OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
CALCULATION COVER SHEET

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1. PURPOSE

The purpose of this calculation is to determine the surface dose rates of the short codisposal waste package (WP) of defense high-level waste (DHLW) and TRIGA (Training, Research, Isotopes, General Atomics) spent nuclear fuel (SNF). The WP contains the TRIGA SNF, in a standardized 18-in. DOE (U.S. Department of Energy) SNF canister, and five 3-m-long Savannah River Site (SRS) DHLW pour glass canisters, which surround the DOE SNF canister.

The results will be used to assess the shielding performance of the 5-DHLW/DOE SNF short single-CRM (corrosion resistant material) WP. This calculation is performed and documented according to the AP-3.12Q (Rev. 0/ICN 0) procedure.

2. METHOD

The Monte Carlo radiation transport method, which is implemented in the MCNP computer code (Briesmeister 1997), is used to calculate surface dose rates of waste packages. MCNP uses the continuous-energy cross sections processed from the evaluated nuclear data files (Briesmeister 1997, Appendix G).

3. ASSUMPTIONS

3.1 The geometry of the 3-m-long SRS canister is represented as a cylinder of nominal length, wall thickness, and outer diameter. The basis for this assumption is that radiation transport in the upper part of the canister is not affected by the canister shape because this portion of the canister is empty and the wall thickness is maintained. This assumption is used throughout Section 5.

3.2 The inner and outer brackets and the divider plates supporting the DHLW canisters are neglected. The basis for this assumption is that neglecting the structural components that would attenuate radiation is conservative for calculating dose rates on the surfaces of the WP. This assumption is used throughout Section 5.

3.3 The contents and radiation source of the DOE SNF canister are homogenized inside the canister cavity. The basis for this assumption is that the dose rates are conservative (higher) when the radiation source is closer to the outer surfaces of the WP, and the self-shielding of the fuel is reduced allowing more particles to reach the outer surface of the WP (CRWMS M&O [Civilian Radioactive Management System Management and Operating Contractor] 1998b, Section 6). This assumption is used throughout Section 5.

3.4 The axial peaking factor that bounds the axial source distribution of the TRIGA SNF is 1.25. This value is based on the heat profile for a representative pressurized water reactor assembly (EPRI [Electric Power Research Institute] 1989, page 3-26). This assumption is used throughout Section 5.

3.5 A Watt fission neutron spectrum is assumed for the neutron spectrum of the TRIGA SNF. The basis for this assumption is that the dose rate evaluation is not sensitive to the neutron spectrum because the TRIGA SNF neutron dose rate contribution to the total dose rate is negligible. This assumption is used throughout Section 5.

3.6 The chemical composition of the TRIGA spent nuclear fuel is assumed to be the same as that of the TRIGA unirradiated (fresh) fuel. The basis for this assumption is that small weight variations of the elements do not affect the accuracy of dose results, as long as the total weight is maintained. This assumption is used throughout Section 5.

3.7 Erbium is neglected in the composition of the TRIGA fresh fuel because photon and neutron cross sections for erbium are not provided by MCNP-4B2. The basis for this is that the calculated dose rates are higher (more conservative) when materials are neglected because materials attenuate radiation. This assumption is used throughout Section 5.

3.8 Stainless steel (SS) 316L is assumed instead of SS 316NG, as specified in Attachment II, 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.

3.9 The material compositions of Alloy 22, SA-516 Carbon Steel Grade 70, SS 304L, SS 316L, and SS 304 have elements with allowable ranges of weight percentage. 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.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

The MCNP V4B2LV computer code is used to calculate neutron and gamma fluxes on the WP surfaces for dose rate evaluations.

- Program Name: MCNP.
- Version/Revision number: Version 4B2.
- Computer Software Configuration Item (CSCI) Number: 30033 V4B2LV (CRWMS M&O 1998a).
- Computer Type: Hewlett Packard (HP) 9000/700 Series workstation.

- The MCNP V4B2LV computer code is an appropriate tool to determine the dose rate on and near the surface of a WP containing DHLW glass and DOE 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

The following sections outline the data used in the calculation of dose rates on the surfaces of the codisposal WP and on surfaces near the codisposal WP outer surface. Each MCNP calculation requires the following input data: geometry, material, and radiation source parameters. The codisposal WP comprises the DHLW disposal container, 5 SRS DHLW glass canisters, the support tube, and the DOE SNF canister, which contains three basket assemblies each loaded with 37 TRIGA SNF rods. Attachment I presents the sketch SK-0124 REV 00 for the TRIGA DOE SNF basket assembly. The sketch for the 5-DHLW/DOE SNF short single-CRM waste package, SK-0143 REV 01, is shown in Attachment II.

The number of digits for the numerical 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.

5.1.1 Disposal Container

Table 1 presents the geometry and material specifications of the short single-CRM disposal container for DHLW glass and DOE SNF. Tables 2 through 4 present the chemical compositions and densities for the structural materials of this container.

Table 1. Geometry and Material Specifications for the Disposal Container

Component	Material	Characteristic	Dimension (mm)
Inner shell	SA-240 (316NG)[a]	Thickness	50
Outer shell	SB-575 N06022[b]	Thickness	25
Top and bottom inner shell lids	SA-240 (316NG)	Thickness	80
Top and bottom outer shell lids	SB-575 N06022	Thickness	25
Cavity	Air	Length	3,040
		Diameter	1,880
Closure lid gap	Air	Thickness	30
Support tube	SA-516 K02700[c]	Outer diameter	565
		Inner diameter	501.5
		Length	3,030

SOURCE: Attachment II, page II-1.
NOTES: [a] SS 316L is used instead (see Assumption 3.8).
[b] Also known as Alloy 22 (CRWMS M&O 1999a, page 30).
[c] Also known as SA-516 Carbon Steel Grade 70 (CRWMS M&O 1999a, page 10).

Table 2. Chemical Composition of Alloy 22

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	12.5-14.5	13.50
Cobalt	2.50 (max)	2.50
Tungsten	2.5-3.5	3.00
Vanadium	0.35 (max)	0.35
Iron	2.0-6.0	4.00
Sulfur	0.02 (max)	0.02
Phosphorus	0.02 (max)	0.02
Nickel	Balance	54.765
Density = 8.69 g/cm^3		

SOURCE: CRWMS M&O 1999a, page 30.

Table 3. Chemical Composition of SS 316L

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		

SOURCE: CRWMS M&O 1999a, page 13.
NOTE: SS 316L is used in this calculation instead of SS 316NG (see Assumption 3.8).

Table 4. Chemical Composition of SA-516 Carbon Steel Grade 70

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		

SOURCE: CRWMS M&O 1999a, page 10.

5.1.2 DHLW Glass Canisters

Tables 5 through 8 provide geometry, material, and radiation source specifications for the SRS DHLW glass canisters.

