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Dounreay PFR Irradiation History for the Joint US/UK Actinide Sample Exposures

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ABSTRACT

The operating history of the Dounreay Prototype Fast Reactor is presented to the extent that it is relevant to the irradiation of actinide specimens that were subsequently analyzed at Oak Ridge National Laboratory (ORNL). Three fuel pins with actinide samples were irradiated from July 1982 to July 1988 and returned to ORNL for analysis. They contained isotopes of elements from thorium to curium. The times when each of these fuel pins were in the reactor core are described as are the operating power levels and neutron spectra. The appendices give daily power levels of the reactor as well as six-group neutron energy spectra for various times and axial positions in the core.

INTRODUCTION

This report describes the power history of the Dounreay Prototype Fast Reactor* (PFR) as it relates to the exposure of the actinide physics specimens for the joint U.S./U.K. actinide experiment. The power history covering all irradiations is described, as well as details of the placement and irradiation of the fuel pins in the reactor core. Three fuel pins containing actinide samples are discussed: FP-1, FP-2, and FP-4. Pins FP-1 and FP-2 were irradiated and removed from the reactor at an early stage. Pin FP-4, loaded at the same time as FP-1 and FP-2, was irradiated at various times over about 6 years. An additional fuel pin, FP-3, was irradiated in a position similar to FP-2; however, this pin was not analyzed by us and will not be discussed in this report. This report refers to the reactor power history (and, hence, the exposure history) experienced by FP-4; this includes that experienced by FP-1 and FP-2 also. This is not a report on the operation of the PFR itself. During the 6 years when the reactor was operating, these pins, at times, were not in the reactor; this report does not describe such periods.

The irradiation of FP-4 containing the physics samples occurred at various times from July 1982 until July 1988. During this time, shorter periods referred to as reactor "runs" occurred. "Runs" are defined as periods between major core reloads. However, some runs are subdivided (e.g., 11a and 11b) because of an operational requirement for a minor core reload that might arise, say, for the replacement of failed fuel. A run consists of periods of low or zero power operation as well as periods of operation at power. Note that FP-4 was not irradiated in consecutive reactor runs and was absent from the core for some runs following run 7 and run 13a. The power history described in this report and used in the simulation of the irradiation was obtained from data files that give date, time of day, and reactor power level. These data files do not contain regular time entries (every two hours, for instance). New entries were made when the reactor power changed by more than 5% of the power level. Therefore, many frequent entries were made during power changes; few entries, during steady or zero power operation.

In discussing the PFR power history during the exposure of FP-4, all times are expressed in days, and we have chosen time zero to be 0000 h on July 1, 1982. Thus, July 1, 1982, is day 1, August 19, 1982, is day 50, etc.

*This report also includes information previously made available in PFR internal notes PFR/EI/US/UK/1 by C. C. Foreman and PFR/EI/US/UK/2 and 3 by W. S. Fraser.

OVERVIEW OF REACTOR RUNS

The exposure history of FP-4 can be described in terms of ten distinct reactor runs interspersed with periods during which the samples were not being irradiated. The run identifying numbers and beginning and ending dates are listed in Table 1. Note that a long period occurred between runs 7 and 11a when FP-4 was absent from the reactor. In fact, if one notes that during run 7 the reactor was operating at about one-third the power level for the other runs, then it can be said that most of the irradiation of FP-4 took place within about 2½ years. The overall power history experienced by FP-4 can be appreciated from Fig. 1, where the top panel displays the first 1100 days of reactor operations; below that is the power history for days 1100 to 2200. Note that 1100 days is just 5 days more than 3 years. For this 6-year period covering all irradiations, most of the exposure occurred in the latter half. Previous results¹ on the irradiation of FP-1 and FP-2 refer to the first 450 days, or thereabouts, when the PFR was operating at a low level. The total irradiation for these earlier experiments is roughly 63 full-power days while the exposure history for FP-4 described in this report is about 492 full-power days.

DETAILS OF REACTOR RUNS

The dates of the individual reactor runs (see Table 1) delimit the periods between reloads when FP-4 was in the core. The data files on reactor power level vs time bracket these dates. In simulating the irradiation of FP-4, we used time-averaged power levels. In doing so we extended our averaging from points in time slightly before the beginning times of the runs to points slightly beyond the nominal ending times.

As noted, run 7 occurs quite early in the irradiation history. Seen in the top part of Fig. 1, it nominally ends at day 447. Runs 11a, 11b, 11c, 12, 13a, 15, 16a, 16b, and 16c all occur during the last 930 days. In Figs. 2 and 3 we present the time periods covering these nine runs in more expanded form. Figure 2 shows days 1250 through 1750 during which runs 11a, 11b, 11c, 12, and 13a occurred; Fig. 3 shows days 1750 through 2250 covering the period of runs 15, 16a, 16b, and 16c. Pin FP-4 was removed from the core at the end of run 7 and was not returned until the beginning of run 11a. Again, following run 13a, FP-4 was removed and was returned at the beginning of run 15. Thus, one can see the reason for the main periods of inactivity that are evident in Fig. 1.

Table 1. Reactor run dates

Run No.	Beginning date (day No.)	Ending date (day No.)
7	July 27, 1982 (27)	September 20, 1983 (447)
11a	December 23, 1985 (1272)	February 14, 1986 (1325)
11b	February 18, 1986 (1329)	March 25, 1986 (1364)
11c	April 12, 1986 (1382)	May 31, 1986 (1431)
12	August 10, 1986 (1502)	December 4, 1986 (1618)
13a	December 21, 1986 (1635)	February 28, 1987 (1704)
15	September 13, 1987 (1901)	October 16, 1987 (1934)
16a	October 24, 1987 (1942)	January 17, 1988 (2027)
16b	February 27, 1988 (2068)	April 30, 1988 (2131)
16c	May 29, 1988 (2160)	July 7, 1988 (2199)

Fig. 1. Thermal power during the exposure of FP-4 in the PFR core. (Day 1 starts at 0000h on July 1, 1982, and midnight of July 7, 1988, represents the completion of day 2199.)

Fig. 2. Power history for days 1250 to 1750.

Fig. 3. Power history for days 1750 to 2250.

Table 2 shows the nominal beginning and ending day numbers for the reactor runs. Because each run represents a different core loading configuration, both the flux level and flux energy spectrum vary from run to run. Within an individual run, the flux at a given axial position is obtained by normalizing to the reactor power using the 600-MW flux values given in Appendix B. More details about the flux and spectra are given later in this report.

In simulating the exposure of the samples in FP-4, it was not practical to follow the details of the variations in power level shown in Figs. 1, 2, and 3. Rather, taking periods of time when the variations were not great, we have simulated the reactor performance with time-averaged power levels for each of these periods. Table 3 summarizes how the power history was simulated in this manner. A calculation that considers this method of simulation and the possible uncertainties associated with it is described in a later section.

The values given in Tables 1 and 2 have been referred to as the nominal beginning and ending dates (and day numbers) for the various reactor runs that are of current interest. They are the dates used by the Dounreay Nuclear Power Development Establishment. As we have alluded to above, when simulating the irradiation of FP-4, we have integrated over periods of time that bracket the periods of time given in Tables 1 and 2, a fact that can be seen from an inspection of Table 3. For instance, run 7 begins nominally at day 27, but in simulating run 7, we include a small amount of reactor activity beginning on day 2 and lasting until day 50. Then, on day 50 significant run 7 reactor activity is evident for the first time. Again, consider run 11a. As can be seen in Table 3, we began the run 11a simulation on day 1270, while nominally, the run begins on day 1272. Then again, note that run 11b ended on day 1364 according to Table 2. Table 3 shows that the significant reactor activity ends on day 1361, and we have actually simulated a low level of activity (i.e., roughly 2 MW) from day 1361 until day 1382 when run 11c begins.

Table 2. Day numbers of reactor runs

Run No.	Beginning day No.	Ending day No.
7	27	447
11a	1272	1325
11b	1329	1364
11c	1382	1431
12	1502	1618
13a	1635	1708
15	1901	1934
16a	1942	2027
16b	2068	2131
16c	2160	2199

Table 3. Details of the power-history simulation

Run No.	Beginning day	Ending day	Total days	Average power	Cumulative MWd
7	2	50	48.34	2.85	138
7	50	120	70.18	152.43	10,835
7	120	200	80.09	2.19	11,011
7	200	255	54.35	49.62	13,708
7	255	321	65.95	153.05	23,801
7	321	349	28.65	2.93	23,885
7	349	366	17.00	177.40	26,901
7	366	430	63.65	171.67	37,828
7	430	457	27.62	2.93	37,909
Decay	457	1,270	812.57	0.00	37,909
11a	1,270	1,307	36.86	309.37	49,312
11a	1,307	1,327	19.67	453.66	58,236
11b	1,327	1,361	33.99	497.73	75,153
11b	1,361	1,382	21.24	2.01	75,196
11c	1,382	1,407	25.14	293.14	82,566
11c	1,407	1,431	23.81	524.20	95,047
Decay	1,431	1,502	71.16	0.00	95,047
12	1,502	1,579	76.66	485.52	132,267
12	1,579	1,597	18.27	350.65	138,673
12	1,597	1,619	21.80	278.04	144,734
Decay	1,619	1,635	16.14	0.00	144,734
13a	1,635	1,649	13.80	370.49	149,847
13a	1,649	1,652	3.03	23.09	149,917
13a	1,652	1,704	52.46	504.56	176,386
Decay	1,704	1,901	196.60	0.00	176,386
15	1,901	1,913	12.10	285.95	179,846
15	1,913	1,935	21.97	421.55	189,108
Decay	1,935	1,942	7.32	0.00	189,108
16a	1,942	2,041	99.38	457.14	234,538
Decay	2,041	2,063	21.22	0.00	234,538
16b	2,063	2,132	68.88	551.92	272,555
Decay	2,132	2,158	26.95	0.00	272,555
16c	2,158	2,200	41.05	558.54	295,483

In summary, the dates and day numbers given in Tables 1 and 2 serve to give a good indication of the time periods for the various runs. But the detailed power history does not show the reactor activity as turning on and off at those times exactly. Furthermore, to produce the simulations of the power history shown in Fig. 1, we have divided the exposure time into steps during which the reactor power levels were reasonably constant. In this way, the exposure of the samples could be simulated by a succession of constant power level episodes whose time integral was equal to that of the actual power history.

