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ZPPR Progress Report: September 1988 through December 1988

Argonne National Laboratory—West, Idaho Falls, Idaho 83403-2528
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ANL-ZPR-489

**ZPPR PROGRESS REPORT:
SEPTEMBER 1988 THROUGH DECEMBER 1988**

edited by

S. B. Brumbach and P. J. Collins

**Engineering Physics Division
Argonne National Laboratory - West
P.O. Box 2528
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January 20, 1989

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ZPPR PROGRESS REPORT: SEPTEMBER 1988 THROUGH DECEMBER 1988

edited by

S. B. Brumbach and P. J. Collins

ABSTRACT

Further results are presented from the JUPITER-III program. Calculation models and k-effective results are given for the three configurations of the large, homogeneous assembly ZPPR-18. Reaction rate results, including sodium activation are given for ZPPR-18A. Also included are spatial decoupling results from ZPPR-18.

As a successor to JUPITER-III, the Io program investigated the effects of uranium fuel distribution in mixed uranium and plutonium fueled assemblies. The ZPPR-19A and 19B assemblies which made up the Io program are described.

1. PROGRAM STATUS (S. B. Brumbach and P. J. Collins)

Experiments in support of the SP-100 Space Power Nuclear Assembly Test (SP-100 NAT) were completed on December 21, 1988. Throughout the period, measurements were made in the engineering mockup critical (EMC) assembly ZPPR-20 which represented various configurations of SP-100. Experiments in the reference flight design configuration, ZPPR-20C, included doppler reactivity coefficients, power distributions, control worths and the worth of water flooding and water immersion. For the flooding experiment, polyethylene replaced lithium in the core and also surrounded and then replaced the reflectors outside the core. The flooded configuration was made critical, and was designated ZPPR-20D. Measurements in ZPPR-20D were worths of control rods and major core constituent materials.

The ZPPR-20E configuration represented earth burial by surrounding the core axially and radially with silica (sand). After demonstrating that ZPPR-20E was subcritical, the NAT EMC was rebuilt as ZPPR-20F. The major experiments in ZPPR-20F were tests of operational instruments to be used in the nuclear assembly test at Hanford. One set of instruments, noise detectors for subcritical reactivity monitoring, required removal of several tubes from the ZPPR matrix.

Processing of experimental data for foil reaction rates, gamma heating and the principal reactivity measurements in ZPPR-20A, 20B and 20C has been completed and the results have been issued as "ZPPR-20 Data Sheets." Processing of reactivity data for ZPPR-20D and 20F is in progress. Only a few configurations of ZPPR-20 can be realistically modeled with two-dimensional transport codes and the detailed analysis is being made by Westinghouse Advanced Energy Systems Division using the MCNP Monte Carlo code.

Experimental data and analysis for ZPPR-17, the axially heterogeneous cores of the JUPITER-III program, have been reported. Most of the data processing and calculations for the large conventional cores, ZPPR-18 and ZPPR-19, have been completed with the exception of reaction rate measurements in ZPPR-19B and a few control rod measurements in ZPPR-18B and

19A. Descriptions of these latter cores and operational measurements are contained in the present report together with reaction rate data and analysis for ZPPR-18A. The reaction rate data include, for the first time at ZPPR, measurements of sodium capture. The principal data that remain to be reported are control rod worths in ZPPR-18A and 19B and reaction rates in ZPPR-18B, 18C and 19B.

2. REFERENCE CONFIGURATIONS FOR THE LARGE HOMOGENEOUS BENCHMARK ASSEMBLY ZPPR-19A (S. B. Brumbach)

The ZPPR-19A assembly was the first in the Io program, successor to the JUPITER-III cooperative program between the USDOE and PNC of Japan. The Io program had two primary objectives. The first was to determine eigenvalue separation and spatial flux sensitivity in a significantly decoupled, 8000 liter homogeneous core. The second was to determine the effect of the ^{235}U fuel distribution on spatially sensitive parameters. The first objective was addressed in the ZPPR-19A assembly and the second in the ZPPR-19B assembly.

ZPPR-19A had the outlines of ZPPR-18A, including distinct ^{235}U and plutonium fuel zones in the outer core, but also had six fully inserted control rods in the inner control ring. The inserted control rods had the effect of reducing the eigenvalue separation to about 2% Δk from the 4% Δk calculated for ZPPR-18A.

The ZPPR-19A assembly was derived directly from ZPPR-18C (see ANL-ZPR-489, p. 19). Zone outlines and cell types were identical in both assemblies. The distinguishing feature in ZPPR-19A was six fully inserted control rods in the inner bank compared to 17 half-inserted rods in the inner and outer banks in ZPPR-18C. Also, because of the smaller amount of boron, ZPPR-19A had fewer double-fuel-column drawers than ZPPR-18C. The locations of operating rods and in-core fission chambers were the same in both assemblies.

2.1 The ZPPR-19A "Almost Critical" Reference Configuration

The most reactive reference in ZPPR-19A was slightly subcritical and is called here the "almost critical" reference. It was established on January 8, 1988 in reactor loading number 6, reactor run number 8. The reactivity measured by inverse kinetics was $-0.43 \pm 0.02\%$ at an average core temperature of 27.85°C. The interface diagram is given in Fig. 2.1 with the matrix locations marked with a solid square containing

double-fuel-column drawers. A drawer loading summary is given in Table 2.1 and the mass summaries for various regions are given in Table 2.2.

2.2 The ZPPR-19A Subcritical Reference Configurations

The ZPPR-19A subcritical reference was established on January 7, 1988 in reactor run number 4, reactor loading number 4. The reactivity was $-24.0 \pm 0.1\phi$ determined by inverse kinetics analysis of a rod drop. The interface diagram is given in Fig. 2.1 with the matrix locations marked with a solid square containing single-fuel-column drawers. The total fissile mass was 4.437 kg less than in the "almost critical" reference and the fissile Pu mass was 4.410 kg less.

TABLE 2.1 Drawer Loading Summary for the ZPPR-19A Almost
Critical Reference

Inner Core

Drawers with one column of plutonium fuel and iron oxide (Includes 20 drawers with fission chambers, two drawers with thermocouples and 16 narrow drawers adjacent to PSRs)	1930
---	------

Drawers with one column of plutonium fuel and depleted uranium metal (Includes nine drawers with fission chambers and 32 narrow drawers adjacent to PSRs)	1200
---	------

Drawers with two columns of plutonium fuel	160
--	-----

Outer Core

Drawers with one column of plutonium fuel (Includes four drawers with fission chambers)	528
--	-----

Drawers with two columns of plutonium fuel (Includes two drawers with fission chambers)	284
--	-----

Drawers with one column of uranium fuel (Includes five drawers with fission chambers)	588
--	-----

Drawers with two columns of uranium fuel (Includes four drawers with fission chambers)	528
---	-----

Control Rod Positions

Drawers filled with sodium cans	288
---------------------------------	-----

Radial Blanket

Drawers containing uranium oxide (Includes 12 drawers with fission chambers)	1840
---	------

Drawers containing uranium metal (Includes four drawers with fission chambers)	300
---	-----

Radial Reflector

Stainless-steel-filled drawers (Includes five drawers with fission chambers)	1860
---	------

Mild-steel-filled drawers	64
---------------------------	----

TABLE 2.2 Mass Summary for Various Regions in the ZPPR-19A "Almost Critical" Reference

Material	Mass, kg ^b						Control Position
	Inner Core	Outer core Plutonium	Outer Core Uranium	Radial Blanket	Axial Blanket	Control Rod	
Total Pu	2150.063	694.548	- - -	- - -	- - -	- - -	- - -
Fissile Pu	1895.307	602.324	- - -	- - -	- - -	- - -	- - -
Total Fissile	1928.937	609.502	1137.474	47.881	31.162	- - -	- - -
²³⁸ Pu	0.932	0.361	- - -	- - -	- - -	- - -	- - -
²³⁹ Pu	1880.853	596.619	- - -	- - -	- - -	- - -	- - -
²⁴⁰ Pu	249.439	89.757	- - -	- - -	- - -	- - -	- - -
²⁴¹ Pu ^a	14.454	5.704	- - -	- - -	- - -	- - -	- - -
²⁴² Pu	3.885	2.106	- - -	- - -	- - -	- - -	- - -
Americium ^a	23.120	9.084	- - -	- - -	- - -	- - -	- - - ^c
²³⁵ U	33.630	7.179	1137.474	47.881	31.162	- - -	- - -
²³⁸ U	15551.750	3333.841	4785.004	22092.750	14345.780	- - -	- - -
Total Heavy Metal	17758.530	4044.650	5938.809	22140.620	14376.940	- - -	- - -
O	1634.076	482.536	772.147	1704.949	1042.820	0.234	0.012
Na	1788.324	437.464	559.521	460.208	1734.130	37.334	234.200
Mo	203.719	64.147	4.438	6.974	23.679	0.297	0.928
Steel ^c	7368.048	1922.300	3235.135	3487.283	8890.004	137.924	460.481
¹⁰ B	- - -	- - -	- - -	- - -	- - -	15.882	- - -
¹¹ B	- - -	- - -	- - -	- - -	- - -	70.825	- - -
C	14.673	20.723	74.900	2.111	4.924	24.630	0.206

^aMasses for all isotopes decayed to 1/11/88.

^bMasses are based on the average masses for plate types.

^cSteel mass is the sum of masses of elements Cr, Mn, Fe, and Ni.

- PU SINGLE - DUF
- PU SINGLE - DUM
- ◊ PU DOUBLE COLUMN
- / U SINGLE COLUMN
- + U DOUBLE COLUMN
- OPERATING ROD
- SINGLE COLUMN IN SUBCRITICAL REFERENCE
- DOUBLE COLUMN IN CRITICAL REFERENCE

Fig. 2.1. Interface Diagram for the ZPPR-19A Reference Configuration

3. REFERENCE CONFIGURATIONS FOR THE LARGE HOMOGENEOUS BENCHMARK ASSEMBLY ZPPR-19B (S. B. Brumbach)

The ZPPR-19B assembly was the second in the Io program. Its purpose was to determine the effect of ^{235}U fuel distribution on spatially sensitive parameters. ZPPR-19B was distinguished by a uniform distribution of uranium and plutonium fuel drawers in the outer core. There were no inserted control rods in ZPPR-19B. The inner core contained only drawers with one column of plutonium fuel. In many ways, ZPPR-19B was an analog of ZPPR-18A, and comparison of C/E values in the two cores can indicate effects of ^{235}U distribution.

The ZPPR-19B critical reference was established on January 29, 1988 in loading number 21, reactor run number 18. The excess reactivity, determined in a positive period measurement, was 13.0¢ at an average core temperature of 26.22°C. The interface diagram is given in Fig. 3.1 with the matrix locations marked with a solid square containing double-fuel-column drawers (uranium fuel). A loading summary is given in Table 3.1 and mass summaries for various regions are given in Table 3.2.

The ZPPR-19B subcritical reference was established on February 8, 1988 in loading number 28, reactor run number 25. The reactivity was determined by inverse kinetics analysis of a rod drop to be -20.9¢. The interface diagram is given in Fig. 3.1 with the matrix locations marked by solid squares containing single-fuel-column drawers (uranium fuel). The fissile mass was 16.397 kg less than in the critical reference.

TABLE 3.1 Drawer Loading Summary for the ZPPR-19B Critical Reference

Inner Core

Drawers with one column of plutonium fuel.

Drawers with iron oxide (Includes 20 drawers with fission chambers and 16 narrow drawers adjacent to PSRs and two drawers with thermocouples) 1930

Drawers with depleted uranium metal (Includes nine drawers with fission chambers and 32 narrow drawers adjacent to PSRs) 1360

Outer Core

Drawers with one column of plutonium fuel (Includes 4 drawers with fission chambers) 600

Drawers with two columns of plutonium fuel (Includes two drawers with fission chambers) 212

Drawers with one column of uranium fuel (Includes five drawers with fission chambers) 676

Drawers with two columns of uranium fuel (Includes four drawers with fission chambers) 440

Control Rod Positions

Drawers filled with sodium cans 288

Radial Blanket

Drawers containing uranium oxide (Includes 12 drawers with fission chambers) 1840

Drawers containing uranium metal (Includes four drawers with fission chambers) 300

Radial Reflector

Stainless-steel-filled drawers (Includes five drawers with fission chambers) 1860

Mild-steel-filled drawers 64

TABLE 3.2 Mass Summary for Various Regions in the ZPPR-19B Critical Reference

Material	Mass, kg ^b				
	Inner Core	Outer Core	Radial Blanket	Axial Blanket	Control Position
Total Pu	2049.885	639.658	- - -	- - -	- - -
Fissile Pu	1807.007	563.796	- - -	- - -	- - -
Total Fissile	1841.140	1648.030	47.881	31.162	- - -
²³⁸ Pu	0.883	0.315	- - -	- - -	- - -
²³⁹ Pu	1793.288	559.279	- - -	- - -	- - -
²⁴⁰ Pu	238.302	74.311	- - -	- - -	- - -
²⁴¹ Pu ^a	13.718	4.516	- - -	- - -	- - -
²⁴² Pu	3.692	1.236	- - -	- - -	- - -
Americium ^a	22.064	6.975	- - -	- - -	- - -
²³⁵ U	34.134	1084.235	47.881	31.162	- - -
²³⁸ U	15779.550	8059.129	22092.750	14345.780	- - -
Total Heavy Metal	17885.580	9805.449	22140.620	14376.950	- - -
O	1588.896	1252.546	1704.949	1042.820	0.016
Na	1793.584	998.886	460.208	1734.844	312.267
Mo	194.636	64.439	6.974	23.832	1.38
Steel ^c	7315.277	5215.006	3487.283	8892.470	614.163

^aMasses for all isotopes decayed to 1/29/88.

^bMasses are based on the average for plate types.

^cSteel mass is the sum of masses of elements Cr, Mn, Fe, and Ni.

- PU SINGLE -- DUF
- PU SINGLE -- DUM
- ◊ PU DOUBLE COLUMN
- / U SINGLE COLUMN
- + U DOUBLE COLUMN
- OPERATING ROD
- SINGLE COLUMN IN SUBCRITICAL REFERENCE
- DOUBLE COLUMN IN CRITICAL REFERENCE

Fig. 3.1. Interface Diagram for the ZPPR-19B Reference Configurations

4. MULTIGROUP CROSS SECTION DATA AND CALCULATION MODELS FOR ZPPR-18A (G. L. Grasseschi and P. J. Collins)

4.1 Multigroup Cross Section Processing

Production of a 21 group cross section library from ENDF/B-V.2 data for calculations in ZPPR-18 followed the same procedure used for ZPPR-17 (ANL-ZPR-476, p. 17) except that group-dependent bucklings were used in the cell-heterogeneity calculations with the SDX code. The bucklings for each cell type in each reactor zone were obtained from a preliminary xyz diffusion calculation for ZPPR-18A in 21 groups which used the cross sections from the ZPPR-17 library. The bucklings represented an average of all occurrences of a given cell type in each zone and were conveniently obtained from the edit system of the DIF3D code.

The single-fuel-column cells in ZPPR-18 were of two types, one with depleted uranium metal called DUM and the other with iron-oxide plates called DUF (ANL-ZPR-485; p 2). These two types are combined in proportions of approximately 1 : 2 to give the required average Pu-U-oxide composition. Separate calculations of heterogeneity were made for each of the two single-fuel-column drawers. The cells processed in this way were as follows:

- (i) Single-column plutonium fuel in inner core, uranium metal (ICSM)
- (ii) Single-column plutonium fuel in inner core, iron oxide (ICSF)
- (iii) Single-column plutonium fuel in outer core, iron oxide (OCSF)
- (iv) Double-column plutonium fuel in outer core, uranium oxide (OCD)
- (v) Single-column uranium fuel in outer core (OCUS)
- (vi) Double column uranium fuel in outer core (OCUD)
- (vii) Radial blanket (RB)
- (viii) Axial blanket (AB)

Data for radial and axial reflectors and for the shim rods (PSR), were taken from ZPPR-17 cross sections (ANL-ZPR-476, p. 18). The outermost uranium blanket in the sectors at the y-axes (master 503), which contained no sodium, used cross sections for the normal radial blanket.

Since the "center-line" cell models do not preserve the homogeneous compositions, the bucklings were uniformly scaled by a factor to produce a k_{eff} of 0.987 in the SDX calculations in each case. The SDX calculations were made with the intermediate library and the bucklings in 21 groups were used in the appropriate subsets of the 230 groups. Since application of bucklings preserves spectra for the cells in the reactor, collapse to 21 groups was made directly from the cell models without using reactor models.

As usual, anisotropic diffusion coefficients were generated for each of the cells using models with the heavy metal plate "stretched" over the matrix pitch in the y-dimension.

4.2 Calculation Model

The reference calculation model for ZPPR-18A uses xyz geometry with 1/8-core symmetry (one-quarter xy, one-half z). The compositions of each distinct drawer master were represented individually, except for the asymmetrically loaded fission chamber and thermocouple drawers which were assigned the compositions of the standard drawers which they replaced. An xy map of the model is shown in Fig. 4.1 with the drawer master numbers shown for each matrix position. An rz diagram with axial zone boundaries is given in Fig. 4.2. A list of the drawer masters and their generic drawer descriptions is given in Table 4.1.

An unfortunate feature of the loading was that the uranium-fuel drawers in sectors about the y-axes had fuel column lengths which are a little longer than the lengths of the plutonium fuel columns. The calculation model adopted used two axial composition regions in the fuel. The first composition corresponds to the nominal core height of the plutonium fuel zones while the second corresponds to the thin slice above this nominal height to match the actual length of the uranium fuel. For the plutonium drawers, the second composition is just axial blanket. The overall fuel lengths including end clads are used in producing the compositions. These compositions preserve the core densities of both

plutonium and uranium drawers as well as total fuel mass while providing flexibility for alternative treatments of the mismatch in height.

The xyz model with individual drawer compositions requires copious input data which is generated from the experimental data base. We show, in Table 4.2, only the simplified compositions which are averaged over all variants of a generic master (Table 4.1). The compositions are given for the axial slices defined in the rz model of Fig. 4.2. The axial dimensions in Table 4.2 are quoted in inches for conciseness. Also included in Table 4.2 are zone-average compositions.

TABLE 4.1 Drawer Masters in ZPPR-18A

Zone	Master	Description
Core	101	Pu Fuel-SC-DUF
	102	Pu Fuel-SC-DUF
	103	Pu Fuel-SC-DUF
	104	Pu Fuel-SC-DUF
	105	Pu Fuel-SC-DUF
	106	Pu Fuel-SC-DUF
	107	Pu Fuel-SC-DUF
	108	Pu Fuel-SC-DUF
	109	Pu Fuel-SC-DUF
	701	Pu Fuel-SC-DUF-FC
	702	Pu Fuel-SC-DUF-FC
	703	Pu Fuel-SC-DUF-FC
	704	Pu Fuel-SC-DUF-FC
	705	Pu Fuel-SC-DUF-FC
	706	Pu Fuel-SC-DUF-FC
	707	Pu Fuel-SC-DUF-FC
	708	Pu Fuel-SC-DUF-FC
	709	Pu Fuel-SC-DUF-FC
	719	Pu Fuel-SC-DUF-FC
	720	Pu Fuel-SC-DUF-FC
	725	Pu-Fuel-SC-DUF, Thermocouple
	801	Pu Fuel-SC-DUF-PSR
	802	Pu Fuel-SC-DUF-PSR
	110	Pu Fuel-SC-DUM
	111	Pu Fuel-SC-DUM
	112	Pu Fuel-SC-DUM
	113	Pu Fuel-SC-DUM
	114	Pu Fuel-SC-DUM
	115	Pu Fuel-SC-DUM
	116	Pu Fuel-SC-DUM
	710	Pu Fuel-SC-DUM-FC
	711	Pu Fuel-SC-DUM-FC
	712	Pu Fuel-SC-DUM-FC
	713	Pu Fuel-SC-DUM-FC
	803	Pu Fuel-SC-DUM-PSR
	804	Pu Fuel-SC-DUM-PSR
	201	Pu Fuel-DC
	202	Pu Fuel-DC
	717	Pu Fuel-DC-FC
	718	Pu Fuel-DC-FC

TABLE 4.1 (contd)

Zone	Master	Description
Core	901	U Fuel-SC-Asymmetric
	902	U Fuel-SC-Asymmetric
	903	U Fuel-SC-Asymmetric
	904	U Fuel-SC-Asymmetric
	721	U Fuel-SC-FC-Asymmetric
	722	U Fuel-SC-FC-Asymmetric
	905	U Fuel-SC-Symmetric
	920	U Fuel-DC
	921	U Fuel-DC
	723	U Fuel-DC-FC
	724	U Fuel-DC-FC
Radial Blanket	501	DU-O
	502	DU-O
	715	DU-O-FC
	503	DU-M
	716	DU-M-FC
Radial Reflector	401	SS
	402	SS
	403	SS
	404	SS
	405	SS
	406	SS
	407	SS
	408	SS
	409	SS
	714	SS-FC
	410	FE
	411	FE
Control Rod Position	601	NA
	602	NA

^aSC is single column, DUF is iron oxide diluent, FC is fission chamber, PSR is adjacent to poison safety rod, DUM is depleted uranium metal diluent, DU-O is depleted uranium oxide, DU-M is depleted uranium metal, SS is stainless steel and FE is mild steel.

