OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

CALCULATION COVER SHEET

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2. Calculation Title

Dose Rate Calculation for the 44-BWR UCF Waste Package

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9. Remarks

Revision History

10. Revision No.	11. Description of Revision
00	Initial Issue
01	Sketches SK-0219 REV 01, page 24, and SK-0192 REV 00, page 1, (Attachments I and II) replaced Sketch SK-0135 REV 00. The surface dose rates were evaluated for the waste package design concept presented in Attachment I, and Tables 11 through 34 were updated. Changes to comply with current procedures were made as nedeed. References were added. Editorial changes were made to the document as needed.

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1. PURPOSE

The objective of this calculation is to evaluate the surface dose rates of a 44-BWR (boiling water reactor) uncanistered fuel (UCF) waste package (WP). The scope is limited to the 44-BWR waste package concept for License Application. Since a sketch for this waste package type is not available, sketch SK-0219 REV 01 for the 21-pressurized water reactor waste package concept for License Application provides the specifications for the waste package disposal container. The results of this calculation will be used to assess the shielding performance of the 44-BWR WP design concept for License Application.

The planning requirements that apply to the generation of this calculation have been identified in *Technical Work Plan for: Waste Package Design Description for SR* (CRWMS M&O [Civilian Radioactive Waste Management and Operator Contractor] 2000a, Waste Package Design Methodology). This calculation is performed and documented according to AP-3.12Q, *Calculations*

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).

The radiation source terms for the BWR SNF were developed in CRWMS M&O (1999, pp. 10 and 45) for spent fuel with various combinations of burnup, enrichment, and cooling time. The initial uranium content considered in radiation source term generation is 200 kg, and the highest fuel burnup and enrichment considered are 75 GWd/MTU and 5.5 wt% ^{235}U, respectively. In this calculation, "bounding BWR SNF" is the spent fuel with a 75-GWd/MTU burnup, 5.5-wt% enrichment, 5-year cooling time, and an initial uranium content of 200 kg. These values bound the initial uranium content (190 kg), burnup (65.55 GWd/MTU), enrichment (4.28 wt% ^{235}U), and cooling time (5 year) of the BWR assemblies in the commercial waste stream that will arrive at the repository (CRWMS M&O 2000b, Attachment III, preblend files). The characteristics of an "average BWR SNF" are defined in Assumption 3.3. Dose rate calculations for a "hypothetical bounding BWR SNF" are also included to evaluate an upper limit for the dose rate at the WP external surfaces (See Section 5.2).

The control of the electronic management of data is accomplished in accordance with the process control evaluation for the technical work plan of this calculation (CRWMS M&O 2000a).

3. ASSUMPTIONS

The assumption is used throughout Section 5.

3.1 It is assumed that the disposal container has thicknesses and material specifications as presented in sketch SK-0219 REV 01, page 24, and accommodates 44 BWR assemblies as specified in sketch SK-0192 REV 00, page 1. The rationale for this assumption is that the design concept for License Application for the disposal container of a 21-pressurized water reactor WP, which is presented in sketch SK-0219 REV 01, is the design concept for disposal containers of all types of uncanistered commercial spent nuclear fuels.

3.2 The radiation source and contents of each assembly region are homogenized inside region volume. The rationale for this assumption is that the surface dose rates of a WP with this geometric representation for the fuel assemblies and of a WP with detailed geometric representation for the fuel assemblies are the same within statistical limits (CRWMS M&O 1998b, Section 6).

3.3 The BWR spent nuclear fuel (SNF) having 3.5-wt% initial ^{235}U, 40-GWd/MTU burnup, and 22-year decay time is assumed to be the SNF with average characteristics. The rationale for this assumption is that the source term for the SNF with these characteristics generates conservative (higher) dose rates for the average BWR SNF. The average BWR SNF is estimated in CRWMS M&O (1999, page 46).

3.4 A peaking factor of 1.4 bounds the axial gamma and neutron source distribution in the active fuel region (CRWMS M&O 1999, page 47). The rationale for this assumption is that this value for the axial peaking factor for a representative BWR SNF assembly at a lower burnup is conservative for dose rate evaluations.

3.5 The chemical composition of the SNF is assumed the same as that of the fresh fuel. The rationale 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.

3.6 The chemical composition of Neutronit A976 is assumed for Neutronit A978, which is a molybdenum alloyed Bohler Neutronit (Kugler 1996). The rationale for this assumption is that by neglecting molybdenum in the Neutronit A976 chemical composition, the balance element iron is increased, which provides conservative (higher) dose rates at the external surfaces of the WP.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

The MCNP 4B2LV computer code is used to calculate neutron and gamma fluxes on the WP surfaces for dose rate evaluations. This computer code is a baseline qualified software.

- 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) workstation "Bloom" (Tag: CRWMS-M&O 700887).
- Operating System: HP-UX (Hewlett Packard UNIX) 10.20.
- The MCNP 4B2LV computer code is an appropriate tool to determine the dose rates on the surface and near the surface of a WP containing 44-BWR SNF assemblies.
- This software has been validated over the range it was used.
- This software was previously obtained from the Software Configuration Management in accordance with appropriate procedures.

The input file for each computer calculation is echoed in the output file of the calculation. The output files are described in Section 8.

4.2 MODELS

None used.

5. CALCULATION

5.1 CALCULATION INPUTS

The following sections outline the information used in the calculation of dose rates on the WP surfaces. Each MCNP calculation requires specifications of the WP geometry, material, and source parameters. The WP consists of the disposal container and 44 BWR SNF assemblies. Sketch SK-0219 REV 01, page 24, which is shown in Attachment I, provides the thickness and material specifications for the components of the disposal container, and sketch SK-0192, page 1, which is

shown in Attachment II, provides the specifications for the cavity and basket assembly dimensions. The information provided by the sketches is that of the potential design of the type of WP considered in this calculation.

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.

5.1.1 Disposal Container

The disposal container consists of the inner reinforcement cylinder, the corrosion resistant outer shell, the inner shell lids, and the outer corrosion resistant shell lids. Table 1 presents the thickness and material specifications for the components of the disposal container, as indicated in sketches SK-0219 REV 01, page 24, and for the basket assembly that accommodates 44 BWR assemblies, as presented in SK-0192 REV 00, page 1. Tables 2 through 6 present the chemical compositions for the structural materials shown in Table 1.

Table 1. Geometry and Material Specifications for the Disposal Container

Component	Material	Characteristic	Dimension (mm)
Inner shell	SA-240 S31600	Thickness	50
Outer shell	SB-575 N06022	Thickness	20
Inner shell bottom lid	SA-240 S31600	Thickness	88.9
Inner shell top lid	SA-240 S31600	Thickness	50.8
Outer shell flat bottom lid	SB-575 N06022	Thickness	25.4
Extended outer shell lid base	SB-575 N06022	Thickness	25.4
Outer shell flat closure lid	SB-575 N06022	Thickness	9.525
Top upper closure gap	Air	Thickness	30.08
Top lower closure gap	Air	Thickness	44.225
Bottom lid gap	Air	Thickness	70
Cavity	Air	Length	4,585
		Inner diameter	1,454
Basket B-sideguide	SA-516 K02700	Thickness	10
Basket cornerguide	SA-516 K02700	Thickness	10
Basket stiffener	SA-516 K02700	Thickness	10
Basket B-stiffener	SA-516 K02700	Thickness	10
Fuel basket A-plate	Neutronit A 978	Thickness	5
Fuel basket B-plate	Neutronit A 978	Thickness	5
Fuel basket C-plate	Neutronit A 978	Thickness	5
Fuel basket D-plate	Neutronit A 978	Thickness	5
Fuel basket E-plate	Neutronit A 978	Thickness	5
Fuel basket F-plate	SB-209 A96061 T4	Thickness	5
Fuel basket G-plate	SB-209 A96061 T4	Thickness	5
Basket assembly	N/A	Length	4,575
Fuel basket tube	SA-516 K02700	Thickness	5
		Inner transverse dimension	155.3

SOURCE: Sketch SK-0219 REV 01, page 24 (see Attachment I), and SK-0192 REV 00, page 1 (see Attachment II).
NOTE: The thicknesses of the top lids used in this calculation slightly differ from those shown in sketch SK-0219 REV 01. However, the total thickness of the top lids used in this calculation is 85 mm, which is 0.725 less than the actual value indicated by the sketch, and provides higher (conservative) dose rates at the top surface of the waste package. Moreover, for conservative evaluations (higher dose rates), the thicknesses of the inner shell, the outer shell, and lids are reduced by 0.25 mm each to account for permissible variations in thickness (ASME 1998, Section II-B, SB-575, page 762, and Section II-A, SA-480, page 877). The loose fit between the inner and outer shells is neglected to obtain slightly higher (conservative) dose rates at the external radial surface.

Table 2. Chemical Composition of SA-516 K02700

Element	Weight Percent Range[a]	Value Used
Carbon	0.27 (max)	0.27
Manganese	0.85-1.20	1.025
Phosphorus	0.035 (max)	0.035
Sulfur	0.035 (max)	0.035
Silicon	0.15-0.40	0.275
Iron	Balance	98.36
Density[b] = 7.85 g/cm^3		

SOURCE: [a] ASME 1998, Section II-A, SA-516, page 925.
[b] ASME 1998, Section II-A, SA-20, page 67.

Table 3. Chemical Composition of SA-240 S31600

Element	Weight Percent Range[a]	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	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	65.495
Density[b] = 7.98 g/cm^3		

SOURCE: [a] ASME 1998, Section II-A, SA-240, page 366.
[b] ASTM G 1-90, page 7.

Table 4. Chemical Composition of SB-575 N06022

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	20.0-22.5	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
Phosphorus	0.02 (max)	0.02
Sulfur	0.02 (max)	0.02
Nickel	Balance	54.765
Density = 8.69 g/cm^3		

SOURCE: ASME 1998, Section II-B, SB-575, pages 760 and 761.

The chemical composition of Neutronit A976 is assumed for Neutronit A978 in this calculation (see Assumption 3.6).

Table 5. Chemical Composition of Neutronit A976

Element	Weight Percent Range[a]	Value Used
Carbon	0.04 (max)	0.04
Chromium	18.5	18.5
Nickel	13.0	13.0
Cobalt	0.20 (max)	0.20
Boron	According to specifications	0.75-1.74[b]
Iron	Balance	67.51 or 66.52
Density[a] = 7.76 g/cm^3		

SOURCE: [a] Kugler 1996, pages 14 and 17.
[b] ASTM A 887-89, page 2.

NOTE: The range of boron content is determined based on those for ASTM A887 types B3 to B6. For conservative (slightly higher) results, 0.75-wt% B is used in the neutron dose rate calculations, and 1.74-wt% B is used in the gamma dose calculations. The natural isotopic content of boron in calculations is 19.9-at% ^{10}B and 80.1-at% ^{11}B (Parrington et al. 1996).

Table 6. Chemical Composition of SB-209 A96061

Element	Weight Percent Range[a]	Value Used
Silicon	0.4-0.8	0.6
Iron	0.7 (max)	0.7
Copper	0.15-0.4	0.275
Manganese	0.15 (max)	0.15
Magnesium	0.8-1.2	1.0
Chromium	0.04-0.35	0.195
Zinc[c]	0.25 (max)	0.25
Titanium	0.15 (max)	0.15
Others (each)	0.05 (max)	0.0
Others (total)	0.15 (max)	0.0
Aluminum	Balance	96.68
Density[b] = 2.7 g/cm^3		

SOURCE: [a] ASME 1998, Section II-B, SB-209, page 236.
[b] ASME 1998, Section II-D, Subpart 2, pages 611 and 612.
NOTE: [c] MCNP does not contain neutron cross-section tables for Zn. Al replaces Zn in this calculation because these two elements have similar neutron cross sections.

5.1.2 BWR SNF Assemblies

The BWR SNF assembly used in this calculation is a General Electric (GE) 2/3 8x8 BWR SNF assembly. CRWMS M&O (1999) provides radiation source term calculations (including the gamma and neutron source terms) and the physical characteristics for this representative BWR assembly. Table 7 presents the light element contents and dimensions for each fuel region. Tables 8, 9, and 10 present the gamma and neutron sources for the bounding BWR SNF, the hypothetical bounding BWR SNF, and the average BWR SNF. The initial uranium content, enrichment, burnup, and decay characteristics of the three BWR SNFs are described in Sections 2 and 5.2.

Table 7. Light Element Mass and Dimensions by Fuel Region for a GE 2/3 8x8 BWR Assembly

Element	Mass[a] (kg)			
	Bottom End-Fitting Region	Active Fuel Region	Plenum Region	Top End-Fitting Region
Oxygen	0.0008	0.050526 + 0.041131 + 0.003732 + 0.00234 = 0.097729	0.0074	0.0012
Aluminum	N/A	0.0023	0.0119	0.0041
Carbon	0.0038	0.0002	0.0015	0.0019
Cobalt	0.0038	0.0033	0.0175	0.0074
Chromium	0.9069	0.1302	0.3784	0.4680
Copper	N/A	0.0013	0.0068	0.0023
Iron	3.2208	0.1889	0.5649	1.3982
Manganese	0.0954	0.0026	0.0259	0.0446
Niobium	N/A	0.0033	0.0170	0.0058
Nitrogen	0.0048	N/A	0.0006	0.0020
Nickel	0.4970	0.2646	1.2610	0.6157
Phosphorus	0.0021	N/A	0.0003	0.0009
Sulfur	0.0014	N/A	0.0004	0.0007
Silicon	0.0358	0.0013	0.0114	0.0173
Tin	0.0111	1.3845	0.1055	0.0169
Titanium	N/A	0.0078	0.0408	0.0139
Zirconium	0.6374	79.6784	6.0704	0.9739
Width[b] (cm)	13.81252[c]	13.81252	13.81252	13.81252
Length[b] (cm)	18.7579	365.76[d]	28.5496	22.2885

SOURCE: [a] CRWMS M&O 1999, Attachment IIR01, page II-11.
[b] CRWMS M&O 1999, page 12.
NOTES: [c] Calculated: 13.40612 (CRWMS M&O 1999, page 12) + 2*0.2032 (CRWMS M&O 1999, page 12).
[d] Calculated: 435.356 (CRWMS M&O 1999, page 12) – 18.7579 – 28.5496 – 22.2885.

Table 8. Gamma and Neutron Sources per Assembly for the Bounding BWR SNF

Gamma Intensity (photons/s)					Neutron Intensity (neutrons/s)	
Upper Energy Boundary (MeV)	Bottom End-Fitting Region	Active Fuel Region	Plenum Region	Top End-Fitting Region	Upper Energy Boundary (MeV)	Active Fuel Region
5.00E-02	3.65E+11	8.13E+14	7.64E+11	3.81E+11	1.00E-08	0.0000E+00
1.00E-01	8.53E+10	2.26E+14	1.50E+11	8.85E+10	3.00E-08	0.0000E+00
2.00E-01	1.51E+11	1.76E+14	1.74E+11	1.52E+11	5.00E-08	0.0000E+00
3.00E-01	2.50E+10	5.06E+13	2.61E+10	2.50E+10	1.00E-07	0.0000E+00
4.00E-01	2.30E+09	3.38E+13	4.96E+09	2.35E+09	2.25E-07	0.0000E+00
6.00E-01	3.20E+10	4.22E+14	6.89E+10	3.20E+10	3.25E-07	0.0000E+00
8.00E-01	9.93E+10	1.59E+15	1.19E+11	9.94E+10	4.00E-07	0.0000E+00
1.00E+00	1.33E+11	1.96E+14	1.11E+11	1.12E+11	8.00E-07	0.0000E+00
1.33E+00	4.01E+12	6.61E+13	2.28E+13	4.96E+12	1.00E-06	0.0000E+00
1.66E+00	1.09E+12	1.86E+13	6.40E+12	1.36E+12	1.13E-06	0.0000E+00
2.00E+00	1.57E+07	3.63E+11	1.57E+07	1.57E+07	1.30E-06	0.0000E+00
2.50E+00	2.56E+07	5.97E+11	1.52E+08	3.20E+07	1.77E-06	0.0000E+00
3.00E+00	3.97E+04	2.55E+10	2.35E+05	4.96E+04	3.05E-06	0.0000E+00
4.00E+00	1.51E-10	3.21E+09	2.82E-10	1.74E-10	1.00E-05	0.0000E+00
5.00E+00	3.83E-11	1.60E+07	3.82E-11	3.82E-11	3.00E-05	0.0000E+00
6.50E+00	1.10E-11	6.41E+06	1.10E-11	1.10E-11	1.00E-04	0.0000E+00
8.00E+00	1.40E-12	1.26E+06	1.40E-12	1.40E-12	5.50E-04	0.0000E+00
10.00E+00	1.87E-13	2.67E+05	1.87E-13	1.87E-13	3.00E-03	0.0000E+00
Total	5.9929E+12	3.5931E+15	3.0618E+13	7.2123E+12	1.70E-02	0.0000E+00
N/A	N/A	N/A	N/A	N/A	1.00E-01	0.0000E+00
N/A	N/A	N/A	N/A	N/A	4.00E-01	1.79E+07
N/A	N/A	N/A	N/A	N/A	9.00E-01	9.16E+07
N/A	N/A	N/A	N/A	N/A	1.40E+00	8.38E+07
N/A	N/A	N/A	N/A	N/A	1.85E+00	6.17E+07
N/A	N/A	N/A	N/A	N/A	3.00E+00	1.09E+08
N/A	N/A	N/A	N/A	N/A	6.43E+00	9.89E+07
N/A	N/A	N/A	N/A	N/A	20.00E+00	8.76E+06
N/A	N/A	N/A	N/A	N/A	Total	4.7166E+08

SOURCE: CRWMS M&O 1999, Attachment VII, BWR.gamma.source and BWR.neutron source files.
NOTE: Initial ^{235}U weight percent of 5.5; average burnup of 75 GWd/MTU; and decay time of 5 years.