Table 5. Geometry and Material Specifications for DHLW Glass Canisters

Component	Material	Characteristic	Value
Canister wall	SS 304L	Outer diameter	610 mm
		Wall thickness	9.525 mm
		Length	3,000 mm
SRS DHLW glass[a]	(provided in Table 7)	Weight	1,682 kg
		Density	2.85 g/cm^3

SOURCE: DOE 1992, pages 3.3-4 through 3.3-6.
NOTE: [a] The average fill temperature (i.e., the average temperature of the glass upon completion of filling to 85% of canister volume) is 825 °C. The glass volume per canister when cooled to 25 °C is about 0.59 m^3. The density of the glass is about 2.69 g/cm^3 at 825 °C and 2.85 g/cm^3 at 25 °C (Stout and Leider 1991, page 2.2.1.1-4).

Table 6. Chemical Composition of SS 304L

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	0.10
Iron	Balance	68.045
Density = 7.94 g/cm^3		

SOURCE: CRWMS M&O 1999a, page 17.

Table 7. Chemical Composition of SRS DHLW Glass

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[a]	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[b]	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			

SOURCE: CRWMS M&O 1999b, p. 7.

NOTES: [a] The neutron and photon cross sections for ^{138}Ba were used in calculations because the cross-section tables for ^{137}Ba are missing from the ENDF/B-V library.

[b] Neutron cross-section tables for Zn are missing from the ENDF/B-V library; therefore, the Al neutron cross-section tables are used instead because of the similarities between neutron cross sections of these two elements.

Table 8. Gamma and Neutron Sources per SRS DHLW Glass Canister at Day 1 After Pouring

Gamma Source		Neutron Source	
Upper Energy Boundary (MeV)	**Intensity (photons/s)**	**Upper Energy Boundary (MeV)**	**Intensity (neutrons/s)**
0.05	1.32E+15	0.10	1.97E+05
0.10	3.96E+14	0.40	1.89E+06
0.20	3.10E+14	0.90	6.34E+06
0.30	8.74E+13	1.40	6.92E+06
0.40	6.39E+13	1.85	6.12E+06
0.60	8.83E+13	3.00	2.61E+07
0.80	1.35E+15	6.43	3.42E+07
1.00	2.13E+13	20.00	3.07E+05
1.33	2.96E+13		
1.66	6.42E+12		
2.00	5.14E+11		
2.50	2.94E+12		
3.00	2.04E+10		
4.00	2.28E+09		
5.00	5.25E+05		
6.50	2.11E+05		
8.00	4.13E+04		
10.00	8.75E+03		
Total	3.68E+15		8.21E+07

SOURCE: CRWMS M&O 1999c, Attachment VIII, page 1, and Attachment IX, page 1.

5.1.3 DOE SNF Canister

Table 9 presents the geometry and material specifications for the short 18-in. DOE standardized SNF canister. The chemical compositions and densities for SS 316L and SA-516 Carbon Steel Grade 70 are given in Tables 3 and 4, respectively.

Table 9. Geometry and Material Specifications for the DOE SNF Canister

Component	Material	Characteristic	Dimension (mm)
Circular cylinder	SS 316L	Outer diameter	457.2
		Wall thickness	9.525
		Internal length	2,547
Impact plate	SA-516 Carbon Steel Grade 70	Thickness	50.8
Top and bottom curved plates	SS 316L	Thickness	9.525

SOURCE: DOE 1998a, page 5 and Appendix A.

In this calculation, the DOE SNF canister is loaded with the TRIGA FLIP (Fuel Improvement Program) SNF. The basket assembly inside the DOE SNF canister consists of three sections, each of which contains 37 SS-316L pipes, accommodating a total of 111 TRIGA SNF elements. Twelve basket support brackets are attached to each section, and three base plates are used to separate the sections (see Attachment I). Table 10 presents the masses for the TRIGA FLIP element and the non-fuel components inside the DOE SNF canister.

Table 10. Material Specifications for the Contents of the DOE SNF Canister

Component	Sub-Component	Material	Characteristic	Value	Reference
Fuel (TRIGA-FLIP)	Fuel section	U-238	Mass/element (g)	59.0	DOE 1999, page 25
		U-235	Mass/element (g)	137.0	
		Zr (as hydrate)	Mass/element (g)	2,060.0	
		Erbium	Mass/element (g)	36.0	
	Zirconium rod	Zr	Mass/element (g)	63.7	
	Reflectors	Graphite	Mass/element (g)	450.0	
	Cladding	SS 304	Mass/element (g)	270.0	
	End fittings	SS 304	Mass/element (g)	530.0	
Basket assembly			Number of sections	3	Attachment I
	SS pipes	SS 316L	Mass/section (g)	235,600.0	CRWMS M&O 1999d, page 8
	Base plates	SS 316L	Mass/section (g)	10,800.0	
	Basket support brackets	SS 316L	Mass/section (g)	10,600.0	

NOTE: The cross-section data for erbium are not available in MCNP-4B2.

The chemical composition for SS 304 is presented in Table 11.

Table 11. Chemical Composition of SS 304

Element	Weight Percent Range	Value Used
Carbon	0.08 (max)	0.08
Chromium	18-20	19.00
Nickel	8-10.5	9.25
Manganese	2.00 (max)	2.00
Phosphorus	0.045 (max)	0.045
Sulfur	0.03 (max)	0.03
Silicon	1.00 (max)	1.00
Nitrogen	0.10 (max)	0.10
Iron	Balance	68.495

SOURCE: ASTM A 240/A 240M-95a, page 2.

Tables 12 and 13 present the gamma and neutron source terms, respectively, provided in DOE 1999. The source terms are for the TRIGA FLIP SNF with the highest burnup and isotopics associated with the following characteristics: SS clad, 8.5-wt% U with 70-wt% ^{235}U initial enrichment, and 66.52-MWd average burnup. Since the neutron source is available at the 20-year decay time, the neutron intensity at 20-year decay time is used to compute the neutron source at 1-year decay time (see Attachment IV).

Table 12. Gamma Source at 1-Year Decay Time for the TRIGA FLIP SNF Element

Upper Energy Boundary[b] (MeV)	Average Group Energy (MeV)	Gamma Intensity[a] (photons/s)
0.02	1.50E-02	3.850E+13
0.03	2.50E-02	8.610E+12
0.05	3.75E-02	9.140E+12
0.07	5.75E-02	7.920E+12
0.10	8.50E-02	5.520E+12
0.15	1.25E-01	6.770E+12
0.30	2.25E-01	4.570E+12
0.45	3.75E-01	2.360E+12
0.70	5.75E-01	1.840E+13
1.00	8.50E-01	1.150E+13
1.50	1.25E+00	1.150E+13
2.00	1.75E+00	5.820E+10
2.50	2.25E+00	2.280E+11
3.00	2.75E+00	1.050E+09
4.00	3.50E+00	1.120E+08
6.00	5.00E+00	2.610E+03
8.00	7.00E+00	3.000E+02
14.00	1.10E+01	3.450E+01
Total		1.251E+14

SOURCE: [a] DOE 1999, page B-7.
[b] DOE 1998b, page B-2.
NOTE: DOE 1999, page B-7, mistakenly lists the following two upper energy boundaries: 8 and 11 MeV for the average group energies 5 and 7 MeV, respectively.