IRRADIATION DETAILS OF THE ACTINIDE EXPERIMENT

The capsules containing actinide samples were prepared by Oak Ridge National Laboratory (ORNL) and Hanford Engineering Development Laboratory and were dispatched to Dounreay in 1981. These capsules were then placed in four fuel pins. ORNL has been involved in the analysis of three of these four fuel pins: FP-1, FP-2, and FP-4. FP-1 and FP-2 contained physics samples in the bottom sections; actinide fuel samples, in the top sections. FP-4 contained just physics samples. The section containing the physics samples was ordered similarly in all three pins (i.e., 3 dosimeter capsules, 13 actinide physics capsules, 3 dosimeter capsules, 13 actinide physics capsules, and 3 dosimeter capsules). The arrangement of the physics samples in FP-4 is illustrated in Walker et al.² While these 35 capsules were contained in the bottom sections of FP-1 and FP-2, they were located in the center portion of FP-4 such that they roughly straddled the core centerline. The pins, in turn, were placed in two specially built clusters of 19 pins. The other pins in these clusters were standard U.K. fuel pins. The arrangement of the 19 pins in a cluster is illustrated in Fig. 4. In turn, six of these 19-pin clusters formed a demountable subassembly (DMSA).

Fig. 4. Top view of the arrangement of fuel pins in a cluster showing the numbering scheme for the pins.

The arrangement of the clusters in a DMSA and the location of the DMSAs in the core are illustrated in Fig. 5. Cluster 1 (ACV 0402 AE 001), containing FP-1, was loaded to core in cluster position 1 at location 0702; cluster 2 (AGV 0402 AE 002), containing FP-2, FP-3, and FP-4, was loaded to core in cluster position 3 at location 0706 in July 1982 for the start of run 7. When loaded in July 1982, FP-1 was in position 10 (see Fig. 4) in cluster 1; FP-2, FP-3, and FP-4 were in positions 5, 14, and 11, respectively, in cluster 2.

Both cluster 1 (ACV 0402 AE 001) and cluster 2 (AGV 0402 AE 002) were discharged from the reactor in late 1983 at the end of run 7. Having completed its scheduled irradiation, FP-1 was broken down, and the physics samples and dosimeters were returned to ORNL. Cluster 2 containing FP-2, FP-3, and FP-4 was placed in storage. Following an analysis of results from both nondestructive and destructive examination of americium and curium samples from FP-1, the U.S. and U.K. participants agreed that only the physics samples of FP-4 should be scheduled for further irradiation. Therefore, FP-2 and FP-3 were removed from positions 5 and 14 in cluster 2 and replaced by regular fuel pins, leaving just FP-4 at position 11.

After nondestructive examination, FP-2 was shipped to ORNL for detailed analysis in July 1985, and the actinide samples from FP-3 were sent to the Atomic Energy Research Establishment, Harwell in July 1986 for detailed chemical analysis.

The rebuilt cluster 2 (AGV 0402 AE 002) was loaded into a new reactor location (i.e., 0702 and cluster position 4) in December 1985 for runs 11, 12, and 13 (this is the DMSA location that had originally contained cluster 1). At the conclusion of run 12, a cumulative total of about 241 effective full-power days (efpd) had been reached. Run 13 started on December 21, 1986, and ran for about 53 efpd until February 27, 1987, when a superheater tube failure led to a station shutdown. Remedial work on the steam-raising plant necessitated two-circuit operation (i.e., 2/3 full power) for the remainder of run 13. During the shutdown, a DMSA was removed from the reactor core and placed in rotor storage to avoid exposure of some other experimental clusters to low-power running conditions. An unfortunate consequence of this was that the actinide cluster AGV, which was also part of this DMSA, was prematurely removed.

Having been removed from the reactor at the end of run 13a, cluster AGV housing FP-4 was returned to a new core location (i.e., cluster position number 4 at 0710) for the start of run 15, which began on September 13, 1987. The cluster was irradiated in this location for a total of 198 efpd in runs 15 and 16 and was permanently removed from the reactor in July 1988 at the end of run 16. At final discharge, the cumulative total irradiation of FP-4 amounted to 492 efpd.

Fig. 5. Location of DMSAs in the core and the location of cluster positions in a DMSA.

THE PFR NEUTRON FLUX

All calculations performed for the analysis and operation of the PFR use the Compatible Open Shop Modular Operating System (COSMOS).³ This system is comprised of many individual modular programs that perform a well-defined part or the whole of a given physical calculation. The modules share, through the use of a data dictionary, common structures for the input/output of data such that the output from one module is valid input for any other module requiring the data. In addition, COSMOS provides a sophisticated database for the storage of data and transmission of data between modules as well as comprehensive supervisor routines for database management.

Within the COSMOS environment, suites of modules have been written that perform specific calculations required on a routine basis to support reactor operations. One such suite is called the reactor history following (RHF) calculations, and it is from these calculations that flux and spectra data have been taken for the analyses of the FP-1, FP-2, and FP-4 irradiations. The functionality of the RHF calculations is outlined as follows:

- assemble a reactor model of the current core loading from a database of subassembly compositions held in the COSMOS database,
- solve for the start-of-run flux distribution and k-effective,
- burn up the fuel compositions through the power operating history experienced in this run, and
- return the burn-up compositions to the COSMOS database to be used in due course to form the reactor model of the next run.

The RHF calculations are run once for each reactor run when the operating history of the run is known. The approximations introduced by performing these calculations only once per run are:

- flux spectra are assumed constant throughout the run,
- flux level changes due to both control rod movement and changes in individual subassembly burnups are assumed negligible, and
- flux levels are assumed to be constant at the start-of-run values other than their proportionality to power.

Although, above, the flux solution is stated to be the second stage of the RHF calculations, the situation is, in fact, a little more complex. Each subassembly in the database of subassembly compositions is modeled as a series of axial slices, each having its own composition. The thickness of these slices is dependent on the individual subassembly design, and the axial divisions of one subassembly will not necessarily match those of another. To solve a reactor model for the flux distribution, all subassemblies must share a common set of axial divisions. Before the flux can be solved, a standard mesh consisting of 17 axial meshes is first superimposed on the reactor model, and region composition is smeared, where necessary, within each subassembly to conform to the standard mesh structure.

Note that when the composition of a new subassembly is defined in the database of compositions, the maximum length of any fueled region is restricted to be less than 10 cm by introducing artificial axial region boundaries. This allows differential burnup in the height of the subassembly to be followed as irradiation proceeds.

The flux solution was obtained using the COSMOS module SNAP,⁴ which is also available as a stand-alone code. The SNAP code uses a mesh centered, finite-difference procedure to solve the diffusion theory approximation to the neutron transport equation. The main features of the model for which fluxes are solved are:

- radial mesh, having 6 triangles per hexagonal subassembly location (see Fig. 5);
- 17 axial meshes, of which 10 are in the core height;
- 6 neutron energy groups;
- subassembly compositions that are assumed homogeneous and uniform over the subassembly hexagonal area (For clusters, compositions are assumed homogeneous over a single triangular mesh. Each cluster contains one experiment, and six clusters may be placed in a DMSA that then occupies one hexagonal reactor location.);
- control rods that are assumed one-third inserted, an approximate average insertion during a run; and
- cross sections that are taken from the Fast Reactor Dataset 5 (FD5) adjusted cross-section set, condensed from 37 to 6 energy groups using standard region-dependent spectra.

The cross-section set FD5 has been derived from the FGL5 2240-group cross-section library.⁵

To obtain fluxes and spectra for the sample positions of FP-1, FP-2, and FP-4, the mesh- average fluxes, given by the SNAP solution, were interpolated to a set of standard axial heights at the position of each pin. Appendix B lists these heights for FP-4. Although these standard heights do not represent the actual heights of specific samples, they do give sufficient information to characterize the irradiation. The interpolation was performed for each run in which FP-4 was present. As an example, the six-group neutron spectra and total fluxes for the midplane position of the FP-4 are reproduced in Table 4 for each of the ten runs

Table 4. PFR six-group midplane neutron energy spectra for FP-4

Run No.	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Total flux (600 MW)
7	0.0863	0.2462	0.4201	0.1704	0.0699	0.0071	4.545E+15
11a	0.0830	0.2393	0.4167	0.1723	0.0801	0.0087	5.534E+15
11b	0.0821	0.2380	0.4169	0.1733	0.0808	0.0088	5.491E+15
11c	0.0816	0.2373	0.4171	0.1739	0.0812	0.0089	5.517E+15
12	0.0804	0.2388	0.4221	0.1739	0.0766	0.0082	5.135E+15
13a	0.0804	0.2395	0.4219	0.1733	0.0766	0.0083	5.240E+15
15	0.0901	0.2508	0.4226	0.1674	0.0637	0.0054	5.312E+15
16a	0.0899	0.2513	0.4232	0.1670	0.0632	0.0054	5.293E+15
16b	0.0884	0.2492	0.4242	0.1683	0.0643	0.0056	5.277E+15
16c	0.0925	0.2542	0.4198	0.1661	0.0621	0.0053	5.398E+15

in which this pin was irradiated. The spectra and fluxes for all axial positions in each run are reproduced in Appendix B; a typical plot of the energy spectrum is shown in Fig. 6 (taken from run 11a). The energy values used by us to define the six-group energy bins are given in Table 5.