Table 9. Gamma and Neutron Sources per Assembly for the Hypothetical Bounding BWR SNF

Gamma Intensity (photons/s)					Neutron Intensity[a] (neutrons/s)	
Upper Energy Boundary (MeV)	Bottom End-Fitting Region[b]	Active Fuel Region[a]	Plenum Region[b]	Top End-Fitting Region[b]	Upper Energy Boundary (MeV)	Active Fuel Region
5.00E-02	3.39E+11	8.13E+14	9.71E+11	3.62E+11	1.00E-08	0.0000E+00
1.00E-01	7.87E+10	2.26E+14	1.85E+11	8.35E+10	3.00E-08	0.0000E+00
2.00E-01	1.11E+11	1.76E+14	1.46E+11	1.12E+11	5.00E-08	0.0000E+00
3.00E-01	1.90E+10	5.06E+13	2.08E+10	1.90E+10	1.00E-07	0.0000E+00
4.00E-01	2.08E+09	3.38E+13	5.97E+09	2.16E+09	2.25E-07	0.0000E+00
6.00E-01	2.51E+10	4.22E+14	7.45E+10	2.51E+10	3.25E-07	0.0000E+00
8.00E-01	7.15E+10	1.59E+15	9.81E+10	7.16E+10	4.00E-07	0.0000E+00
1.00E+00	1.07E+11	1.96E+14	8.24E+10	8.22E+10	8.00E-07	0.0000E+00
1.33E+00	6.68E+12	6.61E+13	3.76E+13	8.08E+12	1.00E-06	0.0000E+00
1.66E+00	1.86E+12	1.86E+13	1.06E+13	2.25E+12	1.13E-06	0.0000E+00
2.00E+00	1.03E+07	3.63E+11	1.03E+07	1.03E+07	1.30E-06	0.0000E+00
2.50E+00	4.40E+07	5.97E+11	2.51E+08	5.34E+07	1.77E-06	0.0000E+00
3.00E+00	6.82E+04	2.55E+10	3.89E+05	8.27E+04	3.05E-06	0.0000E+00
4.00E+00	1.04E-10	3.21E+09	6.79E-10	2.03E-10	1.00E-05	0.0000E+00
5.00E+00	2.64E-11	1.60E+07	2.64E-11	2.64E-11	3.00E-05	0.0000E+00
6.50E+00	7.60E-12	6.41E+06	7.59E-12	7.59E-12	1.00E-04	0.0000E+00
8.00E+00	9.67E-13	1.26E+06	9.66E-13	9.66E-13	5.50E-04	0.0000E+00
10.00E+00	1.29E-13	2.67E+05	1.29E-13	1.29E-13	3.00E-03	0.0000E+00
Total	9.2934E+12	3.5931E+15	4.9784E+13	1.1088E+13	1.70E-02	0.0000E+00
N/A	N/A	N/A	N/A	N/A	1.00E-01	0.0000E+00
N/A	N/A	N/A	N/A	N/A	4.00E-01	1.79E+07
N/A	N/A	N/A	N/A	N/A	9.00E-01	9.16E+07
N/A	N/A	N/A	N/A	N/A	1.40E+00	8.38E+07
N/A	N/A	N/A	N/A	N/A	1.85E+00	6.17E+07
N/A	N/A	N/A	N/A	N/A	3.00E+00	1.09E+08
N/A	N/A	N/A	N/A	N/A	6.43E+00	9.89E+07
N/A	N/A	N/A	N/A	N/A	20.00E+00	8.76E+06
N/A	N/A	N/A	N/A	N/A	Total	4.7166E+08

SOURCE: CRWMS M&O 1999, Attachment VII, BWR.gamma.source and BWR.neutron source files.
NOTE: [a] Initial ^{235}U weight percent of 5.5; average burnup of 75 GWd/MTU; and decay time of 5 years.
[b] Initial ^{235}U weight percent of 0.711; average burnup of 75 GWd/MTU; and decay time of 5 years.

Table 10. Gamma and Neutron Sources per Assembly for the Average BWR SNF

Gamma Intensity (photons/s)					Neutron Intensity (neutrons/s)	
Upper Energy Boundary (MeV)	Bottom-End Fitting	Active Fuel Region	Plenum Region	Top-End Fitting	Upper Energy Boundary (MeV)	Active Fuel Region
5.00E-02	4.34E+10	2.48E+14	7.21E+10	4.48E+10	1.00E-08	0.0000E+00
1.00E-01	5.79E+09	7.24E+13	1.12E+10	6.07E+09	3.00E-08	0.0000E+00
2.00E-01	2.83E+10	4.71E+13	2.96E+10	2.83E+10	5.00E-08	0.0000E+00
3.00E-01	5.40E+09	1.45E+13	5.47E+09	5.40E+09	1.00E-07	0.0000E+00
4.00E-01	4.40E+08	9.92E+12	5.42E+08	4.45E+08	2.25E-07	0.0000E+00
6.00E-01	6.32E+09	7.95E+12	6.70E+09	6.32E+09	3.25E-07	0.0000E+00
8.00E-01	2.13E+10	4.47E+14	2.19E+10	2.14E+10	4.00E-07	0.0000E+00
1.00E+00	2.24E+10	3.93E+12	2.29E+10	2.25E+10	8.00E-07	0.0000E+00
1.33E+00	3.52E+11	6.31E+12	1.92E+12	4.35E+11	1.00E-06	0.0000E+00
1.66E+00	9.01E+10	7.20E+11	5.32E+11	1.13E+11	1.13E-06	0.0000E+00
2.00E+00	3.43E+06	2.54E+10	3.43E+06	3.43E+06	1.30E-06	0.0000E+00
2.50E+00	2.09E+06	1.30E+09	1.26E+07	2.64E+06	1.77E-06	0.0000E+00
3.00E+00	3.24E+03	6.66E+07	1.95E+04	4.10E+03	3.05E-06	0.0000E+00
4.00E+00	2.00E-10	4.21E+06	2.27E-10	2.05E-10	1.00E-05	0.0000E+00
5.00E+00	5.06E-11	1.41E+06	5.06E-11	5.06E-11	3.00E-05	0.0000E+00
6.50E+00	1.46E-11	5.67E+05	1.46E-11	1.46E-11	1.00E-04	0.0000E+00
8.00E+00	1.85E-12	1.11E+05	1.85E-12	1.85E-12	5.50E-04	0.0000E+00
10.00E+00	2.47E-13	2.36E+04	2.47E-13	2.47E-13	3.00E-03	0.0000E+00
Total	5.7546E+11	8.5786E+14	2.6224E+12	6.8324E+11	1.70E-02	0.0000E+00
N/A	N/A	N/A	N/A	N/A	1.00E-01	0.0000E+00
N/A	N/A	N/A	N/A	N/A	4.00E-01	1.58E+06
N/A	N/A	N/A	N/A	N/A	9.00E-01	8.06E+06
N/A	N/A	N/A	N/A	N/A	1.40E+00	7.42E+06
N/A	N/A	N/A	N/A	N/A	1.85E+00	5.54E+06
N/A	N/A	N/A	N/A	N/A	3.00E+00	1.00E+07
N/A	N/A	N/A	N/A	N/A	6.43E+00	8.86E+06
N/A	N/A	N/A	N/A	N/A	20.00E+00	7.68E+05
N/A	N/A	N/A	N/A	N/A	Total	4.2228E+07

SOURCE: CRWMS M&O 1999, Attachment VII, BWR.gamma.source and BWR.neutron source files.
NOTE: Initial ^{235}U weight percent of 3.5; average burnup of 40 GWd/MTU; and decay time of 22 years (see Assumption 3.3).

5.2 DESCRIPTION OF CALCULATIONS

5.2.1 Selection of Source Terms

This calculation provides surface dose rates for the 44-BWR WP containing SNF with the following initial enrichment, burnup, and decay characteristics:

- 5.5-wt% initial ^{235}U enrichment, 75.0-GWd/MTU burnup, and 5-year decay time. Surface dose rates for the WP without the basket assembly inside (see Figure 3) are also calculated.

- 5.5-wt% initial ^{235}U enrichment, 75.0-GWd/MTU burnup, and 5-year decay time for the active fuel region, and 0.711-wt% initial enrichment, 75.0-GWd/MTU burnup, and 5-year decay time for the hardware regions. Since for a given burnup the activation of the hardware regions increases with decreasing initial fuel enrichment, this hypothetical SNF provides upper limits for dose rates due to the hardware regions.

- 3.5-wt% initial ^{235}U enrichment, 40-GWd/MTU burnup, and 22-year decay time. The SNF with these characteristics provides conservative dose rate estimations for the average BWR SNF (see Assumption 3.3). Surface dose rates for a WP containing average SNF are useful for estimating the radiation exposure of the surrounding equipment.

5.2.2 Geometric Representation of the Source Regions

The BWR SNF assemblies contain four distinct source regions: a bottom end-fitting region, an active fuel region, a plenum region, and a top end-fitting region. Each assembly region is homogenized inside its volume (see Figures 1 through 3), resulting in a uniform distribution of the region contents and radiation source inside each region volume (See Assumption 3.2). The study of source geometry effect (CRWMS M&O 1998b) on the surface dose rates for a WP containing 21 PWR SNF assemblies has shown that the detailed representation of the SNF assemblies and the assemblies homogenized inside their transverse dimensions give essentially the same surface dose rates. The MCNP input file specifies these four gamma sources through source distribution numbers that are dependent on geometric cells. Attachment IV provides the fraction of gamma sampling in each assembly region, required by the source probability (sp) card, and the total gamma source intensity, required by the tally multiplier (fm) card.

5.2.3 Material Specification in the MCNP Input

MCNP requires element/isotope compositions of the materials either as weight fractions or atomic densities. The material compositions of the assembly regions are entered as atomic densities, in atoms/b·cm, in the MCNP input. Atomic densities (AD) of the material compositions in each assembly region are calculated according to the following equation (Harmon et al. 1994, Appendix B):

$$AD\ (\text{atoms/b}\cdot\text{cm}) = \frac{\text{mass}_{\text{isotope}}(\text{g}) * N_A(\text{atoms/mole})}{10^{24}(\text{b/cm}^2) * \text{volume}_{\text{region}}(\text{cm}^3) * \text{atomic mass}_{\text{isotope}}(\text{g/mole})} \quad \text{(Eq. 1)}$$

In the above equation, N_A is the Avogadro constant, which has a value of 6.0221367E+23 atoms per mole (Parrington et al. 1996, page 59). The element or isotope atomic masses are provided in Parrington et al. 1996.

The isotopic composition, in weight percent, for commercially available enriched uranium is calculated according to the following equations (Bowman et al. 1995, page 20):

$$\text{wt\% } ^{234}U = 0.007731(\text{wt\% } ^{235}U)^{1.0837}$$

$$\text{wt\% } ^{236}U = 0.0046(\text{wt\% } ^{235}U) \quad \text{(Eq. 2)}$$

$$\text{wt\% } ^{238}U = 100 - (\text{wt\% } ^{234}U) - (\text{wt\% } ^{235}U) - (\text{wt\% } ^{236}U)$$

The calculation of the atomic densities for each assembly region is presented in Attachment III.

5.2.4 Calculation of the Total Dose Rate

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 the group flux and the flux-to-dose rate conversion factor for the energy group (Briesmeister 1997, pages H-5 and H-6).

Since MCNP performs the photon and neutron transport in two separate runs, the total dose rate is the sum of gamma and neutron dose rates. The estimated relative error of the total dose rate is derived from the estimated variance of the total dose rate. The estimated variance of the total dose rate, S^2_{total}, is the sum of the estimated variances of the individual dose rates, S_i^2. The estimated relative error (Briesmeister 1997, p. 2-93) is given by:

$$DR_{total} = DR_{gamma} + DR_{neutron} \quad \text{(Eq. 3)}$$

$$S^2_{total} = S^2_{gamma} + S^2_{neutron} \quad \text{(Eq. 4)}$$

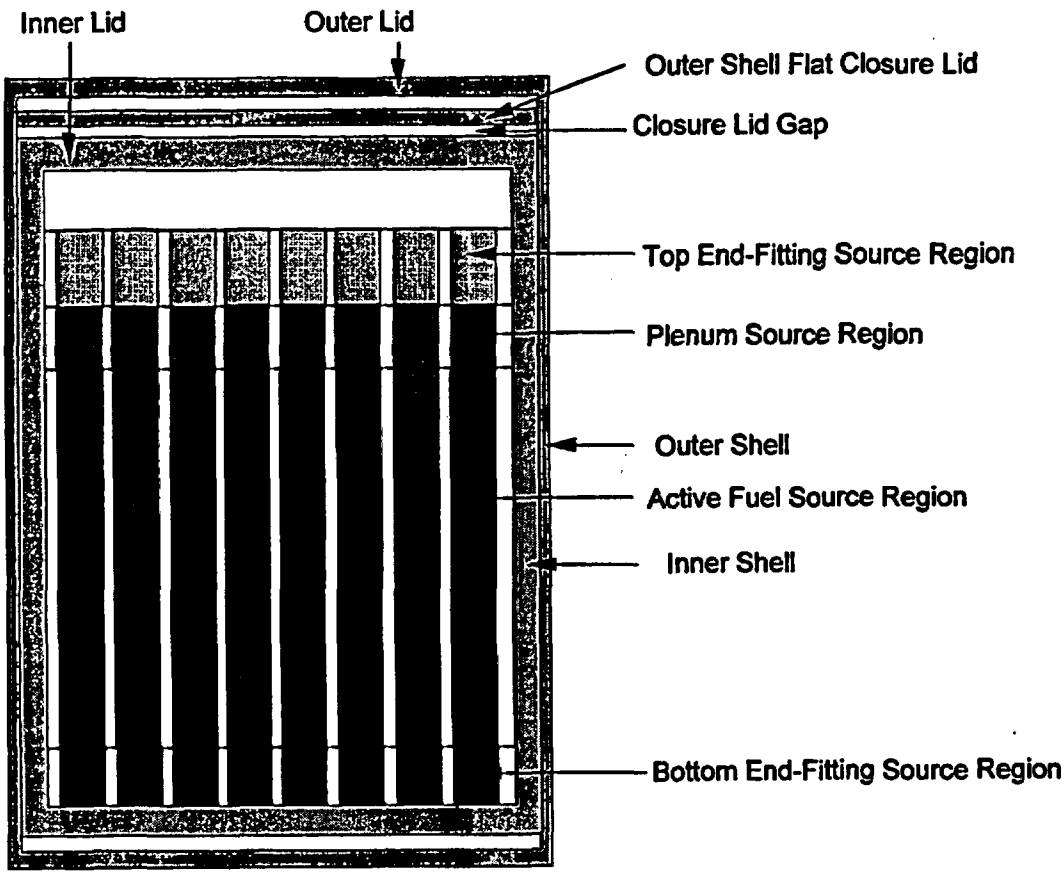
$$R = \frac{\sqrt{S^2_{total}}}{DR_{total}} \quad \text{(Eq. 5)}$$

where

DR = estimated dose rate (rem/h)
S^2 = estimated variance $(rem/h)^2$
R = estimated relative error

