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ARP: Automatic Rapid Process for the Generation of Problem-Dependent SAS2H/ORIGEN-S Cross-Section Libraries

L. C. Leal
O. W. Hermann
S. M. Bowman
C. V. Parks

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L. C. Leal
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S. M. Bowman
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Oak Ridge National Laboratory
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ABSTRACT

In this report, a methodology is described which serves as an alternative to the SAS2H path of the SCALE system to generate cross sections for point-depletion calculations with the ORIGEN-S code. ARP, Automatic Rapid Processing, is an algorithm that allows the generation of cross-section libraries suitable to the ORIGEN-S code by interpolation over pregenerated SAS2H libraries. The interpolations are carried out on the following variables: burnup, enrichment, and water density. The adequacy of the methodology is evaluated by comparing measured and computed spent fuel isotopic compositions for PWR and BWR systems.

1. INTRODUCTION

The SAS2H sequence of the SCALE code system has been used worldwide for treating problems related to the characterization of irradiated light-water-reactor (LWR) fuel for disposal, storage and shipment. The calculations, in general, consist of determining the isotopic compositions of the different materials present in the problem as a function of time, which subsequently enable the determination of the heat generation and radiation source terms. In the SAS2H scheme, time-dependent material concentrations are obtained using the ORIGEN-S code based on a point-depletion calculation that utilizes problem-dependent cross-section libraries generated by functional modules in the SAS2H sequence. This report is concerned with the methodology used in the SAS2H control module to create cross-section libraries for point-depletion calculations with the ORIGEN-S code. A description of the SAS2H scheme is given, and a capability that serves as an alternative to the SAS2H sequence, the automatic rapid processing (ARP) methodology, for generating problem-dependent ORIGEN-S cross-section libraries is discussed. The purpose of this report is to document the work that has been performed at ORNL to date to develop and validate the ARP methodology for LWR spent fuel characterization.

Utility programs developed to support the ARP methodology are documented as well. These utilities provide descriptive information of the contents of the ORIGEN-S cross-section libraries. The ORIGEN-S burnup-dependent, cross-section data can be listed with the XSECLIST utility or displayed in plots using the XSECPLOT utility. In addition, LISTBURN lists the burnups at which ORIGEN-S libraries will be created in a SAS2H calculation.

2. GENERAL DESCRIPTION

The automatic rapid processing (ARP) methodology is intended to generate problem-dependent cross-section libraries for use in point-depletion calculations with the ORIGEN-S code.[1] In the ARP concept, cross-section libraries are created by interpolating over the initial enrichment, burnup and water density for the reactor assembly under consideration. For this purpose, various cross-section libraries have to be created at specific enrichments, burnups and water densities with the SAS2H sequence of the SCALE package[2] over which the interpolations are performed. Note that the ARP methodology is part of the SCALE code system as an option for problem-dependent cross-section generation for point-depletion calculations. Prior to the description of the ARP scheme,[3] the SAS2H sequence is described briefly.

The SAS2H sequence accesses cross-section preparation codes, BONAMI-S, NITAWL-II, and XSDRNPM-S, that perform Bondarenko resonance self-shielding, Nordheim resonance self-shielding, and a one-dimensional (1-D), discrete-ordinates transport calculation, respectively, using a SCALE multigroup library for a specified fuel composition and unit-cell geometry. The problem-dependent cross sections generated in this sequence are converted by the code COUPLE[2] at each time step into a binary form suitable for the ORIGEN-S code which, in turn, performs a point-depletion calculation. The whole sequence is repeated throughout the reactor operating history, generating the number of time-dependent, cross-section libraries specified by user input.

Although in this work the current cross-section libraries for ARP were obtained using the sequence based on the codes BONAMI-S, NITAWL-II, and XSDRNPM-S, other codes can be used. The constraint is that the libraries have to be in the ORIGEN-S format produced by the COUPLE code. Thus, it is possible that future libraries could be generated using improved resonance processing methods or multidimensional transport codes that better model the effect of the fuel assembly geometry. Application of the ARP concept to other point-depletion codes is possible assuming appropriate modifications are made to ensure consistency in the library format.

The purpose of the ARP methodology is to create an alternative that saves substantial computer time for performing point-depletion calculations with the ORIGEN-S code separate from the SAS2H sequence, but conserving the rigor and accuracy of the SAS2H cross-section-generating methodology. An advantage of the method is that it can be readily implemented on a personal computer (PC) and can effectively create ORIGEN-S cross-section libraries with a great reduction of computer time over what is required in the typical SAS2H calculation. In addition, ARP has the capability to vary the number of cross-section libraries generated per cycle, whereas SAS2H generates the same number of libraries for each cycle. Updating libraries more frequently at lower burnups where cross sections change more rapidly may provide improved results. The ARP methodology has been developed in FORTRAN-77 and implemented on both workstation and PC environments.

The intent of this work is fourfold: (1) to present a description of the ARP methodology; (2) to describe the procedure for generating cross-section libraries which serves as the basis for interpolation; (3) to demonstrate the effectiveness of the method by comparing pressurized-water-reactor (PWR) and boiling-water-reactor (BWR) isotope concentrations calculated with ARP to

direct SAS2H calculations and experimental results; and (4) to document ORIGEN-S cross-section library utility programs developed to support the ARP methodology.

Comparative results of PWR spent fuel nuclide concentrations for the H. B. Robinson, Calvert Cliffs (U.S.), and Obrigheim (Germany) reactors will be presented. Likewise, comparative results of BWR spent fuel nuclide concentrations for the Cooper Nuclear Station (U.S.), Japan Power Demonstration Reactor, or JPDR (Japan), and Gundremmingen (Germany) reactors will be given. A complete description of these reactor and assembly designs is given in ref. 4, for PWR, and in ref. 5, for BWR systems.

3. METHODOLOGY DESCRIPTION

The main feature of the ARP methodology is that problem-dependent ORIGEN-S cross-section libraries can be obtained by interpolation. As is well known, the success of an interpolation procedure depends on the choice of independent variables pertinent to the problem under consideration and consequently on the selection of a suitable interpolation scheme that provides results within the accepted error margin. To implement the ARP methodology, cross-section changes vs several parameters were computed, and it was found that enrichment, burnup and water density were the independent variables best suited for interpolation. Therefore, cross-section libraries as a function of enrichment, burnup and water density are created using the SAS2H sequence of the SCALE system. In particular, the water density effects impact BWR systems because the axial liquid-to-steam change in these systems leads to a variation in the water density and significant cross-section changes as a function of the water density are observed. These pregenerated cross sections serve as the basic libraries from which the interpolation is performed. Significant cross-section changes, as a function of these variables, are observed. As an example, cross-section variations with burnup in a typical PWR assembly are illustrated in Fig. 1 for the ^{240}Pu isotope. This situation corresponds to a 15 × 15-type assembly with initial enrichment of 3.0 wt % of ^{235}U, water density 0.7135 g/cm^3 irradiated with a specific power of 40 MW/MTU for 1500 days.

The interpolation on the burnup variable is carried out with a scheme developed by Greene[6] which has been thoroughly tested and validated in the AMPX cross-section processing codes.[7] The interpolation scheme was originally developed for interpolation in Bondarenko factor tables. It states that for a function f(x) with known values at $x_1,x_2,...x_n$ any value $f(x_q)$ can be interpolated according to

$$f(x_q) = f(x_i) + \frac{x_q^p - x_i^p}{x_{i+1}^p - x_i^p}(f(x_{i+1}) - f(x_i)) , \qquad (1)$$

where p is a function of x and is allowed to vary linearly as

$$p(x_q) = p(x_i) + \frac{x_q - x_i}{x_{i+1} - x_i}(p(x_{i+1}) - p(x_i)) . \qquad (2)$$

It is clear that for a constant p equal to 1, this scheme reduces to the familiar linear interpolation method. In general, however, the p values are determined from the known set $\{x_i,f(x_i)\}$ according to Eq. (2) in such a way that the function f(x) is reproduced within the desired accuracy.

Note that the change of the effective absorption cross sections with enrichment has been found to approach a linear shape in a logarithm-linear scale. This feature is shown in Fig. 2 for some isotopes. Therefore, logarithm-linear interpolation is conducted for the cross section as a function of

enrichment. Cross-section change with water density for some isotopes is shown in Fig. 3. Similar to enrichment, the effective absorption cross section varies linearly in a logarithmic-linear scale with the water density, and a logarithmic-linear interpolation is utilized.

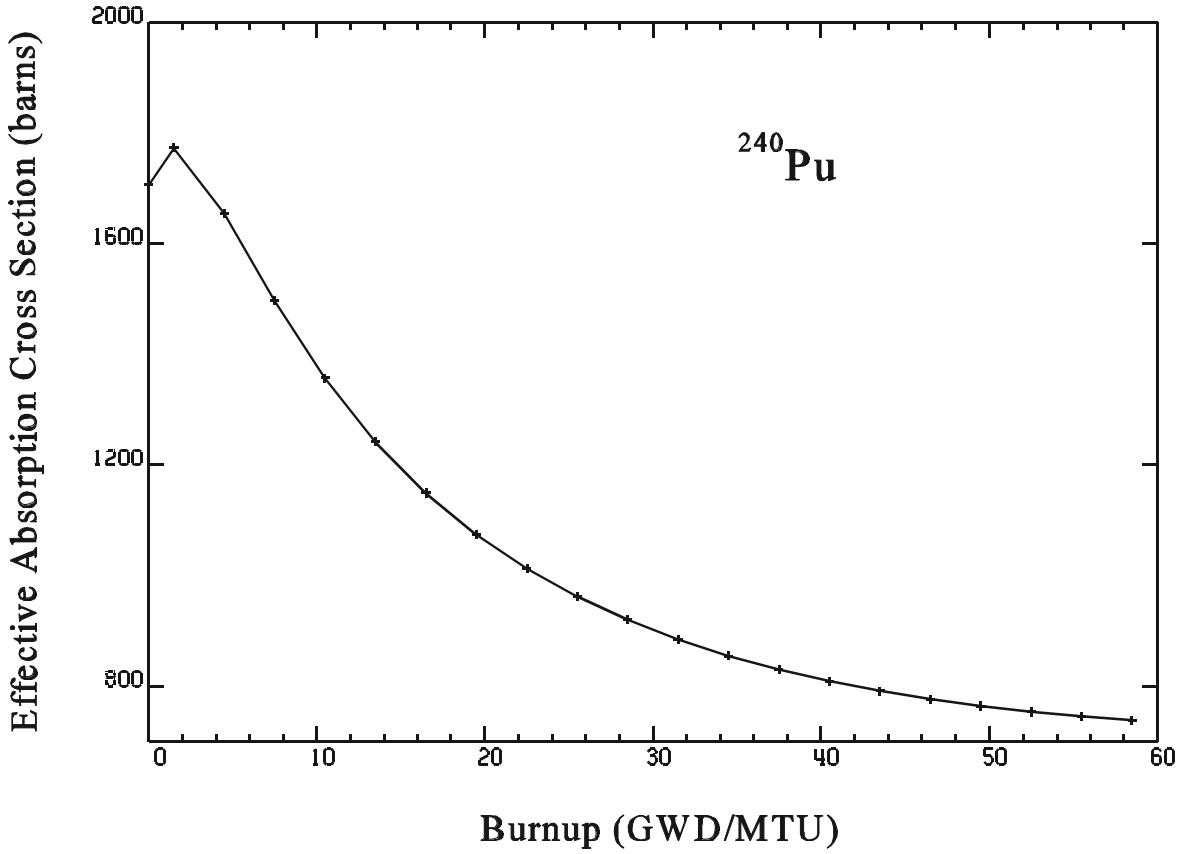

Fig. 1. Effective absorption cross section as a function of burnup for the ^{240}Pu isotope.

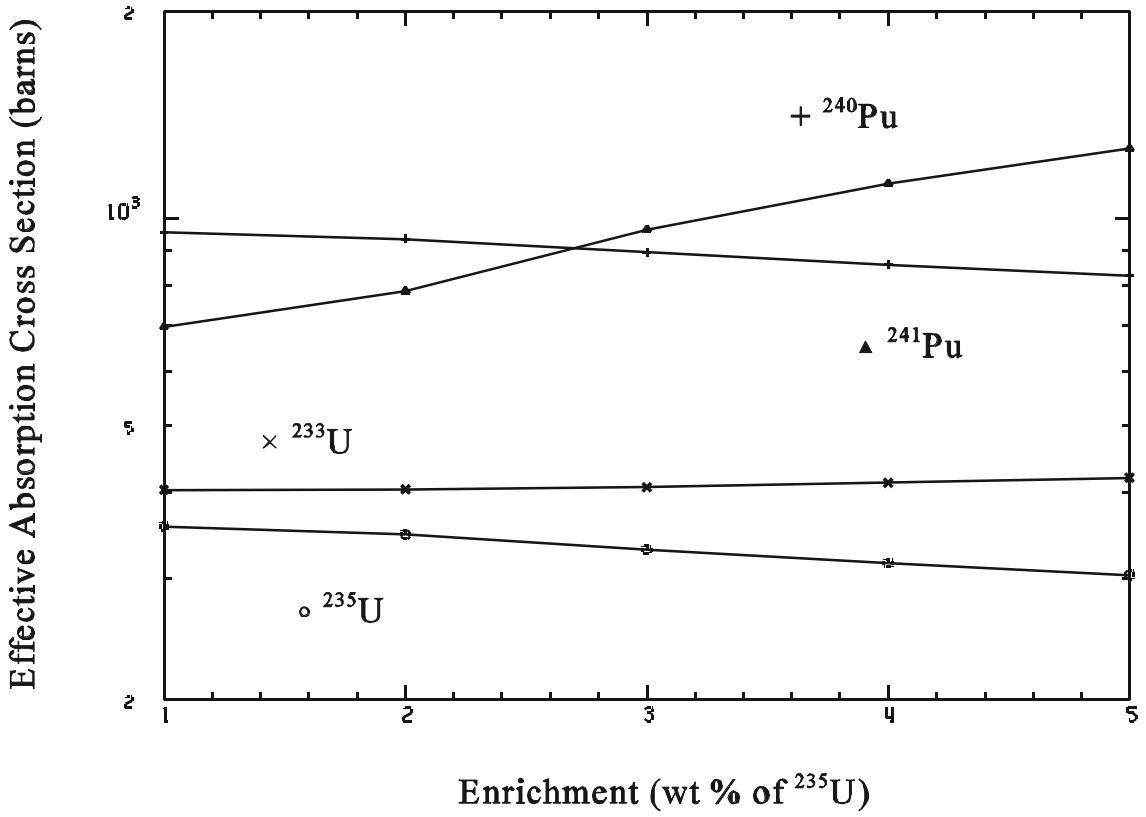

Fig. 2. Effective absorption cross-section changes with enrichment.

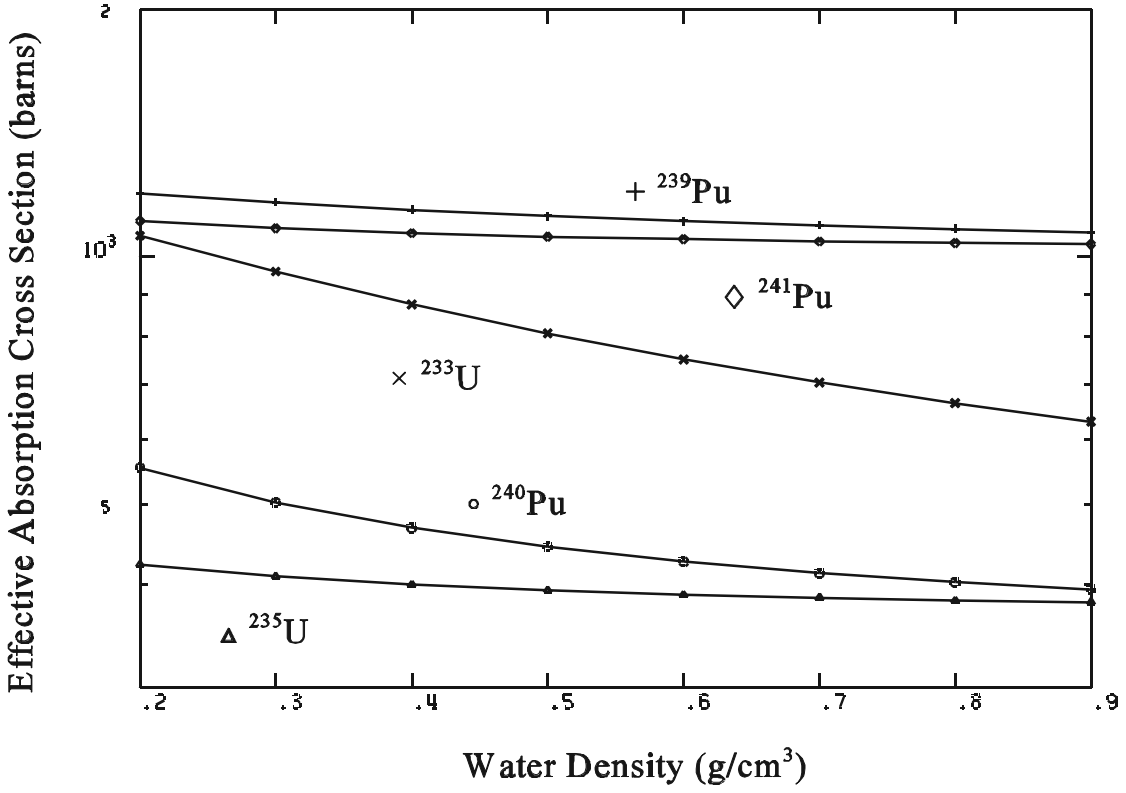

Fig. 3. Effective absorption cross-section changes with water density.

4. BASIC CROSS-SECTION LIBRARY GENERATION FOR ARP

To generate the basic ARP cross-section libraries for a particular LWR fuel assembly type, one needs to follow the steps outlined below. Note that extension beyond 5 wt % enrichment has not been investigated at ORNL. Likewise, extension to non-LWR fuel has not been investigated. Such applications of the ARP methodology should be tested carefully and validated.

1. Construct SAS2H input with the descriptions (pin cell description such as dimensions, concentrations, etc.) of the reactor assembly under consideration for five enrichments, for example, 1.5, 2.0, 3.0, 4.0 and 5.0 wt % of ^{235}U. For a BWR assembly, in addition to enrichment and burnup, one has also to consider the water density variation for each enrichment. The recommended water density values for BWRs are: 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 g/cm^3. No water density variation has been used at ORNL for PWRs.

2. For a fixed enrichment and water density, run SAS2H with 21 cycles and 1 library per cycle. The cross-section libraries created in this step must contain fresh-fuel cross sections for the first cycle. From studies performed with PWR and BWR assemblies, it is recommended that a specific power of 40 MW/MTU and irradiation period of 1500 days be applied to obtain the 21 burnup-dependent cross section libraries. The total burnup is 60000 MWD/MTU which corresponds to 20 burnup steps of 3000 MWD/MTU. With the exception of the first library in the zero-burnup position, the remaining 20 libraries correspond to a burnup position at the midpoint of each burnup step. The burnup positions are listed in Table 1.

3. Reduce the 21 burnups to 10 burnups following these criteria:

    a. retain the fresh-fuel cross sections;

    b. retain the minimum, maximum, and inflection points derived from the shape of the absorption cross sections with burnup for various isotopes of the library; and

    c. select points that best represent the burnup-dependent ^{240}Pu absorption cross sections.

The ten burnup positions resulting from the application of steps a, b and c are: 0, 1500, 4500, 7500, 10500, 13500, 16500, 31500, 46500, and 58500 MWD/MTU for PWR and BWR systems. They are indicated in Table 1 with the superscript letter *a*. The procedure for reducing the burnups from 21 to 10 positions has been implemented in a FORTRAN program, which is listed in Appendix A.

Note that the procedure for generating ARP basic libraries is performed only once for each fuel assembly type and enrichment. Users *should not use* these cross-section libraries for configurations other than the ones for which they were generated.

Table 1. Twenty-one burnup positions of the SAS2H-generated libraries

Position	Burnup (MWd/MTU)
1	0[a]
2	1500[a]
3	4500[a]
4	7500[a]
5	10500[a]
6	13500[a]
7	16500[a]
8	19500
9	22500
10	25500
11	28500
12	31500[a]
13	34500
14	37500
15	40500
16	43500
17	46500[a]
18	49500
19	52500
20	55500
21	58500[a]

[a]These are the 10 burnup positions in the reduced library.