The form of interpolation chosen was to seek a quadratic form to the flux in each energy group which gives both continuity of flux and continuity of neutron current with all neighboring meshes.

The normalization of the total fluxes was performed by calculating the integral reactor power and normalizing it to 600 MW total. The flux normalization is, therefore, closely related to the effective reactor-integrated plutonium fission cross section - about 80% of the reactor power resulting from ^{239}Pu fission.

Several assumptions have been made in using the above data to characterize the irradiations:

- The effects of mesh and energy-group resolution, as well as heterogeneity and transport effects, on group fluxes have been ignored.
- The one-third insertion of the control rods is assumed to model the rod insertion throughout the irradiation.

To calculate the effect of each of the above approximations would not be constructive; a better method is to look for flux adjustments in the light of comparisons of measured and calculated values resulting from the irradiations.

Note, however, that the main changes in flux and spectra that result from core-loading changes have been accounted for, as has the axial variation of these quantities. Figure 7 gives a plot of relative flux values as a function of axial position for a typical reactor run.

Fig. 6. A typical six-group PFR neutron flux spectrum.

Table 5. Six-group neutron spectra energy bins

Group No.	Upper edges (eV)
1	1.65×10^7
2	1.36×10^6
3	3.30×10^5
4	4.50×10^4
5	6.00×10^3
6	5.50×10^2
Lower energy limit: 1.0×10^4 eV

Fig. 7. Relative flux intensity vs axial position in the PFR.

At an earlier point in this work, outer-core neutron spectra in 37 groups were supplied by Dounreay personnel for five axial positions. From among these, the center-plane spectrum was used as a starting point in the development of cross sections to be used in the PFR actinide burnup calculations. This 37-group spectrum (assuming a $1/E$ spectrum shape within each group) was boosted to 238 groups to correspond with a 238-group ENDF/B-V library.⁶ This 238-group library was then collapsed to a six-group library corresponding to the six groups described above. Using this six-group library together with the six-group flux spectra for the various reactor runs, one-group cross sections were computed for the various PFR runs. Furthermore, ENDF/B-VI fission yields were also incorporated as part of this process. The relative flux values for the 37-group spectrum are shown in Table 6 and a plot of the flux spectrum is shown in Fig. 8 for the energy range of 10 eV to 100 MeV.

Table 6. The PFR 37-group outer-core spectrum

Energy group	Upper bound (eV)	Lower bound (eV)	Relative flux
1	1.649E 07	1.000E 07	1.391E-04
2	1.000E 07	6.065E 06	2.707E-03
3	6.065E 06	3.679E 06	1.327E-02
4	3.679E 06	2.231E 06	3.599E-02
5	2.231E 06	1.353E 06	5.199E-02
6	1.353E 06	8.209E 05	6.308E-02
7	8.209E 05	4.979E 05	1.081E-01
8	4.979E 05	3.020E 05	1.023E-01
9	3.020E 05	1.832E 05	1.265E-01
10	1.832E 05	1.111E 05	1.199E-01
11	1.111E 05	6.738E 04	9.338E-02
12	6.738E 04	4.087E 04	7.675E-02
13	4.087E 04	2.479E 04	5.364E-02
14	2.479E 04	1.503E 04	3.948E-02
15	1.503E 04	9.119E 03	3.891E-02
16	9.119E 03	5.531E 03	2.202E-02
17	5.531E 03	3.355E 03	1.323E-02
18	3.355E 03	2.035E 03	4.919E-03
19	2.035E 03	1.234E 03	1.494E-02
20	1.234E 03	7.485E 02	1.016E-02
21	7.485E 02	4.540E 02	5.191E-03
22	4.540E 02	2.754E 02	2.186E-03
23	2.754E 02	1.670E 02	7.800E-04
24	1.670E 02	1.013E 02	2.991E-04
25	1.013E 02	6.144E 01	9.084E-05
26	6.144E 01	3.727E 01	1.758E-05
27	3.727E 01	2.260E 01	7.542E-06
28	2.260E 01	1.371E 01	2.245E-06
29	1.371E 01	8.315E 00	1.439E-06
30	8.315E 00	5.043E 00	2.713E-07
31	5.043E 00	3.059E 00	3.310E-07
32	3.059E 00	1.855E 00	5.356E-07
33	1.855E 00	1.125E 00	5.533E-07
34	1.125E 00	6.826E-01	1.243E-09
35	6.826E-01	4.140E-01	7.139E-09
36	4.140E-01	1.000E-01	1.010E-10
37	1.000E-01	1.000E-04	1.258E-11

Fig. 8. PFR 37-group outer-core spectrum.

EFFECT OF STEP SIZE ON POWER HISTORY SIMULATION

The power history of the PFR is available in very fine detail (i.e., measurements of power levels are about 1 hour apart during times of significant power changes). However, it was not practical to simulate the exposure of all the actinide samples in this amount of detail. Rather, the simulations were performed using time-averaged power levels for a more manageable number of time periods. In light of this, however, it is appropriate to see if there is any effect on the accuracy of the simulation when this simplification is applied.

The simplified power history developed in this report and detailed in Table 3 has been formulated by staff members at ORNL. This was done to simulate the decay and ingrowth of actinides and fission products using the ORIGEN-S code⁷ for eventual comparison with post-irradiation measurements. Totally independently, staff members at Dounreay, the site of the PFR, have also simulated the power history. This second simulation was not performed specifically to analyze the irradiation of FP-4 but, rather, was used in the fuel burnup calculations needed when following the compositional change of the reactor. For one of the actinide sample capsules, concentration values predicted with both methods of power-history simulation were compared. The differences were negligible.

The results of this early comparison were encouraging, and a more extensive study of the effect of power-history simulation detail was eventually undertaken. The PFR power history was simulated in five different levels of detail:

1. Daily average power values calculated for the duration of the exposure. This resulted in about 2200 individual time steps.
2. The Dounreay simulation. This resulted in 160 time steps.
3. The ORNL simulation. This required 33 separate time steps.
4. A simulation using four large time steps. These covered from day 50 to day 460 (37,909 MWd), day 1270 to day 1430 (57,138 MWd), day 1500 to day 1710 (81,339 MWd), and day 1900 to day 2200 (119,097 MWd) for a total of 295,483 MWd.
5. A simulation at a constant power level. Again, four time steps were used. They were centered on the above four time steps but were each at a power level of 600 MW (nominal full power for the PFR). Their lengths were such that the integrated power in each case was equal to that in the corresponding time step above.

These various simulations are shown for comparison purposes in Fig. 9.

For one of the exposed actinide samples (i.e., containing ²³⁹Pu as the principal actinide), a simulation was performed using each of these five methods of power-history simulation. The Dounreay simulation was done with the Dounreay code, and the other four simulations used the ORIGEN-S code. As can be seen, the five methods covered a wide range of detail, and we were particularly interested in determining if the results would show systematic trends as a function of simulation detail. Figure 10 shows the comparisons between the calculated

Fig. 9. The various methods used in the power-history simulation. Power in megawatts is plotted vs day number. Days are counted from July 1, 1982 (July 8, 1988 is day number 2200). (See next page for continuation of this figure.)

Fig. 9. (continued)

Fig. 10. Calculated results for fission products shown as ratios to diurnal simulation results.

fission-product concentrations. Ratios are shown of concentration calculations relative to the detailed (i.e., daily-average) simulation discussed above.

The fission-product nuclides in Fig. 10 are arranged in order of increasing half-life. For ^{137}Cs , the longest lived of these nuclides (i.e., half-life of 30 years), the results calculated by ORIGEN-S are independent of the level of simulation detail. In the case of the other nuclides some small differences are evident. However, the magnitude of these differences is negligible in all cases. For the shortest lived of these fission products (i.e., $^{110\text{m}}\text{Ag}$ with a half-life of 250 days), the spread in calculated values seems to be the most pronounced. It seems possible that there might be an effect associated with rather short-lived species. However, for the purposes at hand, involving species that are not particularly short lived, one can reliably simulate the PFR exposure with manageable approximations to the power history. And, in particular, the ORNL simulation using 33 individual time steps is appropriate.

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APPENDIX A

DAILY POWER HISTORY OF THE PFR

This appendix gives a day-to-day synopsis of the power-history data for the PFR. Daily average power levels for all runs involving FP-4 are given in chronological order. Each page consists of three sets of two columns. The two columns contain a date (with a day number) and the average reactor operating power for that date. The date is to be interpreted in the U.S. sense (i.e., month, day, and year in that order); the day numbers (as explained in the Introduction) consider July 1, 1982, as day 1, and the operating power is in megawatts. This synopsis of the data was chosen because the raw data would require a considerably larger number of pages. The average operating power for any day is obtained by averaging from the last measurement time on the previous day to the last measurement on the day in question. So, although this period is not necessarily a day in length, the quoted averages are to a good approximation for daily intervals occurring successively during the operating history of the PFR. Detailed power-history data were not available for two time periods during run 7 (i.e., April 1 - 30, 1983, and June 15 - July 1, 1983); and average power values have been substituted for these.