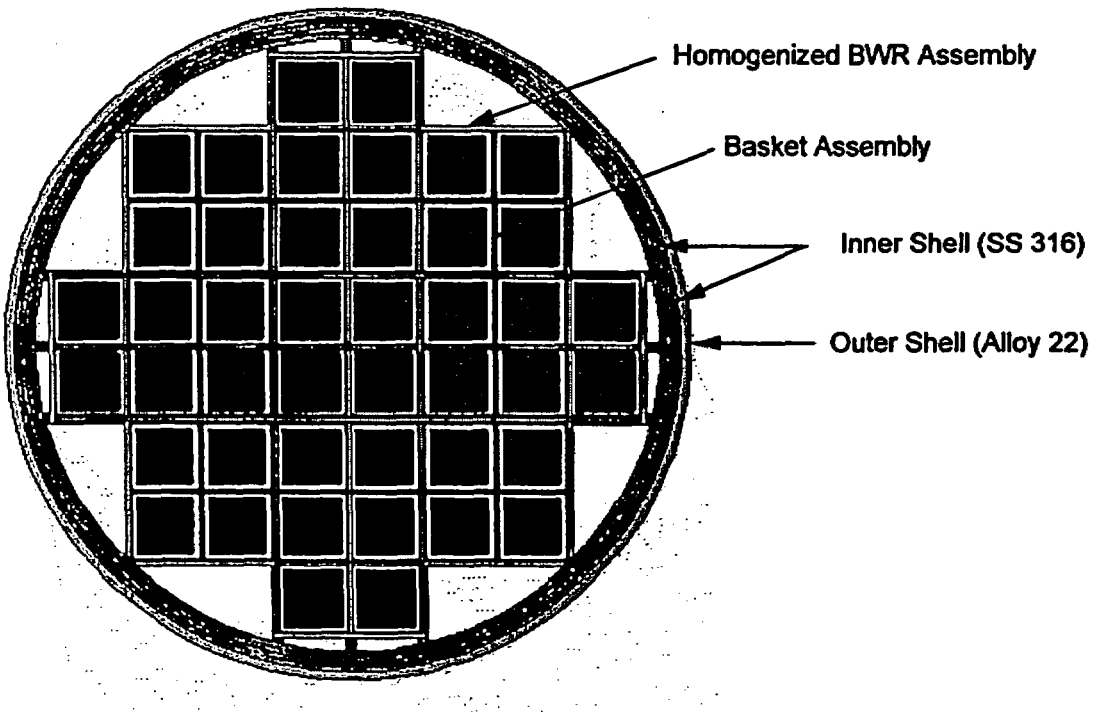
5.2.5 Segments Selected for Surface Dose Rate Calculations

Surface dose rates are calculated for the radial and axial directions of the WP. For each direction, dose rates are determined for segments (see Figures 4, 5, and 6) of 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. Segments 1 to 9 are axial segments that subdivide the five radial surfaces. Segment 1, 23.144-cm tall, corresponds to the void region above fuel assemblies. Segment 2, 22.2885-cm tall, corresponds to the top end-fitting region. Segment 3, 28.5496-cm tall, corresponds to the plenum region. Five segments, Segments 4 to 8, each 73.152-cm tall, are equal segments of the active fuel region. The last axial segment, Segment 9, 18.7579-cm tall, corresponds to the bottom end-fitting region. The top surface of the WP cavity has six segments, Segments 14 to 19, as shown in Figure 5. Figure 6 shows the four segments, Segments 14, 20, 21, and 22, of the bottom surface of the upper outer lid. The bottom surface of the WP cavity, and the bottom surface of the lower inner lid are divided in two segments by a 20-cm radius. The WP top and bottom surfaces and the top and bottom surfaces 1 m from the WP have three segments: Segments 10 to 12. The top and bottom surfaces 2 m from the WP also have three segments: Segments 10, 11, and 13.



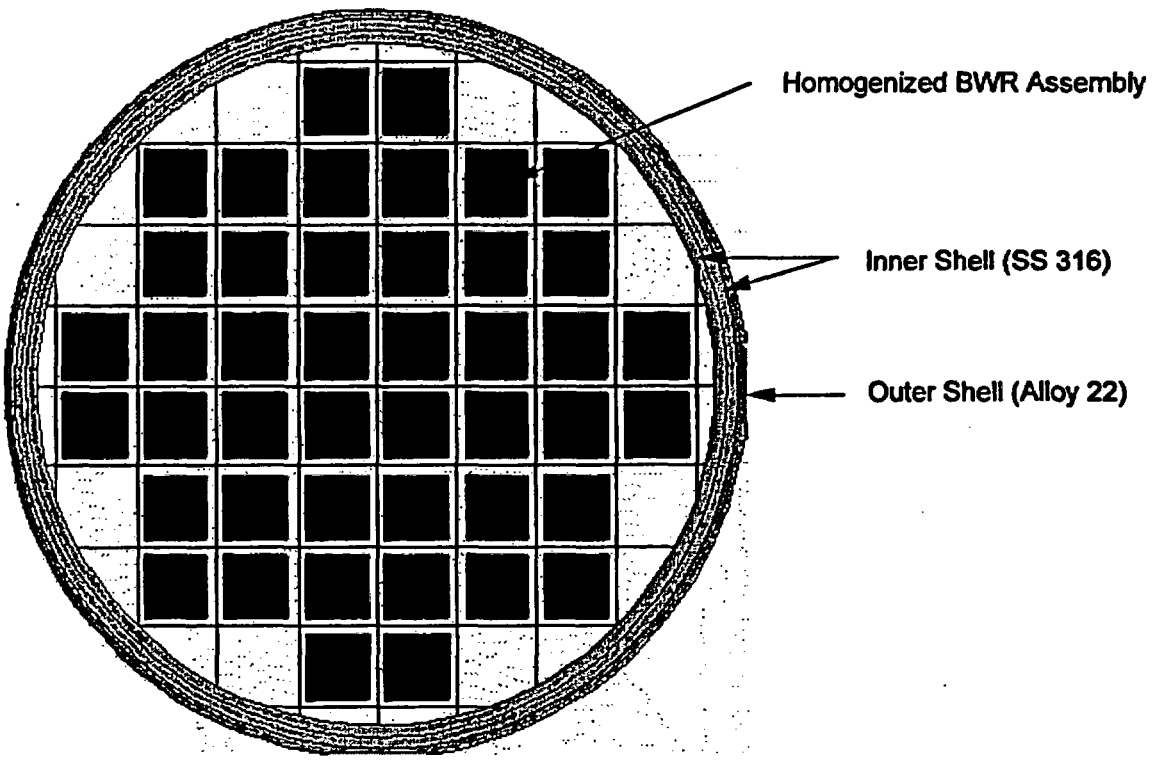
NOTE: Drawing not to scale.

Figure 1. Source Region Representation in MCNP Calculations



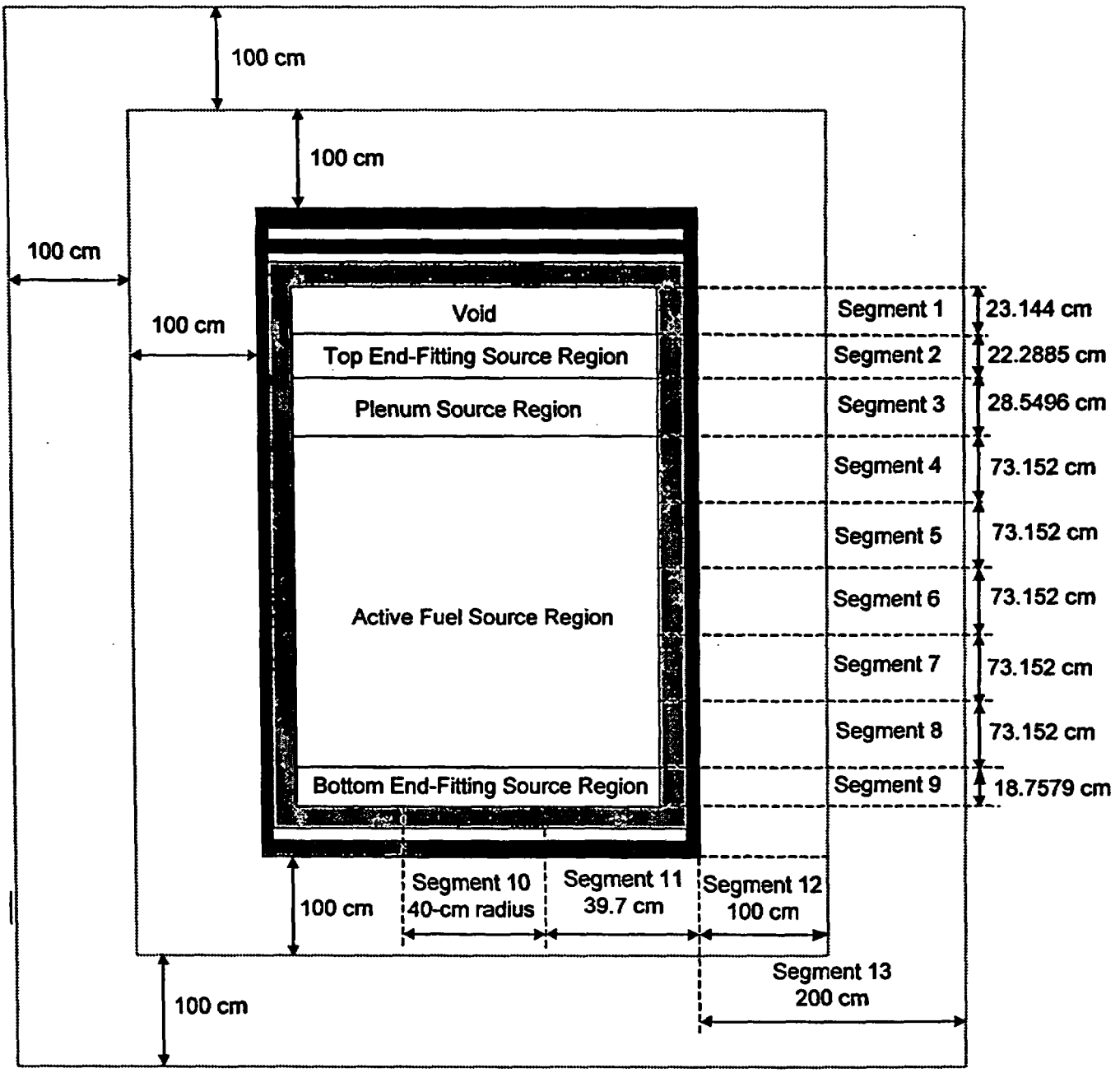
NOTE: The extra-cell shown for the inner shell has been created for geometric importance sampling in MCNP.

Figure 2. Lateral View of WP with Basket Assembly for MCNP Calculations



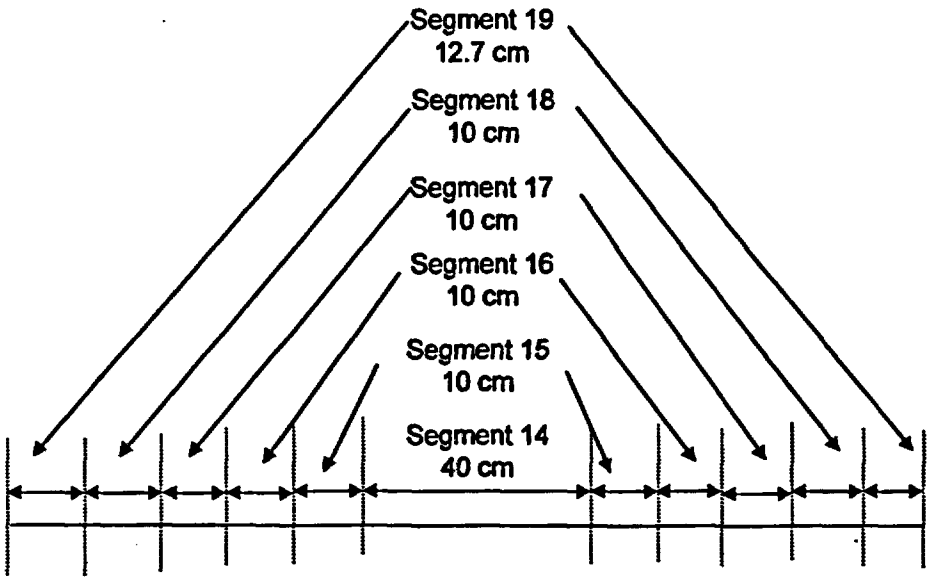
NOTE: The extra-cell shown for the inner shell has been created for geometric importance sampling in MCNP.

Figure 3. Lateral View of WP Without Basket Assembly for MCNP Calculations



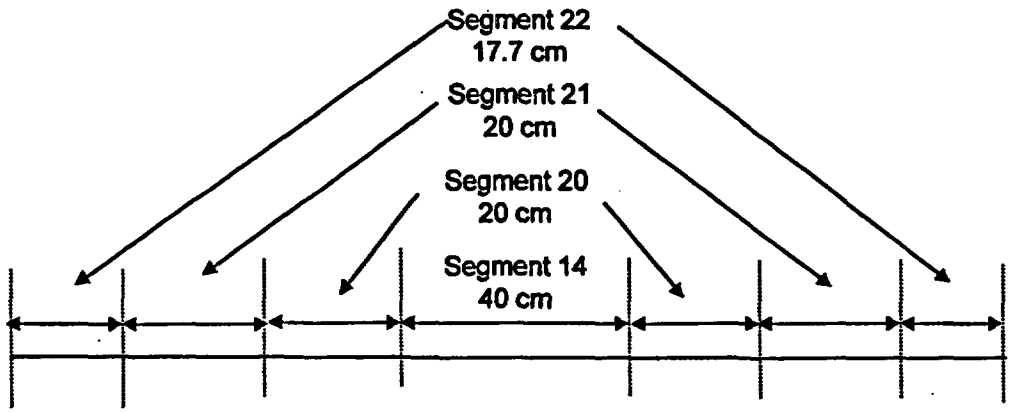
NOTES: [a] Drawing not to scale.
[b] The segments used in dose calculations for the top surface of the WP cavity and bottom surface of the outer top lid are presented in Figures 5 and 6.

Figure 4. Surface Segments Used for Dose Rate Calculations



NOTE: Drawing not to scale.

Figure 5. Segments of the Top Surface of the WP Cavity Used in Dose Rate Calculations



NOTE: Drawing not to scale.

Figure 6. Segments of the Bottom Surface of the Top Outer Lid Used in Dose Rate Calculations

6. RESULTS

The tables included in this section present the gamma and neutron surface dose rates calculated by MCNP, the total surface dose rates calculated using Equation 3, and its associated relative error calculated using Equations 4 and 5. The results presented in Tables 11 through 34 are based on unqualified information (radiation source terms and element compositions of the hardware regions) that requires confirmation.

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 technical product input information quality may be confirmed by review of the DIRS database.

6.1 BOUNDING SOURCE FOR THE ACTIVE FUEL REGION

This section presents surface dose rates for the WP containing BWR SNF with the following characteristics: 5.5-wt% initial ^{235}U, 75.0-GWd/MTU burnup, and a 5-year decay time. The source terms for the BWR SNF assembly with these burnup and decay characteristics generate conservative (higher) surface dose rates only for the active fuel region.

6.1.1 Basket Assembly Inside the WP

Tables 11 through 16 present surface dose rates averaged over segments of the radial and axial surfaces of the 44-BWR WP (see Figures 4, 5, and 6 for segment locations). The WP contains the basket assembly inside.

