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Title CODE TO CODE COMPARISON OF ONE-AND TWO-DIMENSIONAL METHODS

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PURPOSE AND SUMMARY OF RESULTS:

This calculation file provides comparisons of one- and two-dimensional methods for calculating the isotopic content of spent nuclear fuel. The one-dimensional methods use the SAS2H sequence of SCALE 4.4a and the SAS2 sequence of SCALE 5.0. The two-dimensional method uses the TRITON control module along with the T-DEPL sequence of SCALE 5.0. The SAS2H results for SCALE 4.4a are taken from Reference 7.4. Data from previous two-dimensional calculations (Reference 7.5) using CASMO3 are also used for comparisons with TRITON. The results of these comparisons give an indication of the accuracy of each computer code sequence in predicting the isotopic concentrations of spent nuclear fuel. The purpose of this calculation is achieved through considering 3 sets of comparisons. These include comparing:

- boiling water reactor (BWR) radiochemical assay (RCA) data with one- and two-dimensional calculation methods
- one- and two-dimensional depletion calculations for a similar fuel assembly (i.e., to the RCA data assembly) from a BWR commercial reactor criticality (CRC) evaluation (References 7.5 and 7.6)
- one- and two-dimensional depletion calculations for a pressurized water reactor (PWR) fuel assembly at 2.5 wt% ^{235}U from the PWR Isotopic Database (Reference 7.7).

The results from these comparisons indicate that TRITON is a valuable tool for analyzing spent nuclear fuel and shows very good agreement with the CASMO3 code.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:		THE DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK
CODE/VERSION/REV	CODE/VERSION/REV	
SCALE/SAS2 V. 5	SCALE/TRITON V.5	
MCNP V. 4.B2L		☒ YES ☐ NO

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RECORD OF REVISIONS

Revision Number	Date
00 (Initial)	9/30/2004

1. PURPOSE

This calculation file provides comparisons of one- and two-dimensional methods for calculating the isotopic content of spent nuclear fuel. The one-dimensional methods use the SAS2H sequence of SCALE 4.4a (Reference 7.1) and the SAS2 sequence of SCALE 5.0 (Reference 7.2). The two-dimensional method uses the TRITON control module along with the T-DEPL sequence of SCALE 5.0 (Reference 7.3). The SAS2H results for SCALE 4.4a are taken from Reference 7.4. Data from previous two-dimensional calculations (Reference 7.5) using CASMO3 will also be used for comparisons with TRITON. The objective of these comparisons is threefold in nature: [1] to determine the accuracy of each computer code sequence in predicting the isotopic concentrations of spent nuclear fuel, [2] to identify modeling approaches that may affect each code's ability to produce accurate results, and [3] to quantify the overall effect that these modeling approaches have on calculated reactivity.

The purpose of this calculation is achieved through considering 3 sets of comparisons. These include comparing:

- boiling water reactor (BWR) radiochemical assay (RCA) data with one- and two-dimensional calculation methods
- one- and two-dimensional depletion calculations for a similar fuel assembly (i.e., to the RCA data assembly) from a BWR commercial reactor criticality (CRC) evaluation (References 7.5 and 7.6)
- one- and two-dimensional depletion calculations for a pressurized water reactor (PWR) fuel assembly at 2.5 wt% ^{235}U from the PWR Isotopic Database (Reference 7.7).

This report is an engineering calculation supporting the burnup credit methodology validation as described in Section 3.5.3.1.1 of the *Disposal Criticality Analysis Methodology Topical Report* (Reference 7.8). The calculation is performed under Framatome ANP Administrative Procedure 0402-01, Preparing and Processing FANP Calculations (Reference 7.9) and Framatome Quality Management Manual (Reference 7.10).

2. METHOD

For the first set of comparisons, the method used to compare the spent nuclear fuel isotopic concentrations consists of first using results obtained from a radiochemical assay (RCA) of several representative fuel pins from fuel assembly YJ1433 from the Limerick Unit 1 Boiling Water Reactor (Reference 7.11). Comparisons were made between the results of this RCA data and those calculated by the SAS2H sequence of SCALE 4.4a (Reference 7.4). These comparisons were for eight spent fuel samples taken from three fuel rods covering two initial ^{235}U enrichment and eight burnup values. The SAS2H model employed a six-region Path B model. The calculated and measured isotopic concentration values were each arranged into 9X9 Limerick Unit 1 GE-11 BWR fuel assemblies and modeled for criticality in a BWR waste package in MCNP (Reference 7.12). The results of these calculations, which were reported in Reference 7.4, are repeated in this document for comparison purposes.

The second comparison of this set consists of using the Limerick RCA data and calculated isotopic concentration values from the SAS2 sequence of SCALE 5.0. The Path B model was revised from a 6-region model to a 7-region model. The reason for this revision is to provide a more accurate modeling of the moderator that is not part of the central (UO_2-Gd_2O_3 rod) cell, the 500 region fuel cells, inside the water rods, nor external to the channel. This moderator has the same density and temperature of the fuel (UO_2) and Gd (UO_2-Gd_2O_3) rod cells, which is lower than the density of the water inside the water rod and the water external to the channel. This results in a harder neutron spectrum and thus a greater calculated fissile isotope concentration (particularly ^{235}U and ^{239}Pu). The SAS2 model is described in more detail in Section 5 of this document. The SAS2 calculated isotopic concentration values for each of the eight spent fuel samples are placed in the MCNP BWR waste package model and k_{eff} values are calculated for comparison with the MCNP results using the measured RCA values.

The third comparison of this set consists of using the Limerick RCA data and calculated isotopic concentration values from the TRITON control module with the T-DEPL sequence of SCALE 5.0. Moderator density values used for these calculations are the same as those used for the 7-region SAS2 model. However, the TRITON model is an explicit two-dimensional model. The TRITON calculated isotopic concentration values for each of the eight spent fuel samples are placed in the MCNP BWR waste package model and k_{eff} values are calculated for comparison with the MCNP results using the measured RCA values and the SAS2 values. The MCNP waste package model applies isotopic concentration values for a single spent fuel sample (calculated or measured) in all fuel pin locations. Thus, for the eight samples there are eight MCNP waste package calculations.

The final comparison of this set consists of using isotopic concentration values from the BWR isotopic database (Reference 7.13) for comparison with all the other calculated and measured values. It is noted that only values from the Principal Isotope set (Reference 7.8, Table 3-1) are used in these comparisons because they are the only values obtainable from the BWR isotopic database.

For the second set of comparisons, two-dimensional TRITON calculations are performed for a fuel type F assembly from the *CRC Depletion for Grand Gulf Unit 1* (Reference 7.6). The TRITON calculations are for the same compositions, dimensions, and depletion history as the CASMO3 calculations described in Section 4.3 of Reference 7.5. The CASMO3 calculations in Reference 7.5 were performed as part of the control blade model development for the one-dimensional SAS2H method. Thus, isotopic concentrations from TRITON and CASMO3 are compared. Comparisons of isotopic concentrations from SAS2H and CASMO3 are presented in Reference 7.5

The third set of comparisons is for a PWR, 15x15 Mark B fuel assembly. This is the fuel assembly type chosen for the PWR isotopic database (Reference 7.7). A fuel enrichment of 2.5 wt% ^{235}U was chosen for these comparisons. Both one-dimensional (SAS2 from SCALE 5.0) and two-dimensional (TRITON) fuel depletion calculations are performed for a fuel burnup ranging up to 50 GWd/mtU. Isotopic concentrations for the Principal Isotope set are compared as a function of burnup.

3. ASSUMPTIONS

1. For the first set of comparisons based on the Limerick RCA data one additional assumption is added to the Reference 7.4 data for SAS2H. It is assumed that coolant (moderator) density surrounding the water rods and inside the channel is at the same density as the coolant surrounding the fuel pins. The coolant inside the water rod and the coolant density outside the channel are assumed to be at saturation (solid) conditions (same as used Reference 7.4).

2. For the first set of comparisons TRITON calculations, it is assumed that the two large water rods could be modeled as 7 smaller water rods of equal volume. This assumption was made to simplify the two-dimensional TRITON input by allowing the water rods to be modeled with the same lattice structure as the fuel rods. The amount of moderator at saturation (solid) conditions and the amount of low density (high void) moderator in the assembly is preserved.

The data and application of the data for the other two sets of comparisons were taken directly from the cited references with no additional assumptions.

4. USE OF COMPUTER SOFTWARE AND MODELS

1. The SAS2 control module of the baseline SCALE, Version 5, modular code system (Reference 7.2) was used to perform the second assessment fuel assembly depletion calculations. The software specifications are as follows:

    a. SAS2 module of SCALE Version 5 - Full Certification in accordance with procedure 0902-06, Software Certification (Reference 7.14).

2. The TRITON control module of the baseline SCALE, Version 5, modular code system (Reference 7.3) were used to perform the third assessment fuel assembly depletion calculations. The software specifications are as follows:

    a. TRITON module of SCALE Version 5 - Full Certification in accordance with procedure 0902-06, Software Certification (Reference 7.14).

3. The baseline MCNP code (Reference 7.12) is used for the k_{eff} calculations in this document. The software specifications are as follows:

    a. MCNP Version 4.B2L - Full Certification in accordance with procedure 0902-06, Software Certification (Reference 7.14)

5. CALCULATION

This section describes the calculations performed to evaluate the accuracy of the one-and two-dimensional methods in predicting the isotopic concentrations of spent nuclear fuel, as well as the effect of various modeling approaches on the accuracy of the methods. The following calculations are performed in support of three sets of comparisons of isotopic concentration values for spent nuclear fuel.

1. Isotopic concentration values for eight spent fuel samples from a BWR fuel assembly are calculated using the both one- and two-dimensional calculation methods from SCALE 5. The one-dimensional method employs the SAS2 sequence of SCALE 5 and the two-dimensional method employs the TRITON control module from SCALE 5. Comparisons are also made with isotopic concentration values calculated with the one-dimensional SAS2H method (from Reference 7.4).

2. Isotopic concentration values for a type F fuel assembly from Grand Gulf Unit 1 are calculated using a two-dimensional TRITON model. Comparisons are made with isotopic concentration values calculated with a one-dimensional SAS2H model and a two-dimensional CASMO3 model (from Reference 7.5).

3. Isotopic concentration values for a PWR fuel assembly are calculated using a one-dimensional SAS2 model and a two-dimensional TRITON model. These calculations are for a B&W Mark B type fuel assembly at 2.5 wt% ^{235}U and the same conditions as the PWR Isotopic Database (Reference 7.7).

For the first set of comparisons the RCA and calculated isotopic concentration values for each spent fuel sample are input to an MCNP waste package model and k_{eff} values are calculated.

5.1 RADIOCHEMICAL ASSAY

A radiochemical assay was performed on eight samples from three representative fuel rods from the Limerick Unit 1 BWR fuel assembly YJ1433 by GE Nuclear Energy (Reference 7.11) and is used in the study reported in Reference 7.4. This data is also used for this continuance of that study. The isotopic concentrations of 38 key isotopes were measured and referenced as a function of U-238 content. Corrections were made to several short lived isotopes to date correct the data (Reference 7.4, p 11). The date corrected isotopic results are listed in Table 5-1.

Table 5-1. Measured Concentrations for Assembly YJ1433 Samples (Ref 7.4)

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8
Average Burnup (MWd/mtU)	54840	37020	62110	65540	64950	56520	57915	57810
Isotope	Measured Concentration (mg/mg U-238)							
^{234}U	1.61E-4	1.94E-4	1.66E-4	1.63E-4	1.65E-4	1.85E-4	1.80E-4	1.80E-4
^{235}U	4.26E-3	8.72E-3	1.70E-3	2.19E-3	2.69E-3	4.13E-3	4.80E-3	4.88E-3
^{236}U	5.71E-3	5.18E-3	6.00E-3	6.01E-3	6.05E-3	6.01E-3	6.21E-3	6.21E-3
^{238}Pu	4.39E-4	2.55E-4	4.00E-4	5.08E-4	5.43E-4	4.45E-4	5.07E-4	5.08E-4
^{239}Pu	5.46E-3	5.52E-3	3.94E-3	4.77E-3	5.30E-3	5.44E-3	6.14E-3	6.18E-3
^{240}Pu	3.70E-3	2.90E-3	3.12E-3	3.50E-3	3.61E-3	3.35E-3	3.76E-3	3.77E-3
^{241}Pu	1.38E-3	1.14E-3	1.06E-3	1.31E-3	1.43E-3	1.39E-3	1.50E-3	1.50E-3
^{242}Pu	1.19E-3	6.33E-4	1.54E-3	1.62E-3	1.56E-3	1.23E-3	1.16E-3	1.14E-3
^{143}Nd	1.02E-3	9.19E-4	8.52E-4	9.85E-4	1.04E-3	1.04E-3	1.11E-3	1.11E-3
^{145}Nd	1.01E-3	7.99E-4	1.13E-3	1.17E-3	1.16E-3	1.06E-3	1.07E-3	1.07E-3
^{146}Nd	1.23E-3	8.52E-4	1.43E-3	1.52E-3	1.50E-3	1.28E-3	1.32E-3	1.31E-3
^{148}Nd	6.15E-4	4.44E-4	6.96E-4	7.36E-4	7.29E-4	6.37E-4	6.51E-4	6.49E-4
^{150}Nd	3.09E-4	2.16E-4	3.42E-4	3.68E-4	3.65E-4	3.15E-4	3.25E-4	3.23E-4
^{134}Cs (c)	5.74E-5	3.35E-5	5.90E-5	7.17E-5	7.22E-5	5.66E-5	6.24E-5	6.21E-5
^{137}Cs (c)	1.87E-3	1.35E-3	1.99E-3	2.17E-3	2.09E-3	1.78E-3	1.95E-3	1.94E-3
^{151}Eu	4.77E-7	4.32E-7	3.42E-7	4.04E-7	4.38E-7	4.52E-7	5.19E-7	5.26E-7
^{153}Eu	1.94E-4	1.41E-4	2.09E-4	2.21E-4	2.15E-4	2.01E-4	1.97E-4	1.97E-4
^{155}Eu	7.96E-6	5.36E-6	8.01E-6	9.01E-6	8.74E-6	8.00E-6	8.11E-6	8.10E-6
^{147}Sm	2.88E-4	2.58E-4	2.95E-4	2.96E-4	2.90E-4	2.99E-4	2.94E-4	2.95E-4
^{149}Sm	2.69E-6	2.91E-6	1.67E-6	2.35E-6	2.81E-6	3.08E-6	2.94E-6	2.95E-6
^{150}Sm	4.81E-4	3.34E-4	4.98E-4	5.51E-4	5.43E-4	4.90E-4	5.07E-4	5.04E-4
^{151}Sm	1.35E-5	1.23E-5	1.01E-5	1.24E-5	1.35E-5	1.35E-5	1.54E-5	1.53E-5
^{152}Sm	1.52E-4	1.20E-4	1.79E-4	1.76E-4	1.66E-4	1.58E-4	1.49E-4	1.48E-4
^{155}Gd (a)	1.19E-5	9.68E-6	7.80E-6	8.78E-6	9.18E-6	7.79E-6	8.60E-6	8.09E-6
^{241}Am	3.89E-4	3.17E-4	2.83E-4	3.26E-4	3.81E-4	3.69E-4	4.08E-4	4.14E-4
^{242m}Am	1.18E-6	1.16E-6	6.68E-7	8.18E-7	9.90E-7	1.06E-6	1.42E-6	1.46E-6
^{243}Am	3.03E-4	1.30E-4	3.62E-4	3.92E-4	4.19E-4	3.01E-4	2.96E-4	2.97E-4
^{237}Np	7.92E-4	5.40E-4	7.67E-4	9.00E-4	8.86E-4	8.22E-4	8.60E-4	8.65E-4
^{95}Mo	1.27E-3	9.94E-4	1.43E-3	1.42E-3	1.37E-3	1.27E-3	1.28E-3	1.28E-3
^{99}Tc (b)	1.27E-3	9.99E-4	1.39E-3	1.36E-3	1.40E-3	1.16E-3	1.22E-3	1.18E-3
^{101}Ru	1.28E-3	9.56E-4	1.50E-3	1.51E-3	1.47E-3	1.33E-3	1.32E-3	1.36E-3
^{103}Rh	7.45E-4	6.07E-4	7.22E-4	7.59E-4	8.00E-4	7.41E-4	7.54E-4	7.84E-4
^{109}Ag	1.61E-4	1.10E-4	1.46E-4	1.53E-4	1.55E-4	1.21E-4	1.34E-4	1.51E-4
^{242}Cm (c)	4.91E-8	3.73E-8	3.75E-8	3.76E-8	5.28E-8	5.56E-8	4.81E-8	4.27E-8
^{243}Cm	1.15E-6	6.48E-7	8.49E-7	1.13E-6	1.37E-6	1.21E-6	1.24E-6	1.30E-6
^{244}Cm	1.56E-4	4.61E-5	1.81E-4	2.21E-4	2.43E-4	1.51E-4	1.62E-4	1.63E-4
^{245}Cm	1.28E-5	3.28E-6	9.50E-6	1.53E-5	1.90E-5	1.13E-5	1.53E-5	1.53E-5
^{246}Cm	2.94E-6	4.17E-7	3.46E-6	5.10E-6	5.54E-6	2.47E-6	3.10E-6	3.10E-6

NOTE: (a) Not including ^{155}Gd from decay of ^{155}Eu; (b) includes any ^{99}Ru present in the sample solution; (c) decay corrected to July 15, 2002.

5.1.1 Fuel Assembly Design and Sample Parameters

The general fuel assembly design parameters for assembly YJ1433 are taken from Table 5-3 of Reference 7.4 and are repeated in Table 5-2 below.

Table 5-2. Fuel Assembly YJ1433 Geometric and Material Information (Ref 7.4)

Fuel Assembly Parameter	Value
Lattice	9x9
Number of lattice positions occupied by water rods	7
Number of fuel rods	74
Number of rods containing Gd2O3	9
Number of part-length fuel rods	8
Rod pitch (cm)	1.440
Assembly pitch (cm)	15.240
Assembly channel material	Zircaloy-4
Fuel Rod Data	
Cladding outer diameter (cm)	1.1176
Cladding thickness (cm)	0.0711
Cladding inner diameter (cm) (= Outer diameter -2 * Thickness)	0.9754
Fill gas	Helium
Cladding Material	Zircaloy-2
Fuel Pellet Data	
Diameter (cm)	0.9550
Pellet material	UO2

A two-dimensional representation of this fuel assembly is presented in Figure 5-1. The basis for the choice of the pin placement for this assembly is taken from Reference 7.15. The criticality study in Reference 7.15 was for a GE11 9x9 fuel assembly containing two water rods (occupying 7 lattice positions). The equivalent 7-water rod representation of this fuel assembly is presented in Figure 5-2. The radial and axial locations of the 8-spent fuel samples are given in Reference 7.4 and are illustrated in Figures 5-1, 5-2, and 5-3 below. The sample burnup values are also provided in Figure 5.3

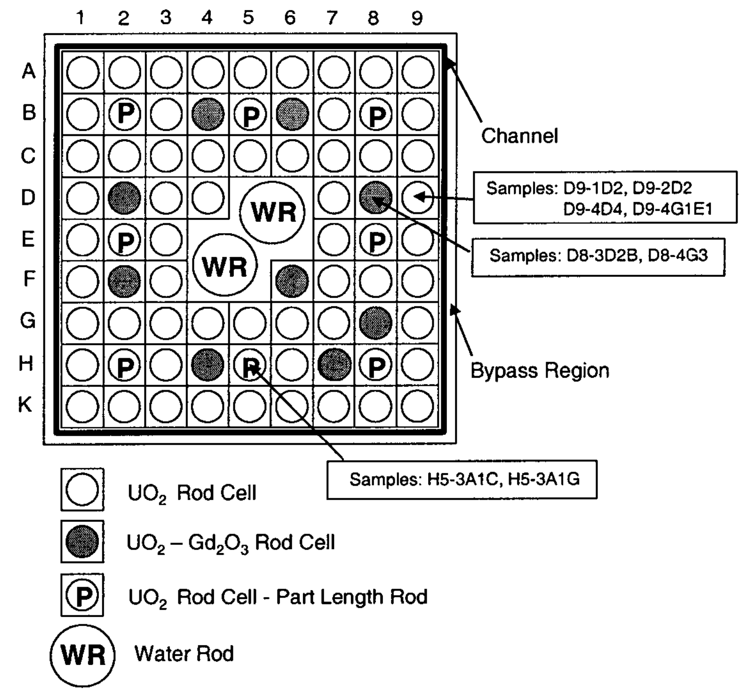


Figure 5-1. Limerick Fuel Assembly YJ1433 with 2-Water Rod Representation

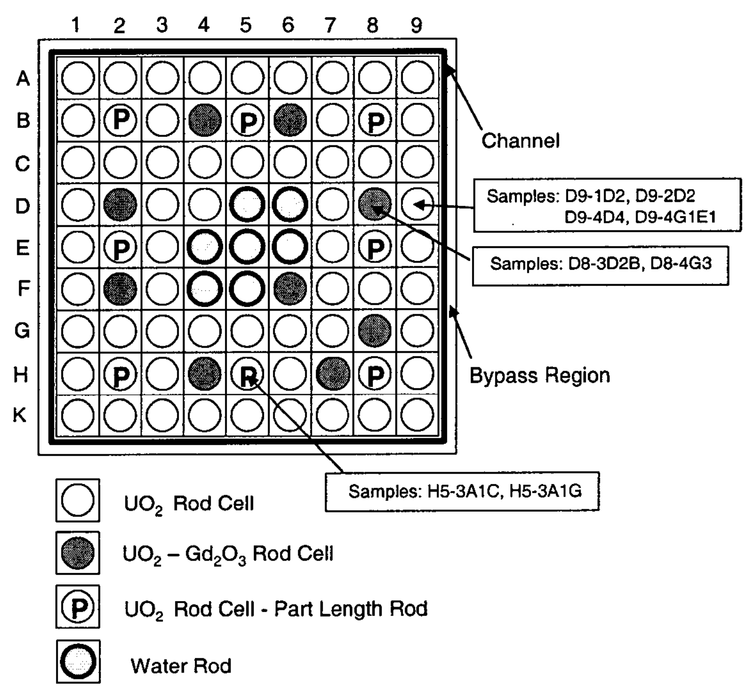


Figure 5-2. Limerick Fuel Assembly YJ1433 with Equivalent 7-Water Rod Representation

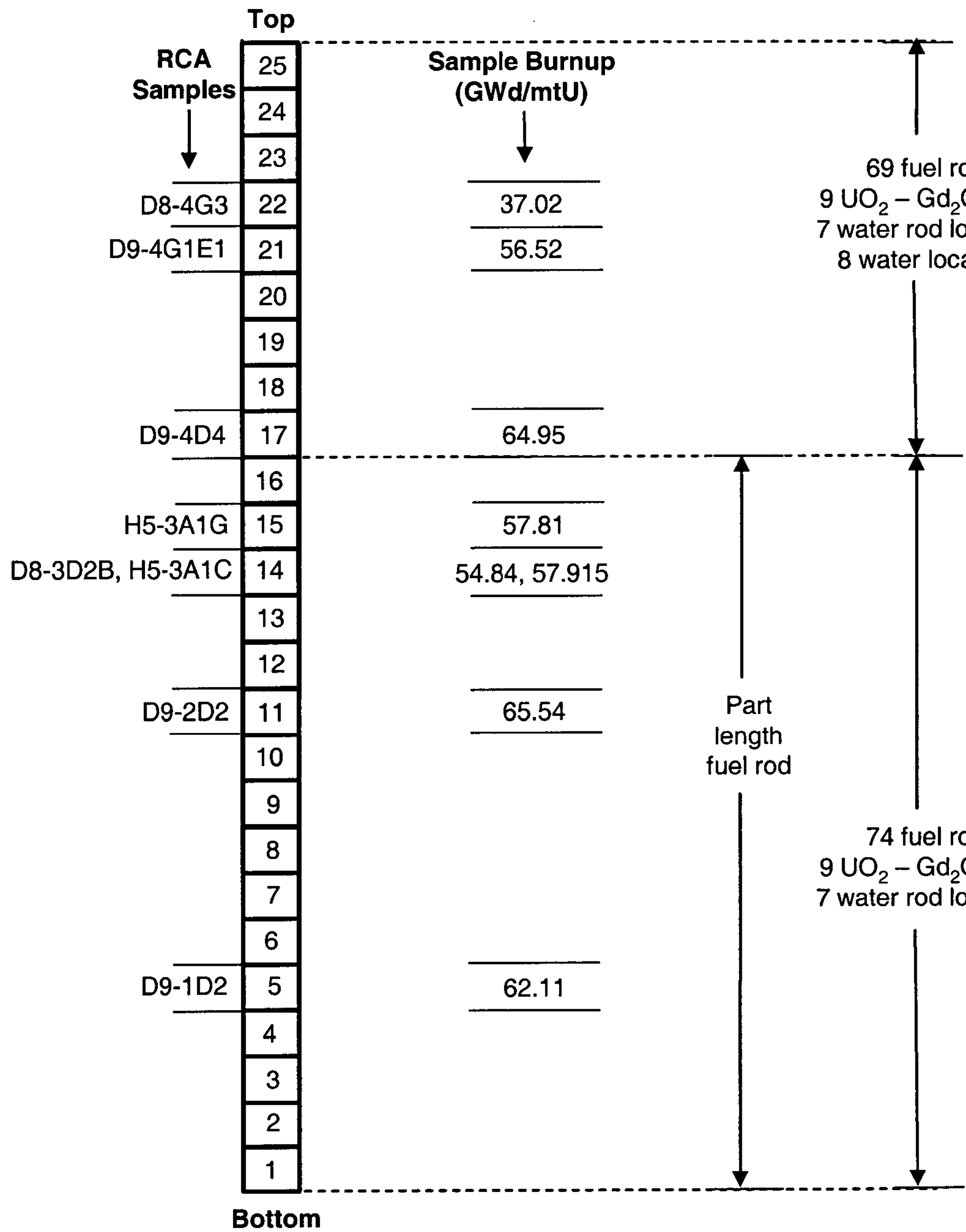


Figure 5-3. Limerick Fuel Assembly YJ1433 Axial Representation

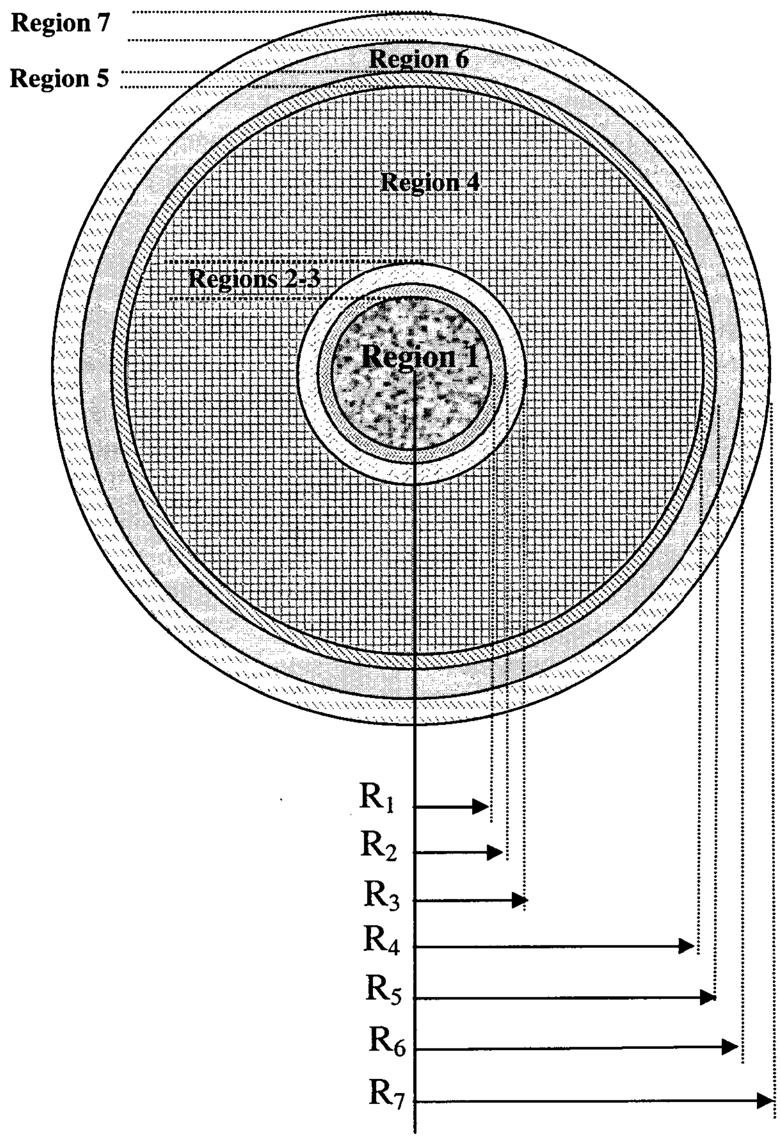
The samples in location D8 had an as-built ^{235}U enrichment of 3.6 wt% and an as-built Gd_2O_3 enrichment of 5.0 wt%. The samples in locations D9 and H5 had an as-built ^{235}U enrichment of 3.95 wt% and no integral burnable absorber (Gd_2O_3). The placement of the part-length fuel rods and the UO_2-Gd_2O_3 rods is based on engineering judgment and is consistent with the placement of the spent fuel samples and reference 7.15.