Table 13. Neutron Source at 20-Year Decay Time for the TRIGA FLIP SNF Element

Nuclide	20-Year Decay Time		
	Activity (Ci)	(α, n) Production (neutrons/s)	Spontaneous Fission (SF) Production (neutrons/s)
Bi-211	3.78E-08	5.51E-03	
Po-212	1.72E-05	1.84E+01	
Po-215	3.78E-08	2.57E-01	
Rn-219	3.78E-08	9.24E-03	
U-235	1.19E-04	9.71E-03	1.82E-02
U-238	1.83E-05	9.49E-04	6.43E-01
Pu-238	3.24E-00	1.31E+03	
Pu-239	9.35E-02	4.66E+01	4.70E-00
Pu-240	7.69E-02	2.70E+01	
Am-241	7.80E-01	4.57E+02	
Total		1.86E+03	5.36E-00

SOURCE: DOE 1999, page B-8.

5.2 DESCRIPTION OF MCNP CALCULATIONS

The contents inside the DOE SNF canister loaded with the TRIGA SNF are homogenized inside the canister volume. The atomic densities (AD) of the materials inside the canister, in atoms/b·cm, are calculated according to the following equation:

$$\text{AD (atoms/b}\cdot\text{cm)} = \frac{\text{mass}_{\text{isotope}}(\text{g}) * N_A(\text{atoms/mole})}{10^{24}(\text{b/cm}^2) * \text{volume}_{\text{region}}(\text{cm}^3) * \text{atomic mass}_{\text{isotope}}(\text{g/mole})}$$

In the above equation, N_A is the Avogadro constant, whose value is 6.0221367E+23 atoms per mole (Parrington et al. 1996, page 59). Attachment III presents atomic density calculations.

Two calculations, one for the gamma and one for the neutron transport, are required. MCNP estimates the gamma or the neutron flux averaged over a surface, and then calculates the surface dose rates in rem/h. The surface dose rate for a certain energy group is the product of group flux and the flux-to-dose conversion factor (Briesmeister 1997, pages H-5 and H-6) for the energy group. Since MCNP performs the photon and neutron transport in two separate runs, the total dose rate is the sum of the gamma and neutron 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. The relative error is given by:

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

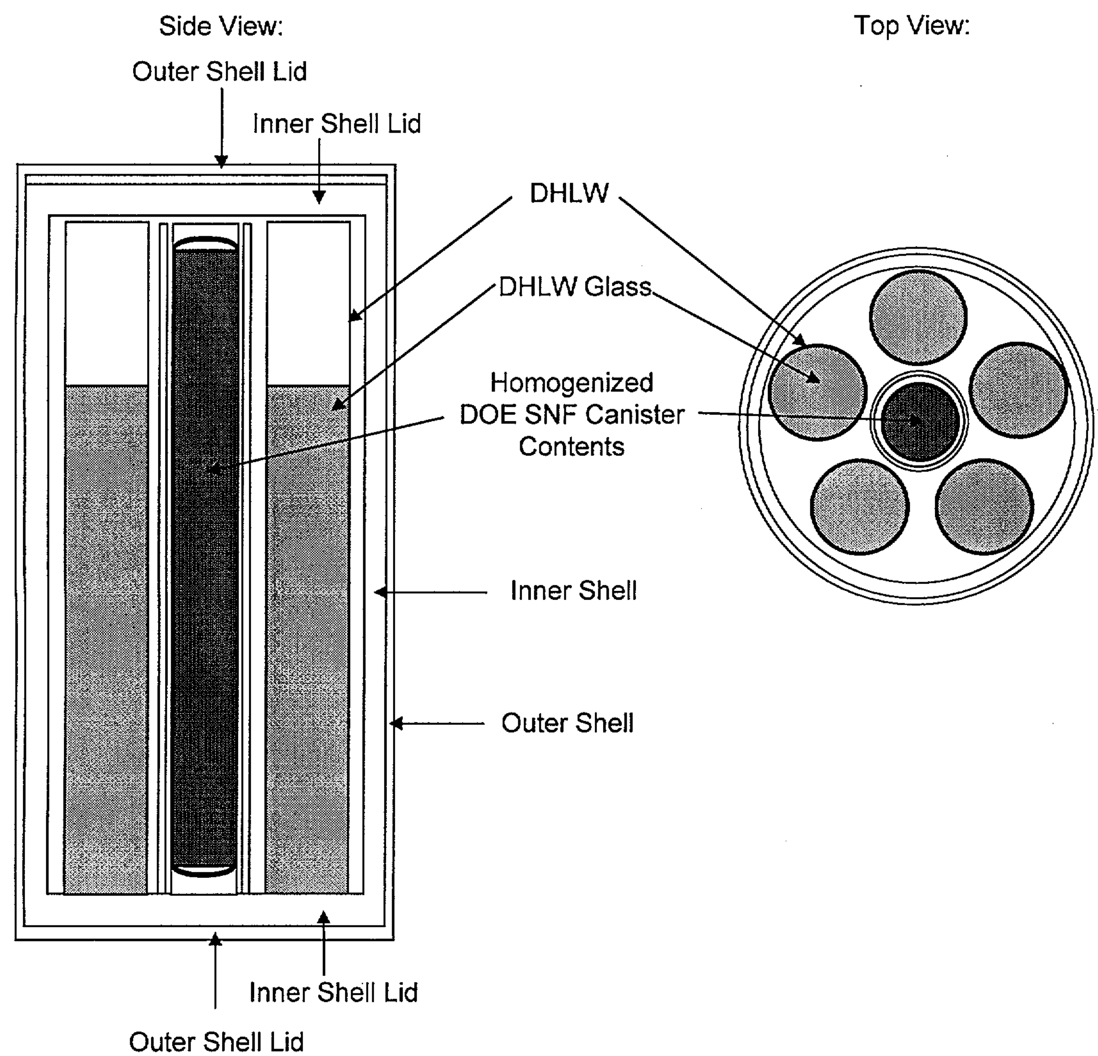
$$\bar{x} = \text{estimated dose rate}$$

For the majority of the surface segments, the total dose rates are dominated by the gamma dose rates. The neutron dose rates are comparable to the statistical uncertainty of the gamma dose rates. Because the neutron dose rate is very small, neither a neutron dose rate calculation in rad/h nor a coupled neutron-photon calculation is necessary. The gamma doses in rem/h and rad/h are identical because the quality factor, which shows the biological effectiveness of the radiation, is unity for photons.

The radiation sources, gamma and neutron, of this WP originate from the six canisters shown in Figure 1. Therefore, the MCNP input file specifies these sources through the source distribution numbers and the geometrical cell specifications. Attachment IV provides the fractions of gamma and neutron source samplings in each canister, required by the source probability (sp) card, and the total source intensity, required by the tally multiplier (fm) card.

