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Calculation Cover Sheet

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TABLES

1. PURPOSE

The purpose of this calculation is to determine the surface dose rates of a codisposal waste package (WP) containing an intact seed assembly of the Shippingport light-water breeder reactor (LWBR) spent nuclear fuel (SNF) and the Savannah River Site (SRS) high-level waste (HLW) in glass form. The Shippingport LWBR SNF is loaded in a Department of Energy (DOE) standardized 18-in. canister. The canister is surrounded by five 4.5-m-long Hanford pour canisters containing the HLW glass. Gamma dose rate calculation for the WP containing only the HLW glass is also performed. The results will provide information about the contribution of DOE SNF to the total dose rate on the WP surfaces.

The long 5-DHLW/DOE (Defense HLW/DOE) SNF disposal container with single CRM (corrosion resistant material) is used in this calculation. The results are to be used for WP design and radiological analyses.

2. METHOD

The Monte Carlo radiation transport code, MCNP V4B2LV (Ref. 7.1), is used to calculate the average dose rates on the surfaces and segments of the WP.

3. ASSUMPTIONS

3.1 The 4.5-m long Hanford canisters are approximated by cylinders of nominal length, wall thickness, and outer diameter. The head and neck of the canisters are neglected. The basis for this assumption is that radiation transport in the upper part of the canister is not affected because this portion of the canister is empty and the wall thickness is maintained. This assumption is used throughout Section 5.

3.2 Some structural components of the WP are neglected. The basis for this assumption is that the calculated dose rates on the surfaces of the package will be conservative since these structural components that would attenuate neutrons and gamma rays are not modeled. These components are: the inner and outer brackets and the divider plates in the single CRM disposal container (see Attachment I); the two A-plates; the two B-plates; the spacers A-plate, B-plate, and C-plate (see Attachment II); and the Al shot in the DOE SNF canister. This assumption is used throughout Section 5.

3.3 Stainless steel (SS) 316L is assumed instead of SS 316NG, as specified in Attachment I, for the inner shell of the WP. The basis for this assumption is that the two materials have the same density, which results in nearly identical radiation attenuation properties. This assumption is used throughout Section 5.

3.4 The active fuel region of the Shippingport LWBR assembly is homogenized inside its transverse dimensions. The basis for this assumption is that the homogenization of the fuel rod inside the assembly gives the same WP surface dose rate as does the heterogeneous representation (Ref. 7.2, pp. 22-23). This assumption is used throughout Section 5.

3.5 The fissile weight fractions for the fresh Shippingport LWBR seed assembly are used in these calculations. The basis for this assumption is that the radiation attenuation characteristics of the fresh and spent fuels are nearly identical. This assumption is used throughout Section 5.

3.6 The Watt fission spectrum is used for the neutron source distribution for the Shippingport LWBR SNF. This option assumes that the most-likely neutron energy is about 1 MeV. The basis for this assumption is that the resulting biological neutron dose is bounding since the neutron quality factor has the highest value for this energy (Ref. 7.3, App. H, p. H-5). This assumption is used throughout Section 5.

3.7 The dose rate due to the secondary gamma rays is negligible. Therefore, no coupled neutron-photon calculation is performed. The basis for this assumption is that the neutron source intensities are 6 and 7 orders of magnitude smaller than the gamma source intensities for the Shippingport LWBR SNF and HLW glass, respectively. This assumption is used throughout Section 5.

3.8 The material compositions of alloys ASTM (American Society for Testing and Materials) B 575 (Alloy 22), ASTM A 516 Grade 70, SS 304L, SS 316L, and Zircaloy-4 are assumed to be representative for materials used in the manufacture of nuclear fuel assemblies. Some of these alloys have elements with allowable range of weight percent. For elements with weight percent range, the midpoint value is used, and the weight percent of the most abundant element is adjusted. The basis for this assumption is that small weight variations for the affected elements do not affect the accuracy of dose results, as long as the total weight is maintained. This assumption is used throughout Section 5.

3.9 The plenum and end-fitting regions of the Shippingport LWBR seed assembly are neglected. The basis for this assumption is that the radiation sources due to neutron activation, if any, are not available and excluding the two components is conservative (higher dose rate) because of less attenuation for radiation particles.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE APPROVED FOR QA WORK

The MCNP V4B2LV computer code is used to calculate dose rates on the WP surfaces.

- Program Name: MCNP
- Version/Revision number: Version 4B2
- Computer Software Configuration Item (CSCI) Number: 30033 V4B2LV (Ref. 7.1)
- Computer Type: Hewlett Packard (HP) 9000 Series: "Bloom" (Tag: CRWMS-M&O 700887).
- The MCNP V4B2LV computer code is an appropriate tool to determine the dose rate on and near the surface of a WP containing HLW and Shippingport LWBR SNF.
- This software has been validated over the range it was used.
- This software was previously obtained from the Software Control Management in accordance with appropriate procedures.

4.2 SOFTWARE ROUTINES

- Title: Excel
- Version/Revision Number: Microsoft Excel 97

The Excel spreadsheet program was used to perform simple numerical calculations, as documented in Section 5 of this calculation. The user-defined formulas, input, and results are documented in sufficient detail in Section 5 to allow independent repetition of the calculations.

4.3 MODELS

None used.

5. CALCULATION

5.1 CALCULATION INPUTS

Unqualified data were used in the development of the results presented in this section. If the results from this section are used as input into documents directly relied upon for safety or waste isolation issues, then they are required to be identified and tracked as TBV (to be verified) in accordance with appropriate procedures.

The following sections outline the data used in the calculation of the dose rates on the surfaces of the codisposal WP. Each MCNP calculation requires geometry, material, and radiation source data. The number of digits in the values cited herein may be the result of a calculation or may reflect the input from another source; consequently, the number of digits should not be interpreted as an indication of accuracy.

The WP consists of the single-CRM disposal container, five 4.5-m-long canisters containing SRS HLW glass, and the DOE SNF canister containing one Shippingport LWBR intact seed assembly. The sketch for the 5-DHLW/DOE SNF-long single CRM disposal container is shown in Attachment I. The sketch for the Shippingport LWBR intact seed assembly basket assembly is shown in Attachment II. As indicated in Attachment I, the disposal container consists of the inner reinforcement cylinder shell, the outer CRM shell, the inner shell lids, the outer shell lids, the basket assembly, and the support tube.

5.1.1 Disposal Container

The material compositions and dimensions for the single-CRM disposal container are presented in Tables 5.1.1-1 through 5.1.1-4.

Table 5.1.1-1. Geometry and Material Specifications for the Single-CRM Disposal Container[1]

Component	Material	Characteristic	Dimension (mm)
Inner shell	316NG[2]	Thickness	50
Outer shell	ASTM B 575 (N06022 or Alloy 22)	Thickness	25
Top and bottom inner shell lids	316NG	Thickness	105
Top and bottom outer shell lids	ASTM B 575	Thickness	25
Cavity	He[3]	Length	4,617
		Diameter	1,880
Closure lid gap	Air	Thickness	30
Support tube	ASTM A 516 Grade 70 (K02700)	Outer diameter	565
		Inner diameter	501.5
		Length	4,607

[1] Attachment I-1.
[2] SS 316 L used in this calculation (see Assumption 3.3).
[3] He density at 1-atmosphere pressure and 300-K temperature is 0.1625 kg/m^3 (Ref. 7.6, p. A17).

Table 5.1.1-2. Chemical Composition of Type 316L Stainless Steel[1]

Element	Weight Percent Range	Value Used
Carbon	0.03 (max)	0.03
Manganese	2.00 (max)	2.00
Phosphorus	0.045 (max)	0.045
Sulfur	0.03 (max)	0.03
Silicon	1.00 (max)	1.00
Chromium	16.00 - 18.00	17.00
Nickel	10.00 - 14.00	12.00
Molybdenum	2.00 - 3.00	2.50
Nitrogen	0.10 (max)	0.10
Iron	Balance	65.295
Density = 7.98 g/cm^3		

[1] Ref. 7.5, p. 13.

Table 5.1.1-3. Chemical Composition of ASTM B 575[1]

Element	Weight Percent Range	Value Used
Carbon	0.015 (max)	0.015
Manganese	0.50 (max)	0.50
Silicon	0.08 (max)	0.08
Chromium	20.00 - 22.50	21.25
Molybdenum	12.50 - 14.5	13.50
Cobalt	2.50 (max)	2.50
Tungsten	2.50 - 3.50	3.00
Vanadium	0.35 (max)	0.35
Iron	2.00 - 6.00	4.00
Sulfur	0.02 (max)	0.02
Phosphorus	0.02 (max)	0.02
Nickel	Balance	54.765
Density = 8.69 g/cm^3		

[1] Ref. 7.5, p. 30.

Table 5.1.1-4. Chemical Composition of ASTM A 516 Grade 70[1]

Element	Weight Percent Range	Value Used
Carbon	0.30	0.30
Manganese	0.85 - 1.20	1.025
Phosphorus	0.035	0.035
Sulfur	0.035	0.035
Silicon	0.15 - 0.40	0.275
Iron	Balance	98.33
Density = 7.85 g/cm^3		

[1] Ref. 7.5, p. 10.