Appendix B illustrates an example of how to generate basic ARP cross-section libraries for a BWR 7 × 7 assembly corresponding to the Cooper nuclear reactor.

A FORTRAN listing of the ARP code is given in Appendix C.

5. PROCEDURE TO EXECUTE ARP OUTSIDE SCALE

In this work we describe the stand-alone use of the ARP methodology as opposed to its use within the ORIGEN-ARP environment provided in the SCALE code system.[8] Very few input data are needed to run the ARP code. In the stand-alone mode the input data are transferred to ARP by answering questions following the eight self-descriptive prompts issued by ARP. The sequences of input data are the following: the fuel assembly configuration, the initial enrichment (in wt % of ^{235}U), the number of depletion cases (number of reactor fuel cycles), fuel irradiation period for each depletion case (in days), the average specific power of the power history for each depletion case (in MW/MTU), the number of libraries requested for each depletion case, the water density (for BWR systems), and the generated library name. A sample case of a typical ARP input is shown in Table 2 in which the prompts are given in bold to differentiate from the input data. In this example the first prompt, **Assembly type**, is the fuel assembly configuration that corresponds to BWR-type 7 × 7 array. The second prompt, **Enrichment**, is the initial enrichment, which is 2.3 wt % of ^{235}U. The third prompt, **Number of cycles**, is the number of reactor fuel cycles (i.e., the number of depletion cases; in this example equal to 4). In the fourth prompt, **Fuel irradiation period for each cycle**, the number of days in which the fuel was irradiated is given. There are four depletion cases corresponding to 200, 250, 300 and 350 days, respectively. The fifth prompt, **Specific power for each cycle**, the average power density (specific power) of the power history for each depletion case is given. They are respectively, 10, 12, 9, and 11 in MW/MTU. Note that the corresponding burnup for the first depletion case is 2000 MWd/MTU (200 days times 10 MW/MTU). The number of libraries requested for each depletion case is given in the sixth prompt, **Number of libraries made per cycle**, which are, respectively, 2, 1, 3, and 2 libraries. The water density is given in the seventh prompt, **Water density (g/cm**3)**, which is 0.3446 g/cm^3. The ORIGEN-S cross-section library name generated by ARP is provided in the eighth prompt, **Interpolated library name**, which in this sample case is called arplib. This library can be used later in an ORIGEN-S depletion/decay calculation.

Table 2. Input to execute ARP in stand-alone mode

Assembly type: 7 × 7
Enrichment: 2.3
Number of cycles: 4
Fuel irradiation period for each cycle: 200.0,250.0,300.0,350.0
Specific power for each cycle: 10.0,12.0,9.0,11.0
Number of libraries made per cycle: 2,1,3,2
Water density (g/cm3):** 0.3446
Interpolated library name: arplib

6. VALIDATION OF THE ARP METHODOLOGY

To evaluate the ARP methodology, results of calculations of PWR and BWR spent fuel nuclide concentrations are compared with those obtained with direct SAS2H calculations and existing measured values. In this regard, fuel assemblies from three PWRs are used, namely, the 14 × 14 Calvert Cliffs, the 14 × 14 Obrigheim, and the 15 × 15 H. B. Robinson. A detailed description of these reactor assemblies, including significant design characteristics and operating conditions, can be found in ref. 5. A similar set of calculations was performed for three BWR assemblies. These reactor assemblies include: the 6 × 6 Gundremmingen, the 6 × 6 JPDR, and the 7 × 7 Cooper. A complete description of these reactor assemblies is given in ref. 4.

6.1 ARP VALIDATION FOR PWR SYSTEMS

The calculations in this work were done using both ARP/ORIGEN-S and SAS2H/ORIGEN-S based on basic actinide data processed from both the ENDF/B-IV and ENDF/B-V nuclear data libraries. The ENDF/B-IV results were obtained with the SCALE 27BURNUPLIB library, a 27-group library which includes actinide data from ENDF/B-IV and fission-product data from ENDF/B-V, whereas the ENDF/B-V results utilized the SCALE 44GROUPNDF5 library, a 44-group library based primarily on ENDF/B-V data.[9] For each reactor assembly, basic ARP cross-section libraries were created with the SAS2H sequence at enrichments 1.5, 2.0, 3.0, 4.0, and 5.0 wt % of ^{235}U. The burnup range in these libraries spans from 0 to 60 GWd/MTU, with ten burnup points selected as previously described.

The ARP interpolated cross-section libraries were generated according to the information provided in Table 3. Subsequently, the ORIGEN-S code performed a point-depletion calculation using these libraries, as discussed in the introduction. The SAS2H/ORIGEN-S calculations performed here are also based on the information given in Table 3. Comparative results of these calculations with available measured data are given in Tables 4 through 9. Comparisons of the measured and computed fuel compositions for the 14 × 14 Obrigheim assembly for the burnup specifications given in Table 3 are shown in Tables 4 and 5. Likewise, the results for the 14 × 14 Calvert Cliffs assembly are shown in Tables 6 and 7, respectively. Comparisons of the results for the 15 × 15 H. B. Robinson assembly are given in Tables 8 and 9. Note that the calculated fuel nuclide concentrations with the cross-section data generated with the ARP methodology are in good agreement with the SAS2H/ORIGEN-S results. These results demonstrate the effectiveness of the ARP methodology in the prediction of nuclide concentrations for PWR systems. In fact, the results of calculations performed with ARP/ORIGEN-S are expected to be as good as that of SAS2H/ORIGEN-S, because the basic cross-section libraries for ARP are created within the SAS2H scheme.

Another interesting point to note in this work is the global improvement obtained in the comparison of results to measured data when the nuclear cross-section library produced from ENDF/B-V data is used as opposed to that produced from ENDF/B-IV data.

Table 3. Input data information for ARP and SAS2H cross-section generation

Assembly type	Enrichment (wt % of ^{235}U)	Burnup (GWd/MTU)	No. of cycles	Libraries/ cycle
14 × 14 Obrigheim	3.13	25.93 27.99	3	1
14 × 14 Calvert Cliffs	3.038	27.35 44.34	4	1
15 × 15 H. B. Robinson	2.561	16.02 31.66	4	1

Table 4. Measured and computed irradiated fuel composition (in units of mg/g of U) for 14 × 14 Obrigheim assembly and 25.93-GWd/MTU burnup

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.[a]	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	10.95	10.59	-3.3	10.59	-3.3	10.63	-2.9	10.68	-2.5
^{236}U	3.59	3.629	1.1	3.628	0.9	3.623	0.9	3.621	0.9
^{238}Pu	0.0801	0.0861	7.5	0.0852	6.3	0.0812	1.4	0.0809	1.1
^{239}Pu	4.805	5.036	4.8	5.098	6.1	4.854	1.0	4.828	0.5
^{240}Pu	1.8	1.741	-3.3	1.705	-5.3	1.824	1.3	1.811	0.6
^{241}Pu	0.978	1.072	9.6	1.051	7.5	1.009	3.2	0.9924	1.5
^{242}Pu	0.312	0.2766	-11.3	0.2749	-11.9	0.3038	-2.6	0.3071	-1.6
^{244}Cm	0.0103	0.0078	-24.3	0.0078	-24.3	0.0092	-10.6	0.0094	-9.0

[a] $\%\ \text{diff} = \dfrac{\text{computed} - \text{measured}}{\text{measured}} \times 100.0$.

Table 5. Measured and computed irradiated fuel composition (in units of mg/g of U) for 14 × 14 Obrigheim assembly and 27.99-GWd/MTU burnup

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	9.85	9.603	-2.5	9.598	-2.6	9.638	-2.1	9.684	-1.7
^{236}U	3.7	3.767	1.8	3.767	1.8	3.763	1.7	3.763	1.7
^{238}Pu	0.0948	0.1039	9.6	0.1028	8.4	0.098	3.1	0.098	3.1
^{239}Pu	4.925	5.104	3.6	5.171	5.0	4.917	-0.2	4.893	-0.7
^{240}Pu	1.92	1.877	-2.2	1.836	-4.4	1.965	2.4	1.947	1.4
^{241}Pu	1.058	1.162	9.9	1.136	7.4	1.093	3.3	1.071	1.2
^{242}Pu	0.372	0.3316	-10.9	0.3298	-11.3	0.3641	-2.1	0.3679	-1.1
^{244}Cm	0.0141	0.0114	-19.5	0.0113	-19.8	0.0134	-5.3	0.0136	-3.7

Table 6. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 14 × 14 Calvert Cliffs assembly and 27.35 GWd/MTU burnup

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.16	0.1607	0.5	0.1612	0.7	0.1574	-1.6	0.1577	-1.5
^{235}U	8.47	8.078	-4.6	8.002	-5.5	8.113	-4.2	8.071	-4.7
^{236}U	3.14	3.24	3.2	3.24	3.2	3.239	3.2	3.233	2.9
^{238}U	842.5	837.3	-0.6	837.3	-0.6	837.3	-0.6	837.3	-0.6
^{238}Pu	0.101	0.099	-2.0	0.0979	-3.1	0.0927	-8.2	0.0926	-8.3
^{239}Pu	4.264	4.388	2.9	4.28	0.4	4.225	-0.9	4.04	-5.3
^{240}Pu	1.719	1.707	-0.7	1.614	-6.1	1.775	3.2	1.709	-0.6
^{241}Pu	0.681	0.7238	6.3	0.7087	4.1	0.681	0.0	0.6681	-1.9
^{242}Pu	0.289	0.2741	-5.1	0.2769	-4.2	0.3024	4.6	0.3082	6.6
^{237}Np	0.268	0.3193	19.1	0.3156	17.8	0.2862	6.8	0.2835	5.8
^{133}Cs	0.86	0.862	0.2	0.860	0.0	0.8651	0.6	0.8634	0.4
^{134}Cs	0.01	0.0101	1.0	0.0101	1.0	0.0097	-3.0	0.0097	-3.0
^{135}Cs	0.36	0.397	10.5	0.3935	9.3	0.3793	5.4	0.3766	4.6
^{137}Cs	0.78	0.785	0.6	0.7832	0.4	0.7846	0.6	0.783	0.4
^{143}Nd	0.613	0.623	1.6	0.621	1.4	0.6185	0.9	0.6166	0.6

Table 7. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 14 × 14 Calvert Cliffs assembly and 44.34-GWd/MTU burnup

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.12	0.125	4.2	0.1255	4.6	0.1213	1.1	0.1217	1.4
^{235}U	3.54	3.124	-11.8	3.199	-9.6	3.148	-11.1	3.231	-8.7
^{236}U	3.69	3.77	2.2	3.753	1.7	3.764	2.0	3.759	1.9
^{238}U	824.9	823.8	-0.1	823.8	-0.1	824.0	-0.1	823.8	-0.1
^{238}Pu	0.269	0.265	1.5	0.2693	0.1	0.2529	-6.0	0.2555	-5.0
^{239}Pu	4.357	4.486	3.0	4.559	4.6	4.329	-0.6	4.292	-1.5
^{240}Pu	2.543	2.477	-2.6	2.324	-8.6	2.484	-2.3	2.444	-3.9
^{241}Pu	1.02	1.057	3.6	1.065	4.4	0.997	-2.3	0.9959	-2.4
^{242}Pu	0.84	0.793	-5.6	0.7858	-6.5	0.8751	4.2	0.8741	4.1
^{237}Np	0.468	0.555	18.6	0.5584	19.3	0.5	6.9	0.5015	7.2
^{133}Cs	1.24	1.279	3.1	1.273	2.7	1.286	3.7	1.282	3.4
^{134}Cs	0.03	0.0252	-16.0	0.0253	-15.5	0.0244	-18.6	0.0244	-18.6
^{135}Cs	0.43	0.457	6.3	0.4605	7.1	0.4328	0.6	0.4372	1.7
^{137}Cs	1.25	1.269	1.5	1.265	1.2	1.268	1.4	1.265	1.2
^{143}Nd	0.763	0.772	1.2	0.7757	1.7	0.763	0.0	0.7667	0.5

Table 8. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 15 × 15 H. B. Robinson assembly and 16.02-GWd/MTU burnup

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	10.7	10.75	0.6	10.76	0.6	10.84	1.3	10.84	1.3
^{236}U	2.19	2.145	-2.1	2.156	-1.5	2.137	-2.4	2.15	-1.8
^{238}U	847.0	847.9	0.1	847.9	0.1	847.9	0.1	847.8	0.1
^{238}Pu	0.0283	0.0285	0.7	0.0287	1.5	0.0266	-6.1	0.0268	-5.3
^{239}Pu	3.64	4.016	10.3	3.894	7.0	3.83	5.2	3.699	1.6
^{240}Pu	1.09	1.043	-4.3	1.073	-1.5	1.108	1.6	1.139	4.5
^{241}Pu	0.304	0.342	12.4	0.3219	5.9	0.326	7.2	0.3059	0.6
^{237}Np	0.155	0.166	6.9	0.1643	6.0	0.146	-5.5	0.1451	-6.4
^{99}Tc	5.44×10^{-6}	6.07×10^{-6}	11.6	6.11×10^{-6}	12.4	6.08×10^{-6}	11.8	6.12×10^{-6}	12.5
^{137}Cs	0.0359	0.0364	1.5	0.0359	0.2	0.0364	1.5	0.0359	0.2

Table 9. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 15 × 15 H. B. Robinson assembly and 31.66-GWd/MTU burnup

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	4.86	4.763	-2.0	5.022	3.3	4.822	-0.8	5.077	4.5
^{236}U	3.0	2.982	-0.6	2.988	-0.4	2.981	-0.6	2.986	-0.5
^{238}U	842.0	835.3	-0.8	835.3	-0.8	835.8	-0.7	835.3	-0.8
^{238}Pu	0.13	0.134	2.3	0.1333	2.6	0.125	-4.0	0.1256	-3.4
^{239}Pu	4.2	4.731	12.6	4.739	12.8	4.475	6.5	4.475	6.5
^{240}Pu	2.122	2.023	-4.6	2.032	-4.1	2.127	0.3	2.138	0.9
^{241}Pu	0.692	0.766	10.7	0.7551	9.1	0.72	4.1	0.7094	2.5
^{237}Np	0.333	0.397	19.2	0.3944	18.4	0.355	6.6	0.3531	6.0
^{99}Tc	1.01×10^{-5}	1.13×10^{-5}	11.6	1.12×10^{-5}	11.2	1.13×10^{-5}	11.8	1.13×10^{-5}	11.8
^{137}Cs	0.0713	0.0727	2.0	0.0724	1.5	0.0727	2.0	0.0724	1.5

6.2 ARP VALIDATION FOR BWR SYSTEMS

The axial water-to-steam change of state in BWR systems leads to variation in the water density and consequently changes the effective group cross section. Although in PWR systems the axial change in the cross sections is not a major effect, these effects play an important role in BWR systems. In a SAS2H calculation the axial water-density change is entered explicitly in the generation of ORIGEN-S cross-section libraries.

Axial water densities were required in a recent ORNL depletion calculation validation study[5] on the use of SAS2H in BWR analysis. Particular water density values were assumed for each SAS2H validation case as listed in Table 10. The same values were used in each ARP validation case. Note that the SAS2H values presented in this section are from preliminary calculations performed for the validation study in Ref. 5. The ARP libraries generated here are consistent with these calculations. The final results reported in Ref. 5 may differ slightly.

To account for the water density effects in the ARP scheme, SAS2H cross section libraries were generated at the water densities of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 g/cm^3. The cross section at any water density is obtained by a logarithmic-linear interpolation on these pre-generated SAS2H libraries.

To demonstrate the feasibility of the ARP approach to generate ORIGEN-S cross section libraries, measured data from three BWR reactor assemblies were compared with calculations performed with ARP. Results of calculations with SAS2H are also included. The input data information provided to SAS2H and ARP are given in Table 10. The 6 × 6 Gundremmingen results are shown in Tables 11 through 18. The 7 × 7 JPDR results are shown in Tables 19 through 34 whereas the 6 × 6 Cooper results are given in Tables 35 through 40.

The ARP/ORIGEN-S calculated fuel nuclide concentrations agree very well with the SAS2H/ORIGEN-S results. For BWR systems, an interpolation on the water density is required in addition to the burnup and enrichment. The results shown in Tables 11 through 40 demonstrate the adequacy of the log-linear interpolation on the water density.

As in the case of PWR systems, the BWR results with calculations using the ENDF/B-V show an improvement over the results with ENDF/B-IV cross-section libraries.

Table 10. Input data information for ARP and SAS2H cross-section generation

Assembly type	Enrichment (wt % of ^{235}U)	Burnup (GWd/MTU)	Water density(g/cm^3)	No. of cycles	Libraries/ cycle
6 × 6 Gundremmingen	2.53	14.39	0.3849	3	1
		17.49	0.3849		
		19.85	0.3849		
		20.30	0.7460		
		21.24	0.3145	4	1
		23.51	0.3145		
		25.73	0.7378		
		27.40	0.3145		
6 × 6 JPDR	2.5966	2.16	0.7701	4	1
		2.65	0.5232		
		2.71	0.5629		
		3.30	0.6075		
		4.04	0.7541		
		4.25	0.6708		
		5.06	0.7534		
		5.09	0.5688		
		5.38	0.7534		
		5.60	0.5688		
		6.04	0.7305		
		6.08	0.6276		
		6.15	0.7642		
		6.51	0.7600		
		6.95	0.6719		
		7.01	0.6719		
7 × 7 Cooper	2.939	17.84	0.3452	7	1
		18.96	0.3446		
		29.23	0.3723		
		30.07	0.4705		
		31.04	0.6124		
		33.94	0.5736		

Table 11. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 14.39-GWd/MTU burnup and 0.3849 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.[a]	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	13.11	12.67	-3.3	12.77	-2.6	12.69	-3.2	12.82	-2.3
^{236}U	2.452	2.290	-6.6	2.286	-6.8	2.283	-6.9	2.280	-7.0
^{238}U	962.10	964.0	0.2	964.0	0.2	964.0	0.2	964.0	0.2
^{238}Pu	0.0330	0.0268	-18.7	0.0275	-16.6	0.0244	-26.1	0.0253	-23.3
^{239}Pu	4.695	3.944	-16.0	3.974	-15.4	3.859	-17.8	3.918	-16.6
^{240}Pu	1.170	1.041	-11.9	1.041	-11.1	1.068	-8.7	1.081	-7.6
^{241}Pu	0.481	0.411	-14.6	0.415	-13.6	0.382	-20.6	0.389	-19.1
^{242}Pu	0.0889	0.0739	-17.0	0.0752	-15.5	0.0792	-11.0	0.0807	-9.3
^{244}Cm	0.0016	0.0006	-57.8	0.0007	-56.6	0.0007	-50.9	0.0008	-48.3

[a] $\%\ \text{diff.} = \dfrac{\text{computed} - \text{measured}}{\text{measured}} \times 100.0$.

