37.8	310.95	100	373.15	8.0
37.8	310.95	150	423.15	10.0
37.8	310.95	200	473.15	12.4
37.8	310.95	250	523.15	15.2
37.8	310.95	300	573.15	18.5
37.8	310.95	350	623.15	22.3
37.8	310.95	400	673.15	26.7
37.8	310.95	450	723.15	31.6
37.8	310.95	500	773.15	37.1
37.8	310.95	550	823.15	43.3
37.8	310.95	600	873.15	50.2
37.8	310.95	650	923.15	57.8
37.8	310.95	700	973.15	66.1
37.8	310.95	750	1023.15	75.3
37.8	310.95	800	1073.15	85.2

Table 5-4. Equivalent Convection Coefficient (Base Case; T_{surr} = 800°C, $\varepsilon_{Outer\ Shell}$ = 0.87)

Surroundings Temperature (°C)	Surroundings Temperature (K)	Waste Package Outer Surface Temperature (°C)	Waste Package Outer Surface Temperature (K)	h_{eff} (W/m²·K)
800	1073.15	100	373.15	103.7
800	1073.15	150	423.15	109.6
800	1073.15	200	473.15	116.0
800	1073.15	250	523.15	123.0
800	1073.15	300	573.15	130.6
800	1073.15	350	623.15	138.9
800	1073.15	400	673.15	147.9
800	1073.15	450	723.15	157.6
800	1073.15	500	773.15	168.1
800	1073.15	550	823.15	179.4
800	1073.15	600	873.15	191.4
800	1073.15	650	923.15	204.3
800	1073.15	700	973.15	217.9
800	1073.15	750	1023.15	232.2

Table 5-5. Equivalent Convection Coefficient (Case #2; T_{surr} = 800°C, $\varepsilon_{Outer\ Shell}$ = 0.87)

Surroundings Temperature (°C)	Surroundings Temperature (K)	Waste Package Outer Surface Temperature (°C)	Waste Package Outer Surface Temperature (K)	h_{eff} (W/m²·K)
800	1073.15	100	373.15	127.0
800	1073.15	150	423.15	132.3
800	1073.15	200	473.15	138.1
800	1073.15	250	523.15	144.5
800	1073.15	300	573.15	151.4
800	1073.15	350	623.15	159.0
800	1073.15	400	673.15	167.2
800	1073.15	450	723.15	176.1
800	1073.15	500	773.15	185.7
800	1073.15	550	823.15	195.9
800	1073.15	600	873.15	206.8
800	1073.15	650	923.15	218.2
800	1073.15	700	973.15	230.1
800	1073.15	750	1023.15	241.8

Table 5-6. Equivalent Convection Coefficient (Case #3; T_{surr} = 37.8°C, $\varepsilon_{Outer\ Shell}$ = 0.5)

Surroundings Temperature (°C)	Surroundings Temperature (K)	Waste Package Outer Surface Temperature (°C)	Waste Package Outer Surface Temperature (K)	h_{eff} (W/m²·K)
37.80	310.95	100	373.15	4.6
37.80	310.95	150	423.15	5.7
37.80	310.95	200	473.15	7.1
37.80	310.95	250	523.15	8.8
37.80	310.95	300	573.15	10.7
37.80	310.95	350	623.15	12.8
37.80	310.95	400	673.15	15.3
37.80	310.95	450	723.15	18.2
37.80	310.95	500	773.15	21.3
37.80	310.95	550	823.15	24.9
37.80	310.95	600	873.15	28.8
37.80	310.95	650	923.15	33.2
37.80	310.95	700	973.15	38.0
37.80	310.95	750	1023.15	43.3
37.80	310.95	800	1073.15	49.0

Table 5-7. Equivalent Convection Coefficient (Case #3; T_{surr} = 800°C, $\varepsilon_{Outer\ Shell}$ = 1.0)

Surroundings Temperature (°C)	**(K)**	**Waste Package Outer Surface Temperature (°C)**	**(K)**	**h_{eff} (W/m²·K)**
800	1073.15	100	373.15	117.5
800	1073.15	150	423.15	124.3
800	1073.15	200	473.15	131.7
800	1073.15	250	523.15	139.8
800	1073.15	300	573.15	148.6
800	1073.15	350	623.15	158.2
800	1073.15	400	673.15	168.6
800	1073.15	450	723.15	179.8
800	1073.15	500	773.15	191.9
800	1073.15	550	823.15	204.9
800	1073.15	600	873.15	218.9
800	1073.15	650	923.15	233.8
800	1073.15	700	973.15	249.6
800	1073.15	750	1023.15	266.1

5.5 THERMAL PROPERTIES

The number of digits in the values cited herein may be the result of a calculation or may reflect the results of a units conversion; consequently, it should not be noted as indication of accuracy. The material properties are used in the ANSYS software through the file shown in Attachment I, at the exception of the SNF effective thermal conducitivity file, shown in Attachment III.

Table 5-8 lists the materials and fill gases used in the 21-PWR waste package fire simulation.

Table 5-8. Waste Package Materials and Fill Gases

Waste Package Component	Material (Attachment IV)
Outer Shell	Alloy 22 (SB-575 N06022)
Inner Shell	316NG (nuclear grade) (SA-240 S31600)
Basket Guides & Basket Tubes	A 516 Grade 70 (SA-516 K02700)
Basket Neutron Absorber Plates	Neutronit A 978
Basket Thermal Shunts	Aluminum 6061 (SB-209 A96061)
Waste Package Fill Gases	
Waste Package Internal Fill Gas	Helium (Reference 11, p. 126)

5.5.1 Alloy 22

Table 5-9 lists the density and emissivity of Alloy 22. The density is taken from Reference 12, Section 7.1 and the emissivity is taken from Reference 13, p. 10-297 for nickel-chromium alloy. Table 5-10 lists the thermal conductivity and specific heat of Alloy 22. Values for thermal conductivity and specific heat are taken from Reference 14, p. 13.

Table 5-9. Density and Emissivity of Alloy 22

Density (kg/m^3) (Ref. 12, Section 7.1)	Emissivity (Ref. 13, p. 10-297)
8690	0.87

Table 5-10. Thermal Conductivity and Specific Heat of Alloy 22 (Ref.14, p. 13)

Temperature (°C)	Thermal Conductivity (W/m·K)	Temperature (°C)	Specific Heat (J/kg·K)
48	10.1	52	414
100	11.1	100	423
200	13.4	200	444
300	15.5	300	460
400	17.5	400	476
500	19.5	500	485
600	21.3	600	514

5.5.2 Stainless Steel 316 NG

Material properties of stainless steel 316 are used for stainless steel 316NG. 316NG, which is a 316 steel with tightened control on carbon and nitrogen content, has the same mechanical and physical properties as stainless steel 316 (Reference 15). Table 5-11 lists the density and emissivity of stainless steel 316NG. The density is taken from Reference 16, Table X1. The emissivity is taken from Reference 17, Table 4.3.2. Since the emissivity is provided as a range of 0.57 to 0.66 in Reference 17, the mean value is used in this calculation. Table 5-12 lists the thermal conductivity and specific heat of stainless steel 316NG. Values for thermal conductivity and thermal diffusivity of stainless steel 316NG (16Cr-12Ni-2Mo) are taken from Reference 18, Section II, Table TCD (p. 606). The conversion of thermal diffusivity to specific heat is performed using Equation 5-1.