5.1.2 HLW Glass Canisters and the Shippingport LWBR SNF

Tables 5.1.2-1 through 5.1.2-4 provide the geometry, material, and source specifications for the HLW glass canisters.

Table 5.1.2-1. Geometry and Material Specifications for the Hanford 4.5-m-Long HLW Glass Canister

Component	Material	Characteristic	Value (mm)	Reference
Canister	SS 304L	Outer diameter	610	7.7, p. 1
		Wall thickness	10.5	7.7, p. 2
		Length	4,572	7.7, p. 1
HLW glass	SRS HLW glass	Glass height	3,355.4	7.8, Att. III-1

Table 5.1.2-2. Chemical Composition of SRS HLW Glass[1, 2]

Element/Isotope	Weight Percent	Element/Isotope	Weight Percent
^{6}Li	9.5955E-02	^{7}Li	1.3804E+00
^{10}B	5.9176E-01	^{11}B	2.6189E+00
O	4.4770E+01	F	3.1852E-02
Na	8.6284E+00	Mg	8.2475E-01
Al	2.3318E+00	Si	2.1888E+01
S	1.2945E-01	K	2.9887E+00
Ca	6.6188E-01	Ti	5.9676E-01
Mn	1.5577E+00	Fe	7.3907E+00
Ni	7.3490E-01	P	1.4059E-02
Cr	8.2567E-02	Cu	1.5264E-01
Ag	5.0282E-02	^{137}Ba	1.1267E-01
Pb	6.0961E-02	Cl	1.1591E-01
^{232}Th	1.8559E-01	^{133}Cs	4.0948E-02
^{135}Cs	5.1615E-03	^{234}U	3.2794E-04
^{236}U	1.0415E-03	Zn	6.4636E-02
^{235}U	4.3514E-03	^{238}U	1.8666E+00
^{238}Pu	5.1819E-03	^{239}Pu	1.2412E-02
^{240}Pu	2.2773E-03	^{241}Pu	9.6857E-04
^{242}Pu	1.9168E-04		
Density at 25 °C = 2.85 g/cm^3 (Ref. 7.10, p. 2.2.1.1-4)			

[1] Ref. 7.9, p. 7.
[2] TBV.

Table 5.1.2-3. Chemical Composition of Type 304L Stainless Steel[1]

Element	Weight Percent Range	Value Used
Carbon	0.03 (max)	0.03
Manganese	2.00 (max)	2.00
Phosphorus	0.045 (max)	0.045
Sulfur	0.03 (max)	0.03
Silicon	0.75 (max)	0.75
Chromium	18.00 - 20.00	19.00
Nickel	8.00 - 12.00	10.00
Nitrogen	0.10 (max)	0.10
Iron	Balance	68.045
Density = 7.94 g/cm³		

[1] Ref. 7.5, p. 17.

Table 5.1.2-4. Gamma and Neutron Sources of SRS HLW Glass at Day 1 After Pouring[1]

Gamma Source		Neutron Source	
Upper Energy Boundary (MeV)	Intensity (photons/s)	Upper Energy Boundary (MeV)	Intensity (neutrons/s)
0.05	2.0480E+15	0.10	3.0535E+05
0.10	6.1351E+14	0.40	2.9342E+06
0.20	4.7986E+14	0.90	9.8224E+06
0.30	1.3546E+13	1.40	1.0724E+07
0.40	9.9093E+13	1.85	9.4907E+06
0.60	1.3681E+14	3.00	4.0517E+07
0.80	2.0891E+15	6.43	5.2948E+07
1.00	3.3083E+13	20.00	4.7557E+05
1.33	4.5956E+13		
1.66	9.9450E+12		
2.00	7.9634E+11		
2.50	4.5524E+12		
3.00	3.1682E+10		
4.00	3.5394E+09		
5.00	8.1428E+09		
6.50	3.2640E+05		
8.00	6.3958E+04		
10.00	1.3569E+04		
Total	5.6962E+15		1.2722E+08

[1] Ref. 7.8, Att. III-1.

5.1.3 DOE SNF Canister and the Shippingport LWBR SNF

The conceptual design of the DOE 18-in. standardized SNF canister is taken from Ref. 7.11, p. 5 and Appendix A. The DOE SNF canister contains four stainless steel (Type 316L) guide plates, forming a rectangular tube into which one Shippingport LWBR SNF seed assembly is loaded. Spacer plates are used at the bottom of the SNF assembly to elevate it above the bottom of the canister. The length of the spacer plates is 75.7 cm (see Attachment II). However, the spacer plates and the A-and B-plates are neglected in the calculation (see Assumption 3.2). A sketch of the Shippingport LWBR intact seed assembly basket assembly is provided in Sketch SK-0134 REV 00 (Attachment II).

The geometry and material specifications for the DOE SNF canister are given in Table 5.1.3-1.

Table 5.1.3-1. Geometry and Material Specifications for the DOE SNF Canister[1]

Component	Material	Characteristic	Dimension (mm)
Cylinder	SS 316L	Outer diameter	457.2
		Wall thickness	9.525
		Internal length	4,117
Impact plates (2)	ASTM A 516 Grade 70	Thickness	50.8
Top and bottom curved plates	SS 316L	Thickness	9.525

[1] Ref. 7.11, p. 5 and Appendix A.

The geometry, material, and radiation source data for the Shippingport LWBR SNF are provided by Ref. 7.4 and are presented in Tables 5.1.3-2 through 5.1.3-4. The Shippingport LWBR was a water-cooled, U-233/Th-232-cycle breeder reactor. The concentration of U-233 relative to Th-232 varied axially and radially across the core to promote high neutron economy. The Shippingport LWBR core consisted of movable seed assemblies, standard blanket assemblies, power-flattening blanket assemblies, and reflector assemblies. In this calculation, the DOE SNF canister is loaded with one seed assembly. The seed assembly has a hexagonal shape in the transverse dimensions. Inside the seed assembly, there are eight different fuel rod types. Each fuel rod has an active fuel region, which is composed of thoria (ThO_2) pellets at the bottom and top and a binary stack of UO_2 + ThO_2 in the middle. The initial fissile mass loading and stack length varied with fuel rod type.

In this calculation, the radiation source and fuel materials are homogenized inside the assembly and the active fuel region (see Assumption 3.4). The plenum and top and bottom end-fitting regions are neglected (see Assumption 3.9). The radiation source specification for the active fuel region is given in Table 5.1.3-4. The peaking factor for a seed assembly is 1.79 (Ref. 7.4, p. 35). This value is rounded up to 2, for conservative (higher) dose rate calculations. The fuel assembly rests on the spacer so that the bottom of the fuel assembly is in contact with the spacer C-plate (see Attachment II). The bottom of the active fuel region is 235 mm above the bottom of the fuel assembly (Ref. 7.4, p. 20). Therefore, the bottom of the active fuel region is 992 mm (235 mm + 757 mm) above the bottom impact plate of the DOE SNF canister.

Table 5.1.3-2. Geometry and Material Specifications for a Shippingport LWBR Seed Assembly

Component	Material	Characteristic	Value	Reference
Assembly		Distance between parallel faces (cm)	24.3586	7.4, p. 22
Assembly shell	Zircaloy-4	Thickness (cm)	0.2032	7.4, p. 20
Active fuel region		Length (cm)	263.525	7.4, p. 18
Uranium in UO_2	U-233	Weight percent	98.23	7.4, p. 4
	U-234		1.29	
	U-235		0.09	
	U-236		0.02	
	U-238		0.37	
Fuel rod type 01		Number per seed assembly	30	7.4, p. 18
		Initial fissile mass loading (g/rod)	14.33	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel rod type 02		Number per seed assembly	84	
		Initial fissile mass loading (g/rod)	14.33	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel rod type 03		Number per seed assembly	72	
		Initial fissile mass loading (g/rod)	19.14	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel rod type 04		Number per seed assembly	66	
		Initial fissile mass loading (g/rod)	23.92	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel rod type 05		Number per seed assembly	181	
		Initial fissile mass loading (g/rod)	34.57	
		Fissile concentration of binary stack (wt%)	5.202	
Fuel rod type 06		Number per seed assembly	150	
		Initial fissile mass loading (g/rod)	34.57	
		Fissile concentration of binary stack (wt%)	5.202	
Fuel rod type 07		Number per seed assembly	30	
		Initial fissile mass loading (g/rod)	14.33	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel rod type 08		Number per seed assembly	6	
		Initial fissile mass loading (g/rod)	14.33	
		Fissile concentration of binary stack (wt%)	4.337	
Fuel pellets	ThO_2 and ThO_2+UO_2	Mass/rod (g)	830	7.4, p. 19
Cladding	Zircaloy-4	Outer diameter (mm)	7.78002	7.4, p. 18
		Thickness (mm)	0.563118	

Table 5.1.3-3. Chemical Composition of Zircaloy-4[1]

Element	Weight Percent Range	Value Used
Oxygen	0.09 - 0.16	0.125
Chromium	0.07 - 0.13	0.10
Iron	0.18 - 0.24	0.21
Tin	1.20 - 1.70	1.45
Iron + Chromium[2]	0.28 - 0.37	0.325
Zirconium	Balance	97.79
Density = 6.56 g/cm^3		

[1] Ref. 7.5, p. 44.
[2] The 0.325-wt% Fe+Cr will be added to Cr weight percent in calculations. Therefore, the weight percent for Cr in calculations is 0.425.