Table 11. Dose Rates on the Inner Surface of the Inner Shell: Bounding BWR SNF

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	5.6240E+03	0.0216	5.6550E+00	0.0108	5.6297E+03	0.0216
Segment 2	1.3850E+04	0.0127	9.0073E+00	0.0089	1.3859E+04	0.0127
Segment 3	2.8091E+04	0.0076	1.7809E+01	0.0059	2.8109E+04	0.0076
Segment 4	3.3824E+04	0.0040	4.1334E+01	0.0028	3.3866E+04	0.0040
Segment 5	3.6222E+04	0.0039	5.1651E+01	0.0024	3.6273E+04	0.0039
Segment 6	3.4280E+04	0.0040	5.2248E+01	0.0024	3.4332E+04	0.0040
Segment 7	3.4250E+04	0.0040	5.1225E+01	0.0024	3.4301E+04	0.0040
Segment 8	3.4499E+04	0.0040	4.2353E+01	0.0027	3.4541E+04	0.0040
Segment 9	1.3655E+04	0.0129	2.1052E+01	0.0064	1.3676E+04	0.0129

Table 12. Dose Rates on the Inner Surface of the Outer Shell: Bounding BWR SNF

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	4.7359E+02	0.0285	2.5325E+00	0.0101	4.7613E+02	0.0283
Segment 2	1.3867E+03	0.0173	4.1106E+00	0.0082	1.3908E+03	0.0172
Segment 3	2.8038E+03	0.0108	8.5294E+00	0.0055	2.8123E+03	0.0108
Segment 4	2.3870E+03	0.0061	2.0281E+01	0.0025	2.4073E+03	0.0060
Segment 5	2.4463E+03	0.0059	2.5212E+01	0.0023	2.4715E+03	0.0058
Segment 6	2.3220E+03	0.0060	2.5409E+01	0.0022	2.3474E+03	0.0059
Segment 7	2.3566E+03	0.0060	2.5092E+01	0.0023	2.3817E+03	0.0059
Segment 8	2.3943E+03	0.0060	2.0747E+01	0.0025	2.4151E+03	0.0059
Segment 9	1.0196E+03	0.0198	1.0088E+01	0.0060	1.0297E+03	0.0196

Table 13. Dose Rates on the WP Outer Radial Surface: Bounding BWR SNF

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	1.5803E+02	0.0322	1.0552E+00	0.0104	1.5908E+02	0.0320
Segment 2	4.7215E+02	0.0193	1.7524E+00	0.0082	4.7391E+02	0.0192
Segment 3	9.3639E+02	0.0124	3.7641E+00	0.0054	9.4015E+02	0.0124
Segment 4	6.6595E+02	0.0074	9.0982E+00	0.0025	6.7505E+02	0.0073
Segment 5	6.6738E+02	0.0072	1.1251E+01	0.0022	6.7863E+02	0.0071
Segment 6	6.3107E+02	0.0074	1.1320E+01	0.0022	6.4239E+02	0.0073
Segment 7	6.4482E+02	0.0073	1.1173E+01	0.0022	6.5599E+02	0.0072
Segment 8	6.5222E+02	0.0073	9.3195E+00	0.0025	6.6154E+02	0.0072
Segment 9	3.0889E+02	0.0239	4.4262E+00	0.0059	3.1332E+02	0.0236

Table 14. Dose Rates on a Radial Surface 1 m from the WP: Bounding BWR SNF

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	1.1905E+02	0.0136	9.5257E-01	0.0038	1.2001E+02	0.0135
Segment 2	1.5726E+02	0.0119	1.2358E+00	0.0034	1.5850E+02	0.0118
Segment 3	1.9705E+02	0.0098	1.6124E+00	0.0027	1.9866E+02	0.0097
Segment 4	2.3312E+02	0.0061	2.3553E+00	0.0017	2.3548E+02	0.0060
Segment 5	2.3958E+02	0.0055	3.0799E+00	0.0015	2.4265E+02	0.0054
Segment 6	2.3687E+02	0.0054	3.2863E+00	0.0014	2.4016E+02	0.0053
Segment 7	2.3145E+02	0.0056	3.0768E+00	0.0015	2.3452E+02	0.0055
Segment 8	1.8594E+02	0.0064	2.3268E+00	0.0017	1.8827E+02	0.0063
Segment 9	1.2249E+02	0.0125	1.6262E+00	0.0032	1.2411E+02	0.0123

Table 15. Dose Rates on a Radial Surface 2 m from the WP: Bounding BWR SNF

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	7.5798E+01	0.0117	7.4946E-01	0.0032	7.6548E+01	0.0116
Segment 2	8.9118E+01	0.0114	8.5887E-01	0.0030	8.9977E+01	0.0113
Segment 3	1.0253E+02	0.0092	9.9650E-01	0.0025	1.0353E+02	0.0091
Segment 4	1.2334E+02	0.0059	1.2520E+00	0.0016	1.2459E+02	0.0058
Segment 5	1.3880E+02	0.0053	1.5344E+00	0.0014	1.4033E+02	0.0052
Segment 6	1.3821E+02	0.0052	1.6334E+00	0.0014	1.3984E+02	0.0051
Segment 7	1.2746E+02	0.0054	1.5300E+00	0.0014	1.2899E+02	0.0053
Segment 8	1.0089E+02	0.0061	1.2345E+00	0.0016	1.0212E+02	0.0060
Segment 9	7.7351E+01	0.0117	9.9713E-01	0.0030	7.8348E+01	0.0116

Table 16. Dose Rates on the Axial Surfaces: Bounding BWR SNF

Surface	Segment	Gamma		Neutron		Total	
		Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Top of the WP cavity (See Figure 5)	Segment 14	1.1941E+04	0.0335	7.9158E+00	0.0205	1.1949E+04	0.0335
	Segment 15	1.1639E+04	0.0306	7.6218E+00	0.0181	1.1647E+04	0.0306
	Segment 16	1.0692E+04	0.0274	7.0729E+00	0.0159	1.0699E+04	0.0274
	Segment 17	9.4588E+03	0.0248	6.6457E+00	0.0143	9.4655E+03	0.0248
	Segment 18	7.7933E+03	0.0259	6.0892E+00	0.0137	7.7994E+03	0.0259
	Segment 19	4.7796E+03	0.0280	5.2235E+00	0.0127	4.7848E+03	0.0280
Bottom of the outer upper lid (See Figure 6)	Segment 14	1.0574E+03	0.0463	3.7255E+00	0.0191	1.0611E+03	0.0461
	Segment 20	9.3543E+02	0.0291	3.4376E+00	0.0123	9.3887E+02	0.0290
	Segment 21	7.3084E+02	0.0260	2.9058E+00	0.0104	7.3374E+02	0.0259
	Segment 22	3.2909E+02	0.0336	1.9195E+00	0.0113	3.3100E+02	0.0334
Top of WP (See Figure 4)	Segment 10	2.9987E+02	0.0309	1.4042E+00	0.0126	3.0127E+02	0.0308
	Segment 11	1.4838E+02	0.0260	8.9147E-01	0.0094	1.4927E+02	0.0258
	Segment 12	6.5519E+01	0.0157	5.4811E-01	0.0039	6.6067E+01	0.0156
1 m from the WP top (See Figure 4)	WP top surface	8.0962E+01	0.0249	2.5339E-01	0.0095	8.1216E+01	0.0248
	Segment 13	2.1402E+01	0.0116	2.4668E-01	0.0028	2.1649E+01	0.0115
2 m from the WP top (See Figure 4)	WP top surface	3.9909E+01	0.0316	1.0180E-01	0.0125	4.0010E+01	0.0315
	Segment 13	1.3474E+01	0.0159	1.2343E-01	0.0036	1.3598E+01	0.0158
Bottom of WP cavity (See Figure 4)	Segment 10	2.5455E+04	0.0170	4.7140E+01	0.0059	2.5502E+04	0.0170
	# Segment 10[a]	1.4324E+04	0.0151	1.5904E+01	0.0060	1.4340E+04	0.0151
Bottom of the inner lower lid (See Figure 4)	Segment 10	3.3287E+02	0.0328	1.1023E+01	0.0067	3.4389E+02	0.0317
	# Segment 10[b]	1.9752E+02	0.0267	6.5085E+00	0.0054	2.0403E+02	0.0258
Bottom of WP (See Figures 4 and 6)	Segment 10	9.2746E+01	0.0416	4.4811E+00	0.0073	9.7227E+01	0.0397
	Segment 11	4.8825E+01	0.0338	2.4348E+00	0.0058	5.1260E+01	0.0322
	Segment 12	6.5158E+01	0.0140	1.2149E+00	0.0031	6.6373E+01	0.0137
Surface 1 m from the WP bottom (See Figure 4)	WP bottom surface	2.4801E+01	0.0332	7.3213E-01	0.0057	2.5533E+01	0.0322
	Segment 13	1.5042E+01	0.0103	4.4140E-01	0.0024	1.5483E+01	0.0100
Surface 2 m from the WP bottom (See Figure 4)	WP bottom surface	1.2020E+01	0.0433	2.8720E-01	0.0073	1.2307E+01	0.0423
	Segment 13	6.5715E+00	0.0150	2.3237E-01	0.0030	6.8039E+00	0.0145

NOTE: [a] The segment outside Segment 10 and delimited by the radius of the cavity.
[b] The segment outside Segment 10 and delimited by the inner surface of the outer shell.

6.1.2 No Basket Assembly Inside the WP

Tables 17 through 22 present surface dose rates averaged over segments of the radial and axial surfaces of the 44-BWR WP (see Figures 4, 5, and 6 for segment locations). The WP basket assembly is neglected.

Table 17. Dose Rates on the Inner Surface of the Inner Shell: Bounding BWR SNF, No Basket

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	3.1480E+04	0.0096	1.4157E+01	0.0072	3.1494E+04	0.0096
Segment 2	5.0318E+04	0.0071	1.8160E+01	0.0064	5.0337E+04	0.0071
Segment 3	7.8947E+04	0.0047	2.8022E+01	0.0047	7.8975E+04	0.0047
Segment 4	9.6089E+04	0.0027	5.6818E+01	0.0024	9.6146E+04	0.0027
Segment 5	9.9138E+04	0.0027	7.2500E+01	0.0021	9.9211E+04	0.0027
Segment 6	9.8720E+04	0.0027	7.4863E+01	0.0020	9.8795E+04	0.0027
Segment 7	9.8566E+04	0.0027	7.2906E+01	0.0021	9.8639E+04	0.0027
Segment 8	9.0635E+04	0.0027	5.8620E+01	0.0024	9.0694E+04	0.0027
Segment 9	4.5210E+04	0.0080	3.4068E+01	0.0050	4.5244E+04	0.0080

Table 18. Dose Rates on the Inner Surface of the Outer Shell: Bounding BWR SNF, No Basket

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	2.6917E+03	0.0123	5.8050E+00	0.0070	2.6975E+03	0.0123
Segment 2	5.1091E+03	0.0092	7.8819E+00	0.0063	5.1170E+03	0.0092
Segment 3	8.0951E+03	0.0064	1.2804E+01	0.0047	8.1079E+03	0.0064
Segment 4	6.9446E+03	0.0036	2.7138E+01	0.0023	6.9717E+03	0.0036
Segment 5	6.7154E+03	0.0036	3.4289E+01	0.0020	6.7497E+03	0.0036
Segment 6	6.6901E+03	0.0036	3.5305E+01	0.0020	6.7254E+03	0.0036
Segment 7	6.7078E+03	0.0036	3.4519E+01	0.0020	6.7423E+03	0.0036
Segment 8	6.4404E+03	0.0037	2.7908E+01	0.0023	6.4683E+03	0.0037
Segment 9	3.1743E+03	0.0112	1.5587E+01	0.0050	3.1898E+03	0.0111

Table 19. Dose Rates on the WP Outer Radial Surface: Bounding BWR SNF, No Basket

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	9.1188E+02	0.0138	2.5740E+00	0.0069	9.1445E+02	0.0138
Segment 2	1.7887E+03	0.0104	3.5034E+00	0.0062	1.7922E+03	0.0104
Segment 3	2.7535E+03	0.0073	5.7800E+00	0.0045	2.7593E+03	0.0073
Segment 4	1.9644E+03	0.0043	1.2466E+01	0.0022	1.9768E+03	0.0043
Segment 5	1.8487E+03	0.0043	1.5665E+01	0.0019	1.8643E+03	0.0043
Segment 6	1.8426E+03	0.0043	1.6069E+01	0.0019	1.8587E+03	0.0043
Segment 7	1.8560E+03	0.0043	1.5754E+01	0.0019	1.8718E+03	0.0043
Segment 8	1.7902E+03	0.0044	1.2779E+01	0.0022	1.8030E+03	0.0044
Segment 9	9.5855E+02	0.0136	6.9907E+00	0.0048	9.6554E+02	0.0135

Table 20. Dose Rates on a Radial Surface 1 m from the WP: Bounding BWR SNF, No Basket

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	4.0494E+02	0.0076	1.4460E+00	0.0033	4.0638E+02	0.0076
Segment 2	5.0330E+02	0.0068	1.8384E+00	0.0029	5.0514E+02	0.0068
Segment 3	5.9852E+02	0.0057	2.3276E+00	0.0024	6.0084E+02	0.0057
Segment 4	6.7847E+02	0.0036	3.3207E+00	0.0015	6.8179E+02	0.0036
Segment 5	6.8580E+02	0.0032	4.3135E+00	0.0013	6.9011E+02	0.0032
Segment 6	6.7916E+02	0.0032	4.6179E+00	0.0012	6.8377E+02	0.0032
Segment 7	6.4836E+02	0.0033	4.3121E+00	0.0013	6.5267E+02	0.0033
Segment 8	5.1838E+02	0.0038	3.2747E+00	0.0015	5.2165E+02	0.0038
Segment 9	3.5083E+02	0.0074	2.3164E+00	0.0028	3.5315E+02	0.0074

Table 21. Dose Rates on a Radial Surface 2 m from the WP: Bounding BWR SNF, No Basket

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	2.4375E+02	0.0069	1.0850E+00	0.0028	2.4484E+02	0.0069
Segment 2	2.7508E+02	0.0064	1.2411E+00	0.0026	2.7632E+02	0.0064
Segment 3	3.0931E+02	0.0055	1.4233E+00	0.0022	3.1073E+02	0.0055
Segment 4	3.6049E+02	0.0035	1.7716E+00	0.0014	3.6226E+02	0.0035
Segment 5	3.9499E+02	0.0031	2.1569E+00	0.0013	3.9714E+02	0.0031
Segment 6	3.9212E+02	0.0031	2.2952E+00	0.0012	3.9441E+02	0.0031
Segment 7	3.5767E+02	0.0032	2.1450E+00	0.0013	3.5981E+02	0.0032
Segment 8	2.8238E+02	0.0036	1.7383E+00	0.0014	2.8412E+02	0.0036
Segment 9	2.1942E+02	0.0068	1.4073E+00	0.0027	2.2083E+02	0.0068

