OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
CALCULATION COVER SHEET

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Evaluation of the Thermal Response of the 5-DHLW Waste Package-Hypothetical Fire Accident

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9. Remarks

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10. Revision No.	11. Description of Revision
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1. PURPOSE

The purpose of this calculation is to determine the thermal response of the 5-defense high level waste (DHLW)/Department of Energy (DOE) codisposal waste package (WP) to the hypothetical fire accident. The objective is to calculate the temperature response of the DHLW glass to the hypothetical short-term fire defined in 10 CFR 71, Section 73(c)(4), Reference 1. The scope of the calculation includes evaluation of the accident with the waste package above ground, at the Yucca Mountain surface facility.

The scope is intended to cover a DHLW WP. This WP is loaded with DHLW canisters containing glass from the Savannah River Site (SRS) and a DOE canister containing Training, Research, and Isotope General Atomics (TRIGA) spent nuclear fuel (SNF).

The information provided by the sketches attached to this calculation is that for the potential design of the type of WP considered in this calculation.

In addition to the nominal design configuration thermal load case, the effects of varying the central DOE canister and DHLW thermal loads are determined. Also, the effects of varying values of the flame and WP outer surface emissivities are evaluated.

The associated activity is the development of engineering evaluations to support the site recommendation (SR) design activities. This document is developed using work planning documents *Deferred Advance EDA II WP Designs (2377) [DHLW and Navy]* (Reference 3) and *Deferred Advance EDA II WP Designs (2377) - 1101 2125 MB, Activity Evaluation* (Reference 33).

This calculation is performed in accordance with AP-3.12Q, *Calculations* (Reference 18).

2. METHOD

The solution method employs finite element analysis (FEA). A two-dimensional (2-D) finite element representation of a short 5-DHLW/DOE codisposal waste package was developed and solved using the thermal analysis capabilities of ANSYS Version 5.4 (described in Section 4.1). Since the focus of this analysis is the maximum temperature of the vitrified DHLW, the SNF inside the DOE canister is not explicitly modeled. The material inside the DOE canister is treated as a homogeneous mixture with effective thermal properties.

Calculation cases have been defined to determine effects on the thermal response of the waste package resulting from variations in parameters of importance. Variations include the relative position of DHLW canisters within the support basket, volumetric heat generation rates, emissivities, solar energy absorption rate, and heat transfer coefficients at the outer surface. These calculations are performed based on exposure of the waste package to the hypothetical fire conditions for a period of 30 minutes, followed by cooldown. An additional case is performed with the duration of the fire extended to 35 minutes.

The control of this document is accomplished in accordance with AP-6.1Q, *Controlled Documents* (Reference 30). The planning documents did not discuss special controls on the electronic management of information. However, the electronic information necessary to make up this document are controlled per AP-SV-1Q, *Control of the Electronic Management of Information* (Reference 31) as recorded in Reference 34.

3. ASSUMPTIONS

The following assumptions were used in developing the WP representation and obtaining the thermal solutions.

3.1 SYSTEM DESCRIPTION DOCUMENT (SDD) ASSUMPTIONS

3.1.1 It is assumed in this calculation that the WP is exposed to the fire conditions for transport packages as defined in 10 CFR 71, Section 73(c)(4). The rationale for this assumption is that it is based on Section 1.2.2.1.11 of Reference 2, which requires that the waste package/disposal container be designed to withstand the same fire criteria as applied to transport packages. This assumption is used in Section 5.1.

3.2 GENERAL ASSUMPTIONS

3.2.1 It is assumed that a 2-D finite element representation of the WP cross section midway along the longitudinal axis will conservatively represent the WP. Inherent to this assumption is that the axial heat transfer does not significantly affect the solution (i.e., the flow of the heat in the radial direction is assumed to dominate the solution since the radial direction represents the path of least thermal resistance). The rationale for this assumption is that the metal thermal conductivity and heat generation distributions are such that axial heat transfer is very small or negligible at the midsection. This assumption is used in Section 5.5.

3.2.2 It is assumed that the mode of heat transfer between the WP outer surface and the surroundings, or environment, is by radiation only, except for the fire condition during which free convection heat transfer heating of the WP shell is included. The rationale for this assumption is that it maximizes the calculated peak temperature in the WP, which is conservative. This assumption is used in Sections 5.1 and 5.4.3.

3.2.3 The calculations are performed assuming a 180-degree segment of the WP cross-section. The basis for this assumption is the following. The geometry of the cross section is symmetrical about the cutting planes of the representation. Therefore, the heat generation paths will also be symmetrical, resulting in no heat conduction across the cutting planes. The radiative heat transfer across these cutting planes is assumed to be negligible relative to the radiative heat transfer in the rest of the cross section. This assumption is used in Sections 5.4.3 and 5.5.

3.2.4 The WP inner shell and basket components (support tube, inner brackets, divider plates, and outer brackets) of the 5-DHLW/DOE codisposal WP (Attachment I), that separate the five HLW canisters and the DOE canister, are assumed to be integrally connected. The rationale for this assumption is that most of the divider plates and barrier components will be in direct contact with the WP placed horizontally. This assumption is used in Section 5.2.1 and 5.5.

3.2.5 It is assumed that no gap exists between the WP inner and outer shells. The rationale for this assumption is that with no gap, the thermal resistance is minimized, thereby maximizing the heat flow to the DHLW canister with heating of the shell by the fire. No credit is taken for contact thermal resistance at the shell to shell interface. This assumption is used in Section 5.5.

3.2.6 The maximum glass temperature resulting from exposure to fire is assumed to occur with the SRS DHLW canister in contact with the WP inner shell (with the WP horizontal). The rationale for this assumption is that although contact between canister and shell minimizes the initial, pre-fire glass temperatures, it maximizes the calculated heat flow to the glass from heating by the fire. This assumption is used in Section 5.5. (Note: A calculation is included to demonstrate the effects of varying the gap distance between the DHLW canister and the WP shell inside diameter.)

3.2.7 The DOE canister is assumed centered in the WP. The rationale for this assumption is that it simplifies the representation without introducing significant error. The impact of this simplification on the results for the peak glass temperatures due to the fire is small. This assumption is used in Section 5.5. (Note: A multiplier applied to the DOE canister heat generation rate in the calculation can be used to effectively account for the local increase in heat generation caused by the canister shifted off-center. A calculation is included to demonstrate that the DOE canister heat load has a small effect on the peak glass temperatures resulting from the fire.)

3.2.8 It is assumed that heat is transferred within the WP by conduction and radiation modes only (i.e., no credit is taken for heat transfer by convection). The rationale for this assumption is based on two considerations. First, the fire-related peak glass temperature occurs near the point of contact of canister and WP inner shell (i.e., in the lower sections of a horizontal WP) where convection does not contribute to the heat transport because the flow is effectively stagnant in this region during the normal, or pre-fire, condition. Secondly, for effects on peak temperatures resulting from the fire condition, convection tends to transfer heat away from the high temperature region at the DHLW canister and WP inner shell point of contact, which diffuses the thermal energy and lowers the peak glass temperature. Therefore, neglecting heat transport by convection is conservative in this case. This assumption is used in Section 5.5.

3.2.9 The 5-DHLW/DOE codisposal WP is assumed to be evacuated and filled with helium gas. The rationale for this assumption is that it is recommended for use in future design work in Reference 4, page 126. Serving as a design basis for this assumption is the recommendation of helium as a fill gas for WP designs. This assumption is used in Sections 5.3.6 and 5.5.

3.2.10 The properties of helium at atmospheric pressure are assumed to be representative of the conditions that these gases will experience within the WP and the DOE canister. The rationale for this assumption is the fact that a one-atmosphere fill pressure at ambient temperature is representative of the industry standard for storage casks. Page 10 of Reference 5 indicates that the highest pressure to which storage casks are filled is approximately 1.5 atmosphere; also, most industry vendors use substantially lower pressure in their designs. Even though the internal pressure of the WP will increase due to the temperature rise, the thermal conductivity of most gases is pressure independent (page 255, Ref. 6). Thus using the thermal conductivity at one atmosphere is reasonable. This assumption is used in Section 5.3.6.

3.2.11 The volumetric heat generation of the DHLW canister is assumed uniformly distributed over the axial and radial cross-sections. The rationale for this assumption is that the heat generating elements are dispersed (from vitrification) through the glass matrix. This assumption is used throughout the calculation.

3.2.12 The fire accident is assumed to occur during preparations for WP emplacement, at the time of emplacement corresponding to the heat load data given in Ref. 12 (p. 2.2.1.3-4, Ref. 12) and modified per Attachment LII of Ref. 8. The rationale for this assumption is that this gives the maximum heat load for the WP consistent with available data for emplacement and is conservative for evaluating the maximum temperatures in the vitrified waste. However, the precise value of this base heat load is not considered important for evaluation of the effects of a short term fire since the heat load has a small effect on the peak value of glass temperature resulting from heating by the fire. (Note also that this calculation includes an evaluation of the effects of increasing the base HLW heat load by 50%, as described in Section 5.1.) This assumption is used in Section 5.4.1.

3.2.13 The spent nuclear fuel within the DOE canister is assumed to be a homogeneous uniform-property heat-generating cylinder. The rationale for this assumption is that since the DOE canister internal temperatures are not of interest in these calculations, uniform material properties for the homogeneous cylinder can be used to represent the loaded DOE canister components. The diameter of the cylinder corresponds to the outer diameter of the DOE standard canister (short). This assumption is used in Sections 5.3.8, 5.4.2 and 5.5.

3.2.14 Material properties for the homogeneous DOE canister will be calculated assuming a temperature of 300 °C for the canister and SNF materials. The rationale for this assumption is that it simplifies the representation by providing a reasonable set of representative material properties for the homogenous DOE canister. Since the DOE canister internal temperatures are not of interest in these calculations, and the volumetric heat rate of the DOE canister will be properly represented in the analysis model, this assumption will not significantly affect the temperatures in the SRS vitrified waste. This assumption is used in Section 5.3.8.

3.2.15 It is assumed that a sleeve of material (hereafter referred to as the "supplementary absorber tubes") will be placed over each TRIGA SNF assembly (assembly includes the TRIGA SNF, zirconium rod, erbium poison, graphite end plugs, cladding and end fittings) such that it rests between the TRIGA assembly and the stainless steel 316L pipe in the basket. The assumed dimensions are 0.1 cm wall thickness (p. 11, Ref. 32), 4.92 cm outer diameter (approximately the same as inner diameter of pipe, Attachment III), and 83.6 cm length (Attachment III). Actually, the supplementary absorber tubes will be placed over only a portion of the TRIGA assemblies in the WP (p. 11, Ref. 32). The rationale for this assumption is that it simplifies the representation without significantly affecting the results for calculated peak HLW glass temperatures. The simplification can be made because the peak temperature in the glass is reached prior to the time that the thermal upset due to the fire propagates into the WP central region containing the DOE canister (i.e., the peak temperatures resulting from the fire are effectively independent of the thermal properties of the central canister). This assumption is used in Section 5.3.8.

3.2.16 The supplementary absorber tubes placed over the TRIGA assemblies are assumed to have the same thermal properties as Alloy 22. The rationale for this assumption is that the absorber tube material is composed of elements similar to Alloy 22 but with 8 atom percent gadolinium (p. 11, Ref. 32). Due to the recent development of this material at the Idaho National Engineering and Environmental Laboratory (INEEL), material property data is unavailable. This assumption is used in Section 5.3.8.

3.2.17 The TRIGA SNF is assumed to be the standard streamlined FLIP (fuel life improvement program) type with an initial 8.5 weight percent uranium concentration and 70 weight percent U-235 initial enrichment, as described on pages 12 to14 of Ref. 7. This loading of U-235 is as high or higher than other fuel elements listed in Ref. 7 and therefore has the highest heat output of any TRIGA SNF type. The rationale for this assumption is that the FLIP SNF thermally bounds all other TRIGA SNF. This assumption is used throughout the calculation.

3.2.18 An axial power peaking factor (PPF) of 1.25 is assumed for the TRIGA SNF. The value of 1.25 is a conservative value given for the pressurized water reactor (PWR) SNF on page 3-29 of Ref. 14, thereby providing the rationale for this assumption. An axial power peaking factor of 1.0 is assumed for the DHLW. The rationale for the assumption of a value of 1.0 for the glass canister is that the HLW canister content is assumed to be a uniformly homogeneous mixture, for which there should be no appreciable axial variation in the distribution of heat generation. Therefore the HLW canister PPF of 1.00 is considered applicable. This assumption is used in Sections 5.4.1 and 5.4.2.

3.2.19 Processing of the TRIGA SNF for emplacement preparations is assumed to occur one year after its discharge, at which time the fire is postulated to occur. The rationale for this assumption is that it is improbable that the TRIGA SNF would be emplaced earlier than one year after its date of discharge. This assumption is used to be consistent with the power history used in Reference 12, as modified by Reference 8, the maximum value of which is used in this calculation. This assumption is used in Section 5.4.2.

3.2.20 For purposes of calculating the effective emissivity for the radiative energy exchange between the WP outer surface and the surroundings, the outer surface is assumed characterized as an ideal gray surface. The rationale for this assumption is that it simplifies the calculation by considering the surface absorptivity equal to the surface emissivity, and maximizes the calculated rate of heating of the WP during the fire for the case where a value of 1.0 is used for emissivity, which is conservative. This assumption is used in Section 5.4.3. (Note that the assumption does not apply to the solar energy incident on the WP outer surface.)

3.2.21 The thermal conductivity of SRS glassified HLW is assumed to be equal to that of borosilicate glass, calculated in the mid-range between temperatures of 100 °C and 500 °C (p. 584, Ref. 9). The density and specific heat of the glassified HLW is assumed equal to that of Pyrex glass at 300 K (p. 755, Ref. 10). The rationale for these assumptions is the fact that the volume fraction of heavy metal present in the glass mixture is sufficiently low enough to be neglected. This assumption is used in Section 5.3.5.

3.2.22 An emissivity of 0.73 is assumed for stainless steel 304L (Unified Numbering System [UNS] designation SA-240 S30403) based on data from Table 4.3.2 on page 4-68 of Ref. 11. (The SRS canister is constructed of this type of stainless steel material.) The emissivity is listed in Ref. 11 as a range of 0.62 to 0.73 for stainless steel 304L under specific heat-treatment conditions. The rationale for this assumption is that a value of emissivity at the high end of the quoted range will maximize heat flow to the SRS canister from the inside surface of the WP shell when heated by the fire, thereby conservatively maximizing the calculated peak glass temperatures. This assumption is used in Section 5.3.2.

3.2.23 The emissivity of 316L stainless steel is assumed to be 0.66. The range of values of emissivity for this material is given as 0.57 to 0.66, per Table 4.3.2 on page 4-68 of Reference 11. The rationale for the assumption to use a value of 0.66 is that it maximizes heat flow to the SRS canister from the inside surface of the WP shell after heating by the fire, thereby conservatively maximizing the calculated peak glass temperatures. This assumption is used in Section 5.3.3.

3.2.24 The heat load of the DOE canister is assumed constant with time during all phases of the fire accident (WP heating and cooling transient). The rationale for this assumption is that the heat load will not decay significantly during the relatively short period of time for the fire accident. (A determination of the sensitivity of the calculated peak glass temperature to the DOE canister heat load is included in the evaluation). The assumption is used in Section 5.1.

3.2.25 The heat load of the DHLW canister is assumed constant with time throughout the fire accident transient. The rationale for this assumption is that the heat load will not decay significantly during the relatively short period of time for the fire accident. (A determination of the sensitivity of the calculated peak glass temperature to the DHLW canister heat load is included in the evaluation.) The assumption is used in Section 5.1.

3.2.26 A temperature of 38°C is assumed for the WP surroundings during pre- and post-fire conditions. The rationale for this assumption is that it is consistent with the requirements for fire-exposure testing of transport casks as given in Section 73(b) of 10 CFR 71, Reference 1, which specifies a maximum of 38°C. The assumption is used in Sections 5.1 and 5.4.3.