$$\text{Specific Heat (Btu / lb}\cdot{}^{\circ}\text{F)} = \frac{\text{Thermal Conductivity (Btu / hr}\cdot\text{ft}\cdot{}^{\circ}\text{F)}}{\text{Density (lb / ft)} \times \text{Thermal Diffusivity (ft}^2\text{ / hr)}}$$

(Equation 5.5-1)

Table 5-11. Density and Emissivity of 316NG

Density (kg/m^3) (Ref. 16, Table X1)	Emissivity (Ref.17, Table 4.3.2)
7980	0.62

Table 5-12. Thermal Conductivity and Specific Heat of 316NG
(Ref. 18, section II, Table TCD [p. 606])

Temperature (°F)	Temperature (°C)	Thermal Diffusivity (ft^2/hr)	Thermal Conductivity (Btu/hr·ft·°F)	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)
70	21.11	0.134	7.7	13.3	483
100	37.78	0.136	7.9	13.7	488
150	65.56	0.138	8.2	14.2	499
200	93.33	0.141	8.4	14.5	501
250	121.11	0.143	8.7	15.1	511
300	148.89	0.145	9.0	15.6	522
350	176.67	0.148	9.2	15.9	522
400	204.44	0.151	9.5	16.4	529
450	232.22	0.153	9.8	17.0	538
500	260.00	0.156	10.0	17.3	539
550	287.78	0.159	10.3	17.8	544
600	315.56	0.162	10.5	18.2	545
650	343.33	0.164	10.7	18.5	548
700	371.11	0.167	11.0	19.0	554
750	398.89	0.170	11.2	19.4	554
800	426.67	0.173	11.5	19.9	559
850	454.44	0.176	11.7	20.3	559
900	482.22	0.178	12.0	20.8	567
950	510.00	0.181	12.2	21.1	566
1000	537.78	0.184	12.4	21.5	566

1050	565.56	0.186	12.7	22.0	574
1100	593.33	0.189	12.9	22.3	574
1150	621.11	0.191	13.1	22.7	576
1200	648.89	0.194	13.3	23.0	576
1250	676.67	0.196	13.6	23.5	583
1300	704.44	0.199	13.8	23.9	583
1350	732.22	0.201	14.0	24.2	585
1400	760.00	0.203	14.2	24.6	588
1450	787.78	0.206	14.4	24.9	587
1500	815.56	0.208	14.6	25.3	590

5.5.3 A 516 Carbon Steel

Table 5-13 lists the density and emissivity of A 516 carbon steel. The density is taken from Reference 19, Section 14.1 and the emissivity (average for smooth oxidized iron) is taken from Reference 17, Section 4.3.2. Table 5-14 lists the thermal conductivity and specific of A516. Values for thermal conductivity and thermal diffusivity of A516 (C-Mn-Si) are taken from Reference 18, Section II, Table TCD (p. 600). The conversion of thermal diffusivity to specific heat is defined in Equation 5.5-1.

Table 5-13. Density and Emissivity of A 516 Carbon Steel

Density (kg/m^3) (Ref. 19, Section 14.1)	**Emissivity** (Ref. 17, Table 4.3.2)
7850	0.80

Table 5-14. Thermal Conductivity and Specific Heat of A 516 Carbon Steel (Ref.18, section II, Table TCD [p. 600])

Temperature		**Thermal Diffusivity**	**Thermal Conductivity**	**Thermal Conductivity**	**Specific Heat**
(°F)	**(°C)**	**(ft^2/hr)**	**(Btu/hr·ft·°F)**	**(W/m·K)**	**(J/kg·K)**
70	21.11	0.454	23.6	40.8	444
100	37.78	0.443	23.9	41.4	461
150	65.56	0.433	24.2	41.9	477
200	93.33	0.422	24.4	42.2	494
250	121.11	0.414	24.4	42.2	504
300	148.89	0.406	24.4	42.2	513
350	176.67	0.396	24.3	42.1	524
400	204.44	0.386	24.2	41.9	536
450	232.22	0.375	23.9	41.4	545
500	260.00	0.364	23.7	41.0	556
550	287.78	0.355	23.4	40.5	563
600	315.56	0.346	23.1	40.0	570
650	343.33	0.333	22.7	39.3	582
700	371.11	0.320	22.4	38.8	598
750	398.89	0.308	22.0	38.1	610
800	426.67	0.298	21.7	37.6	622
850	454.44	0.286	21.2	36.7	633
900	482.22	0.274	20.9	36.2	652

950	510.00	0.262	20.5	35.5	668
1000	537.78	0.248	20.0	34.6	689
1050	565.56	0.237	19.6	33.9	707
1100	593.33	0.228	19.2	33.2	719
1150	621.11	0.213	18.7	32.4	750
1200	648.89	0.197	18.2	31.5	789
1250	676.67	0.179	17.5	30.3	835
1300	704.44	0.155	16.7	28.9	920
1350	732.22	0.119	15.8	27.4	1134
1400	760.00	0.077	15.3	26.5	1698
1450	787.78	0.154	15.1	26.1	838
1500	815.56	0.169	15.1	26.1	763

5.5.4 Aluminum Alloy 6061

Table 5-15 lists the density and emissivity of aluminum alloy 6061. The density is taken from Reference 18, Section II, Table NF-2, and the emissivity is taken from Reference 17, Table 4.3.2 for rough aluminum plate. Table 5-16 lists the thermal conductivity and specific heat of aluminum alloy 6061. Values for thermal conductivity and diffusivity are taken from Reference 18, Section II, Table TCD (p. 612). The conversion of thermal diffusivity to specific heat is defined in Equation 5.5-1.

Table 5-15. Density and Emissivity of Aluminum Alloy 6061

Density (kg/m^3) (Ref. 18, Section II, Table NF-2)	Emissivity (Ref. 17, Table 4.3.2)
2713	0.07

Table 5-16. Thermal Conductivity and Specific Heat of Aluminum Alloy 6061
(Ref.18, section II, Table TCD [p. 612])

Temperature		Thermal Diffusivity	Thermal Diffusivity	Thermal Conductivity	Thermal Conductivity	Specific Heat
(°F)	(°C)	(ft^2/hr)	(m^2/s)	(Btu/hr·ft·°F)	(W/m·K)	(J/kg·K)
70	21.11	2.66	0.0000686	96.1	166.3	893
100	37.78	2.66	0.0000686	96.9	167.7	901
150	65.56	2.65	0.0000684	98.0	169.6	914
200	93.33	2.65	0.0000684	99.0	171.3	924
250	121.11	2.64	0.0000681	99.8	172.7	935
300	148.89	2.63	0.0000679	100.6	174.1	946
350	176.67	2.62	0.0000676	101.3	175.3	956
400	204.44	2.62	0.0000676	101.9	176.4	962

5.5.5 Neutronit A 978

Table 5-17 lists the density and emissivity of boron stainless steel Neutronit A 978. Table 5-18 lists the thermal conductivity and specific heat of boron stainless steel Neutronit A 978. The density, specific heat, and thermal conductivity are taken from Reference 20, and the emissivity is taken from Reference 17, Table 4.3.2 as average for heated stainless steel 316.