date (day no.)	power	date (day no.)	power	date (day no.)	power
7/27/82 (27)	2.93	9/10/82 (72)	184.06	10/25/82 (117)	84.13
7/28/82 (28)	2.93	9/11/82 (73)	182.97	10/26/82 (118)	.00
7/29/82 (29)	2.26	9/12/82 (74)	181.60	10/27/82 (119)	.00
7/30/82 (30)	.00	9/13/82 (75)	181.60	10/28/82 (120)	.00
7/31/82 (31)	.00	9/14/82 (76)	182.44	10/29/82 (121)	.00
8/ 1/82 (32)	.00	9/15/82 (77)	183.48	10/30/82 (122)	.00
8/ 2/82 (33)	.00	9/16/82 (78)	182.14	10/31/82 (123)	.00
8/ 3/82 (34)	.00	9/17/82 (79)	183.36	11/1 - 11/30/82	.00
8/ 4/82 (35)	.70	9/18/82 (80)	184.50	12/ 1/82 (154)	2.93
8/ 5/82 (36)	2.93	9/19/82 (81)	183.55	12/ 2/82 (155)	2.93
8/ 6/82 (37)	2.93	9/20/82 (82)	182.29	12/ 3/82 (156)	2.93
8/ 7/82 (38)	2.93	9/21/82 (83)	181.12	12/ 4/82 (157)	2.93
8/ 8/82 (39)	2.93	9/22/82 (84)	180.15	12/ 5/82 (158)	3.38
8/ 9/82 (40)	3.32	9/23/82 (85)	167.89	12/ 6/82 (159)	2.93
8/10/82 (41)	2.44	9/24/82 (86)	74.43	12/ 7/82 (160)	2.93
8/11/82 (42)	5.87	9/25/82 (87)	70.31	12/ 8/82 (161)	2.93
8/12/82 (43)	8.79	9/26/82 (88)	109.75	12/ 9/82 (162)	2.93
8/13/82 (44)	8.14	9/27/82 (89)	173.51	12/10/82 (163)	2.93
8/14/82 (45)	3.49	9/28/82 (90)	175.70	12/11/82 (164)	2.93
8/15/82 (46)	1.85	9/29/82 (91)	175.70	12/12/82 (165)	2.93
8/16/82 (47)	4.94	9/30/82 (92)	175.70	12/13/82 (166)	2.93
8/17/82 (48)	1.20	10/ 1/82 (93)	178.80	12/14/82 (167)	2.93
8/18/82 (49)	1.47	10/ 2/82 (94)	175.70	12/15/82 (168)	2.93
8/19/82 (50)	2.93	10/ 3/82 (95)	175.49	12/16/82 (169)	2.93
8/20/82 (51)	2.93	10/ 4/82 (96)	178.70	12/17/82 (170)	2.93
8/21/82 (52)	2.15	10/ 5/82 (97)	178.70	12/18/82 (171)	2.93
8/22/82 (53)	16.33	10/ 6/82 (98)	180.15	12/19/82 (172)	2.93
8/23/82 (54)	29.80	10/ 7/82 (99)	178.70	12/20/82 (173)	2.93
8/24/82 (55)	37.16	10/ 8/82 (100)	179.44	12/21/82 (174)	2.93
8/25/82 (56)	140.05	10/ 9/82 (101)	179.36	12/22/82 (175)	2.93
8/26/82 (57)	155.73	10/10/82 (102)	178.70	12/23/82 (176)	2.93
8/27/82 (58)	68.81	10/11/82 (103)	181.60	12/24/82 (177)	2.93
8/28/82 (59)	170.20	10/12/82 (104)	179.46	12/25/82 (178)	2.93
8/29/82 (60)	175.70	10/13/82 (105)	178.70	12/26/82 (179)	2.93
8/30/82 (61)	178.19	10/14/82 (106)	176.80	12/27/82 (180)	2.93
8/31/82 (62)	182.20	10/15/82 (107)	177.95	12/28/82 (181)	2.93
9/ 1/82 (63)	184.50	10/16/82 (108)	178.70	12/29/82 (182)	2.93
9/ 2/82 (64)	182.12	10/17/82 (109)	178.70	12/30/82 (183)	2.93
9/ 3/82 (65)	183.75	10/18/82 (110)	178.70	12/31/82 (184)	2.93
9/ 4/82 (66)	183.05	10/19/82 (111)	181.60	1/ 1/83 (185)	2.93
9/ 5/82 (67)	182.09	10/20/82 (112)	178.70	1/ 2/83 (186)	2.93
9/ 6/82 (68)	183.05	10/21/82 (113)	180.84	1/ 3/83 (187)	2.93
9/ 7/82 (69)	183.05	10/22/82 (114)	179.77	1/ 4/83 (188)	2.93
9/ 8/82 (70)	182.60	10/23/82 (115)	179.40	1/ 5/83 (189)	.00
9/ 9/82 (71)	182.55	10/24/82 (116)	180.83	1/ 6/83 (190)	.00

date (day no.)	power	date (day no.)	power	date (day no.)	power
1/ 7/83 (191)	.00	2/21/83 (236)	179.40	5/ 6/83 (310)	180.88
1/ 8/83 (192)	.00	2/22/83 (237)	178.70	5/ 7/83 (311)	181.94
1/ 9/83 (193)	.00	2/23/83 (238)	181.60	5/ 8/83 (312)	179.47
1/10/83 (194)	2.12	2/24/83 (239)	181.79	5/ 9/83 (313)	181.60
1/11/83 (195)	2.93	2/25/83 (240)	178.70	5/10/83 (314)	181.41
1/12/83 (196)	2.93	2/26/83 (241)	147.09	5/11/83 (315)	179.42
1/13/83 (197)	2.56	2/27/83 (242)	2.53	5/12/83 (316)	180.86
1/14/83 (198)	17.19	2/28/83 (243)	2.94	5/13/83 (317)	180.15
1/15/83 (199)	.00	3/ 1/83 (244)	2.93	5/14/83 (318)	180.15
1/16/83 (200)	.00	3/ 2/83 (245)	2.93	5/15/83 (319)	178.75
1/17/83 (201)	.00	3/ 3/83 (246)	2.93	5/16/83 (320)	19.90
1/18/83 (202)	1.46	3/ 4/83 (247)	2.93	5/17/83 (321)	2.93
1/19/83 (203)	4.65	3/ 5/83 (248)	2.93	5/18/83 (322)	2.93
1/20/83 (204)	39.82	3/ 6/83 (249)	2.93	5/19/83 (323)	2.93
1/21/83 (205)	152.04	3/ 7/83 (250)	2.93	5/20/83 (324)	2.93
1/22/83 (206)	172.80	3/ 8/83 (251)	2.93	5/21/83 (325)	2.93
1/23/83 (207)	141.23	3/ 9/83 (252)	2.93	5/22/83 (326)	2.93
1/24/83 (208)	2.93	3/10/83 (253)	26.33	5/23/83 (327)	2.93
1/25/83 (209)	2.93	3/11/83 (254)	2.93	5/24/83 (328)	2.93
1/26/83 (210)	2.93	3/12/83 (255)	2.93	5/25/83 (329)	2.93
1/27/83 (211)	2.93	3/13/83 (256)	2.93	5/26/83 (330)	2.93
1/28/83 (212)	2.93	3/14/83 (257)	2.93	5/27/83 (331)	2.93
1/29/83 (213)	2.93	3/15/83 (258)	2.93	5/28/83 (332)	2.93
1/30/83 (214)	2.93	3/16/83 (259)	2.93	5/29/83 (333)	2.93
1/31/83 (215)	2.93	3/17/83 (260)	2.93	5/30/83 (334)	2.93
2/ 1/83 (216)	2.93	3/18/83 (261)	2.93	5/31/83 (335)	2.93
2/ 2/83 (217)	2.93	3/19/83 (262)	6.24	6/ 1/83 (336)	2.93
2/ 3/83 (218)	2.93	3/20/83 (263)	21.24	6/ 2/83 (337)	2.93
2/ 4/83 (219)	2.93	3/21/83 (264)	94.61	6/ 3/83 (338)	2.93
2/ 5/83 (220)	2.93	3/22/83 (265)	179.52	6/ 4/83 (339)	2.93
2/ 6/83 (221)	2.93	3/23/83 (266)	178.70	6/ 5/83 (340)	2.93
2/ 7/83 (222)	2.93	3/24/83 (267)	181.60	6/ 6/83 (341)	2.93
2/ 8/83 (223)	2.93	3/25/83 (268)	178.70	6/ 7/83 (342)	2.93
2/ 9/83 (224)	2.93	3/26/83 (269)	178.70	6/ 8/83 (343)	2.93
2/10/83 (225)	2.93	3/27/83 (270)	178.70	6/ 9/83 (344)	2.93
2/11/83 (226)	2.93	3/28/83 (271)	181.60	6/10/83 (345)	2.93
2/12/83 (227)	2.93	3/29/83 (272)	180.89	6/11/83 (346)	2.93
2/13/83 (228)	29.56	3/30/83 (273)	180.87	6/12/83 (347)	2.93
2/14/83 (229)	47.63	3/31/83 (274)	176.68	6/13/83 (348)	2.93
2/15/83 (230)	141.17	4/ 1 - 4/30/83	181.60	6/14/83 (349)	2.93
2/16/83 (231)	175.48	5/ 1/83 (305)	179.70	6/15/83 (350)	177.40
2/17/83 (232)	177.92	5/ 2/83 (306)	180.87	6/16/83 (351)	177.40
2/18/83 (233)	180.15	5/ 3/83 (307)	181.60	6/17/83 (352)	177.40
2/19/83 (234)	179.67	5/ 4/83 (308)	181.60	6/18/83 (353)	177.40
2/20/83 (235)	179.41	5/ 5/83 (309)	181.60	6/19/83 (354)	177.40