Table 12. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 17.49-GWd/MTU burnup and 0.3849 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	10.44	10.78	3.2	10.87	4.1	10.79	3.3	10.88	4.2
^{236}U	2.740	2.589	-5.5	2.585	-5.6	2.583	-5.7	2.580	-5.8
^{238}U	966.1	966.2	0.1	966.2	0.1	966.2	0.1	966.2	0.1
^{238}Pu	0.0410	0.0422	3.0	0.0422	3.0	0.0386	-5.9	0.0392	-4.5
^{239}Pu	4.157	4.220	1.5	4.236	1.5	4.126	-0.7	4.141	-0.4
^{240}Pu	1.442	1.302	-9.7	1.302	-9.7	1.350	-6.4	1.352	-6.2
^{241}Pu	0.533	0.548	2.9	0.554	2.9	0.511	-4.2	0.515	-3.4
^{242}Pu	0.150	0.125	-16.9	0.126	-15.9	0.134	-10.9	0.135	-9.9
^{244}Cm	0.0028	0.0018	-36.3	0.0018	-36.3	0.0021	-26.7	0.0021	-26.7

Table 13. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 19.85-GWd/MTU burnup and 0.3849 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	9.803	9.495	-3.1	9.574	-2.3	9.501	-3.1	9.559	-2.5
^{236}U	2.901	2.785	-4.0	2.782	-4.1	2.780	-4.2	2.777	-4.3
^{238}U	959.1	959.9	0.1	959.9	0.1	960.0	0.1	959.1	0.0
^{238}Pu	0.0480	0.0561	17.0	0.0567	18.0	0.0514	7.0	0.0522	8.7
^{239}Pu	4.418	4.370	-1.1	4.377	-0.9	4.272	-3.3	4.275	-3.2
^{240}Pu	1.533	1.501	-2.1	1.492	-2.7	1.556	1.5	1.552	1.3
^{241}Pu	0.650	0.625	-3.8	0.632	-2.7	0.582	-10.4	0.589	-9.5
^{242}Pu	0.201	0.172	-14.6	0.174	-13.5	0.185	-8.3	0.187	-7.2
^{244}Cm	0.0045	0.0033	-27.9	0.0032	-27.4	0.0037	-17.7	0.0037	-17.7

Table 14. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 19.85-GWd/MTU burnup and 0.7460 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	8.588	8.538	-0.6	8.607	0.2	8.557	-0.4	8.624	-0.4
^{236}U	3.077	2.850	-7.4	2.846	-7.5	2.841	-7.7	2.838	-7.8
^{238}U	961.0	961.0	0.0	960.0	0.0	961.0	0.0	960.0	0.0
^{238}Pu	0.036	0.047	29.4	0.047	31.0	0.044	20.8	0.044	22.8
^{239}Pu	3.635	3.718	2.3	3.726	2.5	3.668	0.9	3.674	1.1
^{240}Pu	1.472	1.473	0.1	1.466	-0.4	1.520	3.3	1.517	3.0
^{241}Pu	0.521	0.553	6.1	0.557	7.0	0.520	-0.1	0.524	0.6
^{242}Pu	0.182	0.178	-2.1	0.180	-1.1	0.189	4.2	0.191	5.2
^{244}Cm	0.0026	0.0024	-7.1	0.0025	-5.9	0.0027	3.7	0.0027	3.7

Table 15. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 21.24-GWd/MTU burnup and 0.3145 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	9.823	8.959	-8.8	9.046	-7.9	8.955	-8.8	9.083	-7.5
^{236}U	2.952	2.886	-2.2	2.885	-2.3	2.883	-2.4	2.881	-2.4
^{238}U	955.9	958.3	0.3	958.2	0.2	958.3	0.3	958.3	0.3
^{238}Pu	0.08300	0.07317	-11.8	0.07380	-11.1	0.06653	-19.8	0.06780	-18.3
^{239}Pu	5.372	4.606	-14.3	4.611	-14.2	4.490	-16.4	4.538	-15.5
^{240}Pu	1.855	1.640	-11.6	1.639	-11.7	1.704	-8.1	1.709	-7.9
^{241}Pu	0.7855	0.7130	-9.2	0.7055	-10.2	6.620	-15.7	6.592	-16.1
^{242}Pu	0.2232	0.2026	-9.2	0.2035	-8.8	0.2175	-2.6	0.2180	-2.3
^{244}Cm	0.008622	0.004911	-43.0	0.004951	-42.6	0.005603	-35.0	0.005741	-33.4

Table 16. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 23.51-GWd/MTU burnup and 0.3145 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	8.618	7.915	-8.2	7.992	-7.3	7.904	-8.3	8.024	-6.9
^{236}U	3.133	3.036	-3.1	3.037	-3.1	3.034	-3.2	3.034	-3.2
^{238}U	954.7	956.4	0.2	956.3	0.2	956.4	0.2	956.3	0.2
^{238}Pu	0.08400	0.09100	8.3	0.09154	9.0	0.8293	-1.3	0.8423	0.3
^{239}Pu	4.820	4.703	-2.4	4.705	-2.4	4.583	-4.9	4.631	-3.9
^{240}Pu	1.845	1.825	-1.1	1.814	-1.7	1.895	2.7	1.893	2.6
^{241}Pu	0.7276	0.7827	7.6	0.7668	5.4	0.7272	-0.1	0.7170	-1.5
^{242}Pu	0.2461	0.2589	5.2	0.2589	5.2	0.2784	13.1	0.2774	12.7
^{244}Cm	0.009176	0.007695	-16.1	0.007748	-15.6	0.008747	-4.7	0.008923	-2.8

Table 17. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 25.73-GWd/MTU burnup and 0.7378 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	6.307	5.961	-5.5	6.017	-4.6	5.973	-5.3	6.027	-4.4
^{236}U	3.280	3.206	-2.3	3.207	-2.2	3.198	-2.5	3.199	-2.5
^{238}U	956.1	956.7	0.1	956.6	0.1	956.7	0.1	956.6	0.1
^{238}Pu	0.06800	0.08539	25.6	0.08581	26.2	0.07990	17.5	0.08021	17.9
^{239}Pu	3.736	3.812	2.0	3.814	2.1	3.762	0.7	3.763	0.7
^{240}Pu	1.815	1.886	3.9	1.874	3.2	1.944	7.1	1.936	6.6
^{241}Pu	0.7052	0.7403	5.0	0.7200	2.1	0.6981	-1.0	0.6796	-3.6
^{242}Pu	0.3305	0.3293	-0.4	0.3282	-0.7	0.3508	6.2	0.3495	5.7
^{244}Cm	0.008868	0.008141	-8.2	0.008213	-7.4	0.008971	1.2	0.009015	1.7

Table 18. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 Gundremmingen assembly for 27.40-GWd/MTU burnup and 0.3145 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	6.741	6.355	-5.7	6.410	-4.9	6.332	-6.1	6.436	-4.5
^{236}U	3.294	3.245	-1.5	3.248	-1.4	3.246	-1.5	3.247	-1.4
^{238}U	951.9	953.0	0.1	953.0	0.1	953.0	0.1	953.0	0.1
^{238}Pu	0.1080	0.1263	17.0	0.1266	17.2	0.1155	6.9	0.1168	8.1
^{239}Pu	4.800	4.815	0.3	4.809	0.2	4.691	-2.3	4.736	-1.3
^{240}Pu	2.168	2.118	-2.3	2.091	-3.5	2.198	1.4	2.184	0.7
^{241}Pu	0.9540	0.9439	-1.1	0.9167	-3.9	0.8781	-8.0	0.8588	-10.0
^{242}Pu	0.4494	0.3683	-18.0	0.3667	-18.4	0.3971	-11.6	0.3934	-12.5
^{244}Cm	0.01977	0.01571	-20.5	0.01582	-20.0	0.01775	-10.2	0.01804	-8.8

Table 19. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 2.16-GWd/MTU burnup and 0.7701 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1510	0.1487	-1.5	0.1487	-1.5	0.1484	-1.7	0.1483	-1.8
^{235}U	23.54	23.47	-0.3	23.47	-0.3	23.47	-0.3	23.47	-0.3
^{236}U	0.5843	0.5855	0.2	0.5853	0.2	0.5837	-0.1	0.5835	-0.1
^{238}U	97.24	97.25	0.0	97.25	0.0	97.25	0.0	97.25	0.0
^{238}Pu	2.511×10^{-4}	2.234×10^{-4}	-11.0	2.234×10^{-4}	-10.4	2.035×10^{-4}	-19.0	2.038×10^{-4}	-18.8
^{239}Pu	0.9554	0.9440	-1.2	0.9443	-1.2	0.9331	-2.3	0.9322	-2.4
^{240}Pu	4.913×10^{-2}	4.814×10^{-2}	-2.0	4.819×10^{-2}	-1.9	4.868×10^{-2}	-0.9	4.870×10^{-2}	-0.9
^{241}Pu	3.955×10^{-3}	3.813×10^{-3}	-3.6	3.825×10^{-3}	-3.3	3.557×10^{-3}	-10.1	3.561×10^{-3}	-10.0
^{242}Pu	1.021×10^{-4}	8.686×10^{-5}	-14.9	8.743×10^{-5}	-14.4	9.151×10^{-5}	-10.4	9.200×10^{-5}	-9.9
^{241}Am	1.023×10^{-3}	1.059×10^{-3}	3.5	1.064×10^{-3}	4.0	9.891×10^{-4}	-3.3	9.920×10^{-4}	-3.0

Table 20. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 2.65-GWd/MTU burnup and 0.5232 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1459	0.1472	0.9	0.1471	0.8	0.1467	0.5	0.1467	0.5
^{235}U	23.18	22.99	-0.8	23.00	-0.8	23.00	-0.8	23.00	-0.8
^{236}U	0.6905	0.6836	-1.0	0.6832	-1.1	0.6812	-1.3	0.6811	-1.4
^{238}U	971.8	972.0	0.0	972.0	0.0	972.0	0.0	972.0	0.0
^{238}Pu	5.236×10^{-4}	4.838×10^{-4}	-7.6	4.846×10^{-4}	-7.1	4.402×10^{-4}	-15.9	4.401×10^{-4}	-15.9
^{239}Pu	1.261	1.301	3.2	1.301	3.2	1.280	1.5	1.278	1.4
^{240}Pu	7.798×10^{-2}	7.892×10^{-2}	1.2	7.884×10^{-2}	1.1	8.005×10^{-2}	2.7	7.994×10^{-2}	2.5
^{241}Pu	8.853×10^{-3}	9.042×10^{-3}	2.1	9.072×10^{-3}	2.5	8.448×10^{-3}	-4.6	8.463×10^{-3}	-4.4
^{242}Pu	2.730×10^{-4}	2.494×10^{-4}	-8.6	2.507×10^{-4}	-8.2	2.658×10^{-4}	-2.6	2.671×10^{-4}	-2.2
^{241}Am	2.242×10^{-3}	2.522×10^{-3}	12.5	2.534×10^{-3}	13.0	2.360×10^{-3}	5.3	2.368×10^{-3}	3.6

Table 21. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 2.71-GWd/MTU burnup and 0.5629 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1469	0.1471	0.2	0.1471	0.2	0.1467	-0.2	0.1466	-0.2
^{235}U	22.96	22.91	-0.2	22.91	-0.2	22.91	-0.2	22.91	-0.2
^{236}U	0.6904	0.6942	0.5	0.6938	0.5	0.6918	0.2	0.6916	0.2
^{238}U	972.0	972.0	0.0	972.0	0.0	972.0	0.0	972.0	0.0
^{238}Pu	3.009×10^{-4}	4.824×10^{-4}	60.3	4.844×10^{-4}	61.0	4.396×10^{-4}	46.1	4.391×10^{-4}	45.9
^{239}Pu	1.229	1.293	5.2	1.292	5.2	1.273	3.6	1.271	3.4
^{240}Pu	7.626×10^{-2}	8.051×10^{-2}	5.6	8.039×10^{-2}	5.4	8.165×10^{-2}	7.1	8.150×10^{-2}	6.9
^{241}Pu	8.451×10^{-3}	9.150×10^{-3}	8.3	9.162×10^{-3}	8.4	8.546×10^{-3}	1.1	8.543×10^{-3}	1.1
^{242}Pu	1.929×10^{-4}	2.603×10^{-4}	35.0	2.612×10^{-4}	35.4	2.768×10^{-4}	43.5	2.776×10^{-4}	43.9
^{241}Am	1.816×10^{-3}	2.551×10^{-3}	40.5	2.558×10^{-3}	40.9	2.387×10^{-3}	31.4	2.389×10^{-3}	31.6

Table 22. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 3.30-GWd/MTU burnup and 0.6075 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1468	0.1460	-0.5	0.1460	-0.5	0.1455	-0.9	0.1454	-0.9
^{235}U	22.52	22.28	-1.1	22.28	-1.1	22.29	-1.0	22.29	-1.0
^{236}U	0.7973	0.7993	0.2	0.7990	0.2	0.7965	-0.1	0.7964	-0.1
^{238}U	971.4	971.7	0.0	971.7	0.0	971.7	0.0	971.7	0.0
^{238}Pu	8.437×10^{-4}	7.092×10^{-4}	-15.9	7.151×10^{-4}	-15.2	6.490×10^{-4}	-23.1	6.511×10^{-4}	-22.8
^{239}Pu	1.531	1.477	-3.5	1.479	-3.4	1.455	-5.0	1.455	-5.0
^{240}Pu	0.1136	0.1103	-2.9	0.1102	-3.0	0.1136	-1.5	0.1119	-1.5
^{241}Pu	1.570×10^{-2}	1.440×10^{-2}	-8.3	1.451×10^{-2}	-7.6	1.345×10^{-2}	-14.4	1.352×10^{-2}	-13.9
^{242}Pu	5.719×10^{-4}	5.085×10^{-4}	-11.1	5.126×10^{-4}	-10.4	5.392×10^{-4}	-5.7	5.433×10^{-4}	-5.0
^{241}Am	3.356×10^{-3}	4.022×10^{-3}	19.8	4.055×10^{-3}	20.8	3.762×10^{-3}	12.1	3.786×10^{-3}	12.8

Table 23. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 4.04-GWd/MTU burnup and 0.7541 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1417	0.1450	2.3	0.1449	2.3	0.1443	1.8	0.1443	1.8
^{235}U	21.54	21.48	-0.3	21.48	-0.3	21.49	-0.2	21.49	-0.2
^{236}U	0.9119	0.9230	1.2	0.9225	1.2	0.9197	0.9	0.9194	0.8
^{238}U	971.3	971.4	0.0	971.4	0.0	971.4	0.0	971.4	0.0
^{238}Pu	1.088×10^{-3}	9.535×10^{-4}	-12.4	9.584×10^{-4}	-11.9	8.777×10^{-4}	-19.3	8.781×10^{-4}	-19.3
^{239}Pu	1.647	1.597	-3.0	1.597	-3.0	1.557	-4.3	1.575	-4.4
^{240}Pu	0.1510	0.1450	-4.0	0.1448	-4.1	0.1472	-2.5	0.1470	-2.7
^{241}Pu	2.145×10^{-2}	2.045×10^{-2}	-4.7	2.054×10^{-2}	-4.2	1.908×10^{-2}	-11.0	1.913×10^{-2}	-10.8
^{242}Pu	1.014×10^{-3}	9.105×10^{-4}	-10.2	9.155×10^{-4}	-9.7	9.597×10^{-4}	-5.4	9.639×10^{-4}	-4.9
^{241}Am	4.931×10^{-3}	5.710×10^{-3}	15.8	5.741×10^{-3}	16.4	5.339×10^{-3}	8.3	5.358×10^{-3}	8.7

Table 24. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 4.25-GWd/MTU burnup and 0.6708 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1456	0.1443	-0.9	0.1442	-0.9	0.1436	-1.4	0.1435	-1.4
^{235}U	21.53	21.29	-1.1	21.29	-1.1	21.30	-1.1	21.30	-1.1
^{236}U	0.9264	0.9625	3.9	0.9620	3.8	0.9590	3.5	0.9587	3.5
^{238}U	971.0	971.2	0.0	971.2	0.0	971.2	0.0	971.2	0.0
^{238}Pu	1.240×10^{-3}	1.187×10^{-3}	-4.3	1.193×10^{-3}	-3.8	1.092×10^{-3}	-11.9	1.093×10^{-3}	-11.9
^{239}Pu	1.701	1.738	2.2	1.738	2.2	1.713	0.72	1.710	0.6
^{240}Pu	0.1599	0.1636	2.3	0.1634	2.2	0.1663	4.0	0.1660	3.8
^{241}Pu	2.392×10^{-2}	2.546×10^{-2}	6.4	2.557×10^{-2}	6.9	2.376×10^{-2}	-0.7	2.382×10^{-2}	-0.4
^{242}Pu	1.203×10^{-3}	1.190×10^{-3}	-1.1	1.196×10^{-3}	-0.6	1.258×10^{-3}	4.6	1.264×10^{-3}	5.1
^{241}Am	5.942×10^{-3}	7.120×10^{-3}	19.8	7.18×10^{-3}	20.5	6.660×10^{-3}	12.1	6.684×10^{-3}	12.5

Table 25. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 5.06-GWd/MTU burnup and 0.7534 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1454	0.1430	-1.7	0.1429	-1.7	0.1421	-2.2	0.1421	-2.3
^{235}U	20.55	20.45	-0.5	20.45	-0.5	20.46	-0.4	20.46	-0.4
^{236}U	1.094	1.096	0.1	1.095	0.1	1.092	-0.2	1.091	-0.3
^{238}U	970.7	970.8	0.0	970.8	0.0	970.8	0.0	970.8	0.0
^{238}Pu	1.894×10^{-3}	1.641×10^{-3}	-13.3	1.651×10^{-3}	-12.8	1.516×10^{-3}	-20.0	1.518×10^{-3}	-19.8
^{239}Pu	1.951	1.893	-3.0	1.893	-3.0	1.867	-4.3	1.865	-4.4
^{240}Pu	0.2176	0.2103	-3.4	0.2101	-3.4	0.2139	-1.7	0.2137	-1.8
^{241}Pu	3.864×10^{-2}	3.585×10^{-2}	-7.2	3.597×10^{-2}	-6.9	3.345×10^{-2}	-13.4	3.351×10^{-2}	-13.3
^{242}Pu	2.441×10^{-3}	2.047×10^{-3}	-16.1	2.060×10^{-3}	-15.6	2.157×10^{-3}	-11.6	2.169×10^{-3}	-11.1
^{241}Am	1.013×10^{-2}	1.002×10^{-2}	-1.1	1.007×10^{-2}	-0.6	9.377×10^{-3}	-7.4	9.407×10^{-3}	-7.1

Table 26. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 5.09-GWd/MTU burnup and 0.5688 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1366	0.1422	4.1	0.1420	4.0	0.1413	3.5	0.1413	3.5
^{235}U	2069	20.52	-0.8	20.53	-0.8	20.54	-0.7	20.54	-0.7
^{236}U	1.097	1.106	0.8	1.105	0.8	1.102	0.4	1.101	0.4
^{238}U	970.2	970.4	0.0	970.4	0.0	970.4	0.0	970.4	0.0
^{238}Pu	2.550×10^{-3}	2.092×10^{-3}	-18.0	2.101×10^{-3}	-17.1	1.921×10^{-3}	-24.7	1.922×10^{-3}	-24.6
^{239}Pu	2.240	2.118	-5.5	2.117	-5.5	2.081	-7.1	2.077	-7.3
^{240}Pu	0.2404	0.2287	-4.9	0.2283	-5.0	0.2331	-3.0	0.2327	-3.2
^{241}Pu	4.974×10^{-2}	4.430×10^{-2}	-10.9	4.439×10^{-2}	-10.8	4.133×10^{-2}	-16.9	4.136×10^{-2}	-16.9
^{242}Pu	3.081×10^{-3}	2.480×10^{-3}	-19.5	2.493×10^{-3}	-19.1	2.634×10^{-3}	-14.5	2.646×10^{-3}	-14.1
^{241}Am	1.269×10^{-2}	1.243×10^{-2}	-2.1	1.247×10^{-2}	-1.7	1.163×10^{-2}	-8.4	1.166×10^{-2}	-8.1

Table 27. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 5.38-GWd/MTU burnup and 0.7534 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	0.1415	0.1424	0.6	0.1423	0.6	0.1415	0.0	0.1415	0.0
^{235}U	20.15	20.14	0.0	20.14	0.0	20.14	0.0	20.14	0.0
^{236}U	1.162	1.148	-1.2	1.147	-1.3	1.144	-1.6	1.144	-1.6
^{238}U	970.6	970.6	0.0	970.6	0.0	970.6	0.0	970.6	0.0
^{238}Pu	2.103×10^{-3}	1.906×10^{-3}	-9.4	1.918×10^{-3}	-8.8	1.761×10^{-3}	-16.3	1.765×10^{-3}	-16.1
^{239}Pu	1.964	1.977	0.7	1.978	0.7	1.950	-0.7	1.948	-0.8
^{240}Pu	0.2353	0.2320	-1.4	0.2319	-1.4	0.2361	0.4	0.2360	0.3
^{241}Pu	4.248×10^{-2}	4.153×10^{-2}	-2.2	4.166×10^{-2}	-1.9	3.875×10^{-2}	-8.8	3.880×10^{-2}	-8.7
^{242}Pu	2.866×10^{-3}	2.540×10^{-3}	-11.4	2.556×10^{-3}	-10.8	2.677×10^{-3}	-6.6	2.692×10^{-3}	-6.1
^{241}Am	1.124×10^{-2}	1.162×10^{-2}	3.3	1.167×10^{-2}	3.8	1.087×10^{-2}	-3.3	1.090×10^{-2}	-3.0