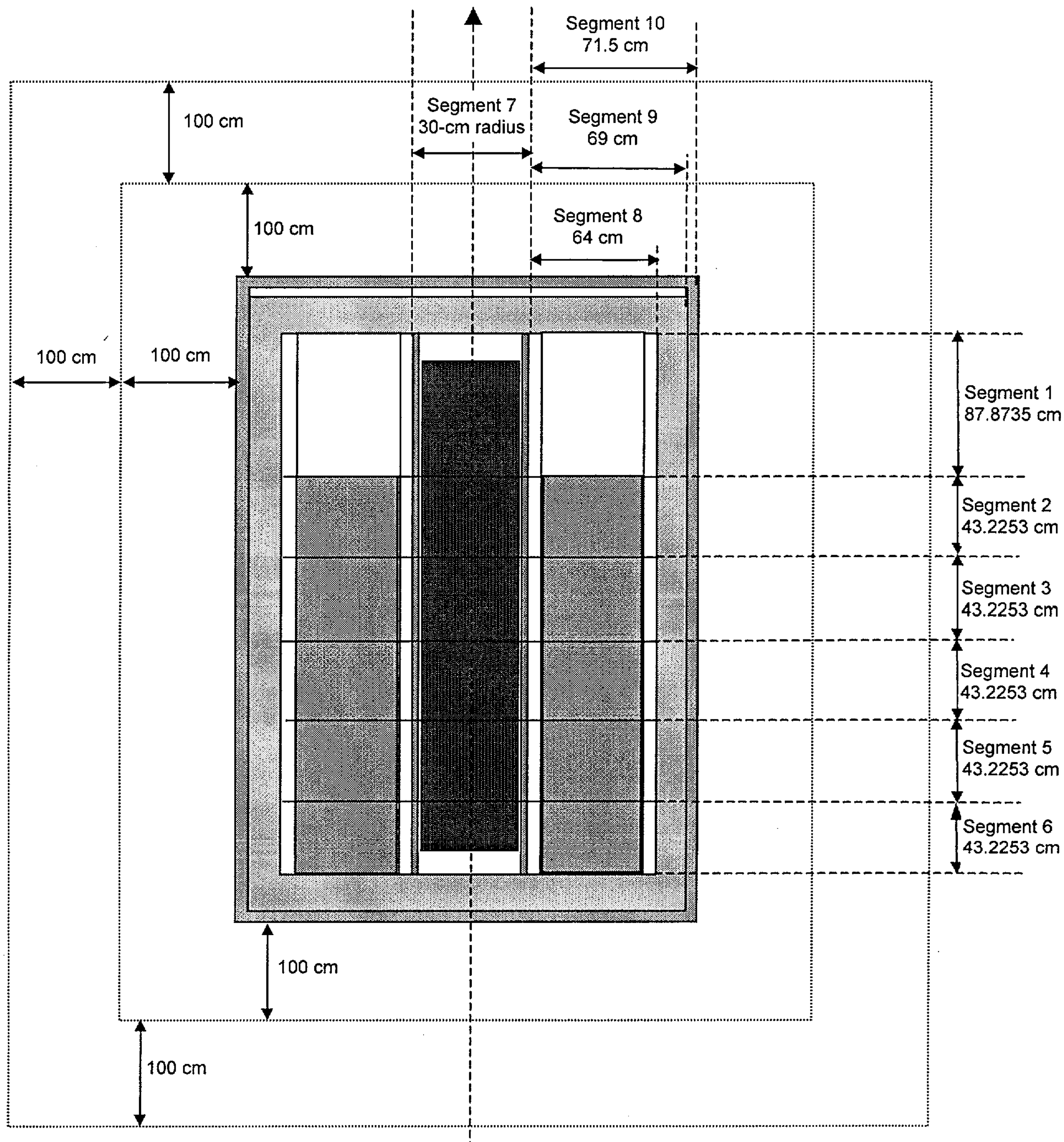
In radiation shielding analysis, particle population diminishes considerably due to attenuation in shield materials. Preliminary calculations of this case have shown that the gamma-ray intensity decreases by a factor of about 18 when passing through the inner barrier and by a factor of about 6 when passing through the outer barrier. 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 techniques 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 (Briesmeister 1997, page 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 not tracking unimportant particles. In this calculation, the relative importances assigned to adjacent cells do not exceed a factor of 4.

The geometry for the MCNP calculation is shown in Figure 1. Figure 2 shows the surfaces and segments used in dose rate tallies. The first radial segment, of 87.8735-cm height, is the portion between the top of WP cavity and the top of DHLW glass. Segments 2 through 6 are radial surface segments of equal size, each of 43.2253-cm height, between the bottom and top planes of DHLW glass. Each WP axial surface is divided into two segments by a circle of 30-cm radius, as shown in Figure 2. The axial dose rates for the surfaces 1 m and 2 m from the WP outer surfaces are averaged on the segments delimited by the outer radius of the WP



NOTE: Drawing not to scale.

Figure 1. Vertical and Horizontal Cross Sections of MCNP Geometric Representation



NOTE: Drawing not to scale.

Figure 2. Surfaces and Segments of WP Used in Dose Rate Calculations

6. RESULTS

This document and its conclusions may be affected by technical product input information that requires confirmation. Any changes to the document or its conclusions 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.

Tables 14 through 19 present the radial and axial dose rates on the WP surfaces and at the distances of 1 m and 2 m from the outer surface of the WP (see Figure 2 for segment locations) containing five SRS DHLW glass pour canisters and the standardized 18-in. DOE SNF canister loaded with the TRIGA SNF. The dose rates in rem/h and rad/h are practically the same because the contribution of neutron dose rate to the total dose rate is insignificant and the quality factor for the gamma photons is unity.

Table 14. Dose Rates on the Radial Surface of the WP Cavity

Axial Location	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	2.7976E+03	0.0023	1.7661E-01	0.0046	2.7978E+03	0.0023
Segment 2	7.9333E+03	0.0018	4.0222E-01	0.0040	7.9337E+03	0.0018
Segment 3	9.0278E+03	0.0017	4.9159E-01	0.0036	9.0283E+03	0.0017
Segment 4	9.1119E+03	0.0017	5.0753E-01	0.0035	9.1124E+03	0.0017
Segment 5	8.9205E+03	0.0017	4.9650E-01	0.0036	8.9210E+03	0.0017
Segment 6	7.5298E+03	0.0019	4.1604E-01	0.0040	7.5302E+03	0.0019

Table 15. Dose Rates on Inner Surface of the Outer Shell

Axial Location	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	1.8738E+02	0.0051	8.5183E-02	0.0040	1.8746E+02	0.0051
Segment 2	4.7901E+02	0.0043	2.0345E-01	0.0036	4.7921E+02	0.0043
Segment 3	5.2425E+02	0.0041	2.5200E-01	0.0032	5.2450E+02	0.0041
Segment 4	5.2845E+02	0.0041	2.5834E-01	0.0031	5.2871E+02	0.0041
Segment 5	5.1267E+02	0.0041	2.5238E-01	0.0032	5.1292E+02	0.0041
Segment 6	4.3334E+02	0.0045	2.0897E-01	0.0035	4.3354E+02	0.0045