date (day no.)	power	date (day no.)	power	date (day no.)	power
6/20/83 (355)	177.40	7/21/83 (386)	175.70	8/21/83 (417)	178.70
6/21/83 (356)	177.40	7/22/83 (387)	176.49	8/22/83 (418)	175.70
6/22/83 (357)	177.40	7/23/83 (388)	178.70	8/23/83 (419)	176.42
6/23/83 (358)	177.40	7/24/83 (389)	178.70	8/24/83 (420)	175.70
6/24/83 (359)	177.40	7/25/83 (390)	175.70	8/25/83 (421)	178.70
6/25/83 (360)	177.40	7/26/83 (391)	178.21	8/26/83 (422)	178.70
6/26/83 (361)	177.40	7/27/83 (392)	175.70	8/27/83 (423)	177.63
6/27/83 (362)	177.40	7/28/83 (393)	176.45	8/28/83 (424)	178.83
6/28/83 (363)	177.40	7/29/83 (394)	178.70	8/29/83 (425)	180.15
6/29/83 (364)	177.40	7/30/83 (395)	178.70	8/30/83 (426)	178.70
6/30/83 (365)	177.40	7/31/83 (396)	178.70	8/31/83 (427)	173.60
7/ 1/83 (366)	177.40	8/ 1/83 (397)	175.70	9/ 1/83 (428)	23.52
7/ 2/83 (367)	178.70	8/ 2/83 (398)	175.70	9/ 2/83 (429)	3.66
7/ 3/83 (368)	179.40	8/ 3/83 (399)	176.46	9/ 3/83 (430)	2.93
7/ 4/83 (369)	178.70	8/ 4/83 (400)	178.70	9/ 4/83 (431)	2.93
7/ 5/83 (370)	178.70	8/ 5/83 (401)	177.93	9/ 5/83 (432)	2.93
7/ 6/83 (371)	180.88	8/ 6/83 (402)	175.70	9/ 6/83 (433)	2.93
7/ 7/83 (372)	178.70	8/ 7/83 (403)	177.68	9/ 7/83 (434)	2.93
7/ 8/83 (373)	178.20	8/ 8/83 (404)	175.70	9/ 8/83 (435)	2.93
7/ 9/83 (374)	178.70	8/ 9/83 (405)	172.80	9/ 9/83 (436)	2.93
7/10/83 (375)	178.70	8/10/83 (406)	175.53	9/10/83 (437)	2.93
7/11/83 (376)	178.70	8/11/83 (407)	178.70	9/11/83 (438)	2.93
7/12/83 (377)	178.70	8/12/83 (408)	178.70	9/12/83 (439)	2.93
7/13/83 (378)	177.20	8/13/83 (409)	175.70	9/13/83 (440)	2.93
7/14/83 (379)	178.70	8/14/83 (410)	178.70	9/14/83 (441)	2.93
7/15/83 (380)	178.70	8/15/83 (411)	178.70	9/15/83 (442)	2.93
7/16/83 (381)	178.70	8/16/83 (412)	178.70	9/16/83 (443)	2.93
7/17/83 (382)	180.15	8/17/83 (413)	178.70	9/17/83 (444)	2.93
7/18/83 (383)	178.70	8/18/83 (414)	178.70	9/18/83 (445)	2.93
7/19/83 (384)	176.51	8/19/83 (415)	178.70	9/19/83 (446)	2.93
7/20/83 (385)	177.95	8/20/83 (416)	178.70	9/20/83 (447)	2.93

run 11a

date (day no.)	power	date (day no.)	power	date (day no.)	power
12/23/85 (1272)	3.52	1/10/86 (1290)	80.36	1/28/86 (1308)	2.89
12/24/85 (1273)	2.37	1/11/86 (1291)	100.24	1/29/86 (1309)	38.16
12/25/85 (1274)	25.52	1/12/86 (1292)	83.91	1/30/86 (1310)	113.31
12/26/85 (1275)	132.79	1/13/86 (1293)	73.12	1/31/86 (1311)	512.19
12/27/85 (1276)	429.07	1/14/86 (1294)	250.34	2/ 1/86 (1312)	645.95
12/28/85 (1277)	528.12	1/15/86 (1295)	620.14	2/ 2/86 (1313)	641.42
12/29/85 (1278)	574.55	1/16/86 (1296)	622.93	2/ 3/86 (1314)	636.64
12/30/85 (1279)	414.69	1/17/86 (1297)	625.10	2/ 4/86 (1315)	637.63
12/31/85 (1280)	116.98	1/18/86 (1298)	642.59	2/ 5/86 (1316)	638.38
1/ 1/86 (1281)	566.43	1/19/86 (1299)	648.03	2/ 6/86 (1317)	634.04
1/ 2/86 (1282)	632.32	1/20/86 (1300)	240.14	2/ 7/86 (1318)	639.11
1/ 3/86 (1283)	545.39	1/21/86 (1301)	581.81	2/ 8/86 (1319)	636.74
1/ 4/86 (1284)	429.93	1/22/86 (1302)	602.44	2/ 9/86 (1320)	639.97
1/ 5/86 (1285)	431.04	1/23/86 (1303)	493.06	2/10/86 (1321)	629.93
1/ 6/86 (1286)	429.96	1/24/86 (1304)	4.14	2/11/86 (1322)	641.39
1/ 7/86 (1287)	364.44	1/25/86 (1305)	2.93	2/12/86 (1323)	637.92
1/ 8/86 (1288)	37.90	1/26/86 (1306)	.00	2/13/86 (1324)	560.68
1/ 9/86 (1289)	52.15	1/27/86 (1307)	.00	2/14/86 (1325)	9.14

run 11b

date (day no.)	power	date (day no.)	power	date (day no.)	power
2/18/86 (1329)	.00	3/ 2/86 (1341)	647.16	3/14/86 (1353)	294.94
2/19/86 (1330)	30.84	3/ 3/86 (1342)	643.54	3/15/86 (1354)	634.13
2/20/86 (1331)	450.24	3/ 4/86 (1343)	643.11	3/16/86 (1355)	645.92
2/21/86 (1332)	636.29	3/ 5/86 (1344)	643.52	3/17/86 (1356)	644.18
2/22/86 (1333)	646.03	3/ 6/86 (1345)	643.82	3/18/86 (1357)	636.65
2/23/86 (1334)	645.55	3/ 7/86 (1346)	639.30	3/19/86 (1358)	540.24
2/24/86 (1335)	642.39	3/ 8/86 (1347)	646.34	3/20/86 (1359)	35.15
2/25/86 (1336)	647.27	3/ 9/86 (1348)	642.61	3/21/86 (1360)	29.30
2/26/86 (1337)	642.68	3/10/86 (1349)	645.02	3/22/86 (1361)	1.41
2/27/86 (1338)	638.75	3/11/86 (1350)	644.50	3/23/86 (1362)	.00
2/28/86 (1339)	645.05	3/12/86 (1351)	644.50	3/24/86 (1363)	.70
3/ 1/86 (1340)	647.06	3/13/86 (1352)	230.43	3/25/86 (1364)	.00

run 11c

date (day no.)	power	date (day no.)	power	date (day no.)	power
4/12/86 (1382)	2.93	4/28/86 (1398)	418.48	5/14/86 (1414)	617.75
4/13/86 (1383)	9.28	4/29/86 (1399)	416.00	5/15/86 (1415)	623.17
4/14/86 (1384)	92.76	4/30/86 (1400)	415.32	5/16/86 (1416)	622.55
4/15/86 (1385)	94.50	5/ 1/86 (1401)	409.92	5/17/86 (1417)	621.27
4/16/86 (1386)	58.54	5/ 2/86 (1402)	412.53	5/18/86 (1418)	615.79
4/17/86 (1387)	44.68	5/ 3/86 (1403)	409.62	5/19/86 (1419)	620.41
4/18/86 (1388)	30.81	5/ 4/86 (1404)	407.72	5/20/86 (1420)	619.15
4/19/86 (1389)	247.42	5/ 5/86 (1405)	417.23	5/21/86 (1421)	618.85
4/20/86 (1390)	417.46	5/ 6/86 (1406)	257.54	5/22/86 (1422)	592.80
4/21/86 (1391)	399.33	5/ 7/86 (1407)	2.93	5/23/86 (1423)	559.83
4/22/86 (1392)	405.35	5/ 8/86 (1408)	3.91	5/24/86 (1424)	602.11
4/23/86 (1393)	409.95	5/ 9/86 (1409)	51.47	5/25/86 (1425)	609.42
4/24/86 (1394)	416.18	5/10/86 (1410)	225.52	5/26/86 (1426)	612.79
4/25/86 (1395)	415.45	5/11/86 (1411)	607.85	5/27/86 (1427)	611.88
4/26/86 (1396)	416.00	5/12/86 (1412)	634.84	5/28/86 (1428)	606.82
4/27/86 (1397)	416.00	5/13/86 (1413)	633.25	5/29/86 (1429)	606.64
				5/30/86 (1430)	576.50
				5/31/86 (1431)	.45