Table 5-17. Density and Emissivity of Boron Stainless Steel Neutronit A 978

Density (kg/m^3) (Ref. 20)	Emissivity (Ref. 17, Table 4.3.2)
7760	0.62

Table 5-18. Thermal Conductivity and Specific Heat of Boron Stainless Steel Neutronit A 978 (Ref.20)

Temperature (°C)	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)
20	10.3	500
130	11.7	
260	13.4	

5.5.6 Helium

Table 5-19 gives the helium density at 27°C. Table 5-20 lists the helium specific heat and thermal conductivity.

Table 5-19. Density of Helium (1 atm) (Ref. 21, p. 19.71)

Density (kg/m^3)
0.1625

Table 5-20. Thermal Conductivity and Specific Heat of Helium (1 atm) (Ref. 21, p. 19.71)

Temperature		Specific Heat		Thermal Conductivity	
(°F)	(°C)	(Btu/lb·°F)	(J/kg·K)	(Btu/hr·ft·°F)	(W/m·K)
0	-17.78	1.2412	5196.7	0.08064	0.1396
40	4.44	1.2412	5196.7	0.08542	0.1478
80	26.67	1.2411	5196.2	0.09008	0.1559
120	48.89	1.2411	5196.2	0.09465	0.1638
160	71.11	1.2411	5196.2	0.09912	0.1716
200	93.33	1.2411	5196.2	0.10351	0.1791
280	137.78	1.2411	5196.2	0.11207	0.1940
320	160.00	1.2411	5196.2	0.11624	0.2012
360	182.22	1.2411	5196.2	0.12036	0.2083
400	204.44	1.2411	5196.2	0.12441	0.2153
440	226.67	1.2411	5196.2	0.12841	0.2222
480	248.89	1.2411	5196.2	0.13236	0.2291
520	271.11	1.2411	5196.2	0.13626	0.2358
560	293.33	1.2411	5196.2	0.14011	0.2425
600	315.56	1.2411	5196.2	0.14392	0.2491

640	337.78	1.2412	5196.7	0.14768	0.2556
720	382.22	1.2412	5196.7	0.15507	0.2684
800	426.67	1.2412	5196.7	0.16235	0.2810

5.5.7 Spent Nuclear Fuel

Table 5-21 lists the density and specific heat of the homogeneous PWR assembly represented in ANSYS. The value for the specific heat is taken from Reference 22, p. 28. The density is calculated based on the fuel assembly mass (773.4 kg - Reference 22, p. 28) and the basket volume (active fuel length × basket width^2). Table 5-22 shows the effective thermal conductivities (Reference 8, p. 146) that correspond to the situation where the baskets are loaded with 14x14 PWR fuel assemblies with helium as the filling gas.

Table 5-21. Density and Specific Heat of Homogeneous PWR Fuel Assembly

Density (kg/m^3)	**Specific Heat (J/kg·K)** (Ref. 22, section 7.2.1.1)
4189.3	274

Table 5-22. Effective Thermal Conductivity of Homogeneous 14×14 PWR SNF Assembly (Ref. 8, p. 146)

Temperature (°C)	**Thermal Conductivity (W/m·K)**
25	0.384
50	0.423
100	0.512
150	0.616
200	0.736
250	0.874
300	1.028
350	1.201
400	1.392

6. RESULTS

6.1 OUTLINE

The results provided in this section are extracted from the ANSYS V5.4 output files (the files are stored on the CD provided with this document).

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

Three cases are analyzed in this calculation. The main features of these cases, from a heat load and boundary condition standpoint, are shown in Table 6-1. Note the base case was more extensively described in Table 5-1. h represents the natural convection relationship shown in Table 6-1. 3·h (for case #2) means that the natural convection coefficient obtained using the natural convection relationship from Table 6-1 is multiplied by 3.

Table 6-1. Cases Description

CASE	Thermal Load per Assembly (W)	Axial Peaking Factor	Surroundings Temperature (°C)	Surroundings Emissivity
Base Case (Fire21pwr.inp)	561.9 / 561.9 / 561.9	1.25 / 1.25 / 1.25	37.8 / 800.0 / 37.8	1.0 / 1.0 / 1.0
Case #2 (Case2.inp)	561.9 / 561.9 / 561.9	1.25 / 1.25 / 1.25	37.8 / 800.0 / 37.8	1.0 / 1.0 / 1.0
Case #3 (Case3.inp)	561.9 / 561.9 / 561.9	1.25 / 1.25 / 1.25	37.8 / 800.0 / 37.8	1.0 / 1.0 / 1.0
CASE	**WP Outer Surface Emissivity**	**Solar Heat Flux (cal/cm²)**	**Natural Convection Relationship**	**Fire Exposure Duration**
Base Case (Fire21pwr.inp)	0.87 / 0.87 / 0.87	400.0 / 400.0 / 400.0	0 / h / 0	30 min
Case #2 (Case2.inp)	0.87 / 0.87 / 0.87	400.0 / 400.0 / 400.0	0 / 3·h / 0	30 min
Case #3 (Case3.inp)	0.5 / 1.0 / 0.5	400.0 / 400.0 / 400.0	0 / h / 0	30 min

The peak cladding temperature for the base case is 379°C. The peak cladding temperatures for Case #2 and Case #3 are 397°C and 438°C, respectively. Additional information regarding the temperature distributions can be found in the two following subsections, Sections 6.3 and 6.4.

6.2 BASE CASE

Table 6-2 shows the temperature variation versus time at selected locations. Time t = 0.0 hr represents the pre-fire steady-state conditions. The fire ends at t = 0.5 hr. The peak cladding temperature is obtained within the baskets the corner of which touches the inner shell wall. Table 6-2 temperatures are plotted in Figure 6-1.

