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**Spent Fuel Assembly Hardware:
Characterization and 10 CFR 61
Classification for Waste Disposal**

**Volume 2—Calculated Activity Profiles of
Spent Nuclear Fuel Assembly Hardware for
Pressurized Water Reactors**

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SPENT FUEL ASSEMBLY HARDWARE:
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CLASSIFICATION FOR WASTE DISPOSAL

Volume 2

Calculated Activity Profiles
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Hardware for Pressurized Water
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ABSTRACT

Consolidation of spent fuel is under active consideration as the U.S. Department of Energy plans to dispose of spent fuel as required by the Nuclear Waste Policy Act of 1982. During consolidation, the fuel pins are removed from an intact fuel assembly and repackaged into a more compact configuration. After repackaging, approximately 30 kg of residual spent fuel assembly hardware per assembly remains that is also radioactive and requires disposal. Understanding the nature of this secondary waste stream is critical to designing a system that will properly handle, package, store, and dispose of the waste.

This report presents a methodology for estimating the radionuclide inventory in irradiated spent fuel hardware. Ratios are developed that allow the use of ORIGEN2 computer code calculations to be applied to regions that are outside the fueled region. The ratios are based on the analysis of samples of irradiated hardware from spent fuel assemblies.

The results of this research are presented in three volumes. In Volume 1, the development of scaling factors that can be used with ORIGEN2 calculations to estimate activation of spent fuel assembly hardware is documented. The results from laboratory analysis of irradiated spent-fuel hardware samples are also presented in Volume 1. In Volumes 2 and 3, the calculated flux profiles of spent nuclear fuel assemblies are presented for pressurized water reactors and boiling water reactors, respectively. The results presented in Volumes 2 and 3 were used to develop the scaling factors documented in Volume 1.

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1.0 INTRODUCTION

The ORIGEN2 computer code is a widely used tool for estimating the radionuclide inventory of irradiated materials. The code requires the user to describe the materials he wishes to irradiate, the irradiation history, and to specify the library that supplies the basic neutronics data with which the code does its calculations. The libraries are supplied to the user by the Radiation Shielding Information Center (RSIC) with the code. The list of available libraries include a nominal and high burnup for PWR's and a nominal burnup library for BWR's. These libraries have in them, in addition to half-lives and decay data, one-group cross-sections.

The one-group cross-sections are developed from multi-group calculations. In the multi-group calculations, the neutron spectrum is divided into many groups and the calculations are performed on a group basis. The interaction between the groups is taken into account during the calculation. The multi-group method is necessary for most problems, such as in the reactor core, because the cross-section (which are a measure of the probability of reaction occurring) vary considerably with neutron energy.

As an example, the continuous cross-section for the activation of natural cobalt to Co-60 [Co-59 (n, γ) Co-60], see Figure 1.1(a), has a value of ~ 37 barns for thermal neutrons (0.0253 eV). For fission neutrons, which are in the range of 1-10 MeV, the cross-section is less than 0.01 barns, or almost four orders of magnitude less. For neutrons with energies just over 100.0 eV, the cross-section has a resonance of nearly 1000.0 barns. It should be apparent that in order to correctly estimate the total Co-59 (n, γ) reaction rate, over all the neutrons, and hence the Co-60 inventory, the energy dependence of the neutrons must be taken into account. This is accomplished by doing a multi-group calculation. The continuous cross-section is divided into a finite number of groups, and a single value for the cross section is determined for each group. The points of division are in part based on how the cross-sections vary with neutron energy. Figure 1.1(b) illustrates a 27-group structure for Co-59 (n, γ) cross-section into. Within any energy band, the value is representative of the true cross-section value. The neutrons that are present

will also affect this choice of energy structure and cross-section value. If all the neutrons are above 1.0 MeV (fast spectrum), then a single value representing the cross-section will be determined by the continuous cross-section above 1.0 MeV. On the other hand, if all the neutrons were less than 1.0 eV (thermal spectrum), the single value representing the cross-section would be considerably different. This single value is referred to as the one-group cross-section. Figure 1.1(c) illustrates what those one-group cross-sections might look like.

Once the neutron spectrum is divided up into groups, all the cross-sections used in that calculation must be divided into the same energy group structure. Then the calculation is performed, and the reaction rate and the total flux are calculated. The total flux can then be divided into the total reaction rate, resulting in a one-group cross-section. This one-group cross-section can be used in subsequent calculations, to multiply by the total flux in order to estimate the reaction rate, if the neutron spectrum does not change significantly. The advantage is that a much larger number of interactions can be accounted for than if the calculations were done in multi-group, in a shorter length of time.

The ORIGEN2 one-group cross-sections were generated using detailed reactor core models and are applicable to estimating activation in neutron fluxes that resemble those in reactor cores. However, when the neutron flux varies significantly, either a new one-group cross-section needs to be developed or an adjustment must be made to the ORIGEN2 results. Much of the hardware that is of interest to us in this study is in the region of the end fittings, which are outside the reactors' fuel region. The neutron spectrum in this region has changed quite a bit from the fueled region. No fissioning is occurring in this region, so as the fast neutrons are thermalized (slowed down in energy), the average neutron energy, and hence the spectrum, shifts downward. From Figure 1.1(a), it can be seen that, the Co-59 (n, γ) cross-section generally increases with decreasing neutron energy. Therefore, it would be expected that the one-group cross-section in the end fitting region would increase as compared to its value in the core region. This change must be accounted for to accurately estimate the amount of Co-60 present in the end fittings.

The purpose of the calculations described in this report is to estimate the relative change of a variety of one-group cross-section in PWRs. We wanted to see how much the cross-sections changed and whether it was significant. We also wanted to identify whether or not all the cross-sections changed in a similar, predictable, manner. Three PWR models were generated in order to also determine whether the one-group cross-sections changed for various fuel designs. A representative model was generated for each of the major PWR vendors: Westinghouse, Babcock & Wilcox, and Combustion Engineering.

The fuel assembly models used for each of the three models are detailed in Section 2. Each reactor was modeled from almost the bottom of the reactor to the top. The greatest amount of detail though was provided in the regions that comprised the fuel assembly. Section 2 provides the necessary information to generate the neutronics models required for these calculations. The information in this section should be of interest to many other people for a variety of uses.

Section 3 is a detailed description of how the neutronics calculations were performed. It is supplemented with an appendix that documents the input streams for the computer programs used in the neutronics analysis. This section would be of most interest to those individuals reviewing the calculations in detail. It requires that the reader have a background in nuclear engineering and be somewhat familiar with the computer codes involved.

Section 4 contains the results of the calculations. From the extensive set of figures in this section, one can see how the reaction rates vary for a great many reactions. A comparison of the results of these calculations with the results of experimental analyses currently being conducted at PNL will culminate in recommendations as to how to use ORIGEN2 in estimating radio-nuclide inventories in regions outside the fueled region.

FIGURE 1.1.1. $^{59}\text{Co}(n, \gamma)^{60}\text{Co}$ Cross Sections

2.0 REACTOR DESIGNS

Each of the reactor designs presented in this section were the reference designs used to make the initial ANISN calculations. Much of the design data were obtained from Westinghouse, Combustion Engineering, and Babcock and Wilcox via submittals they made to ORNL under contract. The data were supplied to support the Waste Systems Data Development Program of ORNL. Follow up phone conversations with each of the reactor vendors were made as required.

2.1 BABCOCK AND WILCOX

The Babcock and Wilcox reactor design was divided into 32 axial regions with the fuel assembly occupying the central regions. A diagram of the fuel assembly portion of this design is shown in Figure 2.1. A brief description and the structural composition of each region is given in Table 2.1. Table 2.2 provides the material composition for each of the structures within each region. This table also shows the water density as a function of axial location. Table 2.3 shows the isotopic content of each of the materials in Table 2.2.

2.2 COMBUSTION ENGINEERING

A total of 49 axial regions were used to model the Combustion Engineering Reactor with the fuel assembly occupying the central regions. Figure 2.2 shows a diagram of the fuel assembly portion of this design. Table 2.4 provides a brief description of each region and the corresponding structural composition. The material composition for each of the structures in each region is given in Table 2.5. This table also shows the water density as a function of axial location. Table 2.6 shows the isotopic concentrations of each of the materials given in Table 2.5.

2.3 WESTINGHOUSE

The Westinghouse reactor design was separated into 29 axial regions with the fuel assembly occupying the central regions. A diagram of the fuel assembly portion of this design is shown in Figure 2.3. A brief description of

each region along with the corresponding structural composition is given in Table 2.7. Table 2.8 provides the material composition for each of the structures within each region. Table 2.8 shows how the boron concentration was varied axially along with the water density as a function of axial location. The isotopic content of each of the materials specified in Table 2.8 is given in Table 2.9.

FIGURE 2.1. Diagram of the Babcock and Wilcox 17 x 17 Fuel Assembly

TABLE 2.1. Babcock and Wilcox Reactor Model for Axial Neutron Flux Distribution Calculation

Region	Description	Axial Location of Outer Boundary (cm)	Composition (volume %)			
			Assembly Hardware	Fuel Rods	Structure	Water
1	Instruments and Guide Tubes	180.0			5.00	95.00
2	Grid Assembly	210.0			55.00	45.00
3	Lower Support Posts	230.6			25.00	75.00
4	Tie Plate	235.7	13.00		23.52	63.48
5	Tie Plate	240.8	29.91			70.09
6	Plenum and Grid	250.0	4.24	41.03		54.73
7	Spacer	251.9	0.64	41.03		58.33
8	10,000 MWd/MTU Fuel	267.2	0.64	41.03		58.33
9	15,000 MWd/MTU Fuel	287.5	0.64	41.03		58.33
10	20,000 MWd/MTU Fuel	302.2	0.64	41.03		58.33
11	20,000 MWd/MTU Fuel and Grid	306.2	7.25	41.03		51.72
12	20,000 MWd/MTU Fuel	355.9	0.64	41.03		58.33
13	20,000 MWd/MTU Fuel and Grid	359.9	7.25	41.03		51.72
14	20,000 MWd/MTU Fuel	409.4	0.64	41.03		58.33
15	20,000 MWd/MTU Fuel and Grid	413.4	7.25	41.03		51.72
16	20,000 MWd/MTU Fuel	432.0	0.64	41.03		58.33
17	20,000 MWd/MTU Fuel	463.0	0.64	41.03		58.33
18	20,000 MWd/MTU Fuel and Grid	467.0	7.25	41.03		51.72
19	20,000 MWd/MTU Fuel	516.6	0.64	41.03		58.33
20	20,000 MWd/MTU Fuel and Grid	520.6	7.25	41.03		51.72
21	20,000 MWd/MTU Fuel	570.2	0.64	41.03		58.33
22	20,000 MWd/MTU Fuel and Grid	574.2	7.25	41.03		51.72
23	20,000 MWd/MTU Fuel	576.5	0.64	41.03		58.33
24	15,000 MWd/MTU Fuel	596.9	0.64	41.03	0.14	58.19
25	10,000 MWd/MTU Fuel	612.1	0.64	41.03	0.14	58.19
26	Spacer	614.0	0.64	41.03	0.14	58.19
27	Plenum	627.4	0.64	41.03	1.95	56.38
28	End Plug and Grid	636.6	0.64	10.00	2.90	86.46
29	Tie Plate	641.7	39.39		2.90	57.71
30	Spring Assembly	646.7	13.91		2.90	83.19
31	Hold Down Plate	667.0			27.70	72.30
32	Control Rod and Guide Tubes	967.0			6.87	93.13

TABLE 2.2. Material Compositions for the Babcock and Wilcox Reactor Model

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
1			5.00% SS-304	0.7457
2			55.00% SS-304	0.7457
3			25.00% SS-304	0.7457
4	13.00% SS-304		23.52% SS-304	0.7457
5	29.27% SS-304 0.64% Zr-4			0.7457
6	0.64% Zr-4 3.60% INC-718	5.85% SS-304 10.00% Zr-4 25.18% Void		0.7457
7	0.64% Zr-4	24.49% Zr-4 16.54% Void		0.7457
8	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7451
9	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7433
10	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
11	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
12	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
13	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
14	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
15	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303
16	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂		0.7303

TABLE 2.2. (contd)

Region	Material Composition (volume %)		Water Density (g/cc)
	Assembly Hardware	Fuel Rods Structure	
17	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
18	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
19	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
20	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
21	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
22	7.25% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
23	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.7042
24	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.03% SS-304 0.11% CRA 0.6881
25	0.64% Zr-4	9.49% Zr-4 31.54% UO ₂	0.03% SS-304 0.11% CRA 0.6857
26	0.64% Zr-4	24.49% Zr-4 16.54% Void	0.03% SS-304 0.11% CRA 0.6849
27	0.64% Zr-4	4.39% SS-304 9.49% Zr-4 27.15% Void	1.84% SS-304 0.11% CRA 0.6849
28	0.64% Zr-4	4.00% Zr-4 6.00% Void	2.03% SS-304 0.87% CRA 0.6849
29	38.75% SS-304 0.64% Zr-4		2.03% SS-304 0.87% CRA 0.6849
30	4.87% SS-304 9.04% INC-718		2.03% SS-304 0.87% CRA 0.6849

TABLE 2.2. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
31			26.83% SS-304 0.87% CRA	0.6849
32			6.00% SS-304 0.87% CRA	0.6849

TABLE 2.3. Isotopic Content of Materials Used in the Babcock and Wilcox Reactor Model

Material	Element/ Isotope	Element/Isotope Composition		
		Composition (weight %)	Atom Density (atoms/b-cm)	
SS-304	Fe	71.00	6.141×10^{-2}	
	Cr	19.00	1.765×10^{-2}	
	Ni	9.00	7.406×10^{-3}	
	Mn	1.00	8.790×10^{-4}	
Zr-4	Zr	98.24	4.216×10^{-2}	
	Sn	1.45	4.660×10^{-4}	
	Fe	0.21	1.472×10^{-4}	
	Cr	0.10	7.530×10^{-5}	
INC-718	Ni	74.20	6.319×10^{-2}	
	Cr	15.50	1.490×10^{-2}	
	Fe	7.00	6.270×10^{-3}	
	Nb	1.00	5.380×10^{-4}	
CRA	Ag-107	51.83	} 80.00	2.315×10^{-2}
	Ag-109	48.17		2.151×10^{-2}
	B-10 for In-115	95.70	} 15.00	7.532×10^{-4}
	B-10 for In-113	4.30		3.384×10^{-4}
	Cd	5.00	2.680×10^{-3}	
Water (1.0 g/cc, 550 ppm Boron)	H		6.692×10^{-2}	
	O		3.346×10^{-2}	
	B-11		2.450×10^{-5}	
	B-10		6.129×10^{-6}	
10,000 MWd/MTU UO ₂ (3.3% U-235 initial enrichment)	U-238		2.093×10^{-2}	
	U-235		5.047×10^{-4}	
	Pu-239		7.139×10^{-5}	
	Pu-240		1.237×10^{-5}	
	Pu-241		4.559×10^{-6}	
	Pu-242		3.489×10^{-7}	
	O		4.372×10^{-2}	
	B-10 (fission product)		6.478×10^{-6}	
15,000 MWd/MTU UO ₂ (3.3% U-235 initial enrichment)	U-238		2.086×10^{-2}	
	U-235		4.162×10^{-4}	
	Pu-239		8.691×10^{-5}	
	Pu-240		2.109×10^{-5}	
	Pu-241		9.463×10^{-6}	
	Pu-242		1.222×10^{-6}	
	O		4.372×10^{-2}	
	B-10 (fission product)		6.525×10^{-6}	

TABLE 2.3. (contd)

Material	Element/ Isotope	Element/Isotope Composition	
		Composition (weight %)	Atom Density (atoms/b-cm)
20,000 MWd/MTU UO ₂ (3.3% U-235 initial enrichment)	U-238		2.078×10^{-2}
	U-235		3.404×10^{-4}
	Pu-239		9.674×10^{-5}
	Pu-240		2.987×10^{-5}
	Pu-241		1.437×10^{-5}
	Pu-242		2.716×10^{-6}
	O		4.372×10^{-2}
	B-10 (fission product)		6.470×10^{-6}

FIGURE 2.2. Diagram of the Combustion Engineering 16 x 16 Fuel Assembly

TABLE 2.4. Combustion Engineering Reactor Model for Axial Neutron Flux Distribution Calculation

Region	Description	Axial Location of Outer Boundary (cm)	Composition (volume %)			
			Assembly Hardware	Fuel Rods	Structure	Water
1	Support Posts	150.0			10.00	90.00
2	Core Support Plates	200.0			55.00	45.00
3	Support Posts	260.0			10.00	90.00
4	Core Support Plates	265.0			55.00	45.00
5	Fittings	273.0	8.00		4.00	88.00
6	Flow Plate	274.7	56.65			43.35
7	End Plug	276.9	3.68	33.50		62.82
8	10,000 MWd/MTU Fuel and Grid	284.6	5.14	40.39		54.47
9	20,000 MWd/MTU Fuel	297.5	0.94	40.39		58.67
10	20,000 MWd/MTU Fuel and Grid	304.5	5.14	40.39		54.47
11	20,000 MWd/MTU Fuel	315.0	0.94	40.39		58.67
12	25,000 MWd/MTU Fuel	335.2	0.94	40.39		58.67
13	25,000 MWd/MTU Fuel and Grid	342.2	5.14	40.39		54.47
14	25,000 MWd/MTU Fuel	372.8	0.94	40.39		58.67
15	25,000 MWd/MTU Fuel and Grid	379.8	5.14	40.39		54.47
16	25,000 MWd/MTU Fuel	410.4	0.94	40.39		58.67
17	25,000 MWd/MTU Fuel and Grid	417.4	5.14	40.39		54.47
18	25,000 MWd/MTU Fuel	448.0	0.94	40.39		58.67
19	25,000 MWd/MTU Fuel and Grid	455.0	5.14	40.39		54.47
20	25,000 MWd/MTU Fuel	467.4	0.94	40.39		58.67
21	25,000 MWd/MTU Fuel	485.6	0.94	40.39		58.67
22	25,000 MWd/MTU Fuel and Grid	492.6	5.14	40.39		54.47
23	25,000 MWd/MTU Fuel	523.3	0.94	40.39		58.67
24	25,000 MWd/MTU Fuel and Grid	530.3	5.14	40.39		54.47
25	25,000 MWd/MTU Fuel	560.9	0.94	40.39		58.67
26	25,000 MWd/MTU Fuel and Grid	567.9	5.14	40.39		54.47
27	25,000 MWd/MTU Fuel	598.5	0.94	40.39		58.67
28	25,000 MWd/MTU Fuel and Grid	605.5	5.14	40.39		54.47
29	25,000 MWd/MTU Fuel	619.8	0.94	40.39		58.67
30	20,000 MWd/MTU Fuel	636.1	0.94	40.39		58.67
31	20,000 MWd/MTU Fuel and Grid	643.1	5.14	40.39		54.47