Table 4.2 Atom Densities by Zone and Drawer Type in ZPPR-18A

Isotope	Inner Core Average 0-20	Axial Blanket (IC) 20-31	Reflector Iron Block (IC) 31-36	Inner Core (ICSF) 0-20	Inner Core (ICFM) 0-20
C	0.0000335	0.0000532	0.0005869	0.0000335	0.0000336
O	0.0117067	0.0088210	0.0	0.0137453	0.0088141
Na	0.0092276	0.0091887	0.0	0.0092715	0.0091653
Si	0.0001588	0.0001923	0.0001243	0.0001581	0.0001598
Al	0.0000040	0.0000029	0.0	0.0000040	0.0000040
Mn	0.0002306	0.0003421	0.0006799	0.0002304	0.0002308
Cr	0.0026920	0.0041655	0.0020863	0.0026879	0.0026978
Fe	0.0115464	0.0148016	0.0756023	0.0129235	0.0095924
Ni	0.0011811	0.0017641	0.0008466	0.0011756	0.0011888
Cu	0.0000303	0.0000439	0.0000264	0.0000296	0.0000314
Mo	0.0002393	0.0000345	0.0000133	0.0002399	0.0002384
U4	0.0	0.0	0.0	0.0	0.0
U5	0.0000171	0.0000179	0.0	0.0000127	0.0000234
U6	0.0	0.0	0.0	0.0	0.0
U8	0.0078140	0.0081561	0.0	0.0058158	0.0106494
P8	0.0000004	0.0	0.0	0.0000004	0.0000005
P9	0.0008843	0.0	0.0	0.0008878	0.0008794
P0	0.0001170	0.0	0.0	0.0001176	0.0001162
P1	0.0000068	0.0	0.0	0.0000066	0.0000070
P2	0.0000018	0.0	0.0	0.0000017	0.0000019
A1	0.0000107	0.0	0.0	0.0000107	0.0000107
P	0.0000052	0.0000102	0.0000236	0.0000053	0.0000051
S	0.0000010	0.0000081	0.0000312	0.0000010	0.0000011
Cl	0.0000003	0.0000003	0.0	0.0000003	0.0000003
Ca	0.0000021	0.0000021	0.0	0.0000021	0.0000021
Co	0.0000014	0.0000014	0.0000007	0.0000008	0.0000023

Table 4.2 (contd)

Isotope	Outer Core Average 0-20	Outer Core Average 20-20.44	Axial Blanket (OC) 20.44-31	Reflector Iron Block (OC) 31-36	Outer Core Pu Fuel 0-20
C	0.0015795	0.0000429	0.0000544	0.0005918	0.0007626
O	0.0158687	0.0088280	0.0088212	0.0	0.0143579
Na	0.0087587	0.0093058	0.0092565	0.0	0.0091344
Si	0.0001680	0.0001697	0.0001999	0.0001149	0.0001662
Al	0.0000043	0.0000028	0.0000029	0.0	0.0000047
Mn	0.0002404	0.0002666	0.0003436	0.0006713	0.0002419
Cr	0.0028508	0.0031905	0.0041048	0.0019290	0.0028375
Fe	0.0147503	0.0113577	0.0146022	0.0759608	0.0123535
Ni	0.0012577	0.0013653	0.0017546	0.0007803	0.0012570
Cu	0.0000317	0.0000359	0.0000414	0.0000272	0.0000319
Mo	0.0001408	0.0000231	0.0000304	0.0000136	0.0003128
U4	0.0000083	0.0000070	0.0	0.0	0.0
U5	0.0008677	0.0007292	0.0000179	0.0	0.0000145
U6	0.0000040	0.0000033	0.0	0.0	0.0
U8	0.0069024	0.0081979	0.0081563	0.0	0.0066366
P8	0.0000003	0.0	0.0	0.0	0.0000007
P9	0.0004929	0.0	0.0	0.0	0.0011702
P0	0.0000652	0.0	0.0	0.0	0.0001549
P1	0.0000040	0.0	0.0	0.0	0.0000095
P2	0.0000011	0.0	0.0	0.0	0.0000025
A1	0.0000060	0.0	0.0	0.0	0.0000144
P	0.0000053	0.0000074	0.0000102	0.0000233	0.0000051
S	0.0000014	0.0000039	0.0000067	0.0000314	0.0000012
Cl	0.0000043	0.0000003	0.0000003	0.0	0.0000022
Ca	0.0000013	0.0000021	0.0000021	0.0	0.0000017
Co	0.0000022	0.0000022	0.0000020	0.0000014	0.0000020

TABLE 4.2 (contd)

Isotope	Axial Blanket (OC-Pu) 20-31	Reflector Iron Block (OC-Pu) 31-36	Outer Core Double Pu (OCD) 0-20	Outer Core Single Pu (OCSF) 0-20	Outer Core U Fuel 0-20	Outer Core U Fuel 20-20.44
C	0.0000531	0.0005923	0.0023106	0.0000335	0.0021738	0.0000343
O	0.0088210	0.0	0.0156589	0.0137451	0.0169673	0.0088278
Na	0.0092558	0.0	0.0087859	0.0092985	0.0084851	0.0093011
Si	0.0001927	0.0001149	0.0001831	0.0001582	0.0001693	0.0001530
Al	0.0000029	0.0	0.0000060	0.0000041	0.0000041	0.0000029
Mn	0.0003418	0.0006718	0.0002667	0.0002302	0.0002393	0.0002117
Cr	0.0041639	0.0019290	0.0031592	0.0026860	0.0028604	0.0024804
Fe	0.0147909	0.0760409	0.0111571	0.0129170	0.0164938	0.0088522
Ni	0.0017670	0.0007803	0.0014319	0.0011747	0.0012581	0.0010726
Cu	0.0000445	0.0000271	0.0000367	0.0000296	0.0000316	0.0000295
Mo	0.0000348	0.0000136	0.0004690	0.0002392	0.0000157	0.0000145
U4	0.0	0.0	0.0	0.0	0.0000144	0.0000120
U5	0.0000179	0.0	0.0000183	0.0000127	0.0014885	0.0012466
U6	0.0	0.0	0.0	0.0	0.0000069	0.0000057
U8	0.0081561	0.0	0.0083531	0.0058281	0.0070956	0.0082277
P8	0.0	0.0	0.0000010	0.0000005	0.0	0.0
P9	0.0	0.0	0.0017747	0.0008855	0.0	0.0
P0	0.0	0.0	0.0002348	0.0001172	0.0	0.0
P1	0.0	0.0	0.0000143	0.0000072	0.0	0.0
P2	0.0	0.0	0.0000039	0.0000019	0.0	0.0
A1	0.0	0.0	0.0000217	0.0000109	0.0	0.0
P	0.0000101	0.0000233	0.0000047	0.0000053	0.0000054	0.0000054
S	0.0000081	0.0000314	0.0000016	0.0000010	0.0000016	0.0000012
Cl	0.0000003	0.0	0.0000062	0.0000003	0.0000058	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000020	0.0000014	0.0000045	0.0000008	0.0000023	0.0000023

TABLE 4.2 (contd)

Isotope	Axial Blanket (OC-U) 20.44-31	Reflector Iron Block (OC-U) 31-36	Outer Core Single U (OCUS) 0-20	Outer Core Single U (OCUS) 20-20.44	Outer Core Double U (OCUD) 0-20	Outer Core Double U (OCUD) 20-20.44
C	0.0000552	0.0005914	0.0021067	0.0000340	0.0023125	0.0000349
O	0.0088210	0.0	0.0171003	0.0088279	0.0166930	0.0088278
Na	0.0092567	0.0	0.0083662	0.0092905	0.0087307	0.0093232
Si	0.0002052	0.0001149	0.0001696	0.0001481	0.0001687	0.0001631
Al	0.0000029	0.0	0.0000043	0.0000029	0.0000036	0.0000028
Mn	0.0003449	0.0006709	0.0002431	0.0002105	0.0002315	0.0002144
Cr	0.0040616	0.0019289	0.0029092	0.0024577	0.0027596	0.0025273
Fe	0.0144644	0.0758999	0.0178576	0.0087816	0.0136764	0.0089981
Ni	0.0017456	0.0007804	0.0012775	0.0010564	0.0012180	0.0011063
Cu	0.0000392	0.0000272	0.0000305	0.0000281	0.0000340	0.0000325
Mo	0.0000272	0.0000136	0.0000148	0.0000133	0.0000176	0.0000169
U4	0.0	0.0	0.0000109	0.0000082	0.0000217	0.0000200
U5	0.0000179	0.0	0.0011314	0.0008546	0.0022262	0.0020565
U6	0.0	0.0	0.0000052	0.0000039	0.0000104	0.0000096
U8	0.0081561	0.0	0.0073446	0.0082051	0.0065812	0.0082747
P8	0.0	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	0.0	0.0	0.0	0.0
P0	0.0	0.0	0.0	0.0	0.0	0.0
P1	0.0	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0	0.0
A1	0.0	0.0	0.0	0.0	0.0	0.0
P	0.0000102	0.0000233	0.0000055	0.0000054	0.0000051	0.0000052
S	0.0000056	0.0000314	0.0000015	0.0000011	0.0000019	0.0000015
Cl	0.0000003	0.0	0.0000056	0.0000003	0.0000062	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000020	0.0000014	0.0000010	0.0000010	0.0000050	0.0000050

TABLE 4.2 (contd)

Isotope	Radial Blanket 0-20	Radial Blanket 20-31	Radial Blanket 31-36	Radial Reflector 0-36	Axial Reflector 36-42	Empty Matrix 0-42
C	0.0000321	0.0000319	0.0005924	0.0002497	0.0002143	0.0000188
O	0.0193179	0.0193406	0.0	0.0	0.0	0.0
Na	0.0036444	0.0036359	0.0	0.0	0.0	0.0
Si	0.0001364	0.0001355	0.0001147	0.0008687	0.0008629	0.0000683
Al	0.0000021	0.0000021	0.0	0.0	0.0	0.0
Mn	0.0001956	0.0001941	0.0006720	0.0014138	0.0015241	0.0001059
Cr	0.0022640	0.0022455	0.0019301	0.0153709	0.0150441	0.0011891
Fe	0.0080983	0.0080330	0.0760500	0.0564101	0.0531084	0.0042791
Ni	0.0009669	0.0009588	0.0007787	0.0066710	0.0066621	0.0004802
Cu	0.0000282	0.0000280	0.0000267	0.0000389	0.0000172	0.0000172
Mo	0.0000133	0.0000131	0.0000134	0.0000323	0.0000083	0.0000083
U4	0.0	0.0	0.0	0.0	0.0	0.0
U5	0.0000369	0.0000370	0.0	0.0	0.0	0.0
U6	0.0	0.0	0.0	0.0	0.0	0.0
U8	0.0168314	0.0168695	0.0	0.0	0.0	0.0
P8	0.0	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	0.0	0.0	0.0	0.0
P0	0.0	0.0	0.0	0.0	0.0	0.0
P1	0.0	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0	0.0
A1	0.0	0.0	0.0	0.0	0.0	0.0
P	0.0000050	0.0000050	0.0000234	0.0000466	0.0	0.0000028
S	0.0000010	0.0000010	0.0000314	0.0000335	0.0	0.0000007
Cl	0.0000001	0.0000001	0.0	0.0	0.0	0.0
Ca	0.0000009	0.0000009	0.0	0.0	0.0	0.0
Co	0.0000015	0.0000015	0.0000010	0.0	0.0	0.0

TABLE 4.2 (contd)

Isotope	Inner Ring Control Position 0-20	Inner Ring Control Position 20-36	Middle Ring Control Position 0-20	Middle Ring Control Position 20-36	Outer Ring Control Position 0-20	Outer Ring Control Position 20-36
C	0.0000312	0.0000309	0.0000312	0.0000309	0.0000311	0.0000309
O	0.0000013	0.0000013	0.0000013	0.0000013	0.0000013	0.0000013
Na	0.0182904	0.0184405	0.0182904	0.0184405	0.0182904	0.0184405
Si	0.0001661	0.0001649	0.0001661	0.0001649	0.0001657	0.0001649
Al	0.0000047	0.0000049	0.0000047	0.0000049	0.0000047	0.0000049
Mn	0.0002451	0.0002443	0.0002451	0.0002443	0.0002448	0.0002443
Cr	0.0029778	0.0029657	0.0029778	0.0029657	0.0029723	0.0029657
Fe	0.0105129	0.0104697	0.0105129	0.0104697	0.0104937	0.0104697
Ni	0.0013332	0.0013281	0.0013332	0.0013281	0.0013307	0.0013281
Cu	0.0000357	0.0000353	0.0000357	0.0000353	0.0000357	0.0000353
Mo	0.0000176	0.0000174	0.0000176	0.0000174	0.0000175	0.0000174
U4	0.0	0.0	0.0	0.0	0.0	0.0
U5	0.0	0.0	0.0	0.0	0.0	0.0
U6	0.0	0.0	0.0	0.0	0.0	0.0
U8	0.0	0.0	0.0	0.0	0.0	0.0
P8	0.0	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	0.0	0.0	0.0	0.0
P0	0.0	0.0	0.0	0.0	0.0	0.0
P1	0.0	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0	0.0
A1	0.0	0.0	0.0	0.0	0.0	0.0
P	0.0000040	0.0000040	0.0000040	0.0000040	0.0000040	0.0000040
S	0.0000012	0.0000012	0.0000012	0.0000012	0.0000012	0.0000012
Cl	0.0000006	0.0000006	0.0000006	0.0000006	0.0000006	0.0000006
Ca	0.0000042	0.0000042	0.0000042	0.0000042	0.0000042	0.0000042
Co	0.0000038	0.0000037	0.0000038	0.0000037	0.0000038	0.0000037

TABLE 4.2 (contd)

Isotope	Radial Blanket Master 501 0-31	Radial Blanket Master 502 0-31	Radial Blanket Master 503 0-31
C	0.0000325	0.0000324	0.0000294
O	0.0226351	0.0220579	0.0
Na	0.0042352	0.0042350	0.0
Si	0.0001398	0.0001417	0.0001099
Al	0.0000024	0.0000024	0.0
Mn	0.0002005	0.0001984	0.0001648
Cr	0.0023279	0.0023140	0.0018487
Fe	0.0083268	0.0082484	0.0066628
Ni	0.0009950	0.0010098	0.0007495
Cu	0.0000275	0.0000317	0.0000249
Mo	0.0000127	0.0000150	0.0000124
U4	0.0	0.0	0.0
U5	0.0000290	0.0000285	0.0000865
U6	0.0	0.0	0.0
U8	0.0133322	0.0131212	0.0387435
P8	0.0	0.0	0.0
P9	0.0	0.0	0.0
P0	0.0	0.0	0.0
P1	0.0	0.0	0.0
P2	0.0	0.0	0.0
A1	0.0	0.0	0.0
P	0.0000052	0.0000047	0.0000046
S	0.0000010	0.0000012	0.0000010
Cl	0.0000001	0.0000001	0.0
Ca	0.0000010	0.0000010	0.0
Co	0.0000007	0.0000045	0.0

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86				
111-	409	409	409	409	409	409	409	409	409	411																																
112-	409	409	409	409	409	409	409	409	409	409	411																															
113-	503	503	503	503	503	401	401	401	401	401	401	407	407	411																												
114-	503	503	503	503	503	503	401	401	401	401	401	407	407	401	401	411																										
115-	503	503	503	503	503	503	503	401	401	401	407	407	401	401	401	411	411																									
116-	501	501	501	501	501	501	501	503	503	503	401	407	407	401	401	401	407	407	410																							
117-	501	501	501	501	501	501	501	501	501	501	501	503	503	407	403	403	403	407	404	404	404	410																				
118-	501	501	501	501	501	501	501	501	501	501	501	501	503	403	403	403	407	404	404	404	404	405	405																			
119-	905	902	920	902	902	501	501	501	501	501	501	501	501	503	403	403	404	404	404	404	405	405	405	405																		
120-	920	902	902	921	904	902	904	501	501	501	501	501	501	501	503	503	404	404	404	404	405	405	405	405	402	402																
121-	905	920	902	902	920	902	920	902	902	501	501	501	501	501	501	501	503	503	404	404	405	405	405	405	402	402	402															
122-	905	902	921	904	902	920	902	904	920	902	902	501	501	501	501	501	501	503	503	405	405	405	405	402	402	402	401															
123-	920	902	904	920	902	902	902	920	902	920	904	902	501	501	501	501	501	501	501	503	503	405	405	402	402	402	403	403	402													
124-	905	921	902	902	920	902	921	902	902	902	920	904	904	902	501	501	501	501	501	501	501	501	503	405	405	402	402	403	403	402	402											
125-	921	902	921	902	902	602	602	902	920	902	902	920	902	920	902	902	501	501	501	501	501	501	501	503	503	402	402	403	403	402	402	402										
126-	109	111	106	803	106	602	602	106	902	921	902	902	920	902	902	921	902	920	501	501	501	501	501	501	501	503	503	403	403	402	402	402	402									
127-	109	109	112	109	111	602	602	111	106	902	921	902	902	902	920	902	920	902	902	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501			
128-	115	104	104	113	104	111	104	113	106	111	920	902	921	902	921	902	902	920	902	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501			
129-	109	111	102	102	111	102	108	111	108	111	109	113	106	902	902	920	902	920	902	921	902	920	902	501	501	501	501	501	501	501	501	501	501	502	402	402	402	402	402	402		
130-	115	106	113	101	101	113	102	108	113	108	113	109	113	106	111	902	920	902	902	902	920	902	920	902	920	902	902	501	501	501	501	501	501	502	404	404	404	404	404	404	404	
131-	601	601	106	111	104	101	116	102	108	111	108	111	108	111	109	111	902	902	920	902	902	902	902	902	902	902	501	501	501	501	501	501	501	502	404	404	404	404	404	404	404	
132-	601	601	111	106	106	112	104	113	102	108	111	108	111	108	111	106	111	602	602	920	902	920	902	921	107	107	501	501	501	501	501	502	502	502	404	404	404	404	404	404	404	404
133-	109	111	105	105	111	106	113	104	111	102	108	112	108	113	108	111	109	602	602	902	921	902	201	107	107	107	501	501	501	501	501	502	502	502	404	404	403	403	403	403	403	403
134-	115	103	103	113	105	111	106	111	104	111	102	108	113	108	111	108	109	602	602	902	902	107	107	107	202	107	201	501	501	501	502	502	502	502	403	403	403	403	403	403	403	403
135-	109	101	112	103	111	105	116	801	804	104	105	113	108	111	108	108	112	109	802	920	107	201	107	201	107	201	107	107	501	501	502	502	502	502	403	403	403	403	403	403	403	403
136-	109	110	101	113	103	111	105	111	106	106	111	104	111	108	108	111	108	108	116	106	201	107	201	107	107	107	107	107	501	501	502	502	502	502	403	403	403	403	403	403	403	403
137-	115	102	110	101	110	103	113	105	106	113	106	111	104	102	113	108	108	113	109	111	107	202	107	107	201	107	202	107	107	501	502	502	502	502	402	402	402	402	402	402	402	403
138-	109	110	102	110	101	112	103	103	111	105	111	106	104	113	102	108	113	108	111	109	106	107	107	202	107	201	107	201	107	501	502	502	502	502	402	402	402	402	402	402	402	403
139-	601	601	110	102	110	101	101	110	103	114	105	106	113	104	601	601	105	114	108	113	109	113	201	107	107	107	107	107	201	501	502	502	502	502	402	402	402	402	402	402	402	403
140-	601	601	107	110	102	102	113	101	110	103	105	113	106	114	601	601	114	108	114	108	114	106	107	107	201	107	107	202	107	501	502	502	502	502	402	402	402	402	402	402	402	408
141-	115	107	110	107	107	110	102	110	101	103	110	105	114	106	601	601	105	114	108	114	109	109	602	602	107	107	201	107	201	501	501	502	502	502	402	402	402	402	402	402	402	408
142-	109	110	102	102	110	107	110	102	102	110	103	112	103	106	113	101	114	103	114	108	108	113	602	602	107	201	107	201	107	501	501	502	502	502	402	402	402	402	402	402	402	408
143-	115	102	107	112	102	110	107	601	601	101	110	105	103	110	104	114	102	113	108	108	112	104	602	602	107	107	107	107	202	501	501	502	502	502	402	402	402	402	402	402	402	408
144-	109	102	112	107	110	102	107	601	601	110	103	105	113	106	114	101	114	103	108	113	108	104	116	106	201	107	201	107	107	501	501	502	502	502	402	402	402	402	402	402	402	408
145-	109	110	102	803	107	102	110	601	601	101	103	110	103	110	104	114	102	103	804	108	108	114	109	114	107	202	107	202	107	501	501	502	502	502	402	402	402	402	402	402	402	406
146-	115	102	110	107	107	112	107	102	110	101	110	105	110	106	116	101	102	116	108	108	112	104	113	106	107	107	107	107	201	501	501	502	502	502	402	402	402	402	402	402	402	406
147-	109	110	102	107	110	102	113	102	102	110	103	110	103	110	103	101	112	103	108	116	108	116	109	113	201	107	202	107	107	501	501	502	502	502	402	402	402	402	402	402	402	402
148-	115	102	102	110	102	110	106	110	102	101	110	105	110	106	103	113	102	103	116	108	113	104	116	106	107	201	107	201	107	501	501	502	502	502	402	402	402	402	402	402	402	402
149-	107	109	115	109	115	109	115	109	115	109	109	115	109	109	115	109	109	115	109	109	115	109	115	109	115	107	107

Fig. 4.2. rz Diagram of ZPPR-18A.

5. CALCULATION MODELS FOR ZPPR-18B (G. L. Grasseschi and P. J. Collins)

In ZPPR-18B, 18 primary control rods (inner and outer rings) were inserted to the midplane and the core was made critical by conversion of single-fuel-column drawers to double-fuel-column drawers in the inner core and in both plutonium and uranium sectors of the outer core (ANL-ZPR-485, p 15).

The calculation model was similar to that for ZPPR-18A except that a full-z representation was necessary to model the half-inserted control rods. The quarter-xy plan of the model for half-one is shown in Fig. 5.1. The only difference for half-two was the substitution of control rod drawers (master 608) for CRP drawers (master 601 and 602) in the 18 inner and outer control bank positions.

Eleven new drawer masters were created for ZPPR-18B, differing from those in ZPPR-18A only in the different piece lengths used. These are described in Table 5.1. Master 203 contains Pu fuel with about 26% ^{240}Pu compared with 11% ^{240}Pu in the normal fuel. Fifty-six master 203 drawers were used, all in the outer core.

Average compositions for the different fuel drawer types and fuel zones of ZPPR-18B are given in Table 5.2. Compositions for the CRPs, blanket and reflector zones are the same as for ZPPR-18A in Table 4.2.

Calculations for ZPPR-18B used the same cross section library with 21 energy groups as for ZPPR-18A.

TABLE 5.1 New Drawer Masters Introduced in ZPPR-18B

Zone	Master	Description
Core	203	Pu Fuel-DC-H240
	204	Pu Fuel-DC
	205	Pu Fuel-DC
	206	Pu Fuel-DC
	207	Pu Fuel-DC
	208	Pu Fuel-DC
	209	Pu Fuel-DC
	210	Pu Fuel-DC
	211	Pu Fuel-DC
	922	U Fuel-DC
	923	U Fuel-DC

^aDC is double fuel column, H240 contains fuel high in ²⁴⁰Pu.