3.2.27 A uniform temperature of 800°C for the WP surroundings, i.e., flame, is assumed for the fire condition. The rationale for this assumption is that it is consistent with the definition of the short-term fire for transport packages per Section 73(c)(4) of 10 CFR 71, Reference 1. The assumption is used in Section 5.1.

3.2.28 A value of 1.0 for the emissivity of the WP surroundings for the pre- and post-fire conditions is assumed. The rationale for this assumption is that this conservatively maximizes the calculated radiative energy incident on the WP outer surface, and maximizes the WP temperatures calculated for both the pre-fire condition and the post-fire cooldown. The assumption is used in Section 5.1.

3.2.29 A value of 1.0 for the emissivity of the flame for the fire condition is assumed. The rationale for this assumption is that this conservatively maximizes heating of the WP and exceeds the minimum value of 0.9 specified in Section 73(c)(4) of 10 CFR 71. The assumption is used in Section 5.1.

3.2.30 A value of 0.87 for the emissivity of the WP outer surface (Alloy 22) is assumed for both the pre- and post-fire conditions. The rationale for this assumption is that it is based on the data given on p. 10-297, Reference 26. The assumption is used in Section 5.1.

3.2.31 A value of 1.0 for emissivity of the WP outer surface for the fire condition is assumed. The rationale for this assumption is that it conservatively maximizes heating of the WP and exceeds the minimum value of 0.8 specified in Section 73(c)(4) of 10 CFR 71, Ref. 1, this assumption is used in Section 5.1.

3.2.32 A constant rate of solar energy incident on the outer surface of the WP equal to 400 cal/cm^2 per 12-hour period is assumed. The rationale for this assumption is that it is consistent with the definition of the short-term fire for transport packages per Section 71(c)(1) of 10 CFR 71, Ref. 1, for the energy incident on the curved surface of a transport cask. The rate of solar energy incidence is maintained constant with time during all phases of the accident, i.e., from pre-fire through post-fire cooling. The assumption is used in Sections 5.1 and 5.4.3.

3.2.33 The solar absorptivity of the WP outer surface is assumed to be 1.0. The rationale for this assumption is that it conservatively maximizes the calculated solar heat flux into the WP surface and maximizes the WP temperatures. The solar absorptivity is maintained constant during all phases of the accident. The assumption is used in Section 5.1 and 5.4.3.

3.2.34 Free-convection heat transfer at the WP outer surface is taken into account only during heating of the WP by the fire, and is assumed to vary based on the correlation for air at normal temperatures and atmospheric pressure per the equation $1.3123(\Delta T^{1/3})$ $w/m^2 \cdot K$, ΔT in degrees-K (equivalent to the equation $0.19\ \Delta T^{1/3}$ $Btu/hr \cdot ft^2 \cdot F$, ΔT in degrees-F, from p.4-88 of Reference 11). The rationale for this assumption is that the equation gives conservatively high values of the heat transfer coefficient for temperatures greater than normal room temperature, maximizing heat flow to the WP shell during the fire. Use of the equation is conservative at temperatures exceeding room temperatures because the free convection heat transfer coefficient decreases with increasing temperature of the gas due to the change in gas properties with temperature. (The free convection film coefficient increases with increasing Grashof number, which varies directly with the coefficient of thermal expansion and inversely with the square of the kinematic viscosity of the gas. Since the coefficient of thermal expansion varies inversely with the absolute temperature of the gas and the kinematic viscosity increases with temperature, the Grashof number therefore decreases with increasing temperature. Consequently, both the Grashof number and the heat transfer coefficient decrease with increasing temperature, so that use of the correlation is conservative in this case.) The assumption is used in Sections 5.1 and 5.4.3.

3.2.35 The heat transfer between the DOE canister and the basket support tube is assumed to occur primarily by conduction, i.e., by conduction through the helium fill gas, thereby simplifying the calculation process used to obtain the temperature distributions within the WP. The rationale for this assumption is that the calculated peak glass temperature resulting from the short-term fire is not significantly affected by the thermal conditions within the DOE canister and the temperatures within the DOE canister are not of interest. This is because the peak temperature in the glass is reached prior to the time that the thermal upset due to the fire propagates into the WP central region containing the DOE canister. This assumption is used in Section 5.5.

3.2.36 For purposes of calculating a value for the effective specific heat of the DOE canister and contents, it is assumed that the density of graphite in the DOE canister is 1730 kg/m^3. The rationale for this is that the range of values from 1710 kg/m^3 to 1730 kg/m^3 given on p. 367 of Reference 24 is small and use of any value within this range other than that chosen will have no significant effect on the results for the peak calculated DHLW glass temperatures for the fire accident. This assumption is used in Section 5.3.7.

3.2.37 It is assumed that the TRIGA fuel characteristics, materials, and component masses as given in Reference 7 and the material properties of zirconium and graphite taken from Reference 10 are acceptable for use in this calculation. The rationale for this assumption is that accurate data are not required for this particular calculation since they have no effect on the calculated values of peak glass temperature associated with the fire accident. (The calculated peak temperature of the DHLW glass due to the fire is entirely independent of the values used to represent the effective thermal characteristics of the materials within the DOE canister). This is because the peak temperature in the glass is reached prior to the time that the thermal upset due to the fire propagates into the WP central region containing the DOE canister. Consequently, these data are considered for reference only. This assumption is used in Sections 5.3.7 and 5.3.8.

3.2.38 It is assumed that the Savannah River Site canister dimensions and volumes as given in Reference 16 are appropriate for use in this calculation. The rationale for this assumption is that these data are the best available information that exists at this time. This assumption is used in Section 5.2.2.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

The FEA computer code used for this calculation is ANSYS Version 5.4 (hereafter called 'ANSYS'), which is identified with the Software Tracking Number 10027-5.4L2-00. ANSYS is a commercially available finite element code and is appropriate for performing thermal analysis of WPs, WP emplacements, and WP environments as utilized in this calculation. ANSYS was operated on a Hewlett-Packard 9000/C200. (Computer ID No. 2002611431, Framatome Technologies, Lynchburg, Virginia.) Software qualification of ANSYS V5.4, including problems of the type analyzed in this report, is summarized in the *Software Qualification Report for ANSYS V5.4L2* (see Reference 13). ANSYS V5.4L2 is the same software as the ANSYS Version 5.4 (V5.4) obtained from the ANSYS distributor. The evaluations performed in this calculation are fully within the range of validation for the ANSYS Version 5.4 code used. Access to and use of the code was granted and performed in accordance with appropriate procedures. Inputs to the ANSYS software and its outputs are included as attachments and are described in this document.

4.2 SOFTWARE ROUTINES

None used.

4.3 MODELS

None used.

5. CALCULATION

When converting values from English to metric units, the added digits of significance are an artifact of the conversion process and do not reflect actual precision of the value as expressed in metric.

References 9 and 10 are accepted data (fact). The rationale is that References 9 and 10 consist of compilations of data derived from handbooks.

5.1 SCENARIO

This calculation determines the thermal response of the 5-DHLW/DOE codisposal WP to the hypothetical fire accident. A set of parametric runs are included to demonstrate sensitivity of the peak DHLW glass temperature to variations in selected parameters. The objective is to calculate the temperature response of the DHLW glass to the hypothetical short-term fire defined in 10 CFR 71, Section 73(c)(4), Reference 1 (Assumption 3.1.1).

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 flame of temperature equal to at least 800 °C, for a period of 30 minutes.
>
> The effective value of 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, whichever is greater. Heat input from hot gases to the waste package will include the free-convection heat transfer mode in addition to thermal radiation (Assumption 3.2.2).
>
> 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 1 specifies a maximum temperature of +38°C for the temperature of ambient air before and after the specified 30-minute duration of the fire (Assumption 3.2.26). Section 71(c)(1) 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 at the surface, loaded, sealed, and in a horizontal position. The WP is at steady thermal conditions with radiation heat transfer to the surroundings balancing the sum of volumetric heat generation rates in the waste canisters and uniform solar radiation incident on the WP outer surface.

The waste package outer surface is instantaneously subjected to the thermal conditions specified for the regulatory fire as described above, producing uniform, rapid heating by both radiation and free convection heat transfer modes. Exposure of the WP 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. No credit is taken for free convection cooling after the fire. Cooling of the WP occurs by radiation to the immediate surroundings only.

The calculations for the fire accident proceed as follows:

(1) A base case FEA representation and set of input variables for calculating the WP thermal response to the fire are first defined. This includes calculation of the effects of varying the radial gap between the HLW canister and WP shell. This is to demonstrate effects of the canister occupying the two extreme radial positions within the confines of the WP basket.

Cases include –

"Base" case – minimum canister-to-shell gap

"GapMax" case – maximum canister-to-shell gap.

(2) The sensitivity of calculated peak HLW glass temperature to variation of each of the following variables is determined in the cases indicated below:

Case 1 - DOE canister thermal load

Case 2 - DHLW canister thermal load

Case 3 - emissivity of the WP outer surface exposed to ambient (i.e., pre- and post-fire)

Case 4 - magnitude of the solar energy absorption rate

Case 5 - value of the free convection heat transfer film coefficient at the WP outer surface, and

Case 6 - duration of the fire.

Table 5-1 lists the parameters defining the "Base" case.

Table 5-1. DHLW/DOE Codisposal Waste Package "Base" Case Evaluation

Item	Accident Condition Initial/Fire/Post-Fire	Description
DOE Canister Thermal Load	Maximum (constant with time)	Design value (for nominal design configuration) (Assumption 3.2.24).
DHLW Canister Thermal Load	Maximum (constant with time)	Design value (for nominal design configuration) (Assumption 3.2.25).
Temperature of Surroundings	38°C/ 800°C/ 38°C	Initial and post-fire value of 38°C is from Section 73(b) of 10 CFR 71 (Assumption 3.2.26). For the fire condition, the value of 800°C is from Section 73(c)(4) of 10 CFR 71 (Assumption 3.2.27).
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 (i.e., temperature of surroundings) (Assumption 3.2.28). 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 3.2.29).
Emissivity of WP Outer Surface	0.87 / 1.0 / 0.87	Initial and post-fire values of 0.87 are used based on the value stated in Section 5.3.4 (Assumption 3.2.30). For the fire condition, a value of 1.0 is selected, which is greater than the minimum value of 0.8 specified for the outer surface when exposed to the flame per Section 73(c)(4) of 10 CFR 71 (Assumption 3.2.31).
Solar Energy Absorption Rate	400 cal/cm^2 per 12 hours (constant with time)	The rate of 400cal/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 3.2.32). Setting the absorption rate equal to the rate of incidence is equivalent to value of 1.0 for solar absorptivity, which is conservative (Assumption 3.2.33).
Free Convection Film Coefficient	$1.3123(\Delta T^{1/3})$ w/m$^2\cdot$K	Film Coefficient from Section 5.4.3 (Assumption 3.2.34)

For these calculations, the nominal design configuration is with the DHLW canisters loaded with glassified defense high level waste from the Savannah River Site, and the DOE canister containing TRIGA spent nuclear fuel.

The "Base" case is defined for the configuration with the DHLW canisters in contact with the waste package shell (Assumption 3.2.5). For purposes of demonstrating the effects of the radial position of the DHLW canister, an additional case is defined similar to the base case except that the DHLW is shifted radially to give a maximum canister-to-shell gap (case "GapMax").

Table 5-2 lists the parametric cases evaluated.

Table 5-2. DHLW/DOE Codisposal Waste Package Parametric Evaluations

Item	Thermal Parameter Varied	Deviation From "Base" Case	Description
Case 1	DOE Canister Thermal Load	+ 20 %	Magnitude of deviation - arbitrary.
Case 2	DHLW Canister Thermal Load	+ 50 %	Same as above.
Case 3	Emissivity of WP Outer Surface (normal)	- 10 %	Reduce Base Case value of 0.87 by an arbitrary amount.
Case 4	Solar Radiation Absorption Rate	+ 60 %	Increase Base Case value by an amount approximating the difference between peak and average for sinusoidal variation with time.
Case 5	Free Convection Heat Transfer Coefficient	+ 20 %	Magnitude of deviation - arbitrary.
Case 6	Duration of Fire	+ 5 minutes	Bounding case with duration of fire increased to 35 minutes.

5.2 WASTE PACKAGE PROPERTIES

5.2.1 5-DHLW/DOE Codisposal Waste Package

The waste package cross-section studied in this calculation consists of the inner and outer barriers, basket, five Savannah River Site HLW glass canisters, and the DOE TRIGA SNF canister. Dimensional information for the WP inner and outer barriers, and basket are shown in Attachment I. All components of the basket are assumed to be integrally connected (Assumption 3.2.4).

Table 5-3. Materials Used and Their UNS Designation

Item	Material Used	UNS Designation
WP Basket	A516 Carbon Steel	SA-516 K02700
WP Outer Shell	Alloy 22	SB-575 N06022
SRS Canister Shell	Stainless Steel 304L	SA-240 S30403
WP Inner Shell	Stainless Steel 316	SA-240 S31600
DOE Canister Shell	Stainless Steel 316L	SA-240 S31603
DOE TRIGA SNF Assembly	Uranium Zirconium Hydride (UZrH)	NA
	Erbium Poison	NA
	Zirconium	NA
	Graphite	NA
SRS Canister Glass	Homogenized Borosilicate Glass	NA
WP and DOE Canister Fill Gas	Helium	NA

5.2.2 HLW Glass Pour Canister

The Savannah River Site HLW canister cross section used in this calculation is shown in Figure 5-1 (Assumption 3.2.38). The geometry was taken from p. 3.3-4, Ref. 16. From Table 3.3.1, p. 3.3-6, of Ref. 16, the glass volume in the SRS pour canister is 0.6256 m^3 (85% of the canister volume of 0.736 m^3) (Assumption 3.2.38). The thermal conductivity of the HLW glass is approximated that for pure borosilicate glass, and the density and specific heat are approximated as those of Pyrex glass (Assumption 3.2.21).

A homogeneous glass with uniform volumetric heat rate will be used to represent the HLW canister (Assumption 3.2.11).

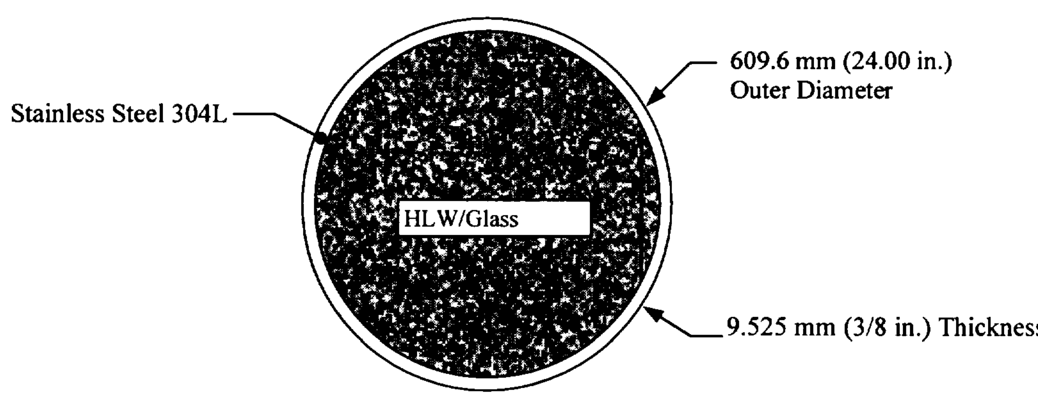

Figure 5-1. Represented Cross-Section of Savannah River Site HLW Canister

5.2.3 5-DHLW/DOE Codisposal Canister

The DOE TRIGA SNF canister geometry and materials are shown in Attachments II and III. Since the internal temperatures of the DOE canister are not of interest in this calculation, the DOE canister cross section is considered a uniformly homogeneous material (Assumption 3.2.13). The outer diameter of the DOE canister is 457.2 mm (Attachment III). The total mass and volume of the DOE canister loaded with the TRIGA SNF will be used to calculate the smeared density for the DOE canister.