Table 5.1.3-4. Gamma and Neutron Sources of a Shipingport LWBR SNF Seed Assembly at Year 2005

Mean Photon Energy[1] (MeV)	Upper Energy Boundary[2] (MeV)	Gamma Intensity[1] (photons/s)			Neutron Intensity[3] (neutrons/s)
		Activation Products	Actinides and Daughters	Fission Products	
1.50E-02	0.02	1.208E+11	1.546E+13	1.123E+15	
2.50E-02	0.03	1.034E+11	1.215E+12	2.340E+14	
3.75E-02	0.05	6.585E+10	9.808E+11	2.006E+14	
5.75E-02	0.07	1.967E+10	1.159E+12	2.185E+14	
8.50E-02	0.10	1.187E+10	7.029E+12	1.322E+14	
1.25E-01	0.15	5.647E+10	5.412E+11	8.913E+13	
2.25E-01	0.30	1.869E+10	9.856E+12	1.143E+14	
3.75E-01	0.45	4.747E+10	7.169E+11	4.979E+13	
5.75E-01	0.70	7.054E+10	6.543E+12	7.568E+14	
8.50E-01	1.00	6.130E+10	3.041E+12	1.275E+13	
1.25E+00	1.50	3.202E+12	1.741E+11	7.310E+12	
1.75E+00	2.00	1.979E+09	5.637E+11	3.450E+11	
2.25E+00	2.50	1.662E+07	3.567E+05	2.293E+07	
2.75E+00	3.00	5.144E+04	5.682E+12	1.706E+04	
3.50E+00	4.00	1.468E-06	2.298E+04	2.219E+03	
5.00E+00	6.00	5.276E-09	7.014E+03	2.227E-05	
7.00E+00	8.00	3.423E-10	5.310E+02	1.445E-06	
1.10E+01	14.00	2.165E-11	4.255E+01	9.138E-08	
Total		3.781E+12	5.296E+13	2.939E+15	5.770E+08

[1] Ref. 7.4, pp. B-2 and B-3.
[2] Ref. 7.14. p. B-2.
[3] Ref. 7.4, p. B-4.

Reference 7.5, from which material compositions and densities are obtained, references standard handbooks. Data from handbooks are established facts and are considered as accepted data. Data from References 7.3 and 7.12 are also considered as accepted data, as they are accepted within the scientific and engineering community and are technically defensible. Data from References 7.4, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, and 7.14 are unqualified data. References 7.1, 7.2, and 7.13 are used only as references in this calculation.

5.2 DESCRIPTION OF MCNP CALCULATIONS

The materials of the active fuel region of the Shippingport LWBR seed assembly are homogenized inside the active fuel region volume (see Table 5.1.3-2 for assembly materials and dimensions), and the corresponding atomic densities (AD) are calculated according to the following formula:

$$AD = \frac{mass_{\text{element or isotope}} * N_A}{volume_{\text{region}} * \text{atomic weight}_{\text{element or isotope}}}$$

In the above equation, N_A is the Avogadro's Number, which equals 6.0221367E+23 atoms/mol (Ref. 7.12, p. 59). The element or isotope atomic weights were obtained from Reference 7.12. These calculations are shown in Attachment IV.

There are two different radiation sources in this calculation, uniformly originating from the SRS HLW glass and the active fuel region of the Shippingport LWBR SNF seed assembly. The total source intensity is used as a tally multiplier, while the source intensity fractions of the SRS HLW glass and the Shippingport LWBR SNF seed assembly are specified as cell-dependent distribution numbers. Attachment III contains the total source intensity and the source intensity fractions of the Shippingport LWBR SNF seed assembly and the SRS HLW glass canisters.

In radiation shielding analysis, particle population diminishes considerably due to attenuation in shield materials. Preliminary calculations of this case show that the gamma-ray intensity decreases by a factor of about 20 when passing through the inner shell and by a factor of about 5 when passing through the outer shell. Therefore, the use of variance reduction techniques is required to increase sampling in regions of the tally. Geometric splitting/Russian roulette across cell boundaries is the variance reduction technique employed. Geometric splitting with Russian roulette is a reliable variance reduction technique when the importances of adjacent cells are different by a factor not greater than 4 (Ref. 7.3, p. 2-121). Each particle is split when entering a cell of higher importance. The number of split particles is proportional to the relative importance of the adjacent cells. The weight of each particle is adjusted by the same factor such that a fair game is preserved. On the other hand, if particles enter a cell of lower importance, Russian roulette is played so as to improve calculational efficiency by tracking fewer unimportant particles. In this calculation, the relative importances assigned to adjacent cells do not exceed a factor of 4.

Two calculation sets, one for gamma and one for neutron transport, are required. The flux averaged over a surface tally is used to calculate surface-averaged dose rates in rem/h and rad/h on selected surfaces of the WP. The results of gamma and neutron dose rates are then summed to yield the total dose rates. The relative error associated with the total dose rate is derived from the variance of the total dose rate. The variance of the total dose rate, σ^2_{total}, is the sum of the variances of the individual dose rates, σ_i^2:

$$\sigma^2_{total} = \sum_i \sigma^2_i$$

The relative error is given by:

$$\text{relative error} = \frac{\sqrt{\sigma^2}}{\overline{x}},$$

$$\overline{x} = \text{estimated dose rate}$$

The quality factors, which represent the biological effectiveness of radiation, are taken from Reference 7.3, App. H, p. H-5. To convert rem to rad, the following relation is used:

1 rem = Quality Factor * 1 rad

The flux-to-dose conversion factors in (rem/h)/(n/cm^2.s) and (rad/h)/(n/cm^2.s) are shown in Attachment V. The surface dose rates in rem/h are presented in Section 6. Attachment VI contains the same dose rates in rad/h on the same surfaces and segments.

The geometric representation for the MCNP calculation is shown in Figure 5.2-1.

Surface dose rates are calculated for the radial, top, and bottom directions of the codisposal WP of HLW glass and the Shippingport LWBR SNF. For each direction, dose rates are determined for the following five surfaces: inner surface of the inner shell, inner surface of the outer shell, WP outer surface, and surfaces at 1 m and 2 m from WP outer surface. As shown in Figure 5.2-2, each radial surface is subdivided into six axial segments. Segment 1 is between the top of the WP cavity and the top of the HLW glass and has a height of 125.11 cm. HLW glass is divided axially into five equal segments of 67.108 cm (Segments 2 through 6). Axially, the top and bottom dose surfaces are circular disks with radii of 94 cm for the inner surface of the inner shell lids, 99 cm for the inner surface of the outer shell lids, and 101.5 cm for the WP outer surface and the surfaces 1 m and 2 m from the WP outer surface.

A peaking factor of 2 is used to bound the axial and radial source profiles of the Shippingport LWBR SNF seed assembly.