5.1.2 SAS2 Calculation

The Path B model used for the SAS2 depletion calculations is illustrated in Figure 5-4. The central cell for this model is a UO_2-Gd_2O_3 rod cell. The gadolonia – fuel pellet is smeared to the clad inner diameter (no gap and pellet density adjusted accordingly) and is represented as region 1. Region 2 is the cladding and region 3 is the water associated with the UO_2-Gd_2O_3 rod cell. Region 4 is the homogenized fuel region representing the fraction of fuel rod cells associated with one UO_2 - Gd_2O_3 rod cell. The Path B representation for the first four regions is identical to the representation in Reference 7.4. The remainder of the Path B model for this calculation is different from Reference 7.4. Region 5 in Reference 7.4 is the assembly channel and region 6 is the bypass moderator. The bypass moderator in the Reference 7.4 representation also included the water inside the water rods and any additional water inside the channel that was not associated with a fuel rod cell or UO_2-Gd_2O_3 rod cell. The density of the water inside the water rods is the same as in the bypass region (i.e. saturated water), whereas the density of the water outside of the water rods, inside the channel, but not part of either the fuel rod cells or UO_2-Gd_2O_3 rod cells is at voided conditions (i.e. same as fueled cells). Thus, the 6-region Path B model of Reference 7.4 was changed to a 7-region Path B model to accommodate the water density differences. Region 5 for this calculation represents the water inside the channel, external to the water rods and fuel/fuel-Gd rod cells, and is at the same density as the water in the fuel/ fuel-Gd rod cells. The amount of water in this region is the amount associated with one UO_2-Gd_2O_3 rod cell. Region 6 is the channel region and represents the amount of channel associated with one fuel-Gd rod cell. Region 7 contains the bypass water, water rod tubes and water inside the water rod. The amount of these materials is that associated with a single fuel-Gd rod.

The equations for the radii of the 7-region Path B model, including the volume fraction of water rod tubes and water in region 7 are presented below. Define:

P_A = Assembly pitch = 15.24 cm
C_{IW} = Channel inner width = 13.2461 cm (Ref 7.6, p 45)
C_{OW} = Channel outer width = 13.8557 cm (Ref 7.6, p 45)
p = Pin pitch = 1.44 cm
N_{FU} = Number of fuel rods in upper region (above part length rods) = 66
N_{FL} = Number of fuel rods in lower region (with part length rods) = 74
N_G = Number of Gd rods = 9
N_{NGU} = Number of non-Gd rods in upper region = $N_{FU} - N_G$ = 57
N_{NGL} = Number of non-Gd rods in lower region = $N_{FL} - N_G$ = 65
N_W = Number of water rods = 2
W_{ID} = Tube inner diameter in water rod cell = 2.3368 cm (Ref 7.15, Table 3.1-1)
W_{OD} = Tube outer diameter in water rod cell = 2.4892 cm (Ref 7.15, Table 3.1-1)



Central Cell:	Region 1 through 3 (Average Gd rod cell)
Region 1:	Gd rod plus gap
Region 2:	Gd rod cladding
Region 3:	Moderator
Region 4:	Homogenized Fuel Region
Region 5:	H_2O inside channel & external to fuel & water rods
Region 6:	Channel
Region 7:	Bypass region water, water rod tubes + water inside

Figure 5-4. Path B Model with Central Cell Representing a Gadolinia Rod

Fuel pellet diameter is the same as the clad inner diameter
C_{ID} = Clad inner diameter = 0.9754 cm
C_{OD} = Clad outer diameter = 1.1176 cm

Equations for radii of Path B model:

$\mathbf{R_1} = C_{ID} / 2 = \underline{0.4877 \text{ cm}}$

$\mathbf{R_2} = C_{OD} / 2 = \underline{0.5588 \text{ cm}}$

Area of central cell = $p^2 = \pi (R_3)^2$

$\mathbf{R_3} = p / [\pi]^{1/2} = \underline{0.81243 \text{ cm}}$

Area of Gd rod cells in fuel assembly = $(N_G) \pi (R_3)^2$

Area of homogenized fuel cells in assembly
$= (N_{NGU})(p)^2 = (N_{NGU}) \pi (R_3)^2$ (for upper region)
$= (N_{NGL})(p)^2 = (N_{NGL}) \pi (R_3)^2$ (for lower region)

Area of homogenized fuel cells in Path B model (i.e., per Gd cell)
$= \pi (R_3)^2 (N_{NGU} / N_G)$ (for upper region)
$= \pi (R_3)^2 (N_{NGL} / N_G)$ (for lower region)

$\pi (R_4)^2 = \pi (R_3)^2 + \pi (R_3)^2 (N_{NGU} / N_G) = \pi (R_3)^2 [1 + N_{NGU} / N_G]$
$= \pi (R_3)^2 [N_{FU} / N_G] = p^2 [N_{FU} / N_G]$ (for upper region)

$\pi (R_4)^2 = \pi (R_3)^2 + \pi (R_3)^2 (N_{NGL} / N_G) = \pi (R_3)^2 [1 + N_{NGL} / N_G]$
$= \pi (R_3)^2 [N_{FL} / N_G] = p^2 [N_{FL} / N_G]$ (for lower region)

$\mathbf{R_4} = p [N_{FU} / (\pi * N_G)]^{1/2} = \underline{2.20008 \text{ cm (for upper region)}}$
$= p [N_{FL} / (\pi * N_G)]^{1/2} = \underline{2.32960 \text{ cm (for lower region)}}$

A_{WXT} = Area of water inside the channel and external to fuel rods and water rod tubes
$= (C_{IW})^2 - p^2 (N_{FX}) - (N_W) \pi (W_{OD} / 2.0)^2$
where
N_{FX} $= N_{FU}$ for upper region
$= N_{FL}$ for lower region

$\pi (R_5)^2 = \pi (R_4)^2 + (A_{WXT} / N_G)$
$= p^2 [N_{FX} / N_G] + (C_{IW})^2 / N_G - p^2 [N_{FX} / N_G] - [N_W / N_G] \pi (W_{OD} / 2.0)^2$

$\mathbf{R_5} = [(C_{IW})^2 / (\pi N_G) - (W_{OD} / 2.0)^2 (N_W / N_G)]^{1/2} = \underline{2.421026 \text{ cm}}$

Area of channel = $(C_{OW})^2 - (C_{IW})^2$
Area of region 6 = $[(C_{OW})^2 - (C_{IW})^2] / N_G$
$\pi (R_6)^2 = \pi (R_5)^2 - [(C_{OW})^2 - (C_{IW})^2] / N_G$

$\mathbf{R_6} = \{(R_5)^2 - [(C_{OW})^2 - (C_{IW})^2] / \pi (N_G)\}^{1/2} = \underline{2.53884 \text{ cm}}$

$\mathbf{R_7} = P_A / [\pi (N_G)]^{1/2} = \underline{2.86608 \text{ cm}}$

Equations for volume fractions of water tubes and water in Region 7:

A_{WT7} = Area of water rod tubes in region 7 = $\{(\pi / 4) [(W_{OD})^2 - (W_{OD})^2] (N_W)\} / N_G$

$\mathbf{VF_{WT}}$ = Volume fraction of water rod tube in region 7 = $A_{WT7} / \pi [(R_7)^2 - (R_6)^2]$
= $\{[(W_{OD})^2 - (W_{OD})^2] (N_W)\} / \{4*(N_G) [(R_7)^2 - (R_6)^2]\}$
= $\underline{0.0231}$

$\mathbf{VF_W}$ = Volume fraction of water in region 7 = 1.0 - VF_{WT} = $\underline{0.9769}$

The fuel/fuel-Gd densities and enrichments for these calculations are the values that are applicable for the particular spent fuel sample being analyzed. Table 5-3 presents the densities and enrichments for regions 1 and 4 of the Path B model for the eight fuel samples. The densities are calculated based on data from Reference 7.11 with the pellet extended to the clad inner diameter (no gap).

Table 5-3. SAS2 Regions 1 and 4 RCA Sample Information

	Region 1 (UO_2-Gd_2O_3)			Region 4	
Sample ID	**Pellet Density (g/cm^3)**	**Enrichment ^{235}U wt%**	**Enrichment Gd_2O_3 wt%**	**Pellet Density (g/cm^3)**	**Enrichment ^{235}U wt%**
D8-3D2B	9.37605	3.60	5.0	9.37605	3.60
D8-4G3	9.37605	3.60	5.0	9.37605	3.60
D9-1D2	10.01868	3.95	5.0	10.01868	3.95
D9-2D2	10.01868	3.95	5.0	10.01868	3.95
D9-4D4	10.01868	3.95	5.0	10.01868	3.95
D9-4G1E1	10.01868	3.95	5.0	10.01868	3.95
H5-3A1C	10.01868	3.95	5.0	10.01868	3.95
H5-3A1G	10.01868	3.95	5.0	10.01868	3.95

Source: Reference 7.11, Table 1-2 and Table 1-3

The initial concentrations of ^{234}U and ^{238}U for these calculations are the same values used for the SAS2H analysis in Reference 7.4 (Table 5-7). The D8 rod samples had an initial concentration of 0.0324 wt% for ^{234}U and 96.3676 wt% for ^{238}U. The D9 and H5 rod samples had an initial concentration of 0.03555 wt% for ^{234}U and 96.01445 wt% for ^{238}U. The trace isotopes specified in the fresh fuel compositions and the Zircaloy-2 and Zircaloy-4 compositions are also the same as used for the SAS2H analysis in Reference 7.4 (Tables 5-5 and 5-6).

The operating history data for the SAS2 depletion calculations are from Table 5-9 of Reference 7.4. This data is repeated in Table 5-4 below. The column headings in Table 5-4 are the same as the keywords used in the power history data block of the SAS2 input. The input for this table is as follows:

power – nodal power (MW) for a given irradiation step

burn – fuel irradiation time, days

down – down time (days) following burn

h2of – node-averaged fraction of first power step moderator density

tmpf – node-averaged fuel temperature for the irradiation step (K)

tmpc – node-averaged fuel clad temperature for the irradiation step (K)

tmpm – node-averaged moderator temperature for the irradiation step (K)

Sample listings of the SAS2H and SAS2 input for the Limerick spent fuel sample calculations are given in Appendix A.

Table 5-4. Operating History Information for Assembly YJ1433

		Node 14 (D8-3D2B)					Node 22 (D8-4G3)				
burn	down	power	h2of	tmpf	tmpc	tmpm	power	h2of	tmpf	tmpc	tmpm
73.0	0	0.19348	1.000	1059	574	561	0.08331	1.000	854	568	561
45.5	0	0.19718	0.877	1068	575	561	0.08553	0.902	862	569	561
45.5	0	0.19718	0.877	1068	575	561	0.08553	0.902	862	569	561
45.5	0	0.20425	0.880	1085	575	561	0.10600	0.896	929	570	561
45.5	0	0.20425	0.880	1085	575	561	0.10600	0.896	929	570	561
45.5	0	0.20348	0.978	1083	575	561	0.12238	0.905	982	572	561
45.5	0	0.20348	0.978	1083	575	561	0.12238	0.905	982	572	561
55.0	0	0.23563	0.878	1160	578	562	0.12725	1.065	998	573	562
53.0	0	0.21628	0.934	1114	577	562	0.12981	1.027	1007	574	562
50.0	0	0.24685	1.073	1183	575	558	0.16590	0.916	1118	573	558
67.0	38	0.20453	1.272	1086	575	561	0.16060	0.827	1103	575	561
57.0	0	0.26255	0.696	1220	577	559	0.12149	1.774	978	570	559
65.0	0	0.24847	0.678	1189	577	560	0.12530	1.511	991	572	560
42.5	0	0.23814	0.725	1164	576	559	0.11584	1.246	960	570	559
42.5	0	0.23814	0.725	1164	576	559	0.11584	1.246	960	570	559
37.0	0	0.23024	0.779	1147	577	562	0.13369	1.140	1019	574	562
67.0	0	0.23010	0.793	1146	576	560	0.13108	1.041	1010	572	560
37.0	0	0.20482	0.819	1086	574	560	0.15234	0.910	1077	573	560
67.0	0	0.22097	0.889	1124	575	560	0.16937	0.835	1130	575	560
35.0	0	0.19817	0.847	1070	574	560	0.11503	0.850	958	571	560
42.0	0	0.21758	0.947	1116	575	560	0.13324	0.900	1016	572	560
43.0	0	0.14627	0.955	945	572	562	0.10259	0.887	918	571	562
43.0	0	0.14627	0.955	945	572	562	0.10259	0.887	918	571	562
60.0	0	0.21285	1.078	1105	574	560	0.16603	0.966	1120	575	560
45.0	27	0.19883	1.293	1072	574	560	0.16373	1.161	1113	575	560
57.0	0	0.16851	0.926	1001	575	563	0.06781	0.951	804	569	563
78.0	0	0.19549	0.873	1065	575	562	0.07698	0.906	834	569	562
60.5	0	0.20135	0.894	1079	576	562	0.09416	0.876	891	571	562
60.5	0	0.20135	0.894	1079	576	562	0.09416	0.876	891	571	562
71.0	0	0.19366	0.952	1061	576	562	0.11309	0.921	953	573	562
74.0	0	0.20782	0.961	1095	576	562	0.10944	0.935	941	572	562
71.0	0	0.18913	1.111	1051	576	563	0.14128	0.992	1044	576	563
81.0	0	0.15965	1.157	979	574	563	0.13612	1.066	1028	575	563
41.0	0	0.15220	1.101	960	572	562	0.13692	1.046	1029	574	562
48.0	0	0.16887	1.000	1002	575	563	0.12618	1.008	996	575	563
48.0	0	0.16091	1.073	983	574	563	0.12809	1.060	1003	575	563
63.0	1510	0.12927	1.307	902	569	560	0.10709	1.247	932	569	560

Table 5-4. Operating History Information for Assembly YJ1433 (continued)

		Node 5 (D9-1D2)					Node 11 (D9-2D2)				
burn	down	power	h2of	tmpf	tmpc	tmpm	power	h2of	tmpf	tmpc	tmpm
73.0	0	0.19255	1.000	1026	573	561	0.23202	1.000	1107	575	561
45.5	0	0.28620	0.939	1233	579	561	0.26529	0.853	1180	578	561
45.5	0	0.28620	0.939	1233	579	561	0.26529	0.853	1180	578	561
45.5	0	0.28423	0.900	1228	579	561	0.25452	0.848	1156	577	561
45.5	0	0.28423	0.900	1228	579	561	0.25452	0.848	1156	577	561
45.5	0	0.25907	0.974	1174	577	561	0.23305	0.977	1110	576	561
45.5	0	0.25907	0.974	1174	577	561	0.23305	0.977	1110	576	561
55.0	0	0.31797	0.927	1301	582	562	0.29177	0.872	1237	580	562
53.0	0	0.23395	0.965	1120	577	562	0.25663	0.933	1162	578	562
50.0	0	0.23235	1.035	1113	573	558	0.28952	1.082	1229	576	558
67.0	38	0.13960	1.073	905	570	561	0.23129	1.268	1106	575	561
57.0	0	0.33150	0.848	1328	580	559	0.33564	0.716	1327	580	559
65.0	0	0.36368	0.805	1396	584	560	0.32068	0.684	1296	581	560
42.5	0	0.36585	0.835	1400	583	559	0.30160	0.726	1256	578	559
42.5	0	0.36585	0.835	1400	583	559	0.30160	0.726	1256	578	559
37.0	0	0.29116	0.845	1244	580	562	0.27503	0.766	1201	579	562
67.0	0	0.30643	0.844	1276	580	560	0.27154	0.773	1193	578	560
37.0	0	0.26226	0.875	1180	576	560	0.23440	0.803	1112	574	560
67.0	0	0.23495	0.971	1120	575	560	0.24842	0.905	1142	575	560
35.0	0	0.22000	0.932	1088	574	560	0.23686	0.844	1118	575	560
42.0	0	0.21928	0.984	1086	574	560	0.25812	0.951	1164	576	560
43.0	0	0.13279	1.001	890	570	562	0.16652	0.969	963	572	562
43.0	0	0.13279	1.001	890	570	562	0.16652	0.969	963	572	562
60.0	0	0.17655	1.040	989	571	560	0.24491	1.098	1135	575	560
45.0	27	0.13438	1.077	893	569	560	0.22816	1.304	1099	575	560
57.0	0	0.15984	1.007	954	573	563	0.21049	0.942	1062	576	563
78.0	0	0.20550	0.977	1057	575	562	0.25345	0.873	1155	578	562
60.5	0	0.20948	0.948	1066	576	562	0.23769	0.888	1121	577	562
60.5	0	0.20948	0.948	1066	576	562	0.23769	0.888	1121	577	562
71.0	0	0.19830	1.001	1041	575	562	0.23943	0.972	1125	578	562
74.0	0	0.18613	1.000	1013	574	562	0.25311	0.983	1154	578	562
71.0	0	0.16350	1.026	962	574	563	0.18066	1.119	996	575	563
81.0	0	0.17005	1.021	977	574	563	0.17242	1.143	977	574	563
41.0	0	0.18649	0.994	1014	574	562	0.18265	1.069	999	573	562
48.0	0	0.23810	0.920	1130	579	563	0.19833	0.957	1035	576	563
48.0	0	0.18756	0.965	1017	575	563	0.18429	1.038	1004	575	563
63.0	1510	0.13378	1.052	891	568	560	0.15039	1.256	925	569	560

Table 5-4. Operating History Information for Assembly YJ1433 (continued)

		Node 17 (D9-4D4)					Node 21 (D9-41GE1)				
burn	down	power	h2of	tmpf	tmpc	tmpm	power	h2of	tmpf	tmpc	tmpm
73.0	0	0.18271	1.000	1062	574	561	0.13137	1.000	930	570	561
45.5	0	0.18458	0.882	1067	575	561	0.13469	0.891	939	571	561
45.5	0	0.18458	0.882	1067	575	561	0.13469	0.891	939	571	561
45.5	0	0.21496	0.874	1143	576	561	0.16663	0.876	1022	573	561
45.5	0	0.21496	0.874	1143	576	561	0.16663	0.876	1022	573	561
45.5	0	0.24941	0.946	1228	579	561	0.19459	0.898	1093	575	561
45.5	0	0.24941	0.946	1228	579	561	0.19459	0.898	1093	575	561
55.0	0	0.26319	0.844	1263	581	562	0.20343	0.959	1116	577	562
53.0	0	0.24836	0.893	1226	580	562	0.20660	0.937	1124	577	562
50.0	0	0.28455	1.023	1312	579	558	0.25913	0.917	1252	577	558
67.0	38	0.23933	1.228	1204	578	561	0.24137	0.978	1210	579	561
57.0	0	0.25400	0.729	1238	578	559	0.19225	1.436	1086	573	559
65.0	0	0.24489	0.700	1217	578	560	0.19441	1.235	1092	574	560
42.5	0	0.23708	0.699	1197	576	559	0.18062	1.009	1056	572	559
42.5	0	0.23708	0.699	1197	576	559	0.18062	1.009	1056	572	559
37.0	0	0.25360	0.759	1239	580	562	0.20588	0.990	1122	577	562
67.0	0	0.26351	0.768	1263	580	560	0.20480	0.922	1119	575	560
37.0	0	0.23457	0.796	1191	577	560	0.23120	0.823	1184	577	560
67.0	0	0.25440	0.858	1240	578	560	0.25640	0.798	1246	578	560
35.0	0	0.20907	0.824	1128	576	560	0.17684	0.815	1048	573	560
42.0	0	0.22919	0.930	1178	577	560	0.20237	0.891	1112	575	560
43.0	0	0.15925	0.953	1002	573	562	0.15184	0.907	984	573	562
43.0	0	0.15925	0.953	1002	573	562	0.15184	0.907	984	573	562
60.0	0	0.23439	1.049	1191	577	560	0.23936	0.986	1204	577	560
45.0	27	0.21826	1.241	1151	576	560	0.23172	1.188	1186	577	560
57.0	0	0.15473	0.931	992	574	563	0.10735	0.948	868	571	563
78.0	0	0.17428	0.887	1041	575	562	0.12128	0.904	904	571	562
60.5	0	0.19138	0.896	1085	576	562	0.14585	0.882	969	573	562
60.5	0	0.19138	0.896	1085	576	562	0.14585	0.882	969	573	562
71.0	0	0.19113	0.943	1084	576	562	0.16984	0.928	1031	575	562
74.0	0	0.19808	0.955	1102	577	562	0.16665	0.942	1023	574	562
71.0	0	0.21880	1.066	1154	579	563	0.21403	1.009	1144	579	563
81.0	0	0.17623	1.138	1047	576	563	0.20274	1.086	1115	578	563
41.0	0	0.17503	1.104	1043	574	562	0.20369	1.062	1117	577	562
48.0	0	0.17902	1.025	1054	576	563	0.18537	1.018	1072	577	563
48.0	0	0.17331	1.087	1040	576	563	0.18472	1.074	1070	577	563
63.0	1510	0.13888	1.304	948	570	560	0.15201	1.264	983	571	560

Table 5-4. Operating History Information for Assembly YJ1433 (continued)

		Node 14 (H5-3A1C)					Node 15 (H5-3A1G)				
burn	down	power	h2of	tmpf	tmpc	tmpm	power	h2of	tmpf	tmpc	tmpm
73.0	0	0.20433	1.000	1104	575	561	0.19860	1.000	1087	575	561
45.5	0	0.20823	0.877	1114	576	561	0.19891	0.881	1089	575	561
45.5	0	0.20823	0.877	1114	576	561	0.19891	0.881	1089	575	561
45.5	0	0.21570	0.880	1132	576	561	0.21298	0.882	1123	576	561
45.5	0	0.21570	0.880	1132	576	561	0.21298	0.882	1123	576	561
45.5	0	0.21489	0.978	1130	576	561	0.21974	0.972	1139	576	561
45.5	0	0.21489	0.978	1130	576	561	0.21974	0.972	1139	576	561
55.0	0	0.24884	0.878	1213	580	562	0.24720	0.871	1206	579	562
53.0	0	0.22841	0.934	1164	578	562	0.22941	0.927	1163	578	562
50.0	0	0.26069	1.073	1239	576	558	0.26297	1.062	1241	577	558
67.0	38	0.21600	1.272	1133	576	561	0.21927	1.261	1138	576	561
57.0	0	0.27727	0.696	1279	579	559	0.26841	0.689	1255	578	559
65.0	0	0.26241	0.678	1245	579	560	0.25473	0.673	1223	578	560
42.5	0	0.25149	0.725	1218	577	559	0.24569	0.715	1201	577	559
42.5	0	0.25149	0.725	1218	577	559	0.24569	0.715	1201	577	559
37.0	0	0.24315	0.779	1199	579	562	0.25029	0.772	1213	579	562
67.0	0	0.24300	0.793	1198	578	560	0.25549	0.788	1225	579	560
37.0	0	0.21630	0.819	1133	575	560	0.21936	0.817	1137	575	560
67.0	0	0.23336	0.889	1174	576	560	0.23707	0.883	1180	577	560
35.0	0	0.20928	0.847	1116	575	560	0.20801	0.844	1110	575	560
42.0	0	0.22978	0.947	1166	577	560	0.22823	0.944	1159	576	560
43.0	0	0.15448	0.955	980	573	562	0.15535	0.955	980	573	562
43.0	0	0.15448	0.955	980	573	562	0.15535	0.955	980	573	562
60.0	0	0.22478	1.078	1153	576	560	0.22645	1.069	1155	576	560
45.0	27	0.20997	1.293	1118	575	560	0.21121	1.275	1118	575	560
57.0	0	0.17795	0.926	1041	576	563	0.17272	0.926	1025	575	563
78.0	0	0.20645	0.873	1110	577	562	0.19865	0.877	1089	576	562
60.5	0	0.21264	0.894	1126	577	562	0.20975	0.895	1116	577	562
60.5	0	0.21264	0.894	1126	577	562	0.20975	0.895	1116	577	562
71.0	0	0.20451	0.952	1106	577	562	0.20211	0.947	1097	577	562
74.0	0	0.21947	0.961	1142	578	562	0.21509	0.958	1129	577	562
71.0	0	0.19974	1.111	1095	577	563	0.21091	1.095	1120	578	563
81.0	0	0.16860	1.157	1017	575	563	0.17305	1.152	1026	575	563
41.0	0	0.16073	1.101	996	573	562	0.16411	1.105	1003	573	562
48.0	0	0.17834	1.000	1042	576	563	0.18076	1.010	1045	576	563
48.0	0	0.16993	1.073	1021	576	563	0.17298	1.079	1026	576	563
63.0	1510	0.13652	1.307	933	570	560	0.13837	1.310	936	570	560

5.1.3 TRITON Calculation

The TRITON calculations use the same material and composition data that is used for the SAS2 calculations. The geometric representation for the SAS 2 Path B model is presented in Figure 5-4. The geometric representation for the TRITON model follows the two-dimensional fuel assembly layout presented in Figure 5-2. A total of eight TRITON calculations are performed (one for each RCA sample). Each depletion calculation was performed to the appropriate burnup for the particular RCA sample analyzed. From Figures 5-2 and 5-3, five of the TRITON calculations contained 74 fuel rods (nine of these fuel rods were $UO_2 - Gd_2O_3$ rods) and seven water rod locations. The other three TRITON calculations contained 69 fuel rods (nine of these fuel rods were $UO_2 - Gd_2O_3$ rods), seven water rod locations, and eight water locations above the part-length fuel rods. The moderator density values and moderator density multipliers presented in Table 5-4 for the SAS2 calculations are used for the TRITON calculations. These moderator density values are used for the low-density moderator (i.e. inside the channel, surrounding "heated" fuel rods, but outside the water rods). The moderator density for the region external to the channel and the region inside the water rods is at saturation (but "solid") condition. This is the same as that modeled in SAS2. The fuel temperature values presented in Table 5-4 for the SAS2 calculations are also used for the TRITON calculations.