Table 16. Dose Rates on the WP Outer Radial Surface

Axial Location	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	4.3531E+01	0.0069	3.4474E-02	0.0039	4.3565E+01	0.0069
Segment 2	9.5541E+01	0.0059	8.4805E-02	0.0034	9.5626E+01	0.0059
Segment 3	1.0272E+02	0.0057	1.0503E-01	0.0031	1.0283E+02	0.0057
Segment 4	1.0358E+02	0.0056	1.0740E-01	0.0030	1.0368E+02	0.0056
Segment 5	9.9835E+01	0.0057	1.0474E-01	0.0031	9.9940E+01	0.0057
Segment 6	8.3158E+01	0.0061	8.6445E-02	0.0034	8.3245E+01	0.0061

Table 17. Dose Rates on a Radial Surface 1 m from the WP Outer Radial Surface

Axial Location	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	2.0111E+01	0.0052	1.5359E-02	0.0022	2.0127E+01	0.0052
Segment 2	3.2629E+01	0.0050	2.4191E-02	0.0021	3.2653E+01	0.0050
Segment 3	3.7622E+01	0.0046	2.8428E-02	0.0020	3.7650E+01	0.0046
Segment 4	3.8410E+01	0.0045	2.9724E-02	0.0019	3.8440E+01	0.0045
Segment 5	3.4292E+01	0.0047	2.7349E-02	0.0020	3.4319E+01	0.0047
Segment 6	2.5982E+01	0.0054	2.1658E-02	0.0023	2.6004E+01	0.0054

Table 18. Dose Rates on a Radial Surface 2 m from the WP Outer Radial Surface

Axial Location	Gamma		Neutron		Total	
	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Segment 1	1.2714E+01	0.0048	9.1685E-03	0.0020	1.2723E+01	0.0048
Segment 2	1.7280E+01	0.0053	1.1878E-02	0.0022	1.7291E+01	0.0053
Segment 3	1.9031E+01	0.0050	1.3002E-02	0.0022	1.9044E+01	0.0050
Segment 4	1.9298E+01	0.0049	1.3235E-02	0.0021	1.9311E+01	0.0049
Segment 5	1.7589E+01	0.0051	1.2547E-02	0.0022	1.7602E+01	0.0051
Segment 6	1.4340E+01	0.0055	1.0929E-02	0.0023	1.4351E+01	0.0055

Table 19. Dose Rates on Segments of the Axial Surfaces

Axial Location	Segment (see Fig. 2)	Gamma Dose Rate (rem/h)	Gamma Relative Error	Neutron Dose Rate (rem/h)	Neutron Relative Error	Total Dose Rate (rem/h)	Total Relative Error
Top surface of the lower inner lid	Segment 7	9.7111E+02	0.0057	1.4623E-01	0.0061	9.7125E+02	0.0057
	Segment 8	5.8537E+04	0.0020	2.9315E+00	0.0039	5.8540E+04	0.0020
Top surface of the lower outer lid	Segment 7	8.3395E+01	0.0319	1.5682E-01	0.0111	8.3552E+01	0.0318
	Segment 9	6.8354E+01	0.0094	1.4817E-01	0.0040	6.8502E+01	0.0094
Bottom surface of WP	Segment 7	2.1915E+01	0.0401	6.2788E-02	0.0109	2.1977E+01	0.0400
	Segment 10	1.2772E+01	0.0134	5.8474E-02	0.0039	1.2830E+01	0.0133
Bottom surface 1 m from WP	WP bottom surface	6.9910E+00	0.0151	1.8712E-02	0.0041	7.0097E+00	0.0151
Bottom surface 2 m from WP	WP bottom surface	3.7383E+00	0.0189	8.0496E-03	0.0048	3.7464E+00	0.0189
Bottom surface of the upper inner lid	Segment 7	2.3543E+02	0.0089	1.1331E-02	0.0195	2.3544E+02	0.0089
	Segment 8	1.1456E+04	0.0037	1.1712E+00	0.0060	1.1457E+04	0.0037
Bottom surface of the upper outer lid	Segment 7	7.0206E+01	0.0309	4.7143E-02	0.0182	7.0253E+01	0.0309
	Segment 9	2.2868E+01	0.0165	5.2399E-02	0.0063	2.2920E+01	0.0165
Top surface of WP	Segment 7	1.9846E+01	0.0416	1.8302E-02	0.0185	1.9864E+01	0.0416
	Segment 10	4.9351E+00	0.0232	2.1180E-02	0.0063	4.9563E+00	0.0231
Top surface 1 m from WP	WP top surface	3.2601E+00	0.0237	6.6427E-03	0.0066	3.2667E+00	0.0237
Top surface 2 m from WP	WP top surface	1.7647E+00	0.0289	3.0004E-03	0.0079	1.7677E+00	0.0289

7. ATTACHMENTS

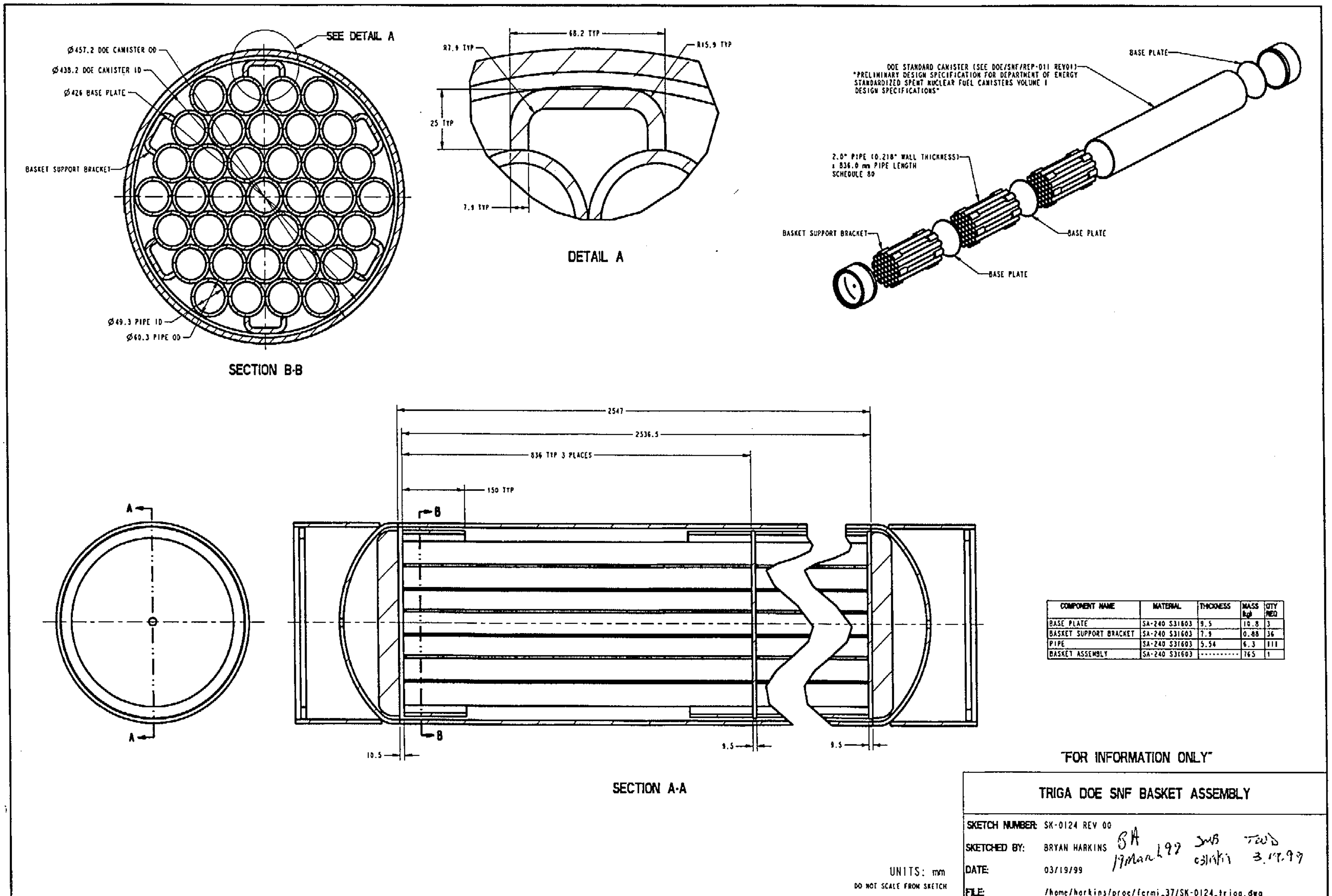
The hardcopy attachments are listed below in Table 20. Electronic output files are provided on a CD (compact disk) (CRWMS M&O 2000), and are listed in Table 21 below. The input files used in this calculation are echoed in the output files. Each output file is identified by its name, size (in bytes), 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 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 HP CD-Writer Plus model 7200e external CD-rewritable drive for personal computers.