TABLE 2.4. (contd)

Region	Description	Axial Location of Outer Boundary (cm)	Composition (volume %)			
			Assembly Hardware	Fuel Rods	Structure	Water
32	20,000 MWd/MTU Fuel	650.3	0.94	40.39		58.67
33	10,000 MWd/MTU Fuel	657.9	0.94	40.39		58.67
34	Spacer	658.9	0.94	40.39		58.67
35	Plenum	663.0	0.94	40.39		58.67
36	Control Tips	665.6	0.94	40.39	1.38	57.29
37	Plenum and Control	673.8	0.94	40.39	1.62	57.05
38	Grid	680.8	5.14	40.39	1.62	52.85
39	Plenum and Control	683.2	0.94	40.39	1.62	57.05
40	End Plug	684.4	0.94	28.00	1.62	69.44
41	Guide Tubes	688.3	0.94		1.62	97.44
42	Flow Plate	690.3	54.14		1.62	44.24
43	Fittings	697.3	16.52		1.62	81.86
44	Spacers	698.6	16.52		1.62	81.86
45	Fittings	705.6	16.52		1.62	81.86
46	Hold Down Plate	707.6	34.43		1.62	63.95
47	Reactor Hold Down Plate	714.1	8.16		41.62	50.22
48	Assembly Guide Tubes	856.1			7.62	92.38
49	Assembly Guide Tubes	896.7			7.59	92.41

TABLE 2.5. Material Compositions for the Combustion Engineering Reactor Model

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
1			10.00% SS-304	0.7421
2			55.00% SS-304	0.7421
3			10.00% SS-304	0.7421
4			55.00% SS-304	0.7421
5	8.00% SS-304		4.00% SS-304	0.7421
6	55.71% SS-304 0.94% Zr-4			0.7421
7	0.94% Zr-4 2.74% INC-718	10.14% Zr-4 23.36% Al_2O_3 (Void)		0.7421
8	0.94% Zr-4 4.20% INC-718	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7418
9	0.94% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7395
10	5.14% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7395
11	0.94% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7395
12	0.94% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7228
13	5.14% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7228
14	0.94% Zr-4	9.88% Zr-4 0.52% $Al_2O_3-B_4C$ 29.99% UO_2		0.7228

TABLE 2.5. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
15	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
16	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
17	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
18	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
19	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
20	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.7228
21	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
22	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
23	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
24	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
25	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903

TABLE 2.5. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
26	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
27	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
28	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
29	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6903
30	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6687
31	5.14% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6687
32	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6687
33	0.94% Zr-4	9.88% Zr-4 0.52% $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ 29.99% UO_2		0.6644
34	0.94% Zr-4	9.88% Zr-4 30.51% Al_2O_3 (Void)		0.6648
35	0.94% Zr-4	12.55% SS-304 9.88% Zr-4 17.96% Void		0.6648
36	0.94% Zr-4	12.55% SS-304 9.88% Zr-4 17.96% Void	1.21% INC-718 0.17% Void	0.6648
37	0.94% Zr-4	12.55% SS-304 9.88% Zr-4 17.96% Void	0.38% INC-718 0.03% Void 1.21% CRA	0.6648

TABLE 2.5. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
38	5.14% Zr-4	12.55% SS-304 9.88% Zr-4 17.96% Void	0.38% INC-718 0.03% Void 1.21% CRA	0.6648
39	0.94% Zr-4	12.55% SS-304 9.88% Zr-4 17.96% Void	0.38% INC-718 0.03% Void 1.21% CRA	0.6648
40	0.94% Zr-4	28.00% Zr-4	0.38% INC-718 0.03% Void 1.21% CRA	0.6648
41	0.94% Zr-4		0.38% INC-718 0.03% Void 1.21% CRA	0.6648
42	54.14% SS-304		0.38% INC-718 0.03% Void 1.21% CRA	0.6648
43	8.16% SS-304 8.36% INC-718		0.38% INC-718 0.03% Void 1.21% CRA	0.6648
44	8.16% SS-304 8.36% INC-718		1.59% INC-718 0.03% Void	0.6648
45	8.16% SS-304 8.36% INC-718		0.38% INC-718 0.03% Void 1.21% B ₄ C	0.6648
46	34.43% SS-304		0.38% INC-718 0.03% Void 1.21% B ₄ C	0.6648
47	8.16% SS-304		40.00% SS-304 0.38% INC-718 0.03% Void 1.21% B ₄ C	0.6648
48			6.00% SS-304 0.38% INC-718 0.03% Void 1.21% B ₄ C	0.6648
49			6.00% SS-304 0.27% INC-718 1.32% B ₄ C	0.6648

TABLE 2.6. Isotopic Content of Materials Used in the Combustion Engineering Reactor Model

Material	Element/ Isotope	Element/Isotope Composition		
		Composition (weight %)	Atom Density (atoms/b-cm)	
SS-304	Fe	71.00	6.141×10^{-2}	
	Cr	19.00	1.765×10^{-2}	
	Ni	9.00	7.406×10^{-3}	
	Mn	1.00	8.790×10^{-4}	
Zr-4	Zr	98.24	4.216×10^{-2}	
	Sn	1.45	4.660×10^{-4}	
	Fe	0.21	1.472×10^{-4}	
	Cr	0.10	7.530×10^{-5}	
INC-718	Ni	63.35	5.395×10^{-2}	
	Cr	21.50	2.067×10^{-2}	
	Mo	9.00	4.690×10^{-3}	
	Nb	3.65	1.964×10^{-3}	
	Fe	2.50	2.238×10^{-3}	
CRA	Ag-107	51.83	79.00	2.288×10^{-2}
	Ag-109	48.17		2.126×10^{-2}
	B-10 for In-115	95.70	15.00	7.532×10^{-4}
	B-10 for In-113	4.30		3.384×10^{-4}
	Cd	5.00	2.680×10^{-3}	
Water (1.0 g/cc, 550 ppm Boron)	H		6.692×10^{-2}	
	O		3.346×10^{-2}	
	B-11		2.450×10^{-5}	
	B-10		6.129×10^{-6}	
10,000 MWd/MTU UO ₂ (4.0% (U-235 initial enrichment)	U-238		2.062×10^{-2}	
	U-235		6.412×10^{-4}	
	Pu-239		6.423×10^{-5}	
	Pu-240		9.782×10^{-6}	
	Pu-241		3.101×10^{-6}	
	Pu-242		1.973×10^{-7}	
	O		4.321×10^{-2}	
	B-10 (fission product)		6.642×10^{-6}	
20,000 MWd/MTU UO ₂ (4.0% (U-235 initial enrichment)	U-238		2.049×10^{-2}	
	U-235		4.540×10^{-4}	
	Pu-239		9.135×10^{-5}	
	Pu-240		2.555×10^{-5}	
	Pu-241		1.101×10^{-5}	
	Pu-242		1.733×10^{-6}	
	O		4.321×10^{-2}	
	B-10 (fission product)		6.615×10^{-6}	

TABLE 2.6. (contd)

Material	Element/ Isotope	Element/Isotope Composition	
		Composition (weight %)	Atom Density (atoms/b-cm)
25,000 MWd/MTU UO ₂ (4.0% (U-235 initial enrichment)	U-238		2.042×10^{-2}
	U-235		3.751×10^{-4}
	Pu-239		9.814×10^{-5}
	Pu-240		3.324×10^{-5}
	Pu-241		1.553×10^{-5}
	Pu-242		3.251×10^{-6}
	O		4.321×10^{-2}
	B-10 (fission product)		6.600×10^{-6}
Al ₂ O ₃ -B ₄ C or B ₄ C	B-11		6.254×10^{-2}
	B-10 78.30		1.720×10^{-2}

FIGURE 2.3. Diagram of the Westinghouse 17 x 17 Fuel Assembly

TABLE 2.7. Westinghouse Reactor Model for Axial Neutron Flux
Distribution Calculation

Region	Description	Axial Location of Outer Boundary (cm)	Composition (volume %)			
			Assembly Hardware	Fuel Rods	Structure	Water
1	Support Posts	149.9			10.00	90.00
2	Core Support	201.3			50.00	50.00
3	Support Posts	262.3			10.00	90.00
4	Support Plate	267.4			55.00	45.00
5	Nozzle Legs	272.3	10.00			90.00
6	Nozzle Plate	274.3	55.80			44.20
7	Guide Tubes	276.6	0.80			99.20
8	End Plug	277.6	0.80	37.35		61.85
9	10,000 MWd/MTU Fuel	279.1	0.80	37.35		61.85
10	10,000 MWd/MTU Fuel and Grid	283.1	7.40	37.35		55.25
11	10,000 MWd/MTU Fuel	292.8	0.80	37.35		61.85
12	15,000 MWd/MTU Fuel	313.2	0.80	37.35		61.85
13	20,000 MWd/MTU Fuel	339.3	0.80	37.35		61.85
14	20,000 MWd/MTU Fuel and Grid	346.3	7.40	37.35		55.25
15	20,000 MWd/MTU Fuel	391.5	0.80	37.35		61.85
16	20,000 MWd/MTU Fuel and Grid	398.5	7.40	37.35		55.25
17	20,000 MWd/MTU Fuel	443.7	0.80	37.35		61.85
18	20,000 MWd/MTU Fuel and Grid	450.7	7.40	37.35		55.25
19	20,000 MWd/MTU Fuel	460.5	0.80	37.35		61.85
20	20,000 MWd/MTU Fuel	495.9	0.80	37.35		61.85
21	20,000 MWd/MTU Fuel and Grid	502.9	7.40	37.35		55.25
22	20,000 MWd/MTU Fuel	548.1	0.80	37.35		61.85
23	20,000 MWd/MTU Fuel and Grid	555.1	7.40	37.35		55.25
24	20,000 MWd/MTU Fuel	600.3	0.80	37.35		61.85
25	20,000 MWd/MTU Fuel and Grid	607.3	7.40	37.35		55.25
26	15,000 MWd/MTU Fuel	628.1	0.80	37.35		61.85
27	10,000 MWd/MTU Fuel	640.8	0.80	37.35		61.85
28	Control Rod Bite In 10,000 MWd/MTU Fuel	643.4	1.57	37.35	1.19	59.89
29	Plenum	654.4	0.80	37.35	4.04	57.04
30	Inconel Grid	658.4	7.10	37.35	4.04	50.74
31	Plenum	660.6	0.80	37.35	4.04	57.04

TABLE 2.7. (contd)

Region	Description	Axial Location of Outer Boundary (cm)	Composition (volume %)			
			Assembly Hardware	Fuel Rods	Structure	Water
32	End Plug	661.6	0.80	37.35	4.04	57.04
33	Guide Tube	663.8	0.80		4.04	95.15
34	Nozzle Plate	665.8	56.80		4.04	39.15
35	Spider Assembly	667.2	14.62		4.04	81.34
36	Nozzle Side	671.2	10.00		6.75	83.25
37	Nozzle Top	673.2	16.50		6.73	76.77
38	Hold Down Spring	675.0	6.50		6.73	86.77
39	Hold Down Plug	682.7			41.00	59.00
40	Guide Tubes	982.7			7.00	93.00

TABLE 2.8. Material Compositions for the Westinghouse Reactor Model

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
1			10.00% SS-304	0.75
2			50.00% SS-304	0.75
3			10.00% SS-304	0.75
4			55.00% SS-304	0.75
5	10.00% SS-304			0.75
6	55.00% SS-304 0.80% Zr-4			0.75
7	0.80% Zr-4			0.75
8	0.80% Zr-4	37.35% Zr-4		0.75
9	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7494
10	0.60% SS-304 0.80% Zr-4 6.00% INC-718	8.75% Zr-4 28.60% UO ₂		0.7494
11	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7494
12	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7475
13	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
14	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
15	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
16	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
17	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165

TABLE 2.8. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
18	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
19	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
20	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
21	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
22	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
23	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
24	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
25	7.40% Zr-4	8.75% Zr-4 28.60% UO ₂		0.7165
26	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.6797
27	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂		0.677
28	0.80% Zr-4	8.75% Zr-4 28.60% UO ₂	0.19% SS-304 0.85% CRA 0.15% Void	0.677
29	0.80% Zr-4	4.70% SS-304 8.75% Zr-4 23.90% Void	3.04% SS-304 0.85% CRA 0.15% Void	0.676
30	0.60% SS-304 0.80% Zr-4 5.70% INC-718	4.70% SS-304 8.75% Zr-4 23.90% Void	3.04% SS-304 0.85% CRA 0.15% Void	0.676
31	0.80% Zr-4	4.70% SS-304 8.75% Zr-4 23.90% Void	3.04% SS-304 0.85% CRA 0.15% Void	0.676

TABLE 2.8. (contd)

Region	Material Composition (volume %)			Water Density (g/cc)
	Assembly Hardware	Fuel Rods	Structure	
32	0.80% Zr-4	37.35% Zr-4	3.04% SS-304 0.85% CRA 0.15% Void	0.676
33	0.80% Zr-4		3.04% SS-304 0.85% CRA 0.15% Void	0.676
34	56.00% SS-304 0.80% Zr-4		3.04% SS-304 0.85% CRA 0.15% Void	0.676
35	14.62% SS-304		3.04% SS-304 0.85% CRA 0.15% Void	0.676
36	10.00% SS-304		4.81% SS-304 0.94% INC-718 0.85% CRA 0.15% Void	0.676
37	10.00% SS-304 6.50% INC-718		4.81% SS-304 0.92% INC-718 0.85% CRA 0.15% Void	0.676
38	6.50% INC-718		4.81% SS-304 0.92% INC-718 0.85% CRA 0.15% Void	0.676
39			40.00% SS-304 0.85% CRA 0.15% Void	0.676
40			6.00% SS-304 0.85% CRA 0.15% Void	0.676

TABLE 2.9. Isotopic Content of Materials Used in the Westinghouse Reactor Model

Material	Element/ Isotope	Element/Isotope Composition		
		Composition (weight %)	Atom Density (atoms/b-cm)	
SS-304	Fe	71.92	6.212×10^{-2}	
	Cr	18.08	1.670×10^{-2}	
	Ni	9.00	7.400×10^{-3}	
	Mn	1.00	8.800×10^{-4}	
Zr-4	Zr	98.20	4.223×10^{-2}	
	Sn	1.50	4.961×10^{-4}	
	Fe	0.30	2.112×10^{-4}	
INC-718	Ni	52.15	4.444×10^{-2}	
	Cr	18.90	1.816×10^{-2}	
	Mo	2.95	1.550×10^{-3}	
	Nb	4.95	2.670×10^{-3}	
	Fe	21.05	1.824×10^{-2}	
CRA	Ag-107	51.83	} 80.00	2.315×10^{-2}
	Ag-109	48.17		2.151×10^{-2}
	B-10 for In-115	95.70	} 15.00	7.532×10^{-4}
	B-10 for In-113	4.30		3.384×10^{-4}
	Cd	5.00	2.680×10^{-3}	
Water (1.0 g/cc, 550 ppm Boron)	H		6.693×10^{-2}	
	O		3.345×10^{-2}	
	B-11		2.449×10^{-5}	
	B-10		6.124×10^{-6}	
10,000 MWd/MTU UO ₂ (3.5% U-235 initial enrichment)	U-238		2.129×10^{-2}	
	U-235		5.465×10^{-4}	
	Pu-239		6.996×10^{-5}	
	Pu-240		1.145×10^{-5}	
	Pu-241		3.927×10^{-6}	
	Pu-242		2.731×10^{-7}	
	O		4.441×10^{-2}	
	B-10 (fission product)		6.478×10^{-6}	
15,000 MWd/MTU UO ₂ (3.5% U-235 initial enrichment)	U-238		2.122×10^{-2}	
	U-235		4.517×10^{-4}	
	Pu-239		8.636×10^{-5}	
	Pu-240		1.998×10^{-5}	
	Pu-241		8.451×10^{-6}	
	Pu-242		9.944×10^{-7}	
	O		4.441×10^{-2}	
	B-10 (fission product)		6.525×10^{-6}	

TABLE 2.9. (contd)

Material	Element/ Isotope	Element/Isotope Composition	
		Composition (weight %)	Atom Density (atoms/b-cm)
20,000 MWd/MTU UO ₂ (3.5% U-235 initial enrichment)	U-238		2.115×10^{-2}
	U-235		3.682×10^{-4}
	Pu-239		9.703×10^{-5}
	Pu-240		2.879×10^{-5}
	Pu-241		1.320×10^{-5}
	Pu-242		2.282×10^{-6}
	O		4.441×10^{-2}
	B-10 (fission product)		6.470×10^{-6}

3.0 APPROACH

A flow diagram displaying the sequence in which the neutronics computer codes were utilized is given in Figure 3.1. The methodology was one of generating the necessary cross-sections utilizing the DASQHE, NITAWL, and XSDRNPM computer codes followed by the calculations necessary to generate the required reaction rates utilizing the GIP and ANISN computer codes. The input decks used in each step shown in the flow diagram are given in Appendix A.

3.1 DESCRIPTION OF COMPUTER CODES

All of the above mentioned computer codes are written in the Fortran language. DASQHE was written by I. Carlvik to utilize a technique that he developed to calculate the Dancoff correction for an infinite array of circular rods in square or hexagonal lattices.⁽¹⁾ NITAWL performs problem-dependent resonance shielding by applying the Nordheim Integral Treatment to generate cross section libraries that have been corrected for resonance self-shielding. The version of NITAWL used in this analysis was that developed for the AMPX system: a system for generating coupled multi-group neutron-gamma libraries from the ENDF/B data base.⁽²⁾

XSDRNPM is a one-dimensional discrete ordinates transport code that serves two functions: 1) to perform a one-dimensional discrete ordinates calculation in slab, cylindrical, or spherical geometry and 2) to use the fluxes determined from its spectral calculation to collapse input cross-sections. The primary feature of XSDRNPM needed for this study was its cross-section cell weighting capability. This study also used the version of XSDRNPM developed for the AMPX system.

GIP is a computer code that accepts nuclide-organized microscopic cross-section data and prepares a group-organized file of microscopic and/or macroscopic cross-sections. This code is especially useful for models, such as those developed for this study, that have a very large number of cross-sections and a very long nuclide mixing table. GIP was developed for the discrete ordinates system (DOS).⁽³⁾

ANISN is a one-dimensional discrete ordinates S_n transport code with general anisotropic scattering.⁽⁴⁾ The primary functions of this code are essentially the same as those for XSDRNPM. However, ANISN does have two features needed in this study that XSDRNPM does not possess, these being: 1) the capability to read in additional cross-sections not present in the primary library and 2) the capability to generate reaction rates for isotopes in regions where they may not be present in the model.