The burn (fuel irradiation time, days) and down (down time in days following burn) data in TRITON is identical to SAS2. The power data is different. For SAS2 power is the nodal power (MW) for a given irradiation step. For TRITON power is the specific power (MW per metric tonne of heavy metal). Table 5-5 presents the power, burn, and down values used for the TRITON calculations.

A sample listing of the TRITON input for the Limerick spent fuel sample calculations is given in Appendix A.

Table 5-5. Operating History Information for Assembly YJ1433 - TRITON

burn	down	Power (MW/MTHM)							
		D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-41GE1	H5-3A1C	H5-3A1G
73.0	0	26.35	12.74	26.23	31.60	27.95	20.10	27.83	27.05
45.5	0	26.86	13.08	38.98	36.14	28.24	20.60	28.36	27.09
45.5	0	26.86	13.08	38.98	36.14	28.24	20.60	28.36	27.09
45.5	0	27.82	16.22	38.72	34.67	32.88	25.49	29.38	29.01
45.5	0	27.82	16.22	38.72	34.67	32.88	25.49	29.38	29.01
45.5	0	27.72	18.72	35.29	31.74	38.15	29.77	29.27	29.93
45.5	0	27.72	18.72	35.29	31.74	38.15	29.77	29.27	29.93
55.0	0	32.10	19.47	43.31	39.74	40.26	31.12	33.90	33.67
53.0	0	29.46	19.86	31.87	34.96	37.99	31.60	31.11	31.25
50.0	0	33.62	25.38	31.65	39.44	43.53	39.64	35.51	35.82
67.0	38	27.86	24.57	19.02	31.50	36.61	36.92	29.42	29.87
57.0	0	35.76	18.59	45.15	45.72	38.86	29.41	37.77	36.56
65.0	0	33.85	19.17	49.54	43.68	37.46	29.74	35.74	34.70
42.5	0	32.44	17.72	49.83	41.08	36.27	27.63	34.26	33.47
42.5	0	32.44	17.72	49.83	41.08	36.27	27.63	34.26	33.47
37.0	0	31.36	20.45	39.66	37.46	38.80	31.50	33.12	34.09
67.0	0	31.34	20.05	41.74	36.99	40.31	31.33	33.10	34.80
37.0	0	27.90	23.30	35.72	31.93	35.88	35.37	29.46	29.88
67.0	0	30.10	25.91	32.00	33.84	38.92	39.22	31.79	32.29
35.0	0	26.99	17.60	29.97	32.26	31.98	27.05	28.51	28.33
42.0	0	29.64	20.38	29.87	35.16	35.06	30.96	31.30	31.09
43.0	0	19.92	15.69	18.09	22.68	24.36	23.23	21.04	21.16
43.0	0	19.92	15.69	18.09	22.68	24.36	23.23	21.04	21.16
60.0	0	28.99	25.40	24.05	33.36	35.86	36.62	30.62	30.85
45.0	27	27.08	25.05	18.30	31.08	33.39	35.45	28.60	28.77
57.0	0	22.95	10.37	21.77	28.67	23.67	16.42	24.24	23.53
78.0	0	26.63	11.78	27.99	34.52	26.66	18.55	28.12	27.06
60.5	0	27.43	14.40	28.53	32.38	29.28	22.31	28.96	28.57
60.5	0	27.43	14.40	28.53	32.38	29.28	22.31	28.96	28.57
71.0	0	26.38	17.30	27.01	32.61	29.24	25.98	27.86	27.53
74.0	0	28.31	16.74	25.35	34.48	30.30	25.49	29.89	29.30
71.0	0	25.76	21.61	22.27	24.61	33.47	32.74	27.21	28.73
81.0	0	21.75	20.82	23.16	23.49	26.96	31.01	22.97	23.57
41.0	0	20.73	20.94	25.40	24.88	26.78	31.16	21.89	22.35
48.0	0	23.00	19.30	32.43	27.02	27.39	28.36	24.29	24.62
48.0	0	21.92	19.60	25.55	25.10	26.51	28.26	23.15	23.56
63.0	1510	17.61	16.38	18.22	20.48	21.25	23.25	18.60	18.85

5.1.4 MCNP Calculation

The RCA and calculated isotopic concentration values for each spent fuel sample are input to an MCNP waste package model and k_{eff} values are calculated. The MCNP waste package model is taken directly from Reference 7.4. The only differences between the calculations from Reference 7.4 and this calculation are the calculated isotopic concentration values. Various material composition values for the MCNP waste package model are provide in Section 5.5 of Reference 7.4 (Table 5-10 through 5-16). Isotopes ^{146}Nd, ^{148}Nd, ^{150}Nd, ^{242}Cm, ^{243}Cm, ^{245}Cm, and ^{246}Cm were omitted from the MCNP cases, which is consistent with Reference 7.4.

A sample listing of the MCNP input for the k_{eff} calculations for the Limerick spent fuel samples is given in Appendix A.

5.2 GRAND GULF UNIT 1 ASSEMBLY TYPE F

Section 4.3 of Reference 7.5 describes a control blade model study performed in the previous code-to-code work. The purpose of that study was to use the two-dimensional CASMO3 code for a Grand Gulf Unit 1 fuel assembly depletion calculation with periodic control blade insertion to develop a SAS2H control blade model. That study concluded that a seven-region SAS2H Path B model (with region 7 representing the control blade) gave the best results. This calculation expands on that work by performing a TRITON depletion calculation (Reference 7.16) for the same type F fuel assembly (axial node 4) with periodic control blade insertion. A direct comparison is made between the two-dimensional CASMO3 calculation and the two-dimensional TRITON calculation. Additional discussion of the CASMO3 and the SAS2H Path B model are provided in Reference 7.17, Section 3.5.1.

The type F assembly in Grand Gulf Unit 1 contained 76 fuel rods (Reference 7.6, Tables 16 and 17), with 8 of the rods containing 5.5 wt% $Gd_2O_3 - UO_2$ fuel. The average enrichment of the fuel rods is 3.80 wt% ^{235}U (Reference 7.6, Tables 16 and 17).

The operating history for the TRITON and CASMO3 depletion calculations is presented in Table 5-6. The cumulative burnup along with the fuel temperature, moderator density, and control blade insertion as a function of burnup is provided. Comparisons of calculated isotopic concentrations from CASMO3 and TRITON for 12 isotopes of interest are presented in Section 6.2 of this calculation. The isotopic concentrations are plotted as a function of burnup.

Table 5-6. Operating History Information for TRITON Depletions of Type F Assembly

Cumulative Burnup (GWd/mtU)	Fuel Temperature (K)	Moderator Density (g/cm^3)	Control Blade Insertion
0.712	998.0	0.3916	
3.827	1057.8	0.4351	
6.941	1057.8	0.4351	
7.804	1113.4	0.4430	
9.618	1058.1	0.4397	
12.638	1013.7	0.4142	
15.658	1013.7	0.4142	
17.297	893.8	0.4319	INSERT
18.936	893.8	0.4319	
21.395	999.7	0.4292	
23.854	999.7	0.4292	INSERT
26.312	999.7	0.4292	
28.771	999.7	0.4292	
30.774	921.1	0.4374	
32.776	921.1	0.4374	INSERT
34.779	921.1	0.4374	
36.781	921.1	0.4374	
37.798	725.0	0.4424	
38.815	725.0	0.4424	
40.003	713.2	0.4505	
41.191	713.2	0.4505	
41.861	667.8	0.4640	
42.532	667.8	0.4640	
43.202	667.8	0.4640	
43.872	667.8	0.4640	

Source: Reference 7.16, Table 5-2

5.3 B&W MARK B TYPE ASSEMBLY

Reference 7.7 describes the generation and verification of a set of isotopic concentrations for the PWR application model. These concentrations were generated based on conservative (with respect to criticality) material and operating history parameters for PWR spent nuclear fuel. Thus, the isotopic concentrations in this "PWR Isotopic Database" should be bounding with respect to criticality when applied in disposal criticality analyses. Requirements A and B in Section 3.5.3.1.2 of the *Disposal Criticality Analysis Methodology Topical Report* (Reference 7.8) were used in confirming the conservatism in this data.

5.3.1 SAS2H Calculation

The fuel assembly chosen for the isotopic database was a B&W Mark B type fuel assembly. A fuel enrichment of 2.5 wt% ^{235}U is used for the one-dimensional (SAS2) and two-dimensional (TRITON) calculations reported in this document. The eight-region Path B model from Reference 7.7 is used for the SAS2 (SCALE 5.0) calculations. The fuel density for these analyses is 10.741 g/cm^3 (98% theoretical density). The fuel is depleted out to 50 GWd/mtU. Thus, the SAS2H Path B model of SCALE 4.4a that was used in Reference 7.7 is rerun with SAS2 of SCALE 5.0.

A sample listing of the SAS2 input for the one-dimensional depletion calculations is given in Appendix B.

5.3.2 TRITON Calculation

The two-dimensional TRITON model uses identical composition and operating history data as the one-dimensional SAS2 model. Although the fuel enrichment is the same in all fuel rods, the TRITON calculation uses three separate materials to represent the fuel rods. There are 208 fuel rods in a Mark B fuel assembly (Reference 7.7, p 14). The outer two rows of fuel rods are material 11 (104 fuel rods). The next three rows (inward) are material 12 (84 fuel rods). The remaining 20 fuel rods in the interior of the fuel assembly are material 13. Each fuel material is depleted separately in TRITON and would have a slightly different neutron spectrum because of the proximity of fuel rods to moderating or absorbing material. Isotopic concentrations from the different materials (set of fuel rods) in the two-dimensional (TRITON) calculation are compared with the single set of concentrations from the one-dimensional (SAS2) calculation, as well as a composite set of the three TRITON material types. Figure 5-5 provides a one-quarter assembly representation of the Mark B assembly illustrating the three material zones. The results of these calculations are presented in Section 6.3 of this document.

A sample listing of the TRITON input for the two-dimensional depletion calculations is given in Appendix B.

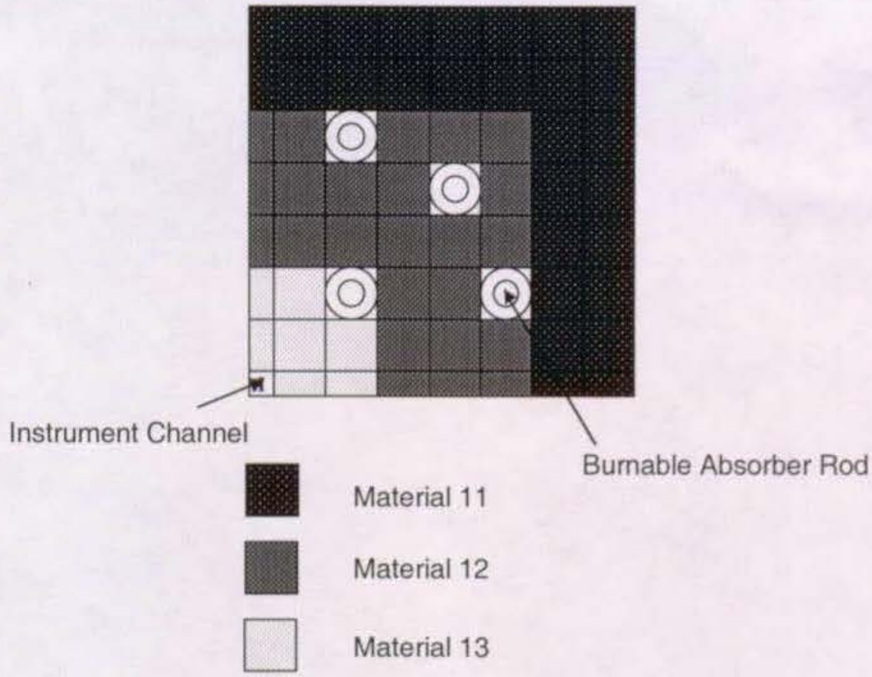


Figure 5-5. One-Quarter Assembly Representation of Mark B Assembly

6. RESULTS

This section presents results of the various calculations described in Section 5. Included are comparisons made between the results from the one-and two-dimensional calculations and measured data, where applicable. Results from the following three sets of calculations are performed.

1. Calculated isotopic concentration values from SAS2H (Reference 7.4), SAS2, and TRITON are compared with measured RCA values from Limerick assembly YJ1433. The isotopic concentrations are reported as the ratio of the mass of the isotope to the mass of ^{238}U. Calculated k_{eff} values from MCNP waste package calculations using measured RCA isotopic concentrations are compared with k_{eff} values from MCNP waste package calculations using the calculated isotopic concentrations from the one-and two-dimensional models. Values of k_{eff} from confirmation of the BWR Isotopic Database using Limerick RCA data (Reference 7.13) are also reported for comparison with the preceding data.

2. Calculated isotopic concentration values from the one-dimensional SAS2H (SCALE 4.4a) model and the two-dimensional CASMO3 model (both from Reference 7.5) are compared with isotopic concentration values from the two-dimensional TRITON model. These calculations are for axial node 4 of a type F BWR fuel assembly from Grand Gulf Unit 1.

3. Calculated isotopic concentration values from the one-dimensional SAS2 (SCALE 5) model are compared with isotopic concentration values from the two-dimensional TRITON (SCALE 5) model for a PWR fuel assembly at 2.5 wt% ^{235}U and the same conditions as the PWR Isotopic Database (Reference 7.7).

6.1 RADIOCHEMICAL ASSAY

Measured isotopic concentrations from the radiochemical assay performed on eight samples from the Limerick Unit 1 BWR fuel assembly YJ1433 are presented in Table 5-1. These values are reported as the ratio of mass of the isotope to the mass of ^{238}U. Calculated isotopic concentrations from the one-dimensional SAS2H model were reported in Table 6-1 of Reference 7.4. These values are repeated in Table 6-1 below. The SAS2H model for these calculations used a 6-region Path B model. Calculated isotopic concentrations from the modified one-dimensional SAS2 model using SCALE 5 are presented in Table 6-2. The SAS2 model for these calculations used a 7-region Path B model that provided a more realistic representation of the moderator outside of the water rods. Calculated isotopic concentrations from the two-dimensional TRITON model using SCALE 5 are presented in Table 6-3. Comparisons of the percent difference between the calculated and measured results are presented in Tables 6-4, 6-5, and 6-6.

Comparisons of k_{eff} values from MCNP waste package calculations using measured RCA isotopic concentrations and calculated isotopic concentrations from the one-and two-dimensional models are presented in Tables 6-7 and 6-8. The k_{eff} values for the RCA and SAS2H are from Reference 7.4. Table 6-9 provides values of k_{eff} from confirmation of the BWR Isotopic Database using Limerick RCA data (Reference 7.13). For the latter comparison only isotopes from the principal isotope set are used in the MCNP waste package calculation.

Table 6-1. Concentrations using SAS2H Model (Ref 7.4)

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8
Average Burnup (MWd/mtU)	54840	37020	62110	65540	64950	56520	57915	57810
Isotope	Calculated Concentration (mg/mg U-238)							
^{234}U	1.49E-4	1.97E-4	1.62E-4	1.56E-4	1.50E-4	1.71E-4	1.73E-4	1.72E-4
^{235}U	2.63E-3	6.62E-3	2.13E-3	2.38E-3	1.68E-3	3.09E-3	4.09E-3	4.20E-3
^{236}U	5.57E-3	5.15E-3	6.11E-3	6.17E-3	6.18E-3	6.17E-3	6.15E-3	6.16E-3
^{238}Pu	4.45E-4	1.87E-4	4.27E-4	5.32E-4	4.61E-4	3.78E-4	4.62E-4	4.68E-4
^{239}Pu	4.85E-3	4.15E-3	4.32E-3	4.95E-3	4.17E-3	4.29E-3	5.31E-3	5.40E-3
^{240}Pu	3.54E-3	2.63E-3	3.33E-3	3.69E-3	3.52E-3	3.33E-3	3.58E-3	3.60E-3
^{241}Pu	1.26E-3	8.58E-4	1.13E-3	1.32E-3	1.11E-3	1.08E-3	1.35E-3	1.36E-3
^{242}Pu	1.50E-3	6.38E-4	1.61E-3	1.71E-3	1.70E-3	1.28E-3	1.33E-3	1.32E-3
^{143}Nd	1.04E-3	9.03E-4	1.00E-3	1.11E-3	9.79E-4	1.01E-3	1.14E-3	1.15E-3
^{145}Nd	1.12E-3	8.42E-4	1.20E-3	1.24E-3	1.22E-3	1.11E-3	1.14E-3	1.13E-3
^{146}Nd	1.40E-3	8.80E-4	1.50E-3	1.60E-3	1.60E-3	1.35E-3	1.38E-3	1.38E-3
^{148}Nd	6.83E-4	4.55E-4	7.27E-4	7.70E-4	7.59E-4	6.58E-4	6.78E-4	6.76E-4
^{150}Nd	3.48E-4	2.18E-4	3.66E-4	3.93E-4	3.85E-4	3.27E-4	3.40E-4	3.40E-4
^{134}Cs	6.10E-5	2.92E-5	6.31E-5	7.20E-5	7.13E-5	5.77E-5	5.86E-5	5.88E-5
^{137}Cs	2.06E-3	1.37E-3	2.18E-3	2.32E-3	2.29E-3	1.98E-3	2.04E-3	2.03E-3
^{151}Eu	5.28E-7	3.94E-7	4.79E-7	5.72E-7	4.86E-7	4.73E-7	5.89E-7	6.00E-7
^{153}Eu	2.37E-4	1.42E-4	2.51E-4	2.65E-4	2.58E-4	2.20E-4	2.31E-4	2.30E-4
^{155}Eu	6.61E-6	3.64E-6	6.84E-6	7.49E-6	7.14E-6	6.03E-6	6.45E-6	6.45E-6
^{147}Sm	2.78E-4	2.67E-4	3.00E-4	2.91E-4	2.85E-4	2.87E-4	2.89E-4	2.87E-4
^{149}Sm	2.46E-6	2.18E-6	2.24E-6	2.63E-6	2.40E-6	2.60E-6	2.69E-6	2.75E-6
^{150}Sm	5.26E-4	3.39E-4	5.45E-4	5.91E-4	5.71E-4	5.01E-4	5.26E-4	5.26E-4
^{151}Sm	1.57E-5	1.16E-5	1.43E-5	1.70E-5	1.46E-5	1.42E-5	1.74E-5	1.77E-5
^{152}Sm	2.23E-4	1.63E-4	2.39E-4	2.44E-4	2.46E-4	2.18E-4	2.19E-4	2.18E-4
^{155}Gd	5.70E-6	3.14E-6	5.88E-6	6.45E-6	6.13E-6	5.18E-6	5.58E-6	5.58E-6
^{241}Am	3.50E-4	2.44E-4	3.09E-4	3.64E-4	2.95E-4	2.90E-4	3.79E-4	3.84E-4
^{241m}Am	1.26E-6	9.37E-7	9.90E-7	1.27E-6	8.59E-7	8.99E-7	1.52E-6	1.55E-6
^{243}Am	4.25E-4	1.25E-4	4.43E-4	5.12E-4	4.74E-4	3.29E-4	3.78E-4	3.77E-4
^{237}Np	7.62E-4	4.56E-4	7.70E-4	8.74E-4	7.86E-4	7.07E-4	8.13E-4	8.18E-4
^{95}Mo	1.32E-3	9.59E-4	1.42E-3	1.47E-3	1.46E-3	1.31E-3	1.33E-3	1.33E-3
^{99}Tc	1.38E-3	1.00E-3	1.48E-3	1.53E-3	1.51E-3	1.36E-3	1.39E-3	1.38E-3
^{101}Ru	1.42E-3	9.58E-4	1.52E-3	1.59E-3	1.57E-3	1.37E-3	1.41E-3	1.40E-3
^{103}Rh	7.21E-4	5.42E-4	7.35E-4	7.73E-4	7.27E-4	6.81E-4	7.29E-4	7.28E-4
^{109}Ag	1.82E-4	1.02E-4	1.87E-4	2.02E-4	1.94E-4	1.60E-4	1.73E-4	1.72E-4
^{242}Cm	4.71E-8	2.83E-8	4.62E-8	5.10E-8	4.45E-8	4.32E-8	4.83E-8	4.90E-8
^{243}Cm	9.82E-7	3.76E-7	8.87E-7	1.11E-6	9.33E-7	8.19E-7	9.91E-7	1.01E-6
^{244}Cm	1.99E-4	3.22E-5	1.96E-4	2.63E-4	2.44E-4	1.40E-4	1.68E-4	1.66E-4
^{245}Cm	8.21E-6	1.02E-6	6.37E-6	1.11E-5	8.77E-6	5.17E-6	7.54E-6	7.74E-6

Table 6-2. Concentrations using SAS2 Model of SCALE 5

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8
Average Burnup (MWd/mtU)	54840	37020	62110	65540	64950	56520	57915	57810
Isotope	Calculated Concentration (mg/mg U-238)							
^{234}U	1.50E-4	1.93E-4	1.62E-4	1.56E-4	1.54E-4	1.72E-4	1.73E-4	1.73E-4
^{235}U	3.07E-3	7.90E-3	2.19E-3	2.72E-3	2.68E-3	4.47E-3	4.64E-3	4.64E-3
^{236}U	5.57E-3	5.12E-3	6.12E-3	6.18E-3	6.22E-3	6.17E-3	6.15E-3	6.15E-3
^{238}Pu	4.72E-4	2.24E-4	4.28E-4	5.56E-4	5.49E-4	4.55E-4	4.91E-4	4.91E-4
^{239}Pu	5.32E-3	5.13E-3	4.38E-3	5.31E-3	5.19E-3	5.52E-3	5.86E-3	5.86E-3
^{240}Pu	3.65E-3	2.79E-3	3.35E-3	3.78E-3	3.81E-3	3.60E-3	3.69E-3	3.69E-3
^{241}Pu	1.38E-3	1.04E-3	1.15E-3	1.42E-3	1.38E-3	1.36E-3	1.47E-3	1.47E-3
^{242}Pu	1.48E-3	6.46E-4	1.60E-3	1.69E-3	1.64E-3	1.24E-3	1.32E-3	1.32E-3
^{143}Nd	1.09E-3	9.49E-4	1.01E-3	1.15E-3	1.13E-3	1.14E-3	1.18E-3	1.18E-3
^{145}Nd	1.13E-3	8.37E-4	1.20E-3	1.25E-3	1.23E-3	1.11E-3	1.14E-3	1.14E-3
^{146}Nd	1.40E-3	8.86E-4	1.51E-3	1.61E-3	1.60E-3	1.35E-3	1.39E-3	1.39E-3
^{148}Nd	6.87E-4	4.58E-4	7.30E-4	7.74E-4	7.65E-4	6.63E-4	6.82E-4	6.82E-4
^{150}Nd	3.51E-4	2.22E-4	3.68E-4	3.96E-4	3.90E-4	3.32E-4	3.44E-4	3.44E-4
^{134}Cs	6.09E-5	3.05E-5	6.25E-5	7.17E-5	7.20E-5	5.91E-5	5.87E-5	5.87E-5
^{137}Cs	2.03E-3	1.35E-3	2.15E-3	2.29E-3	2.26E-3	1.96E-3	2.01E-3	2.01E-3
^{151}Eu	5.71E-7	4.85E-7	4.80E-7	6.06E-7	6.01E-7	6.04E-7	6.40E-7	6.40E-7
^{153}Eu	2.35E-4	1.44E-4	2.49E-4	2.63E-4	2.57E-4	2.19E-4	2.29E-4	2.29E-4
^{155}Eu	6.65E-6	3.75E-6	6.80E-6	7.50E-6	7.35E-6	6.24E-6	6.50E-6	6.50E-6
^{147}Sm	2.74E-4	2.55E-4	2.98E-4	2.87E-4	2.81E-4	2.77E-4	2.84E-4	2.84E-4
^{149}Sm	2.61E-6	2.57E-6	2.24E-6	2.74E-6	2.80E-6	3.10E-6	2.87E-6	2.87E-6
^{150}Sm	5.23E-4	3.41E-4	5.42E-4	5.87E-4	5.81E-4	5.06E-4	5.20E-4	5.20E-4
^{151}Sm	1.69E-5	1.42E-5	1.43E-5	1.80E-5	1.79E-5	1.80E-5	1.88E-5	1.88E-5
^{152}Sm	2.16E-4	1.55E-4	2.35E-4	2.38E-4	2.35E-4	2.07E-4	2.12E-4	2.12E-4
^{155}Gd	5.74E-6	3.25E-6	5.85E-6	6.47E-6	6.34E-6	5.38E-6	5.64E-6	5.64E-6
^{241}Am	3.85E-4	3.00E-4	3.14E-4	3.93E-4	3.77E-4	3.74E-4	4.18E-4	4.18E-4
^{241m}Am	1.49E-6	1.34E-6	1.02E-6	1.46E-6	1.36E-6	1.44E-6	1.80E-6	1.80E-6
^{243}Am	4.32E-4	1.43E-4	4.44E-4	5.17E-4	4.92E-4	3.52E-4	3.85E-4	3.85E-4
^{237}Np	7.91E-4	5.16E-4	7.69E-4	8.97E-4	8.77E-4	7.98E-4	8.44E-4	8.44E-4
^{95}Mo	1.31E-3	9.47E-4	1.41E-3	1.46E-3	1.45E-3	1.30E-3	1.32E-3	1.32E-3
^{99}Tc	1.39E-3	9.99E-4	1.49E-3	1.54E-3	1.52E-3	1.36E-3	1.39E-3	1.39E-3
^{101}Ru	1.46E-3	9.80E-4	1.56E-3	1.63E-3	1.61E-3	1.40E-3	1.44E-3	1.44E-3
^{103}Rh	7.50E-4	5.62E-4	7.54E-4	8.04E-4	7.82E-4	7.23E-4	7.56E-4	7.56E-4
^{109}Ag	1.65E-4	9.29E-5	1.69E-4	1.84E-4	1.79E-4	1.48E-4	1.57E-4	1.57E-4
^{242}Cm	5.04E-8	3.30E-8	4.68E-8	5.38E-8	5.34E-8	5.16E-8	5.15E-8	5.15E-8
^{243}Cm	1.08E-6	4.76E-7	9.02E-7	1.20E-6	1.20E-6	1.05E-6	1.08E-6	1.08E-6
^{244}Cm	2.06E-4	4.09E-5	1.98E-4	2.69E-4	2.63E-4	1.60E-4	1.75E-4	1.75E-4
^{245}Cm	1.18E-5	1.95E-6	8.75E-6	1.56E-5	1.56E-5	9.72E-6	1.08E-5	1.08E-5