5.3 THERMAL PROPERTIES

5.3.1 A516 Carbon Steel

Table 5-4 lists the density and emissivity of A516 carbon steel. The density of A516 (C-Mn-Si) is from p. 9 of Ref. 19. The emissivity (average for smooth oxidized iron) is from Table 4.3.2 on page 4-68 of Ref. 11.

Table 5-5 lists the thermal conductivity and specific heat of A516 carbon steel. Values for thermal conductivity and thermal diffusivity of A516 were taken from Table TCD, Section II , page 600 of Ref. 20, and converted here to conductivity and specific heat in SI units. The conversion of thermal diffusivity (defined in Equation 5.1) to specific heat requires the density listed in Table 5-4.

$$Specific\ Heat\ (Btu/lb{\cdot}^{o}F) = \frac{Thermal\ Conductivity\ (Btu/hr \cdot ft{\cdot}^{o}F)}{Density\ (lb/ft^3) \times Thermal\ Diffusivity\ (ft^2/hr)}$$ [Equation 5.1]

Table 5-4. Density and Emissivity of A516 Carbon Steel

	Density (kg/m^3)	Emissivity
A516 Carbon Steel	7850	0.80

Table 5-5. Thermal Conductivity and Specific Heat of A516 Carbon Steel

Temperature		Thermal Conductivity	Thermal Diffusivity	Thermal Conductivity	Specific Heat
(°F)	(°C)	(Btu/hr·ft·F)	(ft^2/hr)	(W/m·K)	(J/kg·K)
70	21.11	23.6	0.454	40.85	444.11
100	37.78	23.9	0.443	41.36	460.92
150	65.56	24.2	0.433	41.88	477.49
200	93.33	24.4	0.422	42.23	493.98
250	121.11	24.4	0.414	42.23	503.53
300	148.89	24.4	0.406	42.23	513.45
350	176.67	24.3	0.396	42.06	524.26
400	204.44	24.2	0.386	41.88	535.63
450	232.22	23.9	0.375	41.36	544.50
500	260.00	23.7	0.364	41.02	556.26
550	287.78	23.4	0.355	40.50	563.15
600	315.56	23.1	0.346	39.98	570.39
650	343.33	22.7	0.333	39.29	582.39
700	371.11	22.4	0.320	38.77	598.04
750	398.89	22.0	0.308	38.08	610.25
800	426.67	21.7	0.298	37.56	622.12
850	454.44	21.2	0.286	36.69	633.29
900	482.22	20.9	0.274	36.17	651.67
950	510.00	20.5	0.262	35.48	668.48
1000	537.78	20	0.248	34.61	688.99
1050	565.56	19.6	0.237	33.92	706.55
1100	593.33	19.2	0.228	33.23	719.45
1150	621.11	18.7	0.213	32.36	750.06
1200	648.89	18.2	0.197	31.50	789.29
1250	676.67	17.5	0.179	30.29	835.25
1300	704.44	16.7	0.155	28.90	920.49
1350	732.22	15.8	0.119	27.35	1134.34
1400	760.00	15.3	0.077	26.48	1697.60
1450	787.78	15.1	0.154	26.13	837.70
1500	815.56	15.1	0.169	26.13	763.35

5.3.2 Stainless Steel 304L

Table 5-6 lists the density and emissivity of stainless steel 304L. The density is taken from Appendix XI , p. 7, Ref. 21. The emissivity is taken from Table 4.3.2 on p. 4-68 of Ref. 11. For conservatism, the maximum value of emissivity is used from the range given in Reference 11 (Assumption 3.2.22).

Table 5-7 lists the thermal conductivity and specific heat of stainless steel 304L. Values for thermal conductivity and thermal diffusivity were taken from Table TCD, Section II, p. 606 of Ref. 20, converted here to conductivity and specific heat in SI units. The conversion of thermal diffusivity (defined in Equation 5.1) to specific heat requires the density listed in Table 5-6. Stainless steel 304L is listed in Ref. 20 by its chemical composition (18Cr-8Ni).

Table 5-6. Density and Emissivity of Stainless Steel 304L

	Density (kg/m³)	Emissivity
Stainless Steel 304L	7940	0.73

Table 5-7. Thermal Conductivity and Specific Heat of Stainless Steel 304L

Temperature		Thermal Conductivity	Thermal Diffusivity	Thermal Conductivity	Specific Heat
(°F)	(°C)	(Btu/hr·ft·F)	(ft²/hr)	(W/m·K)	(J/kg·K)
70	21.11	8.6	0.151	14.88	481.07
100	37.78	8.7	0.152	15.06	483.46
150	65.56	9.0	0.154	15.58	493.63
200	93.33	9.3	0.156	16.10	503.55
250	121.11	9.6	0.158	16.62	513.21
300	148.89	9.8	0.160	16.96	517.35
350	176.67	10.1	0.162	17.48	526.61
400	204.44	10.4	0.165	18.00	532.39
450	232.22	10.6	0.167	18.35	536.13
500	260.00	10.9	0.170	18.87	541.58
550	287.78	11.1	0.172	19.21	545.10
600	315.56	11.3	0.174	19.56	548.54
650	343.33	11.6	0.177	20.08	553.56
700	371.11	11.8	0.179	20.42	556.82
750	398.89	12.0	0.181	20.77	560.00
800	426.67	12.2	0.184	21.11	560.05
850	454.44	12.5	0.186	21.63	567.65
900	482.22	12.7	0.189	21.98	567.58
950	510.00	12.9	0.191	22.33	570.48
1000	537.78	13.2	0.194	22.85	574.72
1050	565.56	13.4	0.196	23.19	577.47
1100	593.33	13.6	0.198	23.54	580.17
1150	621.11	13.8	0.201	23.88	579.92
1200	648.89	14	0.203	24.23	582.53
1250	676.67	14.3	0.205	24.75	589.20
1300	704.44	14.5	0.208	25.10	588.83
1350	732.22	14.7	0.21	25.44	591.26
1400	760.00	14.9	0.212	25.79	593.65
1450	787.78	15.1	0.214	26.13	596.00
1500	815.56	15.3	0.216	26.48	598.30

5.3.3 Stainless Steel 316 and 316L

Table 5-8 lists the density and emissivity of stainless steel 316 and 316L. The density is taken from Appendix XI, p. 7, Ref. 21. The emissivity is taken from Table 4.3.2, p. 4-68, Ref. 11 and is at the upper end of the range of values for heated stainless steel 316 and 316L (Assumption 3.2.23).

Table 5-9 lists the thermal conductivity and specific heat of stainless steel 316 and 316L. Values for thermal conductivity and thermal diffusivity were taken from Table TCD, Section II, p. 606 of Ref. 20, converted here to conductivity and specific heat in SI units. The conversion of thermal diffusivity (defined in Equation 5.1) to specific heat requires the density listed in Table 5-8. Stainless steel 316 and 316L is listed in Ref. 20 by its chemical composition (16Cr-12Ni-2Mo).

Table 5-8. Density and Emissivity of Stainless Steel 316 and 316L

	Density (kg/m^3)	Emissivity
Stainless Steel 316 and 316L	7980	0.66

Table 5-9. Thermal Conductivity and Specific Heat of Stainless Steel 316 and 316L

Temperature		Thermal Conductivity	Thermal Diffusivity	Thermal Conductivity	Specific Heat
(°F)	(°C)	(Btu/hr·ft·F)	(ft^2/hr)	(W/m·K)	(J/kg·K)
70	21.11	7.7	0.134	13.33	482.93
100	37.78	7.9	0.136	13.67	488.19
150	65.56	8.2	0.138	14.19	499.38
200	93.33	8.4	0.141	14.54	500.68
250	121.11	8.7	0.143	15.06	511.31
300	148.89	9.0	0.145	15.58	521.64
350	176.67	9.2	0.148	15.92	522.43
400	204.44	9.5	0.151	16.44	528.75
450	232.22	9.8	0.153	16.96	538.31
500	260.00	10.0	0.156	17.31	538.74
550	287.78	10.3	0.159	17.83	544.43
600	315.56	10.5	0.162	18.17	544.72
650	343.33	10.7	0.164	18.52	548.33
700	371.11	11.0	0.167	19.04	553.58
750	398.89	11.2	0.170	19.38	553.69
800	426.67	11.5	0.173	19.90	558.67
850	454.44	11.7	0.176	20.25	558.69
900	482.22	12	0.178	20.77	566.58
950	510.00	12.2	0.181	21.11	566.48
1000	537.78	12.4	0.184	21.46	566.38
1050	565.56	12.7	0.186	21.98	573.84
1100	593.33	12.9	0.189	22.33	573.63
1150	621.11	13.1	0.191	22.67	576.42
1200	648.89	13.3	0.194	23.02	576.17
1250	676.67	13.6	0.196	23.54	583.15
1300	704.44	13.8	0.199	23.88	582.81
1350	732.22	14	0.201	24.23	585.37
1400	760.00	14.2	0.203	24.58	587.89
1450	787.78	14.4	0.206	24.92	587.48
1500	815.56	14.6	0.208	25.27	589.92

5.3.4 Alloy 22

Table 5-10 lists the density and emissivity of Alloy 22. The density of Alloy 22 is taken from p. 2, Ref. 15. The emissivity of Alloy 22 is taken from p. 10-297, Ref. 26, for nickel-chromium alloy (Assumption 3.2.30).

Table 5-11 lists the thermal conductivity and specific heat of Alloy 22 taken from p. 13, Ref. 23.

Table 5-10. Density and Emissivity of Alloy 22

	Density (kg/m³)	Emissivity
Alloy 22	8690	0.87

Table 5-11. Thermal Conductivity and Specific Heat of Alloy 22

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

5.3.5 Borosilicate Glass

Table 5-12 lists the thermal conductivity, specific heat, and density of borosilicate glass. The thermal conductivity is taken from p. 584 of Ref. 9 and is the mid-range value for a temperature range of 100°C to 500°C (Assumption 3.2.21). The density and specific heat were assumed equal to that of Pyrex glass at 300K (Assumption 3.2.21) and taken from p. 755 of Reference 10.

Table 5-12. Thermal Properties of Borosilicate Glass

	Density (kg/m³)	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)
Borosilicate Glass	2225	1.1	835

5.3.6 Helium

The WP is assumed to be evacuated and filled with helium (Assumption 3.2.9). Table 5-13 lists the density of helium used for WP fill gas. The value for the density of helium was taken at a temperature of 27°C at one-atmosphere pressure (Assumption 3.2.10). Table 5-14 lists the thermal conductivity and specific heat of helium. All helium properties are taken from p. 19.71 of Ref. 22.

Table 5-13. Density of Helium

	Density (kg/m^3)
Helium (1 atm, 300°K)	0.1626

Table 5-14. Thermal Conductivity and Specific Heat of Helium

Temperature		Thermal Conductivity	Specific Heat
(°F)	(°C)	(W/m·K)	(J/kg·K)
0	-17.78	0.1396	5196.7
20	-6.67	0.1437	5196.7
40	4.44	0.1478	5196.7
60	15.56	0.1519	5196.7
80	26.67	0.1559	5196.2
100	37.78	0.1599	5196.2
120	48.89	0.1638	5196.2
140	60.00	0.1677	5196.2
160	71.11	0.1716	5196.2
180	82.22	0.1754	5196.2
200	93.33	0.1791	5196.2
240	115.56	0.1866	5196.2
280	137.78	0.1940	5196.2
320	160.00	0.2012	5196.2
360	182.22	0.2083	5196.2
400	204.44	0.2153	5196.2
440	226.67	0.2222	5196.2
480	248.89	0.2291	5196.2
520	271.11	0.2358	5196.2
560	293.33	0.2425	5196.2
600	315.56	0.2491	5196.2
640	337.78	0.2556	5196.7
680	360.00	0.2621	5196.7
720	382.22	0.2684	5196.7
760	404.44	0.2747	5196.7
800	426.67	0.2810	5196.7

5.3.7 TRIGA FLIP Spent Nuclear Fuel Miscellaneous Materials

The data compiled in this section are used only to determine the average density and overall effective specific heat of the DOE canister. These data represent the best available information for this purpose (Assumption 3.2.37). Note that the thermal properties of the DOE canister and its contents have no significant effect on the calculations to determine peak glass temperatures in the DHLW canisters. Properties of the DOE canister are included only for purposes of completeness in executing the calculations for the transient response to the fire accident.

Table 5-15 lists values of density and specific heat for miscellaneous materials comprising TRIGA FLIP spent nuclear fuel components. Items listed are for purposes of calculating the effective specific heat of the DOE canister and contents. The density of graphite is based on nuclear grade A graphite (Assumption 3.2.36).

Table 5-15. Density and Specific Heat of TRIGA FLIP Materials

Material	Property	Value	Reference
UZrH Fuel	Density, Kg/m^3	6020 at 300C	Table 3-8, p. 20, Reference 7
	Specific Heat, J/kg·K	551 at 300C	(See note a.)
Erbium	Density, Kg/m^3	9070 at 25C	p. 12-159, Reference 26
	Specific Heat, J/kg·K	168 at 25C	p. 12-159, Reference 26
zirconium	Density, Kg/m^3	6570 at 300K	Table A.1, p. 748, Reference 10
	Specific Heat, J/kg·K	300 at 400K 322 at 600K	Table A.1, p. 748, Reference 10
graphite	Density, Kg/m^3	1730	Table A, p. 367, Reference 24
	Specific Heat, J/kg·K	992 at 400K 1406 at 600K	Table A.2, p. 749, Reference 10

Note a) From Ref. 7, p. 24: ZrH1.6 $C_{p(ZrH)}$ = [0.06976(T) + 33.706]/92.83 = 0.5885 J/g·°C at T = 300°C

From Ref. 7, p. 25: Uranium $C_{p(U)}$ = [1.305E-4(T) + 0.1094] = 0.1486 J/g·°C at T = 300°C

From Ref. 7, p. 25: UZrH $C_p = W_U C_{p(U)} + W_{ZrH} C_{p(ZrH)}$ = (0.085)(0.1486) + (0.915)(0.5885) = 0.5511 J/g·°C at 300°C

where W_U is the mass fraction of uranium and W_{ZrH} is the mass fraction of ZrH.

5.3.8 DOE Canister With TRIGA FLIP Spent Nuclear Fuel

The data compiled in this section are used only to determine the overall effective thermal properties of the DOE canister. These data represent the best available information for this purpose (Assumption 3.2.37). Note that the thermal properties of the DOE canister and its contents have no significant effect on the calculations to determine peak glass temperatures in the DHLW canisters. Properties of the DOE canister are included only for purposes of completeness in executing the calculations for the transient response to the fire accident.

The spent nuclear fuel within the DOE canister is assumed to be a homogeneous smeared-property heat-generating cylinder (Assumption 3.2.13). The effective density of the loaded DOE canister is calculated from the total mass of the loaded canister, divided by the total volume in the basket region (Attachment III) which is 2.527 meters long. The effective specific heat for the DOE canister is calculated as a mass-weighted average of these properties of the individual materials over the same region at a temperature of 300 °C (Assumption 3.2.14). In these calculations, the relatively small mass of the fill gas is neglected.

First, the volumes of some of the DOE canister/basket components will be calculated from the dimensional information in Attachments II and III.