TABLE 5.2 Atom Densities by Zone and Drawer Type for ZPPR-18B

Isotope	Inner Core Average 0-20	Axial Blanket (IC) 20-31	Reflector Iron Block (IC) 31-36	Inner Core (ICSF) 0-20	Inner Core (ICSM) 0-20	Inner Core Single Pu 0-20
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0001716	0.0000532	0.0005873	0.0000332	0.0000332	0.0000332
O	0.0121223	0.0088206	0.0	0.0137453	0.0087984	0.0118940
Na	0.0091937	0.0091882	0.0	0.0092715	0.0091268	0.0092233
Si	0.0001591	0.0001924	0.0001260	0.0001570	0.0001584	0.0001576
Al	0.0000041	0.0000029	0.0	0.0000040	0.0000040	0.0000040
Mn	0.0002309	0.0003419	0.0006822	0.0002287	0.0002285	0.0002288
Cr	0.0027000	0.0041649	0.0021126	0.0026684	0.0026726	0.0026718
Fe	0.0115689	0.0147980	0.0756914	0.0128536	0.0095006	0.0116011
Ni	0.0011881	0.0017649	0.0008584	0.0011678	0.0011793	0.0011729
Cu	0.0000304	0.0000441	0.0000271	0.0000293	0.0000312	0.0000300
Mo	0.0002530	0.0000346	0.0000136	0.0002397	0.0002378	0.0002392
U4	0.0	0.0	0.0	0.0	0.0	0.0
U5	0.0000168	0.0000179	0.0	0.0000127	0.0000234	0.0000167
U6	0.0	0.0	0.0	0.0	0.0	0.0
U8	0.0076724	0.0081558	0.0	0.0058158	0.0106293	0.0076300
P8	0.0000005	0.0	0.0	0.0000004	0.0000005	0.0000004
P9	0.0009382	0.0	0.0	0.0008878	0.0008775	0.0008845
P0	0.0001241	0.0	0.0	0.0001176	0.0001159	0.0001171
P1	0.0000072	0.0	0.0	0.0000066	0.0000069	0.0000067
P2	0.0000019	0.0	0.0	0.0000017	0.0000019	0.0000018
A1	0.0000114	0.0	0.0	0.0000108	0.0000107	0.0000108
P	0.0000052	0.0000102	0.0000237	0.0000053	0.0000051	0.0000052
S	0.0000011	0.0000081	0.0000312	0.0000010	0.0000011	0.0000010
Cl	0.0000007	0.0000003	0.0	0.0000003	0.0000003	0.0000003
Ca	0.0000020	0.0000021	0.0	0.0000021	0.0000021	0.0000021
Co	0.0000016	0.0000016	0.0000009	0.0000008	0.0000024	0.0000014

TABLE 5.2 (contd)

Isotope	Inner Core Double Pu 0-20	Outer Core Average 0-20	Outer Core Average 20-20.44	Axial Blanket (OC) 20.44-31	Reflector Iron Block (OC) 31-36	Outer Core Pu Fuel 0-20
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0023102	0.0016171	0.0000430	0.0000551	0.0005923	0.0008521
O	0.0156589	0.0157816	0.0088280	0.0088212	0.0	0.0144334
Na	0.0087410	0.0087491	0.0093061	0.0092565	0.0	0.0091105
Si	0.0001815	0.0001678	0.0001703	0.0002046	0.0001167	0.0001657
Al	0.0000061	0.0000044	0.0000028	0.0000029	0.0	0.0000048
Mn	0.0002648	0.0002396	0.0002669	0.0003462	0.0006737	0.0002415
Cr	0.0031374	0.0028441	0.0031957	0.0040968	0.0019565	0.0028351
Fe	0.0110787	0.0142917	0.0113732	0.0145816	0.0760544	0.0122104
Ni	0.0014229	0.0012575	0.0013692	0.0017594	0.0007935	0.0012572
Cu	0.0000364	0.0000319	0.0000363	0.0000403	0.0000280	0.0000315
Mo	0.0004674	0.0001447	0.0000234	0.0000286	0.0000141	0.0003215
U4	0.0	0.0000094	0.0000078	0.0	0.0	0.0
U5	0.0000183	0.0009786	0.0008125	0.0000179	0.0	0.0000146
U6	0.0	0.0000045	0.0000037	0.0	0.0	0.0
U8	0.0083334	0.0068553	0.0082027	0.0081563	0.0	0.0067049
P8	0.0000010	0.0000003	0.0	0.0	0.0	0.0000007
P9	0.0017683	0.0005050	0.0	0.0	0.0	0.0011990
P0	0.0002339	0.0000791	0.0	0.0	0.0	0.0001879
P1	0.0000141	0.0000051	0.0	0.0	0.0	0.0000121
P2	0.0000038	0.0000020	0.0	0.0	0.0	0.0000048
A1	0.0000217	0.0000082	0.0	0.0	0.0	0.0000194
P	0.0000044	0.0000052	0.0000073	0.0000102	0.0000233	0.0000051
S	0.0000016	0.0000015	0.0000039	0.0000063	0.0000314	0.0000012
Cl	0.0000062	0.0000044	0.0000003	0.0000003	0.0	0.0000024
Ca	0.0000010	0.0000013	0.0000021	0.0000021	0.0	0.0000017
Co	0.0000045	0.0000025	0.0000025	0.0000023	0.0000018	0.0000019

TABLE 5.2 (contd)

Isotope	Axial Blanket (OC) Pu Fuel 20-31	Reflector Iron Block (OC) Pu Fuel 31-36	Outer Core Double Pu 0-20	Outer Core Single Pu 0-20	Outer Core U Fuel 0-20	Outer Core U Fuel 20-20.44
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0000531	0.0005928	0.0023103	0.0000332	0.0021737	0.0000344
O	0.0088210	0.0	0.0156591	0.0137451	0.0167619	0.0088277
Na	0.0092557	0.0	0.0087757	0.0092985	0.0084858	0.0093008
Si	0.0001926	0.0001164	0.0001813	0.0001570	0.0001693	0.0001539
Al	0.0000029	0.0	0.0000060	0.0000041	0.0000041	0.0000029
Mn	0.0003418	0.0006745	0.0002650	0.0002283	0.0002381	0.0002122
Cr	0.0041642	0.0019579	0.0031381	0.0026649	0.0028506	0.0024891
Fe	0.0147930	0.0761469	0.0110869	0.0128413	0.0158054	0.0088781
Ni	0.0017665	0.0007913	0.0014192	0.0011662	0.0012577	0.0010798
Cu	0.0000444	0.0000274	0.0000355	0.0000293	0.0000321	0.0000303
Mo	0.0000348	0.0000138	0.0004684	0.0002391	0.0000161	0.0000150
U4	0.0	0.0	0.0	0.0	0.0000163	0.0000134
U5	0.0000179	0.0	0.0000180	0.0000127	0.0016800	0.0013905
U6	0.0	0.0	0.0	0.0	0.0000078	0.0000064
U8	0.0081561	0.0	0.0082662	0.0058281	0.0069644	0.0082360
P8	0.0	0.0	0.0000012	0.0000005	0.0	0.0
P9	0.0	0.0	0.0017573	0.0008855	0.0	0.0
P0	0.0	0.0	0.0003137	0.0001172	0.0	0.0
P1	0.0	0.0	0.0000209	0.0000072	0.0	0.0
P2	0.0	0.0	0.0000099	0.0000019	0.0	0.0
A1	0.0	0.0	0.0000343	0.0000110	0.0	0.0
P	0.0000102	0.0000234	0.0000048	0.0000053	0.0000052	0.0000053
S	0.0000081	0.0000314	0.0000015	0.0000010	0.0000017	0.0000013
Cl	0.0000003	0.0	0.0000062	0.0000003	0.0000058	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000019	0.0000012	0.0000038	0.0000008	0.0000030	0.0000030

TABLE 5.2 (contd)

Isotope	Axial Blanket (OC) U Fuel 20.44-31	Reflector Iron Block (OC) U Fuel 31-36	Outer Core Single U (OCUS) 0-20	Outer Core Single U (OCUS) 20-20.44	Outer Core Double U (OCUD) 0-20	Outer Core Double U (OCUD) 20-20.44
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0000565	0.0005918	0.0021064	0.0000340	0.0022414	0.0000349
O	0.0088209	0.0	0.0170999	0.0088277	0.0164216	0.0088278
Na	0.0092566	0.0	0.0083660	0.0092904	0.0086066	0.0093114
Si	0.0002133	0.0001169	0.0001684	0.0001481	0.0001702	0.0001599
Al	0.0000029	0.0	0.0000043	0.0000029	0.0000038	0.0000028
Mn	0.0003493	0.0006730	0.0002412	0.0002105	0.0002350	0.0002140
Cr	0.0040475	0.0019553	0.0028881	0.0024577	0.0028128	0.0025209
Fe	0.0144271	0.0759838	0.0177815	0.0087814	0.0138151	0.0089755
Ni	0.0017541	0.0007952	0.0012690	0.0010563	0.0012464	0.0011034
Cu	0.0000374	0.0000284	0.0000302	0.0000281	0.0000341	0.0000324
Mo	0.0000241	0.0000143	0.0000147	0.0000133	0.0000175	0.0000167
U4	0.0	0.0	0.0000109	0.0000082	0.0000217	0.0000187
U5	0.0000179	0.0	0.0011314	0.0008546	0.0022325	0.0019304
U6	0.0	0.0	0.0000052	0.0000039	0.0000105	0.0000090
U8	0.0081560	0.0	0.0073445	0.0082049	0.0065816	0.0082674
P8	0.0	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	0.0	0.0	0.0	0.0
P0	0.0	0.0	0.0	0.0	0.0	0.0
P1	0.0	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0	0.0
A1	0.0	0.0	0.0	0.0	0.0	0.0
P	0.0000102	0.0000233	0.0000054	0.0000054	0.0000051	0.0000052
S	0.0000050	0.0000314	0.0000015	0.0000011	0.0000018	0.0000015
Cl	0.0000003	0.0	0.0000056	0.0000003	0.0000060	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000026	0.0000021	0.0000010	0.0000010	0.0000050	0.0000049

TABLE 5.2

Isotope	Control Rod	Control Rod
	0-20	20-31
B0	0.0071583	0.0072759
B1	0.0290256	0.0295024
C	0.0094051	0.0095480
O	0.0000006	0.0000068
Na	0.0087470	0.0087131
Si	0.0002035	0.0002034
Al	0.0000054	0.0000048
Mn	0.0002605	0.0002578
Cr	0.0031765	0.0031389
Fe	0.0112393	0.0111169
Ni	0.0014421	0.0014216
Cu	0.0000361	0.0000359
Mo	0.0000178	0.0000177
U4	0.0	0.0
U5	0.0	0.0
U6	0.0	0.0
U8	0.0	0.0
P8	0.0	0.0
P9	0.0	0.0
P0	0.0	0.0
P1	0.0	0.0
P2	0.0	0.0
A1	0.0	0.0
P	0.0000040	0.0000040
S	0.0000012	0.0000012
Cl	0.0000003	0.0000003
Ca	0.0000020	0.0000020
Co	0.0000038	0.0000037

10.	-	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
20.	111-	409	409	409	409	409	409	409	409	409	411																														
30.	112-	409	409	409	409	409	409	409	409	409	411																														
40.	113-	503	503	503	503	503	401	401	401	401	401	401	407	407	411																										
50.	114-	503	503	503	503	503	503	401	401	401	401	401	407	407	401	401	411																								
60.	115-	503	503	503	503	503	503	503	401	401	401	401	407	407	401	401	411	411																							
70.	116-	501	501	501	501	501	501	501	503	503	503	401	407	407	401	401	401	407	407	410																					
80.	117-	501	501	501	501	501	501	501	501	501	503	503	407	403	403	403	407	404	404	410																					
90.	118-	501	501	501	501	501	501	501	501	501	501	501	503	403	403	403	407	404	404	404	404	405	405																		
100.	119-	905	902	920	902	922	501	501	501	501	501	501	501	501	503	403	403	404	404	404	404	405	405	405	405																
110.	120-	920	922	902	921	904	922	904	501	501	501	501	501	501	501	503	503	404	404	404	404	405	405	405	405	402	402														
120.	121-	905	920	902	902	920	922	920	902	902	501	501	501	501	501	501	501	503	503	404	404	405	405	405	405	402	402	402													
130.	122-	905	902	921	904	902	920	902	923	920	902	922	501	501	501	501	501	501	503	503	405	405	405	405	402	402	402	401													
140.	123-	920	902	904	920	922	902	902	920	902	920	904	902	501	501	501	501	501	501	501	501	503	503	405	405	402	402	402	403	403	402										
150.	124-	905	921	902	902	920	902	921	902	902	922	920	904	923	902	501	501	501	501	501	501	501	503	405	405	402	402	403	403	402	402										
160.	125-	921	902	921	922	902	602	602	922	920	902	902	920	902	922	902	501	501	501	501	501	501	501	503	503	402	402	403	403	402	402	402									
170.	126-	109	202	106	803	106	602	602	106	902	921	922	902	920	902	902	921	902	920	501	501	501	501	501	501	503	503	403	403	402	402	402	402								
180.	127-	109	109	112	109	111	602	602	111	106	902	921	902	922	902	902	920	902	902	501	501	501	501	501	501	501	501	402	402	402	402	402									
190.	128-	115	104	104	113	104	111	104	104	113	106	111	920	902	921	902	921	902	922	920	902	922	501	501	501	501	501	501	501	501	402	402	402	402	402						
200.	129-	109	111	102	102	111	102	108	111	108	111	109	113	106	902	922	920	902	920	902	921	902	920	902	501	501	501	501	501	501	501	501	502	402	402	402	402	402			
210.	130-	115	106	208	101	101	211	102	108	113	108	204	109	113	106	111	902	920	902	922	902	920	902	920	922	902	501	501	501	501	501	502	404	404	404	404	404				
220.	131-	601	601	106	111	104	101	116	102	108	111	108	111	108	111	109	111	902	922	920	922	902	922	902	902	920	501	501	501	501	501	501	502	404	404	404	404	404			
230.	132-	601	601	111	106	106	112	104	113	102	108	111	108	111	108	111	106	206	602	602	920	902	920	902	921	107	107	501	501	501	501	502	502	502	404	404	404	404	404		
240.	133-	109	111	105	105	111	106	211	104	111	102	108	112	108	113	108	111	109	602	602	902	921	902	201	107	203	107	501	501	501	501	502	502	502	404	404	403	403	403		
250.	134-	115	103	103	204	105	111	106	111	104	111	102	108	207	108	111	108	109	602	602	922	902	107	107	107	202	107	201	501	501	501	502	502	502	502	403	403	403	403		
260.	135-	109	101	112	103	111	105	116	801	804	104	105	113	108	111	108	108	202	109	802	920	107	201	107	201	107	201	107	107	501	501	502	502	502	502	403	403	403	403		
270.	136-	109	110	101	113	103	111	105	111	106	106	111	104	111	108	108	111	108	108	116	106	201	107	201	107	107	203	107	107	501	501	502	502	502	502	403	403	403	403		
280.	137-	115	102	211	101	110	103	202	105	106	205	106	111	104	102	113	108	108	113	109	111	107	107	203	107	201	107	202	107	107	501	502	502	502	502	402	402	402	403		
290.	138-	109	110	102	110	101	112	103	103	111	105	111	106	104	113	102	108	207	108	111	109	106	107	107	202	107	201	107	201	107	501	502	502	502	502	402	402	402	403		
300.	139-	601	601	110	102	110	101	101	110	103	114	105	106	113	104	601	601	105	114	108	113	109	207	201	107	203	107	107	107	201	501	502	502	502	502	402	402	402	403		
310.	140-	601	601	107	110	102	102	113	101	110	103	105	206	106	114	601	601	114	108	114	108	114	106	107	107	201	107	107	203	107	501	502	502	502	502	402	402	402	408		
320.	141-	115	107	110	107	107	110	102	208	101	103	110	105	114	106	601	601	105	202	108	114	109	109	602	602	107	107	201	107	201	501	501	502	502	502	402	402	402	408		
330.	142-	109	110	102	102	110	107	110	102	102	110	103	112	103	106	113	101	114	103	114	108	108	113	602	602	107	201	107	201	107	501	501	502	502	502	402	402	402	408		
340.	143-	115	102	107	202	102	110	107	601	601	101	110	105	103	110	104	114	102	113	108	108	112	104	602	602	107	107	107	107	107	501	501	502	502	502	402	402	402	408		
350.	144-	109	102	112	107	110	102	107	601	601	110	103	105	207	106	114	101	114	103	108	207	108	104	116	106	201	107	201	107	203	501	501	502	502	502	402	402	402	408		
360.	145-	109	110	102	803	107	102	110	601	601	101	103	110	103	110	104	114	102	103	804	108	108	114	109	114	107	202	107	202	107	501	501	502	502	502	402	402	402	406		
370.	146-	115	102	210	107	107	112	107	102	110	101	110	105	110	106	116	101	102	116	108	108	112	104	113	106	107	107	203	107	201	501	501	502	502	502	402	402	402	406		
380.	147-	109	110	102	107	110	102	113	102	102	110	103	110	103	110	103	101	209	103	108	116	108	206	109	113	201	107	202	107	107	501	501	502	502	502	402	402	402	402		
390.	148-	115	102	102	110	102	207	106	110	102	101	205	105	110	106	103	113	102	103	116	108	113	104	116	106	107	201	107	201	107	501	501	502	502	502	402	402	402	402		
400.	149-	107	109	115	109	115	109	115	109	115	109	109	115	109	109	115	109	109	115	109	115	109	115	109	115	107	107	202	107	107	501	502	502	502	502	402	402	402	402		
410.	-	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		

6. CALCULATION MODELS FOR ZPPR-18C (G. L. Grasseschi and P. J. Collins)

ZPPR-18C was made critical with an outer ring control rod, number 24, withdrawn from the ZPPR-18B pattern, together with a reduction in enrichment by replacing double-fuel-column drawers by single-fuel-column drawers (ANL-ZPR-485, p 19). The core had no symmetry axes and required a full xyz representation. The calculation model for the upper right hand quadrant of half-1 is given in Fig. 6.1. Drawer loadings in the matrix for the other octants are symmetric except for the control rods and CRPs. A description of the drawer types is given in Tables 4.1 and 5.1 of this report. The average compositions for the different fuel types and reactor zones of ZPPR-18C are given in Table 6.1.

Calculations for ZPPR-18C used the cross section library with 21 energy groups produced for ZPPR-18A. The model was too large to run with the nodal codes since these require all data for an energy group to be contained in core. Only one calculation, using the finite-difference option of DIF3D, was made for ZPPR-18C.

TABLE 6.1 Atom Densities by Zone and Drawer Type for ZPPR-18C

Isotope	Inner Core Average 0-20	Axial Blanket (IC) 20-31	Reflector Iron Block (IC) 31-36	Inner Core (ICSF) 0-20	Inner Core (ICSM) 0-20	Inner Core Single Pu 0-20
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0001660	0.0000532	0.0005873	0.0000332	0.0000333	0.0000332
O	0.0121057	0.0088206	0.0	0.0137453	0.0088142	0.0118860
Na	0.0091950	0.0091882	0.0	0.0092715	0.0091444	0.0092235
Si	0.0001590	0.0001924	0.0001260	0.0001570	0.0001587	0.0001576
Al	0.0000041	0.0000029	0.0	0.0000040	0.0000040	0.0000040
Mn	0.0002309	0.0003420	0.0006822	0.0002287	0.0002290	0.0002288
Cr	0.0026989	0.0041649	0.0021127	0.0026684	0.0026775	0.0026718
Fe	0.0115653	0.0147981	0.0756916	0.0128536	0.0095180	0.0115958
Ni	0.0011875	0.0017649	0.0008584	0.0011678	0.0011814	0.0011729
Cu	0.0000304	0.0000441	0.0000270	0.0000293	0.0000313	0.0000300
Mo	0.0002525	0.0000346	0.0000136	0.0002397	0.0002382	0.0002392
U4	0.0	0.0	0.0	0.0	0.0	0.0
U5	0.0000168	0.0000179	0.0	0.0000127	0.0000234	0.0000167
U6	0.0	0.0	0.0	0.0	0.0	0.0
U8	0.0076779	0.0081558	0.0	0.0058158	0.0106481	0.0076376
P8	0.0000005	0.0	0.0	0.0000004	0.0000005	0.0000004
P9	0.0009360	0.0	0.0	0.0008878	0.0008790	0.0008844
P0	0.0001239	0.0	0.0	0.0001176	0.0001161	0.0001170
P1	0.0000071	0.0	0.0	0.0000066	0.0000069	0.0000067
P2	0.0000019	0.0	0.0	0.0000017	0.0000019	0.0000018
A1	0.0000114	0.0	0.0	0.0000108	0.0000107	0.0000108
P	0.0000052	0.0000102	0.0000237	0.0000053	0.0000051	0.0000052
S	0.0000011	0.0000081	0.0000312	0.0000010	0.0000011	0.0000010
Cl	0.0000006	0.0000003	0.0	0.0000003	0.0000003	0.0000003
Ca	0.0000020	0.0000021	0.0	0.0000021	0.0000021	0.0000021
Co	0.0000016	0.0000016	0.0000009	0.0000008	0.0000024	0.0000014

TABLE 6.1 (contd)

Isotope	Inner Core Double Pu 0-20	Outer Core Average 0-20	Outer Core Average 20-20.44	Axial Blanket (OC) 20.44-31	Reflector Iron Block (OC) 31-36	Outer Core Pu Fuel 0-20
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0023102	0.0016223	0.0000431	0.0000552	0.0005939	0.0008521
O	0.0156589	0.0158334	0.0088517	0.0088449	0.0	0.0144334
Na	0.0087393	0.0087699	0.0093313	0.0092814	0.0	0.0091105
Si	0.0001815	0.0001682	0.0001706	0.0002048	0.0001170	0.0001657
Al	0.0000061	0.0000044	0.0000029	0.0000029	0.0	0.0000048
Mn	0.0002648	0.0002402	0.0002675	0.0003469	0.0006755	0.0002415
Cr	0.0031376	0.0028519	0.0032019	0.0041083	0.0019618	0.0028351
Fe	0.0110793	0.0143629	0.0113958	0.0146221	0.0762602	0.0122104
Ni	0.0014230	0.0012609	0.0013717	0.0017637	0.0007955	0.0012572
Cu	0.0000364	0.0000319	0.0000363	0.0000405	0.0000280	0.0000315
Mo	0.0004673	0.0001448	0.0000234	0.0000288	0.0000141	0.0003215
U4	0.0	0.0000094	0.0000078	0.0	0.0	0.0
U5	0.0000183	0.0009747	0.0008096	0.0000179	0.0	0.0000146
U6	0.0	0.0000045	0.0000037	0.0	0.0	0.0
U8	0.0083326	0.0068798	0.0082245	0.0081782	0.0	0.0067049
P8	0.0000010	0.0000003	0.0	0.0	0.0	0.0000007
P9	0.0017680	0.0005050	0.0	0.0	0.0	0.0011990
P0	0.0002339	0.0000791	0.0	0.0	0.0	0.0001879
P1	0.0000141	0.0000051	0.0	0.0	0.0	0.0000121
P2	0.0000038	0.0000020	0.0	0.0	0.0	0.0000048
A1	0.0000217	0.0000082	0.0	0.0	0.0	0.0000194
P	0.0000046	0.0000052	0.0000074	0.0000102	0.0000234	0.0000051
S	0.0000016	0.0000015	0.0000039	0.0000063	0.0000315	0.0000012
Cl	0.0000062	0.0000044	0.0000003	0.0000003	0.0	0.0000024
Ca	0.0000010	0.0000013	0.0000021	0.0000021	0.0	0.0000017
Co	0.0000045	0.0000025	0.0000025	0.0000023	0.0000017	0.0000019

TABLE 6.1 (contd)