Table 6-2. Temperature Summary for the Base Case

	ANSYS FEA Temperatures (°C)			
Time (hrs)	Peak Cladding Temperature at the Center of the Center Cell	Cladding Temperature of the Peak Cladding Temperature Point	Inner Shell Inside Surface Temperature	Outer Shell Outside Surface Temperature
0.00	265	168	159	158
0.08	265	174	253	325
0.17	265	199	321	387
0.25	265	232	379	437
0.33	265	269	429	481
0.42	265	305	473	518
0.50	265	342	**510**	**551**
0.58	265	370	468	458
0.67	265	378	444	434
0.75	265	**379**	424	414
0.83	265	377	408	399
0.92	265	373	393	385
1.00	265	369	381	373
1.50	265	340	330	324
2.00	266	316	299	294
2.50	269	296	278	274
3.50	276	269	250	246
4.50	286	250	232	229
5.50	295	237	220	217
6.50	303	227	211	209
7.50	308	220	205	202
8.50	312	214	200	197
9.50	314	209	195	193
10.50	**314**	205	192	190
11.50	314	202	189	187
12.50	313	199	187	185
13.50	312	196	185	183
14.50	311	194	183	181
15.50	309	193	181	179
16.50	307	191	180	178

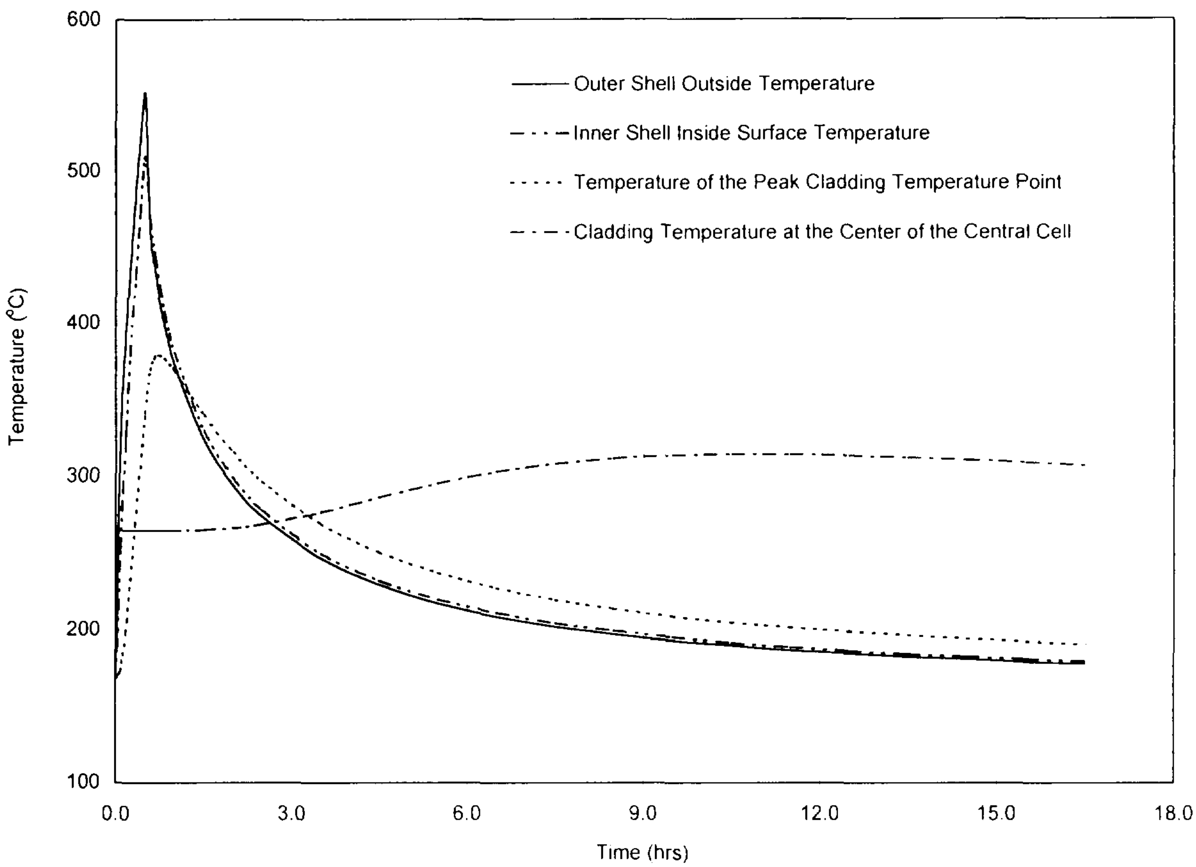

Figure 6-1. Temperature Variation of Selected Locations (Base Case)

6.3 CASE #2

For Case #2, the different conditions used during exposure to fire (as shown in Table 6-1) require the calculation of new equivalent convection coefficients, which are shown in Table 5-5.

Table 6-3 shows the temperature variation versus time at selected locations. Time t = 0.0 hr represents the pre-fire steady-state conditions. The fire ends at t = 0.5 hr. The peak cladding temperature is obtained within the baskets the corner of which are the closest to the inner shell wall. Table 6-3 temperatures are plotted in Figure 6-2.

Table 6-3. Temperature Summary for Case #2

	ANSYS FEA Temperatures (°C)			
Time (hrs)	Peak Cladding Temperature at the Center of the Center Cell	Cladding Temperature of the Peak Cladding Temperature Point	Inner Shell Inside Surface Temperature	Outer Shell Outside Surface Temperature
0.00	265	168	159	158
0.08	265	175	266	345
0.17	265	203	341	409
0.25	265	241	402	462
0.33	265	281	454	506
0.42	265	321	497	544
0.50	265	359	**534**	**574**
0.58	265	388	488	478
0.67	265	396	462	451
0.75	265	**397**	441	431
0.83	265	394	423	413
0.92	265	389	408	399
1.00	265	384	395	386
1.50	265	352	340	334
2.00	266	325	307	302
2.50	269	304	285	280
3.50	277	275	255	251
4.50	288	255	236	233
5.50	298	241	223	221
6.50	306	231	214	212
7.50	311	223	207	205
8.50	315	216	202	200
9.50	317	211	198	196
10.50	**318**	207	194	192
11.50	318	204	191	189
12.50	317	201	188	187
13.50	315	198	186	185
14.50	314	196	184	183
15.50	312	194	183	181
16.50	310	192	181	180