The cross-section library utilized in this study (called CMLIB) was generated at PNL for use in criticality safety analyses and possesses the group structure shown in Table 3.1. This 27 neutron group cross-section library was collapsed from a 218 neutron group library also generated for use in criticality safety analyses. Table 3.2 identifies the isotopes present in both the 27-group and 218-group libraries and also gives information on how the 218-group library was generated from the ENDF/B-IV cross-section data base. The reaction rates associated with the MT numbers specified in this table are given in Table 3.3. Table 3.4 specifies the energy range over which the weighting functions were applied. For further information on how the 218-group cross-section library was generated, refer to reference 5.

3.2 EXPLANATION OF APPROACH

The stepwise process used to arrive at the reaction rates of interest started with DASQHE calculations at three different burnups (10,000, 15,000, and 20,000 Mwd/MTU) to obtain the Dancoff correction factor applicable to all three PWR reactors. The specific inputs for the DASQHE calculations are given in Tables A.1, A.2, and A.3.

The results generated by DASQHE were input to NITAWL to correct isotopes in the cross section library (CMLIB) for resonance self-shielding and generate a library of pin cell isotope cross-sections. The input data for NITAWL is listed in Table A.4. In addition, NITAWL was utilized to generate a library of control cell isotope cross-sections. This input deck is shown in Table A.5.

The NITAWL generated libraries were used to make one control cell and three pin cell (one for each burnup level) XSDRNPM calculations to obtain cell-weighted cross sections. These cell calculations were made specifically for

the Westinghouse 17 x 17 fuel assembly. However, the generated cross sections are also applicable to the other reactor designs because the differences between the three reactor types in the fuel regions are small, as can be seen in Section 2. Figure 3.2 is a diagram of the pin cell and associated dimensions used in the pin cell calculations. A diagram of the control cell and associated dimensions is shown in Figure 3.3. The input data for the three pin cell calculations are contained in Tables A.6, A.7, and A.8 of Appendix A while Table A.9 is the input data for the control cell calculation. Finally, three additional NITAWL calculations were required to combine the four cell-weighted cross-section libraries into one ANISN formatted 27-group P3 library. These input decks are given in Tables A.10, A.11 and A.12 of Appendix A. The cross-sections contained in the master library are given in Table 3.5. This master cross-section library was the library used for all three PWR reactor designs.

Given the large number of materials present in the master library, GIP calculations were made for each reactor design to produce one set of microscopic cross-sections for each region in the reactor models. Sample input decks for three different GIP calculations (one for each reactor design) are given in Tables A.13, A.14, and A.15. The appropriate GIP-generated cross-section libraries were then used to make an ANISN calculation for each reactor design. Sample input decks for these calculations are given in Tables A.16, A.17, and A.18. Additional GIP and ANISN calculations were made as variations in the reactor designs were investigated.

3.3 REFERENCES

1. Traver, T. M. 1969. "User's Manual for DASQHE." BNWL-CC-2274, September.
2. Greene, N. M. et al. 1976. "AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B." ORNL/TM-3706, March.
3. Roades, W. A. and M. B. Emmett. 1982. "DOS: The Discrete Ordinates System." ORNL/TM-8362, September.
4. Engle, Jr., W. W. 1973. "A Users Manual for ANISN: A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering." K-1693, June.

5. Ford, III, W. E. 1976. "A 218-Group Neutron Cross-Section Library in the AMPX Master Interface Format for Criticality Safety Studies." ORNL/CSD/TM-4, July.

FIGURE 3.1. Reactor Modeling Sequence

FIGURE 3.2. Diagram and Dimensions Used in the Pin Cell Calculations

$$\begin{aligned}
 r_1 &= 0.4367 \text{ cm} \\
 r_2 &= 0.4889 \text{ cm} \\
 r_3 &= 0.7480 \text{ cm} \\
 r_4 &= 2.2000 \text{ cm}
 \end{aligned}$$

FIGURE 3.3. Diagram and Dimensions Used in the Control Cell Calculations

TABLE 3.1. CMLIB Group Structure

<u>Group Number</u>	<u>Energy Boundaries (eV)</u>	<u>Lethargy Boundaries</u>	<u>Velocities (cm/s)</u>
1	2.00000+007	-6.93147-001	4.65844+009
2	6.43400+006	4.40989-001	2.89910+009
3	3.00000+006	1.20397+000	2.12293+009
4	1.85000+006	1.68740+000	1.75464+009
5	1.40000+006	1.96611+000	1.46540+009
6	9.00000+005	2.40795+000	1.07137+009
7	4.00000+005	3.21888+000	6.18554+008
8	1.00000+005	4.60517+000	2.80850+008
9	1.70000+004	6.37713+000	1.16884+008
10	3.00000+003	8.11173+000	4.95716+007
11	5.50000+002	9.80818+000	2.11813+007
12	1.00000+002	1.15129+001	1.02363+007
13	3.00000+001	1.27169+001	5.75629+006
14	1.00000+001	1.38155+001	3.25040+006
15	3.05000+000	1.50030+001	2.10829+006
16	1.77000+000	1.55471+001	1.70350+006
17	1.30000+000	1.58557+001	1.52271+006
18	1.13000+000	1.59959+001	1.42604+006
19	1.00000+000	1.61181+001	1.30808+006
20	8.00000-001	1.63412+001	1.04028+006
21	4.00000-001	1.70344+001	8.30516+005
22	3.25000-001	1.72420+001	7.19248+005
23	2.25000-001	1.76098+001	5.35683+005
24	1.00000-001	1.84207+001	3.67794+005
25	5.00000-002	1.91138+001	2.72198+005
26	3.00000-002	1.96247+001	1.82030+005
27	1.00000-002	2.07233+001	2.45959+004
28	1.00000-005	2.76310+001	

TABLE 3.2 Isotopes Available in CMLIB (A 27-Group Cross Section Library)

Nuclide	ENDF/B MAT No.(a)	Resolved Resonance Data	Weight Function(b)	Master Library ID No.	MT Numbers for 1-d Processes in Data Set	MT Numbers for 2-d Processes in Data Set(c)	Remarks
H	1269	No	A	1269	1,2,27,101,102,1099	2,1007	MAT 1002 H+O bound thermal
D	1120	No	A	112003	1,2,16,27,101,102,1099	2,16,1007	MAT 1004 D ₂ O bound thermal
He-4	1270	No	A	1270	1,2,1099		
Li-6	1271	No	A	127103	1,2,4,24,27,101-103,107,1099	2,24,52,91,1007	
Li-7	1272	No	A	127203	1,2,4,16,24,27,101,102,104,1099	2,16,24,51,91,1007	
Be-9	1289	No	B	1289	1,2,16,27,101-105,107,1099	2,6-9,44-49,1007	
B-10	1273	No	A	127303	1,2,4,27,101,103,104,107,113,1099	2,51,85,1007	
B-11	1160	No	A	116003	1,2,4,16,27,101-103,105,107,1099	2,16,51-53,91,1007	
C-12	1274	No	A	127403	1,2,4,27,101,102,107,1099	2,51,91,1007	
N-14	1275	No	A	1275	1,2,4,16,27,101-105,107,108,1099	2,16,51-82,1007	
O-16	1276	No	A	1276	1,2,4,27,101-104,107,1099	2,51-89,1007	
F	1277	No	A	1277	1,2,4,16,22,27,28,101-105,107,1099	2,16,22,28,51-71,91,1007	
Na-23	1156	Yes	B	115602	1,2,4,16,27,101-103,107,1021,1099	2,16,51-68,91,1007	
Mg	1280	No	A	128003	1,2,4,16,22,27,28,101-103,107,1099	2,16,22-28,51-59,1007	
Al-27	1193	No	A	1193	1,2,4,16,27,101-105,107,1099	2,16,51-90,1007	
Si	1194	No	A	119403	1,2,4,16,22,27,28,101-104,107,1099	2,16,22,28,51-72,91,1007	
P-31	7019(d)	No	A	701903	1,2,4,16,27,28,101-103,107,1099	2,16,28,91,1007	
S-32	7020(d)	No	A	702003	1,2,4,16,27,28,101-103,105,107,1099	2,16,28,91,1007	
Cl	1149	No	A	1149	1,2,4,16,22,27,28,101-103,107,1099	2,16,22,28,51-63,91,1007	
K	1150	No	A	1150	1,2,4,16,22,27,28,101-103,107,1099	2,16,22,28,51-67,91,1007	
Ca	1195	No	A	119503	1,2,4,16,22,27,28,101-108,111,112,1099	2,16,22,28,51,73,91,1007	
Tl	1286	No	A	1286	1,2,4,16,27,101-103,107,1099	2,16,51,91,1007	
V	1196	No	A	119603	1,2,4,16,22,27,28,101-105,107,1099	2,16,22,28,51-54,91,1007	
Cr	1191	No	B	119102	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-91,1007	
Cr	1191	No	D	1191104	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-91,1007	
Cr	1191	No	C	1191101	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-91,1007	
Mn-55	1197	Yes	B	119702	1,2,4,16,17,22,27,28,101-104,106,107,1021,1099	2,16,17,22,28,51-55,91,1007	
Fe	1192	No	B	119202	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-76,91,1007	
Fe	1192	No	D	1192104	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-76,91	
Fe	1192	No	C	1192101	1,2,4,16,22,27,28,101-107,1099	2,16,22,28,51-76,91,1007	
Co-59	1199	Yes	B	1199	1,2,4,16,27,101-105,107,1021,1099	2,16,51-59,91,1007	
Ni	1190	No	B	119002	1,2,4,16,27,28,101-103,107,1099	2,16,28,51-65,91,1007	
Ni	1190	No	D	1190104	1,2,4,16,27,28,101-103,107,1099	2,16,28,51-65,91,1007	
Ni	1190	No	C	1190101	1,2,4,16,27,28,101-103,107,1099	2,16,28,51-65,91,1007	
Cu	1295	No	B	129502	1,2,4,16,17,22,27,28,101-104,106,107,1099	2,16,17,22,28,51-61,91,1007	
Zr	7141(d)	No	B	714102	1,2,4,16,17,27,101,103,1099	2,16,17,51-58,91,1007	
ZIRC-2	1286	No	B	128402	1,2,4,16,27,101-103,107,1099	2,16,51-56,91,1007	
Nb-93	1184	Yes	B	1189	1,2,4,16,17,22,27,101-103,107,1021,1099	2,16,22,27,51-62,91,1007	
Mo	1287	No	B	128702	1,2,4,16,17,27,101,102,1099	2,16,17,91,1007	
Ag-107	1138	Yes	B	113802	1,2,4,16,27,101-105,107,1021,1099	2,16,51-56,91,1007	
Ag-109	1139	Yes	B	113902	1,2,4,16,27,101-103,107,1021,1099	2,16,51-55,91,1007	
Cd	1281	No	A	128103	1,2,4,16,27,101-103,107,1099	2,16,51-54,91,1007	
Sn	7039(d)	No	A	703903	1,2,4,16,17,27,101,102,1099	2,16,17,91,1007	
Ba-138	7040(d)	No	A	704003	1,2,4,16,17,27,101-103,107,1099	2,16,17,91,1007	
Cd	1030	No	B	103002	1,2,4,16,17,27,101-102,1099	2,16,17,91,1007	
Dy-164	1031	Yes	B	103102	1,2,4,16,17,27,101-103,107,1021,1099	2,16,17,51-62,91,1007	
Lu-175	1032	Yes	B	103202	1,2,4,16,17,27,101-103,107,1021,1099	2,16,17,51-58,91,1007	
Lu-176	1033	Yes	B	103302	1,2,4,16,17,27,101-103,107,1021,1099	2,16,17,51-58,91,1007	
Hf	1034	No	B	103402	1,2,4,16,27,101-103,1099	2,1007	
Ta-181	1285	No	B	128502	1,2,4,16,17,27,101,102,103,1099	2,16,17,51-60,91,1007	
W-182	1128	Yes	B	1128	1,2,4,16,17,27,28,101,102,103,107,1021,1099	2,16,17,28,51-58,91,1007	
W-183	1129	Yes	B	1129	1,2,4,16,17,27,28,101,102,103,107,1021,1099	2,16,17,28,51-59,91,1007	
W-184	1130	Yes	B	1130	1,2,4,16,17,27,28,101,102,103,107,1021,1099	2,16,17,28,51-59,91,1007	
W-186	1131	Yes	B	1131	1,2,4,16,17,27,28,101,102,103,107,1021,1099	2,16,17,28,51-59,91,1007	
Re-185	1083	Yes	B	1083	1,2,4,16,17,27,101,102,1021,1099	2,16,17,51-59,91,1007	

TABLE 3.2. (contd)

Nuclide	ENDF/B, MAT No. (a)	Resolved Resonance Data	Weight Function (b)	Master Library ID No.	1-d Processes in Data Set	1T Numbers for 2-d Processes in Data Set (c)	Remarks
Re-187	1084	Yes	B	1084	1,2,4,16,17,27,101,102,1021,1099	2,16,17,51-61,91,1007	
Au-197	1283	Yes	B	128302	1,2,4,16,17,26,27,101-103,107,1021,1099	2,16,17,51-64,91,1007	
Pb	1288	No	A	128803	1,2,4,16,17,27,101,102,1099	2,16,17,51-85,91,1007	
Th-232	1296	Yes	B	129602	1,2,4,16,17,18,27,101,102,452,1021,1099,1018	2,16,17,51-58,91,1007	
U-233	1260	Yes	B	126002	1,2,4,16-18,27,101,102,452,1021,1022,1099,1018	2,16,17,51-57,91,1007	
U-234	1043	Yes	B	104302	1,2,4,16-18,27,101,102,452,1021,1099,1018	2,16,51-56,91,1007	
U-235	1261	Yes	B	1261	1,2,4,16-18,27,101-102,452,1018,1021,1022,1099	2,16,17,51-66,1007	
U-236	1163	Yes	B	116302	1,2,4,16-18,27,101,102,452,1021,1099,1018	2,16,51-56,91,1007	
U-238	1262	Yes	B	1262	1,2,4,16-18,27,101,102,452,1018,1021,1022,1099	2,16,17,51-76,91,1007	
Np-237	1263	Yes	B	126302	1,2,4,16-18,27,101,102,452,1021,1022,1099,1018	2,16,17,51-61,91,1007	
Pu-238	1050	Yes	B	1050	1,2,4,16-18,27,101,102,452,1021,1022,1099,1018	2,16,17,51-59,91,1007	
Pu-239	1264	Yes	B	126402	1,2,4,16-18,27,37,101,102,452,1018,1021,1022,1099	2,16,17,51-76,91,1007	
Pu-240	1265	Yes	B	126502	1,2,4,16-18,27,101,102,452,1018,1021,1022,1099	2,16,17,51-62,91,1007	
Pu-241	1266	Yes	B	126602	1,2,4,16-18,27,101,102,452,1018,1021,1022,1099	2,16,17,51-65,91,1007	
Pu-242	1161	Yes	B	1161	1,2,4,16-18,27,101,102,452,1018,1021,1099	2,16,17,51-60,91,1007	
Am-241	1056	Yes	B	1056	1,2,4,18,27,101,102,452,1018,1021,1022,1099	2,91,1007	
Cm-244	1162	Yes	B	116202	1,2,4,16-18,27,101,102,452,1021,1022,1099,1018	2,16,17,51-60,91,1007	

(a) All neutron data from ENDF/B-IV unless otherwise noted.

(b) See Table 3.4 for energy range of weight functions. The following code is used to identify the weight functions:

Code	Weight Function
A	Fission-1/E ₀₁ -Maxwellian
B	Fission-1/E-Maxwellian
C	1/E ₀₁ -incone1-Maxwellian
D	1/E ₀₁ stainless steel 304-Maxwellian

(c) See Table 3.3 for correspondence between 1T numbers and reaction types.

(d) Data from the ENDF library.