Isotope	Axial Blanket (OC) Pu Fuel 20-31	Reflector Iron Block (OC) Pu Fuel 31-36	Outer Core Double Pu 0-20	Outer Core Single Pu 0-20	Outer Core U Fuel 0-20	Outer Core U Fuel 20-20.44
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0000531	0.0005928	0.0023103	0.0000332	0.0021729	0.0000344
O	0.0088210	0.0	0.0156591	0.0137451	0.0167721	0.0088278
Na	0.0092557	0.0	0.0087757	0.0092985	0.0084828	0.0093013
Si	0.0001926	0.0001164	0.0001813	0.0001570	0.0001692	0.0001539
Al	0.0000029	0.0	0.0000060	0.0000041	0.0000041	0.0000029
Mn	0.0003418	0.0006745	0.0002650	0.0002283	0.0002381	0.0002122
Cr	0.0041642	0.0019579	0.0031381	0.0026649	0.0028506	0.0024885
Fe	0.0147930	0.0761469	0.0110869	0.0128413	0.0158460	0.0088763
Ni	0.0017665	0.0007913	0.0014192	0.0011662	0.0012576	0.0010793
Cu	0.0000444	0.0000274	0.0000355	0.0000293	0.0000321	0.0000302
Mo	0.0000348	0.0000138	0.0004684	0.0002391	0.0000161	0.0000149
U4	0.0	0.0	0.0	0.0	0.0000162	0.0000134
U5	0.0000179	0.0	0.0000180	0.0000127	0.0016680	0.0013816
U6	0.0	0.0	0.0	0.0	0.0000078	0.0000064
U8	0.0081561	0.0	0.0082662	0.0058281	0.0069727	0.0082355
P8	0.0	0.0	0.0000012	0.0000005	0.0	0.0
P9	0.0	0.0	0.0017573	0.0008855	0.0	0.0
P0	0.0	0.0	0.0003137	0.0001172	0.0	0.0
P1	0.0	0.0	0.0000209	0.0000072	0.0	0.0
P2	0.0	0.0	0.0000099	0.0000019	0.0	0.0
A1	0.0	0.0	0.0000343	0.0000110	0.0	0.0
P	0.0000102	0.0000234	0.0000048	0.0000053	0.0000052	0.0000053
S	0.0000081	0.0000314	0.0000015	0.0000010	0.0000017	0.0000013
Cl	0.0000003	0.0	0.0000062	0.0000003	0.0000058	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000019	0.0000012	0.0000038	0.0000008	0.0000029	0.0000029

TABLE 6.1 (contd)

Isotope	Axial Blanket (OC) U Fuel 20.44-31	Reflector Iron Block (OC) U Fuel 31-36	Outer Core Single U (OCUS) 0-20	Outer Core Single U (OCUS) 20-20.44	Outer Core Double U (OCUD) 0-20	Outer Core Double U (OCUD) 20-20.44
B0	0.0	0.0	0.0	0.0	0.0	0.0
B1	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0000564	0.0005919	0.0021064	0.0000340	0.0022429	0.0000349
O	0.0088210	0.0	0.0171001	0.0088278	0.0164272	0.0088278
Na	0.0092567	0.0	0.0083645	0.0092909	0.0086072	0.0093121
Si	0.0002127	0.0001169	0.0001684	0.0001481	0.0001701	0.0001600
Al	0.0000029	0.0	0.0000043	0.0000029	0.0000038	0.0000028
Mn	0.0003491	0.0006731	0.0002412	0.0002105	0.0002349	0.0002140
Cr	0.0040484	0.0019555	0.0028881	0.0024576	0.0028112	0.0025211
Fe	0.0144297	0.0759863	0.0177816	0.0087813	0.0138107	0.0089762
Ni	0.0017536	0.0007950	0.0012690	0.0010563	0.0012456	0.0011035
Cu	0.0000375	0.0000283	0.0000302	0.0000281	0.0000341	0.0000324
Mo	0.0000243	0.0000143	0.0000147	0.0000133	0.0000175	0.0000167
U4	0.0	0.0	0.0000109	0.0000082	0.0000217	0.0000188
U5	0.0000179	0.0	0.0011314	0.0008546	0.0022323	0.0019357
U6	0.0	0.0	0.0000052	0.0000039	0.0000105	0.0000090
U8	0.0081561	0.0	0.0073446	0.0082050	0.0065816	0.0082677
P8	0.0	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	0.0	0.0	0.0	0.0
P0	0.0	0.0	0.0	0.0	0.0	0.0
P1	0.0	0.0	0.0	0.0	0.0	0.0
P2	0.0	0.0	0.0	0.0	0.0	0.0
A1	0.0	0.0	0.0	0.0	0.0	0.0
P	0.0000102	0.0000233	0.0000054	0.0000054	0.0000051	0.0000052
S	0.0000050	0.0000314	0.0000015	0.0000011	0.0000018	0.0000015
Cl	0.0000003	0.0	0.0000056	0.0000003	0.0000060	0.0000003
Ca	0.0000021	0.0	0.0000010	0.0000021	0.0000010	0.0000021
Co	0.0000026	0.0000021	0.0000010	0.0000010	0.0000050	0.0000049

TABLE 6.1

Isotope	Control Rod	
	0-20	20-31
B0	0.0071583	0.0072759
B1	0.0290256	0.0295024
C	0.0094051	0.0095480
O	0.0000006	0.0000068
Na	0.0087470	0.0087131
Si	0.0002035	0.0002034
Al	0.0000054	0.0000048
Mn	0.0002605	0.0002578
Cr	0.0031765	0.0031389
Fe	0.0112393	0.0111169
Ni	0.0014421	0.0014216
Cu	0.0000361	0.0000359
Mo	0.0000178	0.0000177
U4	0.0	0.0
U5	0.0	0.0
U6	0.0	0.0
U8	0.0	0.0
P8	0.0	0.0
P9	0.0	0.0
P0	0.0	0.0
P1	0.0	0.0
P2	0.0	0.0
A1	0.0	0.0
P	0.0000040	0.0000040
S	0.0000012	0.0000012
Cl	0.0000003	0.0000003
Ca	0.0000020	0.0000020
Co	0.0000038	0.0000037

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
111-	409	409	409	409	409	409	409	409	409	409	411																												
112-	409	409	409	409	409	409	409	409	409	409	409	411																											
113-	503	503	503	503	503	401	401	401	401	401	401	407	407	411																									
114-	503	503	503	503	503	503	401	401	401	401	401	407	407	401	401	411																							
115-	503	503	503	503	503	503	503	503	401	401	401	407	407	401	401	401	411	411																					
116-	501	501	501	501	501	501	501	503	503	503	401	407	407	401	401	401	407	407	410																				
117-	501	501	501	501	501	501	501	501	501	501	503	503	407	403	403	403	407	404	404	404	410																		
118-	501	501	501	501	501	501	501	501	501	501	501	501	503	403	403	403	407	404	404	404	404	405	405																
119-	905	902	920	902	922	501	501	501	501	501	501	501	501	501	503	403	403	404	404	404	404	405	405	405	405														
120-	920	922	902	921	904	922	904	501	501	501	501	501	501	501	501	503	503	404	404	404	404	405	405	405	405	402	402												
121-	905	920	902	902	920	922	920	902	902	501	501	501	501	501	501	501	501	503	503	404	404	405	405	405	405	402	402	402											
122-	905	902	921	904	902	920	902	923	920	902	922	501	501	501	501	501	501	501	503	503	405	405	405	405	402	402	402	401											
123-	920	902	904	920	922	902	902	920	902	920	904	902	501	501	501	501	501	501	501	501	503	503	405	405	402	402	402	403	403	402									
124-	905	921	902	902	920	902	921	902	902	922	920	904	923	902	501	501	501	501	501	501	501	501	503	405	405	402	402	403	403	402	402								
125-	905	902	921	922	902	602	602	922	920	902	902	920	902	922	902	501	501	501	501	501	501	501	501	503	503	402	402	403	403	402	402	402							
126-	109	202	106	803	106	602	602	106	902	921	922	902	920	902	902	921	902	920	501	501	501	501	501	501	501	501	503	503	403	403	402	402	402	402					
127-	109	109	112	109	111	602	602	111	106	902	921	902	922	902	920	902	920	902	922	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	
128-	115	104	104	113	104	111	104	104	113	106	111	920	902	921	902	921	902	922	920	902	922	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	
129-	109	111	102	102	111	102	108	111	108	111	109	113	106	902	922	920	902	920	902	921	902	920	902	501	501	501	501	501	501	501	501	501	502	402	402	402	402	402	
130-	115	106	208	101	101	211	102	108	113	108	204	109	113	106	111	902	920	902	922	902	920	902	920	922	902	501	501	501	501	501	501	502	404	404	404	404	404		
131-	601	601	106	111	104	101	116	102	108	111	108	111	108	111	109	111	902	922	920	904	902	922	902	902	920	501	501	501	501	501	501	502	404	404	404	404	404		
132-	601	601	111	106	106	112	104	113	102	108	111	108	111	108	111	106	206	602	602	920	902	920	902	921	107	107	501	501	501	501	502	502	502	404	404	404	404	404	
133-	109	111	105	105	111	106	211	104	111	102	108	112	108	113	108	111	109	602	602	902	921	902	201	107	203	107	501	501	501	501	502	502	502	404	404	403	403	403	
134-	115	103	103	204	105	111	106	111	104	111	102	108	207	108	111	108	109	602	602	922	902	107	107	107	202	107	201	501	501	501	502	502	502	502	403	403	403	403	
135-	109	101	112	103	111	105	116	801	804	104	105	113	108	111	108	108	112	109	802	920	107	201	107	201	107	201	107	107	501	501	502	502	502	502	403	403	403	403	
136-	109	110	101	113	103	111	105	111	106	106	111	104	111	108	108	111	108	108	116	106	201	107	201	107	107	203	107	107	501	501	502	502	502	502	403	403	403	403	
137-	115	102	211	101	110	103	202	105	106	205	106	111	104	102	113	108	108	113	109	111	107	107	203	107	201	107	202	107	107	501	502	502	502	502	402	402	402	403	
138-	109	110	102	110	101	112	103	103	111	105	111	106	104	113	102	108	207	108	111	109	106	107	107	202	107	201	107	201	107	501	502	502	502	502	402	402	402	403	
139-	601	601	110	102	110	101	101	110	103	114	105	106	113	104	601	601	105	114	108	113	109	207	201	107	203	107	107	107	201	501	502	502	502	502	402	402	402	403	
140-	601	601	107	110	102	102	113	101	110	103	105	206	106	114	601	601	114	108	114	108	114	106	107	107	201	107	107	203	107	501	502	502	502	502	402	402	402	408	
141-	115	107	110	107	107	110	102	208	101	103	110	105	114	106	601	601	105	202	108	114	109	109	602	602	107	107	201	107	201	501	501	502	502	502	402	402	402	408	
142-	109	110	102	102	110	107	110	102	102	110	103	112	103	106	113	101	114	103	114	108	108	113	602	602	107	201	107	201	107	501	501	502	502	502	402	402	402	408	
143-	115	102	107	202	102	110	107	601	601	101	110	105	103	110	104	114	102	113	108	108	112	104	602	602	107	107	107	107	107	501	501	502	502	502	402	402	402	408	
144-	109	102	112	107	110	102	107	601	601	110	103	105	207	106	114	101	114	103	108	207	108	104	116	106	201	107	201	107	203	501	501	502	502	502	402	402	402	408	
145-	109	110	102	803	107	102	110	601	601	101	103	110	103	110	104	114	102	103	804	108	108	114	109	114	107	202	107	202	107	501	501	502	502	502	402	402	402	406	
146-	115	102	210	107	107	112	107																																

Fig. 6.1. The xyz Calculation Model for ZPPR-18C

7. CALCULATED K-EFFECTIVES, DELAYED NEUTRON PARAMETERS AND ^{241}Pu DECAY COEFFICIENTS FOR ZPPR-18 CORES (G. L. Grasseschi and P. J. Collins)

7.1 k-effectives

The xyz models for ZPPR-18A, 18B and 18C are described in the previous sections. The reference calculations used nodal diffusion (NDT) and nodal transport (NTT) models with 8 or 9 axial nodes spanning the half-height of the assembly. The axial node spacings were approximately 12 cm except for a 5 cm node just above the fuel. Here, the uranium fuel extending beyond the nominal core height (defined by the length of the plutonium fuel columns) was mixed with axial blanket in the proportion 22% fuel, 78% axial blanket. A variation to model the tops of the inserted shim rods (for calculating reaction rates) was also used.

For ZPPR-18C, only a finite-difference diffusion (FDDT) model was possible because of the absence of alternative storage strategies in the nodal versions of DIF3D. FDDT models were also run for 18A and 18B. These used 20 axial meshes over the half-height of the assembly, generally with about 50 mm spacing in the core, but included a fine mesh of 11.18 mm to represent the additional length of the uranium fuel columns.

Most of the calculations for control rod worths were made with 6 energy groups. The data were collapsed using the 21 group xyz fluxes by reactor region: inner core, outer core plutonium sector, outer core uranium sector, radial blanket etc. An xyz calculation with 6 groups was used to calculate pseudo-absorption terms ($D_g B_g^2$'s) to match the leakage at the core/axial blanket interface. These DB^2 terms were used in xy calculations. RZ models were also calculated but were used only to provide a preliminary estimate of delayed neutron parameters.

The calculated k_{eff} s (not C/E results) for the different models of ZPPR-18 are given in Table 7.1. the differences in k_{eff} due to various modelling approximations derived from these results are shown in Table 7.2. The error due to using 55 mm mesh spacing (from NDT-FDDT) is 0.23% in 18B with the control rods inserted compared with only 0.05% in

ZPPR-18A. On the other hand, the transport correction (NTT-NDT) is only a little larger in 18B (+0.25%) than in 18A (0.21%). Neglect of streaming effects in the plate cells gives an error of 0.35%.

Experimental excess reactivities and operational data for the three ZPPR-18 cores are given in Tables 7.3, 7.4 and 7.5. To derive an experimental value for k_{eff} , the data have been corrected to a temperature of 293K (used in generating the cross section libraries). No adjustment is made for the interface gap, but for comparison the subcritical references have been adjusted to the gap of the critical reference and also for ^{241}Pu decay to the same date. No subcritical reference was established for ZPPR-18C. The calculated β_{eff} values are used to convert measurements in cents to Δk units. The uncertainties in these tables are due only to measurements of excess reactivities and the reactivity coefficients. The total uncertainty (strongly correlated between the cores) is dominated by knowledge of fuel masses and is approximately 0.05% Δk .

Table 7.6 compares the criticality predictions for three cores with different calculation models. For ZPPR-18C, a calculation was not made with shim rods withdrawn and the measured shim reactivity is used as a correction (+0.00065 Δk). The nodal transport prediction of 0.9925 in ZPPR-18A is similar to that obtained for other LMR cores with ENDF/B-V.2 data. The prediction for 18B is 0.13% Δk higher. A similar difference was found in analysis of ZPPR-17B and 17C where 17B contained only control positions and 17C had control banks half inserted.

7.2 Delayed Neutron Parameters

Delayed neutron parameters were calculated for ZPPR-18A and 18B using the xyz finite-difference diffusion models with 21 group data. The values are given in Tables 7.7 and 7.8. The β_{eff} values are over 10% higher than those for all-plutonium cores because of the uranium fuel sectors. No calculation was made for ZPPR-18C since the values for 18B are sufficiently accurate for derivation of the experimental k_{eff} .

7.3 Calculated ^{241}Pu Decay Coefficient for ZPPR-18A

The ^{241}Pu decay coefficient for ZPPR-18A was calculated from the first order perturbation worths of ^{241}Pu and ^{241}Am using the 21 group xyz FDDT model. The worth of a uniform decrease of 1% in ^{241}Pu over the core was $-5.503 \times 10^{-5} \Delta k/k$ and the worth of a uniform increase of 1% in ^{241}Am was $-1.0425 \times 10^{-5} \Delta k/k^2$. The atomic ratio of $^{241}\text{Pu}/^{241}\text{Am}$ was 0.659. Using a ^{241}Pu half-life of 14.4 years (decay constant $1.319 \times 10^{-4} \text{ day}^{-1}$) and the calculated β_{eff} of 0.3786%, gave a net decay coefficient of $-0.0002184 \text{ day}^{-1}$. The (1σ) uncertainty on the value is estimated to be 10%.

TABLE 7.1. k-effective Calculations for ZPPR-18

	Core	Reactor Loading ^a	Number of Groups	Geometry	Mesh	Calculation Method ^b	Streaming	Shim Rods ^c	k-effective ^d
1	18A	C	21	xyz	38x39x8	NDT	Y	N	0.991215
2		C	21	xyz	38x39x8	NTT	Y	N	0.993328
3		C	21	xyz	38x39x20	FDDT	Y	N	0.991670
4		C	21	xyz	38x39x20	FDDT	N	N	0.995172
5		C	21	xyz	38x39x9	NTT	Y	Y	0.992875
6		C	21	rz	50x20	FDDT	Y	N	0.990182
7		C	21	rz	50x20	FDDT	N	N	0.993699
8		C	6	xyz	38x39x20	FDDT	Y	N	0.989603
9		S	6	xyz	38x39x8	NDT	Y	N	0.988579
10		S	6	xyz	38x39x8	NTT	Y	N	0.990561
11		C	6	xy	76x78 ^e	FDDT	Y	N	0.990181
12		S	6	xy	76x78 ^e	FDDT	Y	N	0.988948
13		S	6	xy	38x39	FDDT	Y	N	0.988948
14	18B	C	21	xyz	38x39x18	NDT	Y	N	0.992015
15		C	21	xyz	38x39x18	NTT	Y	N	0.994524
16		C	21	xyz	38x39x18	NTT	Y	Y	0.994493
16a		C	21	xyz	38x39x18	NTT	Y	Y	0.994140 ^f
17		C	21	xyz	38x39x40	FDDT	Y	N	0.994296
18	18C	C	21	xyz	76x78x40	FDDT	Y	Y	0.994886

^aC = critical reference, S = subcritical reference.

^bNDT = nodal diffusion, NTT = nodal transport, FDDT = finite-difference diffusion.

^cShim rods if inserted (Y) are close to position during foil irradiations.

^dNot C/E values.

^eFull x, full y model for calculations of asymmetric control rods.

^fUsing cubic polynomial approximation instead of quartic approximation.

TABLE 7.2 Calculation Modelling Effects for ZPPR-18

Correction	Core	Cases ^a	Δk
Transport	18A	1-2 (21 groups)	+0.002133
		10-9 (6 groups)	+0.001982
	18B	15-14 (21 groups)	+0.002509
FDDT Mesh	18A	1-3	-0.000455
	18B	14-17	-0.002281
Streaming	18A	3-4 (xyz)	-0.003502
		6-7 (rz)	-0.003517
Energy Groups	18A	3-8 (FDDT)	+0.002067
Bucklings	18A	8-11	-0.000578

^aRefer to Table 7.1.

TABLE 7.3. Experimental and Calculated k-effective Results for ZPPR-18A

	<u>Critical Reference</u>	<u>Subcritical Reference</u>
Date	10/16/87	10/14/87
Reactor Run Number	18	15
Temperature, K	299.9	303.4
Interface Gap, mil ^a	54.5	53.8
Measured Excess Reactivity, ϕ	$+13.6 \pm 0.1$	-27.4 ± 0.2
Adjustment to 293K, ϕ ^b	$+8.6 \pm 0.8$	$+13.0 \pm 1.1$
Adjustment fo 54.5 mil ^c , ϕ	---	-0.06 ± 0.01
Adjustment to 10.16.87 ^d	---	-0.04 ± 0.01
Adjusted Reactivity, ϕ	$+22.2 \pm 0.8\phi$	-14.5 ± 1.16
Experimental K-effective (E) ^e	1.000836 ± 0.000030	0.999451 ± 0.000044
Calculation, 21G XYZ NDT (C)	0.991191	---
C/E for k-effective	0.990363	---

^aOn a scale with arbitrary zero.

^bUsing measured temperature coefficient $-1.25 \pm 0.11\phi \text{ K}^{-1}$.

^cUsing measured gap coefficient $-0.09 \pm 0.01\phi \text{ mil}^{-1}$.

^dUsing calculated ^{241}Pu decay coefficient $-0.02184\phi \text{ day}^{-1}$.

^eUsing calculated β -effective 0.003786.

TABLE 7.4. Experimental and Calculated k-effective Results for ZPPR-18B

	<u>Critical Reference</u>	<u>Subcritical Reference</u>
Date	12/7/87	12/3/87
Reactor Run Number	98	93
Temperature, K	301.9	301.5
Interface Gap, mil ^a	54.8	54.2
Measured Excess Reactivity, ϕ	$+7.3 \pm 0.1$	-33.2 ± 0.2
Adjustment to 293K, ϕ ^b	$+11.1 \pm 1.0$	$+10.6 \pm 0.9$
Adjustment to 54.8 mil ^c , ϕ	---	-0.05 ± 0.01
Adjustment to 12/7/87 ^d , ϕ	---	-0.09 ± 0.01
Adjusted Reactivity, ϕ	$+18.4 \pm 1.0$	-22.7 ± 1.0
Experimental K-effective (E) ^e	1.000699 ± 0.000038	0.999137 ± 0.000038
Calculation, 21G XYZ NDT (C)	0.992015	---
C/E for k-effective	0.991322	---

^aOn a scale with arbitrary zero.

^bUsing measured temperature coefficient $-1.25 \pm 0.11 \phi \text{ K}^{-1}$. (ZPPR-18A)

^cUsing measured gap coefficient $-0.09 \pm 0.01 \phi \text{ mil}^{-1}$. (ZPPR-18A)

^dUsing calculated ^{241}Pu decay coefficient $-0.02184 \phi \text{ day}^{-1}$. (ZPPR-18A)

^eUsing calculated β -effective 0.003801.

TABLE 7.5. Experimental k-effective Result for ZPPR-18C

	Critical Reference
Date	12/18/87
Reactor Run Number	110
Temperature, K	301.7
Interface Gap, mil ^a	54.2
Measured Excess Reactivity, ϕ	$+17.1 \pm 0.1$
Adjustment to 293K, ϕ ^b	$+10.8 \pm 1.0$
Adjusted Reactivity, ϕ	$+27.9 \pm 1.0$
Experimental K-effective (E) ^c	1.001060 ± 0.000038

^aOn a scale with arbitrary zero.

^bUsing measured temperature coefficient $-1.25 \pm 0.11 \phi \text{ K}^{-1}$. (ZPPR-18A)

^cUsing calculated β -effective 0.003801. (ZPPR-18B)

TABLE 7.6 Comparison of Criticality Predictions for ZPPR-18A, 18B and 18C

Calculation Model ^a	Ratio Calculation/Experiment ^a		
	18A	18B	18C
Finite-difference Diffusion	0.9908	0.9936	0.9945
Nodal Diffusion	0.9904	0.9913	---
Nodal Transport	0.9925	0.9938	---

^aCalculations using xyz models with 21 groups.