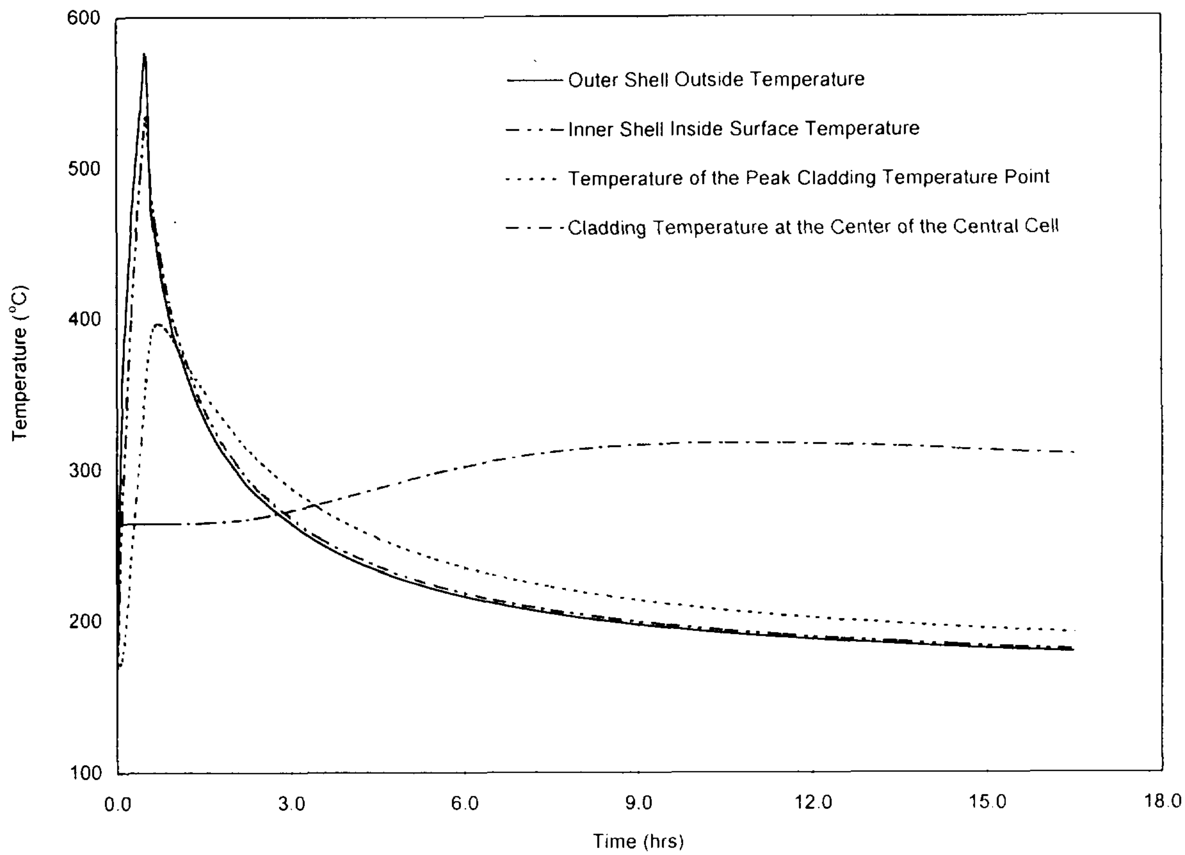

Figure 6-2. Temperature Variation of Selected Locations (Case #2)

6.4 CASE #3

For Case #3, the different conditions used (as shown in Table 6-1) require the calculation of new equivalent convection coefficients, which are shown in Table 5-6 and Table 5-7.

Table 6-4 shows the temperature variation versus time at selected locations. Time t = 0.0 hr represents the pre-fire steady-state conditions. The fire ends at t = 0.5 hr. The peak cladding temperature is obtained within the baskets the corner of which touches the inner shell wall. Table 6-4 temperatures are plotted in Figure 6-3.

Table 6-4. Temperature Summary for Case #3

	ANSYS FEA Temperatures (°C)			
Time (hrs)	Peak Cladding Temperature at the Center of the Center Cell	Cladding Temperature of the Peak Cladding Temperature Point	Inner Shell Inside Surface Temperature	Outer Shell Outside Surface Temperature
0.00	307	216	208	207
0.08	307	222	308	380
0.17	307	250	379	443
0.25	307	286	437	494
0.33	307	324	487	536
0.42	307	363	528	572
0.50	307	399	**562**	**601**
0.58	307	427	525	518
0.67	307	437	502	495
0.75	307	**438**	484	477
0.83	307	437	469	462
0.92	307	434	455	449
1.00	307	430	444	438
1.50	308	404	396	391
2.00	309	380	366	362
2.50	312	362	345	342
3.50	321	334	317	314
4.50	333	315	299	296
5.50	344	301	286	283
6.50	353	290	276	273
7.50	360	282	268	266
8.50	364	275	262	260
9.50	366	269	257	255
10.50	**368**	265	253	251
11.50	368	261	250	248
12.50	367	258	247	245
13.50	366	255	244	243
14.50	364	252	242	241
15.50	362	250	240	238
16.50	360	248	238	237

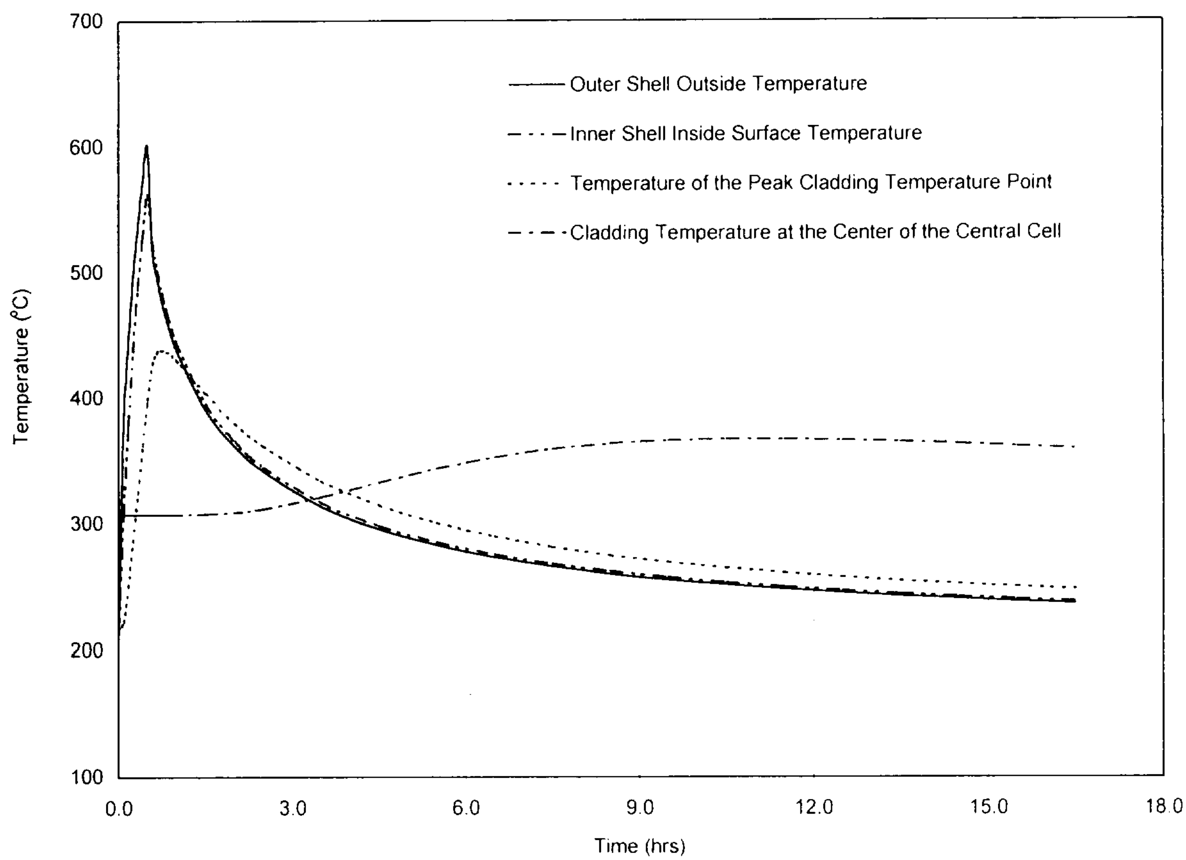

Figure 6-3. Temperature Variation of Selected Locations (Case #3)

7. REFERENCES

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8. ATTACHMENTS

The attachments to this calculation are summarized in Table 8-1.