TABLE 3.3. Definition of Reaction Types

MT Number	Description
1	Total cross section (redundant, equal to the sum of all partial cross sections)
2	Elastic scattering cross section
4	Total inelastic cross section (redundant, equal to the sum of MT=51,52,53,...,90,91)
16	(n,2n) cross section
17	(n,3n) cross section
18	Total fission cross section
22	(n,n') α cross section
23	(n,n')3 α cross section
24	(n,2n) α cross section
25	(n,3n) α cross section
26	(n,2n) isomeric state cross section
27	Absorption cross section (sum of MT=18 and 102)
28	(n,n')p cross section
51	(n,n') to the <u>1st</u> excited state
52	(n,n') to the <u>2nd</u> excited state
.	
.	
.	
90	(n,n') to the <u>40th</u> excited state
91	(n,n') to the continuum
101	Parasitic absorption (redundant, sum of MT=102,103,104,105,106,107,108,109)
102	(n, γ) radiative capture cross section
103	(n,p) cross section
104	(n,d) cross section
105	(n,t) cross section
106	(n,He ³) cross section
107	(n, α) cross section
108	(n,2 α) cross section
109	(n,3 α) cross section

TABLE 3.4. Point-to-Fine Group Weighting Functions

- Non Resonance Materials (fission- $1/E\sigma_T$ -Maxwellian)

<u>Energy Range</u>	<u>Weighting</u>
20-1.4 MeV	Fission
1.4×10^6 -0.1264 eV	$1/E\sigma_T$
0.1264- 1.0×10^{-5} eV	Maxwellian (293°K)

- Resonance Materials (fission- $1/E$ -Maxwellian)

<u>Energy Range</u>	<u>Weighting Spectrum</u>
20-0.1 MeV	Fission
1.0×10^5 -0.1264 eV	$1/E$
0.1264- 1.0×10^{-5} eV	Maxwellian (293°)

- Selected Structural Materials (Fe, Ni, Cr)

<u>Energy Range</u>	<u>Weighting Spectrum</u>
2.0×10^7 -0.1264 eV	{ $(1/E\sigma_T)$ inconel or $(1/E\sigma_T)$ stainless steel 304
0.1264- 1.0×10^{-5} eV	Maxwellian (293°K)

TABLE 3.5. Isotopes Present in the Master Cross Section Library

Number of Neutron Groups	Total Number of Groups	Number of Gamma Groups	Element/ Isotope ID	Element/Isotope Title
27	40	0	1	P0 O-16 1276 218 GP 040375(5)
27	40	0	2	P1 O-16 1276 218 GP 040375(5)
27	40	0	3	P2 O-16 1276 218 GP 040375(5)
27	40	0	4	P3 O-16 1276 218 GP 040375(5)
27	40	0	5	P0 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	6	P1 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	7	P2 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	8	P3 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	9	P0 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	10	P1 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	11	P2 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	12	P3 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	13	P0 CA 1195 218 GP 1/E*SIGT 040375(5)
27	40	0	14	P1 CA 1195 218 GP 1/E*SIGT 040375(5)
27	40	0	15	P2 CA 1195 218 GP 1/E*SIGT 040375(5)
27	40	0	16	P3 CA 1195 218 GP 1/E*SIGT 040375(5)
27	40	0	17	P0 W-182 1128 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	18	P1 W-182 1128 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	19	P2 W-182 1128 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	20	P3 W-182 1128 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	21	P0 CL 1149 218 GP WT 1/EST 042375 P3 293K
27	40	0	22	P1 CL 1149 218 GP WT 1/EST 042375 P3 293K
27	40	0	23	P2 CL 1149 218 GP WT 1/EST 042375 P3 293K
27	40	0	24	P3 CL 1149 218 GP WT 1/EST 042375 P3 293K
27	40	0	25	P0 CO-59 1199 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	26	P1 CO-59 1199 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	27	P2 CO-59 1199 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	28	P3 CO-59 1199 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	29	P0 NB-93 1189 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	30	P1 NB-93 1189 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	31	P2 NB-93 1189 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	32	P3 NB-93 1189 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	33	P0 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	34	P1 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	35	P2 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	36	P3 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	37	P0 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	38	P1 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	39	P2 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	40	P3 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	41	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	42	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	43	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	44	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	45	P0 MO 1287 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	46	P1 MO 1287 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	47	P2 MO 1287 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	48	P3 MO 1287 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	49	P0 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	50	P1 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	51	P2 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	52	P3 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	53	P0 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	54	P1 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0

TABLE 3.5. (contd)

Number of Neutron Groups	Total Number of Gamma Groups	Element/Isotope ID	Element/Isotope Title
27	40	55	P2 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	56	P3 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	57	P0 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	58	P1 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	59	P2 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	60	P3 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	61	P0 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	62	P1 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	63	P2 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	64	P3 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	65	P0 N-14 1275 218 GP 040375(5)
27	40	66	P1 N-14 1275 218 GP 040375(5)
27	40	67	P2 N-14 1275 218 GP 040375(5)
27	40	68	P3 N-14 1275 218 GP 040375(5)
27	40	69	P0 O-16 1276 218 GP 040375(5)
27	40	70	P1 O-16 1276 218 GP 040375(5)
27	40	71	P2 O-16 1276 218 GP 040375(5)
27	40	72	P3 O-16 1276 218 GP 040375(5)
27	40	73	P0 O-16 1276 218 GP 040375(5)
27	40	74	P1 O-16 1276 218 GP 040375(5)
27	40	75	P2 O-16 1276 218 GP 040375(5)
27	40	76	P3 O-16 1276 218 GP 040375(5)
27	40	77	P0 H 1269 F, 1002 T 218 GP 032475(2)
27	40	78	P1 H 1269 F, 1002 T 218 GP 032475(2)
27	40	79	P2 H 1269 F, 1002 T 218 GP 032475(2)
27	40	80	P3 H 1269 F, 1002 T 218 GP 032475(2)
27	40	81	P0 ZR(NAT) 7141 21 NGP WT FIS(0.11020) -1/E-MAX
27	40	82	P1 ZR(NAT) 7141 21 NGP WT FIS(0.11020) -1/E-MAX
27	40	83	P2 ZR(NAT) 7141 21 NGP WT FIS(0.11020) -1/E-MAX
27	40	84	P3 ZR(NAT) 7141 21 NGP WT FIS(0.11020) -1/E-MAX
27	40	85	P0 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	86	P1 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	87	P2 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	88	P3 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	89	P0 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	90	P1 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	91	P2 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	92	P3 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	93	P0 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	94	P1 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	95	P2 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	96	P3 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	97	P0 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	98	P1 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	99	P2 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	100	P3 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	101	P0 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	102	P1 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	103	P2 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	104	P3 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	105	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	106	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	107	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	108	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	109	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	110	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	111	P2 B-10 1273 218NGP 042375 P-3 293K

TABLE 3.5. (contd)

Number of Neutron Groups	Total Number of Groups	Number of Gamma Groups	Element/ Isotope ID	Element/Isotope Title
27	40	0	112	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	113	P0 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	114	P1 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	115	P2 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	116	P3 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	117	P0 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	118	P1 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	119	P2 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	120	P3 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	121	P0 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	122	P1 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	123	P2 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	124	P3 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	125	P0 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	126	P1 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	127	P2 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	128	P3 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	129	P0 O-16 1276 218 GP 040375(5)
27	40	0	130	P1 O-16 1276 218 GP 040375(5)
27	40	0	131	P2 O-16 1276 218 GP 040375(5)
27	40	0	132	P3 O-16 1276 218 GP 040375(5)
27	40	0	133	P0 O-16 1276 218 GP 040375(5)
27	40	0	134	P1 O-16 1276 218 GP 040375(5)
27	40	0	135	P2 O-16 1276 218 GP 040375(5)
27	40	0	136	P3 O-16 1276 218 GP 040375(5)
27	40	0	137	P0 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	138	P1 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	139	P2 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	140	P3 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	141	P0 ZR(NAT) 7141 21 NGP WT FIS(0 1T020)-1/E-MAX
27	40	0	142	P1 ZR(NAT) 7141 21 NGP WT FIS(0 1T020)-1/E-MAX
27	40	0	143	P2 ZR(NAT) 7141 21 NGP WT FIS(0 1T020)-1/E-MAX
27	40	0	144	P3 ZR(NAT) 7141 21 NGP WT FIS(0 1T020)-1/E-MAX
27	40	0	145	P0 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	146	P1 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	147	P2 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	148	P3 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	149	P0 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	150	P1 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	151	P2 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	152	P3 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	153	P0 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	154	P1 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	155	P2 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	156	P3 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	157	P0 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	158	P1 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	159	P2 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	160	P3 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	161	P0 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	162	P1 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	163	P2 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	164	P3 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	165	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	166	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	167	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	168	P3 B-10 1273 218NGP 042375 P-3 293K

TABLE 3.5. (contd)

Number of Neutron Groups	Total Number of Groups	Number of Gamma Groups	Element/ Isotope ID	Element/Isotope Title
27	40	0	169	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	170	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	171	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	172	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	173	P0 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	174	P1 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	175	P2 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	176	P3 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	177	P0 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	178	P1 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	179	P2 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	180	P3 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	181	P0 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	182	P1 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	183	P2 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	184	P3 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	185	P0 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	186	P1 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	187	P2 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	188	P3 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	189	P0 O-16 1276 218 GP 040375(5)
27	40	0	190	P1 O-16 1276 218 GP 040375(5)
27	40	0	191	P2 O-16 1276 218 GP 040375(5)
27	40	0	192	P3 O-16 1276 218 GP 040375(5)
27	40	0	193	P0 O-16 1276 218 GP 040375(5)
27	40	0	194	P1 O-16 1276 218 GP 040375(5)
27	40	0	195	P2 O-16 1276 218 GP 040375(5)
27	40	0	196	P3 O-16 1276 218 GP 040375(5)
27	40	0	197	P0 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	198	P1 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	199	P2 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	200	P3 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	201	P0 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	202	P1 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	203	P2 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	204	P3 ZR(NAT) 7141 21 NGP WT FIS(0.1T020)-1/E-MAX
27	40	0	205	P0 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	206	P1 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	207	P2 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	208	P3 U-235 1261 SIGP=5+4 T=293 218GP 101475(3)
27	40	0	209	P0 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	210	P1 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	211	P2 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	212	P3 U-238 1262 SIGP=5+4 T=293 218GP 092975(5)
27	40	0	213	P0 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	214	P1 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	215	P2 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	216	P3 PU-242 1161 218 GP WT F-1/E-M 042375 P3 293K
27	40	0	217	P0 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	218	P1 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	219	P2 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	220	P3 SN 7039 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	221	P0 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	222	P1 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	223	P2 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	224	P3 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	225	P0 B-10 1273 218NGP 042375 P-3 293K

TABLE 3.5. (contd)

Number of Neutron Groups	Total Number of Groups	Number of Gamma Groups	Element/ Isotope ID	Element/Isotope Title
27	40	0	226	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	227	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	228	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	229	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	230	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	231	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	232	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	233	P0 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	234	P1 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	235	P2 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	236	P3 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	237	P0 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	238	P1 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	239	P2 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	240	P3 PU-239 1264 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	241	P0 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	242	P1 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	243	P2 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	244	P3 PU-240 1265 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	245	P0 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	246	P1 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	247	P2 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	248	P3 PU-241 1266 218NGP WT 1/E P-3 SIGP=5+4 293K
27	40	0	249	P0 O-16 1276 218 GP 040375(5)
27	40	0	250	P1 O-16 1276 218 GP 040375(5)
27	40	0	251	P2 O-16 1276 218 GP 040375(5)
27	40	0	252	P3 O-16 1276 218 GP 040375(5)
27	40	0	253	P0 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	254	P1 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	255	P2 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	256	P3 H 1269 F, 1002 T 218 GP 032475(2)
27	40	0	257	P0 CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	258	P1 CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	259	P2 CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	260	P3 CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	261	P0 AG-107 1138 218 GP 1/E 040375(5)
27	40	0	262	P1 AG-107 1138 218 GP 1/E 040375(5)
27	40	0	263	P2 AG-107 1138 218 GP 1/E 040375(5)
27	40	0	264	P3 AG-107 1138 218 GP 1/E 040375(5)
27	40	0	265	P0 AG-109 1139 218 GP 1/E 040375(5)
27	40	0	266	P1 AG-109 1139 218 GP 1/E 040375(5)
27	40	0	267	P2 AG-109 1139 218 GP 1/E 040375(5)
27	40	0	268	P3 AG-109 1139 218 GP 1/E 040375(5)
27	40	0	269	P0 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	270	P1 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	271	P2 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	272	P3 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
27	40	0	273	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	274	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	275	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	276	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	277	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	278	P1 B-10 1273 218NGP 042375 P-3 293K
27	40	0	279	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	280	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	281	P0 B-10 1273 218NGP 042375 P-3 293K
27	40	0	282	P1 B-10 1273 218NGP 042375 P-3 293K

TABLE 3.5. (contd)

Number of Neutron Groups	Total Number of Groups	Number of Gamma Groups	Element/ Isotope ID	Element/Isotope Title
27	40	0	283	P2 B-10 1273 218NGP 042375 P-3 293K
27	40	0	284	P3 B-10 1273 218NGP 042375 P-3 293K
27	40	0	285	P0 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	286	P1 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	287	P2 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	288	P3 FE 1192 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	289	P0 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	290	P1 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	291	P2 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	292	P3 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	293	P0 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	294	P1 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	295	P2 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	296	P3 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(0
27	40	0	297	P0 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	0	298	P1 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	0	299	P2 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R
27	40	0	300	P3 MN-55 1197 218NGP WT 1/E P-3 293K SIGP=5+4 R

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4.0 RESULTS

The results of ANISN calculations for each of the reactor models are presented in this section. The ANISN calculations provided 27-group neutron fluxes throughout the model. These fluxes were multiplied by the appropriate 27-group cross-sections (see Section 3) within ANISN to provide total production (reaction) rates for the radionuclides of interest. The reaction rate calculated for each reaction of interest was divided by the total neutron flux, resulting in a one-group cross-section for that reaction. These one-group cross-sections are illustrated as functions of axial location for each reaction, for each reactor type. (See Section 5 for a discussion of the one-group cross-sections variability). The total neutron flux as a function of neutron energy (for a mid-core region), the total neutron flux (shown on two different scales to provide different perspectives on the shape of the flux), the reaction rates for the [Co-59 (n, γ) Co-60] reaction, and the one-group cross-sections for each reaction of interest are presented as functions of axial location for each reactor type in the following sections.

4.1 BABCOCK AND WILCOX

Figure 4.1 shows the calculated neutron flux as a function of neutron energy for a mid-core region of the Babcock and Wilcox reactor. Total flux values over the fuel assembly region of the core are shown in Figures 4.2a (logarithmic scale) and 4.2b (linear scale). The Co-59 reaction rate distribution along the fuel assembly region of the core is presented in Figure 4.3. Figures 4.4a through 4.4g show the one-group neutron cross-section distributions for the following reactions:

- a. Co-59 (n, γ)
- b. N-14 (n,p)
- c. Nb-93 (n, γ)
- d. Natural Ni (n, γ)
- e. Natural Ni (n,p)
- f. Ni-60 (n,p)
- g. Natural Fe (n, γ)

4.2 COMBUSTION ENGINEERING

The neutron flux as a function of neutron energy for a mid-core region of the Combustion Engineering reactor is shown in Figure 4.5. Figures 4.6a (logarithmic scale) and 4.6b (linear scale) show the total neutron flux distribution over the fuel assembly portion of the reactor core. The Co-59 reaction rate distribution along the fuel assembly region of the core is shown in Figure 4.7. Figures 4.8a through 4.8g illustrate the one-group neutron cross-section distributions over the fuel assembly region of the core for each of the reactions listed in Section 4.1.

4.3 WESTINGHOUSE

Figure 4.9 shows the neutron flux as a function of neutron energy for a mid-core region of the Westinghouse reactor. The total neutron flux distribution over the fuel assembly region of the reactor core is shown in Figures 4.10a (logarithmic scale) and 4.10b (linear scale). The Co-59 reaction rate distribution over the fuel assembly region of the core is presented in Figure 4.11. Figures 4.12a through 4.12g illustrate the one-group neutron cross-section distributions over the fuel assembly region of the core for each of the reactions listed in Section 4.1.

4.4 DISCUSSION

During the course of reviewing the results of these calculations, initial observations were made indicating potential anomalies regarding the one-group cross-section for the $[N-14 (n,p) C-14]$ reaction. The majority of (n,γ) cross-sections have a $1/E$ tail indicated by a rise in the thermal region. Therefore, the increase in the one-group cross-section in the endfitting region (where the flux is thermalizing) was an expected result. On the other hand, most (n,p) reactions have a threshold energy below which they do not occur. For these reactions, the one-group cross-section would normally go down as the flux thermalized. This is not the case for the $[N-14 (n,p) C-14]$ cross-section. Figure 4.13 shows a plot of that cross-section as a function of energy. The $1/E$ tail is readily apparent below about 30 eV, explaining why the one-group cross-section increases outside the fuel region where the flux is thermalizing.

FIGURE 4.1. Normalized Flux per Neutron Energy
for a Babcock and Wilcox Fuel Assembly

FIGURE 4.2a. Normalized Flux
for a Babcock and Wilcox Fuel Assembly

FIGURE 4.2b. Normalized Flux
for a Babcock and Wilcox Fuel Assembly

FIGURE 4.3. Co-59 (n,gamma) Normalized Reaction Rate for a Babcock and Wilcox Fuel Assembly

FIGURE 4.4a. Co-59 (n,γ) One-Group Cross Section for a Babcock and Wilcox Fuel Assembly

**FIGURE 4.4b. N-14 (n,p) One-Group Cross Section
for a Babcock and Wilcox Fuel Assembly**

FIGURE 4.4c. Nb-93 (n,γ) One-Group Cross Section for a Babcock and Wilcox Fuel Assembly

FIGURE 4.4d. Nat Ni (n,γ) One-Group Cross Section for a Babcock and Wilcox Fuel Assembly

FIGURE 4.4e. Nat Ni (n,p) One-Group Cross Section
for a Babcock and Wilcox Fuel Assembly

**FIGURE 4.4f. Ni-60 (n,p) One-Group Cross Section
for a Babcock and Wilcox Fuel Assembly**

FIGURE 4.4g. Nat Fe (n,gamma) One-Group Cross Section for a Babcock and Wilcox Fuel Assembly

FIGURE 4.5. Normalized Flux per Neutron Energy
for a Combustion Engineering Fuel Assembly

FIGURE 4.6a. Normalized Flux
for a Combustion Engineering Fuel Assembly

FIGURE 4.6b. Normalized Flux
for a Combustion Engineering Fuel Assembly

FIGURE 4.8a. Co-59 (n,gamma) One-Group Cross Section for a Combustion Engineering Fuel Assembly

**FIGURE 4.8b. N-14 (n,p) One-Group Cross Section
for a Combustion Engineering Fuel Assembly**

FIGURE 4.8c. Nb-93 (n, γ) One-Group Cross Section
for a Combustion Engineering Fuel Assembly

FIGURE 4.8d. Nat Ni (n,γ) One-Group Cross Section for a Combustion Engineering Fuel Assembly

**FIGURE 4.8e. Nat Ni (n,p) One-Group Cross Section
for a Combustion Engineering Fuel Assembly**

FIGURE 4.8f. Ni-60 (n,p) One-Group Cross Section
for a Combustion Engineering Fuel Assembly

FIGURE 4.8g. Nat Fe (n,gamma) One-Group Cross Section for a Combustion Engineering Fuel Assembly

FIGURE 4.9. Normalized Flux per Neutron Energy
for a Westinghouse Fuel Assembly

FIGURE 4.10a. Normalized Flux
for a Westinghouse Fuel Assembly

FIGURE 4.10b. Normalized Flux
for a Westinghouse Fuel Assembly

FIGURE 4.11. Co-59 (n, γ mma) Normalized Reaction Rate
for a Westinghouse Fuel Assembly

FIGURE 4.12a. Co-59 (n,gamma) One-Group Cross Section
for a Westinghouse Fuel Assembly

**FIGURE 4.12b. N-14 (n,p) One-Group Cross Section
for a Westinghouse Fuel Assembly**

FIGURE 4.12c. Nb-93 (n,γ) One-Group Cross Section
for a Westinghouse Fuel Assembly

FIGURE 4.12d. Nat Ni (n,gamma) One-Group Cross Section for a Westinghouse Fuel Assembly

FIGURE 4.12e. Nat Ni (n,p) One-Group Cross Section
for a Westinghouse Fuel Assembly

**FIGURE 4.12f. Ni-60 (n,p) One-Group Cross Section
for a Westinghouse Fuel Assembly**

FIGURE 4.12g. Nat Fe (n,gamma) One-Group Cross Section for a Westinghouse Fuel Assembly

FIGURE 4.13. N-14 Cross-Sections (From LA-8374-MS: Graphs of the Cross-Sections in the Recommended Monte Carlo Cross-Section Library at the Los Alamos Scientific Laboratory, May 1980)

5.0 CONCLUSIONS

The purpose of this report was to provide the necessary analytical data to develop factors that could be applied to ORIGEN2 results (which are only applicable to the fueled region) to estimate radionuclide inventories in the fuel assembly end fittings. This has been achieved. The factors could be derived from these calculations alone. However, one key element would be missing, and that would be a comparison of calculational results to measurements of radionuclide concentrations in irradiated hardware. This is currently ongoing at PNL.