Table 20. List of Attachments

Description	Attachment Number	No. of Pages
SK-0124 REV 00 TRIGA DOE SNF Basket Assembly	I	1
SK-0143 REV 01 5-DHLW/DOE SNF Short Single-CRM Waste Package	II	1
Atomic densities for the homogenized content of the DOE SNF canister loaded with TRIGA SNF	III	2
Total source intensity and source intensity fractions of the DOE SNF and SRS DHLW glass canisters	IV	1
Document Input Reference System	V	3

Table 21. File Attributes for the Contents of Electronic Media

File Name	File Size (bytes)	File Date	File Time
dhlwp.io	141,847	01/10/2000	8:06 a.m.
dhlwn.io	140,611	01/09/2000	2:06 p.m.



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	0.88	36
PIPE	SA-240 S31603	5.54	6.3	111
BASKET ASSEMBLY	SA-240 S31603	----------	765	1

"FOR INFORMATION ONLY"

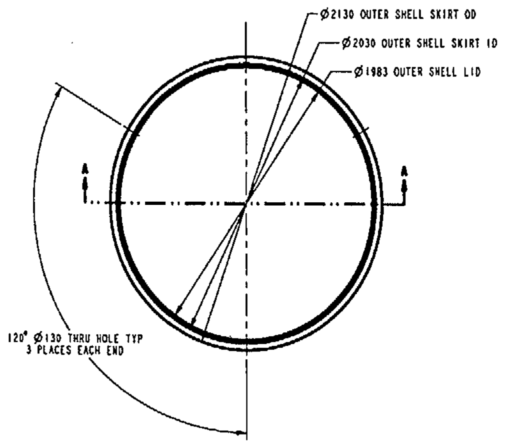
TRIGA DOE SNF BASKET ASSEMBLY

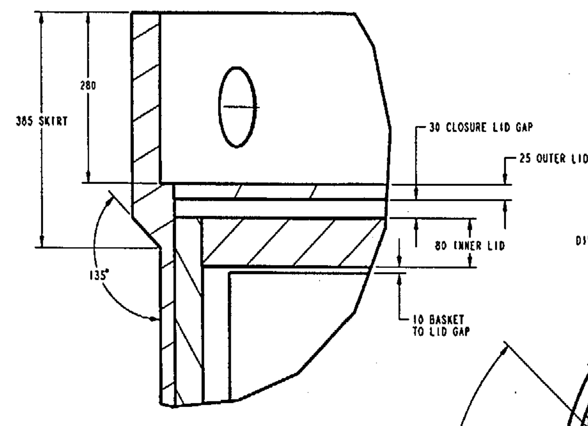
SKETCH NUMBER: SK-0124 REV 00

SKETCHED BY: BRYAN HARKINS BH 19Mar99 JWB 03/19/99 TWD 3.19.99

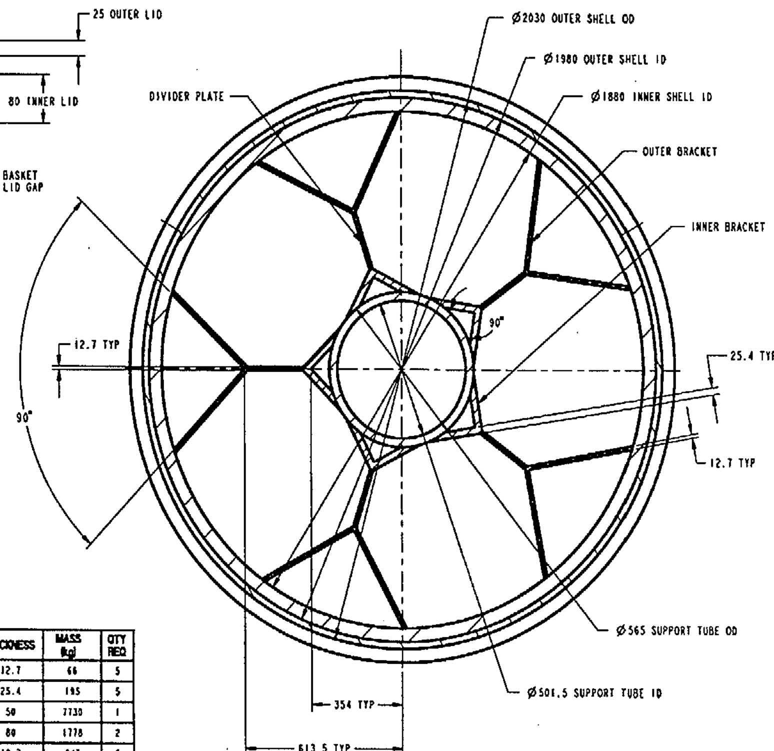
DATE: 03/19/99

FILE: /home/harkins/proe/fermi_37/SK-0124_triga.dwg

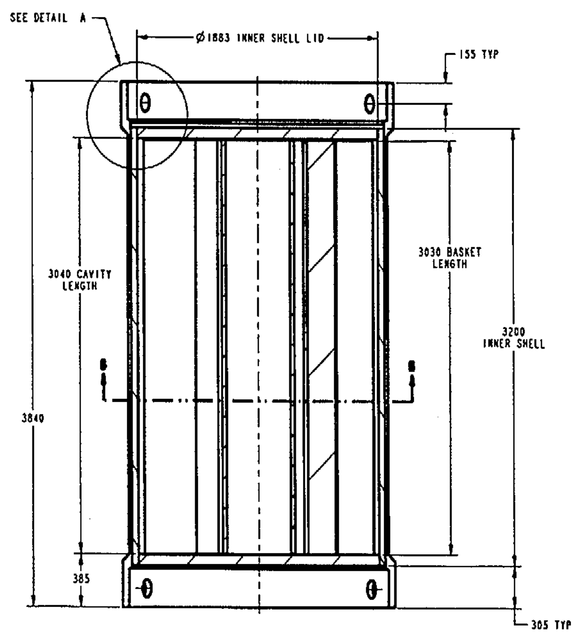




DETAIL A



SECTION B-B



SECTION A-A

COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
DIVIDER PLATE	SA-516 K02700	12.7	66	5
INNER BRACKET	SA-516 K02700	25.4	195	5
INNER SHELL	SA-240 (316NG)	50	7730	1
INNER SHELL LID	SA-240 (316NG)	80	1778	2
OUTER BRACKET	SA-516 K02700	12.7	247	5
OUTER SHELL	SB-575 N06022	25	6510	1
OUTER SHELL LID	SB-575 N06022	25	671	2
SUPPORT TUBE	SA-516 K02700	31.75	1265	1
WASTE PACKAGE ASSEMBLY	-	-	22940	1
HLW GLASS ASSEMBLY	-	-	2500*	5
18" DOE CANISTER SHORT	-	-	2270**	1
WP ASSEMBLY WITH SNF	-	-	37710	1

* DOE 1996 WASTE ACCEPTANCE SYSTEM REQUIREMENTS DOCUMENT DOE/RW-0351P REVISION 02 DCN 02 MAY 13, 1997. VIENNA, VA: CRWMS M&O. ACC: MOV.19970513.0118

**DOE1998. DESIGN SPECIFICATION FOR DEPARTMENT OF ENERGY STANDARDIZED SPENT NUCLEAR FUEL CANISTERS, VOLUME I, DESIGN SPECIFICATION, REV 1. WASHINGTON D.C.: UNITED STATES DEPARTMENT OF ENEGRY. TIC: 241528.

UNITS:mm

DO NOT SCALE

"FOR INFORMATION ONLY"

5-DHLW/DOE SNF SHORT SINGLE CRM WASTE PACKAGE

SKETCH NUMBER: SK-0143 REV 01

SKETCHED BY: BRYAN HARKINS BH 20 Sept 99 SMB 09/20/99 TWD 9.20.99

DATE: 09/20/99

FILE: /home/pro_library/checkout/sketches/5dhlw_home/5dhlw_short/sk-0143.dwg

Mass and Atomic Density Calculation by Element for the Contents of the Standardized 18-in. DOE SNF Canister

Total SS 316L mass (kg)=3*(235.6+10.8+10.6)=771
Total SS 304 mass (g) = 111*(270+530)=88800