Table 6-3. Concentrations using TRITON Model of SCALE 5

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8
Average Burnup (MWd/mtU)	54840	37020	62110	65540	64950	56520	57915	57810
Isotope	Calculated Concentration (mg/mg U-238)							
^{234}U	1.63E-04	2.00E-04	1.59E-04	1.54E-04	1.52E-04	1.70E-04	1.76E-04	1.76E-04
^{235}U	5.06E-03	1.01E-02	1.86E-03	2.26E-03	2.29E-03	3.94E-03	4.72E-03	4.87E-03
^{236}U	5.72E-03	5.06E-03	6.09E-03	6.15E-03	6.21E-03	6.17E-03	6.21E-03	6.21E-03
^{238}Pu	4.49E-04	2.15E-04	4.18E-04	5.34E-04	5.33E-04	4.44E-04	4.90E-04	4.97E-04
^{239}Pu	6.07E-03	5.69E-03	4.23E-03	5.00E-03	4.91E-03	5.22E-03	5.98E-03	6.13E-03
^{240}Pu	3.84E-03	2.84E-03	3.37E-03	3.79E-03	3.84E-03	3.63E-03	3.89E-03	3.92E-03
^{241}Pu	1.48E-03	1.08E-03	1.10E-03	1.33E-03	1.31E-03	1.29E-03	1.46E-03	1.49E-03
^{242}Pu	1.27E-03	5.81E-04	1.64E-03	1.73E-03	1.69E-03	1.27E-03	1.30E-03	1.29E-03
^{143}Nd	1.16E-03	9.54E-04	9.72E-04	1.11E-03	1.10E-03	1.11E-03	1.20E-03	1.21E-03
^{145}Nd	1.08E-03	8.00E-04	1.21E-03	1.26E-03	1.24E-03	1.13E-03	1.16E-03	1.16E-03
^{146}Nd	1.29E-03	8.30E-04	1.54E-03	1.65E-03	1.63E-03	1.38E-03	1.41E-03	1.41E-03
^{148}Nd	6.46E-04	4.35E-04	7.41E-04	7.86E-04	7.79E-04	6.75E-04	6.95E-04	6.93E-04
^{150}Nd	3.30E-04	2.13E-04	3.74E-04	4.02E-04	3.97E-04	3.38E-04	3.52E-04	3.51E-04
^{134}Cs	5.15E-05	2.64E-05	6.39E-05	7.28E-05	7.34E-05	6.01E-05	5.78E-05	5.80E-05
^{137}Cs	1.90E-03	1.28E-03	2.19E-03	2.33E-03	2.30E-03	2.00E-03	2.05E-03	2.04E-03
^{151}Eu	6.46E-07	5.45E-07	4.67E-07	5.74E-07	5.74E-07	5.74E-07	6.58E-07	6.75E-07
^{153}Eu	2.20E-04	1.38E-04	2.52E-04	2.66E-04	2.60E-04	2.22E-04	2.30E-04	2.29E-04
^{155}Eu	6.26E-06	3.57E-06	6.90E-06	7.60E-06	7.47E-06	6.35E-06	6.65E-06	6.66E-06
^{147}Sm	2.89E-04	2.56E-04	2.98E-04	2.90E-04	2.82E-04	2.80E-04	2.96E-04	2.95E-04
^{149}Sm	2.81E-06	2.73E-06	2.20E-06	2.63E-06	2.69E-06	2.96E-06	2.87E-06	2.96E-06
^{150}Sm	4.94E-04	3.23E-04	5.50E-04	5.96E-04	5.91E-04	5.15E-04	5.31E-04	5.31E-04
^{151}Sm	1.89E-05	1.58E-05	1.40E-05	1.71E-05	1.71E-05	1.71E-05	1.93E-05	1.98E-05
^{152}Sm	2.13E-04	1.53E-04	2.43E-04	2.48E-04	2.44E-04	2.15E-04	2.26E-04	2.24E-04
^{155}Gd	8.98E-06	7.46E-06	5.92E-06	6.54E-06	6.43E-06	5.47E-06	5.77E-06	5.78E-06
^{241}Am	4.30E-04	3.21E-04	2.99E-04	3.66E-04	3.56E-04	3.54E-04	4.19E-04	4.27E-04
^{241m}Am	1.92E-06	1.58E-06	9.02E-07	1.25E-06	1.18E-06	1.26E-06	1.77E-06	1.82E-06
^{243}Am	3.75E-04	1.32E-04	4.55E-04	5.26E-04	5.03E-04	3.59E-04	3.90E-04	3.88E-04
^{237}Np	7.81E-04	5.04E-04	7.55E-04	8.74E-04	8.60E-04	7.85E-04	8.47E-04	8.53E-04
^{95}Mo	1.24E-03	8.97E-04	1.43E-03	1.48E-03	1.47E-03	1.32E-03	1.34E-03	1.34E-03
^{99}Tc	1.34E-03	9.58E-04	1.51E-03	1.57E-03	1.55E-03	1.38E-03	1.43E-03	1.43E-03
^{101}Ru	1.36E-03	9.29E-04	1.58E-03	1.66E-03	1.63E-03	1.42E-03	1.46E-03	1.45E-03
^{103}Rh	7.68E-04	5.63E-04	7.57E-04	8.08E-04	7.88E-04	7.30E-04	7.88E-04	7.88E-04
^{109}Ag	1.46E-04	8.69E-05	1.68E-04	1.78E-04	1.73E-04	1.43E-04	1.49E-04	1.48E-04
^{242}Cm	5.17E-08	3.31E-08	4.52E-08	5.13E-08	5.16E-08	4.98E-08	5.13E-08	5.22E-08
^{243}Cm	1.07E-06	4.60E-07	8.73E-07	1.13E-06	1.15E-06	1.01E-06	1.09E-06	1.11E-06
^{244}Cm	1.58E-04	3.55E-05	2.03E-04	2.72E-04	2.68E-04	1.62E-04	1.72E-04	1.73E-04
^{245}Cm	9.10E-06	1.66E-06	8.36E-06	1.43E-05	1.45E-05	9.05E-06	9.87E-06	1.02E-05

Table 6-4. Percent Difference Between Measured and SAS2H Model (Ref 7.4)

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO6**	**NO7**	**NO8**
Average Burnup (MWd/mtU)	**54840**	**37020**	**62110**	**65540**	**64950**	**56520**	**57915**	**57810**
Isotope	**(Calculated Concentration – Measured Concentration) x 100 / (Measured Concentration)**							
^{234}U	-7.4	1.3	-2.5	-4.6	-9.1	-7.7	-4.2	-4.2
^{235}U	-38.3	-24.1	25.1	8.8	-37.7	-28.2	-14.8	-14.0
^{236}U	-2.5	-0.5	1.9	2.7	2.1	2.6	-0.9	-0.9
^{238}Pu	1.4	-26.5	6.9	4.8	-15.1	-15.0	-8.8	-7.9
^{239}Pu	-11.2	-24.8	9.7	3.7	-21.4	-21.1	-13.5	-12.6
^{240}Pu	-4.4	-9.2	6.7	5.4	-2.4	-0.6	-4.8	-4.5
^{241}Pu	-8.5	-24.8	6.7	1.1	-22.7	-22.4	-10.3	-9.1
^{242}Pu	26.0	0.8	4.3	5.5	8.9	3.7	15.0	16.0
^{143}Nd	1.8	-1.8	17.4	12.5	-5.8	-2.6	2.7	3.3
^{145}Nd	11.1	5.4	6.1	5.9	5.2	5.1	6.2	6.0
^{146}Nd	13.7	3.3	5.0	5.5	6.5	5.1	4.4	5.1
^{148}Nd	11.1	2.6	4.5	4.6	4.1	3.3	4.1	4.2
^{150}Nd	12.6	0.9	7.1	6.7	5.5	3.7	4.8	5.3
^{134}Cs	6.2	-12.9	7.1	0.4	-1.3	2.0	-6.1	-5.3
^{137}Cs	9.8	1.6	9.6	6.6	9.3	11.1	4.2	4.6
^{151}Eu	10.6	-8.7	40.0	41.6	11.0	4.6	13.4	14.1
^{153}Eu	22.2	1.0	20.2	20.1	19.9	9.4	17.1	16.8
^{155}Eu	-16.9	-32.2	-14.6	-16.9	-18.3	-24.6	-20.5	-20.3
^{147}Sm	-3.6	3.4	1.9	-1.8	-1.7	-4.1	-1.7	-2.6
^{149}Sm	-8.4	-24.9	34.0	11.9	-14.4	-15.6	-8.5	-6.7
^{150}Sm	9.3	1.6	9.5	7.2	5.1	2.2	3.7	4.3
^{151}Sm	16.0	-5.4	41.5	37.4	8.0	5.0	12.8	15.7
^{152}Sm	46.4	35.7	33.7	38.8	48.1	38.1	46.9	47.2
^{155}Gd	-52.1	-67.6	-24.6	-26.6	-33.3	-33.6	-35.1	-31.0
^{241}Am	-10.1	-23.2	9.2	11.6	-22.5	-21.5	-7.0	-7.2
^{241m}Am	6.6	-19.3	48.3	55.8	-13.2	-15.2	7.2	6.3
^{243}Am	40.4	-3.7	22.3	30.6	13.1	9.3	27.7	26.8
^{237}Np	-3.7	-15.6	0.4	-2.9	-11.3	-14.0	-5.5	-5.5
^{95}Mo	3.7	-3.5	-1.0	3.5	6.4	3.0	3.8	3.6
^{99}Tc	8.9	0.2	6.4	12.7	8.2	17.1	13.6	17.2
^{101}Ru	11.1	0.2	1.1	5.4	7.1	3.0	6.5	3.1
^{103}Rh	-3.2	-10.7	1.8	1.9	-9.1	-8.2	-3.3	-7.1
^{109}Ag	13.1	-7.3	28.0	31.7	25.0	32.6	28.8	14.0
^{242}Cm	-4.0	-24.1	23.2	35.5	-15.7	-22.2	0.3	14.9
^{243}Cm	-14.7	-41.9	4.5	-1.6	-31.9	-32.3	-20.1	-22.3
^{244}Cm	27.5	-30.1	8.3	19.1	0.5	-7.5	3.4	3.2
^{245}Cm	-35.9	-69.0	-29.2	-27.7	-53.9	-54.3	-50.7	-49.4

Table 6-5. Percent Difference Between Measured and SAS2 Model of SCALE 5

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO6**	**NO7**	**NO8**
Average Burnup (MWd/mtU)	**54840**	**37020**	**62110**	**65540**	**64950**	**56520**	**57915**	**57810**
Isotope	**(Calculated Concentration – Measured Concentration) x 100 / (Measured Concentration)**							
^{234}U	-6.9%	-0.4%	-2.6%	-4.1%	-6.4%	-7.0%	-4.1%	-7.7%
^{235}U	-28.0%	-9.4%	29.0%	24.2%	-0.5%	3.8%	-3.4%	-1.8%
^{236}U	-2.4%	-1.2%	1.9%	2.8%	2.8%	2.7%	-0.9%	-0.8%
^{238}Pu	7.5%	-12.3%	7.1%	9.5%	1.1%	2.3%	-3.1%	-1.7%
^{239}Pu	-2.6%	-7.1%	11.3%	11.3%	-2.1%	1.4%	-4.5%	-2.7%
^{240}Pu	-1.3%	-3.9%	7.4%	8.1%	5.6%	7.4%	-1.8%	-1.1%
^{241}Pu	-0.1%	-8.5%	8.3%	8.3%	-3.7%	-2.0%	-2.0%	0.0%
^{242}Pu	24.2%	2.1%	4.1%	4.3%	4.9%	0.4%	13.4%	14.3%
^{143}Nd	6.5%	3.3%	18.0%	16.9%	9.0%	9.4%	6.5%	7.4%
^{145}Nd	11.5%	4.8%	6.5%	6.4%	6.0%	5.1%	6.5%	6.2%
^{146}Nd	14.1%	4.0%	5.5%	6.0%	6.6%	5.6%	5.0%	5.7%
^{148}Nd	11.7%	3.2%	4.9%	5.2%	5.0%	4.1%	4.7%	4.9%
^{150}Nd	13.6%	2.9%	7.6%	7.5%	6.9%	5.5%	5.8%	6.3%
^{134}Cs	6.1%	-8.9%	5.9%	0.0%	-0.3%	4.5%	-5.9%	-4.9%
^{137}Cs	8.6%	0.1%	8.3%	5.5%	8.2%	10.2%	3.2%	3.5%
^{151}Eu	19.6%	12.3%	40.4%	49.9%	37.2%	33.5%	23.3%	25.0%
^{153}Eu	21.2%	2.4%	19.1%	18.9%	19.4%	9.2%	16.0%	15.7%
^{155}Eu	-16.5%	-30.1%	-15.1%	-16.7%	-15.9%	-22.1%	-19.9%	-19.7%
^{147}Sm	-4.9%	-1.3%	0.9%	-2.9%	-3.3%	-7.5%	-3.5%	-4.4%
^{149}Sm	-2.9%	-11.7%	34.1%	16.7%	-0.5%	0.5%	-2.5%	0.2%
^{150}Sm	8.7%	2.2%	8.8%	6.5%	6.9%	3.3%	2.6%	3.2%
^{151}Sm	25.1%	15.5%	41.7%	45.0%	32.4%	33.0%	22.1%	26.3%
^{152}Sm	42.2%	29.5%	31.4%	35.2%	41.3%	30.8%	42.4%	42.5%
^{155}Gd	-51.7%	-66.4%	-25.1%	-26.3%	-31.0%	-30.9%	-34.4%	-30.1%
^{241}Am	-0.9%	-5.3%	11.0%	20.5%	-1.1%	1.5%	2.4%	3.0%
^{241m}Am	26.6%	15.2%	52.5%	78.7%	37.0%	36.2%	27.0%	27.5%
^{243}Am	42.7%	10.2%	22.7%	31.9%	17.5%	16.8%	30.2%	29.4%
^{237}Np	-0.2%	-4.5%	0.3%	-0.4%	-1.0%	-3.0%	-1.8%	-1.5%
^{95}Mo	3.2%	-4.7%	-1.3%	3.1%	5.8%	2.0%	3.3%	3.0%
^{99}Tc	9.5%	0.0%	7.1%	13.4%	8.7%	17.2%	14.2%	17.8%
^{101}Ru	13.9%	2.5%	3.7%	8.2%	9.6%	5.3%	9.2%	5.7%
^{103}Rh	0.7%	-7.4%	4.4%	5.9%	-2.3%	-2.4%	0.2%	-3.6%
^{109}Ag	2.7%	-15.6%	15.6%	20.1%	15.4%	22.0%	16.8%	3.5%
^{242}Cm	2.6%	-11.5%	24.8%	43.1%	1.2%	-7.2%	7.1%	23.0%
^{243}Cm	-6.4%	-26.5%	6.3%	6.0%	-12.7%	-13.1%	-12.6%	-14.4%
^{244}Cm	32.0%	-11.2%	9.3%	21.8%	8.4%	5.8%	7.9%	7.9%
^{245}Cm	-7.4%	-40.6%	-7.9%	1.8%	-18.0%	-14.0%	-29.1%	-26.6%

Table 6-6. Percent Difference Between Measured and TRITON Model of SCALE 5

Sample	D8-3D2B	D8-4G3	D9-1D2	D9-2D2	D9-4D4	D9-4G1E1	H5-3A1C	H5-3A1G
Sample Title	NO1	NO2	NO3	NO4	NO5	NO6	NO7	NO8
Average Burnup (MWd/mtU)	54840	37020	62110	65540	64950	56520	57915	57810
Isotope	(Calculated Concentration – Measured Concentration) x 100 / (Measured Concentration)							
^{234}U	1.5%	3.0%	-4.4%	-5.6%	-8.0%	-8.0%	-2.3%	-5.9%
^{235}U	18.9%	16.2%	9.4%	3.4%	-14.7%	-8.7%	-1.8%	-0.3%
^{236}U	0.2%	-2.4%	1.5%	2.3%	2.6%	2.6%	0.0%	0.1%
^{238}Pu	2.2%	-15.8%	4.5%	5.1%	-1.8%	-0.3%	-3.3%	-2.1%
^{239}Pu	11.1%	3.1%	7.4%	4.8%	-7.3%	-4.0%	-2.6%	-0.8%
^{240}Pu	3.8%	-2.0%	8.0%	8.4%	6.4%	8.2%	3.4%	4.0%
^{241}Pu	7.4%	-4.9%	4.0%	1.7%	-8.5%	-6.9%	-2.4%	-0.6%
^{242}Pu	6.6%	-8.2%	6.5%	7.0%	8.2%	3.2%	12.4%	13.0%
^{143}Nd	13.4%	3.8%	14.1%	12.5%	5.9%	7.1%	8.5%	9.4%
^{145}Nd	7.3%	0.2%	7.5%	7.6%	7.3%	6.6%	8.3%	8.0%
^{146}Nd	4.7%	-2.6%	7.8%	8.3%	9.0%	7.9%	7.0%	7.7%
^{148}Nd	5.0%	-1.9%	6.5%	6.9%	6.9%	5.9%	6.7%	6.8%
^{150}Nd	6.8%	-1.5%	9.4%	9.2%	8.9%	7.3%	8.2%	8.7%
^{134}Cs	-10.4%	-21.2%	8.2%	1.6%	1.6%	6.1%	-7.4%	-6.6%
^{137}Cs	1.6%	-5.2%	10.0%	7.2%	10.2%	12.1%	4.9%	5.2%
^{151}Eu	35.4%	26.1%	36.6%	42.1%	31.1%	27.0%	26.7%	28.4%
^{153}Eu	13.4%	-2.3%	20.4%	20.3%	21.0%	10.5%	16.7%	16.2%
^{155}Eu	-21.4%	-33.4%	-13.9%	-15.6%	-14.6%	-20.6%	-18.0%	-17.8%
^{147}Sm	0.2%	-1.0%	1.1%	-2.1%	-2.6%	-6.3%	0.8%	-0.1%
^{149}Sm	4.6%	-6.2%	31.8%	11.7%	-4.3%	-4.0%	-2.2%	0.2%
^{150}Sm	2.8%	-3.3%	10.4%	8.2%	8.9%	5.2%	4.7%	5.3%
^{151}Sm	39.9%	28.1%	38.2%	37.8%	26.8%	26.7%	25.4%	29.7%
^{152}Sm	40.3%	27.6%	35.6%	40.6%	47.1%	36.1%	51.4%	51.6%
^{155}Gd	-24.6%	-22.9%	-24.1%	-25.5%	-30.0%	-29.8%	-32.9%	-28.5%
^{241}Am	10.7%	1.4%	5.8%	12.3%	-6.6%	-4.2%	2.7%	3.1%
^{241m}Am	62.7%	36.5%	35.1%	52.5%	19.4%	18.8%	24.6%	24.9%
^{243}Am	23.6%	1.2%	25.6%	34.3%	20.0%	19.1%	31.7%	30.8%
^{237}Np	-1.4%	-6.6%	-1.5%	-2.9%	-2.9%	-4.5%	-1.5%	-1.3%
^{95}Mo	-2.2%	-9.8%	-0.1%	4.5%	7.3%	3.6%	4.8%	4.5%
^{99}Tc	5.5%	-4.1%	8.5%	15.1%	10.4%	19.2%	17.2%	20.8%
^{101}Ru	6.6%	-2.8%	5.3%	9.6%	11.1%	6.7%	10.4%	6.8%
^{103}Rh	3.0%	-7.3%	4.8%	6.5%	-1.5%	-1.4%	4.5%	0.5%
^{109}Ag	-9.0%	-21.0%	15.4%	16.5%	11.6%	18.0%	11.3%	-1.8%
^{242}Cm	5.4%	-11.3%	20.6%	36.3%	-2.3%	-10.4%	6.7%	22.3%
^{243}Cm	-7.1%	-29.0%	2.9%	0.0%	-16.1%	-16.4%	-12.2%	-14.3%
^{244}Cm	1.5%	-23.0%	12.0%	23.2%	10.3%	7.2%	6.0%	5.8%
^{245}Cm	-28.9%	-49.3%	-12.0%	-6.6%	-23.6%	-19.9%	-35.5%	-33.5%

Table 6-7. MCNP k_{eff} Results for Spent Nuclear Fuel Samples

Sample	RCA[a]		SAS2H[a]		SAS2[b]		TRITON[b]	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
D8-3D2B	0.55913	0.00052	0.51709	0.00045	0.53945	0.00050	0.57521	0.00055
D8-4G3	0.63515	0.00052	0.57645	0.00049	0.62170	0.00054	0.65377	0.00059
D9-1D2	0.46612	0.00044	0.48665	0.00041	0.48846	0.00044	0.47179	0.00046
D9-2D2	0.50712	0.00047	0.51048	0.00043	0.52745	0.00047	0.50409	0.00046
D9-4D4	0.53262	0.00049	0.46549	0.00041	0.52118	0.00046	0.50072	0.00045
D9-4G1E1	0.56781	0.00048	0.50364	0.00048	0.56452	0.00049	0.54555	0.00046
H5-3A1C	0.58889	0.00047	0.55520	0.00042	0.57681	0.00055	0.57563	0.00048
H5-3A1G	0.59134	0.00051	0.55936	0.00050	0.58166	0.00050	0.58149	0.00048

[a] Reference 7.4, Table 6-4
[b] SCALE 5

Table 6-8. MCNP Δk_{eff} Results for Spent Nuclear Fuel Samples

Sample	SAS2H[a]		SAS2[b]		TRITON[b]	
	Δk_{eff}	σ	Δk_{eff}	σ	Δk_{eff}	σ
D8-3D2B	-0.04204	0.00069	-0.01968	0.00072	0.01608	0.00076
D8-4G3	-0.05870	0.00071	-0.01345	0.00075	0.01862	0.00079
D9-1D2	0.02053	0.00060	0.02234	0.00062	0.00567	0.00064
D9-2D2	0.00336	0.00064	0.02033	0.00066	-0.00303	0.00066
D9-4D4	-0.06713	0.00064	-0.01144	0.00067	-0.03190	0.00067
D9-4G1E1	-0.06417	0.00068	-0.00329	0.00069	-0.02226	0.00066
H5-3A1C	-0.03369	0.00063	-0.01208	0.00072	-0.01326	0.00067
H5-3A1G	-0.03198	0.00071	-0.00968	0.00071	-0.00985	0.00070

[a] Reference 7.4, Table 6-4
[b] SCALE 5
Note: $\Delta k_{eff} = k_{eff}$ (calculated) – k_{eff} (RCA)

Table 6-9. MCNP k_{eff} Comparisons for RCAs and Isotopic Database

Sample	RCA		Isotopic Database			
	k_{eff}	σ	k_{eff}	σ	Δk_{eff}	σ
D8-3D2B	0.56062	0.00044	0.76073	0.00072	0.20011	0.00084
D8-4G3	0.63548	0.00057	0.80084	0.00058	0.16536	0.00081
D9-1D2	0.46859	0.00039	0.75160	0.00055	0.28301	0.00067
D9-2D2	0.50906	0.00042	0.74515	0.00056	0.23609	0.00070
D9-4D4	0.53387	0.00051	0.74679	0.00059	0.21292	0.00078
D9-4G1E1	0.56883	0.00049	0.76307	0.00063	0.19424	0.00080
H5-3A1C	0.59039	0.00052	0.76020	0.00062	0.16981	0.00081
H5-3A1G	0.59217	0.00058	0.75909	0.00064	0.16692	0.00086

Data from Reference 7.13, Table 36

From both the isotopic concentration data (Tables 6-1 through 6-6) and the k_{eff} data (Tables 6-7 and 6-8), it is seen that the SAS2 calculations with the 7-region Path B model shows closer agreement with the RCA data than the SAS2H calculations with the 6-region Path B model. Results from the SAS2 calculations and the TRITON calculations show similar agreement.

However, TRITON is a new tool and its capabilities have not been fully exploited. It is expected that with additional experience, TRITON will yield superior results.

The k_{eff} results in Table 6-9 (from Reference 7.13) show that the BWR isotopic database yields conservative results when compared with the SAS2H, SAS2, or the TRITON results.