The volume of the DOE canister shell material in the basket region is:

$$V_{CM} = (\pi/4)(OD_C^2 - ID_C^2)(L_B)$$

where: OD_C = outer diameter of DOE canister = 0.457 m (Attachment II)
ID_C = inner diameter of DOE canister = 0.438 m (Attachment II)
L_B = length of basket region = 2.527 m (Attachment III)

$$V_{CM} = (\pi/4)((0.457)^2 - (0.438)^2)(2.527) = 0.03375 \text{ m}^3$$

The total volume associated with the DOE canister in the basket region is:

$$V_C = (\pi/4)(OD_C^2)(L_B)$$

where: OD_C = outer diameter of DOE canister = 0.457 m (Attachment II)
L_B = length of basket region = 2.527 m (Attachment III)

$$V_C = (\pi/4)(0.457)^2(2.527) = 0.4145 \text{ m}^3$$

The volume of the 37 stainless steel tubes in the TRIGA DOE SNF basket is:

$V_T = 37(\pi/4)(OD_T^2 - ID_T^2)(L_T)$

where: OD_T = outer diameter of SS tubes = 0.0603 m (Attachment III)
ID_T = inner diameter of SS tubes = 0.0493 m (Attachment III)
L_T = length of SS tubes = 0.836 m (Attachment III)

$V_T = 37(\pi/4)((0.0603)^2 - (0.0493)^2)(0.836) = 0.02929\ m^3$

Based on the dimensions assumed for the supplementary absorber tubes of 0.1 cm wall thickness, 4.72 cm inner diameter, and 83.6 cm length (Assumption 3.2.15), the volume of 37 supplementary absorber tubes is

$V_{ST} = 37(\pi/4)((0.0492)^2 - (0.0472)^2)(0.836) = 0.004684\ m^3$

The volume of a base plate in the TRIGA DOE SNF basket is:

$V_{BP} = (\pi/4)(OD_{BP}^2)(Th_{BP})$

where: OD_{BP} = outer diameter of base plate = 0.426 m (Attachment III)
Th_{BP} = thickness of base plate = 0.0095 m (Attachment III)

$V_{BP} = (\pi/4)(0.426)^2(0.0095) = 0.001354\ m^3$

Table 5-16 lists the material, mass, specific heat and associated references for the DOE canister with the standard FLIP SNF.

Table 5-16. Material Properties of DOE Canister and TRIGA SNF

Component	Material	Density (ρ), kg/m³	Volume (V), m³	Mass (M), kg	Specific Heat, J/kg·K (at 300°C, except as noted)
DOE Canister:					
Shell in Basket Region (2.527 m long)	SS 316L (Attach. II)	7980 (Table 5-8)	0.03375 (See above)	269.3 (ρ x V)	544.6 (Table 5-9)
TRIGA SNF Basket (One):					
SS Tubes (37)	SS 316L (Attach. III)	7980 (Table 5-8)	0.02929 (See above)	233.7 (ρ x V)	544.6 (Table 5-9)
Base Plate (1)	SS 316L (Attach. III)	7980 (Table 5-8)	0.001354 (See above)	10.8 (ρ x V)	544.6 (Table 5-9)
Basket Support Brackets (12)	SS 316L (Attach. III)	7980 (Table 5-8)	0.001323 (M/ρ)	10.56 (Attach. III)	544.6 (Table 5-9)
Supplementary Absorber Tubes (37) (Assumptions 3.2.15 & 16)	Alloy 22 (Assumption 3.2.16)	8690 (Table 5-10)	0.004684 (See above)	40.7 (ρ x V)	460 (Table 5-11)
TOTAL Basket (One)			0.03665	295.8	
TRIGA SNF (One):					
UZrH Fuel	UZrH (Ref. 7, p.20)	6020 (Table 5-15)	0.0003748 (M/ρ)	2.256 (See note a.) (Ref. 7, p.25)	551.1 (Table 5-15)
Erbium Poison	Er (Ref. 7, p.25)	9070 (Table 5-15)	0.0000040 (M/ρ)	0.0360 (Ref. 7, p.25)	168 (at 25C) (Table 5-15)
Zirconium Rod	Zr (Ref. 7, p.25)	6570 (Table 5-15)	0.0000097 (M/ρ)	0.0637 (Ref. 7, p.25)	319 (Table 5-15)
Cladding	SS 304 Series (Ref. 7, p.25)	7940 (Table 5-7)	0.0000340 (M/ρ)	0.270 (Ref. 7, p.25)	546.61 (Table 5-7)
End Reflectors (2)	Graphite (Ref. 7, p.25)	1730 (Table 5-15)	0.0002601 (M/ρ)	0.450 (Ref. 7, p.25)	1350 (Table 5-15)
End Fittings (2)	SS 304 Series (Ref. 7, p.12)	7940 (Table 5-7)	0.0000668 (M/ρ)	0.530 (Ref. 7, p.25)	546.61 (Table 5-7)
TOTAL TRIGA (One)			0.0007494	3.6057	

Note a) From Ref. 7, p. 25: Fuel section total mass is 2355.7 grams, including 36 g Erbium and 63.7 g zirconium rod, leaving 2355.7 –36 –63.7 = 2256 g of UZrH fuel (or 2.256 kg).

The complete DOE canister will consist of three (3) TRIGA SNF baskets and one hundred-eleven (111) TRIGA fuel elements.

From the information in Table 5-16, the total mass of the DOE canister <u>in the basket region</u> with TRIGA SNF is:

$$\text{Total Mass, } M_T = (\text{Canister shell mass in basket region}) + (3)(\text{TRIGA SNF basket mass}) + (111)(\text{TRIGA fuel element mass})$$

$$M_T = (269.3 \text{ kg}) + (3)(295.8 \text{ kg}) + (111)(3.6057 \text{ kg})$$

$$M_T = 1557 \text{ kg}$$

Total Volume, $V_C = 0.4145 \text{ m}^3$ (see above)

Effective Density, $\rho_{eff} = \dfrac{M_T}{V_C} = 3756 \text{ kg/m}^3$ [Equation 5.2]

Since the effective specific heat for the DOE canister will be calculated as a mass-weighted average of these properties of the individual materials in the basket region of the DOE canister, the total mass of each of the materials in the region is needed. Table 5-17 contains a summary of the total mass of each material in this region using the information in Table 5-16.

Table 5-17. Total Mass of Materials of DOE Canister With TRIGA SNF in Basket Region

Material	Components	Total Mass, kg	Mass Fraction
SS 316L	Canister shell SS tubes in basket Basket base plates Basket support brackets	1034.5	0.6645
Alloy 22	Supplementary absorber tubes	122.1	0.0784
UZrH	TRIGA fuel	250.4	0.1608
Erbium	Erbium poison	4.0	0.0026
Zirconium	Zirconium rods	7.1	0.0046
SS 304	TRIGA SNF cladding End fittings	88.8	0.0570
Graphite	End reflectors	50.0	0.0321
Total		1557	1.0000

The effective specific heat for the homogenized DOE canister of TRIGA SNF can be calculated using the information in Tables 5-16 and 5-17:

$$C_{p\_eff} = (x_{SS316L})(C_{p(SS316L)}) + (x_{Alloy22})(C_{p(Alloy22)}) + (x_{UZrH})(C_{p(UZrH)}) + (x_{Er})(C_{p(Er)}) + (x_{Zr})(C_{p(Zr)})$$
$$+ (x_{SS304})(C_{p(SS304)}) + (x_{Graphite})(C_{p(Graphite)}) = 563 \text{ J/kg·K}$$

where: x_i = mass fraction of material i from Table 5-17
$C_{p(i)}$ = specific heat of material i from Table 5-16

An approximate value for the effective thermal conductivity of the homogenized DOE canister of TRIGA SNF is developed as follows:

At 20 years after emplacement:

DOE canister surface temperature = 213.1°C (p. 22 of Ref. 27)

Peak TRIGA fuel cladding temperature = 216.6°C (p. 21 of Ref. 27)

The heat rate from (p. 19 of Ref. 27) is

$$Q = (1.9\ \text{W/Assy})(1.25\ \text{Axial Peaking})(111\ \text{Assy/canister}) = 264\ \text{watts/canister}$$

$$K_{eff} = Q / [4\pi L(T_{PEAK} - T_{CANISTER\ SURFACE})] = 264 / [4\pi(L)(216.6 - 213.1)] = 6.00/L\ \text{watts/m·K}$$

$L \cong L_B$ = length of basket region = 2.527 m (Attachment III)

$$K_{eff} = 6.00 / 2.572 = 2.33\ \text{watts/m·K}$$

For purposes of this calculation, the effective thermal conductivity is rounded to 2.5 W/m·K.

5.4 WASTE PACKAGE HEAT OUTPUT AND BOUNDARY CONDITIONS

5.4.1 Defense High Level Waste Canister Heat Output

The volumetric heat generation of the DHLW canister is assumed constant over the axial and radial cross section (Assumption 3.2.11). Table 5-18 lists the heat output for this defense HLW canister based on the data given on p. 2.2.1.3-4, Ref. 12 and modified per Attachment LII of Ref. 8. The year 2010 is assumed to correspond to the intended time of emplacement of the DHLW canister (Assumption 3.2.12), at which time the fire accident is postulated to occur.

Table 5-18. Thermal Output Per DHLW Canister at Time of Emplacement

Time, Years	Thermal Output, watts
0.000001	710.10

The volumetric heat output applied to the finite elements representing the vitrified waste in the SRS pour canister is the thermal output in Table 5-18 divided by the HLW canister glass volume of

0.6256 m^3 (Table 3.3.1, p. 3.3-6, of Ref. 16). An axial power peaking factor of 1.0 is assumed for the uniformly homogeneous contents of the DHLW canisters in this calculation (Assumption 3.2.18).

5.4.2 Heat Output of DOE Canister With TRIGA SNF

Table 5-19 lists the heat output at one year after discharge for a TRIGA FLIP SNF assembly corresponding to the highest level of burnup listed on p. 16 of Ref. 17. Table 5-19 lists the value used for the TRIGA SNF heat output with axial power peaking factor of 1.25 (Assumption 3.2.18). The volumetric heat output of the DOE canister with TRIGA SNF is homogeneously applied (Assumption 3.2.13) to the finite elements representing the canister starting at one year after discharge (Assumption 3.2.19). This volumetric heat output is the thermal output of the one hundred-eleven (111) TRIGA fuel elements in a canister with the 1.25 axial PPF (Assumption 3.2.18) from Table 5-19, divided by the total volume associated with the DOE canister in the basket region (V_C = 0.4145 m^3) determined in Section 5.3.7.

Table 5-19. Heat Output of TRIGA FLIP SNF Assembly

Time After Reactor Discharge, years	TRIGA FLIP SNF Heat Output, Watts per Assembly	Heat Output of DOE Canister with 111 TRIGA SNF & 1.25 Axial PPF, Watts
1.0	14.970	2077

5.4.3 Waste Package Boundary Conditions

A 2-D, 180-degree, finite element representation of the WP cross-section is used in the calculations (Assumption 3.2.3). Boundary conditions at the outer surface of the WP include the following:

(1) The temperature of the surroundings is set at one of two values, corresponding to the normal ambient or fire condition (Assumptions 3.2.26 and 3.2.27), and

(2) a constant heat flux is imposed at the outer surface of the WP corresponding to the absorption rate of incident solar radiation (Assumptions 3.2.32 and 3.2.33).

The modes of heat transfer between the outer shell and the immediate surroundings at the surface facility include radiation and free convection (Assumptions 3.2.2 and 3.2.34). However, convection effects are taken into account only during heating of the WP by the fire. No credit is taken for convection heat transfer for the normal, i.e., pre-fire, or the post-fire cooldown conditions.

Per Section 5.1, the total solar energy incident on the curved surface of a transport cask over a 12-hour period is 400 cal/cm^2 (Assumption 3.2.32). Using a conservative value of 1.0 for the solar absorptivity at the WP outer surface (Assumption 3.2.33), the average rate of absorption of this energy is calculated as follows:

$$q''_{solar} = (400 \text{ cal/cm}^2) / 12\text{hr}$$

$$= (400 / 12) (\text{cal/cm}^2\cdot\text{hr})(4.184 \text{ J/cal})(100 \text{ cm /m})^2 (\text{hr/3600sec})$$

$$= 387 \text{ J/m}^2\cdot\text{sec} \text{ (or 387 watt/m}^2\text{)}.$$

The heat flux due to solar irradiation is maintained constant during the transient, from initial condition through the post-fire cooldown.

The boundary condition involves a peripherally uniform ambient temperature of the surroundings. Consequently, the heat transfer may be considered similar to the general case of heat exchange between gray, parallel plane surfaces (Assumption 3.2.20). The heat flow at surface 1 with parallel surfaces at temperatures T_1 and T_2, is

$$q_r = \sigma \; \varepsilon_{eff} A (T_1^4 - T_2^4).$$

In this equation, σ is the Stefan-Boltzman constant, equal to 5.67E-8 W/m$^2\cdot$K^4 (p. 561, Ref. 25) and the expression for the effective emissivity, ε_{eff}, is (p. 655, Ref 25)

$$\varepsilon_{eff} \cong [(1/\varepsilon_1) + (1/\varepsilon_2) - 1]^{-1}$$

where ε_1 and ε_2 are the emissivities of surfaces 1 and 2, respectively.

Considering that the view factor, F, is unity for parallel planes, this equation is equivalently,

$$q_r = (\sigma) (\varepsilon_{eff}) (A) (T_1^2 + T_2^2) (T_1 + T_2) (T_1 - T_2)$$

$$= [(\sigma) (\varepsilon_{eff}) (T_1^2 + T_2^2) (T_1 + T_2)] (A) (T_1 - T_2)$$

$$= (h_r) (A) (T_1 - T_2)$$

where the effective coefficient for radiation heat transfer, h_r, is $[(\sigma) (\varepsilon_{eff}) (T_1^2 + T_2^2) (T_1 + T_2)]$.

For air at room temperature and atmospheric pressure, the average value of the convection heat transfer coefficient, h_c, for flow around horizontal cylinders is correlated by the equation (p. 4-88, Reference 11) (Assumption 3.2.34).

$h_c = 0.19\ (\Delta T)^{1/3}$ Btu/hr·ft^2·F, with ΔT in degrees Fahrenheit, for $D^3\Delta T>100$ ft^3·F,

$= 1.3123\ (\Delta T)^{1/3}$ W/m^2·K, with ΔT in degrees Kelvin or Celsius.

The free convection heat transfer coefficient decreases with increasing temperature of the gas due to the change in gas properties with temperature. The above expression for the coefficient is therefore conservative for use during WP heating because of higher temperatures associated with the fire.

The radiation heat transfer on the WP outer surface may be combined with convection heat transfer and characterized as an effective heat transfer coefficient, h_{eff}.

The combined flow of heat via radiation and convection to the surroundings is then

$$q = q_r + q_c,$$

$$q = (h_r + h_c)\,(A)\,(T_1 - T_2)$$

where q_r and q_c are the heat transfer rates for radiation and convection, respectively.

Attachment IV includes tables listing the effective values of heat transfer coefficient used in the calculations for the various cases evaluated.

5.5 FINITE ELEMENT DEVELOPMENT

This section briefly describes the ANSYS Version 5.4 input file format used to develop the ANSYS cases. Each ANSYS Version 5.4 input deck is provided as part of the ANSYS output files on the CD associated with this document. A separate input file is created for each case.

The following simplifying Assumptions were used in the development of the finite element representation: Assumptions 3.2.1, 3.2.3 to 3.2.9, 3.2.11, and 3.2.13.

The basic layout of an ANSYS input file includes the following seven steps:

1. Introduce and identify the problem represented, additional files read by the input deck, and what information is contained in the data files used in the input deck.

2. Define the parameters and dimensions that are used repeatedly in the case.

3. Define the element types that are needed to represent the geometry to perform the calculation.

4. Define the representative geometry and mesh structure.

5. Define all radiation surfaces and create the radiation mesh matrix.

6. Apply the internal heat loads (volumetrically) and the boundary conditions to the appropriate components. Heat loads and boundary conditions are applied at each time step.

7. Select the node sets associated with the various materials and/or components of interest and echo their maximum temperatures for each time step of the transient to the output file.

Tables 5-1 and 5-2 list the cases evaluated in this calculation with the HLW canisters in contact with the WP shell. In each of these cases the applicable finite element representation of the 5-DHLW/DOE codisposal WP is as depicted in Figure 5-2, i.e., with canister and shell in contact. For the case, GapMax, the finite element representation differs only in the position of the HLW canisters, which are effectively shifted radially inward in the WP to give the maximum gap between canister and shell (refer to Figure 5-3).