run 12

date (day no.)	power	date (day no.)	power	date (day no.)	power
8/10/86 (1502)	6.45	9/18/86 (1541)	641.60	10/27/86 (1580)	233.29
8/11/86 (1503)	8.79	9/19/86 (1542)	640.73	10/28/86 (1581)	342.19
8/12/86 (1504)	14.41	9/20/86 (1543)	610.00	10/29/86 (1582)	309.56
8/13/86 (1505)	11.81	9/21/86 (1544)	640.36	10/30/86 (1583)	376.84
8/14/86 (1506)	.00	9/22/86 (1545)	602.54	10/31/86 (1584)	413.59
8/15/86 (1507)	.00	9/23/86 (1546)	612.77	11/ 1/86 (1585)	407.97
8/16/86 (1508)	16.44	9/24/86 (1547)	621.58	11/ 2/86 (1586)	413.32
8/17/86 (1509)	36.37	9/25/86 (1548)	614.13	11/ 3/86 (1587)	415.48
8/18/86 (1510)	55.48	9/26/86 (1549)	613.94	11/ 4/86 (1588)	416.74
8/19/86 (1511)	63.97	9/27/86 (1550)	625.90	11/ 5/86 (1589)	423.22
8/20/86 (1512)	116.50	9/28/86 (1551)	640.59	11/ 6/86 (1590)	427.58
8/21/86 (1513)	63.96	9/29/86 (1552)	642.05	11/ 7/86 (1591)	430.60
8/22/86 (1514)	56.68	9/30/86 (1553)	642.03	11/ 8/86 (1592)	432.78
8/23/86 (1515)	255.92	10/ 1/86 (1554)	642.11	11/ 9/86 (1593)	426.27
8/24/86 (1516)	415.53	10/ 2/86 (1555)	640.72	11/10/86 (1594)	430.85
8/25/86 (1517)	431.77	10/ 3/86 (1556)	639.91	11/11/86 (1595)	396.79
8/26/86 (1518)	523.01	10/ 4/86 (1557)	620.01	11/12/86 (1596)	5.79
8/27/86 (1519)	601.04	10/ 5/86 (1558)	638.83	11/13/86 (1597)	.00
8/28/86 (1520)	609.42	10/ 6/86 (1559)	642.40	11/14/86 (1598)	.00
8/29/86 (1521)	602.97	10/ 7/86 (1560)	639.37	11/15/86 (1599)	2.93
8/30/86 (1522)	603.63	10/ 8/86 (1561)	640.13	11/16/86 (1600)	14.28
8/31/86 (1523)	605.69	10/ 9/86 (1562)	617.59	11/17/86 (1601)	26.30
9/ 1/86 (1524)	617.54	10/10/86 (1563)	639.18	11/18/86 (1602)	43.05
9/ 2/86 (1525)	627.56	10/11/86 (1564)	576.47	11/19/86 (1603)	350.28
9/ 3/86 (1526)	625.82	10/12/86 (1565)	26.89	11/20/86 (1604)	426.40
9/ 4/86 (1527)	627.40	10/13/86 (1566)	57.58	11/21/86 (1605)	430.46
9/ 5/86 (1528)	626.19	10/14/86 (1567)	87.71	11/22/86 (1606)	431.50
9/ 6/86 (1529)	628.63	10/15/86 (1568)	515.78	11/23/86 (1607)	433.13
9/ 7/86 (1530)	595.03	10/16/86 (1569)	635.53	11/24/86 (1608)	431.54
9/ 8/86 (1531)	627.80	10/17/86 (1570)	642.60	11/25/86 (1609)	429.89
9/ 9/86 (1532)	626.92	10/18/86 (1571)	627.21	11/26/86 (1610)	429.87
9/10/86 (1533)	603.05	10/19/86 (1572)	641.04	11/27/86 (1611)	427.70
9/11/86 (1534)	603.90	10/20/86 (1573)	642.09	11/28/86 (1612)	429.15
9/12/86 (1535)	628.14	10/21/86 (1574)	642.57	11/29/86 (1613)	425.08
9/13/86 (1536)	620.31	10/22/86 (1575)	641.81	11/30/86 (1614)	427.70
9/14/86 (1537)	585.21	10/23/86 (1576)	640.95	12/ 1/86 (1615)	404.69
9/15/86 (1538)	628.11	10/24/86 (1577)	643.23	12/ 2/86 (1616)	381.67
9/16/86 (1539)	610.04	10/25/86 (1578)	112.11	12/ 3/86 (1617)	51.64
9/17/86 (1540)	619.07	10/26/86 (1579)	105.91	12/ 4/86 (1618)	43.31

run 13a

date (day no.)	power	date (day no.)	power	date (day no.)	power
12/21/86 (1635)	2.26	1/13/87 (1658)	618.38	2/ 5/87 (1681)	616.65
12/22/86 (1636)	48.49	1/14/87 (1659)	345.19	2/ 6/87 (1682)	629.86
12/23/86 (1637)	203.01	1/15/87 (1660)	36.00	2/ 7/87 (1683)	633.48
12/24/86 (1638)	392.27	1/16/87 (1661)	188.77	2/ 8/87 (1684)	619.33
12/25/86 (1639)	444.97	1/17/87 (1662)	583.14	2/ 9/87 (1685)	637.16
12/26/86 (1640)	448.83	1/18/87 (1663)	633.42	2/10/87 (1686)	640.13
12/27/86 (1641)	450.73	1/19/87 (1664)	636.21	2/11/87 (1687)	640.24
12/28/86 (1642)	454.94	1/20/87 (1665)	623.77	2/12/87 (1688)	642.09
12/29/86 (1643)	453.29	1/21/87 (1666)	637.95	2/13/87 (1689)	638.84
12/30/86 (1644)	451.12	1/22/87 (1667)	635.64	2/14/87 (1690)	625.14
12/31/86 (1645)	451.78	1/23/87 (1668)	638.13	2/15/87 (1691)	634.47
1/ 1/87 (1646)	451.21	1/24/87 (1669)	626.32	2/16/87 (1692)	398.26
1/ 2/87 (1647)	446.89	1/25/87 (1670)	634.83	2/17/87 (1693)	246.81
1/ 3/87 (1648)	423.50	1/26/87 (1671)	465.36	2/18/87 (1694)	582.25
1/ 4/87 (1649)	24.79	1/27/87 (1672)	265.38	2/19/87 (1695)	611.59
1/ 5/87 (1650)	23.12	1/28/87 (1673)	254.56	2/20/87 (1696)	600.18
1/ 6/87 (1651)	23.43	1/29/87 (1674)	494.98	2/21/87 (1697)	617.18
1/ 7/87 (1652)	25.62	1/30/87 (1675)	586.58	2/22/87 (1698)	623.37
1/ 8/87 (1653)	79.32	1/31/87 (1676)	89.18	2/23/87 (1699)	630.45
1/ 9/87 (1654)	506.27	2/ 1/87 (1677)	203.35	2/24/87 (1700)	631.31
1/10/87 (1655)	318.26	2/ 2/87 (1678)	619.33	2/25/87 (1701)	630.16
1/11/87 (1656)	361.27	2/ 3/87 (1679)	624.93	2/26/87 (1702)	624.67
1/12/87 (1657)	614.29	2/ 4/87 (1680)	624.39	2/27/87 (1703)	286.21
				2/28/87 (1704)	2.93

run 15

date (day no.)	power	date (day no.)	power	date (day no.)	power
9/13/87 (1901)	1.53	9/24/87 (1912)	40.53	10/ 5/87 (1923)	584.31
9/14/87 (1902)	7.66	9/25/87 (1913)	1.78	10/ 6/87 (1924)	574.54
9/15/87 (1903)	93.50	9/26/87 (1914)	12.43	10/ 7/87 (1925)	588.07
9/16/87 (1904)	277.41	9/27/87 (1915)	131.72	10/ 8/87 (1926)	594.32
9/17/87 (1905)	415.77	9/28/87 (1916)	528.91	10/ 9/87 (1927)	565.01
9/18/87 (1906)	424.35	9/29/87 (1917)	526.73	10/10/87 (1928)	335.87
9/19/87 (1907)	433.09	9/30/87 (1918)	485.85	10/11/87 (1929)	29.75
9/20/87 (1908)	434.51	10/ 1/87 (1919)	554.77	10/12/87 (1930)	313.73
9/21/87 (1909)	437.18	10/ 2/87 (1920)	584.82	10/13/87 (1931)	576.74
9/22/87 (1910)	438.69	10/ 3/87 (1921)	585.15	10/14/87 (1932)	584.29
9/23/87 (1911)	434.30	10/ 4/87 (1922)	584.24	10/15/87 (1933)	537.48
				10/16/87 (1934)	4.12

run 16a

date (day no.)	power	date (day no.)	power	date (day no.)	power
10/24/87 (1942)	3.31	11/21/87 (1970)	596.17	12/19/87 (1998)	630.02
10/25/87 (1943)	31.88	11/22/87 (1971)	594.99	12/20/87 (1999)	628.64
10/26/87 (1944)	319.09	11/23/87 (1972)	604.50	12/21/87 (2000)	627.56
10/27/87 (1945)	529.48	11/24/87 (1973)	604.55	12/22/87 (2001)	628.65
10/28/87 (1946)	582.27	11/25/87 (1974)	600.73	12/23/87 (2002)	626.60
10/29/87 (1947)	595.90	11/26/87 (1975)	604.93	12/24/87 (2003)	628.48
10/30/87 (1948)	602.74	11/27/87 (1976)	599.11	12/25/87 (2004)	617.42
10/31/87 (1949)	586.09	11/28/87 (1977)	597.76	12/26/87 (2005)	622.10
11/ 1/87 (1950)	407.10	11/29/87 (1978)	606.62	12/27/87 (2006)	511.61
11/ 2/87 (1951)	34.97	11/30/87 (1979)	613.27	12/28/87 (2007)	14.96
11/ 3/87 (1952)	315.72	12/ 1/87 (1980)	613.36	12/29/87 (2008)	213.01
11/ 4/87 (1953)	601.49	12/ 2/87 (1981)	608.80	12/30/87 (2009)	621.37
11/ 5/87 (1954)	603.16	12/ 3/87 (1982)	618.97	12/31/87 (2010)	629.78
11/ 6/87 (1955)	601.95	12/ 4/87 (1983)	625.29	1/ 1/88 (2011)	628.44
11/ 7/87 (1956)	590.21	12/ 5/87 (1984)	617.88	1/ 2/88 (2012)	613.80
11/ 8/87 (1957)	600.63	12/ 6/87 (1985)	626.64	1/ 3/88 (2013)	624.83
11/ 9/87 (1958)	602.03	12/ 7/87 (1986)	630.02	1/ 4/88 (2014)	627.54
11/10/87 (1959)	602.62	12/ 8/87 (1987)	626.62	1/ 5/88 (2015)	627.35
11/11/87 (1960)	597.29	12/ 9/87 (1988)	625.33	1/ 6/88 (2016)	625.60
11/12/87 (1961)	594.88	12/10/87 (1989)	627.31	1/ 7/88 (2017)	627.74
11/13/87 (1962)	603.55	12/11/87 (1990)	626.77	1/ 8/88 (2018)	629.40
11/14/87 (1963)	584.20	12/12/87 (1991)	588.82	1/ 9/88 (2019)	610.82
11/15/87 (1964)	591.43	12/13/87 (1992)	549.23	1/10/88 (2020)	626.79
11/16/87 (1965)	379.43	12/14/87 (1993)	565.41	1/11/88 (2021)	627.22
11/17/87 (1966)	.60	12/15/87 (1994)	627.84	1/12/88 (2022)	626.95
11/18/87 (1967)	5.66	12/16/87 (1995)	625.27	1/13/88 (2023)	622.71
11/19/87 (1968)	10.72	12/17/87 (1996)	101.73	1/14/88 (2024)	627.22
11/20/87 (1969)	376.79	12/18/87 (1997)	478.23	1/15/88 (2025)	610.06
				1/16/88 (2026)	603.98
				1/17/88 (2027)	198.99