Table 8-1. Attachments of Supporting Documentation for 21-PWR WP Analysis

Attachment Number	Description	Pages
I	Material properties file	3
II	Convection coefficient files	3
III	SNF Effective thermal conductivity file	1
IV	Sketches	3
V	List of ANSYS output files contained on CD	1
VI	Compact disk (CD) (1 of 1) containing all the input files and the ANSYS output files (see Attachment V for list of files)	N/A

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/COM,    18      AL 6061               D/E Plates (Thermal Shunts)
/COM,    19      Neutronit A 978       A/B/C Plates
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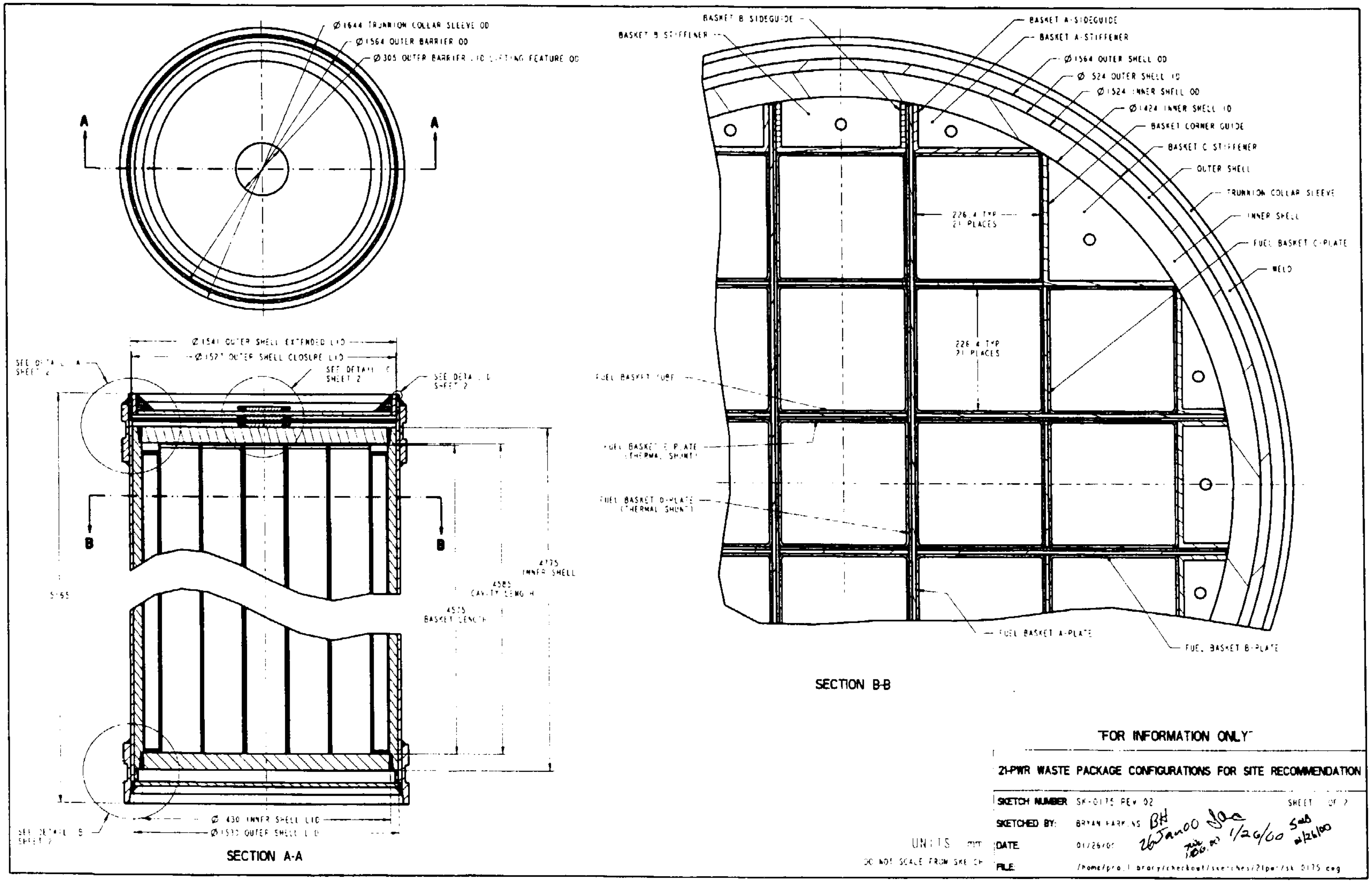
SECTION A-A
SECTION B-B
BASKET B SIDEGUIDE
BASKET B STIFFENER
BASKET A-SIDEGUIDE
BASKET A-STIFFENER
Ø 1564 OUTER SHELL OD
Ø 1424 INNER SHELL ID
BASKET CORNER GUIDE
BASKET C STIFFENER
OUTER SHELL
TRUNNION COLLAR SLEEVE
INNER SHELL
FUEL BASKET C-PLATE
WELD
FUEL BASKET A-PLATE
FUEL BASKET B-PLATE
"FOR INFORMATION ONLY"
21-PWR WASTE PACKAGE CONFIGURATIONS FOR SITE RECOMMENDATION
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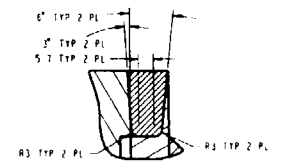
DATE
FILE



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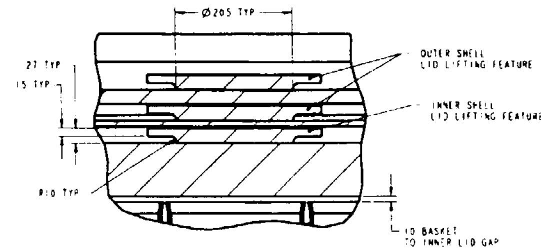

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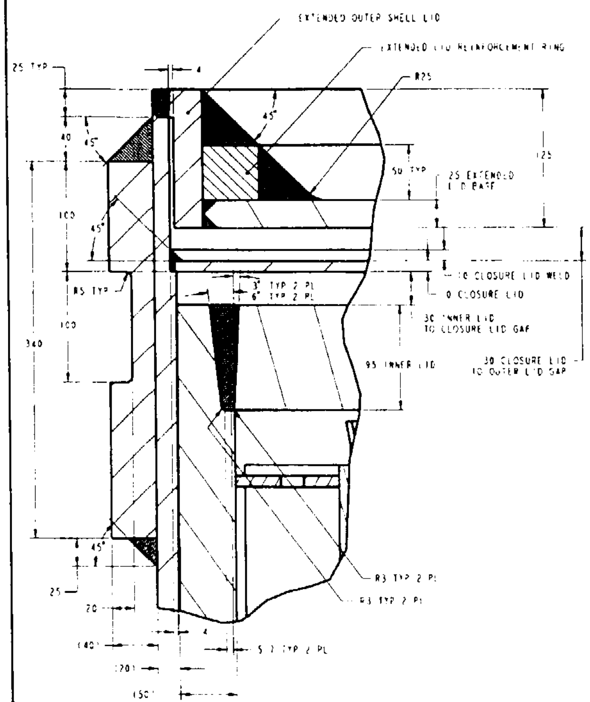