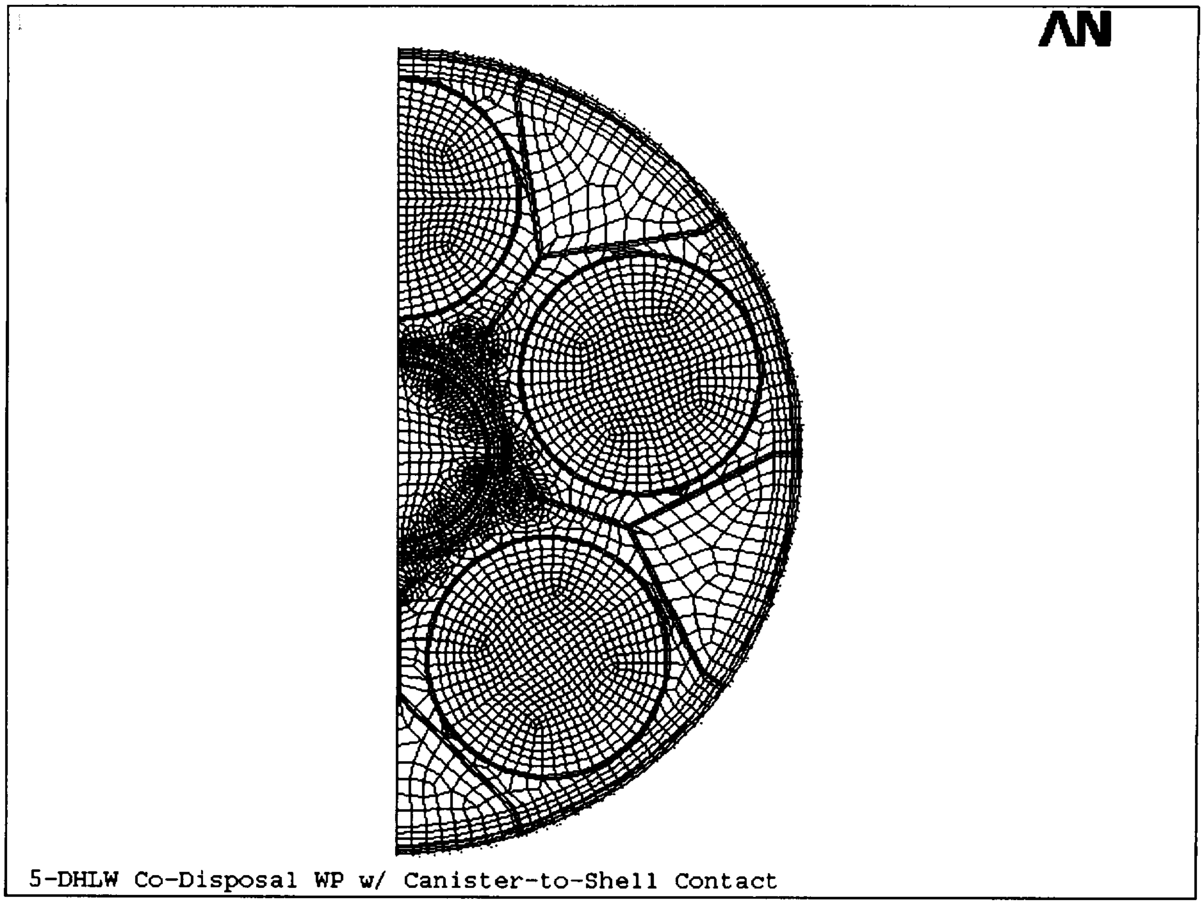

Figure 5-2. Codisposal WP Finite Element Representation, Canister/Shell Contact

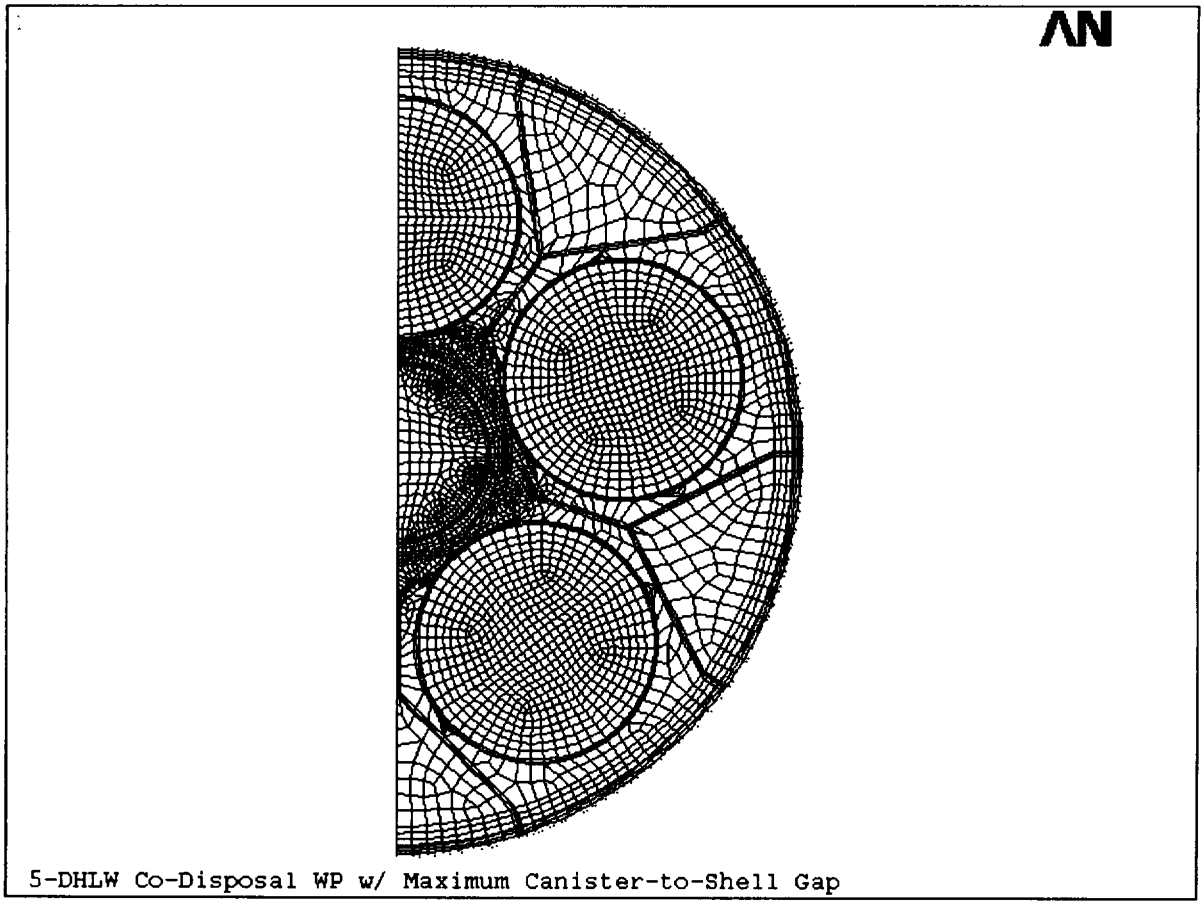

Figure 5-3. Codisposal WP Finite Element Representation, Max. Canister/Shell Gap

6. RESULTS

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.

Table 6-1 shows the "Base" case variations with time of the calculated maximum temperature for each of the following WP or SRS canister components: (1) WP outer shell, (2) WP inner shell, (3) SRS canister shell, (4) SRS vitrified glass, and (5) WP basket angle/divider plate sections. The calculated peak temperature of the SRS glass for the "Base" case is 410.1°C.

Table 6-2 is for the maximum gap case and also shows the variations with time of the calculated maximum temperature for each of the WP or SRS canister components. The calculated peak glass temperature for the maximum canister-to-shell gap is 311.9°C (GapMax case). This is significantly lower than calculated for the case of canister-to-shell contact (i.e., the "Base" case).

Table 6-1. "Base" Case Maximum Temperatures for WP/Canister Components

Time, hrs.	Maximum Temperature of Component, °C					
	WP Support Tube	WP Angles and Divider Plates	SRS Glass	SRS Canister	WP Inner Shell	WP Outer Shell
0.00	217.6	216.4	211.8	211.8	129.4	125.6
0.08	217.6	216.4	211.8	211.8	218.6	320.8
0.17	217.6	216.4	211.8	211.8	291.9	384.0
0.25	217.6	216.4	232.0	242.4	354.5	435.6
0.33	217.6	246.5	283.2	294.4	410.9	482.1
0.42	217.6	289.8	331.7	343.2	461.6	523.8
0.50	217.6	331.7	376.6	388.1	507.1	561.5
0.58	217.7	366.9	408.4	416.5	485.1	483.3
0.67	217.7	380.2	410.1	415.3	470.6	464.6
0.75	217.9	381.4	403.7	407.5	455.6	449.4
0.83	218.0	378.1	395.7	398.7	441.6	435.6
0.92	218.3	373.1	387.6	390.0	428.7	422.9
1.00	218.5	367.3	379.6	381.6	416.8	411.2
1.08	219.0	361.4	372.0	373.7	405.7	400.3
1.17	219.6	355.5	364.8	366.2	395.3	390.2
1.25	220.3	349.7	357.9	359.1	385.7	380.7
1.33	221.0	344.0	351.4	352.4	376.6	371.8
1.42	221.7	338.6	345.2	346.0	368.1	363.5
1.5	222.4	333.4	339.3	340.0	360.1	355.7
2.0	226.6	306.1	309.5	309.6	320.4	316.7
2.5	230.4	284.8	287.4	287.5	291.0	287.7
3.0	233.5	267.8	271.7	271.7	268.4	265.3
3.5	236.0	255.1	259.9	259.9	253.5	248.6
4.0	238.0	245.4	252.1	250.7	241.2	236.3
4.5	239.6	238.9	246.0	243.4	230.7	225.9
5.0	240.8	240.2	241.4	237.7	221.7	216.9
5.5	241.8	241.2	238.1	234.0	213.9	209.2
6.0	242.6	242.0	235.6	235.2	207.1	202.4
7.0	243.8	243.1	237.1	237.1	195.7	191.2
8.0	244.6	243.9	238.5	238.5	186.7	182.2
9.0	245.3	244.4	239.6	239.7	179.4	175.1
10.0	245.8	244.9	240.6	240.6	173.4	169.3
11.0	246.2	245.2	241.3	241.4	168.5	164.5
12.0	246.5	245.5	241.9	241.9	164.4	160.5
13.0	246.7	245.6	242.5	242.3	161.0	157.1
14.0	246.8	245.7	243.1	242.5	158.3	154.2
15.0	246.8	245.8	243.6	242.7	156.1	151.8
16.0	246.8	245.7	243.9	242.7	154.1	149.7
17.0	246.7	245.7	244.1	242.7	152.4	147.9
18.0	246.6	245.5	244.1	242.6	150.9	146.2
19.0	246.5	245.3	243.9	242.4	149.6	144.8
20.0	246.3	245.1	243.7	242.1	148.5	143.6

Table 6-2. "GapMax" Case - Max Temperatures for WP/Canister Components

Time, hrs.	Maximum Temperature of Component, °C					
	WP Support Tube	WP Angles and Divider Plates	SRS Glass	SRS Canister	WP Inner Shell	WP Outer Shell
0.00	229.0	227.9	227.4	227.4	130.2	126.2
0.08	229.0	227.9	227.4	227.4	219.2	321.3
0.17	229.0	227.9	227.4	227.4	292.0	384.1
0.25	229.0	227.9	227.4	227.4	355.0	435.9
0.33	229.0	249.8	227.4	227.4	411.5	482.6
0.42	229.0	294.5	227.4	227.4	462.0	524.2
0.50	229.0	337.8	227.4	227.5	507.5	561.9
0.58	229.0	374.3	250.7	253.9	485.6	483.8
0.67	229.0	388.3	273.4	276.2	471.2	465.1
0.75	229.1	389.6	288.7	291.0	456.4	450.0
0.83	229.2	386.2	298.7	300.7	442.5	436.3
0.92	229.3	381.0	305.0	306.8	429.7	423.7
1.00	229.4	375.0	308.9	310.4	417.9	412.1
1.08	229.6	368.8	311.0	312.3	406.9	401.4
1.17	229.9	362.7	311.9	313.0	396.7	391.3
1.25	230.2	356.6	311.8	312.8	387.1	382.0
1.33	230.6	350.8	311.1	312.0	378.2	373.2
1.42	231.1	345.1	310.0	310.8	369.8	365.0
1.5	231.6	339.7	308.5	309.2	361.9	357.2
2.0	234.6	311.4	296.6	296.9	322.6	318.7
2.5	237.4	289.3	284.0	284.1	293.4	289.9
3.0	240.0	272.2	272.6	272.6	270.7	267.6
3.5	242.3	259.5	262.5	262.5	254.2	249.7
4.0	244.2	250.0	255.2	253.9	241.0	236.3
4.5	245.8	244.8	249.6	247.6	230.0	225.1
5.0	247.1	246.2	245.6	245.2	220.7	215.6
5.5	248.2	247.3	246.3	246.4	212.7	207.6
6.0	249.2	248.3	247.4	247.4	205.8	200.7

Table 6-3 lists glass temperature history results for the "Base" and parametric cases. Table 6-4 lists the peak calculated glass temperatures for the "Base" and parametric cases.

Table 6-3. Maximum Glass Temperatures for the "Base" and Parametric Cases

Time, hours	SRS Glass Temperatures, °C						
	"Base" Case	Case 1 (Vary DOE canister heat load)	Case 2 (Vary DHLW canister heat load)	Case 3 (Vary WP outer surface emissivity)	Case 4 (Vary WP solar heat flux)	Case 5 (Vary free convection heat transfer coefficient)	Case 6 (Vary duration of fire)
0.00	211.8	221.9	242.1	217.5	226.9	211.8	211.8
0.08	211.8	221.9	242.1	217.5	226.9	211.8	211.8
0.17	211.8	221.9	242.1	217.5	226.9	211.8	211.8
0.25	232.0	234.0	242.7	238.1	248.6	233.3	232.0
0.33	283.2	285.1	293.5	289.0	299.0	284.9	283.2
0.42	331.7	333.5	341.4	337.1	346.7	333.7	331.7
0.50	376.6	378.3	385.8	381.7	390.7	378.8	376.6
0.58	408.4	410.0	417.0	413.3	421.5	410.6	417.7
0.67	410.1	411.6	418.3	415.4	422.5	412.2	445.5
0.75	403.7	405.1	411.6	409.4	415.6	405.6	444.1
0.83	395.7	397.1	403.4	401.9	407.3	397.6	435.4
0.92	387.6	388.9	395.2	394.2	398.9	389.3	425.6
1.00	379.6	381.0	387.1	386.6	390.7	381.3	415.8
1.08	372.0	373.4	379.4	379.4	382.9	373.6	406.4
1.17	364.8	366.1	372.1	372.4	375.5	366.3	397.5
1.25	357.9	359.2	365.1	365.8	368.4	359.4	389.1
1.33	351.4	352.7	358.5	359.5	361.8	352.8	381.2
1.42	345.2	346.5	352.3	353.6	355.5	346.5	373.7
1.50	339.3	340.6	346.3	347.9	349.5	340.6	366.6
2.00	309.5	310.8	316.5	319.0	319.3	310.6	331.2
2.50	287.4	288.9	295.9	297.1	297.8	288.3	305.5
3.00	271.7	273.3	281.5	281.2	282.3	272.5	287.2
3.50	259.9	261.9	272.6	269.2	271.4	260.6	273.4
4.00	252.1	254.4	266.2	261.1	263.8	252.8	264.3
4.50	246.0	248.5	261.9	254.5	258.1	246.5	256.9
5.00	241.4	244.2	259.6	250.0	253.8	242.0	251.5
5.50	238.1	244.1	260.9	246.4	250.7	238.6	247.3
6.00	235.6	245.2	261.9	243.7	249.9	236.1	244.1

Table 6-4. Peak Calculated Glass Temperatures

SRS Glass Temperatures, °C						
"Base" Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
410.1	411.6	418.3	415.4	422.5	412.2	445.5

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31. AP-SV.1Q, Rev. 0, ICN 2. *Control of the Electronic Management of Information.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000831.0065.