6.2 GRAND GULF UNIT 1 ASSEMBLY TYPE F

This section presents results of the TRITON depletion calculations. Isotopic concentration values from the two-dimensional TRITON model are compared with the calculated isotopic concentration values from the two-dimensional CASMO3 model. The CASMO3 and TRITON results are from Reference 7.16. Comparisons of assembly type F isotopic concentrations for CASMO3 and SAS2H are presented in References 7.5 and 7.17 (Figures 4-53 through 4-66). A comparison of the results of the SAS2H (with two different Path B models – Reference 7.17), CASMO3, and TRITON shows that the CASMO3/TRITON has much closer agreement than SAS2H.

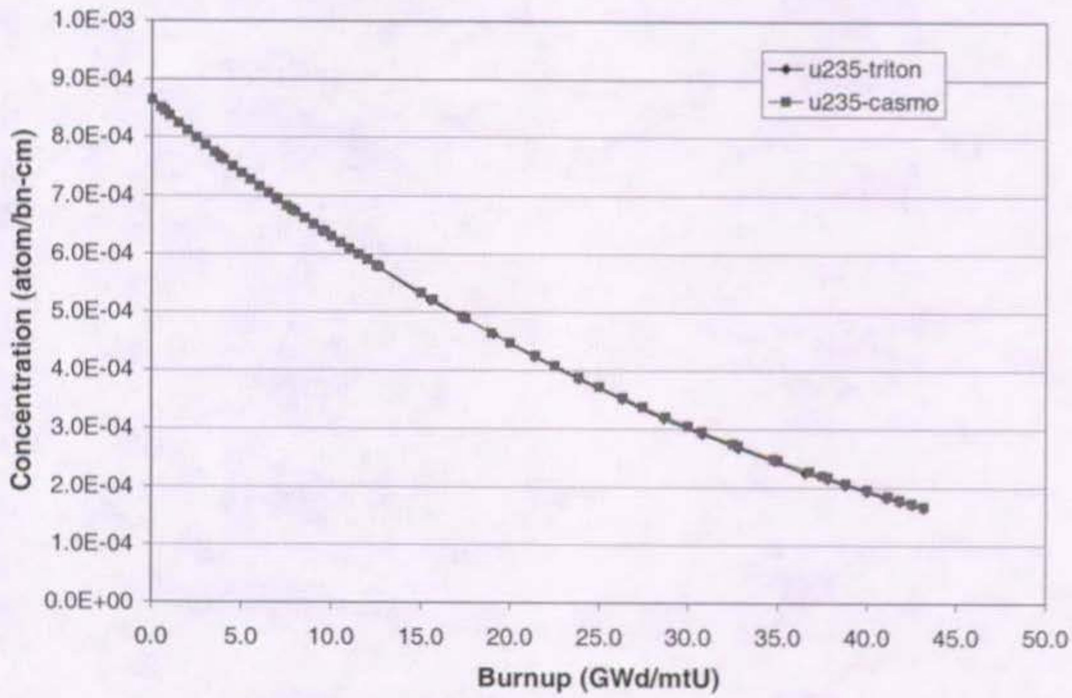


Figure 6-1. Comparisons of Isotopic Concentrations of ^{235}U

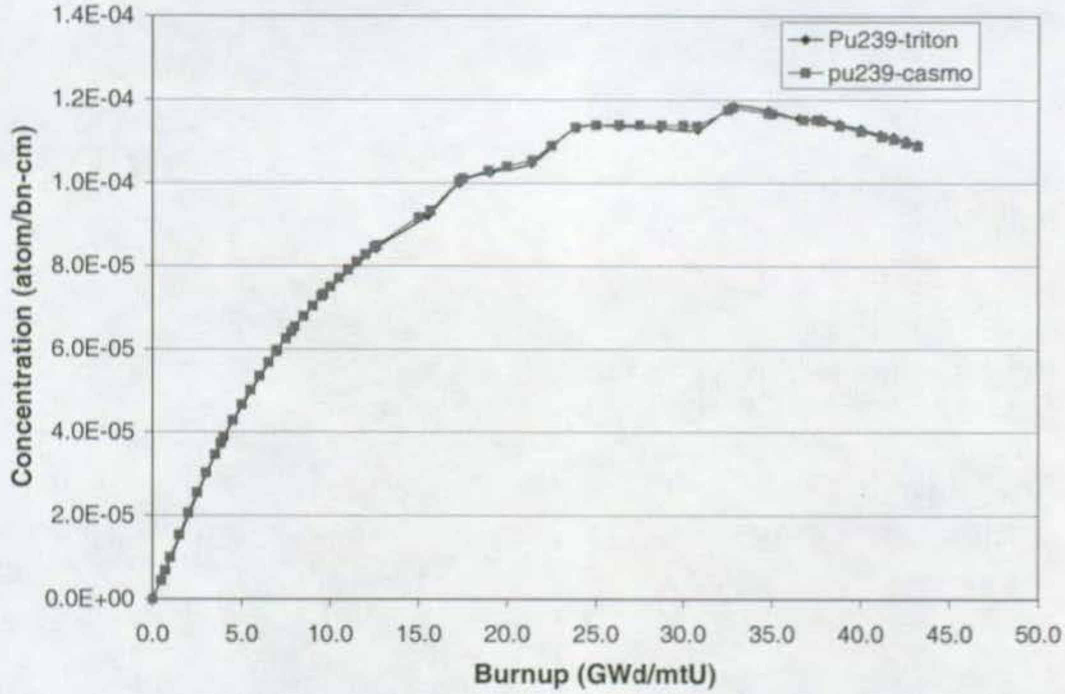


Figure 6-2. Comparisons of Isotopic Concentrations of ^{239}Pu

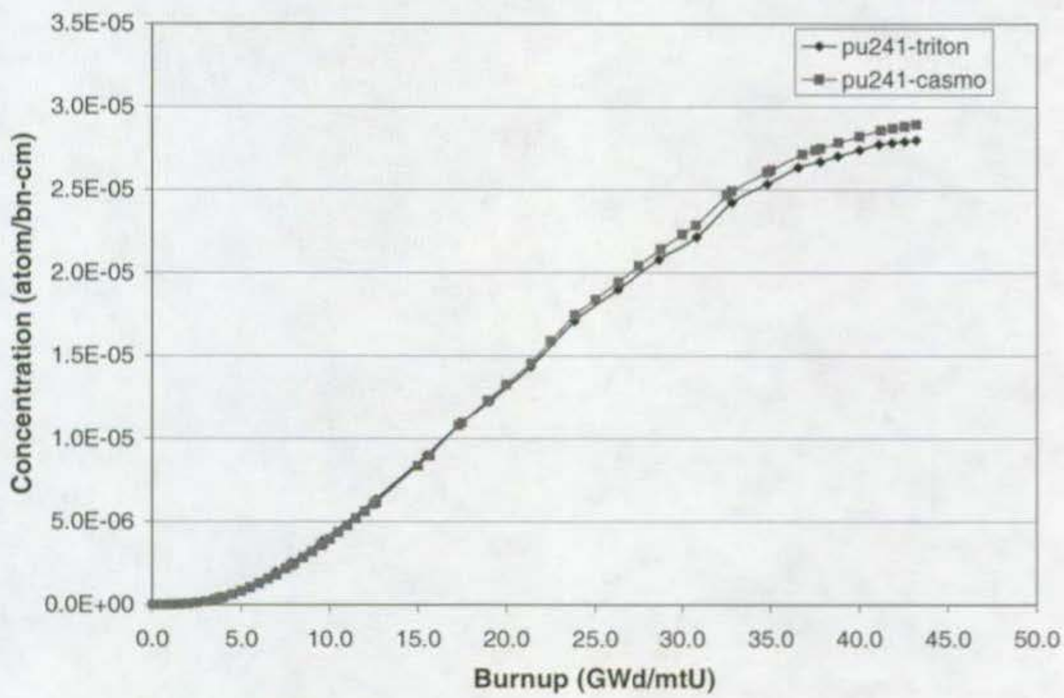


Figure 6-3. Comparisons of Isotopic Concentrations of ^{241}Pu

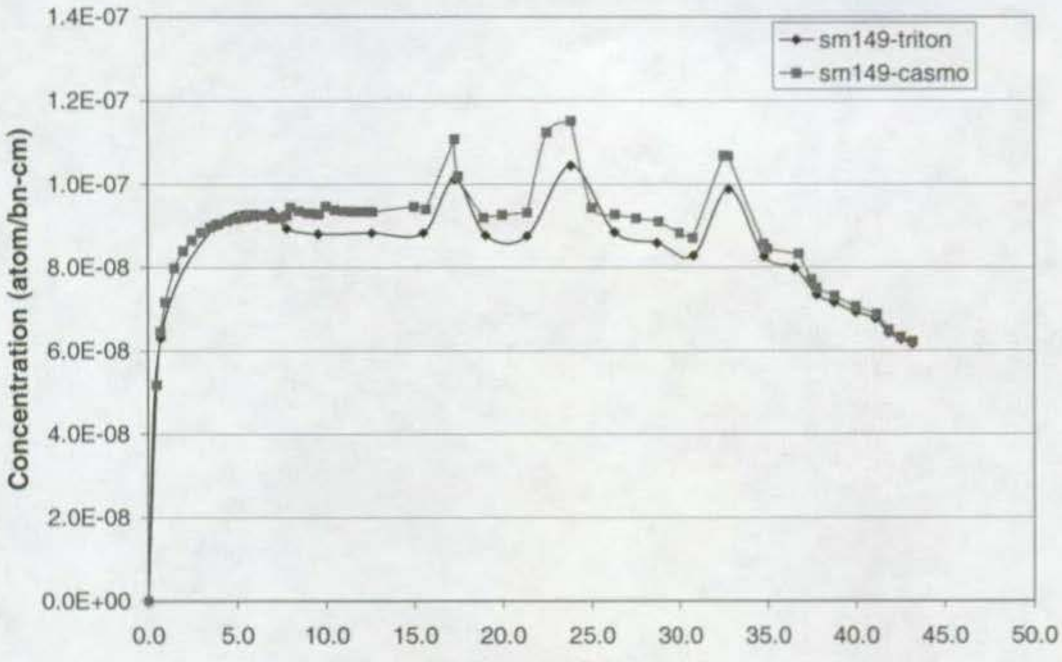


Figure 6-4. Comparisons of Isotopic Concentrations of ^{149}Sm

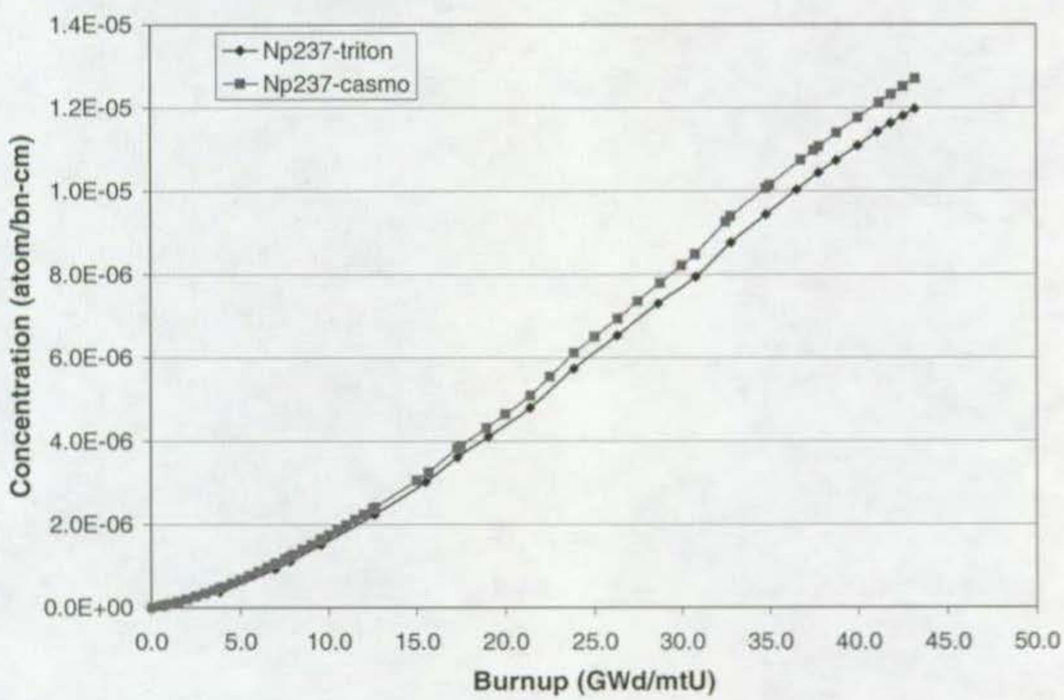


Figure 6-5. Comparisons of Isotopic Concentrations of ^{237}Np

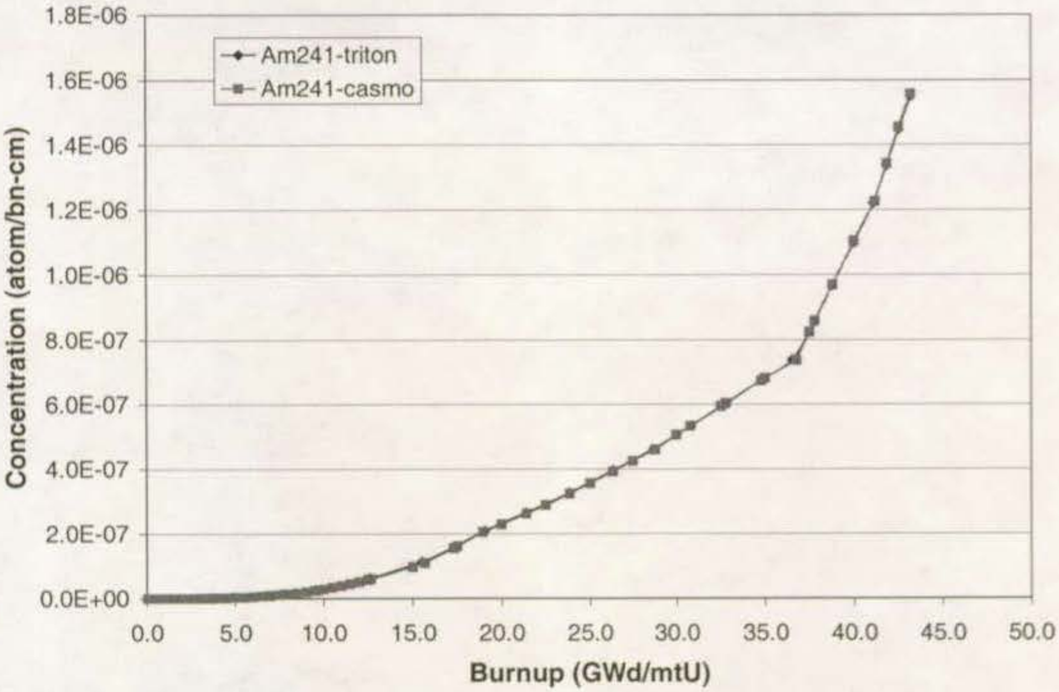


Figure 6-6. Comparisons of Isotopic Concentrations of ^{241}Am

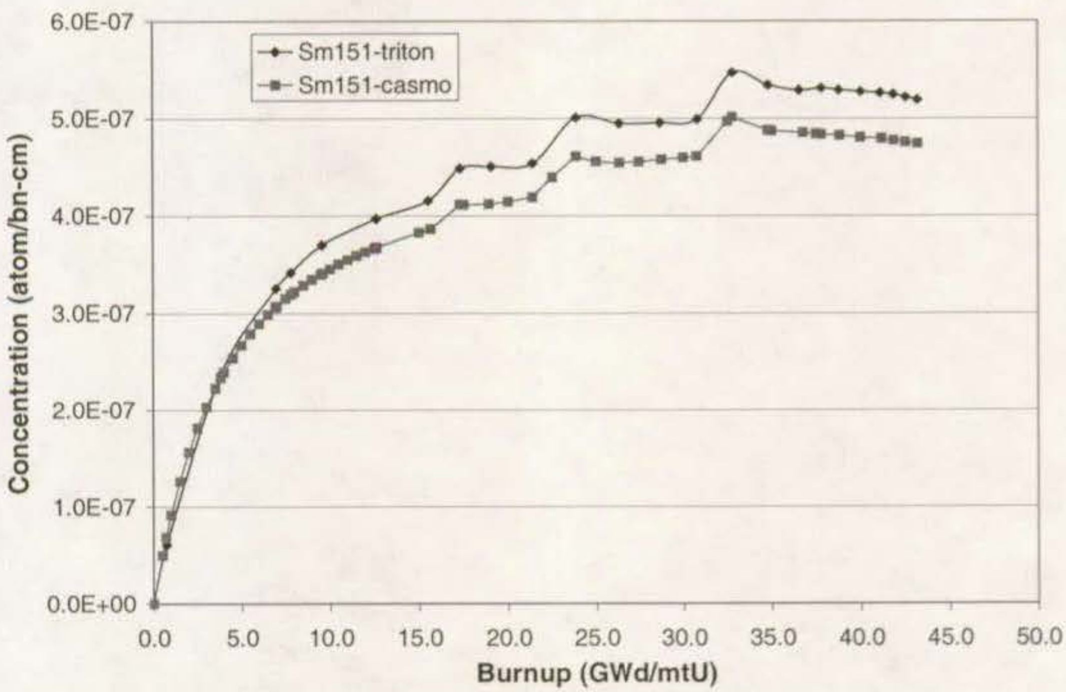


Figure 6-7. Comparisons of Isotopic Concentrations of ^{151}Sm

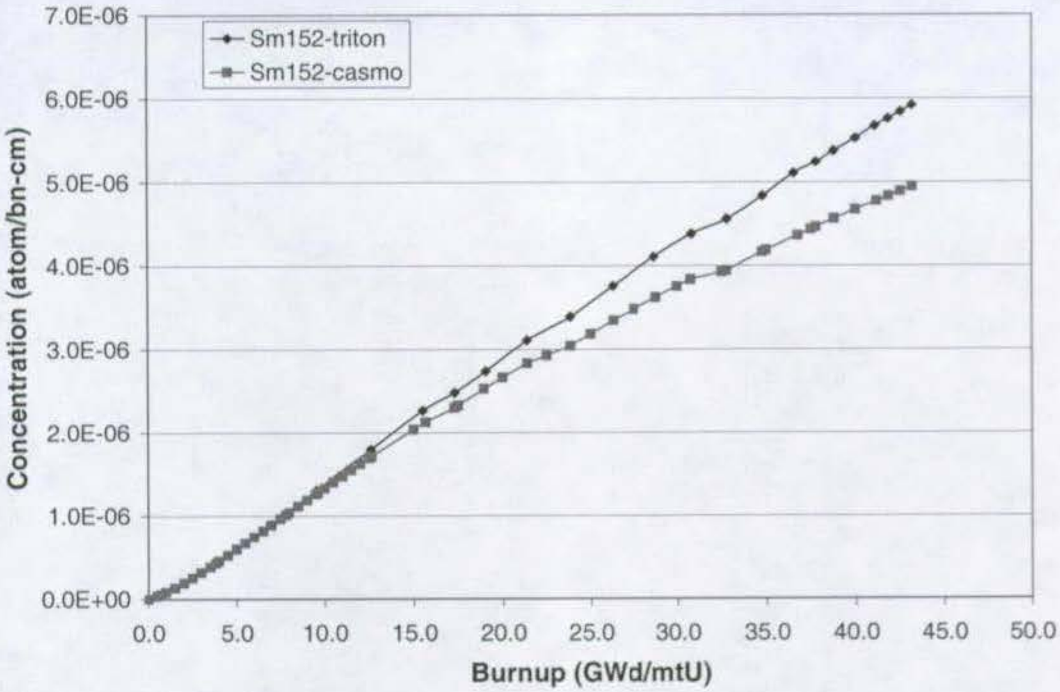


Figure 6-8. Comparisons of Isotopic Concentrations of ^{152}Sm

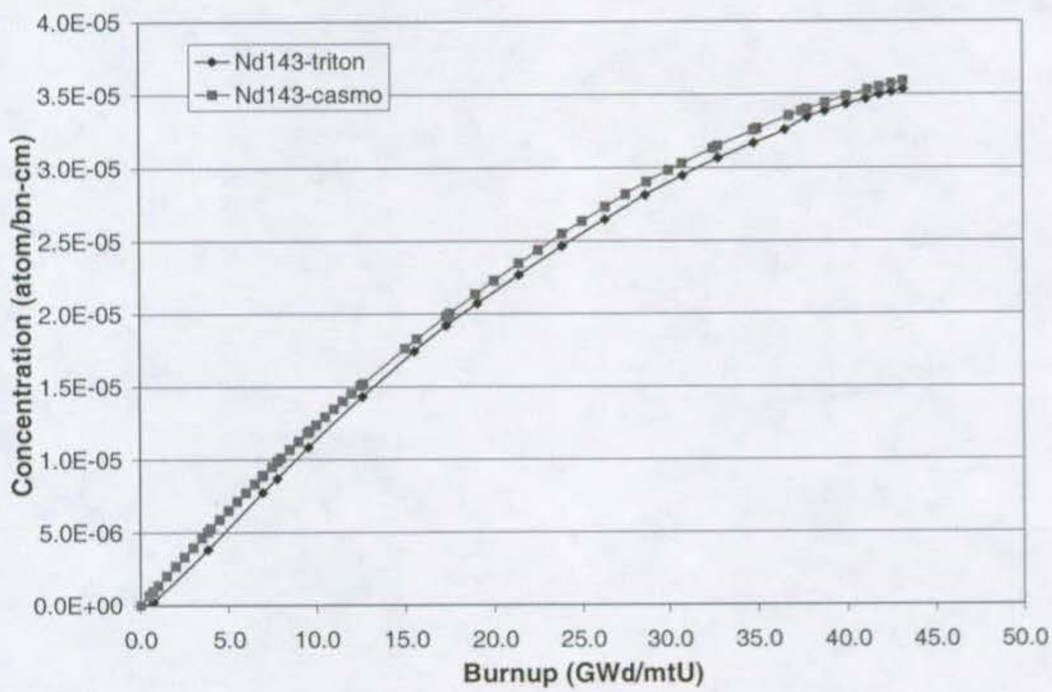


Figure 6-9. Comparisons of Isotopic Concentrations of ^{143}Nd

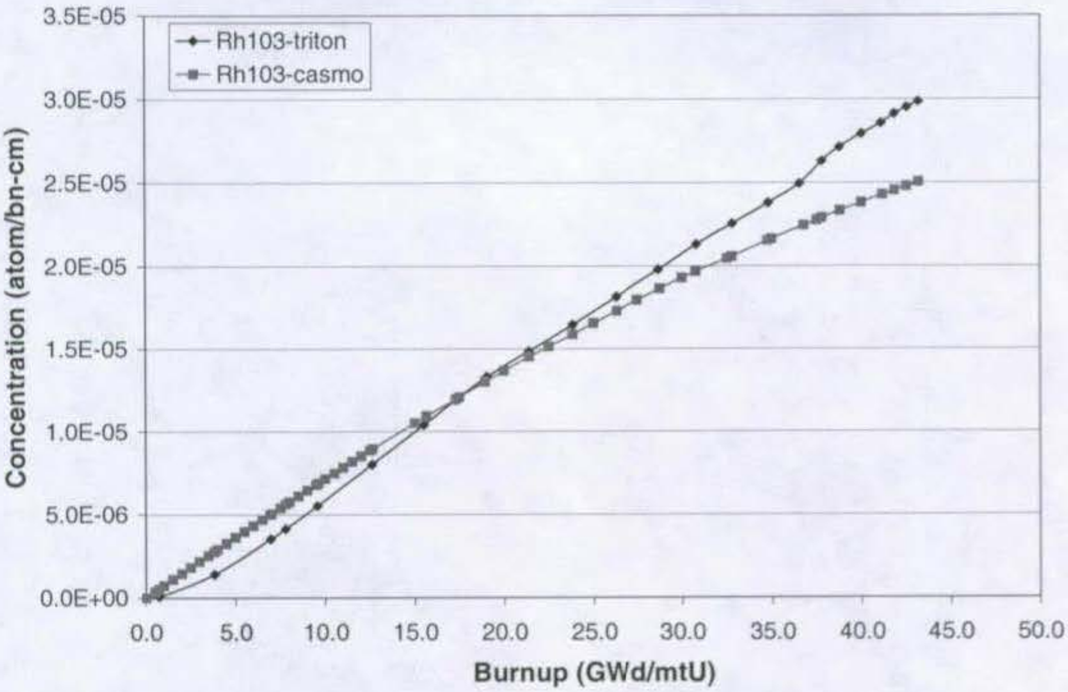


Figure 6-10. Comparisons of Isotopic Concentrations of ^{103}Rh

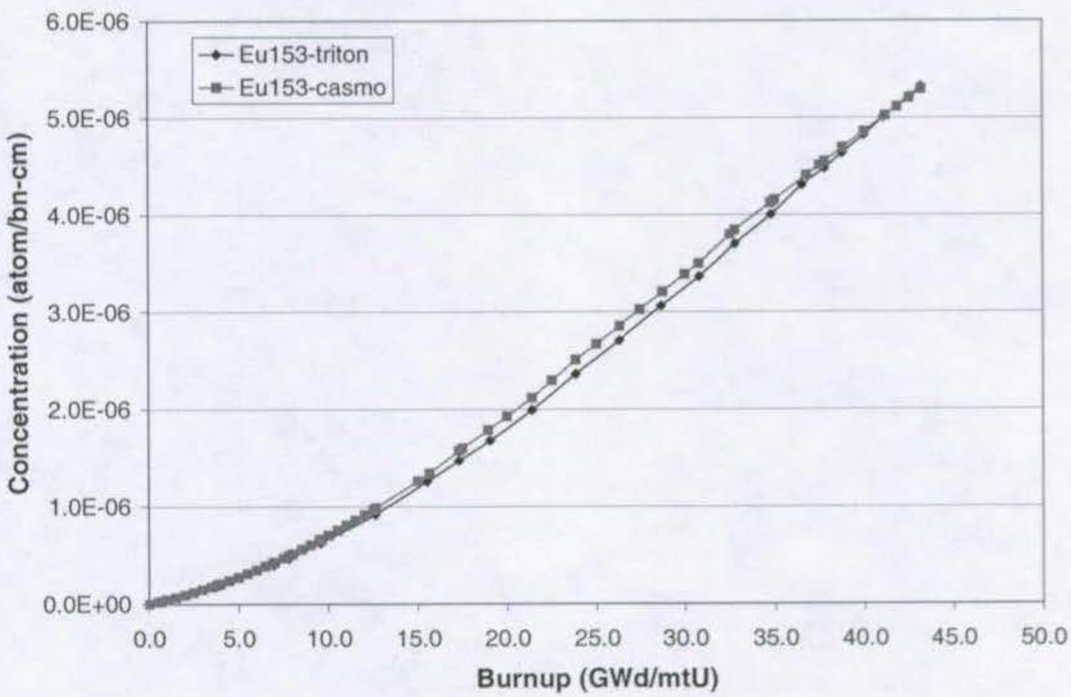


Figure 6-11. Comparisons of Isotopic Concentrations of ^{153}Eu

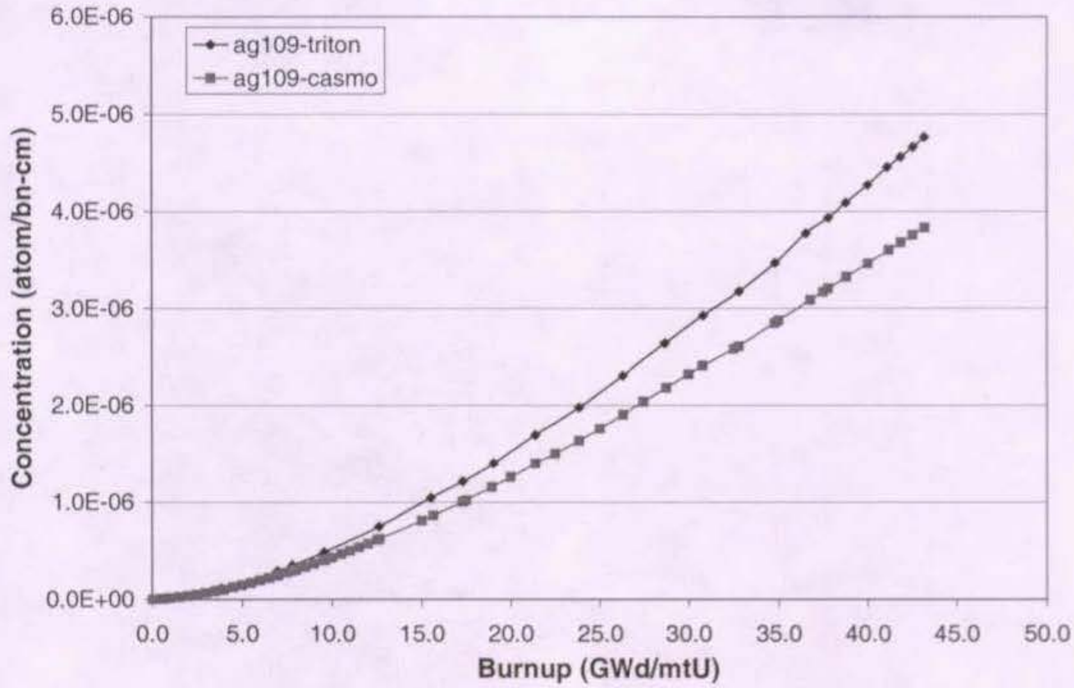


Figure 6-12. Comparisons of Isotopic Concentrations of ^{109}Ag

6.3 B&W MARK B TYPE ASSEMBLY

This section presents the results of the one-dimensional (SAS2) and the two-dimensional (TRITON) depletion calculations for the B&W Mark B type fuel assembly. These calculations are based on the same conservative (as confirmed in Reference 7.7, Section 6.2) material and operating history parameters. Comparisons of the calculated isotopic concentrations (as a function of burnup) for ^{235}U, ^{239}Pu, ^{241}Pu, and ^{149}Sm are provided in Figures 6-13 through 6-16. Each figure provides plots of SAS2 concentration values, TRITON material type 11, TRITON material type 12, and TRITON composite of the material types 11, 12, and 13. The TRITON results for material type 13 were essentially indistinguishable from the material type 11 results.