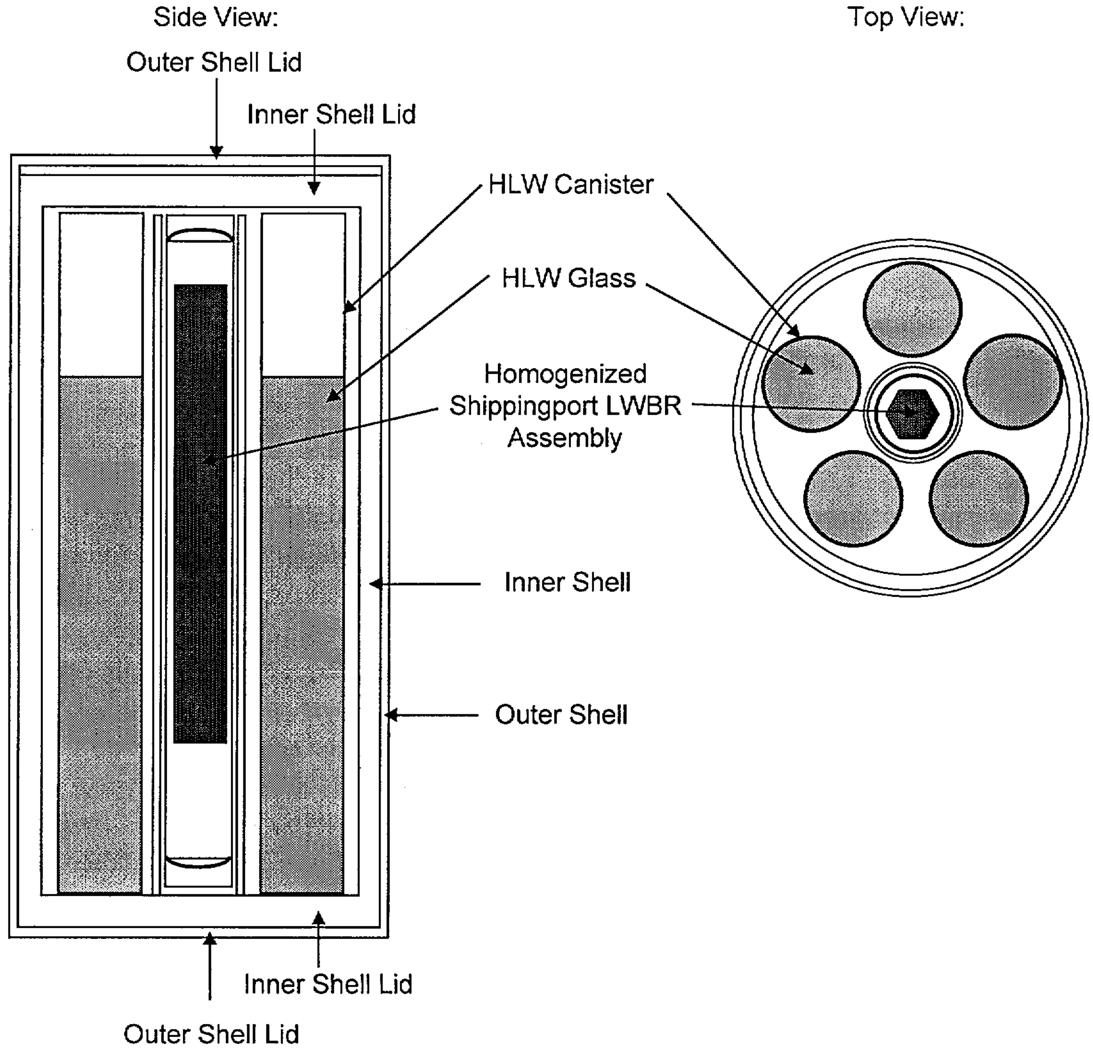


Figure 5.2-1. Vertical and Horizontal Cross Sections of the MCNP Geometric Representation[1]

[1] Drawing not to scale

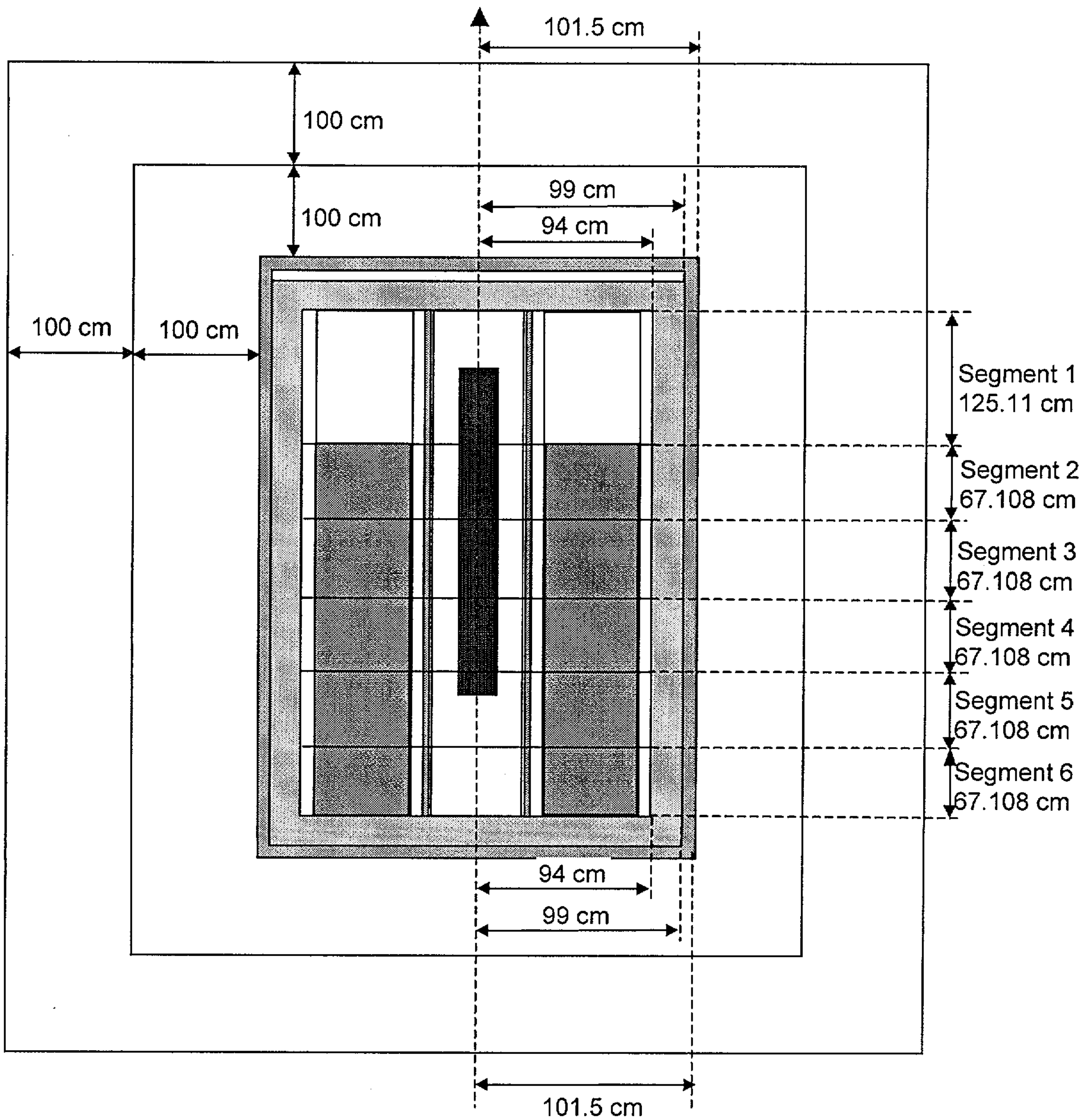


Figure 5.2-2. Surfaces and Segments of the WP Used in Dose Rate Calculations[2]

[2] Drawing not to scale

6. RESULTS

Unqualified data were used in the development of the results presented in this section. If the results from this section are used as input into documents directly relied upon for safety or waste isolation issues, then they are required to be identified and tracked as TBV in accordance with appropriate procedures.

6.1 WP CONTAINING SHIPPINGPORT LWBR SNF AND SRS HLW GLASS

Tables 6.1-1 through 6.1-6 show the dose rates at locations on the WP radial and axial surfaces and at the distances of 1 m and 2 m from the outer surface of the WP containing the SRS HLW glass and the Shippingport LWBR SNF. The dose rates in rad/h are presented in Attachment VI. The dose rates in rem/h and rad/h are practically the same due to the insignificant contribution of neutron dose rate to the total dose rate.

Table 6.1-1. Dose Rates on the Inner Surface of the Inner Shell

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	1.4312E+03	0.0183	1.1116E+00	0.0045	1.4323E+03	0.0183
Segment 2	7.2955E+03	0.0059	1.0901E+00	0.0055	7.2966E+03	0.0059
Segment 3	8.2036E+03	0.0056	1.1045E+00	0.0055	8.2047E+03	0.0056
Segment 4	8.2637E+03	0.0058	1.0050E+00	0.0058	8.2647E+03	0.0058
Segment 5	8.3134E+03	0.0061	7.8581E-01	0.0067	8.3142E+03	0.0061
Segment 6	7.4969E+03	0.0057	5.6983E-01	0.0082	7.4975E+03	0.0057

Table 6.1-2. Dose Rates on the Inner Surface of the Outer Shell

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	5.4374E+01	0.0171	6.2575E-01	0.0038	5.5000E+01	0.0169
Segment 2	3.9317E+02	0.0092	6.1970E-01	0.0049	3.9379E+02	0.0092
Segment 3	4.3751E+02	0.0088	6.2866E-01	0.0049	4.3814E+02	0.0088
Segment 4	4.3372E+02	0.0087	5.6855E-01	0.0052	4.3429E+02	0.0087
Segment 5	4.3607E+02	0.0088	4.1985E-01	0.0062	4.3649E+02	0.0088
Segment 6	4.0788E+02	0.0093	2.8842E-01	0.0075	4.0817E+02	0.0093

Table 6.1-3. Dose Rates on the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	9.6170E+00	0.0191	2.5418E-01	0.0038	9.8712E+00	0.0186
Segment 2	7.2129E+01	0.0109	2.5634E-01	0.0050	7.2385E+01	0.0109
Segment 3	8.0643E+01	0.0104	2.5985E-01	0.0050	8.0902E+01	0.0104
Segment 4	8.0426E+01	0.0104	2.3333E-01	0.0053	8.0660E+01	0.0104
Segment 5	8.1163E+01	0.0106	1.7181E-01	0.0062	8.1334E+01	0.0106
Segment 6	7.4584E+01	0.0109	1.1881E-01	0.0076	7.4703E+01	0.0109