Table 22. Dose Rates on the Axial Surfaces: Bounding BWR SNF, No Basket

Surface	Segment	Gamma		Neutron		Total	
		Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Top of the WP cavity (See Figure 5)	Segment 14	4.4593E+04	0.0171	1.7126E+01	0.0131	4.4610E+04	0.0171
	Segment 15	4.2697E+04	0.0158	1.6191E+01	0.0118	4.2713E+04	0.0158
	Segment 16	4.0012E+04	0.0139	1.5664E+01	0.0101	4.0027E+04	0.0139
	Segment 17	3.6576E+04	0.0129	1.4704E+01	0.0093	3.6591E+04	0.0129
	Segment 18	3.1287E+04	0.0127	1.4182E+01	0.0087	3.1301E+04	0.0127
	Segment 19	2.8504E+04	0.0111	1.3208E+01	0.0076	2.8517E+04	0.0111
Bottom of the outer upper lid (See Figure 6)	Segment 14	3.8447E+03	0.0251	8.8869E+00	0.0136	3.8536E+03	0.0250
	Segment 20	3.2891E+03	0.0154	7.9669E+00	0.0085	3.2971E+03	0.0154
	Segment 21	2.5854E+03	0.0135	6.9208E+00	0.0071	2.5923E+03	0.0135
	Segment 22	1.7198E+03	0.0147	4.8660E+00	0.0075	1.7247E+03	0.0147
Top of WP (See Figure 4)	Segment 10	1.0372E+03	0.0164	3.5115E+00	0.0086	1.0407E+03	0.0163
	Segment 11	5.9798E+02	0.0126	2.3737E+00	0.0061	6.0036E+02	0.0126
	Segment 12	3.0061E+02	0.0086	9.7627E-01	0.0035	3.0159E+02	0.0086
1 m from the WP top (See Figure 4)	WP top surface	2.6105E+02	0.0128	6.5999E-01	0.0062	2.6171E+02	0.0128
	Segment 13	8.6123E+01	0.0063	4.2886E-01	0.0025	8.6552E+01	0.0063
2 m from the WP top (See Figure 4)	WP top surface	1.1867E+02	0.0163	2.6820E-01	0.0082	1.1894E+02	0.0163
	Segment 13	5.2550E+01	0.0083	2.2945E-01	0.0031	5.2780E+01	0.0083
Bottom of WP cavity (See Figure 4)	Segment 10	6.5197E+04	0.0099	7.8194E+01	0.0044	6.5276E+04	0.0099
	# Segment 10[a]	3.5487E+04	0.0088	2.0883E+01	0.0047	3.5508E+04	0.0088
Bottom of the inner lower lid (See Figure 4)	Segment 10	7.0515E+02	0.0221	1.5824E+01	0.0057	7.2097E+02	0.0216
	# Segment 10[b]	4.4217E+02	0.0164	1.0178E+01	0.0044	4.5235E+02	0.0160
Bottom of WP (See Figures 4 and 6)	Segment 10	1.7263E+02	0.0288	6.6265E+00	0.0062	1.7925E+02	0.0277
	Segment 11	9.9993E+01	0.0221	3.9351E+00	0.0047	1.0393E+02	0.0213
	Segment 12	2.0292E+02	0.0081	1.8109E+00	0.0027	2.0473E+02	0.0080
Surface 1 m from the WP bottom (See Figure 4)	WP bottom surface	4.6774E+01	0.0224	1.1305E+00	0.0047	4.7905E+01	0.0219
	Segment 13	4.3144E+01	0.0060	6.5394E-01	0.0021	4.3798E+01	0.0059
Surface 2 m from the WP bottom (See Figure 4)	WP bottom surface	2.1485E+01	0.0292	4.4411E-01	0.0061	2.1929E+01	0.0286
	Segment 13	1.7065E+01	0.0085	3.4864E-01	0.0026	1.7413E+01	0.0083

NOTE: [a] The segment outside Segment 10 and delimited by the radius of the cavity.
[b] The segment outside Segment 10 and delimited by the inner surface of the outer shell.

6.2 HYPOTHETICAL BOUNDING SOURCE

Tables 23 through 28 present dose rates averaged over segments of the WP radial and axial surfaces for a hypothetical BWR SNF (see Figures 4, 5, and 6 for segment locations). The source terms have the following characteristics: 5.5-wt% initial ^{235}U, 75.0-GWd/MTU burnup, and a 5-year decay time for the active fuel, and 0.711-wt% initial ^{235}U, 75.0-GWd/MTU burnup, and a 5-year decay time for the hardware regions. These source terms generate conservative (higher) surface dose rates for the hardware regions. The WP contains the basket assembly inside.

Table 23. Dose Rates on the Inner Surface of the Inner Shell: Hypothetical BWR SNF

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	8.9552E+03	0.0171	5.6550E+00	0.0108	8.9609E+03	0.0171
Segment 2	2.1824E+04	0.0101	9.0073E+00	0.0089	2.1833E+04	0.0101
Segment 3	4.0864E+04	0.0062	1.7809E+01	0.0059	4.0882E+04	0.0062
Segment 4	3.5136E+04	0.0040	4.1334E+01	0.0028	3.5177E+04	0.0040
Segment 5	3.6224E+04	0.0039	5.1651E+01	0.0024	3.6276E+04	0.0039
Segment 6	3.4293E+04	0.0040	5.2248E+01	0.0024	3.4345E+04	0.0040
Segment 7	3.4270E+04	0.0040	5.1225E+01	0.0024	3.4322E+04	0.0040
Segment 8	3.4770E+04	0.0040	4.2353E+01	0.0027	3.4812E+04	0.0040
Segment 9	1.6180E+04	0.0119	2.1052E+01	0.0064	1.6201E+04	0.0119

Table 24. Dose Rates on the Inner Surface of the Outer Shell: Hypothetical BWR SNF

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	7.5592E+02	0.0225	2.5325E+00	0.0101	7.5845E+02	0.0224
Segment 2	2.2845E+03	0.0136	4.1106E+00	0.0082	2.2886E+03	0.0136
Segment 3	4.2884E+03	0.0088	8.5294E+00	0.0055	4.2969E+03	0.0088
Segment 4	2.5087E+03	0.0060	2.0281E+01	0.0025	2.5290E+03	0.0060
Segment 5	2.4464E+03	0.0059	2.5212E+01	0.0023	2.4716E+03	0.0058
Segment 6	2.3226E+03	0.0061	2.5409E+01	0.0022	2.3480E+03	0.0060
Segment 7	2.3569E+03	0.0060	2.5092E+01	0.0023	2.3820E+03	0.0059
Segment 8	2.4219E+03	0.0060	2.0747E+01	0.0025	2.4426E+03	0.0059
Segment 9	1.3255E+03	0.0180	1.0088E+01	0.0060	1.3356E+03	0.0179

Table 25. Dose Rates on the WP Outer Radial Surface: Hypothetical BWR SNF

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	2.5209E+02	0.0253	1.0552E+00	0.0104	2.5315E+02	0.0252
Segment 2	7.8426E+02	0.0153	1.7524E+00	0.0082	7.8602E+02	0.0153
Segment 3	1.4589E+03	0.0101	3.7641E+00	0.0054	1.4627E+03	0.0101
Segment 4	7.0856E+02	0.0072	9.0982E+00	0.0025	7.1765E+02	0.0071
Segment 5	6.6747E+02	0.0072	1.1251E+01	0.0022	6.7872E+02	0.0071
Segment 6	6.3113E+02	0.0074	1.1320E+01	0.0022	6.4245E+02	0.0073
Segment 7	6.4486E+02	0.0073	1.1173E+01	0.0022	6.5604E+02	0.0072
Segment 8	6.6068E+02	0.0073	9.3195E+00	0.0025	6.7000E+02	0.0072
Segment 9	4.1208E+02	0.0214	4.4262E+00	0.0059	4.1651E+02	0.0212

Table 26. Dose Rates on a Radial Surface 1 m from the WP: Hypothetical BWR SNF

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	1.6875E+02	0.0119	9.5257E-01	0.0038	1.6970E+02	0.0118
Segment 2	2.1688E+02	0.0106	1.2358E+00	0.0034	2.1812E+02	0.0105
Segment 3	2.6114E+02	0.0090	1.6124E+00	0.0027	2.6275E+02	0.0089
Segment 4	2.7170E+02	0.0058	2.3553E+00	0.0017	2.7405E+02	0.0058
Segment 5	2.4934E+02	0.0054	3.0799E+00	0.0015	2.5242E+02	0.0053
Segment 6	2.3958E+02	0.0054	3.2863E+00	0.0014	2.4287E+02	0.0053
Segment 7	2.3350E+02	0.0056	3.0768E+00	0.0015	2.3657E+02	0.0055
Segment 8	1.9158E+02	0.0064	2.3268E+00	0.0017	1.9390E+02	0.0063
Segment 9	1.3044E+02	0.0124	1.6262E+00	0.0032	1.3206E+02	0.0122

Table 27. Dose Rates on a Radial Surface 2 m from the WP: Hypothetical BWR SNF

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	9.7198E+01	0.0109	7.4946E-01	0.0032	9.7947E+01	0.0108
Segment 2	1.1260E+02	0.0108	8.5887E-01	0.0030	1.1346E+02	0.0107
Segment 3	1.2539E+02	0.0088	9.9650E-01	0.0025	1.2639E+02	0.0087
Segment 4	1.4231E+02	0.0057	1.2520E+00	0.0016	1.4356E+02	0.0057
Segment 5	1.4926E+02	0.0052	1.5344E+00	0.0014	1.5079E+02	0.0051
Segment 6	1.4354E+02	0.0051	1.6334E+00	0.0014	1.4517E+02	0.0050
Segment 7	1.3058E+02	0.0053	1.5300E+00	0.0014	1.3211E+02	0.0052
Segment 8	1.0430E+02	0.0061	1.2345E+00	0.0016	1.0553E+02	0.0060
Segment 9	8.0782E+01	0.0117	9.9713E-01	0.0030	8.1779E+01	0.0116

Table 28. Dose Rates on the Axial Surfaces: Hypothetical BWR SNF

Surface	Segment	Gamma		Neutron		Total	
		Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Top of the WP cavity (See Figure 5)	Segment 14	2.0066E+04	0.0270	7.9158E+00	0.0205	2.0074E+04	0.0270
	Segment 15	1.9074E+04	0.0244	7.6218E+00	0.0181	1.9081E+04	0.0244
	Segment 16	1.7185E+04	0.0212	7.0729E+00	0.0159	1.7192E+04	0.0212
	Segment 17	1.5577E+04	0.0199	6.6457E+00	0.0143	1.5584E+04	0.0199
	Segment 18	1.2730E+04	0.0202	6.0892E+00	0.0137	1.2736E+04	0.0202
	Segment 19	7.6269E+03	0.0224	5.2235E+00	0.0127	7.6322E+03	0.0224
Bottom of the outer upper lid (See Figure 6)	Segment 14	1.6906E+03	0.0377	3.7255E+00	0.0191	1.6944E+03	0.0376
	Segment 20	1.5320E+03	0.0230	3.4376E+00	0.0123	1.5354E+03	0.0229
	Segment 21	1.1588E+03	0.0208	2.9058E+00	0.0104	1.1617E+03	0.0207
	Segment 22	5.4223E+02	0.0264	1.9195E+00	0.0113	5.4415E+02	0.0263
Top of WP (See Figure 4)	Segment 10	4.9415E+02	0.0244	1.4042E+00	0.0126	4.9555E+02	0.0243
	Segment 11	2.4252E+02	0.0204	8.9147E-01	0.0094	2.4341E+02	0.0203
	Segment 12	9.8722E+01	0.0132	5.4811E-01	0.0039	9.9270E+01	0.0131
1 m from the WP top (See Figure 4)	WP top surface	1.3170E+02	0.0197	2.5339E-01	0.0095	1.3195E+02	0.0197
	Segment 13	3.1543E+01	0.0099	2.4668E-01	0.0028	3.1789E+01	0.0098
2 m from the WP top (See Figure 4)	WP top surface	6.4991E+01	0.0247	1.0180E-01	0.0125	6.5093E+01	0.0247
	Segment 13	2.0729E+01	0.0132	1.2343E-01	0.0036	2.0853E+01	0.0131
Bottom of WP cavity (See Figure 4)	Segment 10	3.7643E+04	0.0148	4.7140E+01	0.0059	3.7690E+04	0.0148
	# Segment 10[a]	2.1402E+04	0.0130	1.5904E+01	0.0060	2.1418E+04	0.0130
Bottom of the inner lower lid (See Figure 4)	Segment 10	5.2189E+02	0.0277	1.1023E+01	0.0067	5.3292E+02	0.0271
	# Segment 10[b]	3.1458E+02	0.0219	6.5085E+00	0.0054	3.2109E+02	0.0215
Bottom of WP (See Figures 4 and 6)	Segment 10	1.4331E+02	0.0342	4.4811E+00	0.0073	1.4779E+02	0.0332
	Segment 11	7.7209E+01	0.0269	2.4348E+00	0.0058	7.9644E+01	0.0261
	Segment 12	7.3153E+01	0.0141	1.2149E+00	0.0031	7.4368E+01	0.0139
Surface 1 m from the WP bottom (See Figure 4)	WP bottom surface	3.9534E+01	0.0274	7.3213E-01	0.0057	4.0266E+01	0.0269
	Segment 13	1.7266E+01	0.0100	4.4140E-01	0.0024	1.7708E+01	0.0098
Surface 2 m from the WP bottom (See Figure 4)	WP bottom surface	1.9128E+01	0.0350	2.8720E-01	0.0073	1.9415E+01	0.0345
	Segment 13	8.5494E+00	0.0144	2.3237E-01	0.0030	8.7817E+00	0.0140

NOTE: [a] The segment outside Segment 10 and delimited by the radius of the cavity.
[b] The segment outside Segment 10 and delimited by the inner surface of the outer shell.

6.3 AVERAGE SOURCE

Tables 29 through 34 present surface dose rates averaged over segments of radial and axial surfaces of the WP containing SNF with the following characteristics: 3.5-wt% initial ^{235}U, 40.0-GWd/MTU burnup, and a 22-year decay time (see Figures 4, 5, and 6 for segment locations). The WP contains the basket assembly inside.

Table 29. Dose Rates on the Inner Surface of the Inner Shell: Average BWR SNF

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	5.0823E+02	0.0353	4.7510E-01	0.0114	5.0870E+02	0.0353
Segment 2	1.2962E+03	0.0210	7.4224E-01	0.0093	1.2969E+03	0.0210
Segment 3	3.2470E+03	0.0108	1.5080E+00	0.0062	3.2485E+03	0.0108
Segment 4	6.6001E+03	0.0043	3.4376E+00	0.0028	6.6035E+03	0.0043
Segment 5	7.3370E+03	0.0041	4.2597E+00	0.0025	7.3412E+03	0.0041
Segment 6	6.9245E+03	0.0042	4.2701E+00	0.0025	6.9288E+03	0.0042
Segment 7	6.9495E+03	0.0043	4.2086E+00	0.0025	6.9537E+03	0.0043
Segment 8	6.9409E+03	0.0042	3.5299E+00	0.0028	6.9444E+03	0.0042
Segment 9	2.3418E+03	0.0150	1.7752E+00	0.0067	2.3436E+03	0.0150

Table 30. Dose Rates on the Inner Surface of the Outer Shell: Average BWR SNF

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	4.1161E+01	0.0463	2.1137E-01	0.0106	4.1373E+01	0.0461
Segment 2	1.2361E+02	0.0284	3.4273E-01	0.0085	1.2395E+02	0.0283
Segment 3	2.7836E+02	0.0159	7.1821E-01	0.0057	2.7908E+02	0.0159
Segment 4	4.3300E+02	0.0064	1.6931E+00	0.0026	4.3470E+02	0.0064
Segment 5	4.6499E+02	0.0061	2.0708E+00	0.0023	4.6706E+02	0.0061
Segment 6	4.3435E+02	0.0063	2.0684E+00	0.0023	4.3642E+02	0.0063
Segment 7	4.4377E+02	0.0063	2.0510E+00	0.0023	4.4582E+02	0.0063
Segment 8	4.4811E+02	0.0063	1.7234E+00	0.0026	4.4983E+02	0.0063
Segment 9	1.4630E+02	0.0229	8.4019E-01	0.0062	1.4714E+02	0.0228

Table 31. Dose Rates on the WP Outer Radial Surface: Average BWR SNF

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	1.3499E+01	0.0534	8.8164E-02	0.0109	1.3587E+01	0.0531
Segment 2	4.2313E+01	0.0318	1.4704E-01	0.0086	4.2460E+01	0.0317
Segment 3	8.7916E+01	0.0189	3.1562E-01	0.0056	8.8231E+01	0.0188
Segment 4	1.1293E+02	0.0077	7.5841E-01	0.0026	1.1369E+02	0.0076
Segment 5	1.1869E+02	0.0073	9.2539E-01	0.0023	1.1961E+02	0.0072
Segment 6	1.1156E+02	0.0075	9.2270E-01	0.0023	1.1248E+02	0.0074
Segment 7	1.1485E+02	0.0075	9.1358E-01	0.0023	1.1576E+02	0.0074
Segment 8	1.1507E+02	0.0075	7.7282E-01	0.0025	1.1584E+02	0.0074
Segment 9	3.9840E+01	0.0287	3.7196E-01	0.0062	4.0212E+01	0.0284