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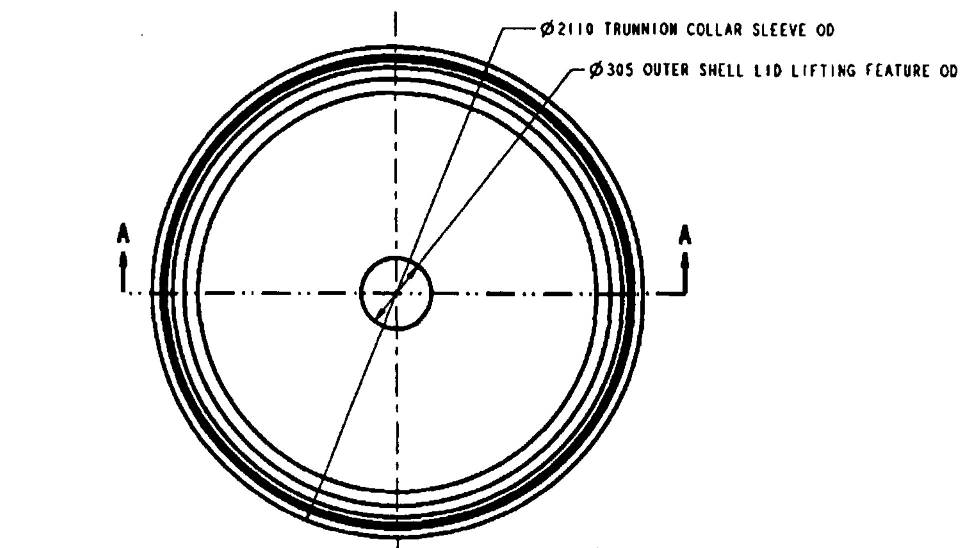
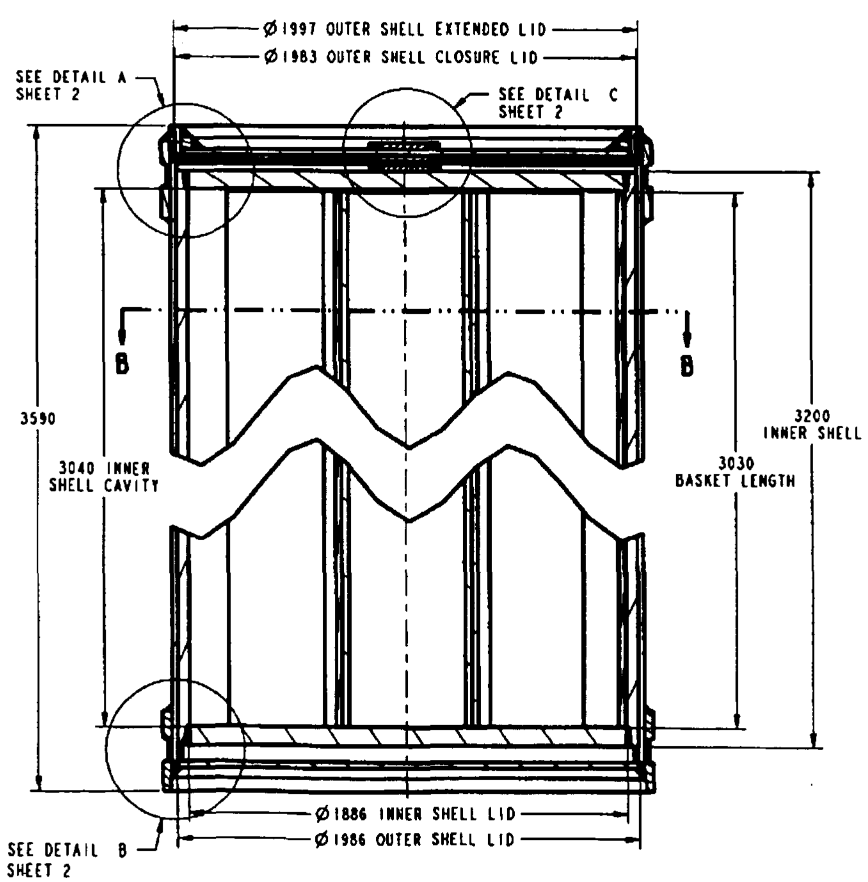
8. ATTACHMENTS

The list of attachments is provided in Table 8-1.

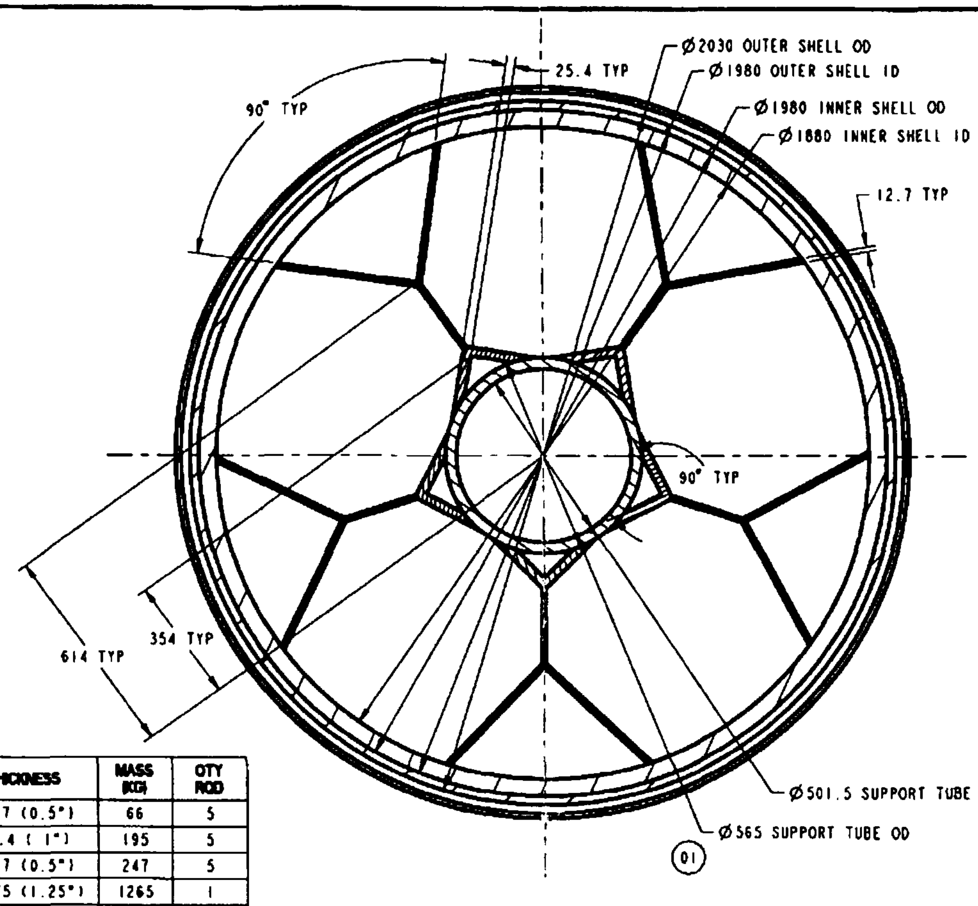
Table 8-1. Supporting Documentation

Attachment Number	Description	Size (pages)
I	5-DHLW/DOE SNF - Short WP Assembly Configuration for Site Recommendation Sketch Number: SK-0196 REV 03, and 5-DHLW/DOE SNF - Short Weld Configuration Sketch Number: SK-0197 REV 00	3
II	DOE Standard Canister (Short) Sketch Number: SK-0129 REV 00	1
III	TRIGA DOE SNF Basket Assembly Sketch Number: SK-0124 REV 00	1
IV	Effective Heat Transfer Coefficient at Waste Package Outer Surface	3
V	File (propwp01.dat) containing tables of material properties	4
VI	File (srscan.dat) containing table for SRS canister heat generation rate	1
VII	List of ANSYS output files contained on CD	1
VIII	CD containing ANSYS files	1 CD





SECTION A-A



SECTION B-B

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY RQD
DIVIDER PLATE	SA-516 K02700	12.7 (0.5")	66	5
INNER BRACKET	SA-516 K02700	25.4 (1")	195	5
OUTER BRACKET	SA-516 K02700	12.7 (0.5")	247	5
SUPPORT TUBE	SA-516 K02700	31.75 (1.25")	1265	1
INNER SHELL	SA-240 S31600	50	7621	1
INNER SHELL LID	SA-240 S31600	80	1765	2
INNER LID LIFTING FEATURE	SA-240 S31600	27	12	1
OUTER SHELL	SB-575 N06022	25	4692	1
EXTENDED OUTER SHELL LID	SB-575 N06022	25	172	1
EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25	629	1
EXTENDED OUTER LID REINFORCING RING	SB-575 N06022	50	129	1
OUTER LID LIFTING FEATURE	SB-575 N06022	27	13	2
OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	10	268	1
OUTER SHELL FLAT BOTTOM LID	SB-575 N06022	25	669	1
UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	655	1
LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	642	1
INNER SHELL SUPPORT RING	SB-575 N06022	20	53	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	325	***
TOTAL 316 WELDS	SFA-5.9 S31680	-	133	***
WASTE PACKAGE ASSEMBLY	-	-	23360	1
HLW GLASS ASSEMBLY	-	-	2500*	5
18" CANISTER SHORT	-	-	2270**	1
WP ASSEMBLY WITH SNF	-	-	38130	-

(03) * WASTE ACCEPTANCE SYSTEM REQUIREMENTS DOCUMENT. E00000000-00811-1708-00001 REV 03, DOE/RW-0351. ACC: HOO.19990226.0001. PAGE 18, SECTION 4.2.3.1.A.4.

** UNITED STATES DEPARTMENT OF ENERGY 1998. DESIGN SPECIFICATION FOR DEPARTMENT OF ENERGY STANDARDIZED SPENT NUCLEAR FUEL CANISTERS, VOLUME 1, DESIGN SPECIFICATION, REV 01. WASHINGTON D.C.: UNITED STATES DEPARTMENT OF ENERGY. TIC: 241528

*** SEE SK-0197 FOR WELD CONFIGURATION AND MASSES

UNITS: mm

DO NOT SCALE FROM SKETCH

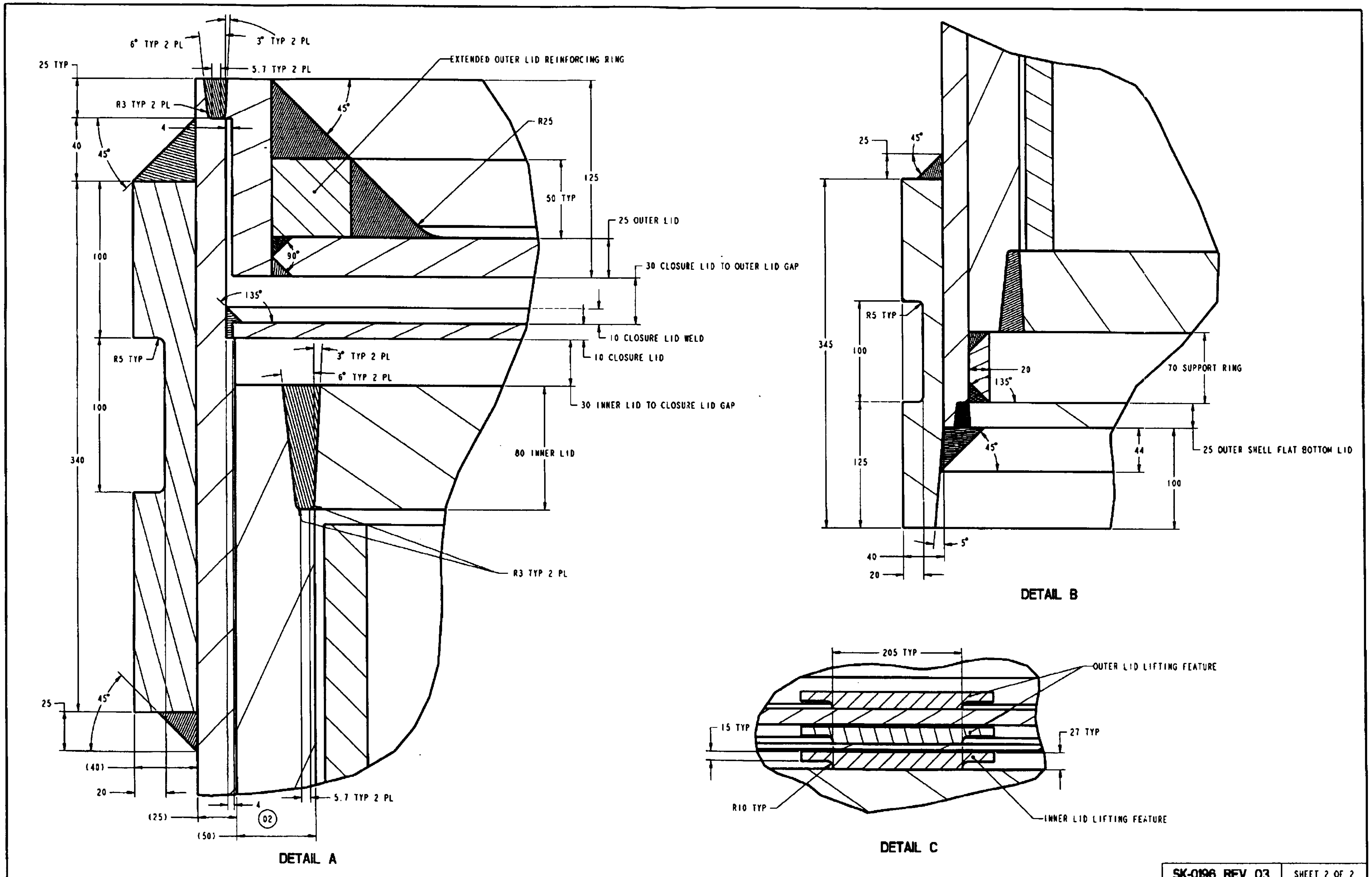
REVISIONS

REV	DESCRIPTION	DRW BY	DATE
00	ISSUED APPROVED	DGM	1/26/00
01	IN SECTIION B-B Ø 565 SUPPORT TUBE OD "WAS" ID	DGM	4/21/00
02	"MODIFIED" REVISION TABLE, "ADDED" DIMENSION 4 TO DETAIL A, "MODIFIED" CROSS HATCHING ON DETAIL A	BH	4/25/00
03	IN NOTE **, DOE/RW-0351 "WAS" DOE/RW-315P, IN REVISION BLOCK REV 00, 1/26/00 "WAS" 1/25/00, "ADDED" REVISION BALLOONS TO SECTION B-B AND DETAIL "A"	EJC	6/5/00

"FOR INFORMATION ONLY"