PNL has acquired 38 samples of activated metals that were obtained from 3 spent fuel assemblies. The fuel assemblies are described in Table 5.1. For the purposes of this report, only the two PWR fuel assemblies are of interest. These fuel assemblies are representative of the type of spent fuel that must be accommodated by the federal waste management system and many utilities. Samples were taken from each grid spacer in each of the fuel assemblies, and from both the bottom and top end fittings. The bottom end fitting is generally a single casting made of stainless steel. The top end fitting however, consists of several different pieces that are composed of Inconel and stainless steel. Samples were obtained that are representative of each of the materials of construction, as well as each of the main parts.

ORIGEN2 calculations will be performed for the specific assemblies sampled. Factors based on these calculations alone will be applied to the ORIGEN2 estimates to predict the radionuclide activity. These will then be compared to the measurements. After all the data and calculations have been

TABLE 5.1. Description of the Fuel Assemblies Being Used in the Experimental Analysis

<u>Fuel Assembly Type</u>	<u>Burnup [MWD/MTU]</u>	<u>Discharge</u>
Westinghouse 14x14	33,000	OCT'81
Combustion Engineering 14x14	42,300	APR'82
General Electric 8x8	27,500	APR'81

analyzed, a final recommendation will be made as to the actual factors that should be used for future calculations. This is ongoing and will be the subject of a future report.

It is interesting to note that most of the one-group cross-sections increase outside the fuel region. This is true because the multi-group cross-sections in general increase with decreasing neutron energy for most reactions. It is also interesting to see how much variation there is in the one-group cross-sections in the end fitting regions as a function of position. This variation is due to the change in the relative amounts of water to metal (either Inconel or stainless steel). The metals are comprised primarily of iron, nickel, and chrome, all of which have thermal cross-sections larger than water. The thermal neutrons are absorbed at a faster rate in these regions as opposed to those regions that have a higher proportion of water. Hence there are fewer neutrons available to interact.

It appears that there is not much difference between the three different PWR models calculated. The main differences seem to be in the end fitting regions. However as discussed above, the water to metal has a significant bearing on the value of the cross-section. The differences between the models appears to be driven more by the differences in the material composition in these regions than any other neutronic reason. We will be able to make a more positive statement on this when we have concluded the experimental analysis.

APPENDIX A

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APPENDIX A

This appendix contains input decks that were used to make DASQHE, NITAWL, XSDRNPM, GIP, and ANISN runs to generate the results presented in this report. The NITAWL and XSDRNPM input decks also show command lines before and after the input data. These command lines were necessary since these runs were made on a UNIVAC system. The GIP and ANISN runs were made on a VAX system while the DASQHE runs were made on an IBM PC/AT.

TABLE A.1. DASQHE Input for 10,000 MWD/MTU Burnup Westinghouse Fuel Assembly

DASQHE L-BAR

O WESTINGHOUSE PWR FUEL + HARDWARE 10000 MWD/MTU FUEL

INPUT FOR DASQUE EXECUTION

NLAT =	4	PITCH =	1.2600000	RADIUS =	0.4000000
GAPWID =	0.0000000	NSIGMA =	1	NALF =	64
NRAD =	64	IRES =	6	NMS =	1

MODERATOR MACROSCOPIC CROSS SECTIONS:
 .9846330E+00

LIGHT ELEMENT SCATTERING CROSS SECTIONS: (Oxygen-16)
 .3704000E+01

HEAVY ELEMENT SCATTERING CROSS SECTIONS: (In Order: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242)
 .1060000E+02 .1010000E+02 .1030000E+02 .1060000E+02 .1050000E+02
 .1040000E+02

LIGHT ELEMENT NUMBER DENSITY (#/B-CM): (Oxygen-16)
 .4440000E-01

HEAVY ELEMENT NUMBER DENSITY (#/B-CM): (In Order: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242)
 .2129000E-01 .5463000E-03 .6997000E-04 .1145000E-04 .3927000E-05
 .2731000E-06

TEMPERATURE OF SYSTEM = 2030.0000
 NAME = WESTING

TABLE A.2. DASQHE Input for 15,000 MWD/MTU Burnup Westinghouse Fuel Assembly

0 WESTINGHOUSE PWR FUEL + HARDWARE 15000 MWD/MTU FUEL
DASQHE L-BAR
INPUT FOR DASQHE EXECUTION

NLAT = 4 PITCH = 1.2600000 RADIUS = .4000000
GAPWID = .0000000 NSIGMA = 1 NALF = 64
NRAD = 64 IRES = 6 NMS = 1

MODERATOR MACROSCOPIC CROSS SECTIONS:
.9846330E+00

LIGHT ELEMENT SCATTERING CROSS SECTIONS: (Oxygen-16)
.3704000E+01

HEAVY ELEMENT SCATTERING CROSS SECTIONS: (In Order: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242)
.1060000E+02 .1010000E+02 .1030000E+02 .1060000E+02 .1050000E+02
.1040000E+02

LIGHT ELEMENT NUMBER DENSITY (#/B-CM): (Oxygen-16)
.4440000E-01

HEAVY ELEMENT NUMBER DENSITY (#/B-CM): (In Order: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242)
.2123000E-01 .4518000E-03 .8636000E-04 .1998000E-04 .8452000E-05
.9943000E-06

TEMPERATURE OF SYSTEM = 2030.0000
NAME = WESTING

TABLE A.3. DASQHE Input for 20,000 MWD/MTU Burnup Westinghouse Fuel Assembly

O WESTINGHOUSE PWR FUEL + HARDWARE (20000 MWD/MTU FUEL) DASQHE L-BAR
INPUT FOR DASQUE EXECUTION

NLAT = 4 PITCH = 1.2600000 RADIUS = .4000000
GAPWID = .0000000 NSIGMA = 1 NALF = 64
NRAD = 64 IRES = 6 NMS = 1

MODERATOR MACROSCOPIC CROSS SECTIONS:
.9846330E+00

LIGHT ELEMENT SCATTERING CROSS SECTIONS: (Oxygen-16)
.3704000E+01

HEAVY ELEMENT SCATTERING CROSS SECTIONS: (In Order: U-238, U-236, Pu-239, Pu-240, Pu-241, Pu-242)
.1060000E+02 .1010000E+02 .1030000E+02 .1060000E+02 .1050000E+02
.1040000E+02

LIGHT ELEMENT NUMBER DENSITY (#/B-CM): (Oxygen-16)
.4440000E-01

HEAVY ELEMENT NUMBER DENSITY (#/B-CM): (In Order: U-238, U-235, Pu-239, Pu-240, Pu-241, Pu-242)
.2115000E-01 .3683000E-03 .9704000E-04 .2879000E-04 .1320000E-04
.2282000E-05

TEMPERATURE OF SYSTEM = 2030.0000
NAME = WESTING

TABLE A.4. NITAWL Input Used to Generate a Cross Section Library to Make Pin Cell Calculations

```

@RUN NITAWL/100/1//,PNL299/SMS299,SHORT,60,200 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,A ORGNT.,///1000
@ERS ORGNT.
@BRKPT PRINT$/ORGNT
@ASG,A NITAWLOUT4B.
@ERS NITAWLOUT4B.
@USE 4,NITAWLOUT4B.
@ASG,A CIL*CMLIB.
@USE 60,CIL*CMLIB.
@ASG,A UPJ*NITAWLPROG.
@XQT UPJ*NITAWLPROG.
0$$ 60 2 3 4 18 19 9 15 20
1$$ 3 58 0 0 0 0 0 24 0 0 0 0 1T
2$$ 1261 -10235 -15235 -20235
    1262 -10238 -15238 -20238
    126402 -10239 -15239 -20239
    126502 -10240 -15240 -20240
    126602 -10241 -15241 -20241
    1161 -10242 -15242 -20242
    1276 -10816 -15816 -20816
    -210816 -215816 -220816
    1269 -10001 -15001 -20001
    127303 -10510 -15510 -20510
    -210510 -215510 -220510
    116003 -10511 -15511 -20511
    703903 -10500 -15500 -20500
    714102 -10400 -15400 -20400
    119202 -10260 -15260 -20260
3**
    1261 2023 2 0.4 0.175487 2612.44 5.463-4 1 16 301.04 1 238
    413.1 1 1
    1262 2023 2 0.4 0.175487 67.035 2.129-2 1 16 7.72 1 235
    0.2592 1 1
    126402 2023 2 0.4 0.175487 20396.98 6.997-5 1 16 2350.40 1 238
    3225.3 1 1
    126502 2023 2 0.4 0.175487 124644.2 1.145-5 1 16 14363.1 1 238
    19709.5 1 1
    126602 2023 2 0.4 0.175487 363426.7 3.927-6 1 16 41878.7 1 238
    57467.3 1 1
    1161 2023 2 0.4 0.175487 5225839. 2.731-7 1 16 602188.2 1 238
    826342. 1 1
    10235 2023 2 0.4 0.3087595 2307.50 5.463-4 1 16 301.04 1 238
    413.1 1 1
    10238 2023 2 0.4 0.3087595 59.210 2.129-2 1 16 7.72 1 235
    0.2592 1 1
    10239 2023 2 0.4 0.3087595 18016.09 6.997-5 1 16 2350.40 1 238
    3225.3 1 1

```

TABLE 3.3. (contd)

<u>MT Number</u>	<u>Description</u>
111	(n,2p) cross section
112	(n,p α) cross section
113	(n,t2 α) cross section
1018	Chi for lowest group
1021	"Background" data for capture reaction to be processed in NITAWL module
1022	"Background" data for fission reaction to be processed in NITAWL module
1023	"Background" data for elastic scattering reaction to be processed in NITAWL module
1099	Point-to-fine group weighting function

TABLE A.4. (contd)

10240	2023	2	0.4	0.3087595	110094.9	1.145-5	1	16	14363.1	1	238
19709.5	1	1									
10241	2023	2	0.4	0.3087595	321004.8	3.927-6	1	16	41878.7	1	238
57467.3	1	1									
10242	2023	2	0.4	0.3087595	4615841.	2.731-7	1	16	602188.2	1	238
826342.	1	1									
15235	2023	2	0.4	0.3087595	2787.32	4.518-4	1	16	364.01	1	238
498.1	1	1									
15238	2023	2	0.4	0.3087595	59.317	2.123-2	1	16	7.75	1	235
0.2149	1	1									
15239	2023	2	0.4	0.3087595	14582.10	8.636-5	1	16	1904.33	1	238
2605.8	1	1									
15240	2023	2	0.4	0.3087595	63028.52	1.998-5	1	16	8231.11	1	238
11263.2	1	1									
15241	2023	2	0.4	0.3087595	148995.5	8.452-6	1	16	19457.83	1	238
26625.4	1	1									
15242	2023	2	0.4	0.3087595	1266529.	9.943-7	1	16	165400.4	1	238
226328.	1	1									
20235	2023	2	0.4	0.3087595	3415.38	3.683-4	1	16	446.53	1	238
608.7	1	1									
20238	2023	2	0.4	0.3087595	59.474	2.115-2	1	16	7.78	1	235
0.1759	1	1									
20239	2023	2	0.4	0.3087595	12962.54	9.704-5	1	16	1694.74	1	238
2310.3	1	1									
20240	2023	2	0.4	0.3087595	43691.74	2.879-5	1	16	5712.32	1	238
7787.08	1	1									
20241	2023	2	0.4	0.3087595	95294.3	1.320-5	1	16	12458.91	1	238
16984.1	1	1									
20242	2023	2	0.4	0.3087595	551220.5	2.282-6	1	16	72067.30	1	238
98242.8	1	1									
4**	28R	2023	8R	500	3R	2023	7R	500	12R	550	
5\$\$	102	103	107	2T							
@MSLIMIT											
@BRKPT PRINT\$											
@FREE ORGNT.											
@SYM,U ORGNT.											
@FIN											

TABLE A.5. NITAWL Input Used to Generate a Cross Section
Library of Control Cell Isotopes

```

@RUN NITAWL/100/1//,SMS299/PNL299,SHORT,20,200 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,A CONTNOUT.,///1000
@BRKPT PRINT$/CONTNOUT
@PRT,S BWR2.CONTN
@ASG,AX NITAWLOUT4C.
@USE 4,NITAWLOUT4C.
@ASG,AX NITAWLOUT4B.
@USE 2,NITAWLOUT4B.
@ASG,AX CIL*CMLIB.
@USE 60,CIL*CMLIB.
@ASG,AX UPJ*NITAWLPROG.
@XQT UPJ*NITAWLPROG.
0$$ 60 E
1$$ 3 24 15 0 A8 0 A11 0 E 1T
2$$ 113802 -11477 113902 -11479 127303 -11493 -11495 -11510
    128103 -11480 119202 -11260 119102 -11240 119002 -11280
    119702 -11255 1276 -11816 1269 -11001 116003 -11511
    10235 10238 10239 10240 10241 10242 10816 10510 10400
    10500 10260 210816 10001 210510 10511
4** 24R 600 8R 2023 3R 550 4R 500
5$$ 102 103 107 2T
@MSLIMIT
@BRKPT PRINT$
@FREE CONTNOUT.
@SYM,U CONTNOUT.
@FIN

```

TABLE A.6. XSDRNPM Input Used to Make a Pin Cell Calculation
10,000 MWD/MTU Burnup 17 x 17 Westinghouse
Fuel Assembly

```

@RUN,N XSDRN/100/1///,PNL299/SMS299,SHORT,30,300 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,A XFP100OUT2.,///1000
@ERS XFP100OUT2.
@BRKPT PRINT$/XFP100OUT2
@PRT,S BWR2.XFPIN10
@ASG,A XFP103B.,///1000
@ERS XFP103B.
@USE 3,XFP103B.
@ASG,AX NITAWLOUT4B.
@USE 4,NITAWLOUT4B.
@ASG,AX UPJ*XSDRNPM.
@XQT UPJ*XSDRNPM.
PWR 10000 MWD/MTU FUEL PIN CELL CALCULATION
1$$ 2 3 20 1 3 3 15 16 3 1 20 20 0 0 0
2$$ A7 0 E
3$$ 1 A6 0 A9 2 E
4$$ -1 27 30 -1 13 14 40 -1 3
5** 2R1.-5 E 1T
12$$ 102 103 107
13$$ 8R1 3R2 4R3
14$$ 10235 10238 10239 10240 10241 10242 10816 10510
      10400 10500 10260
      210816 10001 210510 10511
15** 5.463-4 2.129-2 6.997-5 1.145-5 3.927-6 2.731-7 4.44-2 6.478-6
      4.215-2 4.948-4 2.105-4
      2.502-2 5.015-2 4.590-6 1.836-5 2T
33## F1 4T
35** 8I0.0 1I 0.400 8I 0.4620 0.7480
36$$ 9R1 2R2 9R3
39$$ 1 2 3
40$$ F3
49$$ 10510 210510
50$$ 2R 107
51$$ 25I1 27 5T
@MSLIMIT
@BRKPT PRINT$
@FREE XFP100OUT2
@SYM,U XFP100OUT2.
@FIN

```


TABLE A.7. XSDRNPM Input Used to Make a Pin Cell Calculation
for 15,000 MWD/MTU Burnup 17 x 17 Westinghouse
Fuel Assembly

```
@RUN,N XSDRN/250/1//,PNL299/SMS299,SHORT,30,300 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX XFP15OUT2.,///1000
@ERS XFP15OUT2.
@BRKPT PRINT$/XFP15OUT2
@PRT,S BWR2.XFPIN15
@ASG,AX NITAWLOUT4B.
@USE 4,NITAWLOUT4B.
@ASG,AX XFP153B.,///1000
@USE 3,XFP153B.
@ERS 3.
@ASG,AX UPJ*XSDRNPM.
@XQT UPJ*XSDRNPM.
PWR 15000 MWD/MTU FUEL PIN CELL CALCULATION
1$$ 2 3 20 1 3 3 15 16 3 1 20 20 0 0 0
2$$ A7 0 E
3$$ 1 A6 0 A9 2 E
4$$ -1 27 30 -1 13 14 40 -1 3
5** 2R1.-5 E 1T
12$$ 102 103 107
13$$ 8R1 3R2 4R3
14$$ 15235 15238 15239 15240 15241 15242 15816 15510
    15400 15500 15260
    215816 15001 215510 15511
15** 4.518-4 2.123-2 8.636-5 1.998-5 8.452-6 9.943-7 4.44-2 6.525-6
    4.215-2 4.948-4 2.105-4
    2.501-2 5.002-2 4.580-6 1.831-5 2T
33## F1 4T
35** 8I0.0 1I 0.400 8I 0.4620 0.7480
36$$ 9R1 2R2 9R3
39$$ 1 2 3
40$$ F3
49$$ 15510 215510
50$$ 2R 107
51$$ 25I1 27 5T
@MSLIMIT
@BRKPT PRINT$
@FREE XFP15OUT2
@SYM,U XFP15OUT2.
@FIN
```

TABLE A.8. XSDRNPM Input Used to Make a Pin Cell Calculation
for 20,000 MWD/MTU Burnup 17 x 17 Westinghouse
Assembly

```

@RUN,N XSDRN/250/1//,PNL299/SMS299,SHORT,30,300 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX XFP200UT2.,///1000
@ERS XFP200UT2.
@BRKPT PRINT$/XFP200UT2
@PRT,S BWR2.XFPIN20
@ASG,AX NITAWLOUT4B.
@USE 4,NITAWLOUT4B.
@ASG,AX XFP203B.,///1000
@ERS XFP203B.
@USE 3,XFP203B.
@ASG,AX UPJ*XSDRNPM.
@XQT UPJ*XSDRNPM.
PWR 20000 MWD/MTU FUEL PIN CELL CALCULATION
1$$$ 2 3 20 1 3 3 15 16 3 1 20 20 0 0 0
2$$$ A7 0 E
3$$$ 1 A6 0 A9 2 E
4$$$ -1 27 30 -1 13 14 40 -1 3
5** 2R1.-5 E 1T
12$$$ 102 103 107
13$$$ 8R1 3R2 4R3
14$$$ 20235 20238 20239 20240 20241 20242 20816 20510
      20400 20500 20260
      220816 20001 220510 20511
15** 3.683-4 2.115-2 9.704-5 2.879-5 1.320-5 2.282-6 4.44-2 6.471-6
      4.215-2 4.948-4 2.105-4
      2.397-2 4.795-2 4.390-6 1.755-5
                                     2T
33## F1 4T
35** 8I0.0 1I 0.400 8I 0.4620 0.7480
36$$$ 9R1 2R2 9R3
39$$$ 1 2 3
40$$$ F3
49$$$ 20510 220510
50$$$ 2R 107
51$$$ 25I1 27 5T
@MSLIMIT
@BRKPT PRINT$
@FREE XFP200UT2
@SYM,U XFP200UT2.
@FIN