DETAIL A

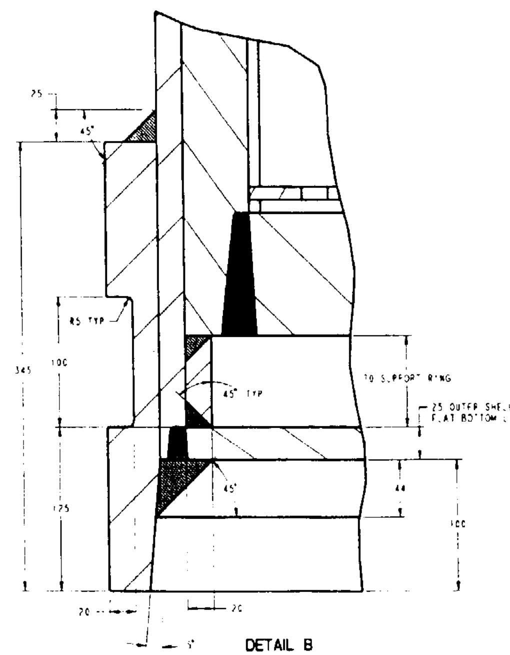
21-PWR WASTE PACKAGE ASSEMBLY WITH STAINLESS STEEL/BORON PLATES

* 21-PWR CONTROL ROD WASTE PACKAGE ASSEMBLY WITH CARBON STEEL PLATES

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY ROD
BASKET A SIDEGUIDE	SA 516 K02700	10	27	32
BASKET A-STIFFENER	SA 516 K02700	10	0.72	64
BASKET B SIDEGUIDE	SA-516 K02700	10	36	16
BASKET B-STIFFENER	SA-516 K02700	10	1.5	32
BASKET C-STIFFENER	SA-516 K02700	10	2.3	32
BASKET CORNERGUIDE	SA 516 K02700	10	42	16
FUEL BASKET A-PLATE	NEUTRONIT A 978	7	85	8
	*SA 516 K02700	*7	*86	*8
FUEL BASKET B PLATE	NEUTRONIT A 978	7	85	8
	*SA-516 K02700	*7	*86	*8
FUEL BASKET C PLATE	NEUTRONIT A 978	7	44	16
	*SA 516 K02700	*7	*45	*16
FUEL BASKET D-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET E PLATE	SB 209 A96061 T4	5	21	8
FUEL BASKET TUBE	SA-516 K02700	5	164	21
INNER SHELL	SA-240 S31600	50	8709	1
INNER SHELL LID	SA-240 S31600	95	1200	2
INNER LID LIFTING FEATURE	SA 240 S31600	27	12	1
OUTER SHELL	SB-575 N06022	20	4193	1
EXTENDED OUTER SHELL LID	SB-575 N06022	25	137	1
EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25	366	1
OUTER LID LIFTING FEATURE	SB-575 N06022	27	13	2
EXTENDED LID REINFORCEMENT RING	SB-575 N06022	50	91	1
OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	10	159	1
OUTER SHELL FLAT BOTTOM LID	SB-575 N06022	25	395	1
UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	507	1
LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	457	1
INNER SHELL SUPPORT RING	SB-575 N06022	20	41	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	249	**
TOTAL 316 WELDS	SFA-5.9 S31680	-	128	**
WASTE PACKAGE ASSEMBLY	-	-	26035	1
			*26059	*1
PWR FUEL ASSEMBLY			773.4*	21
WP ASSEMBLY WITH SNF		-	42277	
		-	*42301	*1

* CRWMS M&O 1997. WASTE CONTAINER CAVITY SIZE DETERMINATION. BBAA00000-01717-0200-00026 REV 00. LAS VEGAS, NV: CRWMS M&O. ACC: MOL.19980106.006

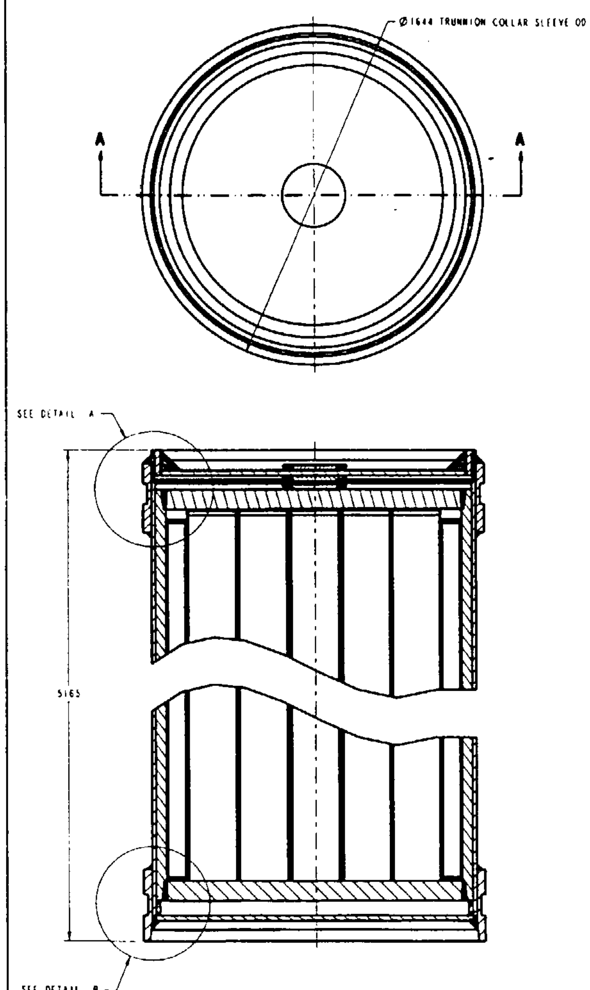
** REFER TO SK-0191 REV 00 "21-PWR WASTE PACKAGE WELD CONFIGURATION"