Table 28. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 5.60-GWd/MTU burnup and 0.5688 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1404	0.1411	0.5	0.1410	0.4	0.1402	-0.1	0.1401	-0.2
^{235}U	20.19	20.04	-0.8	20.04	-0.8	20.05	-0.7	20.05	-0.7
^{236}U	1.177	1.190	1.1	1.189	1.0	1.185	0.7	1.185	0.7
^{238}U	970.0	970.1	0.0	970.1	0.0	970.1	0.0	970.1	0.0
^{238}Pu	2.779×10^{-3}	2.646×10^{-3}	-4.8	2.659×10^{-3}	-4.3	2.433×10^{-3}	-12.5	2.435×10^{-3}	-12.4
^{239}Pu	2.257	2.269	0.5	2.269	0.5	2.229	-1.2	2.226	-1.4
^{240}Pu	0.2644	0.2662	0.7	0.2658	0.5	0.2715	2.7	0.2711	2.5
^{241}Pu	5.623×10^{-2}	5.555×10^{-2}	-1.2	5.562×10^{-2}	-1.1	5.183×10^{-2}	-7.8	5.182×10^{-3}	-7.8
^{242}Pu	3.793×10^{-3}	3.461×10^{-3}	-8.8	3.478×10^{-3}	-8.3	3.676×10^{-3}	-3.1	3.693×10^{-3}	-2.6
^{241}Am	1.424×10^{-2}	1.560×10^{-2}	9.5	1.564×10^{-2}	9.9	1.460×10^{-2}	2.5	1.462×10^{-2}	2.7

Table 29. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 6.04-GWd/MTU burnup and 0.7305 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1442	0.1410	-2.2	0.1409	-2.3	0.1400	-2.9	0.1400	-2.9
^{235}U	19.61	19.51	-0.5	19.51	-0.5	19.51	-0.5	19.51	-0.5
^{236}U	1.260	1.255	-0.4	1.255	-0.4	1.251	-0.7	1.250	-0.8
^{238}U	969.9	970.2	0.0	970.2	0.0	970.2	0.0	970.2	0.0
^{238}Pu	3.290×10^{-3}	2.604×10^{-3}	-20.9	2.622×10^{-3}	-20.3	2.409×10^{-3}	-26.8	2.416×10^{-3}	-26.6
^{239}Pu	2.353	2.169	-7.8	2.171	-7.8	2.137	-9.2	2.136	-9.2
^{240}Pu	0.3038	0.2813	-7.4	0.2812	-7.4	0.2867	-5.6	0.2865	-5.7
^{241}Pu	6.493×10^{-2}	5.583×10^{-2}	-14.0	5.598×10^{-2}	-13.8	5.211×10^{-2}	-19.8	5.215×10^{-2}	-19.7
^{242}Pu	4.976×10^{-3}	3.890×10^{-3}	-21.8	3.914×10^{-3}	-21.3	4.103×10^{-3}	-17.5	4.125×10^{-3}	-17.1
^{241}Am	1.642×10^{-2}	1.563×10^{-2}	-4.8	1.570×10^{-2}	-4.4	1.464×10^{-2}	-10.9	1.468×10^{-2}	-10.6

Table 30. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 6.08-GWd/MTU burnup and 0.6276 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1335	0.1445	8.3	0.1445	8.3	0.1439	7.8	0.1438	7.7
^{235}U	19.88	21.53	8.3	21.53	8.3	21.53	8.3	21.53	8.3
^{236}U	1.266	0.9278	-26.7	0.9274	-26.7	0.9244	-27.0	0.9242	-27.0
^{238}U	969.5	971.2	0.2	971.2	0.2	971.2	0.2	971.2	0.2
^{238}Pu	3.710×10^{-3}	1.115×10^{-3}	-69.9	1.124×10^{-3}	-69.7	1.018×10^{-3}	-72.6	1.021×10^{-3}	-72.5
^{239}Pu	2.472	1.729	-30.0	1.731	-30.0	1.703	-31.1	1.703	-31.1
^{240}Pu	0.3143	0.1540	-51.0	0.1541	-51.0	0.1564	-50.2	0.1563	-50.3
^{241}Pu	7.112×10^{-2}	2.217×10^{-2}	-68.8	2.224×10^{-2}	-68.7	2.068×10^{-2}	-70.9	2.071×10^{-2}	-70.9
^{242}Pu	5.311×10^{-3}	9.792×10^{-4}	-81.6	9.860×10^{-4}	-81.4	1.037×10^{-3}	-80.5	1.043×10^{-3}	-80.4
^{241}Am	1.829×10^{-2}	6.235×10^{-3}	-65.9	6.267×10^{-3}	-65.7	5.829×10^{-3}	-65.9	5.848×10^{-3}	-68.0

Table 31. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 6.15-GWd/MTU burnup and 0.7642 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1433	0.1409	-1.7	0.1408	-1.7	0.1400	-2.3	0.1399	-2.4
^{235}U	18.92	19.39	2.5	19.40	2.5	19.40	2.5	19.41	2.6
^{236}U	1.211	1.271	5.0	1.270	4.9	1.266	4.6	1.266	4.5
^{238}U	970.9	970.2	-0.1	970.2	-0.1	970.2	-0.1	970.2	-0.1
^{238}Pu	2.401×10^{-3}	2.620×10^{-3}	9.1	2.638×10^{-3}	9.9	2.426×10^{-3}	1.0	2.433×10^{-3}	1.3
^{239}Pu	2.016	2.156	7.0	2.158	7.0	2.126	5.5	2.125	5.4
^{240}Pu	0.2722	0.2857	4.9	0.2855	4.9	0.2911	6.9	0.2909	6.9
^{241}Pu	4.812×10^{-2}	5.628×10^{-2}	17.0	5.642×10^{-2}	17.2	5.253×10^{-2}	9.2	5.256×10^{-2}	9.2
^{242}Pu	3.888×10^{-3}	4.015×10^{-3}	3.3	4.039×10^{-3}	3.9	4.231×10^{-3}	8.8	4.252×10^{-3}	9.4
^{241}Am	1.311×10^{-2}	1.575×10^{-2}	20.2	1.582×10^{-2}	20.7	1.475×10^{-2}	12.5	1.479×10^{-2}	12.8

Table 32. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 6.51-GWd/MTU burnup and 0.7600 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	0.1364	0.1402	2.8	0.1401	2.7	0.1392	2.1	0.1391	2.0
^{235}U	19.09	19.05	-0.2	19.05	-0.2	19.06	-0.1	19.06	-0.1
^{236}U	1.314	1.328	1.1	1.328	1.1	1.323	0.7	1.323	0.7
^{238}U	970.1	969.9	0.0	969.9	0.0	970.0	0.0	970.0	0.0
^{238}Pu	2.969×10^{-3}	3.040×10^{-3}	2.4	3.061×10^{-3}	3.1	2.816×10^{-3}	-5.1	2.824×10^{-3}	-4.9
^{239}Pu	2.173	2.246	3.3	2.247	3.4	2.214	1.9	2.212	1.8
^{240}Pu	0.3086	0.3130	1.4	0.3129	1.4	0.3192	3.4	0.3189	3.3
^{241}Pu	5.974×10^{-2}	6.452×10^{-2}	8.0	6.463×10^{-2}	8.2	6.022×10^{-2}	0.8	6.022×10^{-2}	0.8
^{242}Pu	5.187×10^{-3}	4.919×10^{-3}	-5.2	4.945×10^{-3}	-4.7	5.183×10^{-3}	-0.1	5.207×10^{-3}	0.4
^{241}Am	1.609×10^{-2}	1.807×10^{-2}	12.3	1.813×10^{-2}	12.7	1.692×10^{-2}	5.2	1.695×10^{-2}	5.4

Table 33. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 6.95-GWd/MTU burnup and 0.6719 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{235}U	0.1343	0.1389	3.4	0.1388	3.3	0.1379	2.6	0.1377	2.6
^{235}U	18.75	18.71	-0.2	18.71	-0.2	18.71	-0.2	18.71	-0.2
^{236}U	1.375	1.398	1.7	1.397	1.6	1.392	1.3	1.392	1.2
^{238}U	969.5	969.5	0.0	969.5	0.0	969.5	0.0	969.5	0.0
^{238}Pu	3.875×10^{-3}	3.952×10^{-3}	2.0	3.977×10^{-3}	2.6	3.655×10^{-3}	-5.7	3.665×10^{-3}	-5.4
^{239}Pu	2.432	2.459	1.1	2.460	1.2	2.419	-0.5	2.417	-0.6
^{240}Pu	0.3592	0.3563	-0.8	0.3560	-0.9	0.3639	1.3	0.3635	1.2
^{241}Pu	8.111×10^{-2}	8.114×10^{-2}	0.0	8.120×10^{-2}	0.1	7.572×10^{-2}	-6.6	7.565×10^{-2}	-6.7
^{242}Pu	7.181×10^{-3}	6.586×10^{-3}	-8.3	6.616×10^{-3}	-7.9	6.963×10^{-3}	-3.0	6.991×10^{-3}	-2.7
^{241}Am	2.114×10^{-2}	2.277×10^{-2}	7.7	2.283×10^{-2}	8.0	2.133×10^{-2}	0.9	2.135×10^{-2}	1.0

Table 34. Measured and computed irradiated fuel composition (in units of mg/g of U) for 6 × 6 JPDR assembly for 7.01-GWd/MTU burnup and 0.6719 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1353	0.1388	2.6	0.1387	2.5	0.1377	1.8	0.1376	1.7
^{235}U	18.88	18.65	-1.2	18.66	-1.1	18.67	-1.1	18.67	-1.1
^{236}U	1.390	1.406	1.2	1.405	1.1	1.401	0.8	1.401	0.8
^{238}U	969.4	969.4	0.0	969.4	0.0	969.4	0.0	969.4	0.0
^{238}Pu	3.564×10^{-3}	4.033×10^{-3}	13.2	4.059×10^{-3}	13.9	3.730×10^{-3}	4.7	3.740×10^{-3}	4.9
^{239}Pu	2.360	2.471	4.7	2.473	4.8	2.432	3.0	2.429	2.9
^{240}Pu	0.3518	0.3607	2.5	0.3604	2.4	0.3684	4.7	0.3680	4.6
^{241}Pu	7.508×10^{-2}	8.259×10^{-2}	10.0	8.265×10^{-2}	10.1	7.707×10^{-2}	2.7	7.700×10^{-2}	2.6
^{242}Pu	6.739×10^{-3}	6.767×10^{-3}	0.4	6.798×10^{-3}	0.9	7.155×10^{-3}	6.2	7.183×10^{-3}	6.6
^{241}Am	1.825×10^{-2}	2.318×10^{-2}	27.0	2.324×10^{-2}	27.3	2.171×10^{-2}	19.0	2.173×10^{-2}	19.1

Table 35. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 17.84-GWd/MTU burnup and 0.3452 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1740	0.1768	1.6	0.1770	1.7	0.1742	0.1	0.1744	0.2
^{235}U	13.00	12.68	-2.5	12.63	-2.8	12.70	-2.3	12.74	-2.7
^{236}U	2.480	2.474	-0.2	2.474	-0.2	2.470	-0.4	2.470	-0.4
^{238}U	854.5	844.3	-1.2	844.4	-1.2	844.4	-1.2	844.5	-1.2
^{238}Pu	0.05210	0.04839	-7.1	0.04723	-9.3	0.04373	-16.1	0.04265	-18.1
^{239}Pu	4.056	4.025	-0.8	3.974	-2.0	3.927	-3.2	3.872	-4.5
^{240}Pu	1.184	1.073	-9.4	1.071	-9.5	1.138	-3.9	1.132	-4.4
^{241}Pu	0.3415	0.3887	13.8	0.3789	11.0	0.3580	4.8	0.3487	2.1
^{242}Pu	0.08742	0.08980	2.7	0.08867	1.4	0.09593	9.7	0.09438	8.0
^{137}Cs	0.04050	0.04056	0.1	0.04056	0.1	0.04057	0.2	0.04057	0.2

Table 36. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 18.96-GWd/MTU burnup and 0.3446 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1700	0.1741	2.4	0.1742	2.5	0.1713	0.8	0.1715	0.9
^{235}U	11.91	12.06	1.3	12.02	0.9	12.09	1.5	12.03	1.0
^{236}U	2.630	2.573	-2.1	2.574	-2.1	2.570	-2.3	2.569	-2.3
^{238}U	843.7	843.6	0.0	843.6	0.0	843.6	0.0	843.7	0.0
^{238}Pu	0.05350	0.05580	4.3	0.05455	2.0	0.05047	-5.7	0.04930	-7.9
^{239}Pu	3.738	4.104	9.8	4.055	8.5	4.002	7.1	3.949	5.6
^{240}Pu	1.220	1.153	-5.5	1.150	-5.7	1.223	0.3	1.217	-0.2
^{241}Pu	0.3403	0.4210	23.7	0.4094	20.3	0.3877	13.9	0.3769	10.7
^{242}Pu	0.09892	0.1057	6.9	0.1044	5.6	0.1129	14.2	0.1112	12.4
^{137}Cs	0.04270	0.04291	0.5	0.04291	0.5	0.04293	0.5	0.04292	0.5

Table 37. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 29.23-GWd/MTU burnup and 0.3723 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1460	0.1455	-0.3	0.1453	-0.5	0.1418	-2.9	0.1416	-3.0
^{235}U	7.760	6.295	-18.9	6.266	-19.3	6.287	-19.0	6.246	-19.5
^{236}U	3.360	3.394	1.0	3.397	1.1	3.396	1.1	3.397	1.1
^{238}U	849.0	834.6	-1.7	834.6	-1.7	834.7	-1.7	834.7	-1.7
^{238}Pu	0.1460	0.1782	22.0	0.1762	20.7	0.1636	12.1	0.1619	10.9
^{239}Pu	4.526	4.398	-2.8	4.361	-3.7	4.275	-5.6	4.236	-6.4
^{240}Pu	2.164	1.899	-12.2	1.895	-12.4	2.023	-6.5	2.017	-6.8
^{241}Pu	0.6649	0.8006	20.4	0.7686	15.6	0.7419	11.6	0.7133	7.3
^{242}Pu	0.3247	0.3931	21.1	0.3884	19.6	0.4218	29.9	0.4162	28.8
^{137}Cs	0.07250	0.07366	1.6	0.07369	1.6	0.07366	1.6	0.07370	1.7

Table 38. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 30.07-GWd/MTU burnup and 0.4705 g/cm^3 water density

		ENDF/B-IV actinide data				ENDF/B-V actinide data			
Nuclide	Measured	ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1350	0.1451	7.5	0.1449	7.3	0.1414	4.7	0.1410	4.5
^{235}U	5.340	5.564	4.2	5.543	3.8	5.556	4.0	5.525	3.5
^{236}U	3.530	3.451	-2.2	3.456	-2.1	3.452	-2.2	3.455	-2.2
^{238}U	834.6	834.8	0.0	834.7	0.0	834.8	0.0	834.8	0.0
^{238}Pu	0.1743	0.1691	-3.0	0.1675	-3.9	0.1563	-10.3	0.1549	-11.2
^{239}Pu	3.579	4.027	12.5	3.996	11.7	3.922	9.6	3.891	8.7
^{240}Pu	2.216	1.966	-11.3	1.965	-11.3	2.071	-6.5	2.068	-6.7
^{241}Pu	0.6390	0.7327	14.7	0.7144	11.8	0.6832	6.9	0.6673	4.4
^{242}Pu	0.4407	0.4175	-5.3	0.4123	-6.4	0.4473	1.5	0.4414	0.2
^{137}Cs	0.07480	0.07549	0.9	0.07557	1.0	0.07549	0.9	0.07557	1.0

Table 39. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 31.04-GWd/MTU burnup and 0.6124 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1540	0.1509	-2.0	0.1506	-2.2	0.1472	-4.4	0.1466	-4.8
^{235}U	6.280	5.712	-9.1	5.754	-8.4	5.713	-9.0	5.746	-8.5
^{236}U	3.480	3.397	-2.4	3.390	-2.6	3.395	-2.4	3.387	-2.7
^{238}U	845.5	837.3	-1.0	837.2	-1.0	837.3	-1.0	837.4	-1.0
^{238}Pu	0.1389	0.1293	-6.9	0.1323	-4.8	0.1201	-13.5	0.1213	-11.4
^{239}Pu	3.668	3.568	-2.7	3.588	-2.2	3.486	-5.0	3.503	-4.5
^{240}Pu	2.082	1.891	-9.2	1.824	-12.4	1.969	-5.4	1.907	-8.4
^{241}Pu	0.6139	0.6058	-1.3	0.6151	0.2	0.5688	-7.4	0.5771	-6.0
^{242}Pu	0.3823	0.3538	-7.5	0.3573	-6.5	0.3776	-1.2	0.3809	-0.4
^{137}Cs	0.06850	0.07087	3.5	0.07100	3.7	0.07086	3.4	0.07101	3.7

Table 40. Measured and computed irradiated fuel composition (in units of mg/g of UO_2) for 7 × 7 Cooper assembly for 33.94-GWd/MTU burnup and 0.5736 g/cm^3 water density

Nuclide	Measured	ENDF/B-IV actinide data				ENDF/B-V actinide data			
		ARP	% diff.	SAS2H	% diff.	ARP	% diff.	SAS2H	% diff.
^{234}U	0.1440	0.1444	0.3	0.1442	0.1	0.1404	-2.5	0.1400	-2.8
^{235}U	4.830	4.918	1.8	4.899	1.4	4.911	1.7	4.885	1.1
^{236}U	3.630	3.498	-3.6	3.503	-3.5	3.498	-3.6	3.501	-3.6
^{238}U	838.1	834.9	-0.4	834.9	-0.4	835.0	-0.4	834.9	-0.4
^{238}Pu	0.1706	0.1647	-3.5	0.1633	-4.3	0.1533	-10.1	0.1521	-10.8
^{239}Pu	3.336	3.704	11.0	3.679	10.3	3.614	8.3	3.589	7.6
^{240}Pu	2.190	1.974	-9.8	1.973	-9.9	2.068	-5.6	2.066	-5.7
^{241}Pu	0.6201	0.6964	12.3	0.6802	9.7	0.6525	5.2	0.6383	2.9
^{242}Pu	0.4737	0.4467	-5.7	0.4413	-6.8	0.4779	0.9	0.4716	-0.4
^{137}Cs	0.07700	0.07756	0.7	0.07767	0.9	0.07757	0.7	0.07767	0.9

7. LISTBURN UTILITY PROGRAM

This utility program is intended to provide the burnup positions where the cross sections are calculated in a SAS2H calculation. To run this program users are asked to answer some prompts concerning the number of cycles, fuel irradiation period for each cycle, the specific power for each cycle and the number of libraries per cycle. To illustrate the use of the LISTBURN program, let us use the example mentioned in the previous section. The corresponding input would be:

Number of cycles: 21
Fuel irradiation period of each cycle: 0.0 20*75.0
Specific power for each cycle: 21*40.0
Number of libraries per cycle: 21*1
Output filename: outburn

The file named "outburn" will contain the results listed in Table 41. (Note that the data in Table 41 are identical to the data in Table 1.) In Table 41, position 1 corresponds to the cross sections prior to irradiation (i.e., the fresh-fuel cross sections).

Table 41. Twenty-one burnup positions of the SAS2H-generated libraries

Position	Burnup (MWd/MTU)
1	0
2	1500
3	4500
4	7500
5	10500
6	13500
7	16500
8	19500
9	22500
10	25500
11	28500
12	31500
13	34500
14	37500
15	40500
16	43500
17	46500
18	49500
19	52500
20	55500
21	58500

8. XSECLIST UTILITY PROGRAM

The XSECLIST program is intended to provide an interpreted listing of the ORIGEN-S burnup-dependent cross-section library. This utility program allows users to list the information for any or all nuclides in the library as a function of burnup. Information can be given for the absorption cross section and/or fission cross section. To run this program users are inquired to answer some prompts. The absorption cross sections are given for light elements, actinides, and fission products. At the present time there are 689 light-element nuclides, 129 actinides, and 879 fission products, totaling 1697 nuclides. Some of the light-element isotopes present may also appear as fission products; therefore, a few isotopes may be listed twice, but the cross-section values for each listing may be different. Many of the 129 actinides have fission cross sections.