```

TABLE A.9. XSDRNPM Input Used to Make Control Cell Calculation
for 17 x 17 Westinghouse Fuel Assembly

```

@RUN,N XSDRN/250/1//,PNL299/SMS299,SHORT,30,300 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX XCONTCOUT2.,///1000
@ERS XCONTCOUT2.
@BRKPT PRINT$/XCONTCOUT2
@PRT,S BWR2.XCONTC
@ASG,AX NITAWLOUT4C.
@USE 4,NITAWLOUT4C.
@ASG,AX XCONTC3A.,///1000
@ERS XCONTC3A.
@USE 3,XCONTC3A.
@ASG,AX UPJ*XSDRNPM.
@XQT UPJ*XSDRNPM.
PWR CONTROL CELL CALCULATION
1$$ 2 4 60 1 3 4 28 16 3 1 20 20 0 0 0
2$$ A7 0 E
3$$ 1 A6 0 A9 3 E
4$$ -3 27 30 -1 13 14 40 -1 3
5** 2R1.-5 E 1T
12$$ 102 103 107
13$$ 5R1 4R2 4R3 15R4
14$$ 11477 11479 11493 11495 11480
    11260 11240 11280 11255
    11816 11001 11510 11511
    10235 10238 10239 10240 10241 10242 10816 10510
    10400 10500 10260
    210816 10001 210510 10511
15** 2.3147-2 2.15127-2 3.3841-4 7.53159-3 2.68-3
    6.212-2 1.67-2 7.4-3 8.8-4
    2.018-2 4.036-2 3.7-6 1.478-5
    1.5622-4 6.0883-3 2.001-5 3.2743-6 1.123-6 7.8098-8
    1.2697-2 1.8525-6
    4.0261-3 4.7262-5 2.011-5
    1.401-2 2.802-2 2.5669-6 1.0262-5
    2T
33## F1 4T
35** 8I0.0 1I 0.400 8I 0.4620 39I 0.7480 2.2
36$$ 9R1 2R2 9R3 40R4
39$$ 1 2 3 4
40$$ F3
49$$ 10510 210510 11510
50$$ 3R 107
51$$ 25I1 27 5T
@MSLIMIT
@BRKPT PRINT$
@FREE XCONTCOUT2
@SYM,U XCONTCOUT2
@FIN

```

TABLE A.10. NITAWL Input Used to Combine 10,000 and
15,000 MWD/MTU Fuel Assembly Pin Cell
Cross Section Libraries into One Library

```

@RUN NITAWL/100/1//,PNL299/SMS299,SHORT,60,200 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX COMB10UTA.,///1000
@BRKPT PRINT$/COMB10UTA
@PRT,S BWR2.COMB1
@ASG,AX COMB14A.,///1000
@USE 4,COMB14A.
@ASG,AX XFP103B.
@USE 2,XFP103B.
@ASG,AX XFP153B.
@USE 3,XFP153B.
@ASG,AX UPJ*NITAWLPROG.
@XQT UPJ*NITAWLPROG.
1$$ 3 0 15 15 A8 0 A11 0 E 1T
2$$ 10235 10238 10239 10240 10241 10242 10816 10510 10400
    10500 10260 210816 10001 210510 10511
    15235 15238 15239 15240 15241 15242 15816 15510 15400
    15500 15260 215816 15001 215510 15511
4** 8R 2023 3R 550 4R 500
    8R 2023 3R 550 4R 500
5$$ 103 103 107 2T
@MSLIMIT
@BRKPT PRINT$
@FREE COMB10UTA
@SYM,U COMB10UTA.
@FIN

```

TABLE A.11. NITAWL Input Used to Combine the 10,000, 15,000,
and 20,000 MWD/MTU Fuel Assembly Pin Cell Cross
Section Libraries into One Library

```
@RUN NITAWL/100/1//,PNL299/SMS299,SHORT,60,200 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX COMB2OUTA.,///1000
@BRKPT PRINT$/COMB2OUTA
@PRT,S BWR2.COMB2
@ASG,AX COMB24A.,///1000
@USE 4,COMB24A.
@ASG,AX COMB14A.
@USE 2,COMB14A.
@ASG,AX XFP203B.
@USE 3,XFP203B.
@ASG,AX UPJ*NITAWLPROG.
@XQT UPJ*NITAWLPROG.
1$$ 3 0 30 15 A8 0 A11 0 E 1T
2$$ 10235 10238 10239 10240 10241 10242 10816 10510 10400
    10500 10260 210816 10001 210510 10511
    15235 15238 15239 15240 15241 15242 15816 15510 15400
    15500 15260 215816 15001 215510 15511
    20235 20238 20239 20240 20241 20242 20816 20510 20400
    20500 20260 220816 20001 220510 20511
4** 8R 2023 3R 550 4R 500
    8R 2023 3R 550 4R 500
    8R 2023 3R 550 4R 500
5$$ 102 103 107 2T
@MSLIMIT
@BRKPT PRINT$
@FREE COMB2OUTA
@SYM,U COMB2OUTA.
@FIN
```

TABLE A.12. NITAWL Input Used to Combine the Pin Cell and Control Cell Cross Sections into One Master Cross Section Library

```

@RUN NITAWL/150/1//,PNL299/SMS299,SHORT,30,500 .
@IDENT . M SCHUTZ/SIGMA3
@ASG,AX COMB3OUTAA.,///1000
@ERS COMB3OUTAA.
@BRKPT PRINT$/COMB3OUTAA
@PRT,S BWR2.COMB3
@ASG,AX COMB34AA.,///1000
@ERS COMB34AA.
@USE 4,COMB34AA.
@ASG,AX COMB24A.
@USE 2,COMB24A.
@ASG,AX XCONTC3A.
@USE 3,XCONTC3A.
@ASG,T 18.,F3///1000
@ASG,T 19.,F3///1000
@ASG,AX ANISNLIBBA.,///1000
@USE 7,ANISNLIBBA.
@ERS 7.
@ASG,AX CIL*CMLIB.
@USE 60,CIL*CMLIB.
@ASG,AX UPJ*NITAWLPROG.
@XQT UPJ*NITAWLPROG.
0$$ 60 E
1$$ 3 17 45 13 1 13 14 0 40 A11 0 E 1T
2$$ 119102 119702 703903 1276 1269 127303 116003
    1128 1199 119002 1275 1189 128702 714102
    1149 119503 119202
    10235 10238 10239 10240 10241 10242 10816 10510 10400
    10500 10260 210816 10001 210510 10511
    15235 15238 15239 15240 15241 15242 15816 15510 15400
    15500 15260 215816 15001 215510 15511
    20235 20238 20239 20240 20241 20242 20816 20510 20400
    20500 20260 220816 20001 220510 20511
    11477 11479 11493 11495 11480 11260 11240
    11280 11255 11816 11001 11510 11511
4** 17R 820
    8R 2023 3R 550 4R 500
    8R 2023 3R 550 4R 500
    8R 2023 3R 550 4R 500 13R 600
5$$ 102 103 107 2T
@MSLIMIT
@BRKPT PRINT$
@FREE COMB3OUTAA
@SYM,U COMB3OUTAA.
@FIN

```

TABLE A.13. GIP Input for the Babcock and Wilcox Reactor Model

Babcock and Wilcox PWR Reactor Material Mixing Table

1\$\$ 27 13 14 40 517 309 0 482 0 3 2 2 0 A15 10 E

T

10\$\$ 310 311 312 313 3Q4 314 315 316 317 3Q4 318 319 320 321 3Q4
 322 323 324 325 4Q4 326 327 328 329 3Q4 330 331 332 333 7Q4
 334 335 336 337 7Q4 338 339 340 341 7Q4 342 343 344 345 1Q4
 346 347 348 349 1Q4 350 351 352 353 1Q4 354 355 356 357 1Q4
 358 359 360 361 2Q4 362 363 364 365 3Q4 366 367 368 369 1Q4
 370 371 372 373 2Q4 374 375 376 377 2Q4 378 379 380 381 2Q4
 382 383 384 385 2Q4 386 387 388 389 2Q4 390 391 392 393 2Q4
 394 395 396 397 4Q4 398 399 400 401 4Q4 402 403 404 405 3Q4
 406 407 408 409 3Q4 410 411 412 413 3Q4 414 415 416 417 3Q4
 418 419 420 421 3Q4 422 423 424 425 2Q4 426 427 428 429 2Q4
 51I 430 482

11\$\$

' Zircalloy (310 311 312 313)
 2I 18 21 2I 42 45 2I 58 61 2I 66 69

' Stainless Steel (314 315 316 317)
 6I 66 73 6I 58 65

' Inconel (318 319 320 321)
 2I 66 69 6I 58 65 2I 38 41

' Control Rod Alloy (322 323 324 325)
 6I 270 277 2I 266 269 6I 286 293

' H2O at 1 gm/cc with 550 ppm B (326)
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' 20000 MWD/MTU fuel with Zr clad (330)
 2I 198 201 6I 214 221 10I 246 257
 2I 222 225 2I 234 237

' 15000 MWD/MTU fuel with Zr clad (334)
 2I 138 141 6I 154 161 10I 186 197
 2I 162 165 2I 174 177

' 10000 MWD/MTU fuel with Zr clad (338)
 2I 78 81 6I 94 101 10I 126 137
 2I 102 105 2I 114 117

' Region 1 INSTRUMENTS AND GUIDE TUBES (342)
 314 315 316 317 326 327 328 329

' Region 2 GRID ASSEMBLY (346)
 314 315 316 317 326 327 328 329

' Region 3 L. SUPPORT POSTS (350)
 314 315 316 317 326 327 328 329

' Region 4 TIE PLATE (354)
 314 315 316 317 326 327 328 329

' Region 5 TIE PLATE (358)
 310 311 312 313 314 315 316 317 326 327 328 329

' Region 6 PLENUM + GRID (362)
 10I 310 321 326 327 328 329

' Region 7 SPACER (366)
 310 311 312 313 326 327 328 329

TABLE A.13. (contd)

```

' Region 8      L. 10000 FUEL      (370)
310 311 312 313 338 339 340 341 326 327 328 329
' Region 9      L. 15000 FUEL      (374)
310 311 312 313 334 335 336 337 326 327 328 329
' Region 10, 12, 14, 16      L. 20000 FUEL      (378)
310 311 312 313 330 331 332 333 326 327 328 329
' Region 11, 13, AND 15 L. 20000 FUEL + GRID      (382)
310 311 312 313 330 331 332 333 326 327 328 329
' Region 17, 19, 21, AND 23 U. 20000 FUEL      (386)
310 311 312 313 330 331 332 333 326 327 328 329
' Region 18, 20, AND 22 U. 20000 FUEL + GRID      (390)
310 311 312 313 330 331 332 333 326 327 328 329
' Region 24      U. 15000 FUEL      (394)
310 311 312 313 314 315 316 317 322 323 324 325 334 335 336 337
326 327 328 329
' Region 25      U. 10000 FUEL      (398)
310 311 312 313 314 315 316 317 322 323 324 325 338 339 340 341
326 327 328 329
' REGION 26      SPACER      (402)
310 311 312 313 314 315 316 317 322 323 324 325 326 327 328 329
' Region 27      PLENUM      (406)
310 311 312 313 314 315 316 317 322 323 324 325 326 327 328 329
' Region 28      END PLUG + GRID      (410)
310 311 312 313 314 315 316 317 322 323 324 325 326 327 328 329
' Region 29      TIE PLATE      (414)
310 311 312 313 314 315 316 317 322 323 324 325 326 327 328 329
' Region 30      SPRING ASSEMBLY      (418)
314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329
' Region 31      HOLD DOWN PLATE      (422)
314 315 316 317 322 323 324 325 326 327 328 329
' Region 32      CONTROL ROD + GUIDE TUBES      (426)
314 315 316 317 322 323 324 325 326 327 328 329
' nine activity cross sections sets
1 2 3 4 5 6 7 8 9
' Activity cross sections from NITAWL/XSDRN
2I 50 53 2I 26 29 2I 34 37 2I 74 77 2I 38 41
2I 22 25 2I 30 33 2I 62 65 2I 58 61 2I 18 21 2I 54 57
12**
' ZIRCALLOY      1
4R 0.04216 4R 4.660-4 4R 1.472-4 4R 7.53-5
' STAINLESS STEEL      5
4R 0.01765 4R 8.79-4 4R 0.06141 4R 7.406-3
' INCONEL      9
4R 0.01490 4R 6.27-3 4R 0.06319 4R 5.38-4
' CONTROL ROD ALLOY      13
4R 2.315-2 4R 2.151-2 4R 2.68-3 4R 3.384-4 4R 7.532-4
' H2O COOLANT 1 g/cc , 550 ppm B      17
4R 0.06692 4R 6.129-6 4R 2.45-5 4R 0.03346

```


TABLE A.13. (contd)

' 20000 MWD/MTU FUEL + CLAD	29			
4R 1.379-2	4R 1.074-4	4R 6.554-3	4R 3.051-5	
4R 9.421-6	4R 4.532-6	4R 8.566-7	4R 2.041-6	
' 15000 MWD/MTU FUEL + CLAD	25			
4R 1.379-2	4R 1.313-4	4R 6.579-3	4R 2.741-5	
4R 6.652-6	4R 2.985-6	4R 3.854-7	4R 2.058-6	
' 10000 MWD/MTU FUEL + CLAD	21			
4R 1.379-2	4R 1.592-4	4R 6.601-3	4R 2.252-5	
4R 3.902-6	4R 1.438-6	4R 1.1004-7	4R 2.043-6	
' REGION 1	33			
4R 0.05	4R 0.7084			
' REGION 2	37			
4R 0.55	4R 0.3356			
' REGION 3	41			
4R 0.25	4R 0.5593			
' REGION 4	45			
4R 0.3652	4R 0.4734			
' REGION 5	49			
4R 0.0064	4R 0.2927	4R 0.5227		
' REGION 6	53			
4R 0.1064	4R 0.0585	4R 0.036	4R 0.4081	
' REGION 7	57			
4R 0.2513	4R 0.4350			
' REGION 8	61			
4R 0.1013	4R 1.0000	4R 0.4346		
' REGION 9	65			
4R 0.1013	4R 1.0000	4R 0.4336		
' REGION 10, 12, 14, 16			69	
4R 0.1013	4R 1.0000	4R 0.4260		
' REGION 11, 13, 15			73	
4R 0.1674	4R 1.0000	4R 0.3777		
' REGION 17, 19, 21, 23			77	
4R 0.1013	4R 1.0000	4R 0.4108		
' REGION 18, 20, 22			81	
4R 0.1674	4R 1.0000	4R 0.3642		
' REGION 24	85			
4R 0.1013	4R 0.0003	4R 0.0011	4R 1.0000	4R 0.4004
' REGION 25	89			
4R 0.1013	4R 0.0003	4R 0.0011	4R 1.0000	4R 0.399
' REGION 26	93			
4R 0.2513	4R 0.0003	4R 0.0011	4R 0.3985	
' REGION 27	97			
4R 0.1013	4R 0.0623	4R 0.0011	4R 0.3862	
' REGION 28	101			
4R 0.0464	4R 0.0203	4R 0.0087	4R 0.5922	
' REGION 29	105			
4R 0.0064	4R 0.4078	4R 0.0087	4R 0.3953	
' REGION 30	109			
4R 0.0690	4R 0.0904	4R 0.0087	4R 0.5698	

TABLE A.13. (contd)

```

' REGION 31      113
4R 0.2683 4R 0.0087 4R 0.4952
' REGION 32      117
4R 0.06 4R 0.0087 4R 0.6379
' nine activity cross section sets
' 121- flux 122- C135 123- Ni58 124- Ni62 125- Ni60 126- Fe58
' 127- Fe59 128- Zr92 129- Mo92
9R 1.000
' Activity Cross Sections from NITAWL/XSDRN
' 130- B10 134- W182 138- Co59 142- N14 146- Nb93 150- Ca40
' 154- Cl 158- Ni 162- Fe 166- Zr 170- Mo
44R 1.00
T
14**
' FLUX ACTIVITY (1)
1080R 1.0
' CL-35 N-GAMMA ACTIVITY (2) ORIGEN2 ONE GROUP ACTIV.
1080R 3.897+00
' NI-58 N-GAMMA ACTIVITY (3) ORIGEN2 ONE GROUP ACTIV.
1080R 4.866-01
' NI-62 N-GAMMA ACTIVITY (4) ORIGEN2 ONE GROUP ACTIV.
1080R 1.316+00
' NI-60 N-P ACTIVITY (5) BNWL-1312 620-GROUP
40R 0.10878+00 40R 0.17071-01 40R 0.26019-02
960R 0.0
' FE-58 N-GAMMA ACTIVITY (6) BNWL-1312 620-GROUP
40R 0.24311-03 40R 0.87688-03 40R 0.16276-02
40R 0.22508-02 40R 0.37257-02 40R 0.54921-02
40R 0.45653-02 40R 0.56497-02 40R 0.14807-01
40R 0.22390-01 40R 0.85206+00 40R 0.23030-01
40R 0.44721-01 40R 0.77306-01 40R 0.12481+00
40R 0.15247+00 40R 0.17089+00 40R 0.18385+00
40R 0.20242+00 40R 0.25346+00 40R 0.31628+00
40R 0.36517+00 40R 0.49967+00 40R 0.72717+00
40R 0.96065+00 40R 0.14346+01 40R 0.34498+01
' FE-59 N-GAMMA ACTIVITY (7) NO INFORMATION
1080R 0.0
' ZR-92 N-GAMMA ACTIVITY (8) ORIGEN2 ONE GROUP ACTIV.
1080R 5.433-02
' MO-92 N-GAMMA ACTIVITY (9) ORIGEN2 ONE GROUP ACTIV.
1080R 1.643-02
T