Total Zr mass (g) = 111*(2060+63.7)=235730.7
Total graphite mass (g) =111*450=49950
Total U-235 mass (g) =111*137=15207
Total U-238 mass (g) =111*59=6549
DOE SNF canister cavity volume (cm^3)=π*21.9075^2*254.7=384029.3865

Table III-1. Element or Isotope Mass for the Contents Inside the DOE SNF Canister

Element/	SS 316L		SS 304		Zr	Graphite	U-238	U-235	Total
Isotope	wt%	Mass (g)	wt%	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
C	0.03	231.3	0.08	71.04		49950			50,252.3
Mn	2	15,420	2	1,776					17,196
P	0.045	346.95	0.045	39.96					386.91
S	0.03	231.3	0.03	26.64					257.94
Si	1	7,710	1	888					8,598
Cr	17	131,070	19	16,872					147,942
Ni	12	92,520	9.25	8,214					100,734
Mo	2.5	19,275							19,275
N	0.1	771	0.1	88.8					859.8
Fe	65.295	503,424.5	68.495	60,823.56					564,248
Zr					235,730.7				235,731
U-235								15,207	15,207
U-238							6,549		6,549

Table III-2. Element or Isotope Atomic Densities for the Contents of the DOE SNF Canister

Element/Isotope	Atomic Mass[a] (g)	Mass (g)	Atomic Density (atoms/b·cm)
C	12.0107	50,252.34	6.5611E-03
Mn	54.938049	17,196	4.9084E-04
P	30.973761	386.91	1.9589E-05
S	32.066	257.94	1.2614E-05
Si	28.0855	8,598	4.8007E-04
Cr	51.9961	147,942	4.4618E-03
Ni	58.6934	100,734	2.6914E-03
Mo	95.94	19,275	3.1505E-04
N	14.00674	859.8	9.6260E-05
Fe	55.845	564,248	1.5844E-02
Zr	91.224	235,730.7	4.0522E-03
U-235	235.043922	15,207	1.0146E-04
U-238	238.050785	6,549	4.3141E-05
Total			3.5170E-02

SOURCE: [a] Parrington et al. 1996.

Source Intensity Fractions of the TRIGA SNF and 3-m-long SRS Canisters

The calculation of neutron production at 1-year decay time is based on the proportionality between with actinide activity and neutron production.

Table IV-1. TRIGA Neutron Source at 1-Year Decay Time

Nuclide	20-Year Decay Time[a]			1-Year Decay Time		
	Activity (Ci)	(α, n) Production (neutrons/s)	SF Production (neutrons/s)	Activity[b] (Ci)	(α, n) Production (neutrons/s)	SF Production (neutrons/s)
Bi-211	3.78E-08	5.51E-03		3.94E-09	5.74E-04	
Po-212	1.72E-05	1.84E+01		5.90E-06	6.31E+00	
Po-215	3.78E-08	2.57E-01		3.94E-09	2.68E-02	
Rn-219	3.78E-08	9.24E-03		3.94E-09	9.63E-04	
U-235	1.19E-04	9.71E-03	1.82E-02	1.19E-04	9.73E-03	1.82E-02
U-238	1.83E-05	9.49E-04	6.43E-01	1.83E-05	9.50E-04	6.44E-01
Pu-238	3.24E-00	1.31E+03		3.75E+00	1.52E+03	
Pu-239	9.35E-02	4.66E+01	4.70E-00	9.35E-02	4.66E+01	4.70E+00
Pu-240	7.69E-02	2.70E+01		7.66E-02	2.69E+01	
Am-241	7.80E-01	4.57E+02		1.03E-01	6.02E+01	
Total		1.86E+03	5.36E-00		1.66E+03	5.36E+00

SOURCE: [a] DOE 1999, page B-8.
[b] DOE 1999, page B-4.