TABLE 7.7 Delayed Neutron
Parameters for ZPPR-18A

Family	a_i	λ_i, s^{-1}	$\beta_i, \%$
1	0.02476	0.01294	0.00937
2	0.20285	0.03153	0.07679
3	0.18350	0.13297	0.06946
4	0.36913	0.34188	0.13974
5	0.16691	1.3760	0.06318
6	0.05285	3.8000	0.02001

β -effective 0.3786%

Prompt neutron lifetime $5.118 \times 10^{-7}s$

TABLE 7.8. Delayed Neutron
Parameters for ZPPR-18B

Family	a_i	λ_i, s^{-1}	$\beta_i, \%$
1	0.02512	0.01293	0.00955
2	0.20338	0.03153	0.07730
3	0.18372	0.13248	0.06982
4	0.36994	0.34092	0.14060
5	0.16573	1.3763	0.06299
6	0.05211	3.7998	0.01980

β -effective 0.3801%

Prompt neutron lifetime $4.624 \times 10^{-7}s$

8. MEASUREMENTS AND ANALYSIS OF REACTION RATES IN ZPPR-18A (P. J. Collins
J. M. Gasidlo, D. W. Maddison and G. L. Grasseschi)

8.1 Introduction

ZPPR-18 was an experimental simulation of a large LMR core of "conventional" design with two fuel enrichment zones and 24 control rod positions (CRPs). Three critical configurations were built; 18A with no control rods in the core, 18B with 18 control rods half-inserted and 18C with 17 control rods half-inserted. The principal measurements in ZPPR-18 were criticality, control worths and reaction rate distributions.

The ZPPR-18A fissile loading in the core was 3464 kg in a volume of 8500 liters. The inner core was fueled with plutonium (1841 kg fissile) and the outer core contained sectors with 598 kg fissile material in plutonium zones and 1025 kg ^{235}U fuel in uranium zones. The plutonium-fuel sectors were built symmetrically along the x-axis and most reaction rate measurements were made in this vicinity. A detailed description of ZPPR-18A is given in ANL-ZPR-485, p. 2.

Previous analyses of the larger conventional cores, both with JENDL and with ENDF/B cross sections, indicated that substantial mispredictions of fission distributions as a function of radius would be obtained in ZPPR-18. Design studies for ZPPR-18, both at PNC and ANL, showed that reaction rate distributions along the x-axis in the sector loading should have a very similar shape to those of an assembly with an all-plutonium fuel loading in the outer core. Measurements in ZPPR-18A had two aims. First, to study the accuracy of predictions of the spatial distributions and second, the compare with those in cores 18B and 18C with control banks partially inserted. Thus, several of the measured distributions in 18A were chosen to satisfy the second requirement. As will be seen, some surprises were in store regarding the first objective.

This report contains the measured data after adjustment to produce cell-averaged reaction rates and the results of an analysis with ENDF/B-V.2 cross sections and an xyz nodal transport calculation. The results of the

basic foil data and derivation of cell-average/foil adjustment factors will be given in a subsequent ZPR report.

Measurements of capture in sodium were also made in ZPPR-18A. These data are given in the next section of this report.

8.2 Description of the Measurements

The measurements were made in the ZPPR-18A critical reference core (ANL-ZPR-485, p. 4) in loading 38, reactor run 23, on October 21, 1988. During the foil irradiation, eight ZPPR shim control rods, in location 135-67 and the seven symmetric locations were inserted to a distance 36.8 cm from the midplane and had a total worth of 11.8 ϕ .

Reaction rates were measured with the standard ZPPR foil techniques described in ANL-82-38. Statistical uncertainties of the measured reaction rates are in the range 0.4% to 0.7% in the core regions for fission in ^{239}Pu , ^{235}U and capture in ^{238}U and increase to 0.9% deep in the blankets. Statistical uncertainties are larger for fission in ^{238}U and are typically 1.5% to 2.5% in the core increasing to almost 20% deep in the blankets. The detailed estimates will be given with the basic data report. The calibrations of the reaction rates are consistent with those used for ZPPR-17A as described in ANL-87-5.

The reaction rate measurements were as follows:

- (i) Radial distributions along the x-axis at 5 cm and at 28 cm from the midplane.
- (ii) The radial distribution along the y-axis (through the uranium-fueled sector) at $z = 5$ cm using only ^{235}U foils. Measurements of fission and capture in ^{238}U were also made in the outer core at the y-axis but no cell-average/foil factors were obtained).
- (iii) Distributions at 15° to the x-axis, passing through an outer ring CRP, at $z = 5$ cm and $z = 28$ cm.

- (iv) Distributions (inner core only) at 30° to the x-axis, passing through inner and middle bank CRPs, at $z = 5$ cm and $z = 28$ cm.
- (v) Axial distributions at the core center (matrix 149-49), in the outer core (matrix 149-75) and adjacent to an inner-bank CRP (matrix 146-57).

A total of 643 reaction rate values were measured. As usual, the number of ^{239}Pu fission foils was limited by requirements of subsequent phases of the program and ^{235}U foils were used extensively to provide tests of calculated fission rates. The foil locations in the xy-plane are shown in Fig. 8.1.

8.3 Calculation Methods

Calculations were made with ENDF/B-V.2 cross sections in 21 energy groups and an xyz model with the nodal transport path of the DIF3D code. Details of the cross section processing and the model are given in Section 4. Anisotropic transport cross sections, corresponding to Benoist diffusion coefficients were used in the xyz model.

The ZPPR operating control rods were treated in the model using special boron carbide cross sections appropriate to homogenizing the B_4C blades over the matrix area. The rods were inserted in the model to a depth of 35.6 cm from the midplane. The k_{eff} was 0.992819 with shim rods inserted, compared to 0.993297 with shim rods withdrawn, giving a reactivity of 12.8¢ which is sufficiently close to the experimental value of 11.8¢.

Calculated reaction rates were interpolated to the positions of the measurements using a quadratic fit to the node-average values. At the time of this analysis, it was not possible to use the nodal polynomial interpolation procedure because of difficulties in handling the extremely long files in the computer system.

8.4 Experimental Results and Comparison with Calculation

The experimental data and comparisons with calculation (C/E values) are organized into distributions along the axes, at 15° and 30° to the axes, at distances of 5 cm and 28 cm from the midplane and into the three axial distributions. The results are shown by matrix position only. The actual x, y and z locations within a matrix position will be given in the basic data report. For ease in interpretation, the reactor zones are indicated by IC (inner core), OC (outer core), RB (radial blanket), RR (radial reflector), AB (axial blanket) and AR (axial reflectors). Since systematic trends with drawer type are sometimes seen, the single-fuel-column drawers are labelled as SF for drawers with Fe_2O_3 adjacent to the fuel and as SM for drawers with depleted uranium metal adjacent to fuel. These drawers, also denoted DUF and DUM, are described in ANL-ZPR-485, p. 2. Double-fuel-column drawers in the outer core are labelled OC D in the plutonium sector. Double and single fuel column drawers in the uranium sector are labeled OC UD and OC US respectively.

Experimental results are given in units of 10^{-18} reactions per atom per second at a reactor power of approximately 1 watt.

Radial reaction rate distributions and comparison with calculations are given in Tables 8.1 to 8.7 and the axial distribution data are given in Tables 8.8 to 8.10. Figures 8.2 and 8.3 show a summary of the C/E values for ^{235}U fission at 5 cm and at 28 cm above the midplane. In these figures, each result is the mean C/E value for 3 to 5 contiguous matrix locations.

The most significant result of the analysis is that reaction rates along the x-axis are well predicted, but the distribution for ^{235}U fission along the y-axis shows a clear decrease in C/E with radius, with C/E values in the uranium-fuel sector about 6% lower than those near the core center. The good prediction at the x-axis is found, within the uncertainties, for all four reaction types at both $z = 5$ cm and at $z = 28$ cm.

For the distributions at 15° and at 30° to the x-axis, the C/E tend to be 1% to 2% low at the edge of the inner core and in the outer core, relative to the core center.

The analysis of axial reaction rate distributions is similar to that found in other calculations with ENDF/B-V.2 data. Reaction rate distributions are well predicted through the core region, capture in ^{238}U is well predicted with penetration of up to 20 cm in the axial blanket while ^{235}U fission C/Es increase by a few percent. No data for ^{239}Pu fission in the blanket were taken in ZPPR-18A and results for ^{238}U fission are inconclusive due to statistical uncertainties.

In common with previous analyses, using the current method, the C/E results for ^{238}U fission show a systematic increase between the last position in the fuel regions to the first position in the adjacent blanket region. For the radial distributions, this jump is 20% but for axial distributions, the change is only 5%.

8.5 Reaction Rate Ratios

Reaction rate ratios, relative to ^{239}Pu fission are given in Tables 8.11 to 8.13. The ratios are simply calculated from the results at the positions of the foils. Neither the measurement nor the calculation are adjusted to a common foil position in the cell so that C/E results are unaffected by this definition. For simplicity in the tables, the reaction rates are abbreviated to F9, F5, C8 and F8 for fission in ^{239}Pu , etc.

The C/E results for the ratios are summarized in Table 8.14. The standard deviations for the ratios in the inner core are consistent within the experimental statistics. Wider variations are seen in the outer core. There appears to be a significant difference of 1% between the F5/F9 ratio in the axial traverse (149-49) and in the radial distributions.

The overall results of the analysis are as follows:

F5/F9	C/E = 1.004	S.D. = 0.010
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C8/F9	C/E = 1.046	S.D. = 0.010
F8/F9	C/E = 0.986	S.D. = 0.027

8.6 Effects of the ZPPR Structure

The size of the ZPPR-18 loading permitted only 2 rows of radial reflector to be built at the y-axis and for 9 positions on either side of the y-axis (Fig. 8.1). This matrix loading was used in the calculation models but in fact a considerable thickness of steel exists in the ZPPR structure outside the matrix tubes which acts as an additional reflector. Neglect of the ZPPR structure was considered as a possible contributor to the underestimation of ^{235}U fission rates along the y-axis.

To estimate the effect of the extra steel, two xy calculations were compared, one consistent with the xy plan of the xyz model and the other with extra steel included around the matrix. Calculations were made with diffusion theory using a constant axial buckling. Table 8.15 shows the ratios of reaction rates along the x-axis with the extra steel structure to reaction rates with the reference model.

Changes in reaction rates in the outer core are negligible, that is less than 0.1%. The same result was found at the x and y axes so that the neglect of steel structure cannot be a contributor to the low C/E results in the outer core at the y-axis.

Corrections to reaction rates in the radial blanket along the x-axis increase up to 2.4% for ^{235}U fission, 1.4% for ^{238}U capture and to 0.3% for ^{238}U fission at the outer edge. Corrections in the radial blanket along the y-axis may well be somewhat different. However, no measurements were made in the radial blanket adjacent to the thin reflector.

8.7 Summary

The nearly perfect prediction of radial reaction rate distributions along the x-axis of ZPPR-18A was entirely unexpected for an LMR core of this size. The decreasing C/E for ^{235}U fission along the y-axis may be a related effect. Only two explanations seem possible: one is a substantial error lurking in the calculation model and the other is that the results are consistent with nuclear data errors. If the latter does indeed prove to be the case, the ZPPR-18A data will be very interesting additions to the sensitivity/data fitting scheme.

Fig. 8.1. Foil Locations in ZPPR-18A in the xy Plane

Fig. 8.2. Summary of the C/E Results for ^{235}U Fission in ZPPR-18A at 5 cm from the Midplane

Fig. 8.3. Summary of C/E Results for ^{235}U Fission in ZPPR-18A at 28 cm from the Midplane

TABLE 8.1 ZPPR-18A: Radial Reaction Rate Distributions along the X-axis at Z = 5.16 cm

Matrix	Zone	$^{239}\text{Pu}(n,f)$		$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E	Exp.	C/E
149 49	IC SF	8.793	0.997	9.283	1.012	1.2370	1.044	0.2071	1.008
149 50	IC SF	8.749	1.001	9.276	1.012	1.2210	1.058	0.2147	0.973
149 51	IC SM	8.459	1.024	9.100	1.018	1.1490	1.053	0.2083	0.990
149 52	IC SF	8.611	1.001	9.185	1.002	1.2050	1.050	0.2099	0.975
149 53	IC SM	8.459	1.005	8.984	1.010	1.1230	1.055	0.2045	0.985
149 54	IC SF	8.434	1.003	9.229	0.979	1.1750	1.057	0.2052	0.974
149 55	IC SM	8.283	1.008	8.843	1.011	1.1030	1.057	0.1996	0.984
149 56	IC SF	8.331	0.998	8.932	0.999	1.1700	1.048	0.2044	0.954
149 57	IC SM	8.219	1.001	8.745	1.012	1.0890	1.059	0.2002	0.964
149 58	IC SF	8.282	0.991	8.843	0.999	1.1650	1.043	0.1984	0.976
149 59	IC SF	8.063	1.005	8.673	1.002	1.1480	1.040	0.1930	0.993
149 60	IC SM	7.842	1.015	8.342	1.020	1.0540	1.054	0.1888	0.998
149 61	IC SF	7.848	1.008	8.426	1.004	1.1140	1.045	0.1826	1.029
149 62	IC SF	7.796	1.006	8.363	1.005	1.1070	1.045	0.1862	1.003
149 63	IC SM	7.594	1.012	8.178	1.006	1.0330	1.040	0.1823	1.003
149 64	IC SF	7.574	1.002	8.078	1.005	1.0720	1.042	0.1822	0.992
149 65	IC SF	7.405	1.007	7.915	1.009	1.0570	1.040	0.1734	1.027
149 66	IC SM	7.103	1.018	7.558	1.023	0.9500	1.063	0.1719	1.003
149 67	IC SF	7.019	1.004	7.452	1.008	0.9777	1.056	0.1740	0.966
149 68	IC SM	6.732	1.010	7.146	1.012	0.8983	1.051	0.1565	1.036
149 69	IC SF	6.549	1.007	6.995	1.001	0.9164	1.049	0.1588	0.994
149 70	IC SM	6.262	1.012	6.653	1.009	0.7640	1.049	0.1435	1.015
149 71	IC SF	6.064	1.009	6.479	0.999	0.8386	1.056	0.1510	0.985
149 72	IC SM	5.747	1.017	6.115	1.009	0.7640	1.049	0.1435	1.015
149 73	OC SF	5.549	1.009	5.872	1.004	0.7645	1.051	0.1417	1.033
149 74	OC SF	5.200	1.007	5.476	1.001	0.7128	1.046	0.1423	1.023
149 75	OC D	4.683	1.005	4.919	1.009	0.6335	1.049	0.1411	0.964
149 76	OC SF	4.109	0.998	4.409	0.990	0.5698	1.044	0.1070	1.044
149 77	OC SF	3.466	0.995	3.805	1.002	0.4882	1.073	0.0881	0.910
149 78	RB	--	--	3.234	1.016	0.4030	1.046	0.0366	1.108
149 79	RB	--	--	2.641	1.013	0.3192	1.059	0.0202	1.035
149 80	RB	--	--	2.121	1.009	0.2535	1.036	0.0120	0.955
149 81	RB	--	--	1.730	1.009	0.1968	1.024	0.0059	1.092
149 82	RB	--	--	1.455	1.072	0.1608	0.992	0.0041	0.898
149 83	RR	--	--	1.550	1.103	--	--	--	--

TABLE 8.2 ZPPR-18A: Radial Reaction Rate Distributions along the
X-axis at Z = 28.02 cm

Matrix	Zone	$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
149 49	IC SF	7.708	1.002	1.0270	1.036	0.1669	1.013
149 50	IC SF	7.787	0.992	1.0380	1.025	0.1658	1.021
149 51	IC SM	7.549	1.010	0.9544	1.042	0.1644	1.015
149 52	IC SF	7.630	0.993	1.0070	1.034	0.1686	0.984
149 53	IC SM	7.419	1.007	0.9377	1.040	0.1625	1.005
149 54	IC SF	7.493	0.993	0.9866	1.037	0.1609	1.007
149 55	IC SM	7.417	0.993	0.9194	1.044	0.1543	1.032
149 56	IC SF	7.346	1.002	0.9856	1.026	0.1616	0.979
149 57	IC SM	7.285	1.002	0.9150	1.039	0.1589	0.985
149 58	IC SF	7.382	0.987	0.9715	1.031	0.1556	1.009
149 59	IC SF	7.165	0.999	0.9504	1.036	0.1573	0.988
149 60	IC SM	6.957	1.008	0.8821	1.037	0.1480	1.032
149 61	IC SF	6.961	1.001	0.9097	1.053	0.1558	0.977
149 62	IC SF	6.961	0.993	0.9171	1.038	0.1509	1.002
149 63	IC SM	6.749	1.003	0.8454	1.044	0.1468	1.008
149 64	IC SF	6.695	0.997	0.8757	1.049	0.1550	0.944
149 65	IC SF	6.660	0.986	0.8788	1.029	0.1429	1.007
149 66	IC SM	6.324	1.005	0.7943	1.044	0.1367	1.020
149 67	IC SF	6.197	0.996	0.8134	1.043	0.1395	0.973
149 68	IC SM	5.906	1.005	0.7347	1.054	0.1315	0.996
149 69	IC SF	5.751	0.999	0.7518	1.050	0.1362	0.936
149 70	IC SM	5.466	1.007	0.6876	1.043	0.1212	1.014
149 71	IC SF	5.301	1.000	0.7029	1.033	0.1183	1.014
149 72	IC SM	4.982	1.013	0.6294	1.042	0.1150	1.021
149 73	OC SF	4.844	0.994	0.6304	1.042	0.1179	1.000
149 74	OC SF	4.486	0.997	--	--	--	--
149 75	OC D	4.039	1.001	0.5176	1.047	0.1141	0.959
149 76	OC SF	3.582	0.992	--	--	--	--
149 77	OC SF	3.103	1.001	0.4030	1.059	0.0704	0.915
149 78	RB	2.657	1.010	--	--	--	--
149 79	RB	2.179	1.004	--	--	--	--
149 80	RB	1.735	1.010	--	--	--	--
149 81	RB	1.411	1.014	--	--	--	--
149 82	RB	1.194	1.074	--	--	--	--

TABLE 8.3 ZPPR-18A: Radial Reaction Rate Distributions along the Y-axis at Z = 5.16 cm

Matrix	Zone	$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp. ^a	C/E	Exp.	C/E
149 49	IC SF	9.283	1.012	1.2370	1.044	0.2071	1.008
148 49	IC SM	9.202	1.008	--	--	--	--
147 49	IC SF	9.177	1.004	--	--	--	--
146 49	IC SM	8.992	1.013	--	--	--	--
145 49	IC SF	9.193	0.989	--	--	--	--
144 49	IC SF	9.010	1.001	--	--	--	--
143 49	IC SM	8.836	1.004	--	--	--	--
142 49	IC SF	8.890	0.995	--	--	--	--
141 49	IC SM	8.971	0.996	--	--	--	--
	CRP						
138 49	IC SF	8.324	1.001	--	--	--	--
137 49	IC SM	7.909	1.001	--	--	--	--
136 49	IC SF	7.818	0.987	--	--	--	--
135 49	IC SF	7.635	0.988	--	--	--	--
134 49	IC SM	7.423	0.993	--	--	--	--
133 49	IC SF	7.447	0.990	--	--	--	--
	CRP						
130 49	IC SM	6.709	0.979	--	--	--	--
129 49	IC SF	6.334	0.971	--	--	--	--
128 49	IC SM	5.916	0.983	--	--	--	--
127 49	IC SF	5.713	0.970	--	--	--	--
126 49	IC SF	5.420	0.960	--	--	--	--
125 49	OC UD	4.976	0.944	0.6730	0.991	0.1476	0.853
124 49	OC US	4.548	0.961	0.6133	1.000	0.1394	0.814
123 49	OC UD	4.173	0.941	0.5670	0.989	0.1287	0.833
122 49	OC US	3.707	0.948	0.5045	0.995	0.1131	0.770
121 49	OC US	3.178	0.949	0.4354	0.996	0.0989	0.771
120 49	OC UD	2.668	0.937	0.3758	0.980	0.0784	0.836
119 49	OC US	2.211	0.928	0.3067	1.005	0.0580	0.734

^aNo cell-average factors were measured for ^{238}U reaction in the uranium-fuelled sector.