Table 32. Dose Rates on a Radial Surface 1 m from the WP: Average BWR SNF

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	1.3840E+01	0.0175	7.9343E-02	0.0040	1.3919E+01	0.0174
Segment 2	1.9044E+01	0.0147	1.0255E-01	0.0036	1.9147E+01	0.0146
Segment 3	2.6024E+01	0.0115	1.3332E-01	0.0028	2.6157E+01	0.0114
Segment 4	3.6090E+01	0.0066	1.9469E-01	0.0018	3.6285E+01	0.0066
Segment 5	4.1181E+01	0.0056	2.5321E-01	0.0015	4.1435E+01	0.0056
Segment 6	4.1772E+01	0.0055	2.6890E-01	0.0014	4.2041E+01	0.0055
Segment 7	4.0696E+01	0.0057	2.5226E-01	0.0015	4.0948E+01	0.0057
Segment 8	3.2340E+01	0.0066	1.9222E-01	0.0018	3.2533E+01	0.0066
Segment 9	2.0696E+01	0.0129	1.3412E-01	0.0033	2.0830E+01	0.0128

Table 33. Dose Rates on a Radial Surface 2 m from the WP: Average BWR SNF

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	1.0450E+01	0.0136	6.1603E-02	0.0034	1.0512E+01	0.0135
Segment 2	1.2562E+01	0.0129	7.1040E-02	0.0032	1.2633E+01	0.0128
Segment 3	1.5102E+01	0.0103	8.1805E-02	0.0026	1.5184E+01	0.0102
Segment 4	1.9221E+01	0.0064	1.0323E-01	0.0017	1.9324E+01	0.0064
Segment 5	2.3158E+01	0.0056	1.2625E-01	0.0015	2.3284E+01	0.0056
Segment 6	2.3704E+01	0.0053	1.3427E-01	0.0014	2.3838E+01	0.0053
Segment 7	2.2355E+01	0.0056	1.2552E-01	0.0015	2.2480E+01	0.0056
Segment 8	1.7467E+01	0.0063	1.0177E-01	0.0017	1.7568E+01	0.0063
Segment 9	1.3211E+01	0.0118	8.2337E-02	0.0032	1.3293E+01	0.0117

Table 34. Dose Rates on the Axial Surfaces: Average BWR SNF

Surface	Segment	Gamma		Neutron		Total	
		Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error	Dose Rate (rem/h)	Relative Error
Top of the WP cavity (See Figure 5)	Segment 14	1.0983E+03	0.0528	6.7117E-01	0.0212	1.0990E+03	0.0528
	Segment 15	9.9155E+02	0.0504	6.2475E-01	0.0185	9.9218E+02	0.0504
	Segment 16	9.2448E+02	0.0454	5.7584E-01	0.0171	9.2506E+02	0.0454
	Segment 17	8.0901E+02	0.0415	5.5821E-01	0.0153	8.0956E+02	0.0415
	Segment 18	6.5994E+02	0.0416	5.0917E-01	0.0148	6.6045E+02	0.0416
	Segment 19	4.0055E+02	0.0445	4.2946E-01	0.0131	4.0098E+02	0.0445
Bottom of the outer upper lid (See Figure 6)	Segment 14	8.9967E+01	0.0742	3.1328E-01	0.0205	9.0280E+01	0.0739
	Segment 20	8.0749E+01	0.0493	2.8358E-01	0.0129	8.1033E+01	0.0491
	Segment 21	5.7881E+01	0.0441	2.3734E-01	0.0109	5.8118E+01	0.0439
	Segment 22	2.8011E+01	0.0552	1.5860E-01	0.0119	2.8170E+01	0.0549
Top of WP (See Figure 4)	Segment 10	2.5801E+01	0.0519	1.1609E-01	0.0131	2.5917E+01	0.0517
	Segment 11	1.2286E+01	0.0434	7.3945E-02	0.0099	1.2360E+01	0.0431
	Segment 12	6.5810E+00	0.0222	4.5690E-02	0.0041	6.6267E+00	0.0220
1 m from the WP top (See Figure 4)	WP top surface	7.1366E+00	0.0414	2.1091E-02	0.0099	7.1577E+00	0.0413
	Segment 13	2.3134E+00	0.0157	2.0459E-02	0.0029	2.3339E+00	0.0156
2 m from the WP top (See Figure 4)	WP top surface	3.5143E+00	0.0510	8.5238E-03	0.0130	3.5228E+00	0.0509
	Segment 13	1.3111E+00	0.0232	1.0226E-02	0.0038	1.3213E+00	0.0230
Bottom of WP cavity (See Figure 4)	Segment 10	2.9655E+03	0.0219	3.8913E+00	0.0061	2.9693E+03	0.0219
	# Segment 10[a]	1.7264E+03	0.0202	1.3325E+00	0.0062	1.7278E+03	0.0202
Bottom of the inner lower lid (See Figure 4)	Segment 10	3.7348E+01	0.0473	9.0646E-01	0.0071	3.8254E+01	0.0462
	# Segment 10[b]	2.1552E+01	0.0368	5.4788E-01	0.0056	2.2100E+01	0.0359
Bottom of WP (See Figures 4 and 6)	Segment 10	9.4253E+00	0.0636	3.6258E-01	0.0076	9.7879E+00	0.0612
	Segment 11	5.0067E+00	0.0490	2.0311E-01	0.0060	5.2098E+00	0.0471
	Segment 12	1.0192E+01	0.0139	1.0105E-01	0.0032	1.0293E+01	0.0138
Surface 1 m from the WP bottom (See Figure 4)	WP bottom surface	2.4571E+00	0.0503	6.0066E-02	0.0059	2.5171E+00	0.0491
	Segment 13	2.3507E+00	0.0108	3.6579E-02	0.0025	2.3873E+00	0.0106
Surface 2 m from the WP bottom (See Figure 4)	WP bottom surface	1.2209E+00	0.0667	2.3623E-02	0.0077	1.2445E+00	0.0654
	Segment 13	9.2097E-01	0.0171	1.9282E-02	0.0031	9.4025E-01	0.0167

NOTE: [a] The segment outside Segment 10 and delimited by the radius of the cavity.
[b] The segment outside Segment 10 and delimited by the inner surface of the outer shell.

7. REFERENCES

7.1 DOCUMENTS CITED

Bowman, S.M.; Hermann, O.W.; and Brady, M.C. 1995. *Sequoyah Unit 2 Cycle 3.* Volume 2 of *Scale-4 Analysis of Pressurized Water Reactor Critical Configurations.* ORNL/TM-12294/V2. Oak Ridge, Tennessee: Oak Ridge National Laboratory. TIC: 244397.

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7.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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8. ATTACHMENTS

The attachments of this calculation are listed in Table 35. Electronic output files are provided on a compact disk, and are listed in Table 36. Each output file is identified by its name, size (in bytes), and the date and time. The input files used are echoed in the output files. 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.

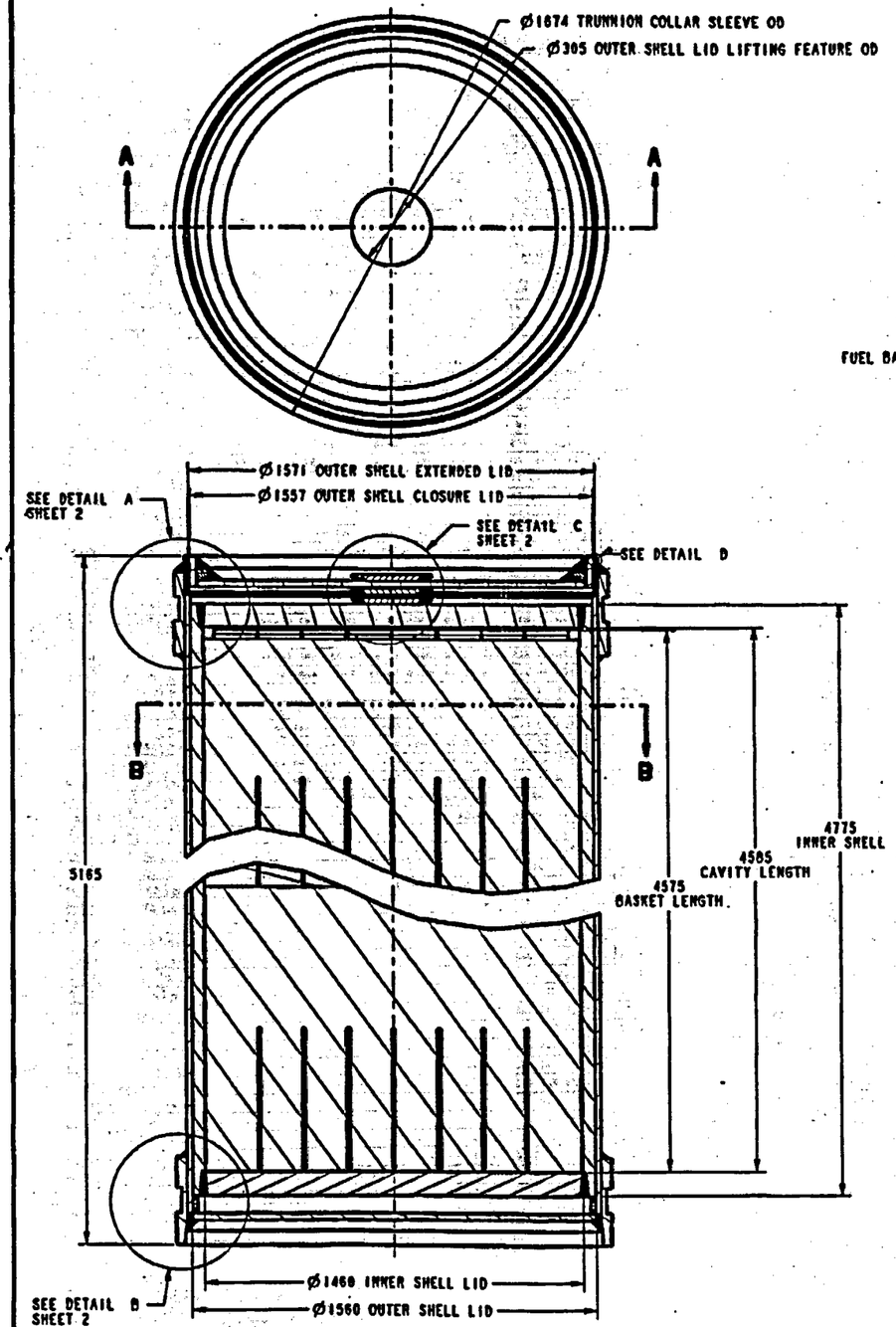
Table 35. List of Attachments

Description	Attachment Number	No. of Pages
SK-0219 REV 01, page 24 21-PWR Waste Package Concept for License Application	I	1
SK-0192 REV 00, page 1 44-BWR Waste Package Configuration for Site Recommendation	II	1
Atomic density calculation for the homogenized assembly regions	III	3
Total intensity and source region fractions	IV	2
MCNP electronic output files (compact disk)	V	N/A

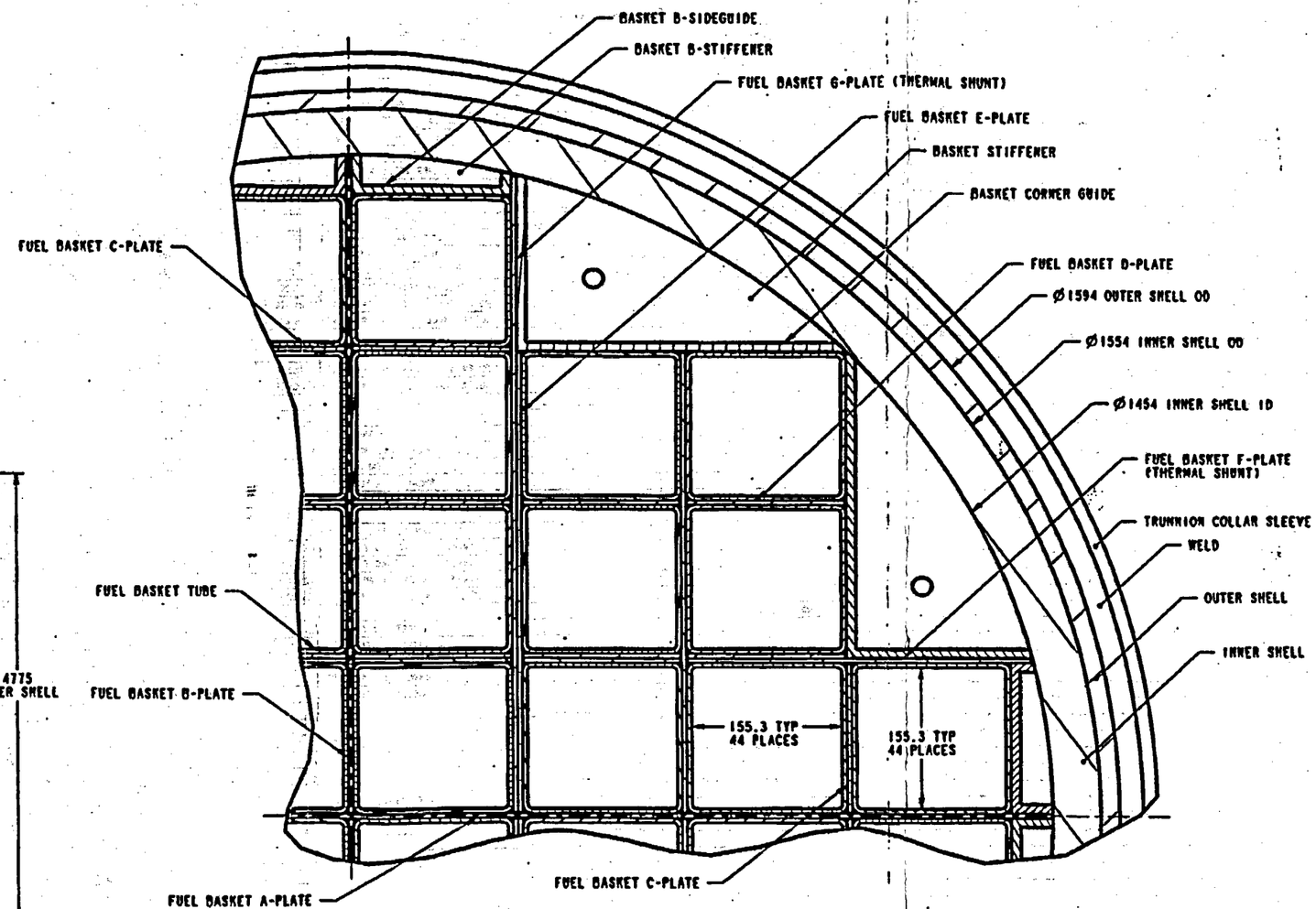
Table 36. File Attributes for the Contents of Electronic Media

File Name	Calculation	File Size (bytes)	File Date	File Time
abg.io	Gamma dose rates for the WP containing the average BWR SNF source	322,111	01/19/2001	4:10 p.m.
abn.io	Neutron dose rates for the WP containing the average BWR SNF source	270,372	01/22/2001	8:37 a.m.
bbg.io	Gamma dose rates for the WP containing bounding BWR SNF source for the active fuel region	297,433	01/22/2001	8:38 a.m.
bbn.io	Neutron dose rates for the WP containing bounding BWR SNF source for the active fuel region	276,019	01/22/2001	8:38 a.m.
b2bg.io	Gamma dose rates for the WP containing the bounding BWR SNF source for the hardware regions	293,512	01/22/2001	8:37 a.m.
bg.io	Gamma dose rates for the WP containing bounding BWR SNF source (basket assembly neglected)	166,678	01/22/2001	8:38 a.m.
bn.io	Neutron dose rates for the WP containing bounding BWR SNF source (basket assembly neglected)	153,963	01/22/2001	8:38 a.m.

NOTE: The MCNP output files listed in the table are text files.