5 DHLW/DOE SNF - SHORT WP ASSSEMBLY CONFIGURATION FOR SITE RECOMENDATION

SKETCH NUMBER:	SK-0196 REV 03 — SHEET 1 OF 2
SKETCHED BY:	EUGENE CONNELL EJC 06/06/00 SMB 06/06/00 SMB for MJA 06/06/00
DATE:	06/05/00
FILE:	/home/pro_library/checkout/sketches/5dhlw_short/sk-0196_rev03.dwg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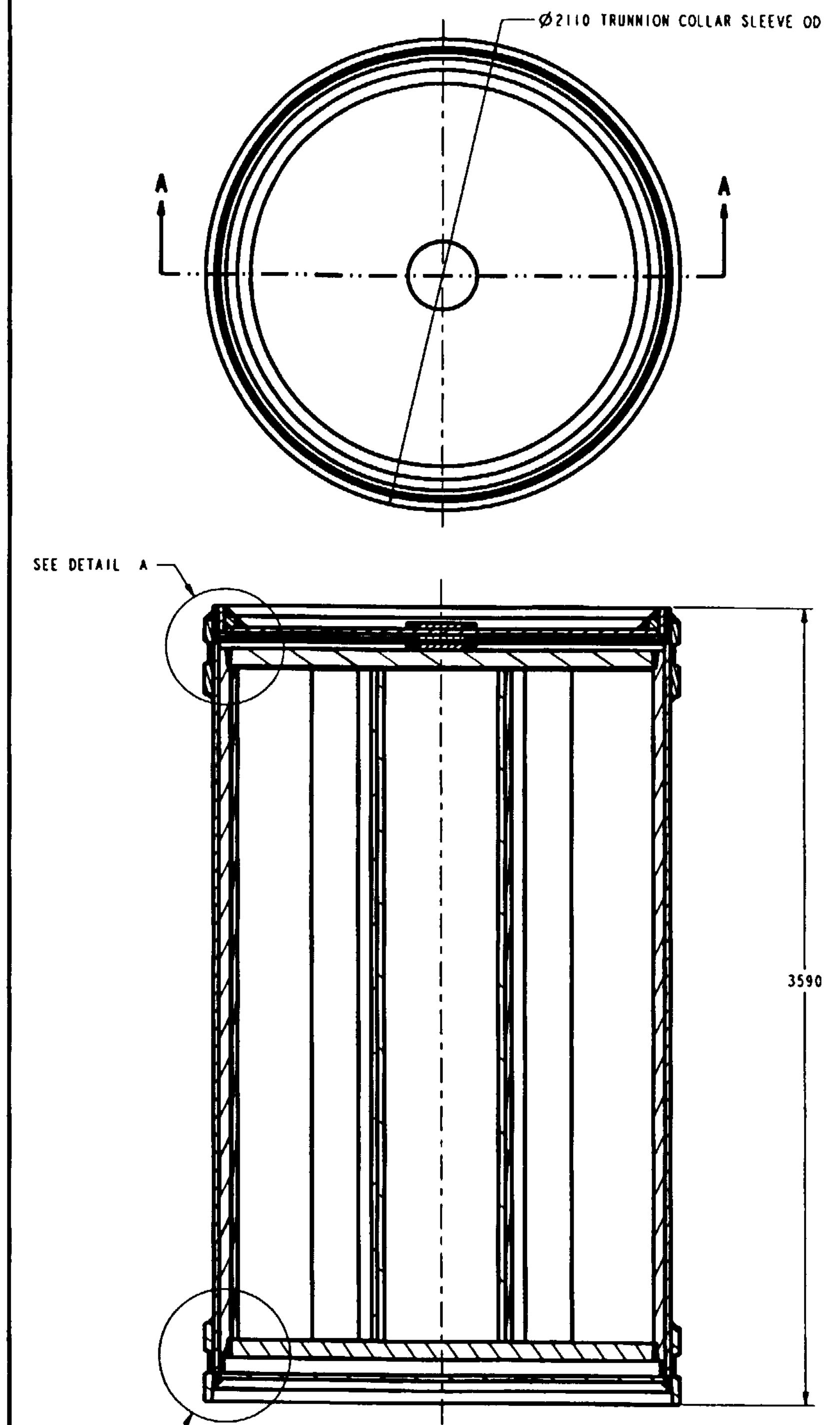
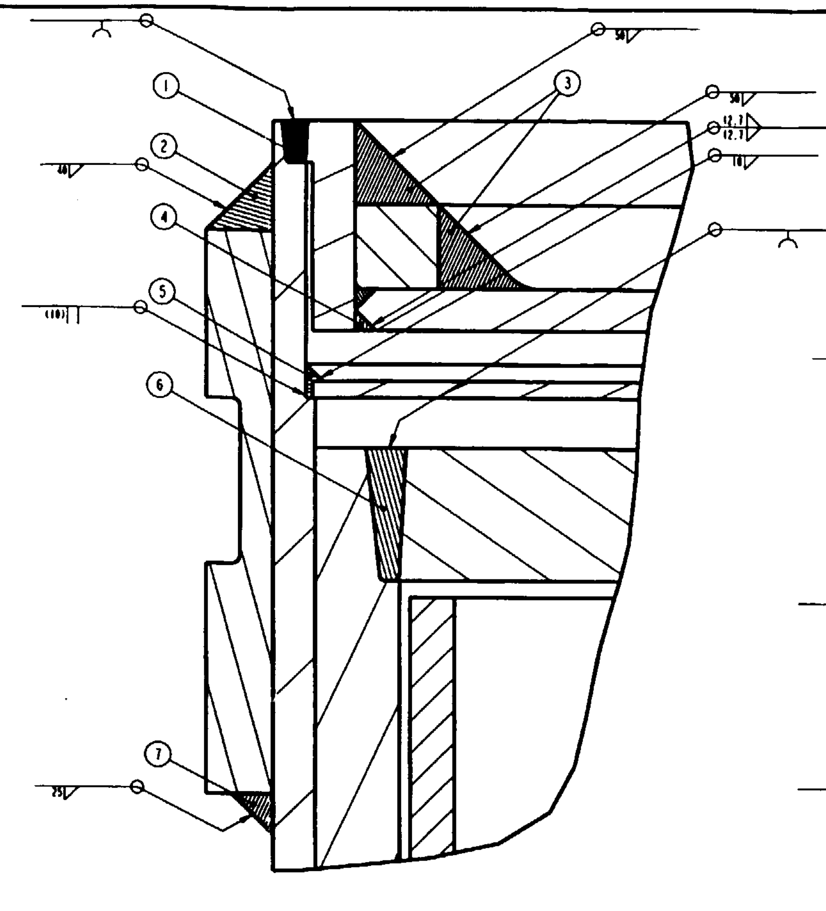
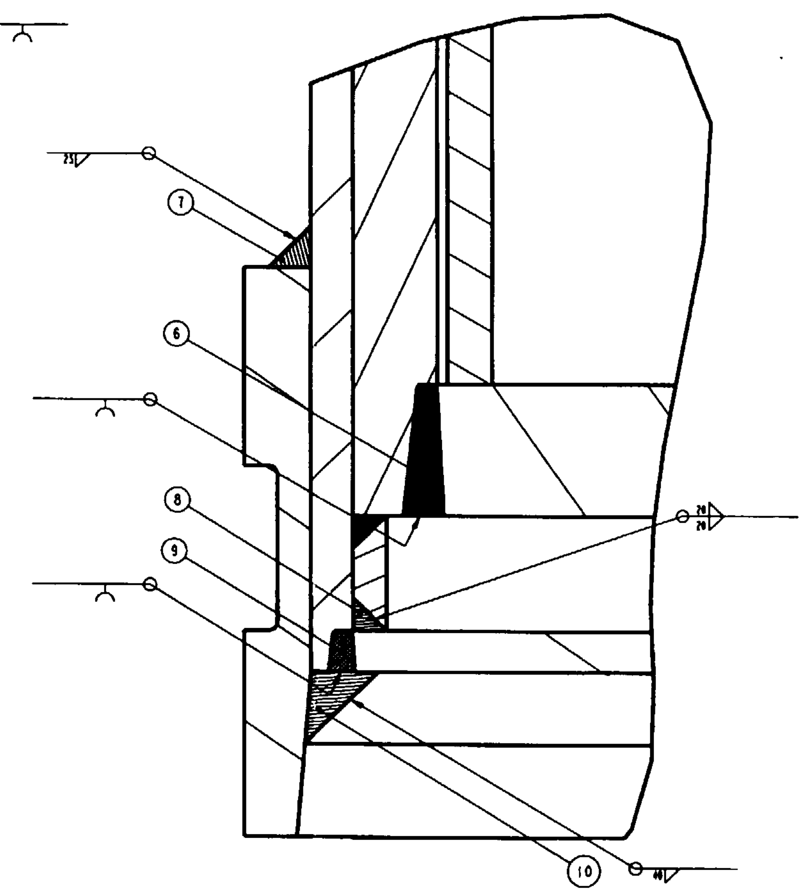
3° TYP 2 PL
25 TYP
5.7 TYP 2 PL
EXTENDED OUTER LID REINFORCING RING
R3 TYP 2 PL
4
45°
R25
40
125
50 TYP
25 OUTER LID
100
90°
30 CLOSURE LID TO OUTER LID GAP
135°
10 CLOSURE LID WELD
R5 TYP
10 CLOSURE LID
3° TYP 2 PL
6° TYP 2 PL
30 INNER LID TO CLOSURE LID GAP
340
80 INNER LID
R3 TYP 2 PL
25
(40)
20
(25)
(50)
02
5.7 TYP 2 PL
DETAIL A
345
135°
20
70 SUPPORT RING
25 OUTER SHELL FLAT BOTTOM LID
44
5°
DETAIL B
205 TYP
OUTER LID LIFTING FEATURE
15 TYP
27 TYP
R10 TYP
INNER LID LIFTING FEATURE
DETAIL C
SK-0196 REV 03
SHEET 2 OF 2



SECTION A-A



DETAIL A



DETAIL B

WELD	MATERIAL	MASS (KG)	QTY ROD
1	SFA-5.14 N06022	18	1
2	SFA-5.14 N06022	45	1
3	SFA-5.14 N06022	127	1
4	SFA-5.14 N06022	4.1	2
5	SFA-5.14 N06022	4.9	1
6	SFA-5.9 S31680	67	2
7	SFA-5.14 N06022	17	2
8	SFA-5.14 N06022	11	2
9	SFA-5.14 N06022	18	1
10	SFA-5.14 N06022	48	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	325	-
TOTAL 316 WELDS	SFA-5.9 S31680	133	-

UNITS: mm

DO NOT SCALE FROM SKETCH

REVISIONS			
REV	DESCRIPTION	DRN BY	DATE
00	ISSUED APPROVED	BH	03/10/00

"FOR INFORMATION ONLY"

5-DHLW/DOE SNF - SHORT WELD CONFIGURATION

SKETCH NUMBER: SK-0197 REV 00

SKETCHED BY: BRYAN HARKINS BH 10 March 00 JMB 03/13/00 3/13/00 3.13.00

DATE: 03/10/00

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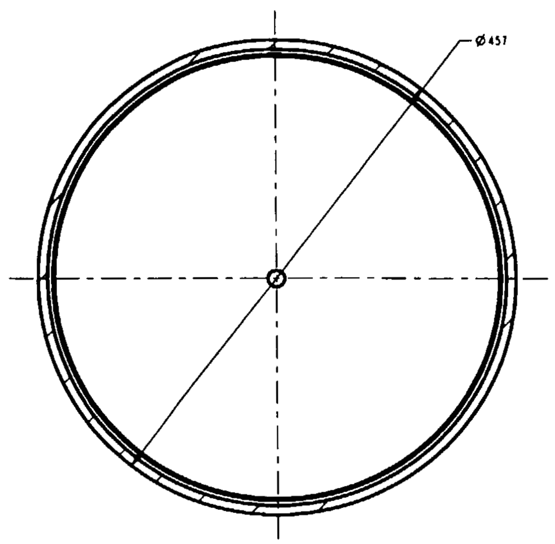
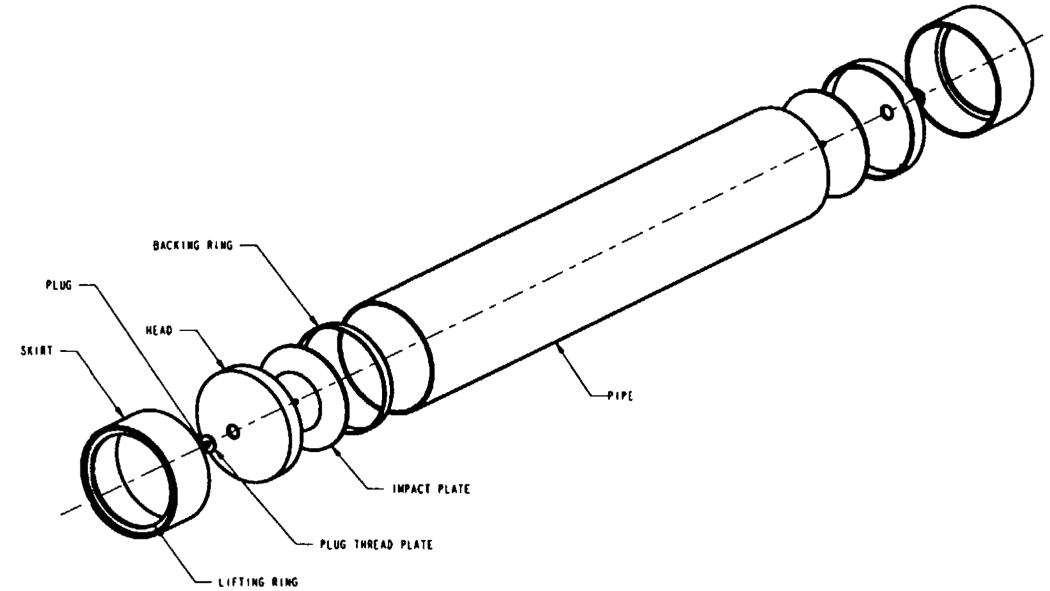
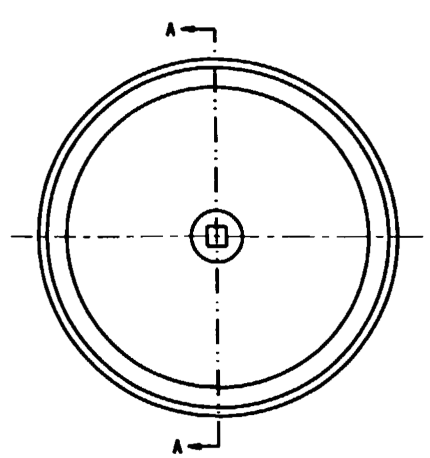
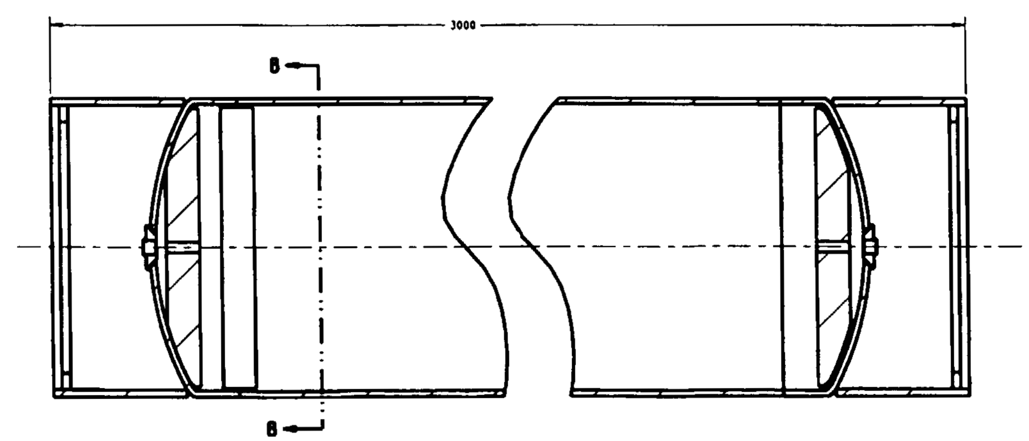


SECTION B-B







SECTION A-A

COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
BACKING RING	SA-240 S31603	4.8	2	1
HEAD	SA-240 S31603	9.5	19	2
IMPACT PLATE	SA-36 K02600	50.8	42	2
LIFTING RING	SA-240 S31603	12.7	3	2
PIPE	SA-312 S31603	9.5	247	1
PLUG	SA-479 S31603	-	.06	2
PLUG THREAD PLATE	SA-479 S31603	-	.3	2
SKIRT	SA-312 S31603	9.5	25	2
CANISTER ASSEMBLY	-	-	427	1

"FOR INFORMATION ONLY"

UNITS: mm

DO NOT SCALE FROM SKETCH

DOE STANDARD CANISTER (SHORT)