TABLE 8.4 ZPPR-18A: Radial Reaction Rate Distributions at 15° to the X-axis at Z = 5.16 cm

Matrix	Zone	$^{239}\text{Pu}(n,f)$		$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E	Exp.	C/E
148 50	IC SF	8.697	1.005	9.221	1.010	1.2150	1.058	0.2130	0.977
148 52	IC SM	8.500	1.010	9.033	1.015	1.1290	1.061	0.2028	1.005
148 53	IC SF	8.568	0.995	9.119	0.998	1.1870	1.055	0.2064	0.980
147 54	IC SF	8.347	1.010	9.193	0.984	1.1730	1.059	0.2008	0.988
147 55	IC SM	8.247	1.011	8.880	1.015	1.1150	1.048	0.1967	0.986
147 56	IC SF	8.322	1.000	9.033	1.005	1.1950	1.038	0.2016	0.951
147 57	IC SF	8.305	0.995	9.029	0.996	1.1800	1.043	0.1966	0.966
146 58	IC SF	8.231	0.989	9.011	0.990	1.1760	1.035	0.1888	0.972
146 59	IC SM	7.925	1.008	8.517	1.013	1.0760	1.040	0.1787	1.034
146 60	IC SF	7.890	1.000	8.452	0.999	1.1090	1.047	0.1838	1.006
145 61	IC SF	7.800	0.989	8.230	1.000	1.0950	1.035	0.1839	0.985
145 62	IC SM	7.499	1.010	8.013	1.006	1.0130	1.040	0.1749	1.017
144 63	IC SM	7.290	1.009	7.776	1.010	0.9864	1.039	0.1742	0.983
144 64	IC SF	7.299	0.994	7.790	0.994	1.0150	1.050	0.1738	0.974
144 65	IC SM	7.056	1.008	7.478	1.012	0.9349	1.058	0.1718	0.970
144 66	IC SF	7.014	0.997	7.469	0.996	0.9739	1.054	0.1702	0.973
143 67	IC SF	6.800	0.988	7.199	0.993	0.9536	1.035	0.1573	1.007
143 68	IC SF	6.595	0.991	7.045	0.991	0.9260	1.039	0.1553	0.991
143 69	IC SM	6.300	1.002	6.723	1.008	0.8457	1.040	0.1481	0.990
143 70	IC SF	6.209	0.987	6.677	0.999	0.8919	1.022	0.1386	0.988
142 70	IC SM	6.044	0.998	6.571	1.003	0.8126	1.043	0.1340	0.994
CRP									
142 73	OC SF	5.427	0.992	5.889	0.998	0.7780	1.028	0.1295	0.970
141 73	OC SF	5.345	0.991	5.658	1.007	0.7601	1.026	0.1278	0.989
141 74	OC SF	4.876	0.991	5.129	0.995	0.6796	1.026	0.1283	0.985
141 75	OC D	4.347	0.982	4.527	0.993	0.5821	1.038	0.1256	0.952
141 76	OC SF	3.756	0.993	3.923	0.996	0.5119	1.048	0.1003	1.020
140 77	OC SF	3.029	0.988	3.221	0.995	0.4214	1.055	0.0810	0.905
140 78	RB	--	--	2.753	0.990	0.3417	1.036	0.0335	1.091
140 79	RB	--	--	2.214	0.998	0.2735	1.034	0.0179	1.031
139 80	RB	--	--	1.673	0.995	0.2021	1.025	0.0112	0.831
139 81	RB	--	--	1.342	1.003	0.1558	1.013	0.0069	0.759
139 82	RB	--	--	1.116	1.069	0.1231	1.007	0.0042	0.707

TABLE 8.5 ZPPR-18A: Radial Reaction Rate Distributions at 15° to the X-axis at Z = 28.02 cm

Matrix	Zone	$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
148 50	IC SF	7.718	0.993	1.0200	1.038	0.1677	1.004
148 52	IC SM	7.495	1.008	0.9408	1.046	0.1621	1.019
148 53	IC SF	7.571	0.990	0.9985	1.033	0.1657	0.990
147 54	IC SF	7.486	0.996	0.9955	1.029	0.1635	0.984
147 55	IC SM	7.396	1.007	--	--	--	--
147 56	IC SF	7.496	1.001	0.9945	1.030	0.1583	0.983
147 57	IC SF	7.458	0.997	0.9991	1.017	0.1568	0.983
146 58	IC SF	7.437	0.993	0.9811	1.026	0.1538	0.968
146 59	IC SM	7.090	1.005	0.8931	1.034	0.1444	1.038
146 60	IC SF	7.026	0.991	--	--	--	--
145 61	IC SF	6.779	1.001	--	--	--	--
145 62	IC SM	6.581	1.009	0.8336	1.040	0.1451	0.993
144 63	IC SM	6.455	1.003	0.8119	1.039	0.1358	1.022
144 64	IC SF	6.433	0.991	--	--	--	--
144 65	IC SM	6.220	1.002	0.7756	1.049	0.1351	0.999
144 66	IC SF	6.147	0.996	--	--	--	--
143 67	IC SF	5.941	0.990	0.7840	1.037	0.1320	0.971
143 68	IC SF	5.800	0.990	--	--	--	--
143 69	IC SM	5.570	1.001	0.6936	1.043	0.1191	0.996
143 70	IC SF	5.508	0.999	0.7363	1.020	0.1125	0.984
142 70	IC SM	5.460	0.996	0.6776	1.030	0.1107	0.973
CRP							
142 73	OC SF	4.876	0.993	0.6453	1.020	0.1058	0.958
141 73	OC SF	4.748	0.986	0.6344	1.011	0.1040	0.980
141 74	OC SF	4.225	0.989	0.5572	1.026	0.1021	0.998
141 75	OC D	3.728	0.985	--	--	--	--
141 76	OC SF	3.238	0.984	0.4213	1.039	0.0820	1.005
140 77	OC SF	2.688	0.971	0.3441	1.053	0.0633	0.932
140 78	RB	2.231	0.997	--	--	--	--
140 79	RB	1.802	1.002	--	--	--	--
139 80	RB	1.363	1.000	--	--	--	--
139 81	RB	1.088	1.014	--	--	--	--
139 82	RB	0.911	1.076	--	--	--	--

TABLE 8.6 ZPPR-18A: Radial Reaction Rate Distributions at 30° to the X-axis at Z = 5.16 cm

Matrix	Zone	$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
146 54	IC SM	8.942	1.010	1.1200	1.048	0.1904	1.023
145 55	IC SM	9.119	1.006	1.1400	1.036	0.1837	0.981
144 58	IC SM	8.817	1.013	1.1150	1.032	0.1727	0.977
143 58	IC SF	8.762	1.000	1.1810	1.022	0.1761	0.965
143 59	IC SM	8.341	1.008	1.0510	1.041	0.1729	1.021
142 60	IC SM	7.990	1.011	1.0100	1.044	0.1759	0.992
142 61	IC SF	8.005	1.001	1.0670	1.036	0.1722	1.002
142 62	IC SF	8.029	0.994	1.0670	1.025	0.1672	0.994
141 62	IC SF	7.943	0.999	1.0670	1.021	0.1649	0.951
140 65	IC SM	7.380	1.007	0.9362	1.025	0.1460	0.967
139 65	IC SF	7.323	0.991	0.9956	1.005	0.1459	0.972
139 66	IC SM	6.862	1.000	0.8558	1.045	0.1491	0.979
138 67	IC SM	6.516	0.993	0.8120	1.040	0.1480	0.980
138 68	IC SF	6.393	0.990	0.8350	1.043	0.1538	0.953
137 68	IC SM	6.176	0.995	0.7760	1.033	0.1495	0.977

TABLE 8.7 ZPPR-18A: Radial Reaction
Rate Distribution at 30° to
the X-axis at Z = 28.02 cm

Matrix	Zone	$^{235}\text{U}(n,f)$	
		Exp.	C/E
146 54	IC SM	7.408	1.007
145 55	IC SM	7.670	0.991
	CRP		
144 58	IC SM	7.302	1.015
143 58	IC SF	7.340	0.989
143 59	IC SM	6.937	1.001
142 60	IC SM	6.668	1.000
142 61	IC SF	6.710	0.986
142 62	IC SF	6.653	0.992
141 62	IC SF	6.584	0.998
	CRP		
140 65	IC SM	6.151	0.999
139 65	IC SF	6.144	0.974
139 66	IC SM	5.766	0.978
138 67	IC SM	5.305	0.996
138 68	IC SF	5.255	0.983
137 68	IC SM	5.047	0.989

TABLE 8.8 ZPPR-18A: Axial Reaction Rate Distributions in Matrix 149-49 (Core Center)

Zone	Z(mm)	$^{239}\text{Pu}(n,f)$		$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E	Exp.	C/E
IC SF	26.2	8.815	0.994	9.305	1.009	1.2440	1.039	0.2090	0.999
IC SF	50.3	8.793	0.997	9.283	1.012	1.2370	1.044	0.2071	1.008
IC SF	77.0	8.695	0.999	9.201	1.011	1.2260	1.044	0.2186	0.946
IC SF	127.8	8.480	0.992	9.015	1.001	1.2060	1.030	0.2013	0.995
IC SF	178.6	8.193	0.995	8.673	1.008	1.1590	1.038	0.1922	1.008
IC SF	229.4	7.763	0.988	8.226	1.003	1.1030	1.029	0.1841	0.988
IC SF	280.2	7.230	0.991	7.708	1.002	1.0270	1.036	0.1669	1.013
IC SF	356.4	6.361	0.983	6.811	1.002	0.9178	1.023	0.1494	0.956
IC SF	380.5	6.036	0.983	6.610	0.986	0.8664	1.035	0.1376	0.968
IC SF	432.6	5.277	0.995	5.752	1.019	0.7693	1.047	0.1151	0.979
IC SF	483.4	4.672	0.977	5.173	1.026	0.6873	1.054	0.0913	0.889
Zone Average C/E			0.990		1.007		1.038		0.977
Standard Deviation			0.007		0.010		0.009		0.037
AB	534.2	--	--	4.843	1.011	0.6267	1.018	0.0486	0.941
AB	585.0	--	--	4.331	1.016	0.5409	1.034	0.0274	1.086
AB	635.8	--	--	3.787	1.046	0.4673	1.039	0.0170	1.034
AB	686.6	--	--	3.348	1.079	0.4022	1.046	0.0119	0.993
AB	737.4	--	--	2.989	1.112	0.3515	1.025	0.0077	0.838
Zone Average C/E		--	--		1.053		1.032		0.978
Standard Deviation		--	--		0.043		0.011		0.095
AR	839.0	--	--	3.219	1.103	--	--	--	--
AR	889.8	--	--	3.046	1.014	--	--	--	--

TABLE 8.9 ZPPR-18A: Axial Reaction Rate
Distribution for ^{235}U Fission
in Matrix 146-57 (Adj. to CRP)

Zone	Z(mm)	$^{235}\text{U}(n,f)$	
		Exp.	C/E
IC SM	26.2	9.154	1.001
IC SM	50.3	9.097	1.007
IC SM	77.0	9.083	1.000
IC SM	127.8	8.858	0.995
IC SM	178.6	8.456	1.011
IC SM	229.4	8.074	1.001
IC SM	280.2	7.584	1.002
IC SM	331.0	6.985	1.011
IC SM	381.8	6.436	1.006
IC SM	432.6	5.803	1.015
IC SM	483.4	5.286	1.022

Zone Average C/E			1.006
Standard Deviation			0.008
AB	534.2	4.999	1.019
AB	585.0	4.556	1.018
AB	635.8	4.066	1.037
AB	686.6	3.688	1.043
AB	737.4	3.361	1.043

Zone Average C/E			1.032
Standard Deviation			0.013

TABLE 8.10 ZPPR-18A: Axial Reaction Rate Distributions
in Matrix 149-75 (Outer Core)

Zone	Z(mm)	$^{235}\text{U}(n,f)$		$^{238}\text{U}(n,\gamma)^a$		$^{238}\text{U}(n,f)$	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
OC D	26.2	4.940	1.005	0.6397	1.039	0.1428	0.953
OC D	50.3	4.919	1.009	0.6335	1.049	0.1411	0.964
OC D	77.0	4.891	1.005	0.6292	1.046	0.1423	0.947
OC D	127.8	4.726	1.007	0.6131	1.040	0.1351	0.965
OC D	178.6	4.595	1.003	0.5877	1.050	0.1291	0.976
OC D	229.4	4.311	1.005	0.5582	1.039	0.1224	0.963
OC D	280.2	4.039	1.001	0.5176	1.047	0.1141	0.959
OC D	331.0	3.678	1.010	0.4757	1.047	0.1021	0.966
OC D	381.8	3.313	1.011	0.4335	1.036	0.0887	0.961
OC D	432.6	2.980	1.000	0.3809	1.050	0.0778	0.924
OC D	483.4	2.579	1.034	0.3337	1.066	0.0603	0.842
		-----		-----		-----	
Zone Average C/E			1.008		1.046		0.947
Standard Deviation			0.009		0.008		0.037
AB	534.2	2.415	1.004	0.2855	--	0.0302	0.909
AB	585.0	2.148	1.008	0.2456	--	0.0161	1.090
AB	635.8	1.885	1.026	0.2124	--	0.0108	0.941
AB	686.6	1.655	1.056	0.1780	--	0.0076	0.889
AB	737.4	1.486	1.070	--	--	--	--
		-----		-----		-----	
Zone Average C/E			1.033		--		0.957
Standard Deviation			0.029		--		0.091
AB	839.0	1.556	1.064	--	--	--	--
AB	889.8	1.492	0.963	--	--	--	--

^aCell factor not measured for ^{238}U capture in the axial blanket.

TABLE 8.11 ZPPR-18A: Reaction Rate Ratios along the X-axis at Z = 5.16 cm

Matrix	Zone	F5/F9		C8/F9		F8/F9	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
149 49	IC SF	1.056	1.015	0.1407	1.047	0.02355	1.011
149 50	IC SF	1.060	1.011	0.1396	1.057	0.02454	0.972
149 51	IC SM	1.076	0.994	0.1358	1.028	0.02462	0.967
149 52	IC SF	1.067	1.001	0.1399	1.049	0.02438	0.974
149 53	IC SM	1.062	1.005	0.1328	1.050	0.02418	0.980
149 54	IC SF	1.094	0.976	0.1393	1.054	0.02433	0.971
149 55	IC SM	1.068	1.003	0.1332	1.049	0.02410	0.976
149 56	IC SF	1.072	1.001	0.1404	1.050	0.02453	0.956
149 57	IC SM	1.064	1.011	0.1325	1.058	0.02436	0.963
149 58	IC SF	1.068	1.008	0.1407	1.052	0.02396	0.985
149 59	IC SF	1.076	0.997	0.1424	1.035	0.02394	0.988
149 60	IC SM	1.064	1.005	0.1344	1.038	0.02408	0.983
149 61	IC SF	1.074	0.996	0.1419	1.037	0.02327	1.021
149 62	IC SF	1.073	0.999	0.1420	1.039	0.02388	0.997
149 63	IC SM	1.077	0.994	0.1360	1.028	0.02401	0.991
149 64	IC SF	1.067	1.003	0.1415	1.040	0.02406	0.990
149 65	IC SF	1.069	1.002	0.1427	1.033	0.02342	1.020
149 66	IC SM	1.064	1.005	0.1337	1.044	0.02420	0.985
149 67	IC SF	1.062	1.004	0.1393	1.052	0.02479	0.962
149 68	IC SM	1.061	1.002	0.1334	1.041	0.02325	1.026
149 69	IC SF	1.068	0.994	0.1399	1.042	0.02425	0.987
149 70	IC SM	1.062	0.997	--	--	--	--
149 71	IC SF	1.068	0.990	0.1383	1.047	0.02490	0.976
149 72	IC SM	1.064	0.992	0.1329	1.031	0.02497	0.998
		-----		-----		-----	
Zone Average C/E		1.000		1.044		0.986	
Standard Deviation		0.008		0.009		0.019	
149 73	OC SF	1.058	0.995	0.1378	1.042	0.02554	1.024
149 74	OC SF	1.053	0.994	0.1371	1.039	0.02737	1.016
149 75	OC D	1.050	1.004	0.1353	1.044	0.03013	0.959
149 76	OC SF	1.073	0.992	0.1387	1.046	0.02604	1.046
149 77	OC SF	1.098	1.007	0.1409	1.078	0.02542	0.915
		-----		-----		-----	
Zone Average C/E		0.998		1.050		0.992	
Standard Deviation		0.007		0.016		0.054	

TABLE 8.12 ZPPR-18A: Reaction Rate Ratios at 15° to the X-axis at Z = 5.16 cm

Matrix	Zone	F5/F9		C8/F9		F8/F9	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
148 50	IC SF	1.060	1.005	0.1397	1.053	0.02449	0.972
148 52	IC SM	1.063	1.005	0.1328	1.050	0.02386	0.995
148 53	IC SF	1.064	1.003	0.1385	1.060	0.02409	0.985
147 54	IC SF	1.101	0.974	0.1405	1.049	0.02406	0.978
147 55	IC SM	1.077	1.004	0.1352	1.037	0.02385	0.975
147 56	IC SF	1.085	1.005	0.1436	1.038	0.02422	0.951
147 57	IC SF	1.087	1.001	0.1421	1.048	0.02367	0.971
146 58	IC SF	1.095	1.001	0.1429	1.047	0.02294	0.983
146 59	IC SM	1.075	1.005	0.1358	1.032	0.02255	1.026
146 60	IC SF	1.071	0.999	0.1406	1.047	0.02330	1.006
145 61	IC SF	1.055	1.011	0.1404	1.047	0.02358	0.996
145 62	IC SM	1.069	0.996	0.1351	1.030	0.02332	1.007
144 63	IC SM	1.067	1.001	0.1353	1.030	0.02390	0.974
144 64	IC SF	1.067	1.000	0.1391	1.056	0.02381	0.980
144 65	IC SM	1.060	1.004	0.1325	1.050	0.02435	0.962
144 66	IC SF	1.065	0.999	0.1389	1.057	0.02427	0.976
143 67	IC SF	1.059	1.005	0.1402	1.048	0.02313	1.019
143 68	IC SF	1.068	1.000	0.1404	1.048	0.02355	1.000
143 69	IC SM	1.067	1.006	0.1342	1.038	0.02351	0.988
143 70	IC SF	1.075	1.012	0.1436	1.035	0.02232	1.001
142 70	IC SM	1.087	1.005	0.1344	1.045	0.02217	0.996
CRP							
			-----			-----	-----
Zone Average C/E			1.002			1.045	0.988
Standard Deviation			0.007			0.009	0.019
142 73	OC SF	1.085	1.006	0.1434	1.036	0.02386	0.978
141 73	OC SF	1.059	1.016	0.1422	1.035	0.02391	0.998
141 74	OC SF	1.052	1.004	0.1394	1.035	0.02631	0.994
141 75	OC D	1.041	1.011	0.1339	1.057	0.02889	0.969
141 76	OC SF	1.044	1.003	0.1363	1.055	0.02670	1.027
140 77	OC SF	1.063	1.007	0.1391	1.068	0.02675	0.916
			-----			-----	-----
Zone Average C/E			1.008			1.048	0.980
Standard Deviation			0.005			0.014	0.037

TABLE 8.13 ZPPR-18A: Reaction Rate Ratios in Matrix 149-49 (Core Center)

Zone	Z(mm)	F5/F9		C8/F9		F8/F9	
		Exp.	C/E	Exp.	C/E	Exp.	C/E
IC SF	26.2	1.056	1.015	0.1411	1.045	0.02371	1.005
IC SF	50.3	1.056	1.015	0.1407	1.047	0.02355	1.011
IC SF	77.0	1.058	1.012	0.1410	1.045	0.02514	0.947
IC SF	127.8	1.063	1.009	0.1422	1.038	0.02374	1.003
IC SF	178.6	1.059	1.013	0.1415	1.043	0.02346	1.013
IC SF	229.4	1.060	1.015	0.1421	1.041	0.02372	1.000
IC SF	280.2	1.066	1.011	0.1420	1.045	0.02308	1.022
IC SF	356.4	1.071	1.019	0.1443	1.041	0.02349	0.973
IC SF	380.5	1.095	1.003	0.1435	1.053	0.02280	0.985
IC SF	432.6	1.090	1.024	0.1458	1.052	0.02181	0.984
IC SF	483.4	1.107	1.050	0.1471	1.079	0.01954	0.910
Zone Average C/E		1.017		1.048		0.987	
Standard Deviation		0.012		0.011		0.033	

TABLE 8.14 ZPPR-18A: Summary of Reaction Rate Ratio Analysis

Distribution	Zone	$^{235}\text{U}(n,f)/^{239}\text{Pu}(n,f)$			$^{238}\text{U}(n,\gamma)/^{239}\text{Pu}(n,f)$			$^{235}\text{U}(n,f)/^{239}\text{Pu}(n,f)$		
		No.	C/E	S.D.	No.	C/E	S.D.	No.	C/E	S.D.
X-axis Z=5 CM	IC	24	1.000	0.008	23	1.044	0.009	23	0.986	0.019
	OC	5	0.998	0.007	5	1.050	0.016	5	0.992	0.054
15-deg. Z=5 CM	IC	21	1.002	0.007	21	1.045	0.009	21	0.988	0.019
	OC	6	1.008	0.005	6	1.048	0.014	6	0.980	0.037
Axial 149-49	IC	11	1.017	0.012	11	1.048	0.011	11	0.987	0.033

All Data		66	1.004	0.010	65	1.046	0.010	65	0.986	0.027

TABLE 8.15 Effect of Reactor Structure on Reaction Rates in ZPPR-18A

Zone	Matrix	Correction Factors for Calculated Reaction Rates		
		$^{235}\text{U}(n,f)$	$^{238}\text{U}(n,\gamma)$	$^{238}\text{U}(n,f)$
Outer Core	149-72	1.0000	1.0001	1.0000
	73	1.0002	1.0001	1.0000
	74	1.0002	1.0001	1.0000
	76	1.0002	1.0002	1.0000
	77	1.0005	1.0004	1.0002
Radial Blanket	78	1.0012	1.0007	1.0002
	79	1.0022	1.0012	1.0005
	80	1.0046	1.0030	1.0009
	81	1.0103	1.0064	1.0014
	82	1.0240	1.0138	1.0029
Radial Reflector	83	1.0517	---	---

9. MEASUREMENTS AND CALCULATIONS OF NEUTRON CAPTURE IN SODIUM IN ZPPR-18A
(W. P. Poenitz, D. W. Maddison, and G. L. Grasseschi)

9.1 Measurements

Neutron capture in sodium was measured and calculated for two locations in ZPPR-18A. The measurements were made over two axial heights of the central drawer in half two (matrix location 249-49). The drawer master was a DUF type (see ANL-ZPR-489, P. 2) with the sodium columns rearranged to accommodate the four 6.4 mm x 50.8 x 101.6 mm and two 12.7 mm x 50.8 mm x 101.6 mm sodium plates whose activity was measured. Two 6.4 mm-thick and one 12.7 mm-thick sodium cans spanned the axial height between 50.8 mm and 152.4 mm from the interface (core region) and another set of three were between 508 mm and 609.6 mm (axial blanket region). The normal drawer loading used only 12.7 mm thick sodium plates.

The neutron capture in sodium was measured as the average over the plate volume. This was achieved by measuring the 1.3686 MeV gamma transition from the decay of ^{24}Na which occurs with 99.99% probability per decay. The sodium cans were positioned ~ 127 mm from a Ge detector on a plane perpendicular to its axis. The dependence of the detector efficiency on the gamma energy was measured with ^{22}Na and ^{60}Co standards and fit with the expression

$$\epsilon = a \cdot E_{\gamma}^b.$$

Table 9.1 compares the experimental values with the values from the fit and gives the uncertainties (A = counting statistics, B = calibration source decay rate, C = half life, D = positioning of calibration source). The effect of the gamma absorption in the sodium and the stainless steel cladding and the efficiency dependence on the distance from the Ge detector along its axis was measured by determining the efficiency for the 1.3325 MeV ^{60}Co gamma transition with the source in front of the sodium can and with the source behind the sodium can. Taking the average of these two values gives a good approximation for the (assumed) homogeneously activated sodium in the can. The factors obtained relative to the values without gamma absorption and for the plane

closest to the Ge detector were $0.9263 \pm 0.6\%$ for the 6.4 mm-thick cans and $0.8788 \pm 0.6\%$ for the 12.7 mm-thick cans.

The variation of the efficiency in the xy plane was measured by mapping at various locations with the 1.3325 MeV Co gamma transition relative to the center ($x = y = z = 0$) and fitting with the expression

$$\epsilon(r) = \frac{\epsilon(0)}{1 + \frac{r^2}{a + br}} .$$

The experimental values are compared with the fit in Table 9.2 and associated uncertainties are given. Integration over the extent of the Na cans results in a factor of $0.9421 \pm 1.7\%$, with the uncertainty based on the largest difference between the measured values and the fitted ratio.

The activities of the sodium cans were measured with statistical uncertainties of $\sim 0.5\%$. Reproducibility was checked by measuring two cans twice and the dead-time correction was checked by measuring one can after 1.5 half-lives again. Consistency within statistical uncertainties was found. A correction of 1.0044 was applied for the flux variation during the irradiation based on a flux monitor mapping. The results for the capture in sodium are given in Table 9.3. The average for the two 6.4 mm-thick cans is $\sim 1.8\%$ higher than for the corresponding 12.7 mm-thick cans; presumably due to the additional stainless steel of the cans and the spacing. The outside 6.4 mm-thick cans (O) indicate $\sim 3.7\%$ more capture than the inside cans (I); presumably due to self-shielding effects.