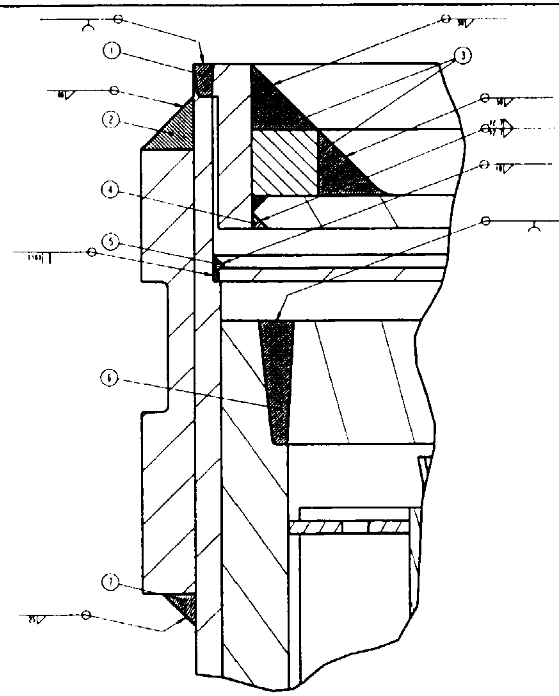
DETAIL B

02 SMB 01/27/00

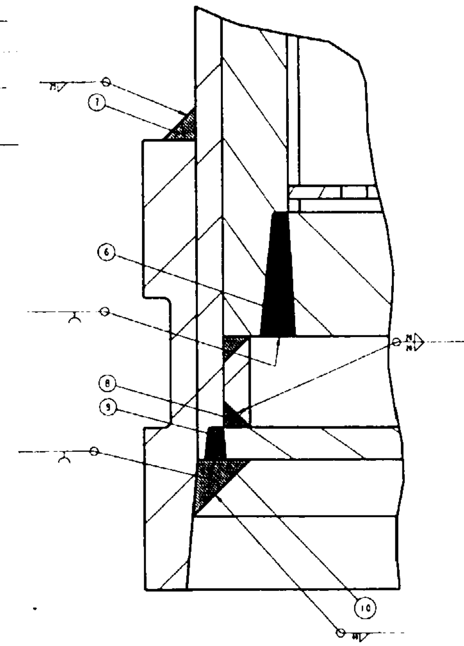
SK-0175 REV 01 SHEET 2 OF 2



SECTION A-A



DETAIL A



DETAIL B

WELD	MATERIAL	MASS (KG)	QTY ROD
1	SFA-5.14 N06022	14	1
2	SFA-5.14 N06022	35	1
3	SFA-5.14 N06022	96	1
4	SFA-5.14 N06022	3.1	2
5	SFA-5.14 N06022	3.8	1
6	SFA-5.9 S31680	64	2
7	SFA-5.14 N06022	13	2
8	SFA-5.14 N06022	8.2	2
9	SFA-5.14 N06022	14	1
10	SFA-5.14 N06022	37	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	249	-
TOTAL 316 WELDS	SFA-5.9 S31680	128	

UNITS: mm
DO NOT SCALE FROM SKETCH

REVISIONS			
REV	DESCRIPTION	APPD BY	DATE
00	ISSUED APPROVED	[illegible]	[illegible]

"FOR INFORMATION ONLY"

21-PWR WASTE PACKAGE WELD CONFIGURATION

SKETCH NUMBER:	SK-0191 REV 00
SKETCHED BY:	BRYAN HARKINS
DATE:	03/09/00
FILE:	/home/pro_library/checkout/sketches/21pwr/sk-0191.dwg

This attachment lists the files necessary for running the ANSYS cases analyzed in this calculation (Table V-1). Table V-1 also lists the ANSYS output files. All these files are contained in the CD associated with this file (Attachment VI).

Table V-1. Compact Disk Contents

File Name	Date	Time	Size (Kbytes)
Fire21pwr.inp	9/08/00	4:16 PM	61
Fire21pwr.out	9/08/00	4:16 PM	1126
Case2.inp	9/08/00	4:32 PM	61
Case2.out	9/08/00	4:32 PM	1122
Case3.inp	9/08/00	4:20 PM	61
Case3.out	9/08/00	4:20 PM	1130
prop21pwr.dat	9/08/00	4:30 PM	7
pwr14dk_mh.parm	9/08/00	4:31 PM	2
convec.dat	9/08/00	4:23 PM	2
convec3.dat	9/08/00	4:30 PM	2
convemiss.dat	9/08/00	4:20 PM	2

MOY-001016-04

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

Complete Only Applicable Items

1. QA: QA

Page: 1 of: 2

This is a placeholder page for records that cannot be scanned or microfilmed

2. Record Date 10/03/2000	3. Accession Number ATT-TO MOL.20001016.0007
4. Author Name(s) FLORENT P. FAUCHER	5. Author Organization N/A
6. Title THERMAL RESPONSE OF THE 21-PWR WASTE PACKAGE TO A FIRE ACCIDENT	
7. Document Number(s) CAL-UDC-TH-000002	8. Version REV. 00
9. Document Type DATA	10. Medium CD-ROM
11. Access Control Code PUB	
12. Traceability Designator DC #26134	

13. Comments

THE IS A SPECIAL PROCESS CD-ROM AND CAN BE LOCATED THROUGH THE RPC

NOTE: PER AP-17.1Q, REV.1, ICN 2, (ELECTRONIC FILES) THE ELECTRONIC INFORMATION ON THIS CD-ROM IS LOCATED AS AN ATTACHMENT TO THIS PAGE

DC# 21634

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ELECTRONIC SOURCE FILE VERIFICATION

QA: N/A
2 OF 2

1. DOCUMENT TITLE: Thermal Response of the 21-PWR Waste Package to a Fire Accident	
2. DOCUMENT IDENTIFIER: CAL-UDC-TH-000002	3. REVISION DESIGNATOR: REV 00

ELECTRONIC SOURCE FILE INFORMATION

4. ELECTRONIC SOURCE FILE NAME WITH FILE EXTENSION PROVIDED BY THE SOFTWARE: 21PWRFireSimul.doc (526 KB); Attachment.doc (713 KB)		
5. DATE LAST MODIFIED: 10/3/2000	6. ELECTRONIC SOURCE FILE APPLICATION: (I.E., EXCEL, WORD, CORELDRAW) Word	7. FILE SIZE IN KILOBYTES: See Item 4
8. FILE LINKAGE INSTRUCTIONS/INFORMATION: N/A		
9. FILE CUSTODIAN: (I.E., DC, OR DC APPROVED CUSTODIAN) DC	10. FILE LOCATION FOR DC APPROVED CUSTODIAN: (I.E., SERVER, DIRECTORY) N/A	
11. PRINTER SPECIFICATION (I.E., HP4SI) INCLUDING POSTSCRIPT INFORMATION (I.E., PRINTER DRIVER) AND PRINTING PAGE SETUP: (I.E., LANDSCAPE, 11 X 17 PAPER) HP4SI. Porrtait		
12. COMPUTING PLATFORM USED: (I.E., SUN) IBM Compatible	13. OPERATING EQUIPMENT USED: (I.E., UNIX, SOLARIS) Windows 95	
14. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S): None	15. ACCESS RESTRICTIONS: (IF ANY) None	

COMMENTS/SPECIAL INSTRUCTIONS

16. N/A

CERTIFICATION

17. NAME (Print and Sign) FOR Florent P. Faucher MICHAEL J. ANDERSON [signature]			18. DATE: 10/3/00
19. ORGANIZATION: FCF	20. DEPARTMENT: Waste Packag Department	21. LOCATION/MAILSTOP: 423	22. PHONE: 804-832-2760

DC USE ONLY

23. DATE RECEIVED: 10/05/00	24. DATE REVIEWED: 10/13/2000	25. DATE FILES TRANSFERRED: 10/13/2000
26. NAME (Print and Sign): Teri McCoy [signature]		27. DATE: 10/13/2000