ORIGEN-S cross sections are normalized to thermal flux, rather than the more conventional method of applying total flux. Either thermal flux or specific power may be input to irradiation cases.

The nuclide ID numbers used in library data have the form IZ*10000 + IA*10 + IS, where:

IZ = the atomic number;
IA = the atomic weight;
IS = 0, for ground state;
= 1, for metastable state.

The following examples illustrate how XSECLIST can be used for listing information for some nuclides in the ORIGEN-S library. (The procedure to list the entire library is identical). The ORIGEN-S library, for which the data are to be listed, was generated in a SAS2H calculation with the same information as that used in the example of the LISTBURN program.

The input sequence for this case is

```
Number of cycles:  21
Fuel irradiation period of each cycle:  0.0 20*75.0
Specific power for each cycle:  21*40.0
Number of libraries per cycle:  21*1
Data (absorption (a), fission (f), or both (b)):  a
List entire library (yes = y, no = n):  n
Enter library name:  inplib
Output filename:  outlist
No. of materials:  5
Material identification:  10010 10030 80160 410930 942400
```

In this example the absorption cross section for five nuclides in the ORIGEN-S library called inplib, namely H, ^{3}H, ^{16}O, ^{93}Nb, and ^{240}Pu, are listed as a function of burnup. The results are in the file called outlist and are listed in Table 42. The SAS2H input to generate the burnup-dependent cross-section library inplib is shown in Appendix D. A list of the burnup-dependent fission cross sections can be obtained in a similar manner.

Table 42. Burnup-dependent absorption cross sections listed from the library name inplib

```
 *** Absorption cross section ***
LIGHT ELEMENTS
 Material  10010  h  1
     Burnup            xsec
  0.00000E+00       2.92297E-01
  1.50000E+00       2.67025E-01
  4.50000E+00       2.69065E-01
  7.50000E+00       2.70637E-01
  1.05000E+01       2.71527E-01
  1.35000E+01       2.71941E-01
  1.65000E+01       2.72022E-01
  1.95000E+01       2.71868E-01
  2.25000E+01       2.71552E-01
  2.55000E+01       2.71128E-01
  2.85000E+01       2.70639E-01
  3.15000E+01       2.70120E-01
  3.45000E+01       2.69602E-01
  3.75000E+01       2.69107E-01
  4.05000E+01       2.68653E-01
  4.35000E+01       2.68251E-01
  4.65000E+01       2.67910E-01
  4.95000E+01       2.67631E-01
  5.25000E+01       2.67413E-01
  5.55000E+01       2.67253E-01
  5.85000E+01       2.67143E-01
 Material  10030  h  3
     Burnup            xsec
  0.00000E+00       2.52490E-06
  1.50000E+00       2.36058E-06
  4.50000E+00       2.36536E-06
  7.50000E+00       2.37026E-06
  1.05000E+01       2.38116E-06
  1.35000E+01       2.39632E-06
  1.65000E+01       2.41435E-06
  1.95000E+01       2.43422E-06
  2.25000E+01       2.45510E-06
  2.55000E+01       2.47627E-06
  2.85000E+01       2.49719E-06
  3.15000E+01       2.51729E-06
  3.45000E+01       2.53615E-06
  3.75000E+01       2.55341E-06
  4.05000E+01       2.56881E-06
  4.35000E+01       2.58219E-06
  4.65000E+01       2.59351E-06
  4.95000E+01       2.60281E-06
  5.25000E+01       2.61020E-06
  5.55000E+01       2.61586E-06
  5.85000E+01       2.61999E-06
```

Table 42 (continued)

Material 80160 o 16

Burnup	xsec
0.00000E+00	2.27990E-02
1.50000E+00	1.77986E-02
4.50000E+00	1.84592E-02
7.50000E+00	1.90129E-02
1.05000E+01	1.93594E-02
1.35000E+01	1.95551E-02
1.65000E+01	1.96438E-02
1.95000E+01	1.96565E-02
2.25000E+01	1.96160E-02
2.55000E+01	1.95404E-02
2.85000E+01	1.94431E-02
3.15000E+01	1.93357E-02
3.45000E+01	1.92275E-02
3.75000E+01	1.91258E-02
4.05000E+01	1.90359E-02
4.35000E+01	1.89616E-02
4.65000E+01	1.89051E-02
4.95000E+01	1.88669E-02
5.25000E+01	1.88467E-02
5.55000E+01	1.88429E-02
5.85000E+01	1.88538E-02

Material 410930 nb 93

Burnup	xsec
0.00000E+00	2.98754E+00
1.50000E+00	2.26611E+00
4.50000E+00	2.31361E+00
7.50000E+00	2.35273E+00
1.05000E+01	2.37533E+00
1.35000E+01	2.38599E+00
1.65000E+01	2.38825E+00
1.95000E+01	2.38462E+00
2.25000E+01	2.37693E+00
2.55000E+01	2.36664E+00
2.85000E+01	2.35483E+00
3.15000E+01	2.34243E+00
3.45000E+01	2.33020E+00
3.75000E+01	2.31873E+00
4.05000E+01	2.30845E+00
4.35000E+01	2.29967E+00
4.65000E+01	2.29254E+00
4.95000E+01	2.28711E+00
5.25000E+01	2.28334E+00
5.55000E+01	2.28108E+00
5.85000E+01	2.28017E+00

Table 42 (continued)

```
ACTINIDES
 Material  942400 pu240
     Burnup            xsec
  0.00000E+00       1.72582E+03
  1.50000E+00       1.25301E+03
  4.50000E+00       1.09789E+03
  7.50000E+00       9.44735E+02
  1.05000E+01       8.26692E+02
  1.35000E+01       7.38705E+02
  1.65000E+01       6.72433E+02
  1.95000E+01       6.21487E+02
  2.25000E+01       5.81527E+02
  2.55000E+01       5.49640E+02
  2.85000E+01       5.23841E+02
  3.15000E+01       5.02758E+02
  3.45000E+01       4.85409E+02
  3.75000E+01       4.71074E+02
  4.05000E+01       4.59202E+02
  4.35000E+01       4.49367E+02
  4.65000E+01       4.41223E+02
  4.95000E+01       4.34489E+02
  5.25000E+01       4.28927E+02
  5.55000E+01       4.24335E+02
  5.85000E+01       4.20545E+02
FISSION PRODUCTS
 Material  10030  h  3
     Burnup            xsec
  0.00000E+00       0.00000E+00
  1.50000E+00       0.00000E+00
  4.50000E+00       0.00000E+00
  7.50000E+00       0.00000E+00
  1.05000E+01       0.00000E+00
  1.35000E+01       0.00000E+00
  1.65000E+01       0.00000E+00
  1.95000E+01       0.00000E+00
  2.25000E+01       0.00000E+00
  2.55000E+01       0.00000E+00
  2.85000E+01       0.00000E+00
  3.15000E+01       0.00000E+00
  3.45000E+01       0.00000E+00
  3.75000E+01       0.00000E+00
  4.05000E+01       0.00000E+00
  4.35000E+01       0.00000E+00
  4.65000E+01       0.00000E+00
  4.95000E+01       0.00000E+00
  5.25000E+01       0.00000E+00
  5.55000E+01       0.00000E+00
  5.85000E+01       0.00000E+00
```

Table 42 (continued)

Material 410930 nb 93

Burnup	xsec
0.00000E+00	2.98754E+00
1.50000E+00	2.26611E+00
4.50000E+00	2.31361E+00
7.50000E+00	2.35273E+00
1.05000E+01	2.37533E+00
1.35000E+01	2.38599E+00
1.65000E+01	2.38825E+00
1.95000E+01	2.38462E+00
2.25000E+01	2.37693E+00
2.55000E+01	2.36664E+00
2.85000E+01	2.35483E+00
3.15000E+01	2.34243E+00
3.45000E+01	2.33020E+00
3.75000E+01	2.31873E+00
4.05000E+01	2.30845E+00
4.35000E+01	2.29967E+00
4.65000E+01	2.29254E+00
4.95000E+01	2.28711E+00
5.25000E+01	2.28334E+00
5.55000E+01	2.28108E+00
5.85000E+01	2.28017E+00

9. XSECPLOT UTILITY PROGRAM

XSECPLOT is a utility program that allows users to obtain ORIGEN-S burnup-dependent cross sections in a graphical form. This program is executed by answering some prompts. Graphical displays can be obtained for the absorption cross section and the fission cross section. Multiple plots of the cross sections for various nuclides can be made with this program. However, there is a limit of ten selected nuclides per plot. The following examples illustrate the use of the XSECPLOT program:

1. Plotting of the absorption cross section

```
Number of cycles:  21
Fuel irradiation period of each cycle:  0.0 20*75.0
Specific power for each cycle:  21*40.0
Number of libraries per cycle:  21*1
Data (absorption (a), fission (f)):  a
Enter library name:  inplib
Number of materials:  4
Material identification:  10010 80160 410930 942400
```

In this example, the absorption cross sections of four nuclides in the ORIGEN-S library inplib are plotted as a function of burnup. The nuclides are H, O, ^{93}Nb, and ^{240}Pu. The results are displayed in Fig. 4.

2. Plotting of the fission cross section

```
Number of cycles:  21
Fuel irradiation period of each cycle:  0.0 20*75.0
Specific power for each cycle:  21*40.0
Number of libraries per cycle:  21*1
Data (absorption (a), fission (f)):  f
Enter library name:  inplib
Number of materials:  5
Material identification:  922350 922380 942390 942400 942400
```

In this example the absorption cross section of five nuclides in the ORIGEN-S library inplib are plotted as a function of burnup. The nuclides are ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu. The results are displayed in Fig. 5.

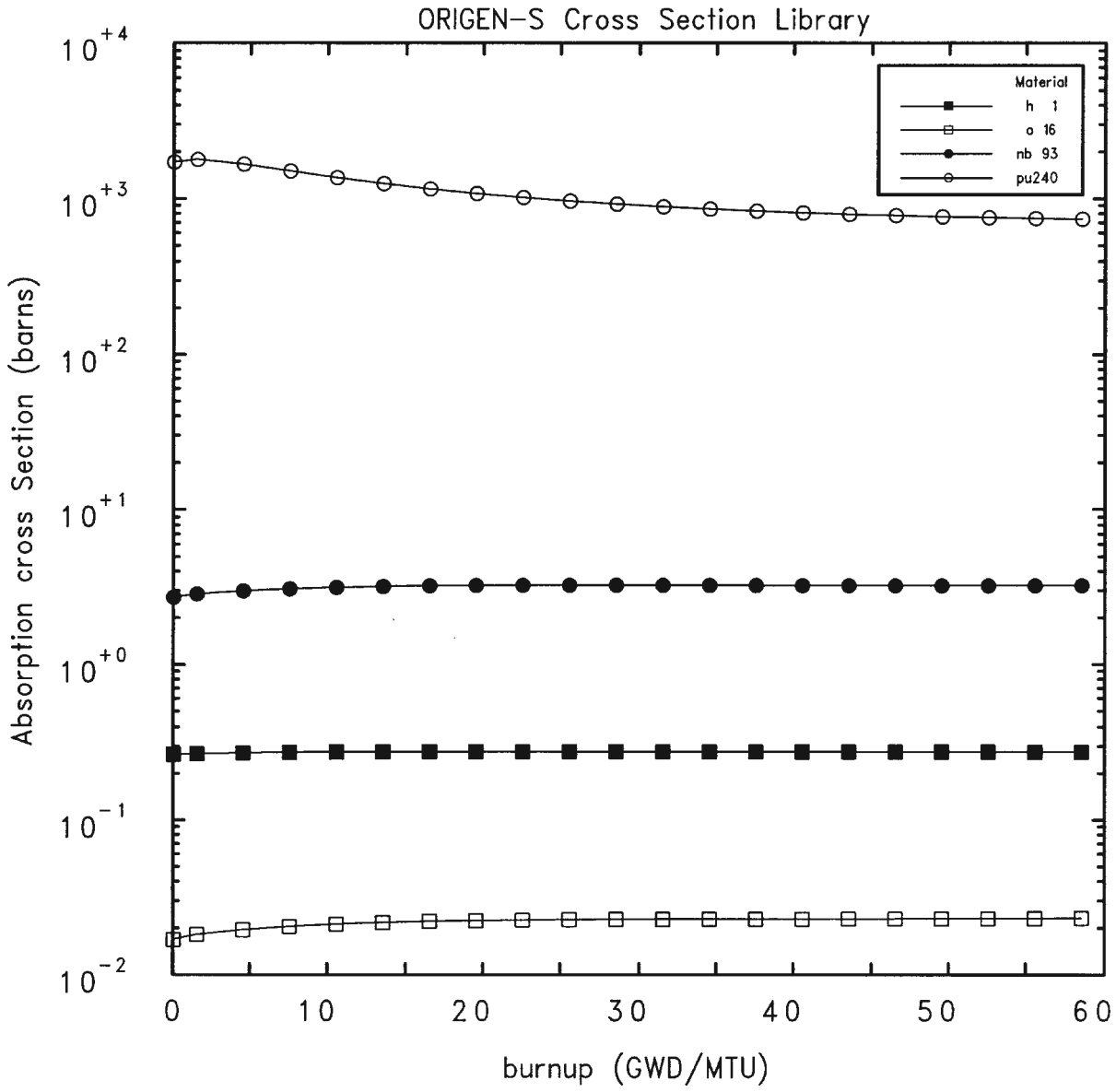

Fig. 4. ORIGEN-S burnup-dependent absorption cross sections for four nuclides: H, O, ^{93}Nb, and ^{240}Pu.

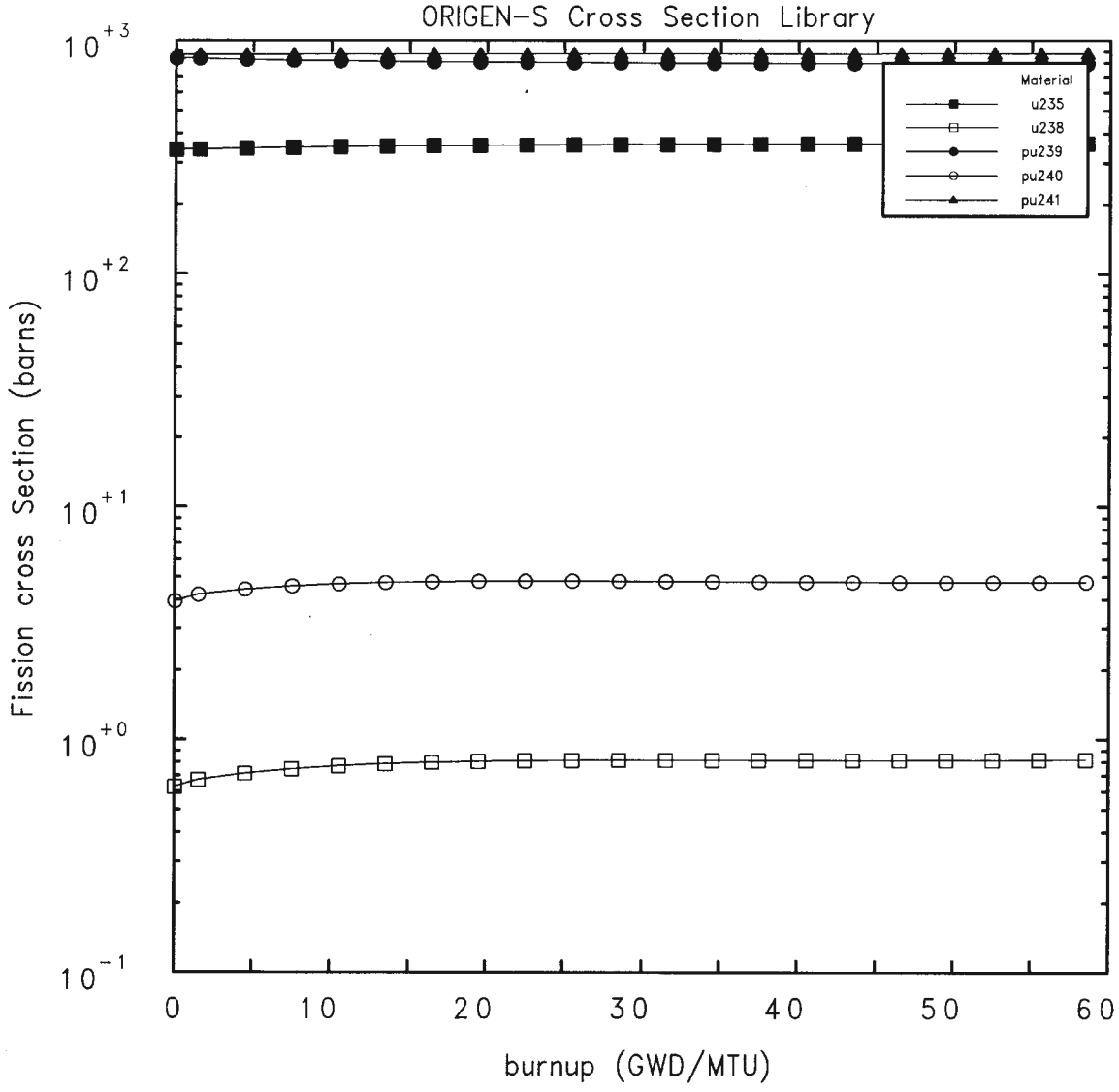

Fig. 5. ORIGEN-S burnup-dependent fission cross sections for five nuclides: ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu.

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APPENDIX A

LISTING OF THE FORTRAN PROGRAM TO REDUCE FROM 21 TO 10 BURNUP POSITIONS

APPENDIX A

LISTING OF THE FORTRAN PROGRAM TO REDUCE FROM 21 TO 10 BURNUP POSITIONS

```
c
      program reduclib
      character*80 file
      dimension r(20000), ir(20000), in(21)
c
      data in/7*1, 4*0, 1, 4*0, 1 , 3*0,1/
c
      ni = 50
      nt = 51
c
c   Filename of the library with 21 burnup points
c
      write(6,'(" Input library name:"$)')
      read(5,'(a)') file
      open(ni,file=file,status='old',form='unformatted')
c
c   Filename which will contain the reduced library
c
      write(6,'(" Reduced library name:"$)')
      read(5,'(a)') file
      open(nt,file=file,status='unknown',form='unformatted')
c
      nl = 21
      do 5 il = 1, nl
        if (il .le. 1) then
          read(ni) (ir(k), k = 1, 14), (r(k), k = 1,4),
     *             (ir(k), k = 15, 16)
          write(nt) (ir(k), k = 1, 14), (r(k), k = 1,4),
     *              (ir(k), k = 15, 16)
          read(ni) j, (r(k), k = 1, j)
          write(nt) j, (r(k), k = 1, j)
          read(ni) j, (ir(k), k = 1, j)
          write(nt) j, (ir(k), k = 1, j)
          read(ni) j, (r(k), k = 1, j)
          write(nt) j, (r(k), k = 1, j)
          do 1 k = 1, 4
            read(ni) j, (ir(kk), kk = 1, j)
            write(nt) j, (ir(kk), kk = 1, j)
 1        continue
          do 2 k = 1, 32
            read(ni) j, (r(kk), kk = 1, j)
            write(nt) j, (r(kk), kk = 1, j)
 2        continue
          else
          if( in(il) .eq. 0 ) then
            do 3 k = 1, 4
              read(ni)
 3          continue
          else
            do 4 k = 1, 4
              read(ni) j, (r(kk), kk = 1, j)
              write(nt) j, (r(kk), kk = 1, j)
 4          continue
          endif
        endif
 5    continue
      stop
      end
```

This program will prompt the following statements:

(a) **Input library name:**

User is required to enter the library name that contains the 21 burnup positions.

(b) **Reduced library name:**

User is required to enter the reduced library name that will have the 10 burnup positions.

APPENDIX B

EXAMPLE ON HOW TO GENERATE ARP BASIC LIBRARIES

APPENDIX B

EXAMPLE ON HOW TO GENERATE ARP BASIC LIBRARIES

Several steps are required to create ARP cross-section libraries. As a matter of example, here a sample case is presented for a BWR 7 × 7 assembly. The example can be used as a guideline to generate ARP cross-section libraries for other reactor assemblies. The steps are as follows:

1. Construction of SAS2H input.

It is assumed that users are familiar with the SCALE system, in particular, with the SAS2H sequence. The BWR 7 × 7 SAS2H input is displayed in Fig. B-1. This input indicates that SAS2H will generate problem-dependent cross sections for an enrichment of 2.0 wt % of ^{235}U and water density of 0.2 g/cm^3. The total number of cycles is 21 with one library per cycle. The burnup position of each library is given in Table 1 (p. 10). Note that the fresh-fuel cross section, corresponding to the first burnup position, is included.