Table 6.1-4. Dose Rates on a Radial Surface 1 m from the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	8.8177E+00	0.0111	7.2330E-02	0.0032	8.8901E+00	0.0110
Segment 2	2.3957E+01	0.0092	8.8621E-02	0.0034	2.4046E+01	0.0092
Segment 3	3.1241E+01	0.0082	8.5521E-02	0.0034	3.1327E+01	0.0082
Segment 4	3.2881E+01	0.0079	7.6481E-02	0.0037	3.2957E+01	0.0079
Segment 5	3.1277E+01	0.0083	6.0670E-02	0.0042	3.1338E+01	0.0083
Segment 6	2.3838E+01	0.0095	4.0905E-02	0.0052	2.3879E+01	0.0095

Table 6.1-5. Dose Rates on a Radial Surface 2 m from the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	7.2116E+00	0.0095	3.7955E-02	0.0031	7.2495E+00	0.0095
Segment 2	1.3570E+01	0.0089	4.5267E-02	0.0035	1.3615E+01	0.0089
Segment 3	1.7145E+01	0.0082	4.4656E-02	0.0035	1.7190E+01	0.0082
Segment 4	1.8508E+01	0.0080	4.0927E-02	0.0037	1.8549E+01	0.0080
Segment 5	1.6863E+01	0.0083	3.4083E-02	0.0041	1.6897E+01	0.0083
Segment 6	1.3373E+01	0.0093	2.5785E-02	0.0048	1.3399E+01	0.0093

Table 6.1-6. Dose Rates on the WP Axial Surfaces

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Inner surface of bottom inner shell lid	6.1497E+03	0.0119	5.4693E-01	0.0096	6.1503E+03	0.0119
Inner surface of bottom outer shell lid	1.5985E+01	0.0293	1.6350E-01	0.0110	1.6148E+01	0.0290
Bottom surface of WP	3.0317E+00	0.0379	6.3251E-02	0.0113	3.0950E+00	0.0371
Bottom surface 1 m from WP	1.5497E+00	0.0436	2.0610E-02	0.0121	1.5703E+00	0.0430
Bottom surface 2 m from WP	8.6537E-01	0.0545	9.1905E-03	0.0157	8.7456E-01	0.0539
Inner surface of top inner shell lid	4.4014E+02	0.0239	7.6083E-01	0.0070	4.4090E+02	0.0239
Inner surface of top outer shell lid	2.6953E+00	0.0720	2.3595E-01	0.0084	2.9313E+00	0.0662
Top surface of WP	6.0081E-01	0.0802	9.0493E-02	0.0088	6.9130E-01	0.0697
Top surface 1 m from WP	3.5259E-01	0.0959	2.8537E-02	0.0095	3.8112E-01	0.0887
Top surface 2 m from WP	2.3327E-01	0.1132	1.2491E-02	0.0121	2.4576E-01	0.1074

6.2 WP CONTAINING SRS HLW GLASS

Tables 6.2-1 and 6.2-2 show the gamma dose rates on radial and axial surfaces of the WP containing the SRS HLW glass canisters and the support tube, without the DOE SNF canister and the Shippingport LWBR SNF.

Table 6.2-1. Gamma Dose Rates on the WP Radial Surfaces

Axial Location (see Fig. 5.2-2)	Inner Surface of Inner Shell		Inner Surface of Outer Shell		WP Outer Radial Surface	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	1.3724E+03	0.0161	4.9868E+01	0.0169	8.2074E+00	0.0201
Segment 2	7.2227E+03	0.0054	3.8978E+02	0.0086	7.1349E+01	0.0101
Segment 3	8.1893E+03	0.0053	4.3787E+02	0.0081	7.9678E+01	0.0096
Segment 4	8.2936E+03	0.0056	4.3389E+02	0.0080	7.9866E+01	0.0096
Segment 5	8.2216E+03	0.0052	4.3292E+02	0.0082	7.9791E+01	0.0097
Segment 6	7.5247E+03	0.0053	4.0919E+02	0.0084	7.5668E+01	0.0100

Table 6.2-2. Gamma Dose Rates on the WP Axial Surfaces

Axial Location (see Fig. 5.2-2)	Dose Rate (rem/h)	Relative Error
Inner surface of bottom inner shell lid	6.1507E+03	0.0097
Inner surface of bottom outer shell lid	1.5793E+01	0.0266
Bottom surface of WP	3.1027E+00	0.0342
Inner surface of top inner shell lid	4.3303E+02	0.0222
Inner surface of top outer shell lid	2.4594E+00	0.0675
Top surface of WP	5.3651E-01	0.0833

7. REFERENCES

7.1 Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O) 1998. *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code*. CSCI: 30033 V4B2LV. DI: 30033-2003 Rev. 01. Las Vegas, Nevada: M&O. ACC: MOL.19980622.0637.

7.2 CRWMS M&O 1998. *Calculation of the Effect of Source Geometry on the 21-PWR WP Dose Rates.* BBAC00000-01717-0210-00004 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990222.0059.

7.3 Briesmeister, J.F., ed. 1997. *MCNP - A General Monte Carlo N-Particle Transport Code, Version 4B.* UC 705 and UC 700, LA-12625-M. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL.19980624.0328.

7.4 U.S. Department of Energy (DOE) 1999. *Shippingport LWBR (Th/U Oxide) Fuel Characteristics for Disposal Criticality Analysis.* DOE/SNF/REP-051. Revision 0. Washington, D.C.: DOE. TIC: 245631.

7.5 CRWMS M&O 1999. *Waste Package Materials Properties.* BBA000000-01717-0210-00017 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990407.0172.

7.6 Incropera, F.P. and Dewitt, D.P. 1996. *Introduction to Heat Transfer*. Third Edition. New York, New York: John Wiley & Sons. TIC: 241057.

7.7 Taylor W.J. 1997. "Incorporating Hanford 15 Foot (4.5 meter) Canister into Civilian Radioactive Waste Management System (CRWMS) Baseline." Memorandum from W.J. Taylor (DOE) to J. Williams (DOE), April 02, 1997, 97-WDD-053. ACC: MOL.19971125.0630.

7.8 CRWMS M&O 1998. *Dose Calculations for the Codisposal WP of HLW Canisters and the Fast Flux Test Facility (FFTF) Fuel.* BBA000000-01717-0210-00019 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990129.0075.

7.9 CRWMS M&O 1999. *DOE SRS HLW Glass Chemical Composition.* BBA000000-01717-0210-00038 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990215.0397.

7.10 Stout, R.B. and Leider, H.R., eds. 1991. *Preliminary Waste Form Characteristics Report.* Version 1.0. Livermore, California: University of California/Lawrence Livermore National Laboratory. ACC: MOL.19940726.0118.

7.11 U.S. DOE 1998. *Preliminary Design Specification for Department of Energy Standardized Spent Nuclear Fuel Canisters, Volume 1-Design Specification.* DOE/SNF/REP-011. Revision 1. Washington, D.C.: DOE. TIC: 241528.

7.12 Parrington, J.R.; Knox, H.D.; Breneman, S.L.; Baum, E.M.; and Feiner, F. 1996. *Nuclides and Isotopes.* Fifteenth Edition. San Jose, California: General Electric Co. and KAPL, Inc. TIC: 233705.

7.13 CRWMS M&O 1999. *Electronic Output Files for Dose Calculations for the Codisposal WP of HLW Glass and the Shippingport LWBR SNF for BBAC00000-01717-0210-00016 REV 00,* Compact Disc. Las Vegas, Nevada: M&O. ACC: MOL.19991012.0117.

7.14 U.S. DOE 1999. *Fermi (U-Mo) Fuel Characteristics for Disposal Criticality Analysis.* DOE/SNF/REP-035. Revision 0. Washington, D.C.: DOE. TIC: 242461.

8. ATTACHMENTS

The hardcopy attachments are listed below in Table 8-1. Electronic output files are provided on a CD (compact disk) (Ref. 7.13) and are listed in Table 8-2 below. Each file is identified by its name, size (in bytes), and the date and time of last access. It should be noted that for files transferred from the HP to the personal computer, the date and time will reflect the time of transfer. The actual date and time of run completion can be found in the file. The CD was written using the Hewlett Packard (HP) CD-Writer Plus model 7200e external CD-rewritable drive for personal computers.