Integration over the corresponding axial regions leads to the final average results for capture in sodium per atom relative to fission in ^{235}U per atom; both normalized to 2637.9 Whrs.

Core	50.8 mm - 152.4 mm	$6.423 \times 10^{-4} \pm 2.5\%$
Blanket	50.8 mm - 609.6 mm	$6.944 \times 10^{-4} \pm 2.5\%$

where the uncertainties are due to statistics (0.3%), Ge detector calibration (2.1%), sodium-weights (0.5%), sodium-can positioning and sodium density inhomogeneity (1.0%), and the fission measurements (0.9%).

The measurements were made on 10/21/87, in loading 38 reactor run 23, which was the reactor run in which many other reaction rate distributions were measured with foils. These foil measurements included an axial ^{235}U fission distribution in 149-49.

9.2 Comparison of Calculation and Experiment

Sodium capture rates were calculated with the xyz nodal transport model used for analysis of the foil reaction rates (Section 8). Cross sections self-shielded for the 12.7 mm sodium plate in the normal cell were used in the edit since cell calculations for the modified cells were not available. For comparison, using cross sections for sodium homogenized over the cells gave capture rates increased by 0.8% in the core and by 1.8% in the axial blanket positions. The capture rates were calculated at the midpoint of the sodium plates and were not integrated over the plates.

The calculated reaction rates were normalized to a mean C/E for all results for fission in ^{239}Pu over the core, consistently with the foil reaction rate analysis. The C/E results for sodium capture are as follows:

Near Core Center	C/E = 1.093
Axial Blanket	C/E = 1.074

Table 9.4 gives the sodium capture cross sections calculated for the 12.7 mm thick sodium plate, the spectrum, and the energy-group contributions to sodium capture for the near core-center position. About 50% of the total capture comes from the region around the 3 keV sodium resonance.

TABLE 9.1. Energy Dependence of the Ge Detector Efficiency

Source	E_γ, MeV	Efficiency, Measured	Efficiency, From Fit	Uncertainties, % ^a				
				A	B	C	D	Total
⁶⁰ Co	1.1732	0.0005970	0.0005959	0.4	0.6	0.0	0.2	0.75
²² Na	1.2745	0.0005484	0.0005513	0.2	0.9	0.1	0.2	0.95
⁶⁰ Co	1.3325	0.0005305	0.0005287	0.3	0.6	0.0	0.2	0.70
²⁴ Na	1.3686	-----	0.0005156	---	---	---	---	1.06

^aSee text

TABLE 9.2. Radial Dependence of the Ge Detector Efficiency

Radius, mm	$\epsilon(r)/\epsilon(o)$, Measured	$\epsilon(r)/\epsilon(o)$ From Fit	Uncertainties, %		
			Statistical	Position	Total
0	1.000	1.000	---	---	---
12.7	0.992	0.990	0.6	0.5	0.8
25.4	0.955	0.961	0.5	0.6	0.8
38.1	0.925	0.921	0.6	0.7	0.9
50.8	0.858	0.873	0.6	0.8	1.0

TABLE 9.3. Measured Sodium Capture Rates

<u>Plate Location^a</u>	<u>Plate Thickness, mm</u>	<u>Measured Rate^b</u>	<u>Mean for 64 mm Plates</u>	<u>Mean for Cell</u>
Core	12.7	5.790		
Core - 0	6.4	6.001		
			5.879	
Core - I	6.4	5.759		5.834
Blanket	12.7	3.144		
Blanket - 0	6.4	3.255		
			3.205	
Blanket - I	6.4	3.153		3.174

^aI is closer to fuel column, 0 is away from fuel column.

^bUnits of 10^{-21} captures per sodium atom per second at an estimated reactor power of 1 watt.

TABLE 9.4 Calculated Energy Dependence of Sodium Capture Near
the Center of ZPPR-18A

Energy Group	Upper Energy, ev	Sodium Capture Cross Section, barns	Flux Spectrum	Fractional Contribution to Sodium to Sodium Capture
1	1.42D+07	1.6876D-04	0.00243	0.00030
2	6.07D+06	1.6144D-04	0.01100	0.00129
3	3.68D+06	1.7636D-04	0.02789	0.00356
4	2.23D+06	2.0006D-04	0.04115	0.00596
5	1.35D+06	2.2992D-04	0.05427	0.00904
6	8.21D+05	3.1929D-04	0.09917	0.02293
7	4.98D+05	4.2210D-04	0.09218	0.02818
8	3.02D+05	9.0166D-04	0.11021	0.07197
9	1.83D+05	9.2809D-04	0.11559	0.07770
10	1.11D+05	1.8684D-05	0.10038	0.00136
11	6.74D+04	8.3335D-04	0.08511	0.05137
12	4.09D+04	2.3100D-03	0.06576	0.11003
13	2.48D+04	2.8776D-05	0.06386	0.00133
14	1.50D+04	9.2337D-05	0.04489	0.00300
15	9.12D+03	1.0096D-03	0.02516	0.01840
16	5.53D+03	5.6160D-03	0.01638	0.06663
17	3.35D+03	6.8296D-02	0.00564	0.27909
18	2.03D+03	1.2288D-02	0.01631	0.14515
19	1.23D+03	6.1680D-03	0.01715	0.07660
20	4.54D+02	6.4899D-03	0.00537	0.02523
21	6.14D+02	1.3748D-02	0.00009	0.00089

10. SPATIAL DECOUPLING IN ZPPR-18 (S. G. Carpenter, S. B. Brumbach, and R. W. Goin)

The sensitivity of the flux distributions in ZPPR-18 to perturbations was studied using noise coherence, boron-oscillator and rod-drop techniques. Calculations of eigenvalue separation indicate that ZPPR-18 is expected to have relatively close spatial coupling (i.e., have flux distributions relatively insensitive to perturbation) even though the 8075 liter core volume is large. The separation between the fundamental and first (azimuthal) eigenvalues for ZPPR-18A was calculated to be about $4\% \Delta k$, which is essentially the same as that calculated for ZPPR-17. Spatial decoupling results from ZPPR-17 were reported in ANL-ZPR-485.

10.1 Noise Coherence Measurements

The short time (millisecond) response of ZPPR-18A and 18B assemblies to a reactivity perturbation was measured by the noise coherence technique. Spatial decoupling was investigated by measuring the noise coherence between neutron detectors in various locations when the assembly was at a constant average power. Noise coherence values were also calculated from the assembly-average kinetics parameters assuming a point-reactor model. Deviations of measured coherence values from those predicted by the point-reactor model indicate that spatial decoupling is present.

Measurements in ZPPR-18A used four lithium-glass detectors. Two detector placement schemes were used. In the first scheme, the detectors were in drawers which replaced sodium-filled control rod position (CRP) drawers in 143-27 (detector A), 155-27 (detector B), 171-55 (detector C) and 155-71 (detector D). These locations are in the outer CRP ring. Two detectors were close together (detectors A and B), a third was 180° away from the closely spaced pair (detector D), and a fourth was 90° away from the closely spaced pair (detector C). This detector configuration is typical of previous ZPPR experiments. The measurements were made on October 20, 1987 in reactor run number 20, loading number 37. Data was collected with the operating rods positioned to give a reactivity of -2.8% .

The second detector placement scheme used four equally spaced detectors. Two detector drawers replaced CRP drawers in 131-49 (detector B) and 167-49 (detector C). The other two detector drawers replaced single-fuel-column drawers in 149-31 (detector A) and 149-67 (detector D). These locations are on the x and y axes of the assembly at the radius of the middle CRP ring. The measurements were made on November 17, 1987 in reactor run number 81, loading number 93. Data was collected with all operating rods fully withdrawn and a reactivity of -30.6ϕ . The low reactivity resulted because the assembly was in the subcritical reference with the two additional fuel drawers missing.

Results from three detector pairs in the unequally spaced case in ZPPR-18A are shown in Figure 10.1. The individual data points are from the detector pair BC. The broken curves are least squares fits to the data points for the three pairs. The solid curve represents the coherence expected for a point reactor with a calculated value of $\beta/\lambda = 7397 \text{ s}^{-1}$. As shown, the intermediately spaced pair BC agrees best with the point model. At high frequencies the widely spaced pair AD shows less and the closely spaced pair AB shows more coherence than the point model prediction. The extent of decoupling indicated in Fig. 10.1 is slightly less than that seen in ZPPR-17.

An alternate way to test the validity of the point model prediction is to fit the measured coherence data to the point-model coherence equation and then examine the goodness of fit (see S. B. Brumbach, et al., "Spatial Kinetics Studies in Liquid-Metal Fast Breeder Reactor Critical Assemblies," Nuclear Science and Engineering, 98 p. 103 (1988)). Results from this procedure from the unequally spaced detector case in ZPPR-18A are given in Table 10.1. The G values in Table 10.1 are proportional to the detector efficiency and are derived in the fit.

The values in Table 10.1 show that the best fit to the point model is with detector pair BC, where the detectors are almost exactly 90° apart. The closely spaced pair AB was the worst fit and the widely spaced pairs have χ^2 values of about 2. The pairs CD and AC have spacings somewhat less than 90° and somewhat greater than 90° respectively, and their χ^2 values are somewhat larger than that for the 90° pair BC.

Results from two detector pairs in the equally spaced case in ZPPR-18A are shown in Figure 10.2. The individual data points are from the detector pair BC (90° separation). The broken curves are least squares fits to the data points. The solid curve represents the coherence expected for a point reactor with a calculated value of $\beta/\lambda = 7397 \text{ s}^{-1}$. As shown, the 90°-spaced pair agrees best with the point model and the 180°-spaced pair shows less coherence than the point model prediction.

The point model fitting parameters for the equally spaced case are given in Table 10.2. The four detector pairs spaced at 90° give rather good agreement with the point model. The two pairs spaced 180° (AD and BC) give less good fit, with a somewhat larger χ^2 for the x-axis pair (AD). The ZPPR-18A calculated eigenvalue separation of 4% was for a node along the y-axis. For a node along the x-axis, the calculated separation was 5%. This difference in eigenvalue separation is consistent with the observation of a worse fit to the point model for detectors on the x-axis.

In ZPPR-18B, measurements were made only with the unequally spaced detector configuration. Results are shown in Fig. 10.3. Again, the data points are from the BC pair. The calculated β/λ was 8220 s^{-1} . These results are essentially the same as observed for ZPPR-18A. Point model fitting parameters are given in Table 10.3. Again, the results are very nearly the same as for ZPPR-18A.

10.2 Boron Oscillator Measurements

Boron oscillator measurements were made in two inner core locations in ZPPR-18A, both asymmetric with respect to the two ex-core BF₃ flux monitors. One location was 157-29, just inside the outer-core plutonium zone, and the other was 169-41, just inside the outer-core uranium zone. The oscillation frequency was varied from 0.5 to 10^{-3} Hz . Power histories during the oscillations were recorded with the ex-core monitors. Inverse kinetics analysis of the power histories can give the difference in boron worth for the in and out positions. If the point-kinetic model were appropriate, both detectors would give the same worth value. The more loosely coupled the assembly, the greater the difference in worth from the two detectors. The

derived worths from the two detectors and the two oscillator locations are given in Table 10.4.

The results in Table 10.4 show that some decoupling is present, but the effects are different in the two locations. Location 157-29 is in a somewhat higher flux region than 169-41 as reflected by the higher worth. The worth ratios for the two detectors are also larger in 157-29 than in 169-41. Worth ratios from the Table 10.4 values are equivalent to the amplitude ratios reported for ZPPR-17 (see Fig. 9.1 in ANL-ZPR-485). For ZPPR-18, the ratios from 157-29 are larger and from 169-41 are smaller than the ZPPR-17 ratios. These results are consistent with approximately equal degrees of decoupling in ZPPR-17 and ZPPR-18A, but calculations would be required to make a detailed comparison.

10.3 Rod Drop Experiments

A common technique to test the time for a new flux distribution to be established is to perturb the power distribution in an assembly by scrambling operating rods into the core and then following the power history recorded by various detectors distributed around the assembly. The time for flux redistribution to occur can be determined by examining the time behavior of the ratio of count rates from two detectors separated in space. As decoupling increases, count rate ratios change more slowly following a rod drop. In ZPPR-18A, the unique pairs of operating rods in one quadrant of the assembly were dropped after establishing a steady state power with all operating rods balanced near the core/axial blanket interface. The ex-core BF_3 flux monitors recorded the power history. In all cases, the new flux distribution was established quickly.

The time response was similar to that observed in ZPPR-17 and ZPPR-9.

TABLE 10.1 Point Model Fitting Parameters for Unequally Spaced
Detector Pairs in ZPPR-18A

Detector Pair	G	$\beta/l, s^{-1a}$	χ^2
AB	2.31	8450	3.31
AC	2.35	6680	1.27
AD	2.49	6461	2.05
BC	2.46	6747	1.06
BD	2.63	6297	1.96
CD	2.52	7345	1.44

^aThe calculated value is $7397 s^{-1}$

TABLE 10.2 Point Model Fitting Parameters for Equally Spaced
Detector Pairs in ZPPR-18A

Detector Pair	G	$\beta/l, s^{-1}a$	χ^2
AB	2.85	6829	1.05
AC	2.92	6812	1.01
AD	2.94	6388	1.78
BC	2.88	6588	1.36
BD	2.96	6909	1.05
CD	3.05	6957	1.06

^aThe calculated value is $7397 s^{-1}$

TABLE 10.3 Point Model Fitting Parameters for Unequally Spaced
Detector Pairs in ZPPR-18B

Detector Pair	G	$\beta/l, s^{-1a}$	χ^2
AB	1.99	9170	3.31
AC	2.10	7295	1.46
AD	2.13	7058	2.15
BC	2.15	7587	1.00
BD	2.15	7120	2.22
CD	2.21	8213	1.42

^aThe calculated value is $8220 s^{-1}$

TABLE 10.4 Peak to Peak Worths, in Cents, from Boron Oscillator
Measurements in ZPPR-18A

<u>Sec/Cycle</u>	<u>157-29</u>		<u>169-41</u>	
	<u>Detector 1</u>	<u>Detector 2</u>	<u>Detector 1</u>	<u>Detector 2</u>
1024	0.255	0.258	0.208	0.209
512	- - -	- - -	0.208	0.211
256	0.253	0.265	0.211	0.217
64	0.248	0.283	0.211	0.230
32	- - -	- - -	0.210	0.235
16	0.240	0.311	0.208	0.246
4	0.233	0.332	0.211	0.260
2	0.229	0.336	0.212	0.266

Fig. 10.1 Coherence as a Function of Frequency for Nonsymmetrical Detector Pairs in ZPPR-18A

Fig. 10.2. Coherence as a Function of Frequency for Symmetric Detector Pairs in ZPPR-18A

Fig. 10.3. Coherence as a Function of Frequency for Detector Pairs in ZPPR-18B

11. ZPPR-18A OPERATIONAL MEASUREMENTS (R. W. Goin)

11.1 Critical Reference Excess Reactivity

In loading 36, the critical reference was established on October 16, 1987, and the excess reactivity was measured in reactor run No. 18, using a positive period method. The average reactor temperature using 14 thermocouples (see Section 4 below) was 26.9°C. The excess reactivity was $13.6 \pm 0.1\phi$. This is recorded as file 11 of DATAZ18A.Z01 on the Perkin-Elmer System.

11.2 Subcritical Reference Reactivity

The subcritical reference configuration was obtained on October 14, 1987, by replacing 12 uranium and 24 plutonium double-fuel-column drawers with single-fuel-column drawers. The reactivity of this subcritical reference was $-27.4 \pm 0.2\phi$ as measured in a rod drop. The data are recorded in File 6 in DATAZ18A.Z01.

11.3 Gap Worth

The gap worth was measured by recording the power history while driving the halves apart on slow speed for 10s. This resulted in a table movement of 60.4×10^{-3} inches as determined from the four corner closure indicator readings before and after the table movement. The resulting reactivity history indicated a gap worth of $-0.090 \pm 0.010 \phi/\text{mil}$ (1 mil = 0.001 inch). This measurement was done in reactor run number 18 and is recorded as file 12 on DATAZ18A.Z01.

11.4 Temperature Coefficient

The temperature coefficient was determined by recording the power history and the output from 16 thermocouples for about 4-1/2 hours starting shortly after the reactor halves were closed. This measurement was done in reactor run number 18 and is recorded as file 9 in DATAZ18A.Z01. After

analyzing the data, the best correlation of temperature to reactivity results from using 14 thermocouples: 3, 4, 6, 41, 42, 51, 52, 53, 54, 58, 59, 62, 94, and 95. The temperature coefficient of reactivity using the mean of these 14 thermocouples was $-1.25 \pm 0.11\phi/^{\circ}\text{C}$.

11.5 Rod Pair Worths

The worths of the pairs of operating rods in one quadrant of ZPPR-18A were determined using the rod drop technique. These measurements were done in reactor runs 26 and 28, and the data are recorded in files 22, 23, 24, 26, and 27 in DATAZ18A.Z01. The measured worths are given in Table 11.1. The ratio of detector efficiency before and after the rod drop, which is also obtained from the inverse kinetics solution of the power history, is given for the two ex-core power monitors (designated EXP 1 and EXP 2). These compare very well with the detector efficiency ratios obtained from the 64 fission chamber data.

11.6 Shim Rod Calibration

All eight rods which were used as shim rods in ZPPR-18A were calibrated in reactor run number 19. The rods were calibrated by driving them through the full range of travel, with three full cycles of travel, then fitting the resulting reactivity history to a fourth-order polynomial in rod position and third-order in time. The resulting calibration coefficients are given in Table 11.2. The data are recorded as files 13 and 15 of DATAZ18A.Z01. To account for the change in detector efficiency caused by moving a particular rod, the inverse kinetics solution used combinations of the two ex-core power monitors based on results of the detector efficiency ratios obtained from rod drops and from the 64 fission detector measurements.

11.7 Delayed Neutron Parameters

The delayed neutron fractions for ZPPR-18A were obtained from a rod drop measurement with the reactor power leveled at 0.9×10^{-6} on

EXP 1. The resulting power history was analyzed using an iterative inverse kinetics solution which solves for the delayed neutron fractions, the reactivity after the drop, the effective source term, and the detector efficiency ratio. The resulting parameters are given in Table 11.3. The decay constants, λ_i , were obtained from an xyz diffusion calculation. This measurement was done in reactor run 18 and is recorded as file 10 on DATAZ18A.Z01.

11.8 Source Term Measurement

The effective source term for the two ex-core power monitors was measured in reactor run 15 and the data recorded as file 6 on DATAZ18A.Z01. The measurement was done starting at 0.9×10^{-8} on EXP 1 and dropping group 2 rods, which perturb the detector efficiency ratio least. The resulting source terms are $953.3 \pm 5.3 \Delta k/k$ counts s^{-1} for EXP 1 and $832.5 \pm 5.0 \Delta k/k$ counts s^{-1} for EXP 2.

TABLE 11.1 Rod Pair Worths in ZPPR-18A

Data File	Rods	Matrix Position	Worth-\$	Detector Efficiency Ratios	
				EXP 1	EXP 2
22	PSR 17&22	1,263-41&42	0.4150 $\pm$ 0.001	0.9629 $\pm$ 0.0003	0.9661 $\pm$ 0.0003
23	PSR 27&34	1,253-46	0.3425 $\pm$ 0.001	1.0074 $\pm$ 0.0003	0.9938 $\pm$ 0.0003
24	PSR 10&19	1,253-31	0.2116 $\pm$ 0.001	1.0225 $\pm$ 0.0003	0.9566 $\pm$ 0.0003
26	PSR 22&23	1,263-41&42	0.3930 $\pm$ 0.001	1.0041 $\pm$ 0.0003	0.9252 $\pm$ 0.0003
27	SR 1&2	1,263-31	0.1575 $\pm$ 0.001	1.0130 $\pm$ 0.0002	0.9175 $\pm$ 0.0003

TABLE 11.2 Shim Rod Calibration Coefficients in ZPPR-18A^a

Shim Rod	Position	$10^2 \times C_1$	$10^3 \times C_2$	$10^4 \times C_3$	$10^6 \times C_4$	RMS Deviation, ϕ	Total Worth, \$
1	163-31	-4.0287	8.7098	-10.847	17.702	0.027	0.0809 $\pm$.0010
2	263-31	-3.8524	8.6042	-10.738	17.389	0.027	0.0805 $\pm$.0010
3	134-67	-3.5144	8.0754	-10.541	17.319	0.035	0.0798 $\pm$.0010
4	235-67	-4.3963	9.2672	-11.219	18.415	0.038	0.0813 $\pm$.0010
5	163-67	-2.9069	7.2691	-10.185	16.683	0.026	0.0808 $\pm$.0010
6	263-67	-3.3483	7.8142	-10.447	17.025	0.024	0.0822 $\pm$.0010
PSR31	135-31	-3.5077	8.0722	-10.605	17.272	0.036	0.0819 $\pm$.0010
PSR30	235-31	-3.7319	8.3399	-10.867	17.948	0.033	0.0817 $\pm$.0010

^a $R = C_1 X + C_2 X^2 + C_3 X^3 + C_4 X^4$; where X is the rod position in inches measured from the fully withdrawn position, and R is the reactivity in cents.

TABLE 11.3 Measured Delayed Neutron Fractions
in ZPPR-18A^a

Group	λ_i (s ⁻¹)	a_i	β_i
1	0.012942	0.022433	0.00008492
2	0.031526	0.205241	0.00077696
3	0.13297	0.180806	0.00068446
4	0.34188	0.367082	0.00138963
5	1.3760	0.186718	0.00070684
6	3.8000	0.037720	0.00014279
Total		1.000000	0.0037856

^aThe λ_i values and $\beta_{\text{eff}} = \sum \beta_i$ were obtained from an xyz diffusion calculation.

12. ZPPR-18B OPERATIONAL MEASUREMENTS (R. W. Goin)

12.1 Subcritical Reference Reactivity

The ZPPR-18B subcritical reference was established on December 7, 1987, in reactor loading number 105, reactor run 93. The reactivity was $-33.2 \pm 0.2\phi$, as determined from a rod drop. The average reactor temperature was 28.5°C . The data is recorded as file 2 of DATAZ18B.Z01 on the Perkin-Elmer System.

12.2 Critical Reference Reactivity

On December 3, 1987, in loading 109, the critical reference was established and the excess reactivity was measured in reactor run 98, using a positive period method. The average reactor temperature was 28.9°C . The excess reactivity was $7.3 \pm 0.1\phi$. This is recorded as file 5 of DATAZ18B.Z01.

12.3 Gap Worth

The gap worth measured in ZPPR-18A was used in ZPPR-18B.

12.4 Temperature Coefficient

The temperature coefficient measured in ZPPR-18A was used in ZPPR-18B.

12.5 Rod Pair and Individual Rod Worths

The worths of unique operating rod pairs in ZPPR-18B were determined using the rod-drop techniques. These measurements were done in reactor run 101 on December 9, 1987. Three individual rod worths were also measured in reactor runs 103, 104, and 106. The measured worths are given in Table 12.1. The ratio of detector efficiency before and after the rod drop, which is also obtained from the inverse kinetics solution of the power

listing, is given for the two ex-core BF_3 chambers. The data are recorded in DATAZ19B.Z01 in the files indicated in Table 12.1.