Problem-dependent cross-section libraries at specific enrichments, 1.5, 2.0, 3.0, 4.0, and 5.0 wt % ^{235}U and water densities 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 g/cm^3 are created by changing the numbers indicated in bold in Fig. B-1. Note that the cross-section library is in the file ft33f001, whereas the file ft71f001 contains the isotopic concentrations. For instance, to generate a cross-section library at 3.0 wt % ^{235}U, modification to the SAS2H input with regard to the fractional composition of enriched uranium has to be made, while keeping other input values unchanged. The changes would be as follows:

```
uo2  1 den=10.32   1  840
 92234 0.0178 92235 2.0 92236 0.0092 92238 97.973 end
```

becomes

```
uo2  1 den=10.32   1  840
 92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
```

Similarly, cross-section libraries for other enrichments are obtained. An analogous procedure is used to generate water-density-dependent cross-section libraries. The following change would be needed to generate problem-dependent cross sections at 0.3 g/cm^3. The changes would be:

```
h2o  3 den=0.2000   1  558 end
```

becomes

```
h2o  3 den=0.3000   1  558 end
```

Note that in the SAS2H input of Fig. B-1, the reactor power history is given in 21 lines, namely, the assembly average specific power (keyword "power="), fuel irradiation period (keyword "burn=") and downtime (keyword "down="). The average specific power for each cycle is 40 MW/MTU, and the fuel irradiation is 75 days, resulting in a burnup per cycle of 3000 MWd/MTU.

Note also that the irradiation time for the first cycle is 1.0×10^{-15}, meaning that the fresh-fuel cross sections are retained.

```
=sas2     parm='halt21,skipshipdata'
sas2 cooper bwr 7×7.
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
27burnuplib    latticecell
uo2  1 den=10.32   1  840
 92234 0.0178 92235 2.0 92236 0.0092 92238 97.973 end
'     bwr7×7
co-59  3 0 1-20 558  end
zr-94  1 0 1-20 840  end
nb-95  1 0 1-20 840  end
mo-95  1 0 1-20 840  end
tc-99  1 0 1-20 840  end
rh-103 1 0 1-20 840  end
rh-105 1 0 1-20 840  end
ru-106 1 0 1-20 840  end
sn-126 1 0 1-20 840  end
xe-131 1 0 1-20 840  end
cs-134 1 0 1-20 840  end
cs-135 1 0 1-20 840  end
cs-137 1 0 1-20 840  end
pr-143 1 0 1-20 840  end
nd-143 1 0 1-20 840  end
ce-144 1 0 1-20 840  end
nd-144 1 0 1-20 840  end
nd-145 1 0 1-20 840  end
nd-146 1 0 1-20 840  end
nd-147 1 0 1-20 840  end
pm-147 1 0 1-20 840  end
sm-147 1 0 1-20 840  end
nd-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-149 1 0 1-20 840  end
sm-149 1 0 1-20 840  end
nd-150 1 0 1-20 840  end
sm-150 1 0 1-20 840  end
sm-151 1 0 1-20 840  end
eu-151 1 0 1-20 840  end
sm-152 1 0 1-20 840  end
eu-153 1 0 1-20 840  end
eu-154 1 0 1-20 840  end
eu-155 1 0 1-20 840  end
zircalloy  2 1  620   end
h2o  3 den=0.2000   1  558 end
'
```

Fig. B-1. SAS2H input for the generation of ARP cross-section library

```
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'   mixtures of larger-unit-cell:
'
uo2  5 den=10.32   1  840
 92234 0.0178 92235 2.0 92236 0.0092 92238 97.973 end
arbm-gdburn  10.32    7 0 1 1
           64154  2.18  64155 14.80  64156 20.47
               64157 15.65  64158 24.84  64160 21.86
                     8016 150.0  5   0.034   840  end

'                ....above is 3.4 wt % gadolinium (as gd2-ox3) in the
'                    burnable poison pins of bwr assembly....
n          6  0  1-5 840  end
zircalloy  7  1  558 end
'                ....above is zircalloy casing around assembly
h2o       11  den=0.7627   1    552  end
'                ....above is channel moderator at higher density
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'      fuel-pin-cell geometry:
'
squarepitch   1.875   1.212   1 3  1.430   2  1.242   0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'    assembly and cycle parameters:
'
npin/assm=49  fuelngth=1944.52  ncycles=21  nlib/cyc=1
printlevel=4  lightel=8  inplevel=2  numzones=7   end
5  0.606   6  0.621   2  0.715   3  1.058
 500 3.311   7 3.412  11  3.845
power=40    burn=1.0e-15 down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=1500.0   end
       h   14.5     o  236      cr  2.1
       mn  0.13    fe  5.8      ni 2.1
       zr  455     sn  7.7
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end
=shell
mv ft33f001     $RTNDIR/bwr7x7e2d2.lib
mv ft71f001     $RTNDIR/bwr7x7e2d2.con
end
```

Fig. B-1 (continued)

2. Reduce Cross-Section Library from 21 to 10 burnups

In using the FORTRAN program listed in Appendix A to reduce from 21-burnup to 10-burnup libraries, users are required to answer prompts, which are the names of the files containing the 21-burnup library and the filename of the 10-burnup library. At this point, users should be aware of the convention in regard to the filename of the 10-burnup library.

APPENDIX C

FORTRAN LISTING OF THE ARP CODE

APPENDIX C

FORTRAN LISTING OF THE ARP CODE

In addition to the FORTRAN program, ARP requires a C routine called **jstime**, which is listed at the end of the ARP listing.

```
      program arp
      parameter (n1=10000, n2=40, n3=2, n4=3000)
c
      character*80 confi, filein, bwr(3)
c
c    This program generates ORIGEN-S cross section libraries by
c    interpolating over burnup, enrichment and water density. SAS2H
c    pre-generated libraries must exist to carry out the interpolation.
c    In this version libraries exist for PWR and BWR system for the
c    following configurations:
c
c          a) PWR systems:
c             14x14, 15x15 and 17x17 configurations.
c             The following example for the 14x14 configuation illustrates
c             how the pre-generated SAS2H libraries are referenced in the
c             program:  s114x14, s214x14 and so on where s114x14 means
c             1.5 % enrichment for the 14x14 configuration, s214x14
c             means 2.0 % enrichment, etc.
c
c          b) BWR systems:
c             6×6, 7×7 and 8x8 configurations.
c             The library names are s16×62, s16×63 and so on. s16×6
c             means 1.5 % enrichment and water density of 0.2 g/cm**3
c             for the 6×6 configuration.
c
c
c                Luiz C. Leal
c                Nuclear Data Group
c                Radiation Information Analysis Section
c                Computational Physics and Engineering Division
c                Oak Ridge National Laboratory
c                e-mail: leallc@ornl.gov
c                http://www.cad.ornl.gov/~ros/NUCDATA/NDgroup.html
c
      dimension a(n1, n2, n3), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *          genu(n4, n2, n3), ir(n4)
c
      common /inp/kj, enrt, ncy, tirad(n2), spf(n2), nlcy(n2), confi,
     *            filein, rho
c
      data bwr/'6×6', '7×7', '8x8'/
c
c   Prompts:
c
      write(6,'(" Assembly type:"$)')
      read(5,'(a)') confi
      write(6,'(" Enrichment:"$)')
      read(5,*) enrt
      write(6,'(" Number of cycle:"$)')
      read(5,*) ncy
      write(6,'(" Fuel irradiation period for each cycle:"$)')
      read(5,*) (tirad(i), i = 1, ncy)
      write(6,'(" Specify power for each cycle:"$)')
      read(5,*) (spf(i), i = 2, ncy+1)
      write(6,'(" Number of libraries made per cycle:"$)')
      read(5,*) (nlcy(i), i = 1, ncy)
      write(6,'(" Water density (g/cm**3):"$)')
```

```
      read(5,*) rho
      write(6,'(" Interpolated library name:"$)')
      read(5,'(a)') filein
c
c     End of prompts
c
      call jstime(j1)
c
c     Define case: PWR (14x14, 15x15, 17x17)
c
c                  BWR (6×6,   7×7,     8x8)
c
      if(confi .eq. bwr(1) .or. confi .eq. bwr(2) .or.
     *   confi .eq. bwr(3)) then
c
c     Perform enrichment and water density interpolation for BWR.
c
        call libdensenrch(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
      else
c
c     Perform enrichment interpolation for PWR.
c
        call libenrch(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
      endif
c
c     Perform interpolation over burnup
c
      call libburn(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
c
c     Interpolated library name
c
      call newlib(a, rcap, rfiss, genu, n1, n2, n3, n4)
      call jstime(j2)
      tlf = (j1 - j2 ) * 0.01
      write(6,'(a, f9.2, a)') ' Cpu time used ', tlf,' seconds'
c
      stop
      end
c
c Perform interpolation in water density and enrichment
c
      subroutine libdensenrch(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
c
      parameter (m1=3000, m2=40, m3=2, m4=5, m5=8, m6=10000)
      character*80 file(100), fileb(40), confi, filein, conf(4), bwr(3)
c
      dimension a(n1, n2, n3), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *          genu(n4, n2, n3), ir(n4)
c
      common /dim/nburnl, na, ncap, nfiss, ngenu
c
      common /inp/kj, enrt, ncy, tirad(m2), spf(m2), nlcy(m2), confi,
     *            filein, rho
c
c     enrichment vector locally dimensioned.
c
      dimension enr(m4), dens(m5), ax(m6, m2), capx(m1, m2),
     *          fisx(m1, m2), genx(m1, m2)
c
c     vector dens contains the water densities for which cross section
c     libraries are tabulated.
c
      data nd, dens/8, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9/
c
c     vector dens contains the water densities for which cross section
c     libraries are tabulated.
c
      data np, enr/5, 1.5, 2.0, 3.0, 4.0, 5.0/
c
```

```
      data bwr/'6×6', '7×7', '8x8'/
c
c    define sas2 library names for five water densities and five
c    enrichments.
c    Examples: a) s16×62 means 1.5 % enrichmement and water of
c    density of 0.2 g/cm**3 for a 6×6 assembly
c    b) s37×74 means 3.0 % enrchmement and water density of
c    0.4 g/cm**3 for a 7×7 assembly
c
c  Configuration: bwr 6×6
c
      data file/
c
c   Configuration: bwr 6×6
c
c  Enrichment 1.5 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g/cm**3
c
     *          's16×62', 's16×63', 's16×64', 's16×65', 's16×66',
     *          's16×67', 's16×68', 's16×69',
c  Enrichment 2.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's26×62', 's26×63', 's26×64', 's26×65', 's26×66',
     *          's26×67', 's26×68', 's26×69',
c  Enrichment 3.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's36×62', 's36×63', 's36×64', 's36×65', 's36×66',
     *          's36×67', 's36×68', 's36×69',
c  Enrichment 4.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's46×62', 's46×63', 's46×64', 's46×65', 's46×66',
     *          's46×67', 's46×68', 's46×69',
c  Enrichment 5.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's56×62', 's56×63', 's56×64', 's56×65', 's56×66',
     *          's56×67', 's56×68', 's56×69',
c
c   Configuration: bwr 7×7
c
c  Enrichment 1.5 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g/cm**3
c
     *          's17×72', 's17×73', 's17×74', 's17×75', 's17×76',
     *          's17×77', 's17×78', 's17×79',
c  Enrichment 2.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's27×72', 's27×73', 's27×74', 's27×75', 's27×76',
     *          's27×77', 's27×78', 's27×79',
c  Enrichment 3.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's37×72', 's37×73', 's37×74', 's37×75', 's37×76',
     *          's37×77', 's37×78', 's37×79',
c  Enrichment 4.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's47×72', 's47×73', 's47×74', 's47×75', 's47×76',
     *          's47×77', 's47×78', 's47×79',
c  Enrichment 5.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's57×72', 's57×73', 's57×74', 's57×75', 's57×76',
     *          's57×77', 's57×78', 's57×79',
c
```

```
c  Configuration: bwr 8x8
c
c  Enrichment 1.5 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g/cm**3
c
     *          's18x82', 's18x83', 's18x84', 's18x85', 's18x86',
     *          's18x87', 's18x88', 's18x89',
c  Enrichment 2.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's28x82', 's28x83', 's28x84', 's28x85', 's28x86',
     *          's28x87', 's28x88', 's28x89',
c  Enrichment 3.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's38x82', 's38x83', 's38x84', 's38x85', 's38x86',
     *          's38x87', 's38x88', 's38x89',
c  Enrichment 4.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's48x82', 's48x83', 's48x84', 's48x85', 's48x86',
     *          's48x87', 's48x88', 's48x89',
c  Enrichment 5.0 %
c  Water densities: 0.2,0.3,0.4,0.5,0.6,0.7,0.8,and 0.9 g.cm**3
c
     *          's58x82', 's58x83', 's58x84', 's58x85', 's58x86',
     *          's58x87', 's58x88', 's58x89'/
c
      if( confi .eq. bwr(1)) then
        l = 0
        do 212 i = 1, 40
          l = l + 1
          fileb(l) = file(i)
 212    continue
      else if( confi .eq. bwr(2)) then
        l = 0
        do 313 i = 41, 80
          l = l + 1
          fileb(l) = file(i)
 313    continue
        do 414 i = 81, 120
          l = l + 1
          fileb(l) = file(i)
 414    continue
      endif
c
c    rho and enr are tested to find library position.
c
      do 11 i1 = 1, nd
        if(dens(i1) .ge. rho) then
          i = i1
          go to 111
        endif
 11   continue
 111  if(i1 .gt. 1) then
        i = i1 - 1
        dens(1) = dens(i1 - 1)
        dens(2) = dens(i1)
      endif
      do 22 j1 = 1, np
        if(enr(j1) .ge. enrt) then
          j = j1
          go to 222
        endif
 22   continue
 222  if(j1 .gt. 1) then
        j = j1 - 1
        enr(1) = enr(j1 - 1)
        enr(2) = enr(j1)
```

```
      endif
      lb = i + (j-1)* nd
c
c    labeled library unit starting from 50.
c
      ki = 50
      kj = ki + 1
      open(ki, file=fileb(lb), status='old', form='unformatted')
      open(kj, file=fileb(lb+1), status='old', form='unformatted')
      mb = lb + 8
      ki = kj + 1
      kj = ki + 1
      open(ki, file=fileb(mb), status='old', form='unformatted')
      open(kj, file=fileb(mb+1), status='old', form='unformatted')
c
c    Perform search over water density range for interpolation purpose.
c    total number of libraries created with sas2: 10 (fresh-fuel cross
c    sections included)
c
c    Number of burnup libraries in the base libraries
c
 33   nl = 10
      ni = 49
      do 777 ip = 1, 2
      do 7 kl = 1, 2
        ni = ni + 1
c
c    loop over libraries
c
        do 6 il = 1, nl
          if (il .le. 1) then
            do 4 k = 1, 4
              read(ni)
 4          continue
            read(ni)j, (ir(k), k = 1, j)
            do 44 k = 6, 22
              read(ni)
 44         continue
            read(ni)j, (a(k, il, kl), k = 1, j)
            na = j
            read(ni)j, (rcap(k, il, kl), k = 1, j)
            ncap = j
            read(ni)j, (rfiss(k, il, kl), k = 1, j)
            nfiss = j
            read(ni)j, (genu(k, il, kl), k = 1, j)
            ngenu = j
            do 5 k = 1, 14
              read(ni)
 5          continue
          else
            read(ni)j, (a(k, il, kl), k = 1, j)
            read(ni)j, (rcap(k, il, kl), k = 1, j)
            read(ni)j, (rfiss(k, il, kl), k = 1, j)
            read(ni)j, (genu(k, il, kl), k = 1, j)
          endif
 6      continue
 7    continue
c
c Interpolates over water density
c
      call linterpa(ip, rho, dens, a, na, nl, n1, n2, n3)
      call linterpb(ip, rho, dens, rcap, ncap, nl, n4, n2, n3)
      call linterpb(ip, rho, dens, rfiss, nfiss, nl, n4, n2, n3)
      call linterpa(ip, rho, dens, genu, ngenu, nl, n4, n2, n3)
c
c Save interpolated water density values for the first enrichment
c
      if(ip .eq. 1) then
        do 888 ix = 1, n1
```

```
          do 999 jx = 1, n2
            ax(ix, jx) = a(ix, jx, ip)
 999      continue
 888    continue
c
        do 555 ix = 1, n4
          do 666 jx = 1, n2
            capx(ix, jx) = rcap(ix, jx, ip)
            fisx(ix, jx) = rfiss(ix, jx, ip)
            genx(ix, jx) = genu(ix, jx, ip)
 666      continue
 555    continue
      endif
 777  continue
c
c Interpolates over enrichment
c
      ip = 1
c
c Recover interpolated water density values for the first enrichment
c
      do 444 ix = 1, n1
        do 333 jx = 1, n2
          a(ix, jx, ip) = ax(ix, jx)
 333    continue
 444  continue
c
      do 202 ix = 1, n4
        do 101 jx = 1, n2
          rcap(ix, jx, ip) = capx(ix, jx)
          rfiss(ix, jx, ip) = fisx(ix, jx)
          genu(ix, jx, ip) = genx(ix, jx)
 101    continue
 202  continue
      call linterpa(ip, enrt, enr, a, na, nl, n1, n2, n3)
      call linterpb(ip, enrt, enr, rcap, ncap, nl, n4, n2, n3)
      call linterpb(ip, enrt, enr, rfiss, nfiss, nl, n4, n2, n3)
      call linterpa(ip, enrt, enr, genu, ngenu, nl, n4, n2, n3)
c
      return
 1000 format(1p, 3(1x, i7, e11.4))
      end
c
c    Carry out interpolation over enrichment
c
      subroutine libenrch(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
      parameter (m1=3000, m2=40, m3=2, m4=5)
      character*80 file(20), confi, filein, conf(4)
      dimension a(n1, n2, n3), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *          genu(n4, n2, n3), ir(n4)
c
      common /dim/nburnl, na, ncap, nfiss, ngenu
c
      common /inp/kj, enrt, ncy, tirad(m2), spf(m2), nlcy(m2), confi,
     *            filein, rho
c
c    enrichment vector locally dimensioned.
      dimension enr(m4), pcap(m1, m2, m3), pfiss(m1, m2, m3)
c
c    vector enr contains the enrichments for which cross section
c     libraries are tabulated.
c
      data np, enr/5, 1.5 , 2.0, 3.0, 4.0, 5.0/
c    define sas2 library names for 1, 3, and 5 % enrichment.
      data file/'s114x14', 's214x14', 's314x14', 's414x14', 's514x14',
     *          's115x15', 's215x15', 's315x15', 's415x15', 's515x15',
     *          's117x17', 's217x17', 's317x17', 's417x17', 's517x17',
     *          's18x8', 's28x8', 's38x8', 's48x8', 's58x8'/
c
```

```
      data conf/'14x14', '15x15', '17x17', '8x8'/
c
c    labeled library unit starting from 50.
c
      npp = 2*np
      do 11 i = 1, npp
        if(confi .eq. conf(i)) go to 22
 11   continue
 22   lb = 5 * i - 5
      kb = 0
      do 1 i = 50, 49+np
        lb = lb + 1
        kb = kb + 1
        if(enrt .ge. enr(kb) .and. enrt .le. enr(kb+1)) then
          ki = i
          kj = i + 1
          open(ki, file=file(lb), status='old', form='unformatted')
          open(kj, file=file(lb+1), status='old', form='unformatted')
          go to 33
        endif
 1    continue
c
c     perform search over enrichment range for interpolation purpose.
c     total number of libraries created with sas2: 10 (fresh-fuel cross
c     sections included in the first burnup position)
c
 33   nl = 10
      do 7 kl = 1, 2
        ni = ki + kl - 1
        enr(kl) = enr(kb+kl-1)
c
c    loop over libraries
c
        do 6 il = 1, nl
          if (il .le. 1) then
            do 4 k = 1, 4
              read(ni)
 4          continue
            read(ni)j, (ir(k), k = 1, j)
            do 44 k = 6, 22
              read(ni)
 44         continue
            read(ni)j, (a(k, il, kl), k = 1, j)
            na = j
            read(ni)j, (rcap(k, il, kl), k = 1, j)
            ncap = j
            read(ni)j, (rfiss(k, il, kl), k = 1, j)
            nfiss = j
            read(ni)j, (genu(k, il, kl), k = 1, j)
            ngenu = j
            do 5 k = 1, 14
              read(ni)
 5          continue
          else
            read(ni)j, (a(k, il, kl), k = 1, j)
            read(ni)j, (rcap(k, il, kl), k = 1, j)
            read(ni)j, (rfiss(k, il, kl), k = 1, j)
            read(ni)j, (genu(k, il, kl), k = 1, j)
          endif
 6      continue
 7    continue
c
c    Perform interpolation on enrichment
c
      ip = 1
      call linterpa(ip, enrt, enr, a, na, nl, n1, n2, n3)
      call linterpb(ip, enrt, enr, rcap, ncap, nl, n4, n2, n3)
      call linterpb(ip, enrt, enr, rfiss, nfiss, nl, n4, n2, n3)
      call linterpa(ip, enrt, enr, genu, ngenu, nl, n4, n2, n3)
```

```
      return
 1000 format(1p, 3(1x, i7, e11.4))
      end
c
c    Linear-linear interpolation on matrix a elements
c
      subroutine linterpa(ip, xp, x, y, nis, nl, na, nb, nc)
      dimension x(nc), y(na, nb, nc)
      do 2 i = 1, nis
        do 1 j = 1, nl
          a = (y(i, j, 2) - y(i, j, 1)) / (x(2) - x(1))
          y(i, j, ip) = y(i, j, 1) + (xp - x(1)) * a
 1      continue
 2    continue
      return
      end
c
c    Log-linear interpolation on absorption cross section
c
      subroutine linterpb(ip, xp, x, y, nis, nl, na, nb, nc)
      dimension x(nc), y(na, nb, nc)
      do 2 i = 1, nis
        do 1 j = 1, nl
          if( y(i, j, 1) .ne. 0.0) then
            y1 = y(i, j, 1)
            aly1 = alog(y(i, j, 1))
            aly2 = alog(y(i, j, 2))
            a = (aly2 - aly1) / (x(2) - x(1))
            aly = aly1 + (xp - x(1)) * a
            y(i, j, ip) = exp(aly)
          else
            y1 = y(i, j, 1)
            a = (y(i, j, 2) - y(i, j, 1)) / (x(2) - x(1))
            y(i, j, ip) = y(i, j, 1) + (xp - x(1)) * a
          endif
 1      continue
 2    continue
      return
      end
c
c    Perform burnup interpolation using interpolation scheme developed
c    by N. M. Greene (NMG)
c
      subroutine libburn(ir, a, rcap, rfiss, genu, n1, n2, n3, n4)
      parameter (m1=3000, m2=40, m3=3)
      character*80 file, confi, filein
      dimension a(n1, n2, n3), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *          genu(n4, n2, n3), ir(n4)
      common /dim/nburnl, na, ncap, nfiss, ngenu
c
      common /inp/kj, enrt, ncy, tirad(m2), spf(m2), nlcy(m2), confi,
     *            filein, rho
c
c    burnup and other vectors locally dimensioned.
c
      dimension burn(m2), burnl(m2), pcap(m1, m2), pfiss(m1, m2)
c
c    burnup values at which cross sections are tabulated.
c
      data nburn, burn/10, 0.0,  1500.0, 4500.0, 7500.0, 10500.0,
     *                   13500.0, 16500.0, 31500.0,
     *                   46500.0, 58500.0/
c
c   this step requires parameters for generating burnup vector,(vector
c   burnl), for interpolation on the cross section table.
c
c   following are the user input from which vector burnl are obtained.
c
c     tirad - irradiation time for each cycle.
```

```
c     ncy   - number of cycle.
c     spf   - specific power for each cycle.
c     nlcy  - number of requested libraries for each cycle.
c
      spf(1) = 0.0
      l = 0
      bas = 0.0
c
c     loop over cycles to determine vector burnl.
c
      do 2 i = 1, ncy
        ncc = nlcy(i)
        if(i .ne. 1) bas = bas + tirad(i-1) * spf(i)
        rat = (tirad(i)/ncc) * spf(i+1)
        do 1 j = 1, nlcy(i)
          l = l + 1
          burnl(l) = bas + 0.5 * (2*j - 1) * rat
 1      continue
 2    continue
      nburnl = l
c
c Offsets burnup vectors for interpolation purpose.
c
      do 3 i = 1, nburn
        burn(i) = burn(i) + 50.0
 3    continue
      do 4 i = 1, nburnl
        burnl(i) = burnl(i) + 50.0
 4    continue
c
c    Generates coeficients for NMG interpolation scheme on
c    burnup.
c
      call nmginterp2(nburn, burn, ncap, rcap, nfiss, rfiss,
     *                pcap, pfiss, n1, n2, n3, n4, m1, m2, m3)
c
c    set aside points for interpolation.
c
      do 8 i = 1, nburnl
        do 7 j = 1, nburn - 1
          if(burnl(i) .gt. burn(j) .and. burnl(i) .le. burn(j+1))
     *      then
            call intburna(i, burnl(i), j, burn(j), burn(j+1),
     *                    a, na, nburn, n1, n2, n3)
            call intburnb(i, burnl(i), j, burn(j), burn(j+1),
     *                    rcap, ncap, nburn, pcap, n4, n2, n3, 1)
            call intburnb(i, burnl(i), j, burn(j), burn(j+1),
     *                    rfiss, nfiss, nburn, pfiss, n4, n2, n3, 1)
            call intburnb(i, burnl(i), j, burn(j), burn(j+1),
     *                    genu, ngenu, nburn, npcap, n4, n2, n3, 0)
            go to 8
          endif
 7      continue
 8    continue
      return
 1000 format(1p, 3(1x, i7, e11.4))
      end
c
c    Scheme developed by N. M. Greene
c
      subroutine nmginterp2(nburn, burn, ncap, rcap, nfiss, rfiss,
     *                      pcap, pfiss, n1, n2, n3, n4, m1, m2, m3)
      dimension burn(m2), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *                         pcap(m1, m2), pfiss(m1, m2)
c
c    Vector locally dimensioned.
c
      dimension yy(21)
c
```

```
c    Compute p's for absorption cross sections.
c
      do 3 i = 1, ncap
        do 1 j = 1, nburn
          if(rcap(i, j, 1) .ne. 0.0) then
            yy(j) = alog(rcap(i, j, 1))
          else
            yy(j) = rcap(i, j, 1)
          endif
 1      continue
        do 2 k = 2, nburn - 1
          xa = burn(k-1)
          ya = yy(k-1)
          xb = burn(k+1)
          yb = yy(k+1)
          x = burn(k)
          y = yy(k)
          call pfit33(xa, ya, xb, yb, x, y, p)
          pcap(i, k) = p
 2      continue
        pcap(i, 1) = pcap(i, 2) + (burn(1) - burn(2)) *
     *               (pcap(i, 3) - pcap(i, 2)) /
     *               (burn(3) - burn(2))
        pcap(i, nburn) = pcap(i, nburn-1) +
     *                   (burn(nburn) - burn(nburn-1)) *
     *                   (pcap(i, nburn-1) - pcap(i, nburn-2)) /
     *                   (burn(nburn-1) - burn(nburn-2))
 3    continue
c
c    Compute p's fo fission cross sections.
c
      do 6 i = 1, nfiss
        do 4 j = 1, nburn
          if(rfiss(i, j, 1) .ne. 0.0) then
            yy(j) = alog(rfiss(i, j, 1))
          else
            yy(j) = rfiss(i, j, 1)
          endif
 4      continue
        do 5 k = 2, nburn - 1
          xa = burn(k-1)
          ya = yy(k-1)
          xb = burn(k+1)
          yb = yy(k+1)
          x = burn(k)
          y = yy(k)
          call pfit33(xa, ya, xb, yb, x, y, p)
          pfiss(i, k) = p
 5      continue
        pfiss(i, 1) = pfiss(i, 2) + (burn(1) - burn(2)) *
     *                (pfiss(i, 3) - pfiss(i, 2)) /
     *                (burn(3) - burn(2))
        pfiss(i, nburn) = pfiss(i, nburn-1) +
     *                    (burn(nburn) - burn(nburn-1)) *
     *                    (pfiss(i, nburn-1) - pfiss(i, nburn-2)) /
     *                    (burn(nburn-1) - burn(nburn-2))
 6    continue
      return
      end
c
c    Interpolation is carried out based on the formalism:
c
c    y=ya+(x**p-xa**p)*(yb-ya)/(xb**p-xa**p)
c
c    where p varies with x according to:
c
c    p(x) = pa + (pb - pb)*(x-xa)/(xb-xa)
c
      subroutine pfit33(xa,ya,xb,yb,x,y,p)
```

```
      f(x,xa,ya,xb,yb,p)=ya+((x/xa)**p-1.0)*(yb-ya)/((xb/xa)**p-1.0)
      df(x,xa,ya,xb,yb,p)=(yb-ya)*(((xb/xa)**p-1.0)*
     * ((x/xa)**p*(alog(x)-alog(xa)))-((x/xa)**p-1.0)*
     * ((xb/xa)**p*(alog(xb)-alog(xa))))/((xb/xa)**p-1.0)**2
c
c   calculate p's in y=ya+(x**p-xa**p)*(yb-ya)/(xb**p-xa**p) fit
c
      eps=0.001
      n6 = 6
c
c *** do 3-point p-fits
c
      pmax = 5.0
            p=1.0
            ic=0
            if (y.eq. 0.0) go to 150
            if (y.lt.ya.and.y.lt.yb) go to 150
            if (y.gt.ya.and.y.gt.yb) go to 150
c
c *** the two preceeding statements test for non-monotonicity
c *** the following checks for the case when it's unnecessary to interp
c
            if (abs((ya-y)/y).le.eps.and.abs((yb-y)/y).le.eps) go to 150
  140       v=f(x,xa,ya,xb,yb,p)
            dv=df(x,xa,ya,xb,yb,p)
            nline=nline+1
            if (abs((v-y)/y).le.1.0e-5) go to 150
            if (dv.eq.0.0) dv=1.0
            p = amin1(pmax,p-(v-y)/dv)
            ic=ic+1
            if (ic.le.10) go to 140
  150 continue
  160 continue
      if(ic.gt.10)return 1
      return
      end
c
c
c
      subroutine intburna(ip, xp, iq, xa, xb, y, nis, nburn, n1, n2, n3)
      dimension y(n1, n2, n3)
      do 1 i = 1, nis
          a = (y(i, iq+1, 1) - y(i, iq, 1)) / (xb - xa)
          y(i, ip, 2) = y(i, iq, 1) + (xp - xa) * a
 1    continue
      return
      end
c
c
c
      subroutine intburnb(ip, xp, iq, xa, xb, y, nis, nburn, p,
     *                    n4, n2, n3, key)
      dimension y(n4, n2, n3), p(n4, n2)
      if(key .eq. 0) then
      do 1 i = 1, nis
            a = (y(i, iq+1, 1) - y(i, iq, 1)) / (xb - xa)
            y(i, ip, 2) = y(i, iq, 1) + (xp - xa) * a
 1    continue
      else
      do 2 i = 1, nis
        if(y(i, iq, 1) .le. 0.0) go to 2
        alogy1 = alog(y(i, iq, 1))
        alogy2 = alog(y(i, iq+1, 1))
        pv = p(i, iq) + (xp - xa) * (p(i, iq+1) - p(i, iq)) / (xb -xa)
        prta = ((xp/xa) ** pv - 1.0) * (alogy2 - alogy1) /
     *         ((xb/xa) ** pv - 1.0)
        alogy = alogy1 + prta
        y(i, ip, 2) = exp(alogy)
 2    continue
```

```
      endif
      return
 1000 format(1p, 3(1x, i7, e11.4))
      end
c
c    Create interpolated cross section library
c
      subroutine newlib(a, rcap, rfiss, genu, n1, n2, n3, n4)
      parameter (m1=20000, m2=40)
      character*80 file, confi, filein
      dimension a(n1, n2, n3), rcap(n4, n2, n3), rfiss(n4, n2, n3),
     *          genu(n4, n2, n3)
c
      dimension r(m1), ir(m1)
c
      common /dim/nl, na, ncap, nfiss, ngenu
c
      common /inp/kj, enrt, ncy, tirad(m2), spf(m2), nlcy(m2), confi,
     *            filein
c
c    Uses existing open libraries to store new library
c
      ni = kj
      rewind ni
      nt = 34
      open(nt,file=filein,status='unknown',form='unformatted')
      do 4 il = 1, nl
        if (il .le. 1) then
          read(ni) (ir(k), k = 1, 14), (r(k), k = 1,4),
     *             (ir(k), k = 15, 16)
          write(nt) (ir(k), k = 1, 14), (r(k), k = 1,4),
     *              (ir(k), k = 15, 16)
          read(ni) j, (r(k), k = 1, j)
          write(nt) j, (r(k), k = 1, j)
          read(ni) j, (ir(k), k = 1, j)
          write(nt) j, (ir(k), k = 1, j)
          read(ni) j, (r(k), k = 1, j)
          write(nt) j, (r(k), k = 1, j)
          do 1 k = 1, 4
            read(ni) j, (ir(kk), kk = 1, j)
            write(nt) j, (ir(kk), kk = 1, j)
 1        continue
          do 2 k = 1, 14
            read(ni) j, (r(kk), kk = 1, j)
            write(nt) j, (r(kk), kk = 1, j)
 2        continue
          read(ni)
          write(nt) na, (a(k, il, 2), k = 1, na)
          read(ni)
          write(nt) ncap, (rcap(k, il, 2), k = 1, ncap)
          read(ni)
          write(nt) nfiss, (rfiss(k, il, 2), k = 1, nfiss)
          read(ni)
          write(nt) ngenu, (genu(k, il, 2), k = 1, ngenu)
          do 3 k = 1, 14
            read(ni) j, (r(kk), kk = 1, j)
            write(nt) j, (r(kk), kk = 1, j)
 3        continue
          else
c         read(ni)
          write(nt) na, (a(k, il, 2), k = 1, na)
c         read(ni)
          write(nt) ncap, (rcap(k, il, 2), k = 1, ncap)
c         read(ni)
          write(nt) nfiss, (rfiss(k, il, 2), k = 1, nfiss)
c         read(ni) j, (r(k), k = 1, j)
          write(nt) ngenu, (genu(k, il, 2), k = 1, ngenu)
        endif
 4    continue
```

```
      return
      end
```