run 16b

date (day no.)	power	date (day no.)	power	date (day no.)	power
2/27/88 (2068)	114.00	3/19/88 (2089)	67.15	4/ 9/88 (2110)	606.79
2/28/88 (2069)	397.68	3/20/88 (2090)	584.05	4/10/88 (2111)	628.49
2/29/88 (2070)	610.22	3/21/88 (2091)	630.33	4/11/88 (2112)	633.27
3/ 1/88 (2071)	635.08	3/22/88 (2092)	632.95	4/12/88 (2113)	631.12
3/ 2/88 (2072)	630.90	3/23/88 (2093)	626.04	4/13/88 (2114)	628.15
3/ 3/88 (2073)	629.67	3/24/88 (2094)	626.84	4/14/88 (2115)	617.26
3/ 4/88 (2074)	635.70	3/25/88 (2095)	631.20	4/15/88 (2116)	629.40
3/ 5/88 (2075)	621.72	3/26/88 (2096)	609.88	4/16/88 (2117)	608.60
3/ 6/88 (2076)	633.29	3/27/88 (2097)	629.67	4/17/88 (2118)	628.23
3/ 7/88 (2077)	637.20	3/28/88 (2098)	629.70	4/18/88 (2119)	625.69
3/ 8/88 (2078)	636.39	3/29/88 (2099)	632.13	4/19/88 (2120)	632.77
3/ 9/88 (2079)	630.66	3/30/88 (2100)	607.84	4/20/88 (2121)	628.32
3/10/88 (2080)	630.76	3/31/88 (2101)	626.89	4/21/88 (2122)	626.76
3/11/88 (2081)	638.54	4/ 1/88 (2102)	635.07	4/22/88 (2123)	631.12
3/12/88 (2082)	613.82	4/ 2/88 (2103)	609.66	4/23/88 (2124)	617.13
3/13/88 (2083)	638.72	4/ 3/88 (2104)	607.58	4/24/88 (2125)	631.42
3/14/88 (2084)	638.60	4/ 4/88 (2105)	632.43	4/25/88 (2126)	629.86
3/15/88 (2085)	638.42	4/ 5/88 (2106)	632.37	4/26/88 (2127)	622.70
3/16/88 (2086)	631.75	4/ 6/88 (2107)	628.36	4/27/88 (2128)	626.24
3/17/88 (2087)	632.81	4/ 7/88 (2108)	632.75	4/28/88 (2129)	624.64
3/18/88 (2088)	534.91	4/ 8/88 (2109)	632.78	4/29/88 (2130)	543.36
				4/30/88 (2131)	27.02

run 16c

date (day no.)	power	date (day no.)	power	date (day no.)	power
5/29/88 (2160)	140.46	6/11/88 (2173)	624.68	6/24/88 (2186)	628.63
5/30/88 (2161)	393.59	6/12/88 (2174)	633.25	6/25/88 (2187)	631.11
5/31/88 (2162)	596.93	6/13/88 (2175)	632.67	6/26/88 (2188)	638.28
6/ 1/88 (2163)	628.87	6/14/88 (2176)	631.66	6/27/88 (2189)	636.33
6/ 2/88 (2164)	625.74	6/15/88 (2177)	634.99	6/28/88 (2190)	639.17
6/ 3/88 (2165)	629.49	6/16/88 (2178)	355.43	6/29/88 (2191)	632.50
6/ 4/88 (2166)	631.06	6/17/88 (2179)	571.17	6/30/88 (2192)	255.48
6/ 5/88 (2167)	628.06	6/18/88 (2180)	624.94	7/ 1/88 (2193)	603.29
6/ 6/88 (2168)	631.41	6/19/88 (2181)	633.63	7/ 2/88 (2194)	616.73
6/ 7/88 (2169)	632.90	6/20/88 (2182)	634.84	7/ 3/88 (2195)	632.29
6/ 8/88 (2170)	631.93	6/21/88 (2183)	632.83	7/ 4/88 (2196)	619.57
6/ 9/88 (2171)	632.09	6/22/88 (2184)	543.15	7/ 5/88 (2197)	637.04
6/10/88 (2172)	632.04	6/23/88 (2185)	253.75	7/ 6/88 (2198)	629.47
				7/ 7/88 (2199)	293.56

APPENDIX B

SIX-GROUP NEUTRON SPECTRA FOR THE PFR RUNS

The following tables contain the six-group neutron spectra for the PFR runs covering the irradiation of the FP-4 physics samples. For each run, there is a separate six-group spectrum and the total flux corresponding to 600 MW at each of 13 different axial positions. The six groups are defined in Table 5 and Fig. 6.

Table B.1. PFR run 7 spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0855	0.2450	0.4220	0.1705	0.0698	0.0072	3.5868E+15
201.8	0.0857	0.2456	0.4218	0.1703	0.0696	0.0071	3.8691E+15
155.7	0.0858	0.2460	0.4214	0.1701	0.0695	0.0071	4.0966E+15
109.6	0.0859	0.2461	0.4209	0.1702	0.0698	0.0071	4.2920E+15
63.5	0.0861	0.2461	0.4205	0.1703	0.0699	0.0071	4.4353E+15
17.4	0.0862	0.2462	0.4203	0.1703	0.0699	0.0071	4.5301E+15
0.0	0.0863	0.2462	0.4201	0.1704	0.0699	0.0071	4.5450E+15
-28.7	0.0864	0.2462	0.4201	0.1704	0.0698	0.0070	4.5708E+15
-74.8	0.0866	0.2463	0.4199	0.1704	0.0699	0.0070	4.5598E+15
-120.9	0.0870	0.2463	0.4198	0.1705	0.0694	0.0069	4.4913E+15
-166.9	0.0879	0.2469	0.4203	0.1706	0.0677	0.0065	4.3603E+15
-212.9	0.0885	0.2468	0.4204	0.1710	0.0669	0.0063	4.1826E+15
-286.8	0.0885	0.2452	0.4198	0.1727	0.0673	0.0065	3.7932E+15

Table B.2. PFR run 11a spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0825	0.2383	0.4180	0.1745	0.0783	0.0084	4.21428E+15
201.8	0.0828	0.2395	0.4180	0.1735	0.0780	0.0083	4.56888E+15
155.7	0.0828	0.2398	0.4177	0.1730	0.0783	0.0084	4.89207E+15
109.6	0.0828	0.2399	0.4175	0.1726	0.0787	0.0085	5.14800E+15
63.5	0.0828	0.2397	0.4171	0.1725	0.0794	0.0086	5.35809E+15
17.4	0.0829	0.2394	0.4168	0.1723	0.0799	0.0087	5.49786E+15
0.0	0.0830	0.2393	0.4167	0.1723	0.0801	0.0087	5.53428E+15
-28.7	0.0831	0.2390	0.4165	0.1722	0.0805	0.0088	5.57676E+15
-74.8	0.0833	0.2387	0.4163	0.1722	0.0808	0.0088	5.58263E+15
-120.9	0.0835	0.2383	0.4161	0.1723	0.0810	0.0088	5.51714E+15
-166.9	0.0838	0.2381	0.4162	0.1724	0.0808	0.0087	5.38677E+15
-212.9	0.0844	0.2383	0.4164	0.1725	0.0799	0.0085	5.18702E+15
-286.8	0.0842	0.2365	0.4163	0.1737	0.0806	0.0086	4.75048E+15

Table B.3. PFR run 11b spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0817	0.2372	0.4183	0.1754	0.0789	0.0085	4.18604E+15
201.8	0.0820	0.2383	0.4183	0.1744	0.0786	0.0084	4.53669E+15
155.7	0.0820	0.2385	0.4180	0.1739	0.0791	0.0085	4.85601E+15
109.6	0.0820	0.2386	0.4177	0.1736	0.0795	0.0086	5.10893E+15
63.5	0.0820	0.2384	0.4174	0.1735	0.0801	0.0087	5.31664E+15
17.4	0.0821	0.2381	0.4170	0.1734	0.0806	0.0088	5.45471E+15
0.0	0.0821	0.2380	0.4169	0.1733	0.0808	0.0088	5.49061E+15
-28.7	0.0822	0.2378	0.4166	0.1733	0.0812	0.0089	5.53253E+15
-74.8	0.0824	0.2374	0.4164	0.1733	0.0815	0.0089	5.53776E+15
-120.9	0.0826	0.2370	0.4164	0.1735	0.0816	0.0089	5.47190E+15
-166.9	0.0829	0.2368	0.4164	0.1737	0.0815	0.0088	5.34217E+15
-212.9	0.0834	0.2369	0.4165	0.1739	0.0807	0.0086	5.14364E+15
-286.8	0.0832	0.2350	0.4162	0.1751	0.0816	0.0088	4.70790E+15