SECTION A-A



SECTION B-B

"FOR INFORMATION ONLY"

UNITS: mm

DO NOT SCALE FROM SKETCH

44-BWR WASTE PACKAGE CONFIGURATION FOR SITE RECOMMENDATION	
SKETCH NUMBER: SK-0192 REV 00	SHEET 1 OF 2
SKETCHED BY: BRYAN HARKINS BH 21Jan00	
DATE: 01/21/00 Joe 1/24/00 SNB 01/24/00	
FILE: home/pro_library/checkout/sketches/44bwr/sk-0192.dwg	

GR 05130/01

COMPONENT LIST

ITEM NUMBER	ASSEMBLY	SUBASSEMBLY	SUBASSEMBLY	SUBASSEMBLY	COMPONENT CODE	MATERIAL	THICKNESS	MASS (KG)	QTY REQD
-1	21-PWR WASTE PACKAGE ASSEMBLY	-	-	-	-	-	-	28935	1
		-	-	-	-	-	-	△ 25357	△ 1
-2	-	OUTER SHELL ASSEMBLY	-	-	-	-	-	5729	1
1	-	-	-	-	OUTER SHELL	SB-575 N06022	29	4194	1
2	-	-	-	-	UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	446	1
3	-	-	-	-	LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	436	1
4	-	-	-	-	SHELL INTERFACE RING	SA-240 S31600	30	86	1
5	-	-	-	-	INNER SHELL SUPPORT RING	SB-575 N06022	40	67	1
6	-	-	-	-	OUTER SHELL FLAT BOTTOM LID	SB-575 N06022	25.4	423	1
-3	-	EXTENDED OUTER SHELL LID ASSEMBLY	-	-	-	-	-	713	1
7	-	-	-	-	EXTENDED OUTER SHELL LID	SB-575 N06022	25	193	1
8	-	-	-	-	EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25.4	317	1
9	-	-	-	-	LARGE REINFORCEMENT RING	SB-575 N06022	50	98	1
10	-	-	-	-	SMALL REINFORCEMENT RING - TOP	SB-575 N06022	25	25	1
11	-	-	-	-	SMALL REINFORCEMENT RING - BOTTOM	SB-575 N06022	25	23	1
12	-	-	-	-	OUTER SHELL LID LIFTING FEATURE PLATE-1	SB-575 N06022	6.35	0.94	1
13	-	-	-	-	OUTER SHELL LID LIFTING FEATURE PLATE-2	SB-575 N06022	6.35	1.2	1
-4	-	OUTER SHELL FLAT CLOSURE LID ASSEMBLY	-	-	-	-	-	156	1
14	-	-	-	-	OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	9.525	154	1
12	-	-	-	-	OUTER SHELL LID LIFTING FEATURE PLATE-1	SB-575 N06022	6.35	0.94	1
13	-	-	-	-	OUTER SHELL LID LIFTING FEATURE PLATE-2	SB-575 N06022	6.35	1.2	1
-5	-	INNER SHELL ASSEMBLY	-	-	-	-	-	10725	1
			-	-	-	-	-	△ 10748	△ 1
15	-	-	-	-	INNER SHELL	SA-240 S31600	50	8554	1
16	-	-	-	-	INNER SHELL BOTTOM LID	SA-240 S31600	88.9	1274	1
17	-	-	-	-	FUEL BASKET TUBE	SA-516 K02700	5	164	21
18	-	-	-	-	SHEAR RING SECTION-1	SA-240 S31600	22.225	5.2	2
19	-	-	-	-	SHEAR RING SECTION-2	SA-240 S31600	22.225	7.8	1
-6	-	-	INNER SHELL TOP LID ASSEMBLY	-	-	-	-	875	1
20	-	-	-	-	INNER SHELL TOP LID	SA-240 S31600	50.8	872	1
21	-	-	-	-	INNER LID LIFTING FEATURE PLATE-1	SA-240 S31600	6.35	0.89	1
22	-	-	-	-	INNER LID LIFTING FEATURE PLATE-2	SA-240 S31600	6.35	1.1	1
23	-	-	-	-	EVACUATION-BACKFILL QUICK RELEASE VALVE	SA-240 S31600	12.7	0.06	1
24	-	-	-	-	EVACUATION-BACKFILL PORT COVER PLATE	SA-240 S31600	6.35	0.02	1
-7	-	-	END SIDEGUIDE ASSEMBLY	-	-	-	-	29	32
25	-	-	-	-	BASKET A-SIDEGUIDE	SA-516 K02700	10	27	32
26	-	-	-	-	BASKET A-STIFFENER	SA-516 K02700	10	0.72	64
-8	-	-	SIDEGUIDE ASSEMBLY	-	-	-	-	39	16
27	-	-	-	-	BASKET B-SIDEGUIDE	SA-516 K02700	10	36	16
28	-	-	-	-	BASKET B-STIFFENER	SA-516 K02700	10	1.8	32
-9	-	-	CORNERGUIDE ASSEMBLY	-	-	-	-	47	16
29	-	-	-	-	BASKET C-STIFFENER	SA-516 K02700	10	2.3	32
30	-	-	-	-	BASKET CORNERGUIDE	SA-516 K02700	10	42	16
-10	-	-	FUEL PLATE ASSEMBLY	-	-	-	-	599	4
	-	-		-	-	-	-	△ 605	△ 4
31	-	-	-	-	FUEL BASKET C-PLATE	NEUTRONIT A 978	7	44	16
	-	-	-	-		△ SA-516 K02700	△ 7	△ 46	△ 16
-11	-	-	-	FUEL PLATE A-B ASSEMBLY	-	-	-	105	8
	-	-	-		-	-	-	△ 107	△ 8
32	-	-	-	-	FUEL BASKET A-PLATE	NEUTRONIT A 978	7	85	8
	-	-	-	-		△ SA-516 K02700	△ 7	△ 89	△ 8
33	-	-	-	-	FUEL BASKET B-PLATE	SB-209 A96061 T4	5	21	8
-12	-	-	-	FUEL PLATE B-E ASSEMBLY	-	-	-	105	8
	-	-	-		-	-	-	△ 107	△ 8
34	-	-	-	-	FUEL BASKET B-PLATE	NEUTRONIT A 978	7	85	8
	-	-	-	-		△ SA-516 K02700	△ 7	△ 89	△ 8
35	-	-	-	-	FUEL BASKET E-PLATE	SB-209 A96061 T4	5	21	8
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	TOTAL CARBON STEEL WELDS	SFA-5.18 E70S6	-	34	-
-	-	-	-	-	TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	102	-
-	-	-	-	-	TOTAL 316 WELDS	SFA-5.9 S31600	-	41	-
-	-	-	-	-	-	-	-	-	-
-	-	-	PWR FUEL ASSEMBLY	-	-	-	-	△ 773.4	21
-	21-PWR UP ASSEMBLY WITH SHF	-	-	-	-	-	-	41574	1
		-	-	-	-	-	-	△ 41998	△ 1

REVISION HISTORY

ZONE	REV	DESCRIPTION	DATE	APPROVED
D3-1	-	CONTINUED FROM SHEET 1	02/22/01	SMB
A4-6	01	34.9 WAS 37	02/23/01	SMB
A6-6	01	ADDED DETAIL CC CALLOUT	02/23/01	SMB
C6-7	01	ADDED SECTION W	02/27/01	SMB
B7-7	01	ADDED SECTION V	02/27/01	SMB
-	01	ADDED ITEM 10 IN ZONES C5-7, B7-13, C8-24, AND A4-22	02/23/01	SMB
-	01	ADDED ITEM 9 IN ZONES B4-7, C8-24, AND A2-22	02/27/01	SMB
C2-7	01	INNER SHELL ASSEMBLY PERSPECTIVE VIEW MODIFIED TO SHOW EXPLODED FUEL BASKET TUBES AND PLATE ASSEMBLY	02/22/01	SMB
-	01	ITEM 15 WAS ITEM 14 IN ZONES C2-7, C8-13, B3-13, B8-19, AND C8-24	02/22/01	SMB
-	01	ITEM 16 WAS ITEM 15 IN ZONES B4-7, C8-13, C5-19, AND C8-24	02/23/01	SMB
-	01	ITEM 17 WAS ITEM 16 IN ZONES C4-7, A2-19, AND C8-24	02/23/01	SMB
B8-7	01	4782 WAS 4772	02/22/01	SMB
-	01	88.9 WAS 38 IN ZONES A8-7, C5-19, AND C4-24	02/27/01	SMB
-	01	ITEM 20 WAS ITEM 17 IN ZONES C3-8, C1-12, B8-13, A4-12, B8-20, AND C8-24	02/22/01	SMB
A4-8	01	ADDED DETAIL BB TO SHOW CALLOUTS OF ITEM 21 AND ITEM 22	02/23/01	SMB
B7-8	01	ADDED DETAIL BB CALLOUT	02/23/01	SMB
A3-8	01	ADDED ITEM 26 CALLOUT	02/23/01	SMB
C2-12	01	ADDED ITEM 22	02/23/01	SMB
-	01	ITEM 23 WAS ITEM 19 IN ZONES A2-8, A4-12, A6-20, AND B6-24	02/22/01	SMB
-	01	ITEM 24 WAS ITEM 20 IN ZONES B2-8, B5-12, B2-21, AND B8-24	02/23/01	SMB
A8-8	01	76.2 WAS 77	02/23/01	SMB
B5-8	01	3464 WAS 4439	02/22/01	SMB
B6-8	01	ADDED SECTION R	02/22/01	SMB
-	01	DELETED 10 TYP IN ZONES B5-8, C5-8, AND B5-9	02/23/01	SMB
-	01	ADDED 20 TYP IN ZONES B5-8, C5-8, AND B5-9	02/27/01	SMB
-	01	ITEM 21 WAS ITEM 22 IN ZONES B7-8, A7-21, AND B8-24	02/23/01	SMB
-	01	ITEM 25 WAS ITEM 21 IN ZONES B6-8, C7-21, AND B8-24	02/23/01	SMB
-	01	ITEM 26 WAS ITEM 24 IN ZONES C7-8, B1-21, AND B8-24	02/23/01	SMB
-	01	ITEM 27 WAS ITEM 23 IN ZONES B7-21, C6-8, AND B8-24	02/22/01	SMB
C8-8	01	ADDED SECTION T	02/22/01	SMB
-	01	ITEM 30 WAS ITEM 26 IN ZONES B6-8, B3-22, AND B8-24	02/22/01	SMB
-	01	ITEM 29 WAS ITEM 25 IN ZONES B6-22, B7-8, AND B8-24	02/23/01	SMB
B8-8	01	ADDED SECTION U	02/27/01	SMB
-	01	ITEM 31 WAS ITEM 27 IN ZONES C4-10, A8-22, AND B8-24	02/23/01	SMB
-	01	ITEM 33 WAS ITEM 29 IN ZONES C4-11, C2-23, AND B8-24	02/23/01	SMB
-	01	ITEM 32 WAS ITEM 28 IN ZONES B2-11, C8-23, AND B8-24	02/23/01	SMB
-	01	ITEM 35 WAS ITEM 31 IN ZONES B4-11, B1-23, AND A8-24	02/23/01	SMB
-	01	ITEM 34 WAS ITEM 30 IN ZONES B2-11, A6-23, AND A8-24	02/23/01	SMB
-	01	6.35 WAS 12.7 IN ZONES B4-12 AND B2-12	02/22/01	SMB
D3-12	01	ADDED W9 IN 2 PLACES	02/27/01	SMB
B6-25	01	ADDED WELD 9	02/22/01	SMB
D3-12	01	ADDED W7 IN 2 PLACES	02/23/01	SMB
B4-12	01	ADDED W10	02/23/01	SMB
-	01	ADDED ITEM 13 CALLOUT IN ZONES B2-12 AND B5-12	02/23/01	SMB
C2-12	01	ITEM 21 WAS ITEM 18	02/22/01	SMB
C8-25	01	ADDED WELD 19	02/27/01	SMB
C4-12	01	W10 WAS W14	02/23/01	SMB
C8-25	01	WELD 18 WAS WELD 14	02/22/01	SMB
C4-12	01	6.35 WAS 12.7	02/23/01	SMB
C3-12	01	W17 WAS W13	02/22/01	SMB
C8-25	01	WELD 17 WAS WELD 13	02/27/01	SMB
C4-12	01	ADDED W17	02/23/01	SMB
B1-12	01	W21 WAS W16	02/23/01	SMB
C8-25	01	WELD 21 WAS WELD 16	02/22/01	SMB
A2-12	01	W20 WAS W15	02/23/01	SMB
C8-25	01	WELD 20 WAS WELD 15	02/22/01	SMB
C8-13	01	W18 WAS W9	02/22/01	SMB
C8-25	01	WELD 18 WAS WELD 9	02/27/01	SMB
C8-13	01	12.7 WAS 12.5 IN 2 PLACES	02/22/01	SMB
-	01	TYP WAS REMOVED FROM DIMENSIONS IN ZONES A3-13 AND B4-13	02/27/01	SMB
-	01	REFERENCE NOTE.) CALLOUT WAS REMOVED IN ZONES A3-13 AND B4-13	02/22/01	SMB
C8-25	01	ADDED WELD 13 AND WELD 14	02/22/01	SMB
D3-25	-	CONTINUED ON SHEET 25	02/22/01	SMB

WASTE PACKAGE DEPARTMENT
M&O Yucca Mountain Waste Management System
MANAGEMENT & OPERATING CONTRACTOR

DRAWING NUMBER	REVISION
SK-0219	01
SCALE 0.125	SHEET 24 OF 25

This attachment presents the atomic density calculations for the homogenized assembly regions using Equations 1 and 2 in Section 5.2.3.

Table III-1. Fuel Region Volume

Fuel Region	Formula	Volume (cm^3)
Bottom end-fitting region volume	13.81252^2*18.7579	3578.73925
Active fuel region volume	13.81252^2*365.76	69781.7808
Plenum region volume	13.81252^2*28.5496	5446.85567
Top end-fitting region volume	13.81252^2*22.2885	4252.32727

Table III-2. Light Element Mass by Fuel Region for a GE 2/3 8x8 BWR Fuel Assembly

Element	Mass (kg)			
	Bottom End-Fitting Region	Active Fuel Region	Plenum Region	Top End-Fitting Region
O	0.0008	0.0977[a]	0.0074	0.0012
Al	-	0.0023	0.0119	0.0041
C	0.0038	0.0002	0.0015	0.0019
Co	0.0038	0.0033	0.0175	0.0074
Cr	0.9069	0.1302	0.3784	0.4680
Cu	-	0.0013	0.0068	0.0023
Fe	3.2208	0.1889	0.5649	1.3982
Mn	0.0954	0.0026	0.0259	0.0446
Nb	-	0.0033	0.0170	0.0058
N	0.0048	-	0.0006	0.0020
Ni	0.4970	0.2646	1.2610	0.6157
P	0.0021	-	0.0003	0.0009
S	0.0014	-	0.0004	0.0007
Si	0.0358	0.0013	0.0114	0.0173
Sn	0.0111	1.3845	0.1055	0.0169
Ti	-	0.0078	0.0408	0.0139
Zr	0.6374	79.6784	6.0704	0.9739

NOTE: [a] Oxygen from cladding, channel, spacers, and water rod.

Table III-3. UO_2 Composition

Isotope/Element	5.5-wt% ^{235}U		3.5-wt% ^{235}U	
	wt% in U[a]	Mass (g)	wt% in U[a]	Mass (g)
U235	5.5	11000	3.5	7000
U234	0.0490	98.0837	0.0300	60.0997
U236	0.0253	50.6	0.0161	32.2
U238	94.4257	188851.3163	96.4538	192907.7003
O[b]		23713.3389		23707.952

NOTES: [a] The isotopic composition for the enriched uranium is calculated according to the equations provided in Bowman et al. 1995 (see Section 5.2).
[b] Oxygen mass is the molecular mass for oxygen times the number of UO_2 moles in 200 kg UO_2.