1. Neutron source strength (peaking factor for TRIGA fuel: 1.25 [see Assumption 3.4])

Total neutron source strength (neutrons/s): TRIGA: 1.25*111*(1.66E+3+5.36E+0)=2.31E+5
SRS: 5*8.21E+7=4.105E+8
Total: 4.105E+8+2.31E+5=4.107E+8

Fractions: SRS: 8.21E+7/4.107E+8=0.1999
TRIGA: 2.31E+5/4.107E+8=0.0005

2. Gamma source strength fractions for source probability (SP) card (peaking factor for TRIGA fuel: 1.25 [see Assumption 3.4])

Total gamma source strength (photons/s): TRIGA: 1.25*111*1.251E+14=1.7358E+16
SRS: 5*3.68E+15=1.84E+16
Total: 1.84E+16+1.7358E+16=3.5758E+16

Fractions: SRS: 3.68E+15/3.5758E+16=0.1029
TRIGA: 1.7358+16/3.5758E+16=0.4855

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:
CAL-DDC-NU-000001 REV 00	N/A	Dose Rate Calculation for the DHLW/DOE SNF Codisposal Waste Package

Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
2a 1	CRWMS M&O 1998a. *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: CRWMS M&O. ACC: MOL.19980622.0637.	Entire	N/A-Reference Only	4	Reference to Software Qualification Report	N/A	N/A	N/A	N/A
2	CRMWS M&O 1998b. *Calculation of the Effect of Source Geometry on the 21-PWR WP Dose Rates*. BBAC00000-01717-0210-00004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990222.0059.	6	N/A-Reference Only	3	Reference for geometric representation of source regions	N/A	N/A	N/A	N/A
3	CRMWS M&O 1999a. *Waste Package Materials Properties*. BBA000000-01717-0210-00017 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990407.0172.	pp. 13 and 30 pp. 10 and 17	TBV-3885 TBV-3149	5.1 5.1	Chemical composition and density for Alloy C-22 and stainless steel 316L Materials composition; compositions and densities of 304L and A516L	3 3	X X	N/A N/A	N/A N/A
4	CRMWS M&O 1999b. *DOE SRS HLW Glass Chemical Composition*. BBA000000-01717-0210-00038 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990215.0397.	p. 7	TBV-3022	5.1	SRS chemical composition of HLW glass	3	X	N/A	N/A
5	CRMWS M&O 1999c. *Source Terms for DHLW Canisters for Waste Package Design*. BBA000000-01717-0210-00044 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990222.0176.	Att. VIII and IX	TBV-4063	5.1	Photon and neutron spectra for SRS DHLW glass.	3	X	N/A	N/A

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Input Document							8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
6	CRMWS M&O 1999d. *Volume/Mass of DOE Canister and TRIGA SNF*. BBA000000-01717-0210-00046 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990713.0238.	p. 8	TBV-4066	5.1	Mass of TRIGA DOE SNF basket assembly	3	X	N/A	N/A
7	CRMWS M&O 2000. *Electronic Output Files for Dose Rate Calculation for the DHLW/DOE SNF Codisposal Waste Package.* CAL-DDC-NU-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.2000125.0684.	Entire	N/A – Reference Only	7	MCNP output files for this calculation	N/a	N/A	N/A	N/A
8	ASTM A 240/A 240M-95a. 1995. *Standard Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels.* Philadelphia, Pennsylvania: American Society for Testing and Materials. TIC: 242434.	p. 2	N/A – Accepted Data (Fact)	5.1	Chemical composition for stainless steel 304	N/A	N/A	N/A	N/A
9	DOE (U.S. Department of Energy) 1992. *Characteristics of Potential Repository Wastes.* DOE/RW-0184-R1. Volume 1. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: HQO.19920827.0001.	pp. 3.3-4 to 3.3-6	TBV-3150	5.1	HLW glass canister dimensions, composition, and weight of the glass	3	X	N/A	N/A
10	DOE (U.S. Department of Energy) 1998a. "Design Specification." Volume 1 of *Preliminary Design Specification for Department of Energy Standardized Spent Nuclear Fuel Canisters.* DOE/SNF/REP-011, Rev. 1. Washington, D.C.: U.S. Department of Energy, Office of Spent Fuel Management and Special Projects. TIC: 241528.	p. 5 and App. A	TBV-3151	5.1	DOE SNF canister dimensions and materials	3	X	N/A	N/A

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1. Document Identifier No./Rev.:	Change:	Title:
CAL-DDC-NU-000001 REV 00	N/A	Dose Rate Calculation for the DHLW/DOE SNF Codisposal Waste Package

Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
11	DOE (U.S. Department of Energy) 1998b. *FFTF (MOX) Fuel Characteristics for Disposal Criticality Analysis*. DOE/SNF/REP-032, Rev. 0. Washington, D.C.: U.S. Department of Energy. TIC: 241492.	App. B, p. B-2	N/A – Reference Only	5.1	Upper energy boundaries for gamma source	N/A	N/A	N/A	N/A
12	DOE (U.S. Department of Energy) 1999. *TRIGA (UzrH) Fuel Characteristics for Disposal Criticality Analysis*. DOE/SNF/REP-048, Rev. 0. Washington, D.C.: U.S. Department of Energy. TIC: 244162.	p. 25	TBV-4065	5.1	Initial heavy metal loading in TRIGA fuel elements	3	X	N/A	N/A
		pp. B-7 and B-8	TBV-4064	5.1 and Att. IV	Gamma and neutron sources for a TRIGA-FLIP SNF	3	X	N/A	N/A
		p. B-4	N/A- Not Critical	Att. IV	Actinide activities	N/A	N/A	N/A	N/A
13	EPRI (Electric Power Research Institute) 1989. *Testing and Analyses of the TN-24P PWR Spent-Fuel Dry Storage Cask Loaded with Consolidated Fuel*. EPRI NP-6191. Palo Alto, California Electric Power Research Institute. TIC: 207047.	p. 3-26	TBV-3770	3	Peaking factor value	3	X	N/A	N/A
14	Stout, R.B. and Leider, H.R., eds. 1991. *Preliminary Waste Form Characteristics Report*. Version 1.0. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19940726.0118.	p. 2.2.1.1-4	TBV-3152	5.1	Density of HLW glass	3	X	N/A	N/A
15	Parrington, J.R.; Knox, H.D.; Breneman, S.L.; Baum, E.M.; and Feiner, F. 1996. *Nuclides and Isotopes, Chart of the Nuclides*. 15th Edition. San Jose, California: General Electric Company and KAPL, Inc. TIC: 233705.	Entire	N/A – Accepted Data (fact)	5.2 and Att. III	Atomic mass of elements/isotopes and Avogadro constant	N/A	N/A	N/A	N/A
16	Briesmeister, J.F., ed. 1997. *MCNP-A general Monte Carlo N-particle Transport Code*. LA-12625-M, Version 4B. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL:19980624.0328.	Entire	N/A – Reference Only	2 and 5.2	Reference to software users' manual	N/A	N/A	N/A	N/A