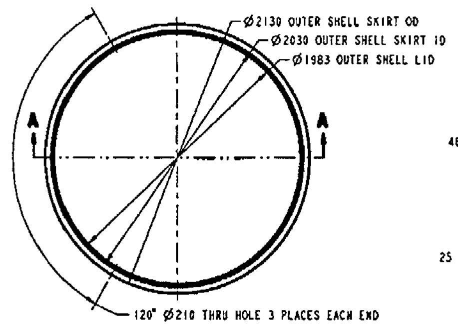
Table 8-1. List of Attachments

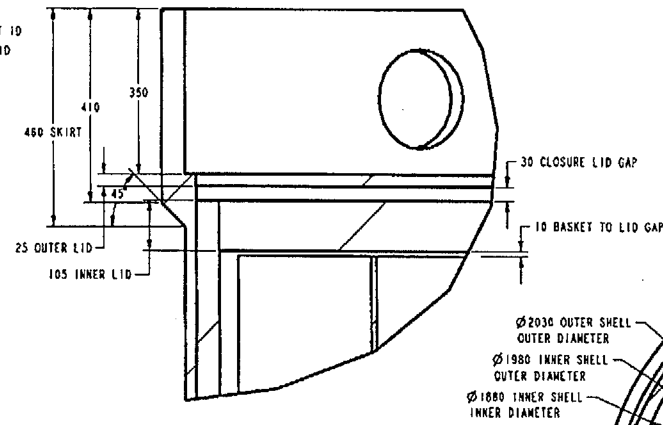
Description	Attachment Number	No. of Pages
SK-0141 REV 01	I	1
SK-0134 REV 00	II	1
Total source intensity and source intensity fractions of the DOE SNF and 4.5-m Long Hanford HLW canisters	III	2
Atomic densities for the homogenized active fuel region of the Shippingport LWBR seed assembly	IV	3
Flux-to-dose conversion factors in (rad/h)/(n/cm^2.s)	V	1
Total dose rates in rad/h	VI	2

The input files used are echoed in the output files, which are listed in Table 8-2.

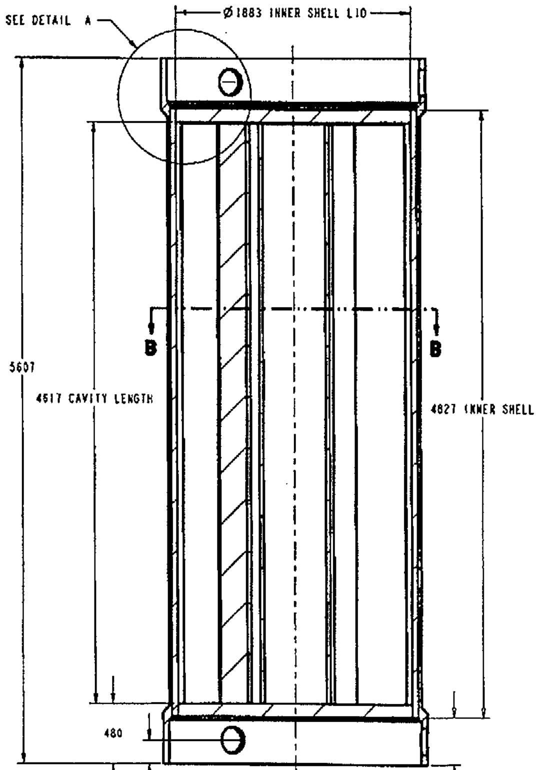
Table 8-2. File Attributes for the Contents of Electronic Media

File Name	Case	File Size (bytes)	File Date	File Time
Shippingport_lwbr_p.io	Gamma dose rate calculation for the codisposal WP	177,811	06/20/99	1:06 p.m.
Shippingport_lwbr_n.io	Neutron dose rate calculations for the codisposal WP	256,918	06/18/99	8:17 a.m.
hlw_crm_p.io	Gamma dose rate calculation for the WP containing only SRS HLW glass and the support tube	131,967	06/25/99	8:45 a.m.

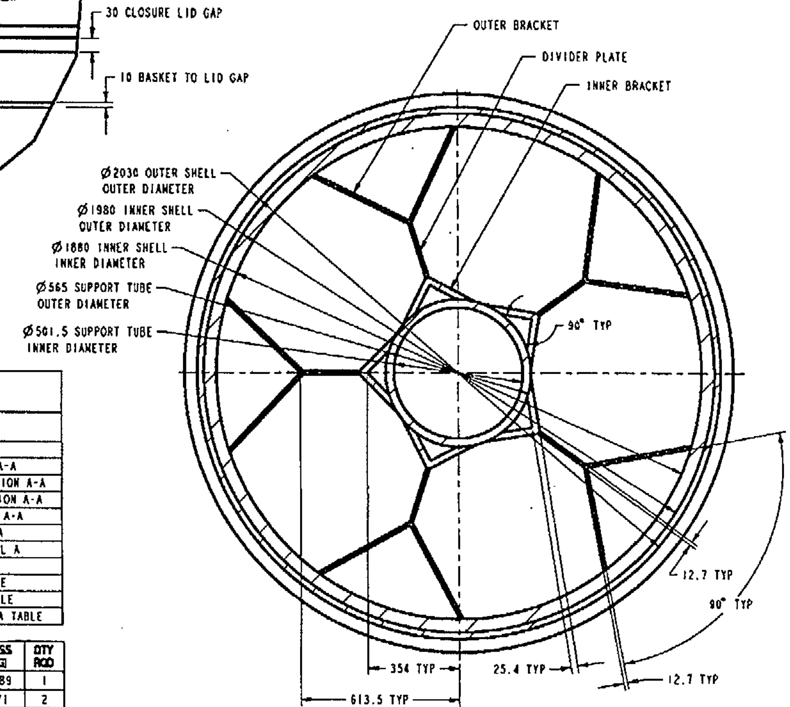




DETAIL A



SECTION A-A



SECTION B-B

REVISION 01

ITEM NUMBER	ITEM
1	Ø210 LIFTING FEATURE WAS Ø70 ON TOP VIEW
2	5607 WP ASSEMBLY LENGTH WAS 5357 ON SECTION A-A
3	480 SKIRT END TO INNER LID LENGTH WAS 355 ON SECTION A-A
4	190 SKIRT END TO LIFTING FEATURE WAS 115 ON SECTION A-A
5	375 SKIRT END TO OUTER LID WAS 250 ON SECTION A-A
6	460 FLARED SKIRT LENGTH WAS 335 ON DETAIL A
7	410 FLARED SKIRT EDGE LENGTH WAS 285 ON DETAIL A
8	350 SKIRT LENGTH WAS 225 ON DETAIL A
9	9089 OUTER SHELL MASS WAS 8460 ON DATA TABLE
10	32542 WP ASSEMBLY MASS WAS 31913 ON DATA TABLE
11	56263 WP ASSEMBLY WITH SNF MASS WAS 55634 ON DATA TABLE

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY RQD
OUTER SHELL	SB-575 N06022	25	9089	1
OUTER SHELL LID	SB-575 N06022	25	671	2
INNER SHELL	SA-240 (316 NG)	50	11663	1
INNER SHELL LID	SA-240 (316 NG)	105	2333	2
DIVIDER PLATE	SA-516 K02700	12.7	100	5
INNER BRACKET	SA-516 K02700	25.4	296	5
OUTER BRACKET	SA-516 K02700	12.7	375	5
SUPPORT TUBE	SA-516 K02700	31.75	1924	1
WASTE PACKAGE ASSEMBLY	-	-	32542	1
HLW GLASS ASSEMBLY	-	-	4200*	5
18" DOE CANISTER LONG	-	-	2721**	1
WP ASSEMBLY WITH SNF	-	-	56263	1

* CRWMS M&O INTEROFFICE CORRESPONDENCE, C. HEATH TO D. FOUST, DC.WMI.CAH. 5/97.02, MAY 13, 1997. VIENNA, VA: CRWMS M&O. ACC: MOV.19970602.0021.

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

UNITS: mm

DO NOT SCALE FROM SKETCH

"FOR INFORMATION ONLY"