The **jstime** routine

```
    Date the module was last permanently updated:    93/07/22
    Time the module was last permanently updated:    07:38:55
    Programmer name:                                 L.M.PETRIE
    Module name:                                     ULJSTIME
    Current archiving level number:                  00001
    Current number of permanent updates:             00001
    Date of last access by librarian:                93/07/22
    Dataset name:  X4S.SCALE4.MASTER


########################################################################
*/
#include <sys/times.h>

#ifdef UNDERSCORE
#define JSTIME jstime_
#else
#define JSTIME jstime
#endif

 extern void JSTIME (long *time_left)

{

  struct tms buf,*buffer;

  double time_used;

  long time_gms;
    buffer = &buf;
  time_gms = (long)times(buffer);

  if (time_gms != -1)

     {
     time_used = (buffer->tms_utime + buffer->tms_stime +
               buffer->tms_cutime + buffer->tms_cstime)/60.;
  *time_left = 100.*(20000000.-time_used);
  return;
     }

  else

    {
  *time_left = 0L;

  return;
    }
}
```

APPENDIX D

FORTRAN LISTING OF THE LISTBURN UTILITY PROGRAM

APPENDIX D

FORTRAN LISTING OF THE LISTBURN UTILITY PROGRAM

```
      program listburn
      dimension tirad(30), spf(30), nlcy(30), burnl(30)
      character*80 filein
c
c   This program generates burnup positions at which ORIGEN-S libraries were
c   created in the SAS2H sequence. The input variables are similiar to that of the
c   SAS2H input.
c
c
c     tirad - irradiation time for each cycle.
c     ncy   - number of cycle.
c     spf   - specific power for each cycle.
c     nlcy  - number of requested libraries for each cycle.
c
      write(6,'(" Number of cycle:"$)')
      read(5,*) ncy
      write(6,'(" Fuel irradiation period for each cycle:"$)')
      read(5,*) (tirad(I), I = 1, ncy)
      write(6,'(" Specific power for each cycle:"$)')
      read(5,*) (spf(I), I = 2, ncy+1)
      write(6,'(" Number of libraries per cycle:"$)')
      read(5,*) (nlcy(I), I = 1, ncy)
      write(6,'(" Output filename:"$)')
      read(5,'(a)') filein
      no = 22
      open(no,file=filein,status='unknown')
      spf(1) = 0.0
      l = 0
      bas = 0.0
c
c     loop over cycles to determine vector burnl.
c
      write(no,*)'Burnup position of the SAS2H generated libraries'
      write(no,*)'Position           Burnup (GWD/MTU)'
      do 2 i = 1, ncy
        ncc = nlcy(i)
        if(i .ne. 1) bas = bas + tirad(i-1) * spf(i)
        rat = (tirad(i)/ncc) * spf(i+1)
        do 1 j = 1, nlcy(i)
          l = l + 1
          burnl(l) = bas + 0.5 * (2*j - 1) * rat
          burnl(l) = burnl(l) / 1000.0
          write(no,1000)l, burnl(l)
 1      continue
c
 2    continue
      stop
 1000 format(1x, i4, 16x, f10.5)
      end
```