This study of the Mark B type assembly indicates that with the same conservative input assumptions, TRITON isotopic concentrations for the fissile isotopes investigated (^{235}U, ^{239}Pu, and ^{241}Pu) are more conservative than the SAS2 results and is less conservative for the one fission product (^{149}Sm). Further investigations should be performed before any definite conclusions are drawn.

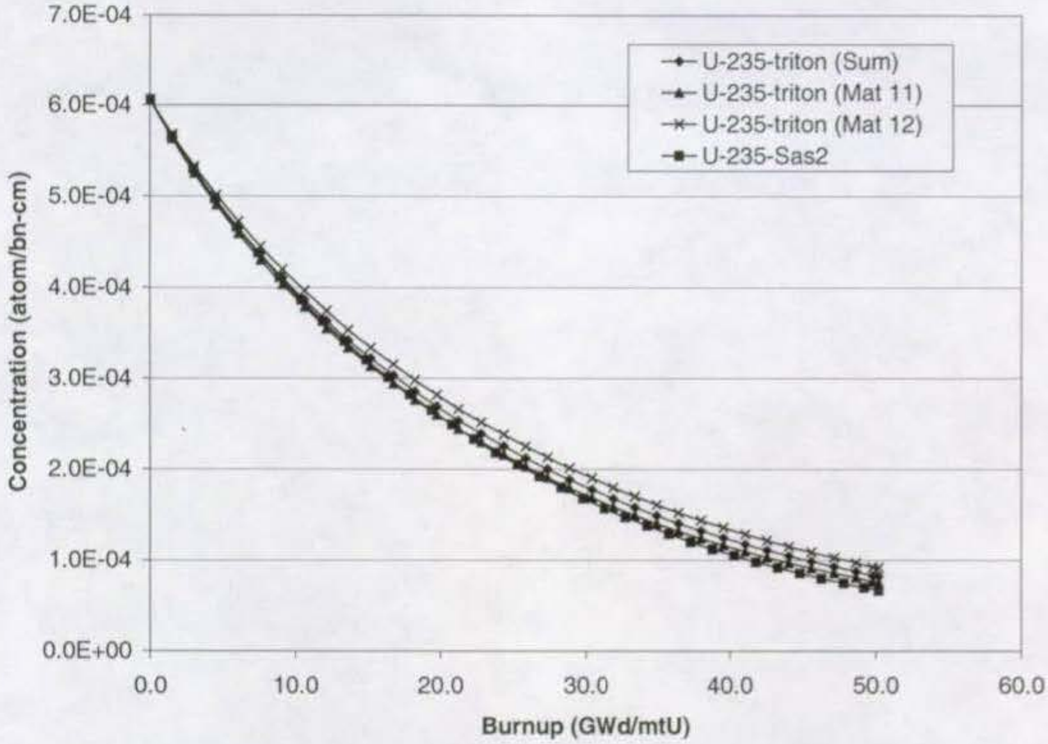


Figure 6-13. Comparison of Isotopic Concentration of ^{235}U for Mark B Type Assembly

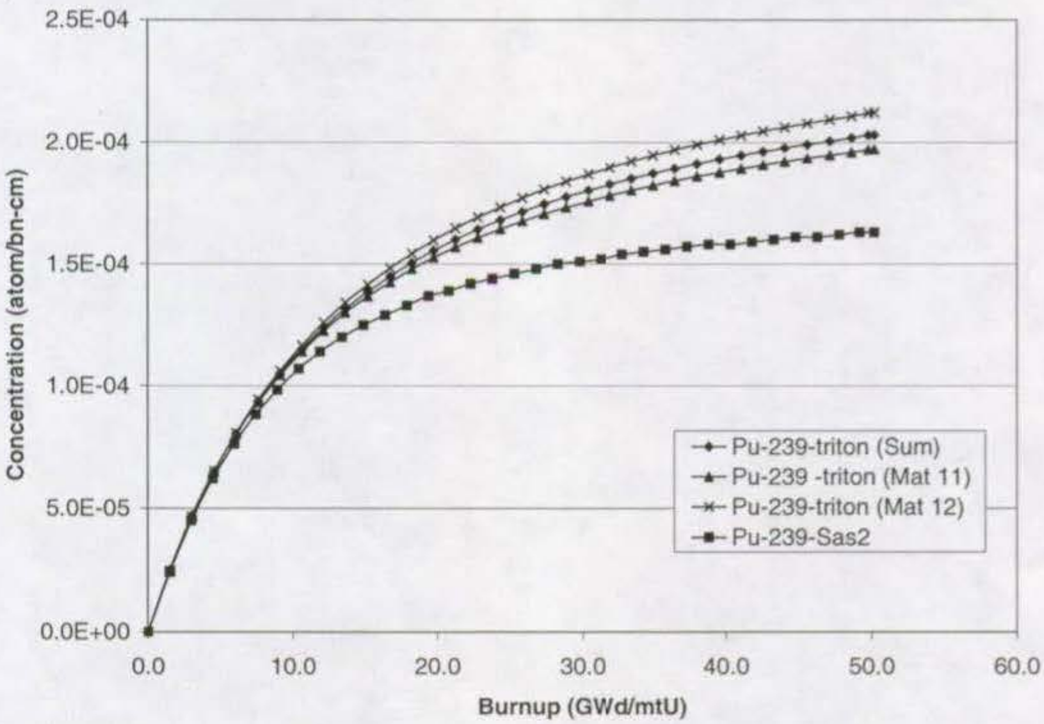


Figure 6-14. Comparison of Isotopic Concentration of ^{239}Pu for Mark B Type Assembly

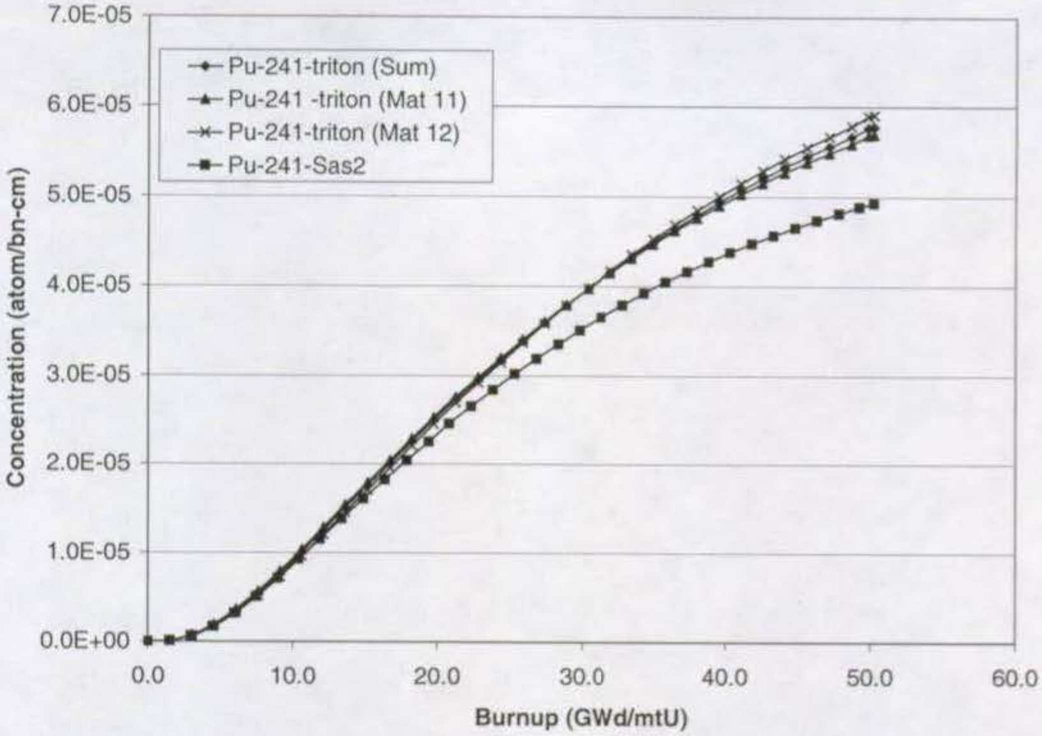


Figure 6-15. Comparison of Isotopic Concentration of ^{241}Pu for Mark B Type Assembly

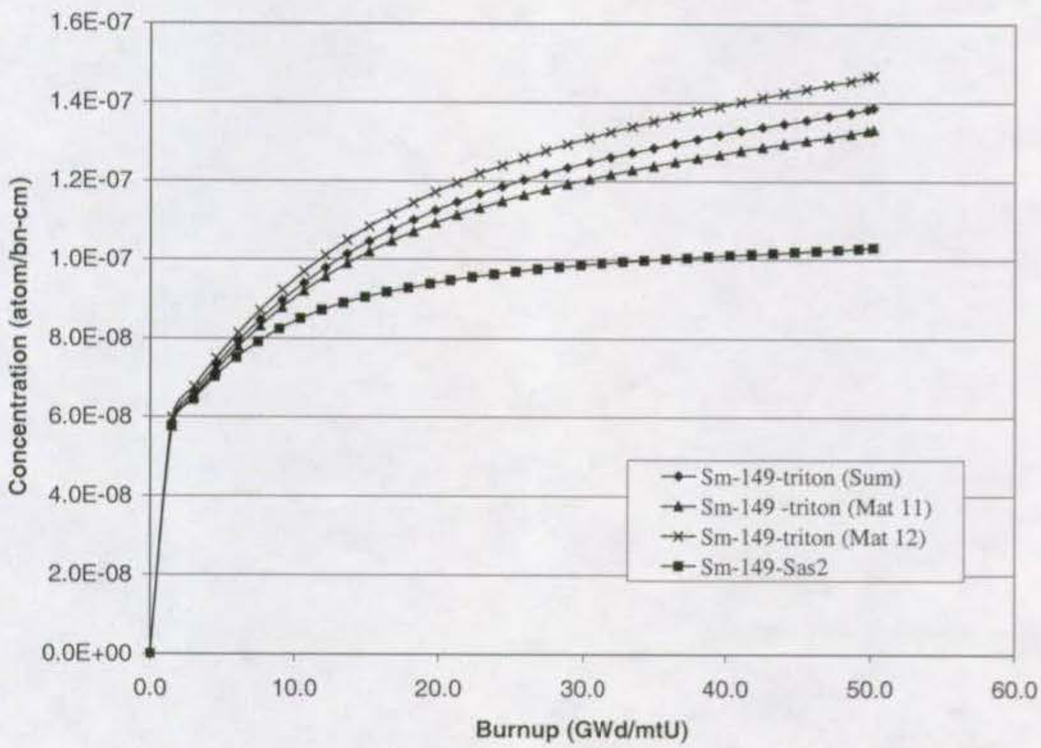


Figure 6-16. Comparison of Isotopic Concentration of ^{149}Sm for Mark B Type Assembly

7. REFERENCES

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8. COMPUTER OUTPUT (COLD FILES)

The SAS2 module of SCALE 5.0 output files, TRITON module of SCALE 5.0 output files, and the MCNP 4.B2L output files associated with this engineering calculation are located on COLD and the listing is provided below.

File Name	Doc ID	Date	Time
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N01C-a.inp.out	32-5048840-00	9/23/2004	10:11:37 AM
N01C.ft72f001	32-5048840-00	9/28/2004	11:25:26 AM
N01C.output	32-5048840-00	9/28/2004	12:54:44 PM
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N02C.output	32-5048840-00	9/28/2004	11:25:29 AM
N03C.ft72f001	32-5048840-00	9/28/2004	11:25:33 AM
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N04C.ft72f001	32-5048840-00	9/28/2004	11:25:37 AM
N04C.output	32-5048840-00	9/28/2004	11:25:37 AM
N05C.ft72f001	32-5048840-00	9/28/2004	11:25:47 AM
N05C.output	32-5048840-00	9/28/2004	11:25:48 AM
N06C.ft72f001	32-5048840-00	9/28/2004	11:25:58 AM
N06C.output	32-5048840-00	9/28/2004	11:25:59 AM
N07C.ft72f001	32-5048840-00	9/28/2004	11:26:10 AM
N07C.output	32-5048840-00	9/28/2004	11:26:11 AM
N08C.ft72f001	32-5048840-00	9/28/2004	11:26:22 AM
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trit-NO8.out	32-5048840-00	9/25/2004	12:36:26 AM

APPENDIX A: RCA CALCULATION SAMPLE INPUT LISTING FOR SCALE AND MCNP

A.1 SCALE 4.4A/SAS2H AND SCALE 5/SAS ISOTOPIC CONCENTRATION ANALYSIS FOR LIMERICK FUEL ASSEMBLY YJ1433

SAS2H Input Listing for Sample D8-3D2B:

```
=sas2h     parm=skipshipdata
Limerick 1, Assembly YJ1433, Rod D8, Node 14, Sample D8-3D2B
44group       latticecell
uo2 1 den=9.37605       1 1059 92234 .0324 92235 3.6 92238 96.3676 end
   kr-83 1 0 1-21       1059    end
   kr-85 1 0 1-21       1059    end
   sr-90 1 0 1-21       1059    end
    y-89 1 0 1-21       1059    end
   mo-95 1 0 1-21       1059    end
   zr-93 1 0 1-21       1059    end
   zr-94 1 0 1-21       1059    end
   zr-95 1 0 1-21       1059    end
   nb-94 1 0 1-21       1059    end
   nb-95 1 0 1-21       1059    end
   tc-99 1 0 1-21       1059    end
  rh-103 1 0 1-21       1059    end
  rh-105 1 0 1-21       1059    end
  ru-101 1 0 1-21       1059    end
  ru-106 1 0 1-21       1059    end
  pd-105 1 0 1-21       1059    end
  pd-108 1 0 1-21       1059    end
  ag-109 1 0 1-21       1059    end
  sb-124 1 0 1-21       1059    end
  sn-126 1 0 1-21       1059    end
  xe-131 1 0 1-21       1059    end
  xe-132 1 0 1-21       1059    end
  xe-135 1 0 1-21       1059    end
  xe-136 1 0 1-21       1059    end
  cs-134 1 0 1-21       1059    end
  cs-135 1 0 1-21       1059    end
  cs-137 1 0 1-21       1059    end
  ba-136 1 0 1-21       1059    end
  la-139 1 0 1-21       1059    end
  ce-144 1 0 1-21       1059    end
  pr-141 1 0 1-21       1059    end
  pr-143 1 0 1-21       1059    end
  nd-143 1 0 1-21       1059    end
  nd-144 1 0 1-21       1059    end
  nd-145 1 0 1-21       1059    end
  nd-146 1 0 1-21       1059    end
  nd-147 1 0 1-21       1059    end
  nd-148 1 0 1-21       1059    end
  nd-150 1 0 1-21       1059    end
  pm-147 1 0 1-21       1059    end
  pm-148 1 0 1-21       1059    end
  pm-149 1 0 1-21       1059    end
```

```
  sm-147 1 0 1-21        1059    end
  sm-148 1 0 1-21        1059    end
  sm-149 1 0 1-21        1059    end
  sm-150 1 0 1-21        1059    end
  sm-151 1 0 1-21        1059    end
  sm-152 1 0 1-21        1059    end
  gd-154 1 0 1-21        1059    end
  gd-155 1 0 1-21        1059    end
  gd-157 1 0 1-21        1059    end
  gd-158 1 0 1-21        1059    end
  gd-160 1 0 1-21        1059    end
  eu-151 1 0 1-21        1059    end
  eu-153 1 0 1-21        1059    end
  eu-154 1 0 1-21        1059    end
  eu-155 1 0 1-21        1059    end
  u-232 1 0 1-21         1059    end
  u-233 1 0 1-21         1059    end
arbmzr2 6.55 6 0 0 0 50000 1.45 26000 .135 28000 .055
           24000 .1 8016 .125 40000 98.135 2 1.0 574 end
h2o 3 den=.37557 1 561 end
uo2 4 den=9.37605 1 1059 92234 .0324 92235 3.6 92238 96.3676 end
arbm-gd2o3 9.37605 2 0 1 1 64000 2 8016 3 4 .05 1059 end
arbmzr4 6.56 5 0 0 0 50000 1.45 26000 .21
           24000 .1 8016 .125 40000 98.115 5 1.0 561 end
h2o 6 den=.73648 1.0 561 end
end comp
squarepitch 1.44 .9754 1 3 1.1176 2 end
more data szf=.5 end
npin/assm=74 fuelngth=15.24 ncycles=37 nlib/cyc=1 lightel=0
printlevel=5 inplevel=2 numztotal=6 mxrepeats=1 mixmod=3 facmesh=.5 end
  4 .4877 2 .5588 3 .81243 500 2.3296 5 2.45181 6 2.86608
power=.19348 burn=73.0 down=0 h2of=1.000 tmpf=1059 tmpc=574 tmpm=561 end
power=.19718 burn=45.5 down=0 h2of=0.877 tmpf=1068 tmpc=575 tmpm=561 end
power=.19718 burn=45.5 down=0 h2of=0.877 tmpf=1068 tmpc=575 tmpm=561 end
power=.20425 burn=45.5 down=0 h2of=0.880 tmpf=1085 tmpc=575 tmpm=561 end
power=.20425 burn=45.5 down=0 h2of=0.880 tmpf=1085 tmpc=575 tmpm=561 end
power=.20348 burn=45.5 down=0 h2of=0.978 tmpf=1083 tmpc=575 tmpm=561 end
power=.20348 burn=45.5 down=0 h2of=0.978 tmpf=1083 tmpc=575 tmpm=561 end
power=.23563 burn=55.0 down=0 h2of=0.878 tmpf=1160 tmpc=578 tmpm=562 end
power=.21628 burn=53.0 down=0 h2of=0.934 tmpf=1114 tmpc=577 tmpm=562 end
power=.24685 burn=50.0 down=0 h2of=1.073 tmpf=1183 tmpc=575 tmpm=558 end
power=.20453 burn=67.0 down=38 h2of=1.272 tmpf=1086 tmpc=575 tmpm=561 end
power=.26255 burn=57.0 down=0 h2of=0.696 tmpf=1220 tmpc=577 tmpm=559 end
power=.24847 burn=65.0 down=0 h2of=0.678 tmpf=1189 tmpc=577 tmpm=560 end
power=.23814 burn=42.5 down=0 h2of=0.725 tmpf=1164 tmpc=576 tmpm=559 end
power=.23814 burn=42.5 down=0 h2of=0.725 tmpf=1164 tmpc=576 tmpm=559 end
power=.23024 burn=37.0 down=0 h2of=0.779 tmpf=1147 tmpc=577 tmpm=562 end
power=.23010 burn=67.0 down=0 h2of=0.793 tmpf=1146 tmpc=576 tmpm=560 end
power=.20482 burn=37.0 down=0 h2of=0.819 tmpf=1086 tmpc=574 tmpm=560 end
power=.22097 burn=67.0 down=0 h2of=0.889 tmpf=1124 tmpc=575 tmpm=560 end
power=.19817 burn=35.0 down=0 h2of=0.847 tmpf=1070 tmpc=574 tmpm=560 end
power=.21758 burn=42.0 down=0 h2of=0.947 tmpf=1116 tmpc=575 tmpm=560 end
power=.14627 burn=43.0 down=0 h2of=0.955 tmpf=945 tmpc=572 tmpm=562 end
power=.14627 burn=43.0 down=0 h2of=0.955 tmpf=945 tmpc=572 tmpm=562 end
power=.21285 burn=60.0 down=0 h2of=1.078 tmpf=1105 tmpc=574 tmpm=560 end
power=.19883 burn=45.0 down=27 h2of=1.293 tmpf=1072 tmpc=574 tmpm=560 end
```

```
power=.16851 burn=57.0 down=0 h2of=0.926 tmpf=1001 tmpc=575 tmpm=563 end
power=.19549 burn=78.0 down=0 h2of=0.873 tmpf=1065 tmpc=575 tmpm=562 end
power=.20135 burn=60.5 down=0 h2of=0.894 tmpf=1079 tmpc=576 tmpm=562 end
power=.20135 burn=60.5 down=0 h2of=0.894 tmpf=1079 tmpc=576 tmpm=562 end
power=.19366 burn=71.0 down=0 h2of=0.952 tmpf=1061 tmpc=576 tmpm=562 end
power=.20782 burn=74.0 down=0 h2of=0.961 tmpf=1095 tmpc=576 tmpm=562 end
power=.18913 burn=71.0 down=0 h2of=1.111 tmpf=1051 tmpc=576 tmpm=563 end
power=.15965 burn=81.0 down=0 h2of=1.157 tmpf=979 tmpc=574 tmpm=563 end
power=.15220 burn=41.0 down=0 h2of=1.101 tmpf=960 tmpc=572 tmpm=562 end
power=.16887 burn=48.0 down=0 h2of=1.000 tmpf=1002 tmpc=575 tmpm=563 end
power=.16091 burn=48.0 down=0 h2of=1.073 tmpf=983 tmpc=574 tmpm=563 end
power=.12927 burn=63.0 down=1510 h2of=1.307 tmpf=902 tmpc=569 tmpm=560 end
end
```