```

TABLE A.14. GIP Input for the Combustion Engineering Reactor Model

```

Combustion Eng. PWR Reactor Material Mixing Table
1$$ 27 13 14 40 685    309 0 514 0 3    2 2 0 A15 10 E
T
10$$ 310 311 312 313 3Q4    314 315 316 317 3Q4    318 319 320 321 4Q4
      322 323 324 325 4Q4    326 327 328 329 3Q4    330 331 332 333 9Q4
      334 335 336 337 9Q4    338 339 340 341 9Q4    342 343 344 345 1Q4
      346 347 348 349 1Q4    350 351 352 353 1Q4    354 355 356 357 2Q4
      358 359 360 361 2Q4    362 363 364 365 3Q4    366 367 368 369 2Q4
      370 371 372 373 2Q4    374 375 376 377 2Q4    378 379 380 381 2Q4
      382 383 384 385 2Q4    386 387 388 389 2Q4    390 391 392 393 2Q4
      394 395 396 397 2Q4    398 399 400 401 2Q4    402 403 404 405 1Q4
      406 407 408 409 2Q4    410 411 412 413 3Q4    414 415 416 417 4Q4
      418 419 420 421 4Q4    422 423 424 425 3Q4    426 427 428 429 3Q4
      430 431 432 433 3Q4    434 435 436 437 3Q4    438 439 440 441 2Q4
      442 443 444 445 4Q4    446 447 448 449 4Q4    450 451 452 453 4Q4
      454 455 456 457 4Q4    458 459 460 461 4Q4
      51I 462 514
11$$
' Zircalloy (310 311 312 313)
  2I 18 21    2I 42 45    2I 58 61    2I 66 69
' Stainless Steel (314 315 316 317)
  6I 66 73    6I 58 65
' Inconel (318 319 320 321)
  2I 66 69    6I 58 65    2I 54 57    2I 38 41
' Control Rod Alloy (322 323 324 325)
  6I 270 277    2I 266 269    6I 282 289
' H2O at 1 gm/cc with 550 ppm B (326)
  2I 14 17    2I 50 53    2I 46 49    2I 10 13
' 25000 MWD/MTU fuel with Zr clad and B4C (330)
  2I 310 313    2I 234 237    2I 230 233    2I 198 201
  6I 214 221    10I 246 257    2I 222 225
' 20000 MWD/MTU fuel with Zr clad and B4C (334)
  2I 310 313    2I 234 237    2I 230 233    2I 198 201
  6I 214 221    10I 246 257    2I 222 225
' 10000 MWD/MTU fuel with Zr clad and B4C (338)
  2I 310 313    2I 114 117    2I 110 113    2I 78 81
  6I 94 101    10I 126 137    2I 102 105
' Region 1 AND 3 L. SUPPORT POSTS (342)
  314 315 316 317    326 327 328 329
' Region 2 AND 4 L. CORE SUPPORT PLATES (346)
  314 315 316 317    326 327 328 329
' Region 5 L. FITTINGS (350)
  314 315 316 317    326 327 328 329
' Region 6 L. FLOW PLATE (354)
  310 311 312 313    314 315 316 317    326 327 328 329
' Region 7 L. END PLUG (358)
  310 311 312 313    318 319 320 321    326 327 328 329
' Region 8 L. 10000 FUEL + GRID (362)
  310 311 312 313    318 319 320 321    338 339 340 341    326 327 328 329

```

TABLE A.14. (contd)

'	Region 9 AND 11	L. 20000 FUEL	(366)						
310	311	312	313	334	335	336	337	326	327 328 329
'	Region 10	L. 20000 FUEL + GRID	(370)						
310	311	312	313	334	335	336	337	326	327 328 329
'	Region 12, 14, 16, 18, AND 20	L. 25000 FUEL	(374)						
310	311	312	313	330	331	332	333	326	327 328 329
'	Region 13, 15, 17, AND 19	L. 25000 FUEL + GRID	(378)						
310	311	312	313	330	331	332	333	326	327 328 329
'	Region 21, 23, 25, 27, AND 29	U. 25000 FUEL	(382)						
310	311	312	313	330	331	332	333	326	327 328 329
'	Region 22, 24, 26, AND 28	U. 25000 FUEL + GRID	(386)						
310	311	312	313	330	331	332	333	326	327 328 329
'	Region 30 AND 32	U. 20000 FUEL	(390)						
310	311	312	313	334	335	336	337	326	327 328 329
'	Region 31	U. 20000 FUEL + GRID	(394)						
310	311	312	313	334	335	336	337	326	327 328 329
'	Region 33	U. 10000 FUEL	(398)						
310	311	312	313	338	339	340	341	326	327 328 329
'	Region 34	SPACER	(402)						
310	311	312	313	326	327	328	329		
'	Region 35	PLENUM	(406)						
310	311	312	313	314	315	316	317	326	327 328 329
'	Region 36	CONTROL TIPS	(410)						
310	311	312	313	314	315	316	317	318 319	320 321 326 327 328 329
'	Region 37 AND 39	PLENUM + CONTROL	(414)						
310	311	312	313	314	315	316	317	318 319	320 321 322 323 324 325
326	327	328	329						
'	Region 38	U. GRID	(418)						
310	311	312	313	314	315	316	317	318 319	320 321 322 323 324 325
326	327	328	329						
'	Region 40	U. END PLUG	(422)						
310	311	312	313	318	319	320	321	322 323	324 325 326 327 328 329
'	Region 41	U. GUIDE TUBES	(426)						
310	311	312	313	318	319	320	321	322 323	324 325 326 327 328 329
'	Region 42	U. FLOW PLATE	(430)						
314	315	316	317	318	319	320	321	322 323	324 325 326 327 328 329
'	Region 43	U. FITTINGS	(434)						
314	315	316	317	318	319	320	321	322 323	324 325 326 327 328 329
'	Region 44	SPACERS	(438)						
314	315	316	317	318	319	320	321	326 327	328 329
'	Region 45	U. FITTINGS	(442)						
314	315	316	317	318	319	320	321	2I 290 293	2I 278 281
326	327	328	329						
'	Region 46	U. HOLD DOWN PLATE	(446)						
314	315	316	317	318	319	320	321	2I 290 293	2I 278 281
326	327	328	329						
'	Region 47	REACTOR HOLD DOWN PLATE	(450)						
314	315	316	317	318	319	320	321	2I 290 293	2I 278 281
326	327	328	329						

TABLE A.14. (contd)

' Region 48	ASSY. GUIDE TUBES	(454)			
314 315 316 317	318 319 320 321	2I 290 293	2I 278 281		
326 327 328 329					
' Region 49	ASSY. GUIDE TUBES	(458)			
314 315 316 317	318 319 320 321	2I 290 293	2I 278 281		
326 327 328 329					
' nine activity cross sections sets					
1 2 3 4 5 6 7 8 9					
' Activity cross sections from NITAWL/XSDRN					
2I 50 53	2I 26 29	2I 34 37	2I 74 77	2I 38 41	
2I 22 25	2I 30 33	2I 62 65	2I 58 61	2I 18 21	2I 54 57
12**					
' ZIRCALLOY	1				
4R 0.04216	4R 4.660-4	4R 1.472-4	4R 7.53-5		
' STAINLESS STEEL	5				
4R 0.01765	4R 8.79-4	4R 0.06141	4R 7.406-3		
' INCONEL	9				
4R 0.02067	4R 2.238-3	4R 0.05395	4R 4.69-3	4R 1.964-3	
' CONTROL ROD ALLOY	13				
4R 2.2880-2	4R 2.1260-2	4R 2.68-3	4R 3.3841-4	4R 7.53159-4	
' H2O COOLANT 1 g/cc , 550 ppm B	17				
4R 0.06692	4R 6.129-6	4R 2.45-5	4R 0.03346		
' 25000 MWD/MTU FUEL + CLAD + B4C	29				
4R 0.0988	4R 1.973-6	4R 0.0	4R 1.296-2	4R 1.125-4	4R 6.124-3
4R 2.943-5	4R 9.969-6	4R 4.657-6	4R 9.750-7		
' 20000 MWD/MTU FUEL + CLAD + B4C	25				
4R 0.0988	4R 1.984-6	4R 0.0	4R 1.296-2	4R 1.362-4	4R 6.145-3
4R 2.74-5	4R 7.662-6	4R 3.302-6	4R 5.197-7		
' 10000 MWD/MTU FUEL + CLAD + B4C	21				
4R 0.0988	4R 1.992-6	4R 0.0	4R 1.296-2	4R 1.923-4	4R 6.184-3
4R 1.926-5	4R 2.934-6	4R 9.2999-7	4R 5.917-8		
' REGION 1 AND 2	33				
4R 0.10	4R 0.6679				
' REGION 2 AND 3	37				
4R 0.55	4R 0.3339				
' REGION 5	41				
4R 0.12	4R 0.6530				
' REGION 6	45				
4R 0.0094	4R 0.5571	4R 0.3217			
' REGION 7	49				
4R 0.1108	4R 0.0274	4R 0.4662			
' REGION 8	53				
4R 0.0094	4R 0.042	4R 1.0	4R 0.4041		
' REGION 9 AND 11	57				
4R 0.0094	4R 1.0	4R 0.4339			
' REGION 10	61				
4R 0.0514	4R 1.0	4R 0.4028			
' REGION 12, 14, 16, 18, AND 20	65				
4R 0.0094	4R 1.0	4R 0.4241			

TABLE A.14. (contd)

' REGION 13, 15, 17, AND 19	69			
4R 0.0514 4R 1.0 4R 0.3937				
' REGION 21, 23, 25, 27, AND 29	73			
4R 0.0094 4R 1.0 4R 0.4050				
' REGION 22, 24, 26, AND 28	77			
4R 0.0514 4R 1.0 4R 0.3760				
' REGION 30 AND 32	81			
4R 0.0094 4R 1.0 4R 0.3923				
' REGION 31 85				
4R 0.0514 4R 1.0 4R 0.3642				
' REGION 33 89				
4R 0.0094 4R 1.0 4R 0.3898				
' REGION 34 93				
4R 0.1082 4R 0.3900				
' REGION 35 97				
4R 0.1082 4R 0.1255 4R 0.3900				
' REGION 36 101				
4R 0.1082 4R 0.1255 4R 0.0121 4R 0.3809				
' REGION 37 AND 39 105				
4R 0.1082 4R 0.1255 4R 0.0038 4R 0.0121 4R 0.3793				
' REGION 38 109				
4R 0.1502 4R 0.1255 4R 0.0038 4R 0.0121 4R 0.3513				
' REGION 40 113				
4R 0.2894 4R 0.0038 4R 0.0121 4R 0.4616				
' REGION 41 117				
4R 0.0094 4R 0.0038 4R 0.0121 4R 0.6478				
' REGION 42 121				
4R 0.5414 4R 0.0038 4R 0.0121 4R 0.2941				
' REGION 43 125				
4R 0.0816 4R 0.0874 4R 0.0121 4R 0.5442				
' REGION 44 129				
4R 0.0816 4R 0.0995 4R 0.5442				
' REGION 45 133				
4R 0.0816 4R 0.0874 4R 0.0 4R 0.0 4R 0.5442				
' REGION 46 137				
4R 0.3443 4R 0.0038 4R 0.0 4R 0.0 4R 0.4251				
' REGION 47 141				
4R 0.4816 4R 0.0038 4R 0.0 4R 0.0 4R 0.3339				
' REGION 48 145				
4R 0.06 4R 0.0038 4R 0.0 4R 0.0 4R 0.6141				
' REGION 49 149				
4R 0.06 4R 0.0027 4R 0.0 4R 0.0 4R 0.6143				
' nine activity cross section sets				
' 153- flux 154- Cl35 155- Ni58 156- Ni62 157- Ni60 158- Fe58				
' 159- Fe59 160- Zr92 161- Mo92				
9R 1.000				
' Activity Cross Sections from NITAWL/XSDRN				
' 162- B10 166- W182 170- Co59 174- N14 178- Nb93 182- Ca40				

TABLE A.14. (contd)

186- Cl	190- Ni	194- Fe	198- Zr	202- Mo
44R 1.00				
T				
14**				
FLUX ACTIVITY (1)				
1080R 1.0				
CL-35 N-GAMMA ACTIVITY (2) ORIGEN2 ONE GROUP ACTIV.				
1080R 3.897+00				
NI-58 N-GAMMA ACTIVITY (3) ORIGEN2 ONE GROUP ACTIV.				
1080R 4.866-01				
NI-62 N-GAMMA ACTIVITY (4) ORIGEN2 ONE GROUP ACTIV.				
1080R 1.316+00				
NI-60 N-P ACTIVITY (5) BNWL-1312 620-GROUP				
40R 0.10878+00	40R 0.17071-01		40R 0.26019-02	
960R 0.0				
FE-58 N-GAMMA ACTIVITY (6) BNWL-1312 620-GROUP				
40R 0.24311-03	40R 0.87688-03		40R 0.16276-02	
40R 0.22508-02	40R 0.37257-02		40R 0.54921-02	
40R 0.45653-02	40R 0.56497-02		40R 0.14807-01	
40R 0.22390-01	40R 0.85206+00		40R 0.23030-01	
40R 0.44721-01	40R 0.77306-01		40R 0.12481+00	
40R 0.15247+00	40R 0.17089+00		40R 0.18385+00	
40R 0.20242+00	40R 0.25346+00		40R 0.31628+00	
40R 0.36517+00	40R 0.49967+00		40R 0.72717+00	
40R 0.96065+00	40R 0.14346+01		40R 0.34498+01	
FE-59 N-GAMMA ACTIVITY (7) NO INFORMATION				
1080R 0.0				
ZR-92 N-GAMMA ACTIVITY (8) ORIGEN2 ONE GROUP ACTIV.				
1080R 5.433-02				
MO-92 N-GAMMA ACTIVITY (9) ORIGEN2 ONE GROUP ACTIV.				
1080R 1.643-02				
T				

TABLE A.15. GIP Input for the Westinghouse Reactor Model

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Westinghouse PWR Reactor Material Mixing Table (improved)
1$$ 27 13 14 40 1169 309 0 494 0 3 2 2 0 A15 10 E
T
10$$ 310 311 312 313 2Q4 314 315 316 317 3Q4 318 319 320 321 4Q4
      322 323 324 325 4Q4 326 327 328 329 14Q4 330 331 332 333 14Q4
      334 335 336 337 14Q4 338 339 340 341 16Q4 342 343 344 345 6Q4
      346 347 348 349 7Q4 350 351 352 353 6Q4 354 355 356 357 6Q4
      358 359 360 361 6Q4 362 363 364 365 6Q4 366 367 368 369 5Q4
      370 371 372 373 6Q4 374 375 376 377 6Q4 378 379 380 381 6Q4
      382 383 384 385 5Q4 386 387 388 389 5Q4 390 391 392 393 14Q4
      394 395 396 397 14Q4 398 399 400 401 16Q4 402 403 404 405 14Q4
      406 407 408 409 4Q4 410 411 412 413 4Q4 414 415 416 417 5Q4
      418 419 420 421 4Q4 422 423 424 425 4Q4 426 427 428 429 4Q4
      430 431 432 433 4Q4 434 435 436 437 4Q4 438 439 440 441 14Q4
      51I 442 494
11$$
' Zircalloy (310 311 312 313)
  2I 18 21 2I 42 45 2I 58 61
' Stainless Steel (314 315 316 317)
  6I 66 73 6I 58 65
' Inconel (318 319 320 321)
  2I 66 69 6I 58 65 2I 54 57 2I 38 41
' Control Rod Alloy (322 323 324 325)
  6I 270 277 2I 266 269 6I 282 289
' Regions 13,15,17,19,20,22,24 20000 MWD/MTU fuel (326)
  2I 206 209 2I 238 241 2I 230 233 2I 202 205
  2I 242 245 2I 210 213 2I 226 229 6I 214 221
10I 246 257 2I 222 225 2I 198 201 2I 234 237
' Region 26 15000 MWD/MTU fuel (330)
  2I 146 149 2I 178 181 2I 170 173 2I 142 145
  2I 182 185 2I 150 153 2I 166 169 6I 154 161
10I 186 197 2I 162 165 2I 138 141 2I 174 177
' Region 27 10000 MWD/MTU fuel (334)
  2I 86 89 2I 118 121 2I 110 113 2I 82 85
  2I 122 125 2I 90 93 2I 106 109 6I 94 101
10I 126 137 2I 102 105 2I 78 81 2I 114 117
' Region 28 Control Rod Bite in 10000 MWD/MTU fuel (338)
  2I 86 89 2I 118 121 2I 110 113 2I 82 85
  2I 122 125 2I 90 93 2I 106 109 6I 94 101
10I 126 137 2I 102 105 2I 78 81 2I 114 117
      314 315 316 317 322 323 324 325
' Region 29 Plenum (342)
  310 311 312 313 322 323 324 325 314 315 316 317
  2I 14 17 2I 50 53 2I 46 49 2I 10 13
' Region 30 Inconel Grid (346)
  310 311 312 313 322 323 324 325 314 315 316 317 318 319 320 321
  2I 14 17 2I 50 53 2I 46 49 2I 10 13

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TABLE A.15. (contd)

Region 31 Upper Plenum (350)												
310	311	312	313	322	323	324	325	314	315	316	317	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 32 End Plug (354)												
310	311	312	313	322	323	324	325	314	315	316	317	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 33 Guide Tubes (358)												
310	311	312	313	322	323	324	325	314	315	316	317	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 34 Nozzle Plate (362)												
310	311	312	313	322	323	324	325	314	315	316	317	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 35 Spider Assembly (366)												
314	315	316	317	322	323	324	325					
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 36 Nozzle Side (370)												
314	315	316	317	318	319	320	321	322	323	324	325	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 37 Nozzle Top (374)												
314	315	316	317	318	319	320	321	322	323	324	325	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 38 Hold Down Spring (378)												
314	315	316	317	318	319	320	321	322	323	324	325	
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 39 Hold Down Plug (382)												
314	315	316	317	322	323	324	325					
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 40 Guide Tubes (386)												
314	315	316	317	322	323	324	325					
2I	14	17	2I	50	53	2I	46	49	2I	10	13	
Region 12 15000 MWD/MTU fuel (390)												
2I	146	149	2I	178	181	2I	170	173	2I	142	145	
2I	182	185	2I	150	153	2I	166	169	6I	154	161	
10I	186	197	2I	162	165	2I	138	141	2I	174	177	
Region 11 10000 MWD/MTU fuel (394)												
2I	86	89	2I	118	121	2I	110	113	2I	82	85	
2I	122	125	2I	90	93	2I	106	109	6I	94	101	
10I	126	137	2I	102	105	2I	78	81	2I	114	117	
Region 10 Inconel grid and fuel (398)												
2I	86	89	2I	118	121	2I	110	113	2I	82	85	
2I	122	125	2I	90	93	2I	106	109	6I	94	101	
10I	126	137	2I	102	105	2I	78	81	2I	114	117	
314	315	316	317	318	319	320	321					
Region 9 10000mwd/mtu fuel (402)												
2I	86	89	2I	118	121	2I	110	113	2I	82	85	
2I	122	125	2I	90	93	2I	106	109	6I	94	101	
10I	126	137	2I	102	105	2I	78	81	2I	114	117	

TABLE A.15. (contd)

' Region 8 End Plug (406)
 310 311 312 313
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 7 Guide Tubes (410)
 310 311 312 313
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 6 Nozzle Plate (414)
 310 311 312 313 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 5 Nozzle Legs (418)
 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 4 Support Plate (422)
 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 3 Support Posts (426)
 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 2 Lower Core Support (430)
 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Region 1 Support Posts (434)
 314 315 316 317
 2I 14 17 2I 50 53 2I 46 49 2I 10 13