APPENDIX E

FORTRAN LISTING OF THE XSECLIST UTILITY PROGRAM

APPENDIX E

FORTRAN LISTING OF THE XSECLIST UTILITY PROGRAM

```
      program xseclist
      dimension tirad(30), spf(30), nlcy(30), burnl(30)
c
c    This program in intended to list ORIGEN-S/SAS2H cross sections
c    library as a function of the burnup.
c
c
c     tirad - irradiation time for each cycle.
c     ncy   - number of cycle.
c     spf   - specific power for each cycle.
c     nlcy  - number of requested libraries for each cycle.
c
      write(6,'(" Number of cycle:"$)')
      read(5,*) ncy
      write(6,'(" Fuel irradiation period for each cycle:"$)')
      read(5,*) (tirad(i), i = 1, ncy)
      write(6,'(" Specifc power for each cycle:"$)')
      read(5,*) (spf(i), i = 2, ncy+1)
      write(6,'(" Number of libraries per cycle:"$)')
      read(5,*) (nlcy(i), i = 1, ncy)
      spf(1) = 0.0
      l = 0
      bas = 0.0
c
c     loop over cycles to determine vector burnl.
c
      do 2 i = 1, ncy
        ncc = nlcy(i)
        if(i .ne. 1) bas = bas + tirad(i-1) * spf(i)
        rat = (tirad(i)/ncc) * spf(i+1)
        do 1 j = 1, nlcy(i)
          l = l + 1
          burnl(l) = bas + 0.5 * (2*j - 1) * rat
          burnl(l) = burnl(l) / 1000.0
c         write(no,1000)l, burnl(l)
 1      continue
c
 2    continue
      call listxsec(l, burnl)
      stop
 1000 format(1x, i4, 16x, f10.5)
      end
c
c
c


      subroutine listxsec(nl, burn)
      character*1 char1(3), char2, chard, charl, id*6
c
      parameter (icf=2000, inl=30)
      dimension mtrd(icf), ir(icf), id(icf), rcap(icf, inl),
     *          rfiss(icf, inl), burn(nl)
c
      common /char/char1, char2, chard, charl
c
      data char1, char2/'a', 'f', 'b', 'n'/
c
      write(6,'(" Data (absorption (a),  fission (f), or both (b)): "$)')
      read(5,'(a)') chard
```

```
      write(6,'(" List entire library (yes=y, no=n): "$)')
      read(5,'(a)') charl
c
      call rdlib(icf, inl, ir, rcap, rfiss, nl, kcap, kfiss)
      call select(mtrd, ir, id, burn, rcap, rfiss, icf, inl, nl,
     *            kcap, kfiss)
c
      stop
      end
      subroutine rdlib(icf, inl, ir, rcap, rfiss, nl, kcap, kfiss)
      character*80 file
      dimension ir(icf), rcap(icf, inl), rfiss(icf, inl)
c
      common/couter/itot, ilite, iact, ifp
c
      write(6,'(" Enter library name: "$)')
      read(5,'(a)') file
c
      ni = 1
      open(ni,file=file,status='old',form='unformatted')
c    Loop over libraries
      do 5 il = 1, nl
        if (il .le. 1) then
          do 1 k = 1, 4
            read(ni)
 1        continue
          read(ni)j, (ir(k), k = 1, j)
          do 2 k = 6, 23
            read(ni)
 2        continue
c
          read(ni) j, (rcap(k, il), k = 1, j)
          kcap = j
          read(ni) j , (rfiss(k, il), k = 1, j)
          kfiss = j
          do 3 k = 1, 4
            read(ni)
 3        continue
            read(ni) itot
            read(ni) ilite
            read(ni) iact
            ifp = itot - ilite - iact
            do 4 k = 1, 8
              read(ni)
 4          continue
        else
          read(ni)
          read(ni) j, (rcap(k, il), k = 1, j)
          read(ni) j, (rfiss(k, il), k = 1, j)
          read(ni)
        endif
 5    continue
c
      return
 1000 format(1p, 3(5x,i7,e15.3) )
      end
      subroutine select(mtrd, ir, id, burn, r1, r2, icf, inl, nl,
     *                  kcap, kfiss)
      character*1 char1(3), char2, chard, charl, id*6, filein*80
c
      parameter (mtd=2000)
c
      dimension mtrd(icf), ir(inl), id(icf), r1(icf,inl),
     *          r2(icf, inl), burn(nl)
c
      common /char/char1, char2, chard, charl
```

```
c
      common/couter/itot, ilite, iact, ifp
c
      no = 22
      write(6,'(" Output filename:"$)')
      read(5,'(a)') filein
      open(no, file=filein, status='unknown')
      key = 0
      if(charl .eq. char2) then
        write(6,'(" No. of materials: "$)')
        read(5,*)mt
        write(6,'(" Material identification: "$)')
        read(5,*)(mtrd(i), i = 1, mt)
        key = 1
      endif
      if(chard .eq. char1(1)) then
        write(no,*)'*** Absorption cross section ***'
        do 4 i = 1, kcap
          if( i .eq. 1) then
            write(no,*)'LIGHT ELEMENTS'
          endif
          if( i .eq. ilite) then
            write(no,*)'ACTINIDES'
          endif
          ilia = ilite + iact
          if( i .eq. ilia) then
            write(no,*)'FISSION PRODUCTS'
          endif
          if(key .eq. 0) then
            call noah(ir(i), id(i))
            write(no,*)' Material ', ir(i), id(i)
            write(no,*)'     Burnup            xsec'
            do 1 j = 1, nl
              write(no,1000) burn(j), r1(i,j)
 1          continue
          else if(key .eq. 1) then
            do 3 k = 1, mt
              if(mtrd(k) .eq. ir(i)) then
              call noah(ir(i), id(k))
                write(no,*)' Material ', ir(i), id(k)
                write(no,*)'     Burnup            xsec'
                do 2 j = 1, nl
                  write(no, 1000) burn(j), r1(i,j)
 2              continue
              endif
 3          continue
          endif
 4      continue
      else if(chard .eq. char1(2)) then
        write(no,*)'*** Fission cross section ***'
        do 8 i = 1, kfiss
          if(key .eq. 0) then
            call noah(ir(i+689), id(i))
            write(no,*)' Material ', ir(i+689), id(i)
            write(no,*)'     Burnup            xsec'
            do 5 j = 1, nl
              write(no,1000) burn(j), r2(i,j)
 5          continue
          else if(key .eq. 1) then
            do 7 k = 1, mt
              if(mtrd(k) .eq. ir(i+689)) then
                call noah(ir(i+689), id(i))
                write(no,*)'Material ', ir(i+689), id(i)
                write(no,*)'     Burnup            xsec'
                do 6 j = 1, nl
                  write(no,1000) burn(j), r2(i,j)
```

```
6             continue
              endif
7           continue
            endif
8       continue
      else if(chard .eq. char1(3)) then
        if(key .eq. 0) then
          write(no,*)'*** Absorption cross section ***'
          do 10 i = 1, kcap
            if( i .eq. 1) then
              write(no,*)'LIGHT ELEMENTS'
            endif
            if( i .eq. ilite) then
              write(no,*)'ACTINIDES'
            endif
            ilia = ilite + iact
            if( i .eq. ilia) then
              write(no,*)'FISSION PRODUCTS'
            endif
            call noah(ir(i), id(i))
            write(no,*)'Material ', ir(i), id(i)
            write(no,*)'     Burnup            xsec'
            do 9 j = 1, nl
              write(no,1000) burn(j), r1(i,j)
9           continue
10        continue
          write(no,*)'*** Fission cross section ***'
          do 12 i = 1, kfiss
            call noah(ir(i+689), id(i))
            write(no,*)'Material ', ir(i+689), id(i)
            write(no,*)'     Burnup            xsec'
            do 11 j = 1, nl
              write(no,1000) burn(j), r2(i,j)
11          continue
12        continue
        else if (key .eq. 1) then
          write(no,*)'*** Absorption cross section ***'
          do 15 i = 1, kcap
            if( i .eq. 1) then
              write(no,*)'LIGHT ELEMENTS'
            endif
            if( i .eq. ilite) then
              write(no,*)'ACTINIDES'
            endif
            ilia = ilite + iact
            if( i .eq. ilia) then
              write(no,*)'FISSION PRODUCTS'
            endif
            do 14 k = 1, mt
              if(mtrd(k) .eq. ir(i)) then
                call noah(ir(i), id(k))
                write(no,*)'Material ', ir(i), id(k)
                write(no,*)'     Burnup            xsec'
                do 13 j = 1, nl
                  write(no,1000) burn(j), r1(i,j)
13              continue
              endif
14          continue
15        continue
          write(no,*)'*** Fission cross section ***'
          do 18 i = 1, kfiss
            do 17 k =1 , mt
              if(mtrd(k) .eq. ir(i+689)) then
                call noah(ir(i+689), id(k))
                write(no,*)'Material ', ir(i+689), id(k)
                write(no,*)'     Burnup            xsec'
```

```
               do 16 j = 1, nl
                 write(no,1000) burn(j), r2(i,j)
 16            continue
              endif
 17         continue
 18       continue
        endif
      endif
      return
 1000 format(1p,2x,e12.5,6x,e12.5)
      end
c
c
c
      subroutine noah(nucli,name)
c     subroutine noah converts six digit identifier to alphameric symbol
      character name*6,buf*8
c
      character*2 ele(99), sta(2)
      data ele/  ' h','he','li','be',' b',' c',' n',' o',' f','ne',
     * 'na','mg','al','si',' p',' s','cl','ar',' k','ca','sc','ti',' v',
     * 'cr','mn','fe','co','ni','cu','zn','ga','ge','as','se','br','kr',
     * 'rb','sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd','in',
     * 'sn','sb','te',' i','xe','cs','ba','la','ce','pr','nd','pm','sm',
     * 'eu','gd','tb','dy','ho','er','tm','yb','lu','hf','ta',' w','re',
     * 'os','ir','pt','au','hg','tl','pb','bi','po','at','rn','fr','ra',
     * 'ac','th','pa',' u','np','pu','am','cm','bk','cf','es'/
c
      data sta/'  ','m'/
      is     = mod(nucli,10)+1
      nz     = nucli/10000
      mw     = nucli/10-nz *1000
      write(buf,'(a2,i3,a1)') ele(nz),mw,sta(is)
c   ..changed nuclide names back to use blanks, not 0's, 2/26/88 owh
      name   = buf(1:6)
      return
      end
```

APPENDIX F

FORTRAN LISTING OF THE XSECPLOT UTILITY PROGRAM

APPENDIX F

FORTRAN LISTING OF THE XSECPLOT UTILITY PROGRAM

```
      program xsecplot
      dimension tirad(30), spf(30), nlcy(30), burnl(30)
c
c   This program is intended to generate burnup dependent ORIGEN-S cross
c   cross section data in graphical form
c
c
c     tirad - irradiation time for each cycle.
c     ncy   - number of cycle.
c     spf   - specific power for each cycle.
c     nlcy  - number of requested libraries for each cycle.
c
      write(6,'(" Number of cycle:"$)')
      read(5,*) ncy
      write(6,'(" Fuel irradiation period for each cycle:"$)')
      read(5,*) (tirad(i), i = 1, ncy)
      write(6,'(" Specific power for each cycle:"$)')
      read(5,*) (spf(i), i = 2, ncy+1)
      write(6,'(" Number of libraries per cycle:"$)')
      read(5,*) (nlcy(i), i = 1, ncy)
      spf(1) = 0.0
      l = 0
      bas = 0.0
c
c     loop over cycles to determine vector burnl.
c
      do 2 i = 1, ncy
        ncc = nlcy(i)
        if(i .ne. 1) bas = bas + tirad(i-1) * spf(i)
        rat = (tirad(i)/ncc) * spf(i+1)
        do 1 j = 1, nlcy(i)
          l = l + 1
          burnl(l) = bas + 0.5 * (2*j - 1) * rat
          burnl(l) = burnl(l) / 1000.0
c         write(no,1000)l, burnl(l)
 1      continue
c
 2    continue
      call plotxsec(l, burnl)
      stop
 1000 format(1x, i4, 16x, f10.5)
      end
c
c
c
      subroutine plotxsec(nl, burn)
      character*1 char1(2), char2, chard, charl, id*6
c
      parameter (icf=2000, inl=30)
      dimension mtrd(icf), ir(icf), id(icf), rcap(icf, inl),
     *          rfiss(icf, inl), burn(inl), xsec(inl, icf)
c
      common /char/char1, chard
c
      data char1/'a', 'f'/
c
      write(6,'(" Data (absorption (a),  fission (f): "$)')
      read(5,'(a)') chard
c
      call rdlib(icf, inl, ir, rcap, rfiss, nl, kcap, kfiss)
      call select(mtrd, ir, id, burn, xsec, rcap, rfiss, icf, inl,
     *            nl, kcap, kfiss)
c
      stop
      end
      subroutine rdlib(icf, inl, ir, rcap, rfiss, nl, kcap, kfiss)
```

```
      character*80 file
      dimension ir(icf), rcap(icf, inl), rfiss(icf, inl)
c
      write(6,'(" Enter library name: "$)')
      read(5,'(a)') file
c
      ni = 1
      open(ni,file=file,status='old',form='unformatted')
c    Loop over libraries
      do 4 il = 1, nl
        if (il .le. 1) then
          do 1 k = 1, 4
            read(ni)
 1        continue
          read(ni)j, (ir(k), k = 1, j)
          do 2 k = 6, 23
            read(ni)
 2        continue
c
          read(ni) j, (rcap(k, il), k = 1, j)
          kcap = j
          read(ni) j , (rfiss(k, il), k = 1, j)
          kfiss = j
          do 3 k = 1, 15
            read(ni)
 3        continue
        else
          read(ni)
          read(ni) j, (rcap(k, il), k = 1, j)
          read(ni) j, (rfiss(k, il), k = 1, j)
          read(ni)
        endif
 4    continue
c
      return
 1000 format(1p, 3(5x,i7,e15.3) )
      end
      subroutine select(mtrd, ir, id, burn, xsec, r1, r2, icf, inl,
     *                  nl, kcap, kfiss)
      character*1 char1(2), char2, chard, charl, id*6
c
      dimension mtrd(icf), ir(icf), id(icf), r1(icf,inl),
     *          r2(icf, inl), burn(inl), xsec(inl, icf)
c
      common /char/char1, chard
c
      write(6,'(" No. of materials: "$)')
      read(5,*) mt
      write(6,'(" Material indentification: "$)')
      read(5,*) (mtrd(i), i = 1, mt)
      do 5 k = 1, mt
      if(chard .eq. char1(1)) then
        do 2 i = 1, kcap
          if(mtrd(k) .eq. ir(i)) then
            call noah(mtrd(k), id(k))
            do 1 j = 1, nl
              xsec(j,k) = r1(i,j)
 1          continue
          endif
 2      continue
      else if(chard .eq. char1(2)) then
        do 4 i = 1, kfiss
          if(mtrd(k) .eq. ir(i+689)) then
            call noah(mtrd(k), id(k))
            do 3 j = 1, nl
              xsec(j,k) = r2(i,j)
 3          continue
          endif
 4      continue
      endif
 5    continue
c
      call order(nl, mt, inl, icf, xsec, ymin, ymax)
      call pplot(nl, mt, inl, icf, mtrd, id, burn, xsec, ymin, ymax)
```

```
c
      return
      end
c
      subroutine noah(nucli,name)
c     subroutine noah converts six digit identifier to alphameric symbol
      character name*6,buf*8
c
      character*2 ele(99), sta(2)
      data ele/  ' h','he','li','be',' b',' c',' n',' o',' f','ne',
     * 'na','mg','al','si',' p',' s','cl','ar',' k','ca','sc','ti',' v',
     * 'cr','mn','fe','co','ni','cu','zn','ga','ge','as','se','br','kr',
     * 'rb','sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd','in',
     * 'sn','sb','te',' i','xe','cs','ba','la','ce','pr','nd','pm','sm',
     * 'eu','gd','tb','dy','ho','er','tm','yb','lu','hf','ta',' w','re',
     * 'os','ir','pt','au','hg','tl','pb','bi','po','at','rn','fr','ra',
     * 'ac','th','pa',' u','np','pu','am','cm','bk','cf','es'/
c
      data sta/'  ','m'/
      is     = mod(nucli,10)+1
      nz     = nucli/10000
      mw     = nucli/10-nz *1000
      write(buf,'(a2,i3,a1)') ele(nz),mw,sta(is)
c   ..changed nuclide names back to use blanks, not 0's, 2/26/88 owh
      name   = buf(1:6)
      return
      end
c
      subroutine pplot(n, mt, inl, icf, mtrd, id, x, y, ymin, ymax)
      character*50 char1(2)*1, chard*1, top, xlab, ylab, sym(10)*1,
     *             text*30, txt, id*6
      dimension x(n), y(inl, icf), id(icf), yhelp(30), mtrd(mt),
     *          kolin(6)
      common /char/char1, chard
      data sym/'!', '&', '?', '<', '>', '@', 'a', '^', ';',
     *         'g'/
      parameter (linlogx=0, interval=1, join=1, isort=0,
     *           ixscale=0, iyscale=1)
      call pinicd(90)
      linlogy = 0
      newpage = 1
      xmin = x(1)
      xmax = x(n)
      yrate = ymax / ymin
      yrate = alog(yrate)
      if(yrate .gt. 2.0) linlogy = 1
      call openv(40,'xxppttoo')
      call mwrtcs(2)
      xlab='burnup (GWD/MTU)'
      if(chard .eq. char1(1)) then
        ylab='Absorption cross Section (()barns)'
      else if(chard. eq. char1(2)) then
        ylab='Fission cross Section (()barns)'
      endif
      top='             ORIGEN-S Cross Section Library'
      txt='            Material'
      call plebcd(-1, txt, 7, 3, ' ', 0.0, 0, 0.0)
      call psympr(3, 2.0, 0.0)
      do 2 k = 1, mt
        do 1 i = 1, n
          yhelp(i) = y(i,k)
 1      continue
        if( k .gt. 1) newpage = 0
        text = id(k)
      call plotcd(linlogx, linlogy, x, yhelp, n, interval, join, isort,
     *            sym(k), top, xlab, ylab, newpage, ixscale, xmin, xmax,
     *            iyscale, ymin, ymax)
      call pleacd(text)
c     call plebcd(0, text, 0, 1, sym(k), 0, -1, 1)
      call penqcd(ncurve, nlegends)
 2    continue
      kolin(1) = 7
      kolin(2) = 3
      kolin(3) = 0
```

```
      kolin(4) = 4
      kolin(5) = 7
      kolin(6) = 0
      call pdrwcd(kolin, 2, 0., 0., 1, x, yhelp)
      call pendcd
      call closev (0)
      return
      end
c
      subroutine order(n, mt, inl, icf, y, ymin, ymax)

      dimension y(inl, icf)
      dimension yaux(50)
      kl = 1
      nl = n
      do 44 k = 1, mt
        is = 0
        do 1 i = kl,  nl
          is = is + 1
          yaux(i) = y(is,k)
 1      continue
        kl = k * n + 1
        nl = n * (k + 1)
 44   continue
      nl = mt * n
      n1 = nl - 1
      do 3 i = 1, n1
        i1 = i + 1
        do 2 j = i1, nl
          if(yaux(i) .le. yaux(j))go to 2
          temp = yaux(i)
          yaux(i) = yaux(j)
          yaux(j) = temp
 2      continue
 3    continue
      ymin = yaux(1)
      ymax = yaux(nl)
      return
      end
```

APPENDIX G

SAS2H INPUT FILE TO GENERATE THE INPLIB ORIGEN-S CROSS-SECTION LIBRARY

APPENDIX G

SAS2H INPUT FILE TO GENERATE THE INPLIB ORIGEN-S CROSS-SECTION LIBRARY

```
=sas2     parm='halt21,skipshipdata'
gundremmingen bwr, assy b23, rod a1, 268 cm, 27.400 gwd/mtu b5 7/97 4.3r
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
44group        latticecell
uo2  1 den=9.866 1  923  92234  0.0267  92235 3.0    92236 0.0138
                      92238 96.9595  end
co-59  3 0 1-20 549  end
h-3    1 0 1-20 923  end
zr-94  1 0 1-20 923  end
nb-95  1 0 1-20 923  end
mo-95  1 0 1-20 923  end
tc-99  1 0 1-20 923  end
rh-103 1 0 1-20 923  end
rh-105 1 0 1-20 923  end
ru-106 1 0 1-20 923  end
sn-126 1 0 1-20 923  end
xe-131 1 0 1-20 923  end
cs-134 1 0 1-20 923  end
cs-135 1 0 1-20 923  end
cs-137 1 0 1-20 923  end
pr-143 1 0 1-20 923  end
nd-143 1 0 1-20 923  end
ce-144 1 0 1-20 923  end
nd-144 1 0 1-20 923  end
nd-145 1 0 1-20 923  end
nd-146 1 0 1-20 923  end
nd-147 1 0 1-20 923  end
pm-147 1 0 1-20 923  end
sm-147 1 0 1-20 923  end
nd-148 1 0 1-20 923  end
pm-148 1 0 1-20 923  end
sm-148 1 0 1-20 923  end
pm-149 1 0 1-20 923  end
sm-149 1 0 1-20 923  end
nd-150 1 0 1-20 923  end
sm-150 1 0 1-20 923  end
sm-151 1 0 1-20 923  end
eu-151 1 0 1-20 923  end
sm-152 1 0 1-20 923  end
eu-153 1 0 1-20 923  end
eu-154 1 0 1-20 923  end
gd-154 1 0 1-20 923  end
eu-155 1 0 1-20 923  end
gd-155 1 0 1-20 923  end
gd-157 1 0 1-20 923  end
gd-158 1 0 1-20 923  end
gd-160 1 0 1-20 923  end
'   need the following to use endf/b5 library:
zirc2    2 1   620   end
'
h2o  3 den=0.4      1  549 end
'
```

```
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of larger-unit-cell:
'
'   need the following to use endf/b5 library:
zirc2    7 1   549   end
'
'                 ....above is zircalloy casing around assembly
h2o         8   den=0.7750     1   539 end
b-10        8  0    4.0-5  539  end
h2o        12   den=0.7750     1   539 end
b-10       12  0    6.0-6  539  end
'                 ....above is channel moderator at higher density
uo2  9 den=9.866 1  923  92234  0.0267  92235 3.0    92236 0.0138
                      92238 96.9595  end
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.780  1.250  1 3  1.428  2  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'    assembly and cycle parameters:
'
npin/assm=36  fuelngth=2601.4  ncycles=21  nlib/cyc=1
printlevel=4  lightel=8  inplevel=2  numzones=7
mxrepeats=0   end
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405    8 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405    8 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405    8 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405    8 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405    8 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
```

```
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
9  0.625   2  0.714   3  1.0043
 500 6.026   3 6.235    7 6.405   12 7.390
power=40    burn=1.0e-15 down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=1500.0   end
       h   16.4     o  265.0    cr  2.4
       mn  0.15    fe  6.6      ni 2.4
       zr  516.0   sn  8.7
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end
```

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