Table III-4. Atomic Density by Element in the Active Fuel Region

Element/ Isotope	Nuclide ID[a]	Atomic Mass[b] (g)	5.5-wt% ^{235}U		3.5-wt% ^{235}U	
			Mass (g)	Atomic Density (atoms/b•cm)	Mass (g)	Atomic Density (atoms/b•cm)
O	8000.50c	15.9994	23811.109	1.2844E-02	23805.681	1.2841E-02
Al	13027.50c	26.981538	2.3	7.3565E-07	2.3	7.3565E-07
C	6000.50c	12.0107	0.2	1.4370E-07	0.2	1.4370E-07
Co	27059.50c	58.9332	3.3	4.8324E-07	3.3	4.8324E-07
Cr	24000.50c	51.9961	130.2	2.1610E-05	130.2	2.1610E-05
Cu	29000.50c	63.546	1.3	1.7655E-07	1.3	1.7655E-07
Fe	26000.50c	55.845	188.9	2.9191E-05	188.9	2.9191E-05
Mn	25055.50c	54.938049	2.6	4.0842E-07	2.6	4.0842E-07
Nb	41093.50c	92.90638	3.3	3.0653E-07	3.3	3.0653E-07
N	7014.50c	14.00674	0	0.0000E+00	0	0.0000E+00
Ni	28000.50c	58.6934	264.6	3.8905E-05	264.6	3.8905E-05
P	15031.50c	30.973761	0	0.0000E+00	0	0.0000E+00
S	16000.60c	32.066	0	0.0000E+00	0	0.0000E+00
Si	14000.50c	28.0855	1.3	3.9946E-07	1.3	3.9946E-07
Sn	50000.35c	118.71	1384.5	1.0065E-04	1384.5	1.0065E-04
Ti	22000.50c	47.867	7.8	1.4063E-06	7.8	1.4063E-06
Zr	40000.60c	91.224	79678.4	7.5377E-03	79678.4	7.5377E-03
^{234}U	92234.50c	234.040945	98.083672	3.6167E-06	60.099687	2.2161E-06
^{235}U	92235.50c	235.043922	11000	4.0388E-04	7000	2.5701E-04
^{236}U	92236.50c	236.045561	50.6	1.8500E-06	32.2	1.1772E-06
^{238}U	92238.50c	238.050785	188851.32	6.8463E-03	192907.7	6.9934E-03
Total				2.7831E-02		2.7827E-02

SOURCE: [a] Briesmeister 1997, Appendix G.
[b] Parrington et al. 1996.
NOTE: Nuclide identifier in the MCNP neutron data tables. The identifier for each element in the MCNP photon data tables is ZZZ000.01p, where ZZZ is the atomic number (Briesmeister 1997, pages 2-16 through 2-22).

Table III-5. Atomic Density by Element in the Hardware Regions

Element/ Isotope	Nuclide ID[a]	Atomic Mass[b] (g)	Bottom-End Fitting		Plenum		Top-End Fitting	
			Mass (g)	Atomic Density (atoms/b•cm)	Mass (g)	Atomic Density (atoms/b•cm)	Mass (g)	Atomic Density (atoms/b•cm)
O	8000.50c	15.9994	0.8	8.4141E-06	7.4	5.1137E-05	1.2	1.0622E-05
Al	13027.50c	26.981538	0.0	0.0000E+00	11.9	4.8762E-05	4.1	2.1520E-05
C	6000.50c	12.0107	3.8	5.3240E-05	1.5	1.3808E-05	1.9	2.2403E-05
Co	27059.50c	58.9332	3.8	1.0850E-05	17.5	3.2831E-05	7.4	1.7783E-05
Cr	24000.50c	51.9961	906.9	2.9350E-03	378.4	8.0461E-04	468.0	1.2747E-03
Cu	29000.50c	63.546	0.0	0.0000E+00	6.8	1.1831E-05	2.3	5.1258E-06
Fe	26000.50c	55.845	3220.8	9.7051E-03	564.9	1.1184E-03	1398.2	3.5458E-03
Mn	25055.50c	54.938049	95.4	2.9221E-04	25.9	5.2123E-05	44.6	1.1497E-04
Nb	41093.50c	92.90638	0.0	0.0000E+00	17.0	2.0231E-05	5.8	8.8411E-06
N	7014.50c	14.00674	4.8	5.7667E-05	0.6	4.7361E-06	2.0	2.0222E-05
Ni	28000.50c	58.6934	497.0	1.4249E-03	1261.0	2.3754E-03	615.7	1.4856E-03
P	15031.50c	30.973761	2.1	1.1409E-05	0.3	1.0709E-06	0.9	4.1150E-06
S	16000.60c	32.066	1.4	7.3469E-06	0.4	1.3792E-06	0.7	3.0916E-06
Si	14000.50c	28.0855	35.8	2.1450E-04	11.4	4.4877E-05	17.3	8.7234E-05
Sn	50000.35c	118.71	11.1	1.5735E-05	105.5	9.8258E-05	16.9	2.0162E-05
Ti	22000.50c	47.867	0.0	0.0000E+00	40.8	9.4239E-05	13.9	4.1125E-05
Zr	40000.60c	91.224	637.4	1.1758E-03	6070.4	7.3572E-03	973.9	1.5119E-03
Total				1.5912E-02		1.2131E-02		8.1952E-03

SOURCE: [a] Briesmeister 1997, Appendix G.
[b] Parrington et al. 1996.

NOTE: Nuclide identifier in the MCNP neutron data tables. The identifier for each element in the MCNP photon data tables is ZZZ000.01p, where ZZZ is the atomic number (Briesmeister 1997, pages 2-16 through 2-22).

This attachment presents the calculations of total neutron and gamma intensities and gamma source region fractions.

1. Bounding BWR SNF: Gamma Sources

Total intensity per assembly (photons/s) = Peaking factor * Gamma intensity in the fuel region (photons/s) + Gamma intensity in the bottom end-fitting region (photons/s) + Gamma intensity in the plenum region (photons/s) + Gamma intensity in the top end-fitting region (photons/s) = 1.4 * 3.5931E+15 + 5.9929E+12 + 3.0618E+13 + 7.2123E+12 = 5.0741E+15

Total intensity per WP (photons/s) = 44 * Total intensity per assembly (photons/s) = 44 * 5.0741E+15 = 2.2326E+17

Intensity fraction for each assembly region to be entered on the sp (source probability) card = Gamma source intensity for each assembly region in the WP / Total intensity per WP.

Intensity fraction for the active fuel region = 44 * 1.4 *3.5931E+15 / 2.2326E+17 = 9.9136E-01
Intensity fraction for the bottom end-fitting region = 44 * 5.9929E+12 / 2.2326E+17 = 1.1811E-03
Intensity fraction for the plenum region = 44 * 3.0618E+13 / 2.2326E+17 = 6.0341E-03
Intensity fraction for the top end-fitting region = 44 * 7.2123E+12 / 2.2326E+17 = 1.4214E-03

2. Hypothetical BWR SNF: Hardware and Active Fuel Region Gamma Sources

Total intensity per assembly (photons/s) = Peaking factor * Gamma intensity in the fuel region (photons/s) + Gamma intensity in the bottom end-fitting region (photons/s) + Gamma intensity in the plenum region (photons/s) + Gamma intensity in the top end-fitting region (photons/s) = 1.4 * 3.5931E+15 + 9.2934E+12 + 4.9784E+13 + 1.1088E+13 = 5.1005E+15

Total intensity per WP (photons/s) = 44 * Total intensity per assembly (photons/s) = 44 * 5.1005E+15 = 2.2442E+17

Intensity fraction for each assembly region to be entered on the sp (source probability) card = Gamma source intensity for each assembly region in the WP / Total intensity per WP.

Intensity fraction for the active fuel region = 44 * 1.4 *3.5931E+15 / 2.2442E+17 = 9.8624E-01
Intensity fraction for the bottom end-fitting region = 44 * 9.2934E+12 / 2.2442E+17 = 1.8221E-03
Intensity fraction for the plenum region = 44 * 4.9784E+13 / 2.8009E+17 = 9.7606E-03
Intensity fraction for the top end-fitting region = 44 * 1.1088E+13 / 2.2442E+17 = 2.1738E-03

3. Bounding BWR SNF: Neutron Source

Total intensity per WP (neutrons/s) = 44 * Peaking factor * Total intensity per active fuel region (neutrons/s) = 44 * 1.4 * 4.7166E+08 = 2.9054E+10

4. Average BWR SNF: Gamma Source

Total intensity per assembly (photons/s) = Peaking factor * Gamma intensity in the fuel region (photons/s) + Gamma intensity in the bottom end-fitting region (photons/s) + Gamma intensity in the plenum region (photons/s) + Gamma intensity in the top end-fitting region (photons/s) = 1.4 * 8.5786E+14 + 5.7546E+11 + 2.6224E+12 + 6.8324E+11 = 1.2049E+15

Total intensity per WP (photons/s) = 44 * Total intensity per assembly (photons/s) = 44 * 1.2049E+15 = 5.3015E+16

Intensity fraction for each assembly region to be entered on the sp (source probability) card = Gamma source intensity for each assembly region in the WP / Total intensity per WP.

Intensity fraction for the active fuel region = 44 * 1.4 * 8.5786E+14 / 5.3015E+16 = 9.9678E-01
Intensity fraction for the bottom end-fitting region = 44 * 5.7546E+11 / 5.3015E+16 = 4.7760E-04
Intensity fraction for the plenum region = 44 * 2.6224E+12 / 5.3015E+16 = 2.1765E-03
Intensity fraction for the top end-fitting region = 44 * 6.8324E+11 / 5.3015E+16 = 5.6706E-04

5. Average BWR SNF: Neutron Source

Total intensity per WP (neutrons/s) = 44 * Peaking factor * Total intensity per active fuel region (neutrons/s) = 44 * 1.4 * 4.2228E+07 = 2.6012E+09

File Listing KLQ 6/29/01

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA 3

Page: 1 of: 1

Complete Only Applicable Items

VMB 6/29/01

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2. Record Date	3. Accession Number
06/06/2001	ATT=TO MOL.20010629.0077
4. Author Name(s)	**5. Author Organization**
GEORGETA RADULESCU	

6. Title/Description
DOSE RATE CALCULATION FOR THE 44-BWR UCF WASTE PACKAGE

7. Document Number(s)	8. Version Designator
CAL-UDC-NU-000003	REV. 01

9. Document Type	10. Medium
DATA	CD-ROM

11. Access Control Code
PUB

12. Traceability Designator
DC #27737

13. Comments
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DI#27737 1 of 2

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ELECTRONIC SOURCE FILE VERIFICATION

QA: N/A

1. DOCUMENT TITLE:	
Dose Rate Calculation for the 44-BWR UCF Waste Package	
2. DOCUMENT IDENTIFIER:	3. REVISION DESIGNATOR:
CAL-UDC-NU-000003	01

ELECTRONIC SOURCE FILE INFORMATION

4. ELECTRONIC SOURCE FILE NAME WITH FILE EXTENSION PROVIDED BY THE SOFTWARE:		
CAL-UDC-NU-000003 REV01.doc		
5. DATE LAST MODIFIED:	6. ELECTRONIC SOURCE FILE APPLICATION: (I.E., EXCEL, WORD, CORELDRAW)	7. FILE SIZE IN KILOBYTES:
05/25/2001	WORD 97	1,122

8. FILE LINKAGE INSTRUCTIONS/INFORMATION:	
None	
9. FILE CUSTODIAN: (I.E., DC, OR DC APPROVED CUSTODIAN)	10. FILE LOCATION FOR DC APPROVED CUSTODIAN: (I.E., SERVER, DIRECTORY)
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11. PRINTER SPECIFICATION (I.E., HP4SI) INCLUDING POSTSCRIPT INFORMATION (I.E., PRINTER DRIVER) AND PRINTING PAGE SETUP: (I.E., LANDSCAPE, 11 X 17 PAPER)
Hewlett Packard Laser Jet 5 Si Landscape, 11x17, paper for Attachments I and II Portrait, 8.5x11, paper for the remainder

12. COMPUTING PLATFORM USED: (I.E., SUN)	13. OPERATING EQUIPMENT USED: (I.E., UNIX, SOLARIS)
PC 113412	WINDOWS
14. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S):	15. ACCESS RESTRICTIONS: (IF ANY)
None	None

COMMENTS/SPECIAL INSTRUCTIONS

16.
Attachment V for CAL-UDC-NU-000003 REV 01 is provided on a compact disk.
See attached #5, 6, and 7.

CERTIFICATION

17. NAME (Print and Sign)		18. DATE:
Georgeta Radulescu	Georgeta Radulescu	05/30/2001

19. ORGANIZATION:	20. DEPARTMENT:	21. LOCATION/MAILSTOP:	22. PHONE:
BSC	Waste Package	1026E	5-4546

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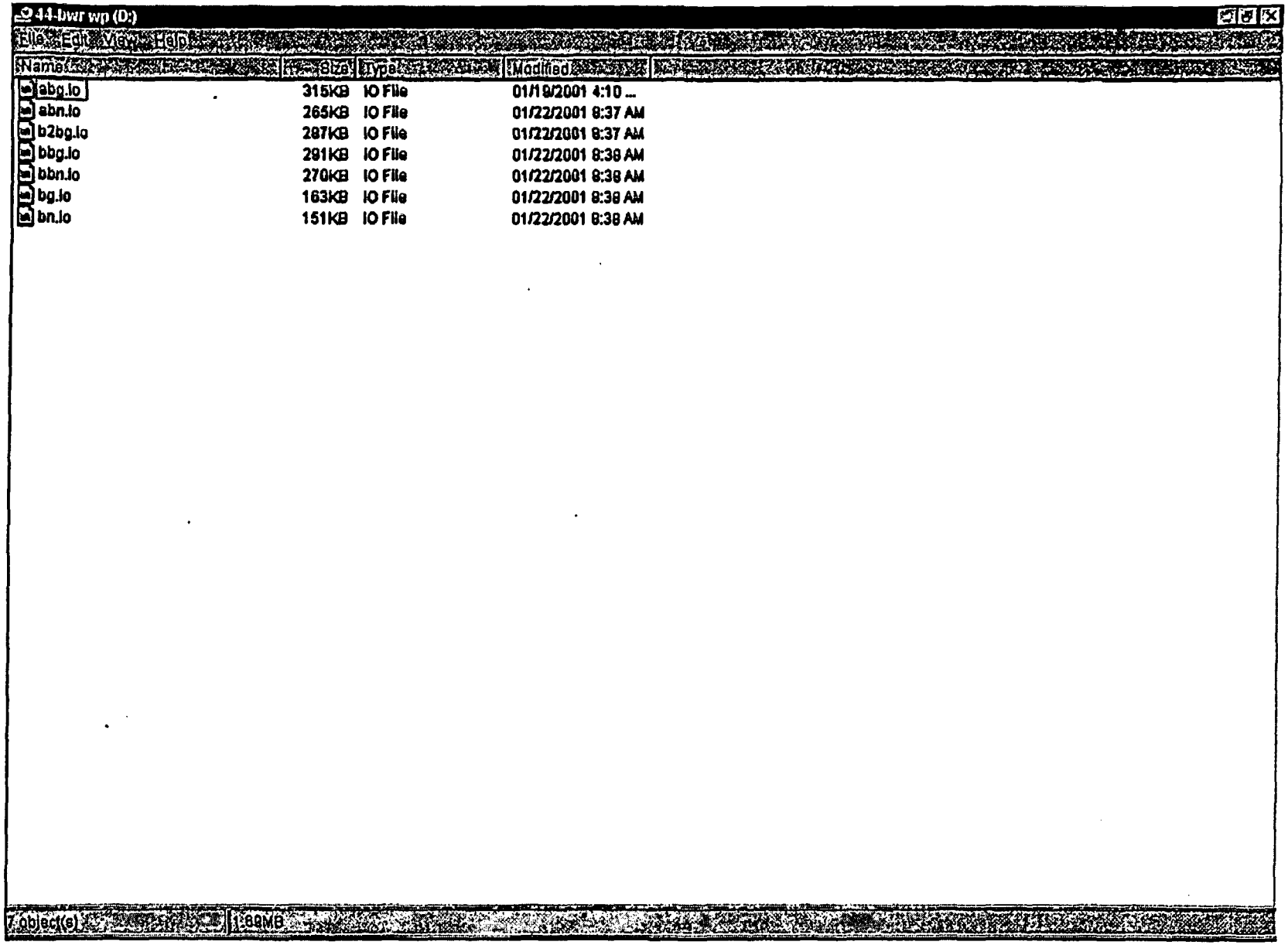
23. DATE RECEIVED:	24. DATE REVIEWED:	25. DATE FILES TRANSFERRED:
05/31/01	06/07/2001	06/07/2001
26. NAME (Print and Sign):		27. DATE:
Marina Blackwell	Marina Blackwell	06/07/2001

2 of 2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