Table B.4. PFR run 11c spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0814	0.2368	0.4183	0.1757	0.0792	0.0086	4.21424E+15
201.8	0.0817	0.2378	0.4183	0.1748	0.0789	0.0085	4.56509E+15
155.7	0.0816	0.2381	0.4181	0.1743	0.0793	0.0086	4.88440E+15
109.6	0.0816	0.2381	0.4178	0.1740	0.0797	0.0087	5.13681E+15
63.5	0.0815	0.2378	0.4176	0.1740	0.0804	0.0088	5.34318E+15
17.4	0.0816	0.2375	0.4172	0.1739	0.0810	0.0089	5.48081E+15
0.0	0.0816	0.2373	0.4171	0.1739	0.0812	0.0089	5.51668E+15
-28.7	0.0818	0.2370	0.4168	0.1739	0.0816	0.0090	5.55873E+15
-74.8	0.0819	0.2367	0.4166	0.1739	0.0819	0.0090	5.56404E+15
-120.9	0.0821	0.2362	0.4165	0.1740	0.0821	0.0090	5.49845E+15
-166.9	0.0824	0.2360	0.4166	0.1742	0.0818	0.0089	5.36877E+15
-212.9	0.0831	0.2363	0.4170	0.1743	0.0807	0.0086	5.17187E+15
-286.8	0.0829	0.2345	0.4164	0.1756	0.0818	0.0089	4.73244E+15

Table B.5. PFR run 12 spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0799	0.2366	0.4208	0.1769	0.0774	0.0084	3.97119E+15
201.8	0.0802	0.2380	0.4212	0.1757	0.0766	0.0082	4.29383E+15
155.7	0.0801	0.2383	0.4212	0.1751	0.0770	0.0083	4.59158E+15
109.6	0.0802	0.2387	0.4216	0.1745	0.0768	0.0083	4.81653E+15
63.5	0.0802	0.2388	0.4221	0.1742	0.0764	0.0082	4.98920E+15
17.4	0.0803	0.2388	0.4222	0.1740	0.0765	0.0082	5.10553E+15
0.0	0.0804	0.2388	0.4221	0.1739	0.0766	0.0082	5.13536E+15
-28.7	0.0806	0.2385	0.4220	0.1738	0.0769	0.0082	5.17094E+15
-74.8	0.0808	0.2382	0.4218	0.1738	0.0772	0.0082	5.17023E+15
-120.9	0.0809	0.2378	0.4214	0.1738	0.0778	0.0083	5.10850E+15
-166.9	0.0812	0.2375	0.4212	0.1740	0.0778	0.0082	4.97687E+15
-212.9	0.0819	0.2377	0.4214	0.1740	0.0769	0.0081	4.76462E+15
-286.8	0.0812	0.2345	0.4192	0.1755	0.0808	0.0088	4.38744E+15

Table B.6. PFR run 13a spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0799	0.2374	0.4208	0.1764	0.0771	0.0084	4.07054E+15
201.8	0.0802	0.2387	0.4213	0.1752	0.0764	0.0082	4.39828E+15
155.7	0.0801	0.2391	0.4214	0.1745	0.0767	0.0083	4.69907E+15
109.6	0.0801	0.2395	0.4216	0.1739	0.0765	0.0083	4.92568E+15
63.5	0.0802	0.2397	0.4219	0.1736	0.0764	0.0083	5.09912E+15
17.4	0.0803	0.2396	0.4219	0.1734	0.0765	0.0083	5.21233E+15
0.0	0.0804	0.2395	0.4219	0.1733	0.0766	0.0083	5.24026E+15
-28.7	0.0805	0.2392	0.4218	0.1733	0.0770	0.0083	5.27167E+15
-74.8	0.0806	0.2388	0.4217	0.1734	0.0773	0.0083	5.26125E+15
-120.9	0.0807	0.2381	0.4215	0.1736	0.0778	0.0083	5.18576E+15
-166.9	0.0807	0.2374	0.4216	0.1740	0.0780	0.0083	5.03893E+15
-212.9	0.0809	0.2370	0.4221	0.1744	0.0774	0.0082	4.80850E+15
-286.8	0.0783	0.2316	0.4204	0.1773	0.0831	0.0093	4.39993E+15

Table B.7. PFR run 15 spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0906	0.2508	0.4224	0.1681	0.0627	0.0054	3.96311E+15
201.8	0.0907	0.2517	0.4225	0.1672	0.0626	0.0053	4.32673E+15
155.7	0.0901	0.2515	0.4223	0.1669	0.0637	0.0055	4.66407E+15
109.6	0.0900	0.2512	0.4224	0.1671	0.0639	0.0055	4.93390E+15
63.5	0.0900	0.2510	0.4226	0.1673	0.0636	0.0054	5.14287E+15
17.4	0.0900	0.2509	0.4226	0.1673	0.0637	0.0054	5.27789E+15
0.0	0.0901	0.2508	0.4226	0.1674	0.0637	0.0054	5.31181E+15
-28.7	0.0900	0.2506	0.4227	0.1674	0.0638	0.0054	5.35127E+15
-74.8	0.0901	0.2504	0.4226	0.1676	0.0639	0.0055	5.35303E+15
-120.9	0.0902	0.2501	0.4224	0.1677	0.0641	0.0055	5.28471E+15
-166.9	0.0902	0.2497	0.4222	0.1680	0.0644	0.0055	5.15283E+15
-212.9	0.0903	0.2493	0.4220	0.1683	0.0646	0.0055	4.95218E+15
-286.8	0.0901	0.2476	0.4212	0.1695	0.0658	0.0057	4.50520E+15

Table B.8. PFR run 16a spectrum

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0903	0.2510	0.4228	0.1680	0.0626	0.0053	3.94391E+15
201.8	0.0905	0.2519	0.4229	0.1671	0.0624	0.0053	4.30690E+15
155.7	0.0899	0.2518	0.4228	0.1668	0.0634	0.0054	4.64403E+15
109.6	0.0898	0.2516	0.4229	0.1669	0.0635	0.0054	4.91388E+15
63.5	0.0899	0.2514	0.4232	0.1670	0.0631	0.0054	5.12330E+15
17.4	0.0899	0.2513	0.4232	0.1670	0.0632	0.0054	5.25896E+15
0.0	0.0899	0.2513	0.4232	0.1670	0.0632	0.0054	5.29316E+15
-28.7	0.0899	0.2511	0.4233	0.1671	0.0632	0.0054	5.33356E+15
-74.8	0.0899	0.2509	0.4233	0.1672	0.0634	0.0054	5.33525E+15
-120.9	0.0900	0.2507	0.4231	0.1673	0.0635	0.0054	5.26552E+15
-166.9	0.0901	0.2503	0.4229	0.1676	0.0638	0.0054	5.13370E+15
-212.9	0.0902	0.2499	0.4226	0.1678	0.0640	0.0055	4.93416E+15
-286.8	0.0901	0.2484	0.4220	0.1691	0.0649	0.0056	4.48637E+15

Table B.9. PFR run 16b

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0893	0.2495	0.4236	0.1689	0.0632	0.0054	3.94345E+15
201.8	0.0893	0.2502	0.4238	0.1682	0.0631	0.0054	4.30480E+15
155.7	0.0887	0.2499	0.4239	0.1681	0.0639	0.0055	4.63730E+15
109.6	0.0885	0.2497	0.4240	0.1682	0.0641	0.0055	4.90061E+15
63.5	0.0884	0.2494	0.4242	0.1683	0.0641	0.0055	5.10916E+15
17.4	0.0884	0.2493	0.4242	0.1683	0.0642	0.0055	5.24339E+15
0.0	0.0884	0.2492	0.4242	0.1683	0.0643	0.0056	5.27671E+15
-28.7	0.0883	0.2490	0.4241	0.1684	0.0646	0.0056	5.31458E+15
-74.8	0.0883	0.2488	0.4240	0.1685	0.0648	0.0056	5.31688E+15
-120.9	0.0883	0.2486	0.4239	0.1686	0.0649	0.0056	5.24947E+15
-166.9	0.0884	0.2483	0.4237	0.1688	0.0651	0.0056	5.11825E+15
-212.9	0.0887	0.2479	0.4235	0.1691	0.0651	0.0056	4.92222E+15
-286.8	0.0888	0.2467	0.4229	0.1702	0.0657	0.0057	4.48241E+15

Table B.10. PFR run 16c

Axial position (mm)	1	2	3	4	5	6	Total flux (600 MW)
250.2	0.0929	0.2539	0.4196	0.1669	0.0616	0.0052	4.05957E+15
201.8	0.0931	0.2547	0.4197	0.1661	0.0612	0.0051	4.43207E+15
155.7	0.0927	0.2548	0.4199	0.1659	0.0615	0.0052	4.76784E+15
109.6	0.0926	0.2548	0.4199	0.1658	0.0616	0.0052	5.02908E+15
63.5	0.0926	0.2546	0.4198	0.1658	0.0619	0.0052	5.23871E+15
17.4	0.0926	0.2543	0.4198	0.1660	0.0620	0.0052	5.36808E+15
0.0	0.0925	0.2542	0.4198	0.1661	0.0621	0.0053	5.39784E+15
-28.7	0.0925	0.2540	0.4198	0.1662	0.0622	0.0053	5.42700E+15
-74.8	0.0924	0.2535	0.4198	0.1666	0.0625	0.0053	5.40947E+15
-120.9	0.0922	0.2529	0.4198	0.1670	0.0628	0.0053	5.31546E+15
-166.9	0.0915	0.2515	0.4200	0.1678	0.0637	0.0055	5.15292E+15
-212.9	0.0907	0.2497	0.4203	0.1690	0.0647	0.0056	4.91450E+15
-286.8	0.0854	0.2429	0.4218	0.1734	0.0700	0.0065	4.39850E+15

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