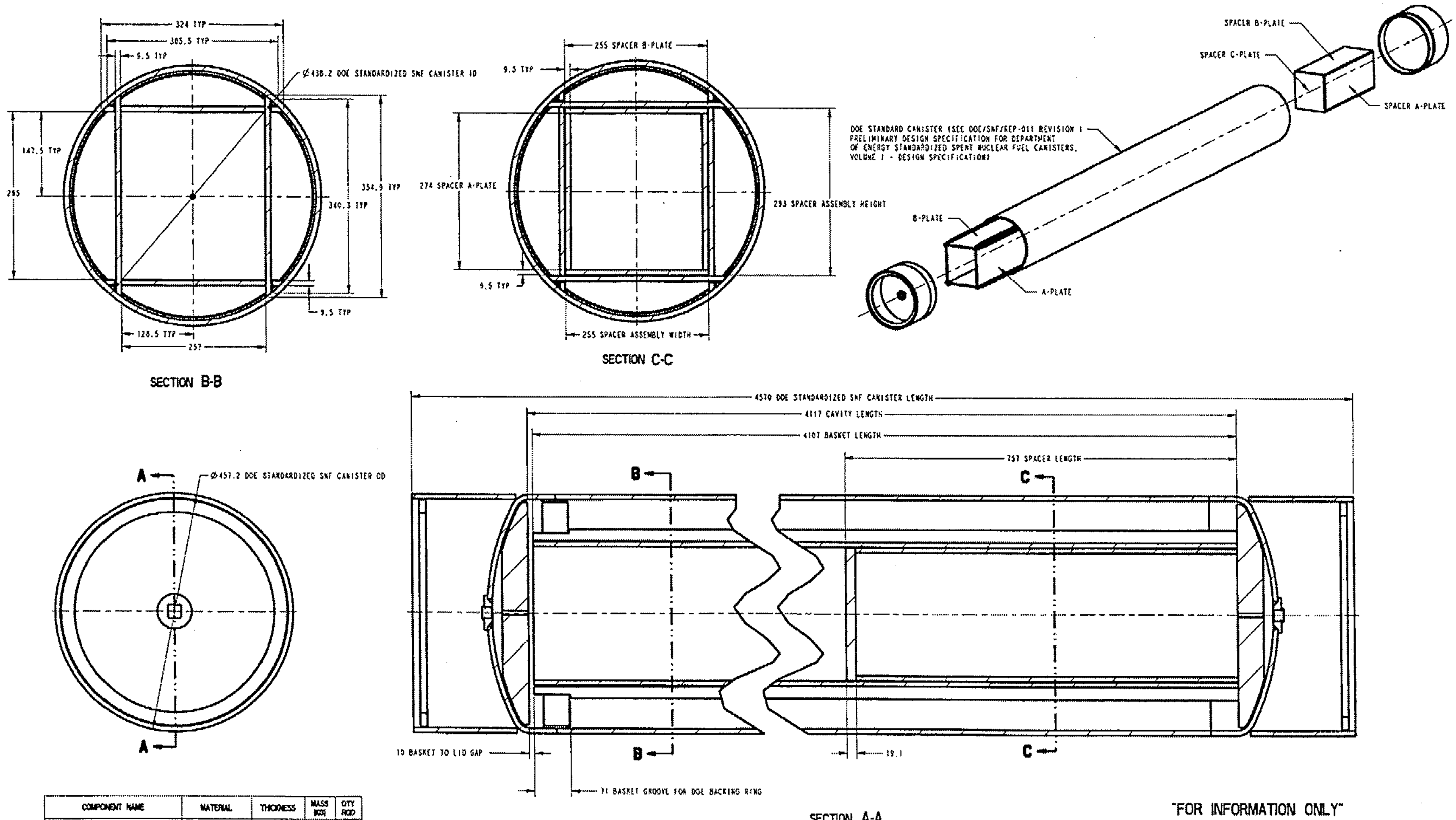
5-DHLW/DOE SNF-LONG SINGLE CRM DISPOSAL CONTAINER

SKETCH NUMBER: SK-0141 REV 01

SKETCHED BY: BRYAN HARKINS BH 05Aug99 SMB 08/06/99 TWD 8.9.99

DATE: 08/05/99

FILE: /home/pro_library/checkout/sketches/5dhlw_home/snf_long_single_sk-0141



COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY REQ
A-PLATE	SA-240 S31603	9.5	105	2
B-PLATE	SA-240 S31603	9.5	95	2
SPACER A-PLATE	SA-240 S31603	9.5	15	2
SPACER B-PLATE	SA-240 S31603	9.5	14	2
SPACER C-PLATE	SA-240 S31603	15.1	11	1
DOE STANDARDIZED SNF CANISTER	-	-	607	1
LWBR CANISTER ASSEMBLY	-	-	1077	1

"FOR INFORMATION ONLY"

UNITS: mm

DO NOT SCALE FROM SKETCH

SHIPPINGPORT LWBR INTACT SEED ASSEMBLY BASKET ASSEMBLY

SKETCH NUMBER: SK-0134 REV 00

SKETCHED BY: BRYAN HARKINS BH 11 May 99 SMS 05/11/99 TWD 5-11-99

DATE: 05/11/99

FILE: /home/harkins/proe/shp_prf_lwbr/sk-0134.dwg

Total Source Intensity and Source Intensity Fractions of the DOE SNF and 4.5-m-Long Hanford HLW Canisters

Table III-1. Gamma Source for the Shippingport LWBR Seed Assembly at Year 2005

Upper Group Energy (MeV)	Activation Products (photons/s)	Actinides and Daughters (photons/s)	Fission Products (photons/s)	Total Intensity (photons/s)
0.02	1.208E+11	1.546E+13	1.123E+15	1.139E+15
0.03	1.034E+11	1.215E+12	2.340E+14	2.353E+14
0.05	6.585E+10	9.808E+11	2.006E+14	2.016E+14
0.07	1.967E+10	1.159E+12	2.185E+14	2.197E+14
0.1	1.187E+10	7.029E+12	1.322E+14	1.392E+14
0.15	5.647E+10	5.412E+11	8.913E+13	8.973E+13
0.3	1.869E+10	9.856E+12	1.143E+14	1.242E+14
0.45	4.747E+10	7.169E+11	4.979E+13	5.055E+13
0.7	7.054E+10	6.543E+12	7.568E+14	7.634E+14
1	6.130E+10	3.041E+12	1.275E+13	1.585E+13
1.5	3.202E+12	1.741E+11	7.310E+12	1.069E+13
2	1.979E+09	5.637E+11	3.450E+11	9.107E+11
2.5	1.662E+07	3.567E+05	2.293E+07	3.991E+07
3	5.144E+04	5.682E+12	1.706E+04	5.682E+12
4	1.468E-06	2.298E+04	2.219E+03	2.520E+04
6	5.276E-09	7.014E+03	2.227E-05	7.014E+03
8	3.423E-10	5.310E+02	1.445E-06	5.310E+02
14	2.165E-11	4.255E+01	9.138E-08	4.255E+01
Total	3.780E+12	5.296E+13	2.939E+15	2.995E+15

Intensity Fractions

1. Neutron source strength fractions for source probability (SP) card: peaking factor for Shippingport LWBR fuel = 2

Total neutron source strength (neutrons/s): Shippingport LWBR: 2*5.77E+8=1.154E+9
SRS: 5*1.2722E+8 =6.361E+8
Total: 6.361E+8 + 1.154E+9 = 1.7901E+9

Fractions: SRS: 1.2722E+8/1.7901E+9=0.071
Shippingport LWBR: 1.154E+9/1.7901E+9=0.645

2. Gamma source strength fractions for SP card: peaking factor for Shippingport LWBR fuel = 2

Total gamma source strength (photons/s): Shippingport LWBR: 2*2.995E+15=5.99E+15
SRS: 5*5.6962E+15 = 2.8481E+16
Total: 2.8481E+16 + 5.99E+15 = 3.4471E+16

Fractions: SRS: 5.6962E+15/3.4471E+16=0.165
Shippingport LWBR: 5.99+15/3.4471E+16=0.175

Atomic Density Calculations for the Homogenized Active Fuel Region of the Shippingport LWBR Seed Assembly

Length of active fuel region (cm): 263.525
Shape of inner cavity: hexagonal
Cladding thickness (cm): 0.2032
Distance between parallel faces (cm): 9.59*2.54-2*0.2032=23.9522
Hexagon face (cm): 23.9522/2/cos30=13.82880912
Inner cavity area (cm^2): 23.9522*13.82881+((23.9522)^2)/2*tan30=496.845603
Volume for fuel region homogenization (cm^3): 130931.237
Fuel rods per assembly: 619
Fuel pellet mass per rod (g): 830
Fuel pellet mass per assembly (g): 619*830=513770

Cladding:

Material: Zircaloy-4
Density (g/cm^3): 6.56
Outer diameter (cm): 0.778002
Thickness (cm): 0.0563118
Mass per rod (g):
6.56*263.525*π*((0.778002/2)^2-((0.778002-2*0.056312)/2)^2)=220.711901
Mass per assembly (g): 136620.6668

Mass Calculation for the Elements/Isotopes in the Binary Stack Region

Table IV-1. Fuel Mass in the Binary Stack Region

Fuel Rod Type	Number/ Assembly	Initial Fissile Mass (g/rod)	Fissile Concentration (wt%)	Fuel Rod Mass (g)	Fuel Mass (g)	Fissile Mass (g)
01	30	14.33	4.337	330.4127	9912.3818	429.90
02	84	14.33	4.337	330.4127	27754.6691	1203.72
03	72	19.14	4.337	441.3189	31774.9596	1378.08
04	66	23.92	4.337	551.5333	36401.1990	1578.72
05	181	34.57	5.202	664.5521	120283.9290	6257.17
06	150	34.57	5.202	664.5521	99682.8143	5185.50
07	30	14.33	4.337	330.4127	9912.3818	429.90
08	6	14.33	4.337	330.4127	1982.4764	85.98
Total	619				337704.8110	16548.97

Table IV-2. Uranium Isotopes Mass in the Binary Stack Region

	U-235 (g)	U-233 (g)	U-234 (g)	U-236 (g)	U-238 (g)
wt%	0.09	98.23	1.29	0.02	0.37
Fuel Rod Type					
01	0.3935	429.5065	5.6405	0.0874	1.6178
02	1.1019	1202.6181	15.7933	0.2449	4.5299
03	1.2615	1376.8185	18.0810	0.2803	5.1860
04	1.4451	1577.2749	20.7135	0.3211	5.9411
05	5.7277	6251.4423	82.0967	1.2728	23.5471
06	4.7467	5180.7533	68.0360	1.0548	19.5142
07	0.3935	429.5065	5.6405	0.0874	1.6178
08	0.0787	85.9013	1.1281	0.0175	0.3236
Total	15.1486	16533.8214	217.1295	3.3663	62.2775