SKETCH NUMBER: SK-0129 REV 00

SKETCHED BY: GENE CONNELL

DATE: 03/16/99

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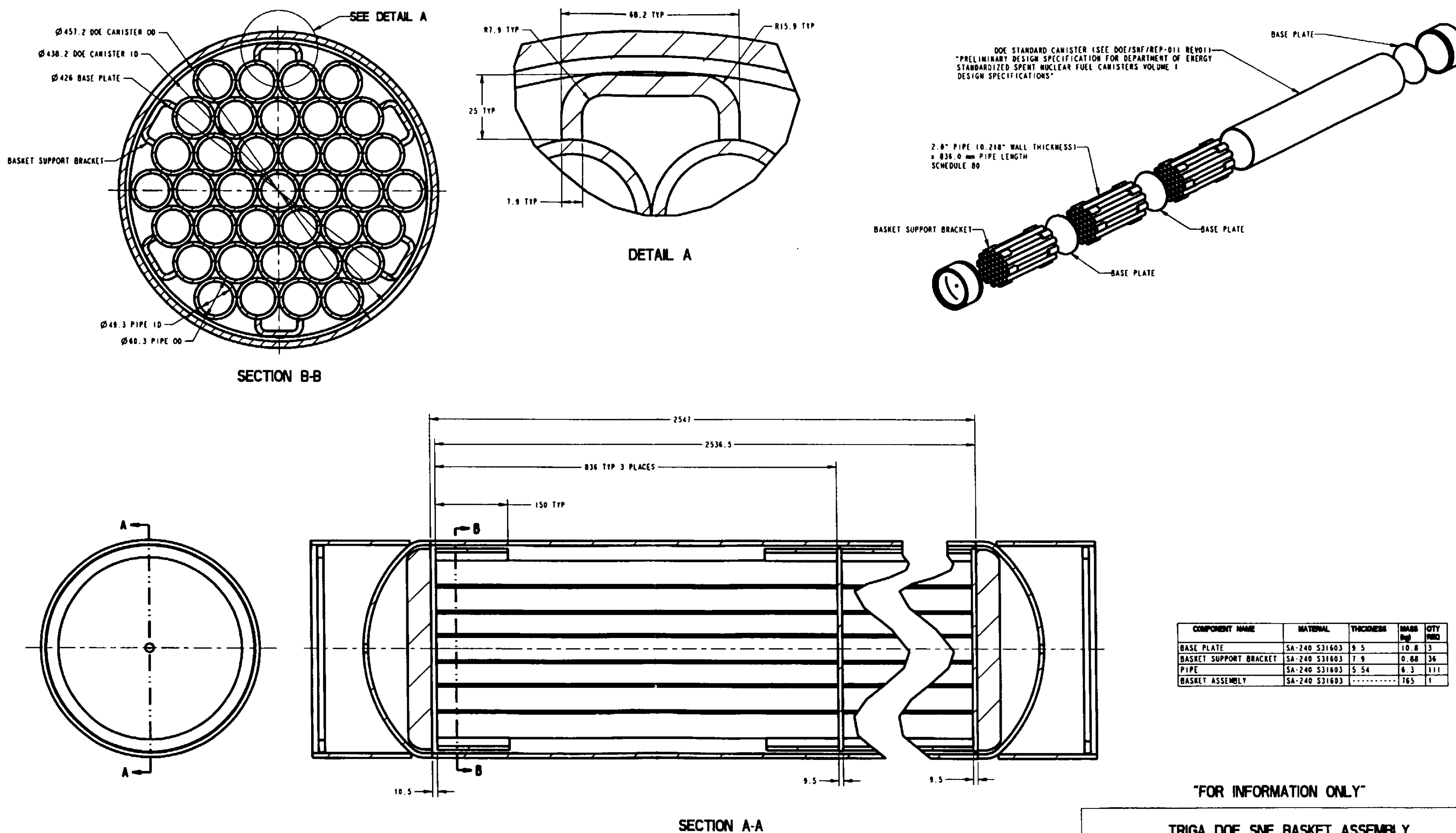

COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
BASE PLATE	SA-240 S31603	9.5	10.8	3
BASKET SUPPORT BRACKET	SA-240 S31603	7.9	0.68	36
PIPE	SA-240 S31603	5.54	6.3	111
BASKET ASSEMBLY	SA-240 S31603	----------	765	1

"FOR INFORMATION ONLY"

UNITS: mm
DO NOT SCALE FROM SKETCH

TRIGA DOE SNF BASKET ASSEMBLY

SKETCH NUMBER: SK-0124 REV 00
SKETCHED BY: BRYAN HARKINS
DATE: 03/19/99
FILE: /home/harkins/proe/fermi_37/SK-0124_triga.dwg

BA 19Mar99 JWB 03/19/99 TLD 3.19.99

Heat Transfer Coefficients at Waste Package Outer Surface:

Values of heat transfer coefficient at the waste package (WP) outer surface are given in the table below for various conditions. For particular cases or conditions not listed, "Base" Case values apply. An example calculation is included.

CASE	"BASE"	"BASE"	3	5
Condition	w/o flame	w/ flame	w/o flame	w/ flame
Emissivity:				
Alloy 22	0.87	1	0.783	1
Surroundings	1	1	1	1
Effective	0.87	1	0.783	1
Temperature, °C:				
Surroundings	38.0	800	38.0	800
Free-Convection Multiplier	0	1	0	1.2
	Effective Heat Transfer Coefficient, W/m^2·K			
Temperature of WP Surface, °C				
37.78	5.9	110.0	5.3	112.4
100	8.0	117.5	7.2	119.8
150	10.0	124.3	9.0	126.5
200	12.4	131.7	11.2	133.9
250	15.2	139.8	13.7	141.9
300	18.6	148.6	16.7	150.7
350	22.4	158.2	20.1	160.2
400	26.7	168.6	24.0	170.5
450	31.6	179.8	28.5	181.7
500	37.2	191.9	33.4	193.7
550	43.3	204.9	39.0	206.6
600	50.2	218.9	45.2	220.4
650	57.8	233.8	52.0	235.2
700	66.1	249.6	59.5	250.8
750	75.3	266.1	67.7	267.1
800	85.3	280.3	76.7	280.3

An example calculation of effective heat transfer coefficient at the WP outer surface follows:

Conditions -

Temperature of surroundings (e.g., for flame)

$$T_{SURR} = 800°C + 273.15$$

$$= 1073.15K$$

Temperature of WP outside surface

$$T_{WPOS} = 37.78°C + 273.15$$

$$= 310.93°K$$

Emissivity of surroundings

$$\varepsilon_{SURR} = 1.0$$

Emissivity of WP outer surface

$$\varepsilon_{WPOS} = 1.0$$

Effective emissivity -

$$\varepsilon_{EFF} = [(1/\varepsilon_{WPOS})+(1/\varepsilon_{SURR}) - 1]^{-1}$$

$$= [(1/1.0)+(1/1.0) - 1]^{-1}$$

$$= 1.0$$

Effective heat transfer coefficient for radiation -

$$h_R = (\sigma)(\varepsilon_{EFF})[(T_{SURR})^2 + (T_{WPOS})^2](T_{SURR} + T_{WPOS})$$

$$= (5.67E\text{-}8)(1.0)[(1073.15)^2 + (310.93)^2](1073.15 + 310.93)$$

$$= 98.0\ W/m^2 \cdot K$$

Film coefficient for heating

$$h_C = (1.3123)\ (T_{SURR} - T_{WPOS})^{1/3}$$

$$= (1.3123)\ (1073.15 - 310.93)^{1/3}$$

$$= 12.0\ W/m^2 \cdot K$$

Total effective heat transfer coefficient -

$$h_{EFF} = h_R + h_C$$

$$= 98.0 + 12.0$$

$$= 110.0 \text{ W/m}^2\cdot\text{K}$$

This attachment presents a listing of the ANSYS input file of material properties.

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/COM,   4       Argon                   Canister Fill Gas (NOT USED)
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/COM,   6       Stainless Steel 316 NG  Canister Shell
/COM,   7       Alloy 22 Carbon Steel   Canister Shell
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MPTEMP,  13,  137.78,  160.00,  182.22,  204.44,  226.67,  248.89,
MPTEMP,  19,  271.11,  293.33,  315.56,  337.78,  360.00,  382.22,
MPTEMP,  25,  404.44,  426.67,
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MPDATA, KXX, 2, 7, 0.1638, 0.1677, 0.1716, 0.1754, 0.1791, 0.1866,
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MPDATA, KXX, 2,19, 0.2358, 0.2425, 0.2491, 0.2556, 0.2621, 0.2684,
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MPTEMP,  13,  343.33,  371.11,  398.89,  426.67,  454.44,  482.22,
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MPDATA,   C, 5,13, 582.39, 598.04, 610.25, 622.12, 633.29, 651.67,
MPDATA,   C, 5,19, 668.48, 688.99, 706.55, 719.45, 750.06, 789.29,
MPDATA,   C, 5,25, 835.25, 920.49,1134.34,1697.60, 837.70, 763.35,
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MPDATA,   C, 6, 7, 522.43, 528.75, 538.31, 538.74, 544.43, 544.72,
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MPDATA,   C, 6,25, 583.15, 582.81, 585.37, 587.89, 587.48, 589.92,
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MPTEMP,   1,   21.11,   37.78,   65.56,   93.33,  121.11,  148.89,
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MPDATA, C,   7, 7,  514,
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/COM,
/COM,   REF1    ASTM A 20/A 20M-97a. 1997. Standard Specification for General
/COM,           Requirements for Steel Plates for Pressure Vessels. West Conshohocken,
/COM,           Pennsylvania: American Society for Testing
/COM,           and Materials. TIC: 242529.
/COM,
/COM,   REF2    ASTM G 1-90 (Reapproved 1999). 1990. Standard Practice for Preparing,
```

```
/COM,          Cleaning, and Evaluating Corrosion Test Specimens.West Conshohocken,
/COM,          Pennsylvania: American Society for Testing and Materials. TIC: 238771.
/COM,
/COM,   REF3   American Society of Mechanical Engineers (ASME) 1995.  1995 ASME Boiler and
/COM,          Pressure Vessel Code - Section II Materials.  New York, New York: ASME.
/COM,          TIC: 245287.
/COM,
/COM,   REF4   ASTM B 575-97. 1998. Standard Specification for Low-Carbon Nickel-Molybdenum
/COM,          -Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium
/COM,          -Molybdenum-Copper and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy

/COM,          Plate, Sheet, and Strip.  West Conshohocken, Pennsylvania: American Society
/COM,          for Testing and Materials. TIC: 241816.
/COM,
/COM,   REF5   Kugler, A., Dr. 1997. Sheet and Plate for Nuclear Engineering, Bohler Neutronit
/COM,          A976. Houston, Texas. Bohler Bleche GmbH. TIC: 246410.
/COM,
/COM,   REF6   Lide, David R., ed.  CRC Handbook of Chemistry and Physics,
/COM,          76th Edition 1995-1996.  Boca Raton, FL: CRC Press.  TIC: 216194.
/COM,
/COM,   REF7   Avallone, E.A. and Baumeister, T. 1987. Marks' Standard Handbook for Mechanical
/COM,          Engineers, 9th Edition. New York, New York: McGraw-Hill Book Co. TIC: 206891
/COM,
/COM,   REF8   American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
/COM,          1997 ASHRAE Handbook Fundamentals, Inch-Pound Edition. Ch.19.  Atlanta, GA:
/COM,          ASHRAE.  TIC: 237824 or 240756.
/COM,
/COM,   REF9   Haynes International. 1988. Hastelloy Alloy C-22. Kokomo, Indiana. Haynes
/COM,          International. TIC: 239938.
/COM,
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/COM,   **      End of Material Property List                          **
/COM,   ****************************************************************
/EOF,
/COM,   ****************************************************************
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This attachment presents a listing of the ANSYS input file containing the table used for the SRS canister heat generation rate. (A single value of the heat generation rate is used in this calculation since the value is held constant during both heating and cooling phases of the hypothetical fire accident.)

```
/COM, *****************************************************************
/COM, ** DHLW Glass Pour Canister Heat Generation Rate               **
/COM, ** For the SRS Configuration                                   **
/COM, ** Heat rate is from Ref. 12                                   **
/COM, **                                                             **
/COM, **  Output File Name     : srscan.dat                           **
/COM, **  Emplacement Year     : 2010                                **
/COM, **  Start Age (years)    : 0.0                                 **
/COM, **  Decay Period (years) : 10000.                              **
/COM, **  Assembly Type        : SRS Pour Canister                   **
/COM, **                                                             **
/COM, ** ASSY(#,1) is the pour canister heat in watts.               **
/COM, ** ASSY(#,0) is the time post emplacement in years.            **
/COM, *****************************************************************
ASSY(  1,0)= 0.000001,    1.00,
ASSY(  1,1)=   710.10,   710.10,
ASSY(  0,1)=1.0
/COM, *******************************************************************
/EOF
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OK 11/16/00

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Complete Only Applicable Items

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

2. Record Date 10/20/2000	3. Accession Number ATT TO MOL.20001103.0003
4. Author Name(s) R.W. MOORE	5. Author Organization N/A

6. Title
EVALUATION OF THE THERMAL RESPONSE OF THE 5-DHLW WASTE PACKAGE-HYPOTHETICAL FIRE ACCIDENT ATTACHMENT VIII

7. Document Number(s) CAL-WIS-TH-000008	8. Version REV. 00
9. Document Type DATA	10. Medium CD-ROM

11. Access Control Code
PUB

12. Traceability Designator
DC #26230

13. Comments
THIS IS A SPECIAL PROCESS DISK AS PART OF ATTACHMENTVIII AND CAN BE LOCATED THROUGH THE RPC.

NOTE: SEE ATTACHMENT TO THIS SIS SHEET FOR THE ELECTRONIC SOURCE FILE VERIFICATION FORM SATISFYING AP-17.1Q REV. 1/ICN 2 : ELECTRONIC RECORDS.

DC#26230

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ELECTRONIC SOURCE FILE VERIFICATION

QA: N/A

2 OF 2

1. DOCUMENT TITLE: Evaluation of the Thermal Response of the 5-DHLW Waste Package-Hypothetical Fire Accident	
2. DOCUMENT IDENTIFIER: CAL-WIS-TH-000008	3. REVISION DESIGNATOR: REV 00

ELECTRONIC SOURCE FILE INFORMATION

4. ELECTRONIC SOURCE FILE NAME WITH FILE EXTENSION PROVIDED BY THE SOFTWARE: rev00.doc, dwgs1.ppt		
5. DATE LAST MODIFIED: 10/20/2000	6. ELECTRONIC SOURCE FILE APPLICATION: (I.E., EXCEL, WORD, CORELDRAW) rev00.doc (Word), dwgs1.ppt (PowerPoint)	7. FILE SIZE IN KILOBYTES: rev00.doc (542 KB), dwgs1.ppt (589 KB)
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) ~~NA~~ OPDD aa 10/24/00	
11. PRINTER SPECIFICATION (i. e., HP4SI) INCLUDING POSTSCRIPT INFORMATION (I.E., PRINTER DRIVER) AND PRINTING PAGE SETUP (I.E., LANDSCAPE, 11 X 17 PAPER) Attachments I, II, and III require 11x17 paper		
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): NA	15. ACCESS RESTRICTIONS: (IF ANY) NA	

COMMENTS/SPECIAL INSTRUCTIONS

16.

CERTIFICATION

17. NAME (Print and Sign) Ronald W. Moore *Ronald W Moore*			18. DATE: 10/20/2000
19. ORGANIZATION FTI	20. DEPARTMENT Waste Package Department	21. LOCATION/MAIN STOP OF 53	22. PHONE (804) 832-2648

DC USE ONLY

23. DATE RECEIVED: 10/24/00	24. DATE REVIEWED: ~~10~~ 11/1/00	25. DATE FILES TRANSFERRED: 10/24/00
26. NAME (Print and Sign): JANAE' ROBISON *Janae' Robinson*		27. DATE: ~~10~~ 11/1/00

Table VII-1 in this attachment presents the list of ANSYS output files that contain the ANSYS input file listing and the thermal analysis results for this calculation. These files are contained on the CD (Attachment VIII) associated with this file.

Table VII-1. List of Files Contained on the CD

File Name	Date	Time	Size, byte
Base.out	08/29/00	9:11am	474579
GapMax.out	08/29/00	9:12am	444181
Case1.out	08/29/00	9:11am	401177
Case2.out	08/29/00	9:11am	401023
Case3.out	08/29/00	9:12am	396914
Case4.out	08/29/00	9:12am	395650
Case5.out	08/29/00	9:12am	395311
Case6.out	08/29/00	9:12am	396622