SAS2 Input Listing for Sample D8-3D2B:

```
=sas2     parm=skipshipdata
Limerick 1, Assembly YJ1433, Rod D8, Node 14, Sample D8-3D2B
44group       latticecell
uo2 1 den=9.37605       1 1059 92234 .0324 92235 3.6 92238 96.3676 end
   kr-83 1 0 1-21       1059    end
   kr-85 1 0 1-21       1059    end
   sr-90 1 0 1-21       1059    end
    y-89 1 0 1-21       1059    end
   mo-95 1 0 1-21       1059    end
   zr-93 1 0 1-21       1059    end
   zr-94 1 0 1-21       1059    end
   zr-95 1 0 1-21       1059    end
   nb-94 1 0 1-21       1059    end
   nb-95 1 0 1-21       1059    end
   tc-99 1 0 1-21       1059    end
  rh-103 1 0 1-21       1059    end
  rh-105 1 0 1-21       1059    end
  ru-101 1 0 1-21       1059    end
  ru-106 1 0 1-21       1059    end
  pd-105 1 0 1-21       1059    end
  pd-108 1 0 1-21       1059    end
  ag-109 1 0 1-21       1059    end
  sb-124 1 0 1-21       1059    end
  sn-126 1 0 1-21       1059    end
  xe-131 1 0 1-21       1059    end
  xe-132 1 0 1-21       1059    end
  xe-135 1 0 1-21       1059    end
  xe-136 1 0 1-21       1059    end
  cs-134 1 0 1-21       1059    end
  cs-135 1 0 1-21       1059    end
  cs-137 1 0 1-21       1059    end
  ba-136 1 0 1-21       1059    end
  la-139 1 0 1-21       1059    end
  ce-144 1 0 1-21       1059    end
  pr-141 1 0 1-21       1059    end
  pr-143 1 0 1-21       1059    end
  nd-143 1 0 1-21       1059    end
  nd-144 1 0 1-21       1059    end
  nd-145 1 0 1-21       1059    end
  nd-146 1 0 1-21       1059    end
```

```
  nd-147 1 0 1-21        1059    end
  nd-148 1 0 1-21        1059    end
  nd-150 1 0 1-21        1059    end
  pm-147 1 0 1-21        1059    end
  pm-148 1 0 1-21        1059    end
  pm-149 1 0 1-21        1059    end
  sm-147 1 0 1-21        1059    end
  sm-148 1 0 1-21        1059    end
  sm-149 1 0 1-21        1059    end
  sm-150 1 0 1-21        1059    end
  sm-151 1 0 1-21        1059    end
  sm-152 1 0 1-21        1059    end
  gd-154 1 0 1-21        1059    end
  gd-155 1 0 1-21        1059    end
  gd-157 1 0 1-21        1059    end
  gd-158 1 0 1-21        1059    end
  gd-160 1 0 1-21        1059    end
  eu-151 1 0 1-21        1059    end
  eu-153 1 0 1-21        1059    end
  eu-154 1 0 1-21        1059    end
  eu-155 1 0 1-21        1059    end
  u-232 1 0 1-21         1059    end
  u-233 1 0 1-21         1059    end
arbmzr2 6.55 6 0 0 0 50000 1.45 26000 .135 28000 .055
           24000 .1 8016 .125 40000 98.135 2 1.0 574 end
h2o 3 den=.37557 1 561 end
uo2 4 den=9.37605 1 1059 92234 .0324 92235 3.6 92238 96.3676 end
arbm-gd2o3 9.37605 2 0 1 1 64000 2 8016 3 4 .05 1059 end
h2o 5 den=.37557 1.0 561 end
arbmzr4 6.56 5 0 0 0 50000 1.45 26000 .21
           24000 .1 8016 .125 40000 98.115 6 1.0 561 end
h2o 7 den=.71947 1.0 561 end
arbmzr4 6.56 5 0 0 0 50000 1.45 26000 .21
           24000 .1 8016 .125 40000 98.115 7 0.0231 561 end
end comp
squarepitch 1.44 .9754 1 3 1.1176 2 end
more data szf=.5 end
npin/assm=74 fuelngth=15.24 ncycles=37 nlib/cyc=1 lightel=0
printlevel=5 inplevel=2 numztotal=7 mxrepeats=1 mixmod=3 facmesh=.5 end
  4 .4877 2 .5588 3 .81243 500 2.3296 5 2.421026 6 2.53884 7 2.86608
power=.19348 burn=73.0 down=0 h2of=1.000 tmpf=1059 tmpc=574 tmpm=561 end
power=.19718 burn=45.5 down=0 h2of=0.877 tmpf=1068 tmpc=575 tmpm=561 end
power=.19718 burn=45.5 down=0 h2of=0.877 tmpf=1068 tmpc=575 tmpm=561 end
power=.20425 burn=45.5 down=0 h2of=0.880 tmpf=1085 tmpc=575 tmpm=561 end
power=.20425 burn=45.5 down=0 h2of=0.880 tmpf=1085 tmpc=575 tmpm=561 end
power=.20348 burn=45.5 down=0 h2of=0.978 tmpf=1083 tmpc=575 tmpm=561 end
power=.20348 burn=45.5 down=0 h2of=0.978 tmpf=1083 tmpc=575 tmpm=561 end
power=.23563 burn=55.0 down=0 h2of=0.878 tmpf=1160 tmpc=578 tmpm=562 end
power=.21628 burn=53.0 down=0 h2of=0.934 tmpf=1114 tmpc=577 tmpm=562 end
power=.24685 burn=50.0 down=0 h2of=1.073 tmpf=1183 tmpc=575 tmpm=558 end
power=.20453 burn=67.0 down=38 h2of=1.272 tmpf=1086 tmpc=575 tmpm=561 end
power=.26255 burn=57.0 down=0 h2of=0.696 tmpf=1220 tmpc=577 tmpm=559 end
power=.24847 burn=65.0 down=0 h2of=0.678 tmpf=1189 tmpc=577 tmpm=560 end
power=.23814 burn=42.5 down=0 h2of=0.725 tmpf=1164 tmpc=576 tmpm=559 end
power=.23814 burn=42.5 down=0 h2of=0.725 tmpf=1164 tmpc=576 tmpm=559 end
power=.23024 burn=37.0 down=0 h2of=0.779 tmpf=1147 tmpc=577 tmpm=562 end
```

```
power=.23010 burn=67.0 down=0 h2of=0.793 tmpf=1146 tmpc=576 tmpm=560 end
power=.20482 burn=37.0 down=0 h2of=0.819 tmpf=1086 tmpc=574 tmpm=560 end
power=.22097 burn=67.0 down=0 h2of=0.889 tmpf=1124 tmpc=575 tmpm=560 end
power=.19817 burn=35.0 down=0 h2of=0.847 tmpf=1070 tmpc=574 tmpm=560 end
power=.21758 burn=42.0 down=0 h2of=0.947 tmpf=1116 tmpc=575 tmpm=560 end
power=.14627 burn=43.0 down=0 h2of=0.955 tmpf=945 tmpc=572 tmpm=562 end
power=.14627 burn=43.0 down=0 h2of=0.955 tmpf=945 tmpc=572 tmpm=562 end
power=.21285 burn=60.0 down=0 h2of=1.078 tmpf=1105 tmpc=574 tmpm=560 end
power=.19883 burn=45.0 down=27 h2of=1.293 tmpf=1072 tmpc=574 tmpm=560 end
power=.16851 burn=57.0 down=0 h2of=0.926 tmpf=1001 tmpc=575 tmpm=563 end
power=.19549 burn=78.0 down=0 h2of=0.873 tmpf=1065 tmpc=575 tmpm=562 end
power=.20135 burn=60.5 down=0 h2of=0.894 tmpf=1079 tmpc=576 tmpm=562 end
power=.20135 burn=60.5 down=0 h2of=0.894 tmpf=1079 tmpc=576 tmpm=562 end
power=.19366 burn=71.0 down=0 h2of=0.952 tmpf=1061 tmpc=576 tmpm=562 end
power=.20782 burn=74.0 down=0 h2of=0.961 tmpf=1095 tmpc=576 tmpm=562 end
power=.18913 burn=71.0 down=0 h2of=1.111 tmpf=1051 tmpc=576 tmpm=563 end
power=.15965 burn=81.0 down=0 h2of=1.157 tmpf=979 tmpc=574 tmpm=563 end
power=.15220 burn=41.0 down=0 h2of=1.101 tmpf=960 tmpc=572 tmpm=562 end
power=.16887 burn=48.0 down=0 h2of=1.000 tmpf=1002 tmpc=575 tmpm=563 end
power=.16091 burn=48.0 down=0 h2of=1.073 tmpf=983 tmpc=574 tmpm=563 end
power=.12927 burn=63.0 down=1510 h2of=1.307 tmpf=902 tmpc=569 tmpm=560 end
end
```

A.2 SCALE 5/TRITON ISOTOPIC CONCENTRATION ANALYSIS FOR LIMERICK FUEL ASSEMBLY YJ1433

TRITON Input Listing for Sample D8-3D2B:

```
=t-depl
32-5048840-00 Limerick 1, Assembly YJ1433, Gd Rod D8-3D2Bc, Node 14
80
44groupndf
read alias
$fuel 11-16 end
$clad 21-26 end
$mod  31-36 end
end alias
read comp
'*****
'U pin cell    mat # 11
uo2    11     den=10.01868       1      854
      92234 0.03555      92235 3.95   92238 96.01445    end
'*****
'U part length mat # 12
uo2    12     den=10.01868       1      854
      92234 0.03555      92235 3.95   92238 96.01445    end
'*****
'U/Gd pin cell mat # 13
uo2    13     den=9.37605 1      854
      92234 0.0324       92235 3.6    92238 96.3676             end
arbm-gd2o3  9.37605      2      0      1      1
      64000 2     8016   3      13     0.05   854    end
'*****
'U D9/I4 pin   mat # 14
uo2    14     den=10.01868       1      854
```

```
      92234 0.03555      92235 3.95   92238 96.01445     end
'*****
' U Pl H5/D8pin mat # 15

uo2    15     den=10.01868        1      854
      92234 0.03555      92235 3.95   92238 96.01445     end
'*****
'U/Gd D8/H4 pin   mat # 16
uo2    16     den=9.37605 1      854
      92234 0.0324       92235 3.6    92238 96.3676              end
arbm-gd2o3   9.37605      2      0      1      1
      64000 2      8016   3      16     0.05   854    end
'*****
'Clad  all pin mat #'s 21-26 $clad

arbmzr4      6.56   5      0      0      0      50000 1.45   26000
      0.21   24000 0.1    8016   0.125 40000 98.115       $clad
             1      561 end
'***** mat # 31 is fillmix background
'Mod all pins mat #'s 31-36 $mod

h2o    $mod  den=0.37557 1      561                    end

'*****
'non-heated water mat # 30

h2o    30    den=.73648  1      561                    end

'*****
' Channel mat # 43
arbmzr4      6.56   5      0      0      0      50000 1.45   26000
      0.21   24000 0.1    8016   0.125 40000 98.115       43
             1      561 end
'*****
'Blade Wing mat # 42
h2o    42    den=.73648  1      561                    end

'*****
'BladeCenter Cross mat # 41

h2o    41    den=.73648  1      561                    end

'**************************************************************************
end comp
read celldata
latticecell squarepitch pitch=1.44 $mod   fuel=0.4877 $fuel clad=0.5588
$clad end
end celldata
read depletion 11 12    13     -16 end depletion
read timetable
densmult     $mod  0
0.00  1.000              73.00 1.000 73.01 0.877
118.50       0.877 118.51       0.877 164.00       0.877 164.01       0.880

209.50       0.880 209.51       0.880 255.00       0.880 255.01       0.978
```

```
300.50       0.978 300.51     0.978 346.00     0.978 346.01     0.878

401.00       0.878 401.01     0.934 454.00     0.934 454.01     1.073

504.00       1.073 504.01     1.272 609.00     1.272 609.01     0.696

666.00       0.696 666.01     0.678 731.00     0.678 731.01     0.725

773.50       0.725 773.51     0.725 816.00     0.725 816.01     0.779

853.00       0.779 853.01     0.793 920.00     0.793 920.01     0.819

957.00       0.819 957.01     0.889 1024.00    0.889 1024.01    0.847

1059.00      0.847 1059.01    0.947 1101.00    0.947 1101.01    0.955

1144.00      0.955 1144.01    0.955 1187.00    0.955 1187.01    1.078

1247.00      1.078 1247.01    1.293 1292.00    1.293 1292.01    0.926

1376.00      0.926 1376.01    0.873 1454.00    0.873 1454.01    0.894

1514.50      0.894 1514.51    0.894 1575.00    0.894 1575.01    0.952

1646.00      0.952 1646.01    0.961 1720.00    0.961 1720.01    1.111

1791.00      1.111 1791.01    1.157 1872.00    1.157 1872.01    1.101

1913.00      1.101 1913.01    1.000 1961.00    1.000 1961.01    1.073

2009.00      1.073 2009.01    1.307 2072.00    1.307 end
temperfuel       $fuel
0      1059 73      1059
73.01 1068 118.5   1068
118.51       1068 164     1068
164.01       1085 209.5   1085
209.51       1085 255     1085
255.01       1083 300.5   1083
300.51       1083 346     1083
346.01       1160 401     1160
401.01       1114 454     1114
454.01       1183 504     1183
504.01       1086 609     1086
609.01       1220 666     1220
666.01       1189 731     1189
731.01       1164 773.5   1164
773.51       1164 816     1164
816.01       1147 853     1147
853.01       1146 920     1146
920.01       1086 957     1086
957.01       1124 1024    1124
1024.01      1070 1059    1070
1059.01      1116 1101    1116
1101.01      945 1144     945
1144.01      945 1187     945
1187.01      1105 1247    1105
```

```
1247.01      1001 1376   1001
1376.01      1065 1454   1065
1454.01      1079 1514.5 1079
1514.51      1079 1575   1079
1575.01      1061 1646   1061
1646.01      1095 1720   1095
1720.01      1051 1791   1051
1791.01      979 1872    979
1872.01      960 1913    960
1913.01      1002 1961   1002
1961.01      983 2009    983
2009.01      902 3582    902 end
end timetable
read burndata
power=       2.635E+01   burn= 73.0   down= 0      end
power=       2.686E+01   burn= 45.5   down= 0      end
power=       2.686E+01   burn= 45.5   down= 0      end
power=       2.782E+01   burn= 45.5   down= 0      end
power=       2.782E+01   burn= 45.5   down= 0      end
power=       2.772E+01   burn= 45.5   down= 0      end
power=       2.772E+01   burn= 45.5   down= 0      end
power=       3.210E+01   burn= 55.0   down= 0      end
power=       2.946E+01   burn= 53.0   down= 0      end
power=       3.362E+01   burn= 50.0   down= 38     end
power=       2.786E+01   burn= 67.0   down= 0      end
power=       3.576E+01   burn= 57.0   down= 0      end
power=       3.385E+01   burn= 65.0   down= 0      end
power=       3.244E+01   burn= 42.5   down= 0      end
power=       3.244E+01   burn= 42.5   down= 0      end
power=       3.136E+01   burn= 37.0   down= 0      end
power=       3.134E+01   burn= 67.0   down= 0      end
power=       2.790E+01   burn= 37.0   down= 0      end
power=       3.010E+01   burn= 67.0   down= 0      end
power=       2.699E+01   burn= 35.0   down= 0      end
power=       2.964E+01   burn= 42.0   down= 0      end
power=       1.992E+01   burn= 43.0   down= 0      end
power=       1.992E+01   burn= 43.0   down= 0      end
power=       2.899E+01   burn= 60.0   down= 0      end
power=       2.708E+01   burn= 45.0   down= 27     end
power=       2.295E+01   burn= 57.0   down= 0      end
power=       2.663E+01   burn= 78.0   down= 0      end
power=       2.743E+01   burn= 60.5   down= 0      end
power=       2.743E+01   burn= 60.5   down= 0      end
power=       2.638E+01   burn= 71.0   down= 0      end
power=       2.831E+01   burn= 74.0   down= 0      end
power=       2.576E+01   burn= 71.0   down= 0      end
power=       2.175E+01   burn= 81.0   down= 0      end
power=       2.073E+01   burn= 41.0   down= 0      end
power=       2.300E+01   burn= 48.0   down= 0      end
power=       2.192E+01   burn= 48.0   down= 0      end
power=       1.761E+01   burn= 63.0   down= 1510   end
end burndata
read opus
units=atom symnuc=u-234 u-235 u-236 u-238
o-16
pu-238
```

```
pu-239
pu-240
pu-241
pu-242
cs-134
cs-137
nd-143
nd-145
eu-151
eu-153
eu-155
sm-147
sm-149
sm-150
sm-151
sm-152
gd-155
cm-244
am-241
am-242m
am-243
np-237
mo-95
tc-99
ru-101
rh-103
ag-109
nd-146
nd-148
nd-150
cm-242
cm-243
cm-245
cm-246 end
matl=0 16  end
end opus
'***
'* Begin reading newt input data
'***
read model
Limerick 1, Assembly YJ1433, Gd Rod D8-3D2Bc, Node 14 NEWT 32-5048840-00
read parm
  drawit=yes
  run=yes  fillmix=31
  sn=6 inners=10 outers=200 epsinner=1e-3 epsouter=1e-3 epseigen=1e-3
  hybrid=yes critical=yes
  timed=yes
end parm
read materials
$fuel 1     !fuel materials 11-16!        end
$clad 0     !clad materials 21-26!        end
$mod  2     !mod materials 31-36!         end
30    2     !non-heated water!            end
41    1     !Cross SS304!                 end
42    1     !Active Blade!                end
43    0     !Zirc Channel !               end
```

```
end materials
read geom
domain       15.24 15.24 12    12
boundary     1     1     1     1
rectangle    31    0.9969       0.9969       14.2431      14.2431
                   !water inside channel!  end
rectangle    43    0.6921       0.6921       14.5479      14.5479
                   ! channel!  end
rectangle    30    0.4166       0.4166       14.8234      14.8234
                   !water outside channel! end
rectangle    42    0     2.7884       0.4166      13.2715
                   !vertical active blade! end
rectangle    41    0     13.2715      0.4166      15.24
                   !vertical inactive blade!     end
rectangle    41    0.4166       14.8234      1.9685       15.24
                   !horizontal inactive blade!   end
rectangle    42    1.9685       14.8234      12.4516      15.24

                   !horizontal active blade!     end
rectangle    30    0     0      0.4166      2.7884
                   !water vertical left!   end
rectangle    30    0.4166       0      15.24 0.4166
                   !water horizontal bottom!     end
rectangle    30    14.8234      0.4166       15.24 15.24
                   !water vertical right!  end
rectangle    30    12.4516      14.8234      14.8234      15.24
                   !water horizontal top!  end
'subgrid 1 is a U mat #11 rod
subgrid      1     1.44  1.4400      4     4
cylinder     11    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end
'subgrid 2 is a U part length mat #12 rod
subgrid      2     1.44  1.44  4     4
cylinder     12    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end
'subgrid 3 is a Gd mat #13 rod
subgrid      3     1.44  1.44  4     4
cylinder     13    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end

'subgrid 4 is a U-D9 node 22 mat #14 rod
subgrid      4     1.44  1.44  4     4
cylinder     14    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end
'subgrid 5 is a U Part Length H5 node 15 mat #15 rod

subgrid      5     1.44  1.44  4     4
cylinder     15    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end
'subgrid 6 is a Gd- D8 node 22 mat #16 rod
subgrid      6     1.44  1.44  4     4
cylinder     16    0.72  0.72  0.4877       !fuel!       end
cylinder     21    0.72  0.72  0.5588       !clad!       end
'subgrid 7 is a  cold water hole mat # 30 rod with clad

subgrid      7     1.44  1.44  4     4
```

```
cylinder    30    0.72  0.72  0.6246      !COLD water hole! end
cylinder    21    0.72  0.72  0.6652      !clad!      end
'subgrid 8 is heated water mat # 31 no clad
subgrid     8     1.44  1.44  4     4
rectangle   31    0     0     1.44 1.44 !HOT water hole!    end
array 1.1849      1.1849      9     9
1     1     1     1     1     1     1     1     1
1     2     1     3     2     3     1     2     1
1     1     1     1     1     1     1     1     1
1     3     1     1     7     7     1     6     1
1     2     1     7     7     7     1     2     1
1     3     1     7     7     3     1     1     1
1     1     1     1     1     1     1     3     1
1     2     1     3     2     1     3     2     1
1     1     1     1     1     1     1     1     1
end geom
end model
'***
'* end of newt transport model
'***
end
```