' Regions 14,16,18,21,23,25 20000 MWD/MTU fuel & grid (438)
 2I 206 209 2I 238 241 2I 230 233 2I 202 205
 2I 242 245 2I 210 213 2I 226 229 6I 214 221
 10I 246 257 2I 222 225 2I 198 201 2I 234 237

' nine activity cross sections sets
 1 2 3 4 5 6 7 8 9

' Activity cross sections from NITAWL/XSDRN
 2I 50 53 2I 26 29 2I 34 37 2I 74 77 2I 38 41
 2I 22 25 2I 30 33 2I 62 65 2I 58 61 2I 18 21 2I 54 57

12**

' ZIRCALLOY 1
 4R 0.04223 4R 4.961-4 4R 2.112-4

' STAINLESS STEEL 5
 4R 0.0167 4R 8.8-4 4R 0.06212 4R 7.400-3

' INCONEL 9
 4R 0.01816 4R 0.01824 4R 0.04444 4R 1.55-3 4R 2.67-3

' CONTROL ROD ALLOY 13
 4R 2.3147-2 4R 2.15127-2 4R 2.68-3 4R 3.3841-4 4R 7.53159-4

' REGIONS 13,15,17,19,20,22,24 17
 4R 2.966-2 4R 2.714-6 4R 1.085-5 4R 1.482-2 4R 2.017-5 4R 4.033-3
 4R 4.738-5 4R 1.053-4 4R 6.050-3 4R 2.775-5 4R 8.235-6 4R 3.775-6
 4R 6.527-7 4R 1.270-2 4R 1.851-6

TABLE A.15. (contd)

' REGION 26	21					
4R 2.814-2	4R 2.574-6	4R 1.030-5	4R 1.406-2	4R 2.017-5	4R 4.033-3	
4R 4.738-5	4R 1.292-4	4R 6.070-3	4R 2.470-5	4R 5.714-6	4R 2.417-6	
4R 2.844-7	4R 1.270-2	4R 1.866-6				
' REGION 27	25					
4R 2.803-2	4R 2.564-6	4R 1.026-5	4R 1.401-2	4R 2.017-5	4R 4.033-3	
4R 4.738-5	4R 1.563-4	4R 6.090-3	4R 2.001-5	4R 3.275-6	4R 1.123-6	
4R 7.81-8	4R 1.270-2	4R 1.853-6				
' REGION 28	29					
4R 2.749-2	4R 2.483-6	4R 1.006-5	4R 1.356-2	4R 2.017-5	4R 4.033-3	
4R 4.738-5	4R 1.563-4	4R 6.090-3	4R 2.001-5	4R 3.275-6	4R 1.123-6	
4R 7.81-8	4R 1.270-2	4R 1.853-6	4R 0.0019	4R 0.0085		
' REGION 29	33					
4R 0.0955	4R 0.0085	4R 0.0774	4R 2.580-2	4R 2.36-6	4R 9.45-6	
4R 1.290-2						
' REGION 30	37					
4R 0.0955	4R 0.0085	4R 0.0834	4R 0.057	4R 2.295-2	4R 2.10-6	
4R 8.40-6	4R 1.148-2					
' REGION 31	41					
4R 0.0955	4R 0.0085	4R 0.0774	4R 2.580-2	4R 2.36-6	4R 9.45-6	
4R 1.290-2						
' REGION 32	45					
4R 0.3815	4R 0.0085	4R 0.0304	4R 2.580-2	4R 2.36-6	4R 9.45-6	
4R 1.290-2						
' REGION 33	49					
4R 0.008	4R 0.0085	4R 0.0304	4R 4.304-2	4R 3.94-6	4R 1.576-5	
4R 2.152-2						
' REGION 34	53					
4R 0.008	4R 0.0085	4R 0.5904	4R 1.771-2	4R 1.62-6	4R 6.48-6	
4R 8.855-3						
' REGION 35	57					
4R 0.1766	4R 0.0085	4R 3.680-2	4R 3.37-6	4R 1.347-5	4R 1.840-2	
' REGION 36	61					
4R 0.1481	4R 0.0094	4R 0.0085	4R 3.766-2	4R 3.45-6	4R 1.379-5	
4R 1.883-2						
' REGION 37	65					
4R 0.1481	4R 0.0742	4R 0.0085	4R 3.473-2	4R 3.18-6	4R 1.271-5	
4R 1.736-2						
' REGION 38	69					
4R 0.0481	4R 0.0742	4R 0.0085	4R 3.925-2	4R 3.60-6	4R 1.437-5	
4R 1.963-2						
' REGION 39	73					
4R 0.400	4R 0.0085	4R 2.669-2	4R 2.445-6	4R 9.77-6	4R 1.334-2	
' REGION 40	77					
4R 0.060	4R 0.0085	4R 4.207-2	4R 3.854-6	4R 1.540-5	4R 2.103-2	
' REGION 12	81					
4R 3.094-2	4R 2.831-6	4R 1.132-5	4R 1.546-2	4R 2.017-5	4R 4.033-3	
4R 4.738-5	4R 1.292-4	4R 6.070-3	4R 2.470-5	4R 5.714-6	4R 2.417-6	
4R 2.844-7	4R 1.270-2	4R 1.866-6				

TABLE A.15. (contd)

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' REGION 11      85
4R 3.102-2 4R 2.838-6 4R 1.136-5 4R 1.550-2 4R 2.017-5 4R 4.033-3
4R 4.738-5 4R 1.563-4 4R 6.090-3 4R 2.001-5 4R 3.275-6 4R 1.123-6
4R 7.81-8 4R 1.270-2 4R 1.853-6
' REGION 10      89
4R 2.771-2 4R 2.536-6 4R 1.014-5 4R 1.385-2 4R 2.017-5 4R 4.033-3
4R 4.738-5 4R 1.563-4 4R 6.090-3 4R 2.001-5 4R 3.275-6 4R 1.123-6
4R 7.81-8 4R 1.270-2 4R 1.853-6 4R 0.006 4R 0.06
' REGION 9       93
4R 3.102-2 4R 9.838-6 4R 1.136-5 4R 1.550-2 4R 2.017-5 4R 4.033-3
4R 4.738-5 4R 1.563-4 4R 6.090-3 4R 2.001-5 4R 3.275-6 4R 1.123-6
4R 7.81-8 4R 1.270-2 4R 1.853-6
' REGION 8       97
4R 0.3815 4R 3.104-2 4R 2.84-6 4R 1.136-5 4R 1.552-2
' REGION 7      101
4R 0.008 4R 4.979-2 4R 4.56-6 4R 1.823-5 4R 2.489-2
' REGION 6      105
4R 0.008 4R 0.550 4R 2.218-2 4R 2.03-6 4R 8.12-6 4R 1.109-2
' REGION 5      109
4R 0.1000 4R 4.517-2 4R 4.14-6 4R 1.654-5 4R 2.259-2
' REGION 4      113
4R 0.5500 4R 2.259-2 4R 2.07-6 4R 8.270-6 4R 1.129-2
' REGION 3      117
4R 0.1000 4R 4.517-2 4R 4.14-6 4R 1.654-5 4R 2.259-2
' REGION 2      121
4R 0.5000 4R 2.510-2 4R 2.30-6 4R 9.180-6 4R 1.255-2
' REGION 1      125
4R 0.1000 4R 4.517-2 4R 4.14-6 4R 1.654-5 4R 2.259-2
' REGIONS 14,16,18,21,23,25 129
4R 2.650-2 4R 2.424-6 4R 9.695-6 4R 1.324-2 4R 3.411-5 4R 6.820-3
4R 8.012-5 4R 1.053-4 4R 6.050-3 4R 2.775-5 4R 8.235-6 4R 3.775-6
4R 6.527-7 4R 1.270-2 4R 1.851-6
' nine activity cross section sets
' 133- flux 134- Cl35 135- Ni58 136- Ni62 137- Ni60 138- Fe58
' 139- Fe59 140- Zr92 141- Mo92
9R 1.000
' Activity Cross Sections from NITAWL/XSDRN
' 142- B10 146- W182 150- Co59 154- N14 158- Nb93 162- Ca40
' 166- Cl 170- Ni 174- Fe 178- Zr 182- Mo
44R 1.00
T
14**
' FLUX ACTIVITY (1)
1080R 1.0
' CL-35 N-GAMMA ACTIVITY (2) ORIGEN2 ONE GROUP ACTIV.
1080R 3.897+00
' NI-58 N-GAMMA ACTIVITY (3) ORIGEN2 ONE GROUP ACTIV.
1080R 4.866-01

```

TABLE A.15. (contd)

' NI-62 N-GAMMA ACTIVITY	(4) ORIGEN2 ONE GROUP ACTIV.
1080R 1.316+00	
' NI-60 N-P ACTIVITY	(5) BNWL-1312 620-GROUP
40R 0.10878+00	40R 0.17071-01 40R 0.26019-02
960R 0.0	
' FE-58 N-GAMMA ACTIVITY	(6) BNWL-1312 620-GROUP
40R 0.24311-03	40R 0.87688-03 40R 0.16276-02
40R 0.22508-02	40R 0.37257-02 40R 0.54921-02
40R 0.45653-02	40R 0.56497-02 40R 0.14807-01
40R 0.22390-01	40R 0.85206+00 40R 0.23030-01
40R 0.44721-01	40R 0.77306-01 40R 0.12481+00
40R 0.15247+00	40R 0.17089+00 40R 0.18385+00
40R 0.20242+00	40R 0.25346+00 40R 0.31628+00
40R 0.36517+00	40R 0.49967+00 40R 0.72717+00
40R 0.96065+00	40R 0.14346+01 40R 0.34498+01
' FE-59 N-GAMMA ACTIVITY	(7) NO INFORMATION
1080R 0.0	
' ZR-92 N-GAMMA ACTIVITY	(8) ORIGEN2 ONE GROUP ACTIV.
1080R 5.433-02	
' MO-92 N-GAMMA ACTIVITY	(9) ORIGEN2 ONE GROUP ACTIV.
1080R 1.643-02	
T	

TABLE A.16. ANISN Input for the Babcock and Wilcox Reactor Model

```

Babcock and Wilcox PWR full axial activation run
15$$$ 1 0 3 4 1 0 0 32 687 1 27 13 14 40 0 0 173 173 0 0
      0 0 0 25 2 1 21 1 40 0 0 0 0 2R 1 0
16** 0.0 0.0 0.0001 1.420892 0.0 0.0 0.0 1.0 0.0 0.5
      0.001 0.05 0.003 0.75
T
3** F1.0
T
1** 0.02279 0.19055 0.22656 0.21597 0.20186 0.14227 F0.0
4** 90I 0.0 10I 180.00 15I 210.00 6I 230.64 6I 235.72
      2I 240.80 2I 250.01 16I 251.91 21I 267.15 15I 287.47
      4I 302.20 50I 306.20 4I 355.86 50I 359.86 4I 409.44
      19I 413.44 31I 432.00 4I 463.02 50I 467.02 4I 516.60
      50I 520.60 4I 570.18 3I 574.18 21I 576.53 16I 596.85
      2I 612.09 14I 613.99 10I 627.36 5I 636.57 5I 641.65
      21I 646.73 101I 667 967
5** F1.0
6** 0.0 .1666667 .3333333 1N2
7** -.936742 -.868890 -.350021 1M2
8$$$ 91R 1 11R 2 16R 3 7R 4 7R 5 3R 6 3R 7 17R 8
      22R 9 16R 10 5R 11 51R 12 5R 13 51R 14 5R 15 20R 16
      32R 17 5R 18 51R 19 5R 20 51R 21 5R 22 4R 23 22R 24
      17R 25 3R 26 15R 27 11R 28 6R 29 6R 30 22R 31 102R 32
9$$$ 33 37 41 45 49 53 57 61 65 69 73 69 73 69 73 69 77 81 77 81
      77 81 77 85 89 93 97 101 105 109 113 117
19$$$ F3
' FLUX B-10 W-182 Co-59 N-14
22$$$ -121 -130 -134 -138 -142
' Nb-93 Ca-40 Cl (nat) Cl-35 Ni (nat,n,gam) Ni (nat,n,p)
      -146 -150 -154 -122 -158 -158
' Ni-58 Ni-62 Ni-60 Fe (nat) Fe-58
      -123 -124 -125 -162 -126
' Fe-59 Zr (nat) Zr-92 Mo (nat) Mo-92
      -127 -166 -128 -170 -129
' 1= (N,GAMMA) 2= (N,P) 3= (N,ALPHA)
23$$$ 1 3 1 1 2 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1
T
T

```

TABLE A.17. ANISN Input for the Combustion Engineering Reactor Model

```

      Combustion Eng. PWR full axial activation run (no B4C)
15$$ 1 0 3 4 1 0 0 49 865 1 27 13 14 40 0 0 205 205 0 0
      0 0 0 25 2 1 21 1 40 0 0 0 0 1 1 0
16** 0.0 0.0 0.00001 1.420892 182.88 168.0 0.0 1.0 0.0 0.5
      0.0001 0.05 0.003 0.75
      T
3** F1.0
      T
1** 0.02279 0.19055 0.22656 0.21597 0.20186 0.14227 F0.0
4** 140I 0.0 50I 150.00 50I 200.00 5I 260.00 8I 265.00
      1I 273.00 2I 274.68 6I 276.94 10I 284.56 6I 297.52
      10I 304.52 20I 315.04 6I 335.15 30I 342.15 6I 372.77
      30I 379.77 6I 410.40 30I 417.40 6I 448.02 12I 455.02
      18I 467.44 6I 485.64 30I 492.64 6I 523.26 30I 530.26
      6I 560.89 30I 567.89 6I 598.51 14I 605.51 16I 619.84
      6I 636.14 6I 643.14 6I 650.32 1I 657.94 2I 658.94
      2I 663.02 6I 665.56 6I 673.76 1I 680.76 1I 683.16
      2I 684.43 1I 688.32 6I 690.32 1I 697.31 6I 698.58
      1I 705.56 6I 707.56 130I 714.08 30I 856.06 896.70
5** F1.0
6** 0.0 .1666667 .3333333 1N2
7** -.936742 -.868890 -.350021 1M2
8$$ 141R 1 51R 2 51R 3 6R 4 9R 5 2R 6 3R 7 7R 8
      11R 9 7R 10 11R 11 21R 12 7R 13 31R 14 7R 15 31R 16
      7R 17 31R 18 7R 19 13R 20 19R 21 7R 22 31R 23 7R 24
      31R 25 7R 26 31R 27 7R 28 15R 29 17R 30 7R 31 7R 32
      7R 33 2R 34 3R 35 3R 36 7R 37 7R 38 2R 39 2R 40
      3R 41 2R 42 7R 43 2R 44 7R 45 2R 46 7R 47 131R 48
      31R 49
9$$ 33 37 33 37 41 45 49 53 57 61 57 65 69 65 69
      65 69 65 69 65 73 77 73 77 73 77 73 77 73 81
      85 81 89 93 97 101 105 109 105 113 117 121 125 129 133
      137 141 145 149
19$$ F3
      ' FLUX B-10 W-182 Co-59 N-14
22$$ -153 -162 -166 -170 -174
      ' Nb-93 Ca-40 Cl (nat) Cl-35 Ni (nat,n,gam) Ni (nat,n,p)
      -178 -182 -186 -154 -190 -190
      ' Ni-58 Ni-62 Ni-60 Fe (nat) Fe-58
      -155 -156 -157 -194 -158
      ' Fe-59 Zr (nat) Zr-92 Mo (nat) Mo-92
      -159 -198 -160 -202 -161
      ' 1= (n,gamma) 2= (n,p) 3= (n,alpha)
23$$ 1 3 1 1 2 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1 1
      T
      T

```

TABLE A.18. ANISN Input for the Westinghouse Reactor Model

```

      Westinghouse PWR full axial activation run (improved)
15$$ 1 0 3 4 1 0 0 40 827 1 27 13 14 40 185 0 185 185 0 0
      0 0 0 25 2 1 21 1 40 0 0 0 0 1 1 0
16** 0.0 0.0 0.00001 1.420892 182.88 168.0 0.0 1.0 0.0 0.5
      0.001 0.05 0.003 0.75
      T
3** F1.0
      T
1** 0.02279 0.19055 0.22656 0.21597 0.20186 0.14227 F0.0
4** 150I 0.0 50I 149.88 25I 201.32 4I 262.28 4I 267.36
      2I 272.31 2I 274.31 1I 276.60 2I 277.60 5I 279.08
      12I 283.08 20I 292.84 25I 313.16 6I 339.30 46I 346.30
      6I 391.50 46I 398.50 6I 443.70 9I 450.70 35I 460.48
      6I 495.89 46I 502.89 6I 548.09 46I 555.09 6I 600.29
      20I 607.29 12I 628.12 3I 640.82 5I 643.36
      3I 654.42 2I 658.42 2I 660.56 3I 661.56 2I 663.84
      1I 665.84 3I 667.16 3I 671.16 2I 673.16 10I 675.03
      150I 682.65 982.65
5** F1.0
6** 0.0 .1666667 .3333333 1M2
7** -.936742 -.868890 -.350021 1M2
8$$ 151R 1 51R 2 26R 3 5R 4 5R 5 3R 6 3R 7 2R 8
      3R 9 6R 10 13R 11 21R 12 26R 13 7R 14 47R 15 7R 16
      47R 17 7R 18 10R 19 36R 20 7R 21 47R 22 7R 23 47R 24
      7R 25 21R 26 13R 27 4R 28 6R 29 4R 30 3R 31 3R 32
      4R 33 3R 34 2R 35 4R 36 4R 37 3R 38 11R 39 151R 40
9$$ 125 121 117 113 109 105 101 97 93 89 85 81 17 129 17
      129 17 129 17 17 129 17 129 17 129 21 25 29 33 37
      41 45 49 53 57 61 65 69 73 77
10$$ 183I 1 185
11$$ F 0
12** F 1.0
19$$ F3
' FLUX B-10 W-182 Co-59 N-14
22$$ -133 -142 -146 -150 -154
' Nb-93 Ca-40 Cl (nat) Cl-35 Ni (nat,n,gam) Ni (nat,n,p)
      -158 -162 -166 -134 -170 -170
' Ni-58 Ni-62 Ni-60 Fe (nat) Fe-58
      -135 -136 -137 -174 -138
' Fe-59 Zr (nat) Zr-92 Mo (nat) Mo-92
      -139 -178 -140 -182 -141
' 1= (n,gamma) 2= (n,p) 3= (n,alpha)
23$$ 1 3 1 1 2 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1 1
      T
      T

```


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