Table IV-3. ThO_2 Mass in the Binary Stack Region

Isotope	Atomic Mass (g)	wt%	Element/ Oxide	Atomic Mass (g)	Mass (mole)	Mass (g)
U-233	233.039627	98.23	U	233.0734903	72.2165	16831.7433
U-234	234.040945	1.29	O	15.9994	144.4329	2310.8402
U-235	235.043922	0.09	UO_2			19142.5835
U-236	236.045561	0.02	ThO_2			318562.2279
U-238	238.050785	0.37				

ThO_2 Mass Calculation in the Thoria Region

Total fuel mass (g/rod): 830
Total fuel mass (g): 513770
ThO_2 mass (g): 176065.189

Total ThO_2 in the seed assembly (g): 494627.4165

Table IV-4. Element Mass in ThO_2

Element	Atomic Mass (g)	Mass (mole)	Mass (g)
Th	232.03805		434683.1937
O	15.9994		59944.2229
ThO_2	264.03685	1873.3272	

Table IV-5. Isotope/Element Mass in the Active Fuel Region

Fuel		**Cladding**		
Isotope/Element	**Mass (g)**	**Element**	**wt%**	**Mass (g)**
U-233	16533.8214	O	0.125	170.7758
U-234	217.1295	Cr	0.425	580.6378
U-235	15.1486	Fe	0.21	286.9034
U-236	3.3663	Sn	1.45	1980.9997
U-238	62.2775	Zr	97.79	133601.3501
Th-232	434683.1937			
O	62255.0630			
Total	451514.9370		100	136620.6668

Table IV-6. Atomic Densities in the Active Fuel Region

Element/Isotope	**Atomic Mass (g)**	**Mass (g)**	**Atomic Density (atoms/cm.barn)**
U-233	233.039627	16533.8214	3.2632E-04
U-234	234.040945	217.1295	4.2670E-06
U-235	235.043922	15.1486	2.9643E-07
U-236	236.045561	3.3663	6.5593E-08
U-238	238.050785	62.2775	1.2033E-06
Th-232	232.03805	434683.1937	8.6161E-03
O	15.9994	62425.8389	1.7946E-02
Cr	51.9961	580.6378	5.1361E-05
Fe	55.845	286.9034	2.3629E-05
Sn	118.71	1980.9997	7.6753E-05
Zr	91.224	133601.3501	6.7360E-03
Total			3.3782E-02

Table V-1. Flux-to-Dose Conversion Factors for Neutrons

Upper Energy Boundary (MeV)	Flux-to-Dose Conversion Factor[1] (rem/h)/(n/cm^2.s)	Quality Factor[1]	Flux-to-Dose Conversion Factor (rad/h)/(n/cm^2.s)
2.50E-08	3.67E-06	2	1.84E-06
1.00E-07	3.67E-06	2	1.84E-06
1.00E-06	4.46E-06	2	2.23E-06
1.00E-05	4.54E-06	2	2.27E-06
1.00E-04	4.18E-06	2	2.09E-06
1.00E-03	3.76E-06	2	1.88E-06
1.00E-02	3.56E-06	2.5	1.42E-06
1.00E-01	2.17E-05	7.5	2.89E-06
5.00E-01	9.26E-05	11	8.42E-06
1	1.32E-04	11	1.20E-05
2.5	1.25E-04	9	1.39E-05
5	1.56E-04	8	1.95E-05
7	1.47E-04	7	2.10E-05
10	1.47E-04	6.5	2.26E-05
14	2.08E-04	7.5	2.77E-05
20	2.27E-04	8	2.84E-05

[1] Ref. 7.3, App. H, p. H-5.

Table VI-1. Dose Rates on the Inner Surface of the Inner Shell

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Segment 1	1.3912E+03	0.0188	1.2438E-01	0.0041	1.3913E+03	0.0188
Segment 2	7.2733E+03	0.0059	1.2535E-01	0.0049	7.2734E+03	0.0059
Segment 3	8.2040E+03	0.0056	1.2800E-01	0.0048	8.2041E+03	0.0056
Segment 4	8.2691E+03	0.0058	1.1628E-01	0.0051	8.2692E+03	0.0058
Segment 5	8.3338E+03	0.0061	9.0593E-02	0.0060	8.3339E+03	0.0061
Segment 6	7.5126E+03	0.0057	6.5441E-02	0.0073	7.5126E+03	0.0057

Table VI-2. Dose Rates on the Inner Surface of the Outer Shell

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Segment 1	5.4374E+01	0.0171	6.9378E-02	0.0035	5.4443E+01	0.0171
Segment 2	3.9317E+02	0.0092	7.0187E-02	0.0044	3.9324E+02	0.0092
Segment 3	4.3751E+02	0.0088	7.1758E-02	0.0044	4.3758E+02	0.0088
Segment 4	4.3372E+02	0.0087	6.4641E-02	0.0047	4.3378E+02	0.0087
Segment 5	4.3607E+02	0.0088	4.7579E-02	0.0056	4.3612E+02	0.0088
Segment 6	4.0788E+02	0.0093	3.2641E-02	0.0068	4.0791E+02	0.0093

Table VI-3. Dose Rates on the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Segment 1	9.6170E+00	0.0191	2.6432E-02	0.0036	9.6434E+00	0.0190
Segment 2	7.2129E+01	0.0109	2.6999E-02	0.0047	7.2156E+01	0.0109
Segment 3	8.0643E+01	0.0104	2.7473E-02	0.0047	8.0670E+01	0.0104
Segment 4	8.0426E+01	0.0104	2.4644E-02	0.0049	8.0451E+01	0.0104
Segment 5	8.1163E+01	0.0106	1.8137E-02	0.0059	8.1181E+01	0.0106
Segment 6	7.4584E+01	0.0109	1.2533E-02	0.0072	7.4597E+01	0.0109

Table VI-4. Dose Rates on a Radial Surface 1 m from the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Segment 1	8.8177E+00	0.0111	7.5584E-03	0.0030	8.8253E+00	0.0111
Segment 2	2.3957E+01	0.0092	9.3132E-03	0.0032	2.3966E+01	0.0092
Segment 3	3.1241E+01	0.0082	9.0240E-03	0.0032	3.1250E+01	0.0082
Segment 4	3.2881E+01	0.0079	8.0863E-03	0.0035	3.2889E+01	0.0079
Segment 5	3.1277E+01	0.0083	6.4134E-03	0.0040	3.1283E+01	0.0083
Segment 6	2.3838E+01	0.0095	4.3240E-03	0.0049	2.3842E+01	0.0095

Table VI-5. Dose Rates on a Radial Surface 2 m from the WP Outer Radial Surface

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Segment 1	7.2116E+00	0.0095	3.9722E-03	0.0029	7.2155E+00	0.0095
Segment 2	1.3570E+01	0.0089	4.7560E-03	0.0033	1.3575E+01	0.0089
Segment 3	1.7145E+01	0.0082	4.7056E-03	0.0033	1.7150E+01	0.0082
Segment 4	1.8508E+01	0.0080	4.3173E-03	0.0035	1.8512E+01	0.0080
Segment 5	1.6863E+01	0.0083	3.5980E-03	0.0039	1.6867E+01	0.0083
Segment 6	1.3373E+01	0.0093	2.7201E-03	0.0045	1.3376E+01	0.0093

Table VI-6. Dose Rates on the WP Axial Surfaces

Axial Location (see Fig. 5.2-2)	Gamma		Neutron		Total	
	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error	Dose Rate (rad/h)	Relative Error
Inner surface of bottom inner shell lid	6.1497E+03	0.0119	6.3333E-02	0.0087	6.1498E+03	0.0119
Inner surface of bottom outer shell lid	1.5985E+01	0.0293	1.8778E-02	0.0099	1.6004E+01	0.0293
Bottom surface of WP	3.0317E+00	0.0379	6.6975E-03	0.0105	3.0384E+00	0.0378
Bottom surface 1 m from WP	1.5497E+00	0.0436	2.1869E-03	0.0113	1.5519E+00	0.0435
Bottom surface 2 m from WP	8.6537E-01	0.0545	9.7342E-04	0.0147	8.6634E-01	0.0544
Inner surface of top inner shell lid	4.4014E+02	0.0239	8.7711E-02	0.0062	4.4022E+02	0.0239
Inner surface of top outer shell lid	2.6953E+00	0.0720	2.7466E-02	0.0075	2.7228E+00	0.0713
Top surface of WP	6.0081E-01	0.0802	9.6751E-03	0.0081	6.1048E-01	0.0789
Top surface 1 m from WP	3.5259E-01	0.0959	3.0540E-03	0.0088	3.5564E-01	0.0951
Top surface 2 m from WP	2.3327E-01	0.1132	1.3327E-03	0.0112	2.3460E-01	0.1126