A.3 MCNP CRITICALITY ANALYSIS FOR LIMERICK FUEL ASSEMBLY YJ1433 IN WASTE PACKAGE

MCNP Input Listing for Sample D8-3D2B:

```
    init-mcnp-work-file
C     OUTSIDE WORLD
1     0 -50:1:-2:3:-51 IMP:N=0
C     REFLECTOR REGION ARROUND WASTE PACKAGE (12" of Water)
2     1 -1.0 50 51 -1 2 -3 (8:13:-11) IMP:N=1
C     Outer Barrier
8     2 -8.69 50 51 11 -8 -13 10 IMP:N=1
C     Gap between Inner lid and basket
13    1 -1.0 50 51 -16 -170 17 IMP:N=1
C     Inner Barrier
14    3 -7.98 50 51 -10 -13 16 11 #16 #15 IMP:N=1
C     Inner Barrier Lid
15    3 -7.98 50 51 -13 -16 170 IMP:N=1
C     Inner Barrier Bottom
16    3 -7.98 50 51 11 -16 -15 IMP:N=1
C
C     BASKET PLATES
17    4 -7.76 15 -17 51 50 -16 (-32:-18) IMP:N=1 $ QUARTER BOUNDARY
18    4 -7.76 15 -17 32 20 -21 -33 IMP:N=1 $ PLATE 1
19    4 -7.76 15 -17 35 20 -21 -36 IMP:N=1 $ PLATE 2
20    4 -7.76 15 -17 37 20 -21 -38 IMP:N=1 $ PLATE 3
21    4 -7.76 15 -17 32 22 -23 -33 IMP:N=1 $ PLATE 4
24    4 -7.76 15 -17 35 22 -23 -36 IMP:N=1 $ PLATE 5
27    4 -7.76 15 -17 37 22 -23 -38 IMP:N=1 $ PLATE 6
30    4 -7.76 15 -17 32 24 -25 -33 IMP:N=1 $ PLATE 7
33    4 -7.76 15 -17 34 18 -35 -24 IMP:N=1 $ PLATE 8
36    4 -7.76 15 -17 36 18 -37 -24 IMP:N=1 $ PLATE 9
```

```
39     4 -7.76 15 -17 38 18 -39 -19 IMP:N=1 $ PLATE 10
C
C      SHUNTS
40     5 -2.7065 15 -17 32 19 -20 -33 IMP:N=1 $ SHUNT 1
41     5 -2.7065 15 -17 35 19 -20 -36 IMP:N=1 $ SHUNT 2
42     5 -2.7065 15 -17 37 19 -20 -16 IMP:N=1 $ SHUNT 3
43     5 -2.7065 15 -17 33 -34 18 -16 IMP:N=1 $ SHUNT 4
C
C      WATER FILLED REGIONS BY SIDE GUIDES
50     1 -1.0 29 45 -28 -16 15 -17 IMP:N=1 $ BOTTOM
51     1 -1.0 27 40 -16 15 -17     IMP:N=1 $ MID BOTTOM
52     1 -1.0 26 41 -16 15 -17     IMP:N=1 $ MID TOP
53     1 -1.0 42 31 -43 -16 15 -17 IMP:N=1 $ TOP
C
C      LOADED ASSEMBLIES
63     0 15 -17 18 -33 -19 32 FILL=20 (8.515 8.515 0)    IMP:N=1 $ Assembly 1
64     0 15 -17 18 -36 -19 35 FILL=20 (26.045 8.515 0)   IMP:N=1 $ Assembly 2
65     0 15 -17 18 -38 -19 37 FILL=20 (43.075 8.515 0)   IMP:N=1 $ Assembly 3
66     0 15 -17 18 -44 -19 39 FILL=20 (60.105 8.515 0)   IMP:N=1 $ Assembly 4
67     0 15 -17 21 -33 -22 32 FILL=20 (8.515 26.045 0)   IMP:N=1 $ Assembly 5
68     0 15 -17 21 -36 -22 35 FILL=20 (26.045 26.045 0) IMP:N=1 $ Assembly 6
69     0 15 -17 21 -38 -22 37 FILL=20 (43.075 26.045 0) IMP:N=1 $ Assembly 7
70     0 15 -17 23 -33 -24 32 FILL=20 (8.515 43.075 0)   IMP:N=1 $ Assembly 8
71     0 15 -17 23 -36 -24 35 FILL=20 (26.045 43.075 0) IMP:N=1 $ Assembly 9
72     0 15 -17 23 -38 -24 37 FILL=20 (43.075 43.075 0) IMP:N=1 $ Assembly 10
73     0 15 -17 25 -33 -30 32 FILL=20 (8.515 60.105 0)   IMP:N=1 $ Assembly 11
C
C      BASKET SIDE GUIDE
84     50 -7.85 15 -17 18 44 -19 (28:-45:-29) -16 IMP:N=1 $ BOTTOM
85     50 -7.85 15 -17 20 (-40:-27) -16 38 IMP:N=1 $ MID BOTTOM
86     50 -7.85 15 -17 (-41:-26) -16 24 34 -38  IMP:N=1 $ MID TOP
87     50 -7.85 15 -17 32 30 -33 (-42:-31:43) -16 IMP:N=1 $ TOP
C
90     10 -6.56 (161 -165 -177 178):(-162 166 176 -175):
                (-160 164 -177 178):(163 -167 -175 176):
                (-182 186 175 -178):(-183 187 -176 -178):
                (185 -181 -176 177):(-180 184 177 175) U=3 IMP:N=1
91     0 (176 -175 -166 167):(165 -176 -177 178):(175 -164 -177 178):
         (-185 -176 177):(-184 175 177):(-186 175 -178):
         (-187 -176 -178) FILL=1 (0 0 -16.415) U=3 IMP:N=1
C      Water Outside Channel
92     1 -1.0 (-161:162:160:-163):(181 -176 177):(180 175 177):(182 -178 175):
              (183 -176 -178) U=3 IMP:N=1
C
C      Fuel Tube
136    0 -58 59 -60 61 660 -650 FILL=3 U=20 IMP:N=1
137    50 -7.85 (58:-59:60:-61) U=20 IMP:N=1
138    1  -1.0  -58  59 -60 61 -660 U=20 IMP:N=1
139    1  -1.0  -58  59 -60 61  650 U=20 IMP:N=1
C
C      Fuel Assembly (GE 9x9) Universe
270    1 -1.0 -320 +330 -340 +350 IMP:N=1 U=1 LAT=1
       FILL -5:5 -5:5 0:0
       1 1 1 1 1 1 1 1 1 1 1
       1 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 1
```

```
      1 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 1 1 2 2 2 1
      1 2 2 2 1 1 1 2 2 2 1
      1 2 2 2 1 1 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 1
      1 1 1 1 1 1 1 1 1 1 1
C
C     Fuel Rod Universe
290   12 -6.55      -420 +430 -460 +470 IMP:N=1 U=2 $ Clad
200   6  6.4316E-02 -430  450 -440 IMP:N=1 U=2 $ Fuel node 1
310   12 -6.55      -420 +460 -480 IMP:N=1 U=2 $ Upper End Cap
320   12 -6.55      -420 -470 +490 IMP:N=1 U=2 $ Lower End Cap
330   14 -0.178     -430 -460 +440 IMP:N=1 U=2 $ Upper Plenum
340   12 -6.55      -430 -450 +470 IMP:N=1 U=2 $ Lower End Cap at Bottom of
Active Fuel
350   1  -1.0       +420 -640 +500 IMP:N=1 U=2 $ Moderator
440   17 -1.0       +640 +420 IMP:N=1 U=2 $ Upper End Fitting
450   18 -1.0       +420 -500 +490 IMP:N=1 U=2 $ Lower End Fitting
460   1  -1.0       -490 IMP:N=1 U=2 $ Lower End Fitting
C
C     Central Water Rod Universe
C
C     Guide Tube Universe
860   12 -6.55 -380 +390 +670 IMP:N=1 U=5 $ Water Rod Tube
861   1  -1.0  +380 -640 +500 IMP:N=1 U=5 $ Moderator
862   1  -1.0  -390 +670 IMP:N=1 U=5 $ Moderator
864   17 -1.0  +380 +640 IMP:N=1 U=5 $ Upper Tie Plate Portion
866   1  -1.0  -670 IMP:N=1 U=5 $ Lower End Fitting
867   18 -1.0  +380 -500 +670 IMP:N=1 U=5 $ Lower End Fitting
C
870   10 -6.56 -321 +331 -341 +351 FILL=5 (0.8228 0.8228 0) U=6 IMP:N=1
871   10 -6.56 -321 +331 -341 +351 FILL=5 (-0.8228 0.8228 0) U=7 IMP:N=1
872   10 -6.56 -321 +331 -341 +351 FILL=5 (-0.8228 -0.8228 0) U=8 IMP:N=1
873   10 -6.56 -321 +331 -341 +351 FILL=5 (0.8228 -0.8228 0) U=9 IMP:N=1

C ________________________Surface Cards________________
C Reflector
1*  cz  133.2
2*  pz -269.75
3*  pz  273.75
8   CZ  79.7   $ IR Skirt OR outer barrier
10  cz  77.7   $ IR outer shell = OR inner barrier
11  PZ -238.25 $ bottom inner barrier
13  PZ  239.25 $ Top Inner Shell Lid
15  PZ -228.75 $ bottom basket
16  CZ  72.7   $ IR inner shell
170 PZ  229.75 $ top inner gap = bottom inner lid
17  PZ  228.75 $ top basket
C Basket Plate and Thermal Shunt Surfaces
18    PY 0.25
19    PY 16.78
20    PY 17.28
21    PY 17.78
22    PY 34.31
```

```
23    PY 34.81
24    PY 51.34
25    PY 51.84
26    PY 52.34
27    PY 18.28
28    PY 15.78
29    PY 1.25
30    PY 68.37
31    PY 69.37
C     Quarter Slices
50*   PY 0.0  $ Horizontal slice
51*   PX 0.0  $ Vertical slice
C
32    PX   0.25
33    PX   16.78
34    PX   17.28
35    PX   17.78
36    PX   34.31
37    PX   34.81
38    PX   51.34
39    PX   51.84
40    PX   52.34
41    PX   18.28
43    PX   15.78
42    PX   1.25
44    PX   68.37
45    PX   69.37
C
58    PX   7.765
59    PX  -7.765
60    PY   7.765
61    PY  -7.765
C
160   PX  6.92785  $ Channel Outer Eastern Surface
161   PX -6.92785  $ Channel Outer Western Surface
162   PY  6.92785  $ Channel Outer Northern Surface
163   PY -6.92785  $ Channel Outer Southern Surface
164   PX  6.62305  $ Channel Inner Eastern Surface
165   PX -6.62305  $ Channel Inner Western Surface
166   PY  6.62305  $ Channel Inner Northern Surface
167   PY -6.62305  $ Channel Inner Southern Surface
175   PX  5.89026  $ Ambiguous Surface
176   PX -5.89026  $ Ambiguous Surface
177   PY  5.89026  $ Ambiguous Surface
178   PY -5.89026  $ Ambiguous Surface
C
180   C/Z  5.89026  5.89026 1.037 $ NE Channel Outer Corner Radius
181   C/Z -5.89026  5.89026 1.037 $ NW Channel Outer Corner Radius
182   C/Z  5.89026 -5.89026 1.037 $ SE Channel Outer Corner Radius
183   C/Z -5.89026 -5.89026 1.037 $ SW Channel Outer Corner Radius
184   C/Z  5.89026  5.89026 0.73  $ NE Channel Inner Corner Radius
185   C/Z -5.89026  5.89026 0.73  $ NW Channel Inner Corner Radius
186   C/Z  5.89026 -5.89026 0.73  $ SE Channel Inner Corner Radius
187   C/Z -5.89026 -5.89026 0.73  $ SW Channel Inner Corner Radius
C
320    PX  0.71501 $ Fuel Pin Cell Eastern Surface
```

```
330    PX -0.71501 $ Fuel Pin Cell Western Surface
340    PY  0.71501 $ Fuel Pin Cell Northern Surface
350    PY -0.71501 $ Fuel Pin Cell Southern Surface
C
321    PX  0.8228  $ AMBIGUOUS SURFACE FOR WATER ROD
331    PX -0.8228  $ AMBIGUOUS SURFACE FOR WATER ROD
341    PY  0.8228  $ AMBIGUOUS SURFACE FOR WATER ROD
351    PY -0.8228  $ AMBIGUOUS SURFACE FOR WATER ROD
C
380    CZ  1.309      $ Water Rod Outer Radius
390    CZ  1.228      $ Water Rod Inner Radius
420    CZ  0.5588     $ Fuel Rod Clad Outer Radius
430    CZ  0.4877     $ Fuel Rod Clad Inner Radius
440    PZ  186.03     $ Fuel Top Surface
450    PZ  -182.88    $ Fuel Bottom Surface
460    PZ  214.5796   $ Fuel Clad Top Surface
470    PZ  -184.4675  $ Fuel Clad Bottom Surface
480    PZ  218.8722   $ Fuel Rod Upper End Cap Top Surface
490    PZ  -186.0423  $ Fuel Rod Lower End Cap Bottom Surface
500    PZ  -184.4675  $ Lower Tie Plate Portion Top Surface
640    PZ  216.7132   $ Upper Tie Plate Portion Bottom Surface
650    PZ  202.4572   $ Upper Tie Plate Portion Top Surface
660    PZ  -202.4572  $ Lower Tie Plate Portion Bottom Surface
670    PZ  -190.777   $ Guide Tube Bottom Surface

MODE   N
KCODE   10000 1 25 150
SDEF   AXS= 0 0 1 EXT=D1 RAD=D2 ERG=D3 POS= D4
SI1    -180 180
SI2    0.0 7.75
SP3    -2
SI4 L  8.515 8.515 0
       26.045 8.515 0
       43.075 8.515 0
       60.105 8.515 0
       8.515 26.045 0
       26.045 26.045 0
       43.075 26.045 0
       8.515 43.075 0
       26.045 43.075 0
       43.075 43.075 0
       8.515 60.105 0
SP4    1 1 1 1 1 1 1 1 1 1 1
C ______________________MATERIAL Cards_________________
C WATER AT 300 K d=1.0000 g/cc
M1     1001.50C     2
       8016.50C     1
MT1    LWTR.01T
C ALLOY 22 d=8.69 g/cc outer corrosion barrier material
M2     6000.50c    -0.0150
      25055.50c    -0.5000
      14000.50c    -0.0800
      24050.60c    -0.8879
      24052.60c   -17.7863
      24053.60c    -2.0554
      24054.60c    -0.5202
```

```
     28058.60c   -36.8024
     28060.60c   -14.6621
     28061.60c    -0.6481
     28062.60c    -2.0975
     28064.60c    -0.5547
     42000.50c   -13.5000
     27059.50c    -2.5000
     74182.55c    -0.7877
     74183.55c    -0.4278
     74184.55c    -0.9209
     74186.55c    -0.8636
     23000.50c    -0.3500
     26054.60c    -0.2260
     26056.60c    -3.6759
     26057.60c    -0.0865
     26058.60c    -0.0116
     16032.50c    -0.02
     15031.50c    -0.02
C SS316NG d=7.98 g/cc inner corrosion barrier material
M3     6000.50c    -0.0200
       7014.50c    -0.0800
     14000.50c    -1.0000
     15031.50c    -0.0450
     16032.50c    -0.0300
     24050.60c    -0.7103
     24052.60c   -14.2291
     24053.60c    -1.6443
     24054.60c    -0.4162
     25055.50c    -2.0000
     26054.60c    -3.6911
     26056.60c   -60.0322
     26057.60c    -1.4119
     26058.60c    -0.1897
     28058.60c    -8.0641
     28060.60c    -3.2127
     28061.60c    -0.1420
     28062.60c    -0.4596
     28064.60c    -0.1216
     42000.50c    -2.5000
c
c Neutronit A978 dens=7.76 g/cc i/s support structure liner material
M4     5010.50c    -0.2986
       5011.56c    -1.3214
       6000.50c    -0.0400
     24050.60c    -0.7730
     24052.60c   -15.4846
     24053.60c    -1.7894
     24054.60c    -0.4529
     26054.60c    -3.6411
     26056.60c   -59.2189
     26057.60c    -1.3928
     26058.60c    -0.1872
     27059.50c    -0.2000
     28058.60c    -8.7361
     28060.60c    -3.4805
     28061.60c    -0.1539
```

```
     28062.60c    -0.4979
     28064.60c    -0.1317
     42000.50c    -2.2000
C ASTM A516 Grade 70 carbon steel dens=7.85 g/cc i/s support structure
material
M50   6000.50c    -0.2700
     25055.50c    -1.0450
     15031.50c    -0.0350
     16032.50c    -0.0350
     14000.50c    -0.2900
     26054.60c    -5.5558
     26056.60c   -90.3584
     26057.60c    -2.1252
     26058.60c    -0.2856
C Aluminum 6061 dens=2.7065 g/cc i/s support structure material
M5   14000.50c    -0.6000 $ Al Alloy (SB-209 A96061 T4)
     26054.60c    -0.0396
     26056.60c    -0.6433
     26057.60c    -0.0151
     26058.60c    -0.0020
     29063.60c    -0.1884 $ Zn added to Al
     29065.60c    -0.0866
     25055.50c    -0.1500
     12000.50c    -1.0000
     24050.60c    -0.0081
     24052.60c    -0.1632
     24053.60c    -0.0189
     24054.60c    -0.0048
     22000.50c    -0.1500
     13027.50c   -96.9300
C Zircaloy-4 dens=6.56 g/cc fuel structure material
M10  24050.60c    -0.0042
     24052.60c    -0.0837
     24053.60c    -0.0097
     24054.60c    -0.0024
     26054.60c    -0.0119
     26056.60c    -0.1930
     26057.60c    -0.0045
     26058.60c    -0.0006
      8016.50c    -0.1250
     40000.60c   -98.1150
     50000.35c    -1.4500
C Zircaloy-2 dens=6.55 g/cc Fuel Rod Clad material
M12   8016.50c    -0.1250
     24050.60c    -0.0042
     24052.60c    -0.0837
     24053.60c    -0.0097
     24054.60c    -0.0024
     26054.60c    -0.0076
     26056.60c    -0.1241
     26057.60c    -0.0029
     26058.60c    -0.0004
     28058.60c    -0.0370
     28060.60c    -0.0147
     28061.60c    -0.0007
     28062.60c    -0.0021
```

```
     28064.60c    -0.0006
     50000.35c    -1.4500
     40000.60c   -98.1350
C
M14   2004.50c    1   $ Upper Fuel Rod Plenum (represented as He gas)
C
M17   1001.50c      2.0000 $ Upper Tie Plate (Represented as moderator for
conservatism)
      8016.50c      1.0000
MT17 lwtr.01t
C
M18   1001.50c      2.0000 $ Lower Tie Plate (Represented as moderator for
conservatism)
      8016.50c      1.0000
MT18 lwtr.01t
M6          $
          92234.50c      3.1980E-06 $ 234U
          92235.50c      9.8700E-05 $ 235U
          92236.50c      1.1110E-04 $ 236U
          92238.50c      1.9250E-02 $ 238
          8016.50c       4.4170E-02 $ O
          94238.50c      8.6430E-06 $ 238Pu
          94239.55c      1.1630E-04 $ 239Pu
          94240.50c      7.3270E-05 $ 240Pu
          94241.50c      2.8170E-05 $ 241Pu
          94242.50c      2.4010E-05 $ 242Pu
          55134.60c      1.7590E-06 $ 134Cs
          55137.60c      6.3550E-05 $ 137Cs
          60143.50c      3.7060E-05 $ 143Nd
          60145.50c      3.4240E-05 $ 145Nd
          63151.55c      1.9590E-08 $ 151Eu
          63153.55c      6.5890E-06 $ 153Eu
          63155.50c      1.8490E-07 $ 155Eu
          62147.50c      8.9960E-06 $ 147Sm
          62149.50c      8.6460E-08 $ 149Sm
          62150.50c      1.5100E-05 $ 150Sm
          62151.50c      5.7290E-07 $ 151Sm
          62152.50c      6.4280E-06 $ 152Sm
          64155.50c      2.6520E-07 $ 155Gd
          96244.50c      2.9730E-06 $ 244Cm
          95241.50c      8.1810E-06 $ 241Am
          95242.50c      3.6340E-08 $ 242mAm
          95243.50c      7.0620E-06 $ 243Am
          93237.50c      1.5090E-05 $ 237Np
          42095.50c      5.9890E-05 $ 95Mo
          43099.50c      6.2010E-05 $ 99Tc
          44101.50c      6.1860E-05 $ 101Ru
          45103.50c      3.4140E-05 $ 103Rh
          47109.60c      6.1550E-06 $ 109Ag
PRINT  128
```

APPENDIX B: B&W MARK B PWR ASSEMBLY CALCULATION INPUT LISTINGS

B.1 SCALE 5/SAS2 ISOTOPIC CONCENTRATION ANALYSIS FOR B&W MARK B TYPE ASSEMBLY

SAS2 Input Listing for PWR One-and Two-Dimensional Study

```
=sas2h        parm=skipshipdata
Generic PWR based on B&W Mk-B, 15x15, 98% TD, Enr: 2.5    BU: 50.
44group       latticecell
'  Mix              Fuel Temp        wt%          wt%          wt%          wt%
uo2 1 den=10.741 1 1144.1 92234 0.021 92235 2.500 92236 0.012 92238 97.468
end
       kr-83   1 0 1.00e-20  1144.1 end
       kr-85   1 0 1.00e-20  1144.1 end
        y-89   1 0 1.00e-20  1144.1 end
       sr-90   1 0 1.00e-20  1144.1 end
       zr-93   1 0 1.00e-20  1144.1 end
       zr-94   1 0 1.00e-20  1144.1 end
       nb-94   1 0 1.00e-20  1144.1 end
       zr-95   1 0 1.00e-20  1144.1 end
       mo-95   1 0 1.00e-20  1144.1 end
       tc-99   1 0 1.00e-20  1144.1 end
      ru-101   1 0 1.00e-20  1144.1 end
      rh-103   1 0 1.00e-20  1144.1 end
      rh-105   1 0 1.00e-20  1144.1 end
      pd-105   1 0 1.00e-20  1144.1 end
      ru-106   1 0 1.00e-20  1144.1 end
      pd-108   1 0 1.00e-20  1144.1 end
      ag-109   1 0 1.00e-20  1144.1 end
      sb-124   1 0 1.00e-20  1144.1 end
      xe-131   1 0 1.00e-20  1144.1 end
      xe-132   1 0 1.00e-20  1144.1 end
      cs-134   1 0 1.00e-20  1144.1 end
      xe-135   1 0 1.00e-20  1144.1 end
      cs-135   1 0 1.00e-20  1144.1 end
      xe-136   1 0 1.00e-20  1144.1 end
      ba-136   1 0 1.00e-20  1144.1 end
      cs-137   1 0 1.00e-20  1144.1 end
      la-139   1 0 1.00e-20  1144.1 end
      ce-144   1 0 1.00e-20  1144.1 end
      nd-143   1 0 1.00e-20  1144.1 end
      nd-145   1 0 1.00e-20  1144.1 end
      nd-147   1 0 1.00e-20  1144.1 end
      pm-147   1 0 1.00e-20  1144.1 end
      sm-147   1 0 1.00e-20  1144.1 end
      pm-148   1 0 1.00e-20  1144.1 end
      sm-149   1 0 1.00e-20  1144.1 end
      sm-150   1 0 1.00e-20  1144.1 end
      sm-151   1 0 1.00e-20  1144.1 end
      sm-152   1 0 1.00e-20  1144.1 end
      eu-153   1 0 1.00e-20  1144.1 end
```

```
      eu-154    1 0 1.00e-20  1144.1 end
      eu-155    1 0 1.00e-20  1144.1 end
      gd-155    1 0 1.00e-20  1144.1 end
arbm-zirc4 6.56 5 0 0 0 8016 0.125 24000 0.100 26000 0.210 50000 1.450
                       40000 98.115 2 1.0 588.6 end
h2o        3 den=0.6905   1.  588.6 end
boron      3 den=0.6905   1000e-6 588.6 end
' --------end unit cell description
n  4 0 5-5   588.6 end
arbm-LBP     3.7        5   0   0   0
               5010        0.5023
               5011        2.2370
               6012        0.7608
               8016       45.4273
              13000       51.0727
                  5 1.0  588.6   end
end comp
'            pin pitch   pel OD     mx  cladOD     cladID
squarepitch   1.44272   0.9398    1  3  1.0922  2  0.95758  0  end
more data szf=0.50 end
npin/assm=208 fuelngth=357.111 ncycles=34 nlib/cyc=1
lightel=0  printlevel=5 inplevel=2 numztotal=8 mxrepeats=0 mixmod=3
facmesh=.50 end
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
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5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
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5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
```

```
5 .4318 4 .4572 2 .5461 3 .6325 2 .6731 3 .8140 500 3.0456 3 3.0764
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=50.00 down= 0 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1 end
power=14.51 burn=31.25 down= 1826 h2ofrac=1.000  bfrac=1.000 tmpfuel=1144.1
end
end
```

B.2 SCALE 5/TRITON ISOTOPIC CONCENTRATION ANALYSIS FOR B&W MARK B TYPE ASSEMBLY

TRITON Input Listing for PWR One-and Two-Dimensional Study

```
=t-depl
Depletion example
' Generic BW MK10 2-D depletion 15x15 (1/4  assembly)
44groupndf
read alias
$fuel 11-13 end
$clad 21-23 end
$gap 24-26 end
$mod 31-33 end
end alias
read comp
'Fuel       2.5 wt%
```

```
uo2  11 den=10.741 1 1144.1 92234 0.021 92235 2.500 92236 0.012 92238 97.468
end
uo2  12 den=10.741 1 1144.1 92234 0.021 92235 2.500 92236 0.012 92238 97.468
end
uo2  13 den=10.741 1 1144.1 92234 0.021 92235 2.500 92236 0.012 92238 97.468
end
' Clad
zirc4 $clad 1 588.6 end
' Moderator
h2o   $mod den=0.6905 1 588.6 end
arbm-boron  0.6905 1 1 0 0 5000 100 $mod 1000e-6 588.6 end
' --------end unit cell description
n  $gap 0 5-5   588.6 end
' Burnable poison rod
arbm-LBP          3.7 5   0   0   0
                 5010        0.5023
                 5011        2.2370
                 6012        0.7608
                 8016       45.4273
                13000       51.0727
               27 1.0      588.6    end
end comp
read celldata
latticecell squarepitch   pitch=1.44272 $mod fuelr=0.4699 $fuel
                          cladr=0.5461  $clad gap=0.47879 $gap  end
end celldata
read depletion $fuel end depletion
read burndata
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
```

```
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=50.00 down= 0  nlib=1  end
power=30.3983 burn=5.00  down= 1826  nlib=1  end
end burndata
read model
Generic BW MK10 2-D
read parm
   run=yes
   drawit=yes echo=yes
   xnlib=4 run=yes collapse=yes fillmix=31  prtmxsec=no prtbroad=yes
   sn=8 inners=10 outers=200 epsinner=1e-3 epsouter=1e-3
   epseigen=1e-3 prtmxtab=no prtflux=yes hybrid=yes critical=yes

end parm
read materials
  11     1   !  2.5 wo uo2 fuel  ! end
  12     1   !  2.5 wo uo2 fuel  ! end
  13     1   !  2.5 wo uo2 fuel  ! end
  21     1   !  zirc cladding    ! end
  27     1   !  LBA rod          ! end
  31     1   !  water            ! end
end materials
'read hmog
'501 Rod_1  11 12 13 21 31 end
'end hmog
'read collapse
'25r1 19r2
'end collapse
'read fluxplane
'rightside 10.83 0.0 10.83  10.83
'topside 0.0 10.83  10.83  10.83
'end fluxplane
read geom
'subgrid    1  is a material 11 rod
subgrid    1  1.44272 1.44272 4 4
cylinder   11  0.72136 0.72136 0.4699   !fuel! end
circle     21  0.72136 0.72136 0.5461  !clad! end
'subgrid    2  is a material 12 rod
subgrid    2  1.44272 1.44272 4 4
cylinder   12  0.72136 0.72136 0.4699   !fuel! end
circle     21  0.72136 0.72136 0.5461  !clad! end
'subgrid    3  is a material 13 rod
subgrid    3  1.44272 1.44272 4 4
cylinder   13  0.72136 0.72136 0.4699   !fuel! end
circle     21  0.72136 0.72136 0.5461  !clad! end
'subgrid    4  is a water rod (swapped with control rod
'subgrid  4  1.44272 1.44272 4 4
'cylinder 31   0.72136 0.72136 0.63245  !water in GT! end
'cylinder 21   0.72136 0.72136 0.6731  !GT radius! end
'subgrid 35 is a LBA Rod
subgrid 35  1.44272 1.44272 4 4
cylinder 27   0.72136 0.72136 0.4572   !LBA! end
cylinder 21   0.72136 0.72136 0.5461  !LBA Clad! end
```

```
cylinder 31   0.72136 0.72136 0.63245  !water in GT! end
cylinder 21   0.72136 0.72136 0.6731  !GT radius! end
'subgrid 51 is fuel rod
subgrid 51  0.72136 1.44272 2 4
cylinder 11   0.000 0.72136 0.4699  !fuel! end
cylinder 21   0.000 0.72136 0.5461  !clad! end
'subgrid 52 is fuel rod
subgrid 52  0.72136 1.44272 2 4
cylinder 12   0.000 0.72136 0.4699   !fuel! end
cylinder 21   0.000 0.72136 0.5461  !clad! end
'subgrid 53 is fuel rod
subgrid 53  0.72136 1.44272 2 4
cylinder 13   0.000 0.72136 0.4699  !fuel! end
cylinder 21   0.000 0.72136 0.5461  !clad! end
'subgrid 61 is a material #11 rod
subgrid 61  1.44272 0.72136 4 2
cylinder  11  0.72136 0.0000 0.4699   !fuel! end
cylinder  21  0.72136 0.0000 0.5461  !clad! end
'subgrid 63 is a material #12 rod
subgrid 62  1.44272 0.72136 4 2
cylinder  12  0.72136 0.0000 0.4699  !fuel! end
cylinder  21  0.72136 0.0000 0.5461  !clad! end

'subgrid 63 is a material #13 rod
subgrid 63  1.44272 0.72136 4 2
cylinder  13  0.72136 0.0000 0.4699  !fuel! end
cylinder  21  0.72136 0.0000 0.5461  !clad! end
'subgrid 45 is the  water hole
subgrid 45 1.44272 0.72136 4 2
cylinder 31  0.72136 0.000 0.4699   !water hole! end
cylinder 21  0.72136 0.000 0.5461  !guide tube! end
'subgrid 25 is the  water hole
subgrid 25  0.72136 1.44272 2 4
cylinder 31  0.000 0.72136 0.4699   !water hole! end
cylinder 21  0.000 0.72136 0.5461  !guide tube! end
'subgrid 46 is the  water hole
subgrid 46  0.72136 0.72136 2 2
cylinder 31  0.000 0.000 0.63245   !water hole! end
cylinder 21  0.000 0.000 0.6731    !guide tube! end
array 0.0 0.0 8 8
 51  1  1   1  1   1   1  1
 51  1  1   1  1   1   1  1
 52  2  35  2  2   2   1  1
 52  2  2   2  35  2   1  1
 52  2  2   2  2   2   1  1
 53  3  35  2  2  35   1  1
 53  3  3   2  2   2   1  1
 46 63 63  62 62  62  61 61
domain 10.83 10.83 30 30
boundary 1 1 1 1
end geom
end model
end
```

9. DESIGN VERIFICATION CHECKLIST

Document Identifier 32 - 5048840 - 00

Title CODE TO CODE COMPARISON OF TRITON - NEWT VS. SAS2H

		Y	N	N/A
1.	Were the inputs correctly selected and incorporated into design or analysis?	☒	☐	☐
2.	Are assumptions necessary to perform the design or analysis activity adequately described and reasonable? Where necessary, are the assumptions identified for subsequent re-verifications when the detailed design activities are completed?	☒	☐	☐
3.	Are the appropriate quality and quality assurance requirements specified? Or, for documents prepared per FANP procedures, have the procedural requirements been met?	☒	☐	☐
4.	If the design or analysis cites or is required to cite requirements or criteria based upon applicable codes, standards, specific regulatory requirements, including issue and addenda, are these properly identified, and are the requirements/criteria for design or analysis met?	☐	☐	☒
5.	Have applicable construction and operating experience been considered?	☐	☐	☒
6.	Have the design interface requirements been satisfied?	☐	☐	☒
7.	Was an appropriate design or analytical method used?	☒	☐	☐
8.	Is the output reasonable compared to inputs?	☒	☐	☐
9.	Are the specified parts, equipment and processes suitable for the required application?	☐	☐	☒
10.	Are the specified materials compatible with each other and the design environmental conditions to which the material will be exposed?	☐	☐	☒
11.	Have adequate maintenance features and requirements been specified?	☐	☐	☒
12.	Are accessibility and other design provisions adequate for performance of needed maintenance and repair?	☐	☐	☒

13.	Has adequate accessibility been provided to perform the in-service inspection expected to be required during the plant life?	☐ Y	☐ N	☒ N/A
14.	Has the design properly considered radiation exposure to the public and plant personnel?	☐ Y	☐ N	☒ N/A
15.	Are the acceptance criteria incorporated in the design documents sufficient to allow verification that design requirements have been satisfactorily accomplished?	☐ Y	☐ N	☒ N/A
16.	Have adequate pre-operational and subsequent periodic test requirements been appropriately specified?	☐ Y	☐ N	☒ N/A
17.	Are adequate handling, storage, cleaning and shipping requirements specified?	☐ Y	☐ N	☒ N/A
18.	Are adequate identification requirements specified?	☐ Y	☐ N	☒ N/A
19.	Is the document prepared and being released under the FANP Quality Assurance Program? If not, are requirements for record preparation review, approval, retention, etc., adequately specified?	☒ Y	☐ N	☐ N/A

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