12.6 Shim Rod Calibration

Shim rods 1, 2, 3, and 4 were calibrated in reactor run no. 103, loading no. 113. The rods were calibrated by driving them through their full range of travel, with three full cycles of travel, then fitting the resulting reactivity history to a polynomial fourth-order in rod position and third-order in time. The resulting calibration coefficients are given in Table 12.2. The data are recorded as file 16 in DATAZ18B.Z01. To account for the change in detector efficiency caused by moving a particular rod, the inverse kinetics solution used combinations of EXP 1 and EXP 2 based upon results of the detector efficiency ratios obtained from rod drops and from the 64-fission-detector measurements.

12.7 Delayed Neutron Parameters

A delayed neutron fraction measurement was done in ZPPR-18B in reactor run 102, loading 112. They were obtained from a rod-drop measurement with the power leveled at 0.9×10^{-5} on EXP 1. The resulting power history was analysed using an iterative inverse kinetics solution which solves for the delayed neutron fractions, the reactivity after the drop, the effective source term, and the detector efficiency ratio. The resulting parameters are given in Table 12.3. The decay constants and β_{eff} were obtained from an xyz diffusion calculation. This data is recorded as file 15 on DATAZ18B.Z01.

12.8 Source Term Measurement

The effective source term for the two ex-core power monitors was measured in reactor run no. 101, loading 112, and the data is recorded as file 13 of DATAZ18B.Z01. The measurement was done starting at 0.9×10^{-7} on EXP 1, and dropping group 2 rods (which perturb the detector efficiency

ratio least). The resulting source terms are $114.7 \pm 0.1 \Delta k/k$ counts s^{-1} for EXP 1, and $97.8 \pm 0.1 \Delta k/k$ counts s^{-1} for EXP 2.

TABLE 12.1 Worths of Rod Pairs and Individual Rods in ZPPR-18B

Data File	Rods	Matrix Position	Worth,\$	Detector Efficiency Ratios	
				EXP 1	EXP 2
7	SR 1&2	1,263-31	0.1331 ± 0.0003	1.0107 ± 0.0004	0.9205 ± 0.0004
8	PSR 6&7	1,272-46	0.1320 ± 0.0003	0.9894 ± 0.0004	0.9778 ± 0.0004
10	PSR 22&23	1,263-41,42	0.4584 ± 0.0004	1.0066 ± 0.0004	0.9184 ± 0.0004
11	PSR 27&34	1,253-46	0.2947 ± 0.0003	1.0111 ± 0.0004	0.9979 ± 0.0004
12	PSR 10&19	1,253-31	0.2010 ± 0.0003	1.0241 ± 0.0004	0.9611 ± 0.0004
17	PSR 6	272-46	0.0557 ± 0.0002	0.9962 ± 0.0004	0.9921 ± 0.0004
21	PSR 34	253-46	0.1271 ± 0.0003	1.0065 ± 0.0004	1.0002 ± 0.0004
23	PSR 10	253-31	0.0969 ± 0.0003	1.0113 ± 0.0004	0.9814 ± 0.0004

TABLE 12.2 Shim Rod Calibration Coefficients in ZPPR-18B^a

Shim Rod	Position	$10^2 \times C_1$	$10^3 \times C_2$	$10^4 \times C_3$	$10^6 \times C_4$	RMS Deviation, ϕ	Total Worth, \$
1	163-31	-4.6139	10.570	-14.017	25.725	0.0263	0.0872 $\pm$ -0.001
2	263-31	-1.5876	4.0526	-4.6015	5.3897	0.0238	0.0472 $\pm$ -0.001
3	134-67	-4.2611	9.9516	-13.646	25.175	0.0501	0.0859 $\pm$ -0.001
4	235-67	-1.8554	4.5818	-5.0400	6.2644	0.0313	0.0479 $\pm$ -0.001

^a $R = (C_1 X + C_2 X^2 + C_3 X^3 + C_4 X^4)$; where X is the rod position in inches measured from the fully withdrawn position, and R is the reactivity in cents.

TABLE 12.3 Measured Delayed Neutron Fractions
in ZPPR-18B

Group	λ_i (s^{-1})	a_i	β_i
1	0.012933	0.023541	0.00008947
2	0.031530	0.209410	0.00079589
3	0.132480	0.183158	0.00069612
4	0.34092	0.367916	0.00139832
5	1.3763	0.175402	0.00066664
6	3.7998	0.040573	0.00015420
Total		1.000000	0.00380064 ^a

^aThe λ_i values and β_{eff} were obtained from an xyz diffusion calculation.

13. ZPPR-18C OPERATIONAL MEASUREMENTS (R. W. Goin)

13.1 Critical Reference Reactivity

The ZPPR-18C critical reference was established on December 18, 1987, in loading 120, reactor run 110. The excess reactivity was determined by a positive period measurement to be $17.1 \pm 0.1\phi$. The average reactor temperature was 28.7°C . The data are recorded as file 3 in DATAZ18C.Z01.

13.2 Gap Worth

The gap worth measured in ZPPR-18A was used in ZPPR-18C.

13.3 Temperature Coefficient

The temperature coefficient measured in ZPPR-18A was used in ZPPR-18C.

13.4 Shim Rod Calibration

Shim rods 1, 2, 3, and 4 were calibrated in Assembly 18C in the same manner as 18B. The calibration was done in loading 120, reactor run 110. The resulting calibration coefficients are given in Table 13.1.

13.5 Source Term Measurement

The effective source term for the two ex-core power monitors was measured in reactor run no. 110, loading 120, and the data are recorded as file 6 of DATAZ18C.Z01. The measurement was done starting at 0.9×10^{-7} on EXP 1, and dropping group 2 rods (which perturb the detector efficiency ratio least). The resulting source terms are $115.1 \pm 0.1 \Delta k/k$ counts s^{-1} for EXP 1, and $91.0 \pm 0.1 \Delta k/k$ counts s^{-1} for EXP 2.

TABLE 13.1 Shim Rod Calibration Coefficients in ZPPR-18C^a

Shim Rod	Position	$10^2 x C_1$	$10^3 x C_2$	$10^4 x C_3$	$10^6 x C_4$	RMS Deviation, ϕ	Total Worth, \$
1	163-31	-3.7184	8.4241	-11.482	21.072	0.0247	0.0733 $\pm$ -0.001
2	263-31	-1.2478	3.0578	-3.6377	4.1348	0.0248	0.0393 $\pm$ -0.001
3	134-67	-5.6780	13.365	-17.513	31.881	0.0586	0.1089 $\pm$ -0.001
4	235-67	-1.8883	5.3532	-6.7781	8.9282	0.0350	0.0658 $\pm$ -0.001

^a $R = C_1 X + C_2 X^2 + C_3 X^3 + C_4 X^4$; where X is the rod position in inches measured from the fully withdrawn position, and R is the reactivity in cents.

14. ZPPR-19A OPERATIONAL MEASUREMENTS (R. W. Goin)

14.1 "Almost Critical" Reference Reactivity

The reactivity of the more reactive reference configuration was slightly negative. The value was $-0.43 \pm 0.02\%$ as determined from an inverse kinetics measurement in reactor run number 8, loading number 6 on January 8, 1988. The average reactor temperature was 28.4°C . The data are recorded as file 5 on DATAZ19A.Z01.

14.2 Subcritical Reference Reactivity

The subcritical reference for ZPPR-19A was achieved on January 8, 1988 in reactor run number 6, loading number 4. The reactivity was obtained from the inverse kinetics analysis of a rod drop and was $-24.0 \pm 0.1\%$. The average temperature was 27.8°C . The data are recorded as file 3 in DATAZ19A.Z01.

14.3 Gap Worth

The gap worth measured in ZPPR-18A was used in ZPPR-19A.

14.4 Temperature Coefficient

The temperature coefficient measured in ZPPR-18A was used in ZPPR-19A.

14.5 Rod Pair Worths

The worths of five rod pairs in ZPPR-19A were measured using the rod drop technique. These measurements were made in reactor runs 8 and 9 and the data are recorded in DATAZ19A.Z01. The measured worths are given in Table 14.1, along with detector efficiency ratios (before/after the drop) for the ex-core BF_3 chambers. The ratios are obtained from the inverse kinetics fitting of the power history data.

14.6 Source Term Measurement

The effective source terms for the two ex-core BF³ chambers was measured in reactor run number 8 and the data recorded as file 7 in DATAZ19A.Z01. The measurement was done starting at 0.9×10^{-7} on EXP 1, and dropping group 2 rods. The resulting source terms are $133.44 \pm 0.20 \Delta k/k \text{ s}^{-1}$ for EXP 1 and $114.21 \pm 0.20 \Delta k/k \text{ s}^{-1}$ for EXP 2.

TABLE 14.1 Rod Pair Worths in ZPPR-19A

Data File	Rods	Matrix Position	Worth,\$	Detector Efficiency Ratios	
				EXP 1	EXP 2
6	PSRs 10&19	1,253-31	0.2179 ± 0.001	1.0047 ± 0.0005	1.0021 ± 0.0005
8	SR 1&2	1,263-31	0.1948 ± 0.001	1.0211 ± 0.0003	0.8950 ± 0.0003
9	PSR 6&7	1,272-46	0.1691 ± 0.001	0.9812 ± 0.0004	0.9657 ± 0.0004
10	PSR 27&34	1,253-46	0.1117 ± 0.001	1.0037 ± 0.0003	0.9940 ± 0.0003
11	PSR 22&23	1,263-41,42	0.3295 ± 0.001	1.0013 ± 0.0003	0.9090 ± 0.0003

15. ZPPR-19B OPERATIONAL MEASUREMENTS (R. W. Goin)

15.1 Critical Reference Excess Reactivity

In loading 21, the critical reference was established on January 29, 1988, and the excess reactivity was measured in reactor run 18, using a positive period method. The average reactor temperature using 14 thermocouples was 26.22°C. The excess reactivity was $13.0 \pm 0.1\%$. The data are recorded as file 3 in DATAZ19B.Z01.

15.2 Subcritical Reference Reactivity

The subcritical reference was established on February 8, 1988, in loading 28, reactor run 25, by replacing 24 uranium double-fuel-column drawers with uranium single-fuel-column drawers. The reactivity of this subcritical reference was $-27.4 \pm 0.2\%$ as measured in a rod drop. The average reactor temperature was 27.48°C. The data are recorded as file 24 on DATAZ19B.Z01.

15.3 Gap Worth

The gap worth measured in ZPPR-18A was used in ZPPR-19B.

15.4 Temperature Coefficient

The temperature coefficient measured in ZPPR-18A was used in ZPPR-19B.

15.5 Rod Pair Worths

The worths of the pairs of operating rods in one quadrant of ZPPR-19B were measured using the rod drop technique. These measurements were made in reactor runs 18 and 19 and the data are recorded in DATAZ19B.Z01. The measured worths are given in Table 15.1. The ratio of detector efficiency before and after the rod drop, which is also obtained

from the inverse kinetics solution of the power history, is given for the two ex-core power monitors (designated EXP1 and EXP2).

15.6 Shim Rod Calibration

Seven shim rods in ZPPR-19B were calibrated in reactor run 9. The rods were calibrated by driving them through their full range of travel, with three full cycles of travel, then fitting the resulting reactivity history to a fourth-order polynomial in rod position and a third order in time (to correct for reactor drift). The resulting calibration coefficients are given in Table 15.2. The data are recorded as files 7 and 8 in DATAZ19B.Z01. To account for the change in detector efficiency caused by moving a particular rod, the inverse kinetics solution used combinations of the two ex-core detectors based upon detector efficiency ratios obtained from rod drops and from the 64 in-core fission detector measurements. Note that PSR31 was not calibrated.

15.7 Delayed Neutron Parameters

The delayed neutron fractions were measured in ZPPR-19B using a rod drop technique with the reactor power leveled at 0.9×10^{-5} on EXP1. This measurement was done on February 1, 1988, in reactor run 19, loading 22. The power history of the rod drop was analyzed using an iterative inverse kinetics solution which solves for the delayed neutron fractions, the reactivity after the rod drop, the effective source term and the detector efficiency ratio. The decay constants of the six delayed neutron precursor groups and β_{eff} were obtained from an xyz diffusion calculation. The resulting delayed neutron fractions are given in Table 15.3.

15.8 Source Term

The effective source term for two ex-core power monitors was measured in reactor run 18 and the data recorded as file 10 in DATAZ19B.Z01. The measurement was done starting at 0.8×10^{-7} on the EXP1 detector and dropping the group 2 rods, which perturb the detector

efficiency ratio least. The resulting source terms are $102.9 \pm 0.2 \Delta k/k$ counts s^{-1} for EXP1 and $89.1 \pm 0.2 \Delta k/k$ counts s^{-1} for EXP2.

TABLE 15.1 Rod Pair Worths in ZPPR-19B

Data File	Rods	Matrix Position	Worth, \$	Detector Efficiency Ratios	
				EXP1	EXP2
4	PSRs 6 & 7	1,272-46	0.1337 ± 0.001	0.9883 ± 0.0003	0.9760 ± 0.0003
5	PSRs 27 & 34	1,253-46	0.3430 ± 0.001	1.01147 ± 0.0003	0.9972 ± 0.0003
6	PSRs 22 & 23	1,263-41,42	0.4045 ± 0.001	1.0050 ± 0.0003	0.9239 ± 0.0003
9	PSRs 10 & 19	1,253-31	0.1989 ± 0.001	1.0226 ± 0.0003	0.9641 ± 0.0003
11	SR 1 & 2	1,263-31	0.1295 ± 0.001	1.0108 ± 0.0003	0.9323 ± 0.0003

TABLE 15.2 Shim Rod Calibration Coefficients in ZPPR-19B^a

Shim Rod	Position	$10^2 x C_1$	$10^3 x C_2$	$10^4 x C_3$	$10^6 x C_4$	RMS Deviation, ϕ	Total Worth \$
1	163-31	-3.7159	+8.2183	-10.523	17.138	0.029	0.0805 $\pm$ 0.001
2	263-31	-3.5250	8.1970	-10.556	17.247	0.031	0.0798 $\pm$ 0.001
3	134-67	-3.4436	7.7748	-10.312	16.799	0.032	0.0804 $\pm$ 0.001
4	235-67	-3.6072	8.0247	-10.531	17.169	0.029	0.0816 $\pm$ 0.001
5	163-67	-3.3111	7.4002	-10.059	16.512	0.025	0.0787 $\pm$ 0.001
6	263-67	-3.4848	7.9538	-10.500	17.182	0.025	0.0815 $\pm$ 0.001
PSR 30	235-31	-3.9006	8.4849	-10.921	17.826	0.033	0.0831 $\pm$ 0.001

^a $R = C_1 + C_2 X^2 + C_3 X^3 + C_4 X^4$ where X is the rod position in inches measured from the fully withdrawn position and R is the reactivity in cents.

TABLE 15.3 Measured Delayed Neutron Fractions in ZPPR-19B^a

<u>Group</u>	<u>λ_i (s⁻¹)</u>	<u>a_i</u>	<u>β_i</u>
1	0.012933	0.0231316	0.00008943
2	0.031539	0.2073353	0.00080145
3	0.13239	0.1812886	0.00070077
4	0.34088	0.3681837	0.00142321
5	1.37710	0.1758726	0.00067984
6	3.80500	0.0441832	0.00017079
Total		1.0000000	0.00386559

^aThe λ_i values and β_{eff} were obtained from an xyz diffusion calculation.

16. BASIC DATA FOR REACTION RATE DISTRIBUTIONS IN ZPPR-17B AND ZPPR-17C

(D. W. Maddison and J. M. Gasidlo)

16.1 Introduction

Reaction rate maps are measured by first choosing a location in a cell to place the irradiation foil. These "mapping" foils are always placed in the same location in a drawer for a specific type of cell. Then, a pattern of drawers is chosen to provide the reactor distribution desired, such as a radial map or an axial distribution.

16.2 Discussion of Foil Locations

The foils were first placed in stainless steel foil holders which were then loaded into the drawers between the vertical columns* of materials. For drawers with one fuel column the foil was placed adjacent to the fuel on the side closer to the core center. For drawers with two fuel columns, the foil was placed adjacent to the fuel plate closer to the core center on the side of the plate closer to the drawer center. The mapping foil locations for any location in the reactor are given below.

Reactor Half 1	<u>Matrix Columns $\leq$ 49</u>		<u>Matrix Column $\geq$ 50</u>	
	<u>SC</u>	<u>DC</u>	<u>SC</u>	<u>DC</u>
CB	HI	HI	HI	HI
Core	IJ	JK	GH	FG
AB	IJ	IJ	GH	GH
RB		IJ		GH
RR/AR		TC		TC

*ZPPR drawers are divided into sixteen 3.175 mm (1/8 in.) wide vertical columns designed by letters A through P. The letter A denotes the column at the left as one faces the drawer. The letters FG, for example, indicate the foil is between columns F and G, and is centered 19.050 mm (0.750 in.) from the left side of the drawer.

Matrix Columns < 49Matrix Column > 50

Reactor Half 2	<u>SC</u>	<u>DC</u>	<u>SC</u>	<u>DC</u>
CB	HI	HI	HI	HI
Core	GH	FG	IJ	JK
AB	GH	GH	IJ	IJ
RB		GH		IJ
RR/AR		TC		TC

Where SC is a drawer with one fuel column, DC is a drawer with two fuel columns, CB is the central blanket region, core is the fueled region, AB is the axial blanket in a fueled drawer, RB is the radial blanket and RR is the radial reflector. There are some ^{235}U foils in the axial and radial reflectors which are given a drawer location of "TC". For this location, the foil holder was placed horizontally across the top of the drawer. The foil was centered above drawer columns HI and the foil was centered 25.654 mm above the mid-height of the drawer.

The basic data for the radial maps and axial distributions in ZPPR-17B are given in Tables 16.1 - 16.3. The basic data for ZPPR-17C were measured in two irradiations. There were 16 common locations for ^{235}U foils in the two irradiations for comparing the power histories. The weighted average fission ratio of the common foils was 0.9973 with one standard deviation of 0.0019. Since this was close to unity, the two data sets were merged using the average of the two foils for the common locations. The basic data for the merged data sets are given in Tables 16.4 - 16.7.

In both 17B and 17C, all foils were centered on the listed axial positions as measured from the reactor midplane. The ^{235}U foils were centered 13.8 mm above, the ^{238}U foils were centered on, and the ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

The core configurations and operating rod parameters for 17B and 17C are given in ANL-ZPR-485, Sections 6 and 7.

16.3 Discussion of Foil Data and Uncertainties

In all of the tables, the data are given in units of 10^{-18} fissions or captures per sec per atom in the irradiated foil at an estimated reactor power of one watt. The second number associated with each reaction rate is a one standard deviation estimate of the random uncertainty. The uncertainties given in the tables are solely due to counting statistics and data reduction. They include the effects of peak integration, interference peak corrections, corrections for other reactions in the foils, irradiation history and foil positioning in the counter system. Other uncertainties due to cell-averaging factors are discussed in Section 17. Other uncertainties such as those due to detector calibrations are not included. The uncertainties are discussed in greater detail by Brumbach and Gasidlo.¹

REFERENCE

1. "In-Cell Reaction Rate Distributions and Cell-Average Reaction Rates in Fast Critical Assemblies," ANL-85-44, August 1985.

TABLE 16.1 Basic Data for $^{239}\text{Pu}(n,f)$ and $^{235}\text{U}(n,f)$ Radial Distributions in ZPPR-17B

Matrix	Loc ^a	z=51.6 mm ^b		Loc ^a	z=178.6 mm ^b		z=280.2 mm ^b	
Basic Data for ²³⁹ Pu(n,f) ^c on the X Axis								
147 50	HI	7.082	0.043	FG	6.294	0.039	6.248	0.039
147 51	HI	7.006	0.054	GH	6.237	0.037	6.089	0.044
148 52	HI	6.895	0.039	GH	6.233	0.037	6.120	0.036
148 53	HI	6.938	0.045	GH	6.260	0.040	6.208	0.039
148 54	HI	7.028	0.043	FG	6.255	0.058	6.119	0.036
148 55	HI	7.129	0.040	GH	6.406	0.037	6.209	0.034
148 56	HI	7.464	0.041	GH	6.607	0.039	6.366	0.037
147 56	HI	7.445	0.044	FG	6.537	0.036	6.341	0.038
147 57	HI	7.697	0.041	GH	6.824	0.038	6.517	0.038
Basic Data for ²³⁵ U(n,f) ^c on the X Axis								
147 50	HI	8.000	0.041	FG	6.994	0.039	6.556	0.036
147 51	HI	7.998	0.042	GH	7.017	0.038	6.493	0.037
148 52	HI	8.009	0.042	GH	6.986	0.037	6.520	0.036
148 53	HI	7.995	0.042	GH	6.945	0.037	6.570	0.037
148 54	HI	8.169	0.043	FG	6.980	0.036	6.609	0.036
148 55	HI	8.223	0.042	GH	7.253	0.038	6.685	0.036
148 56	HI	8.592	0.042	GH	7.536	0.041	6.964	0.038
147 56	HI	8.481	0.043	FG	7.289	0.039	6.838	0.038
147 57	HI	8.792	0.043	GH	7.601	0.039	6.998	0.037
147 58	HI	9.001	0.046	GH	7.786	0.041	7.140	0.042
147 59	HI	9.059	0.047	FG	7.836	0.043	7.175	0.039
148 59	HI	9.197	0.052	GH	8.035	0.044	7.383	0.042
148 60	HI	9.216	0.046	FG	7.814	0.042	7.224	0.041
148 61	HI	9.315	0.049	GH	8.026	0.044	7.380	0.041
148 62	HI	9.426	0.049	GH	8.225	0.044	7.405	0.038
148 63	HI	9.501	0.048	FG	8.258	0.044	7.639	0.057
148 64	HI	9.545	0.053	GH	8.468	0.043	7.753	0.040
148 65	HI	9.286	0.047	GH	8.467	0.043	7.804	0.055
148 66	FG	8.861	0.051	FG	8.329	0.045	7.608	0.044
148 67	GH	8.565	0.047	GH	8.038	0.048	7.425	0.040
148 68	GH	8.249	0.048	GH	7.902	0.043	7.147	0.039
148 69	FG	7.905	0.048	FG	7.504	0.043	6.771	0.042
148 71	GH	6.643	0.039	GH			5.631	0.036
148 72	FG	5.833	0.038	FG	5.526	0.035	4.878	0.030
148 73	GH	4.957	0.030	GH	4.663	0.031	4.185	0.030
148 74	GH	4.224	0.022	GH	3.927	0.021	3.481	0.019
148 75	GH	3.418	0.019	GH	3.183	0.019	2.822	0.018
148 76	GH	2.665	0.015	GH	2.503	0.015	2.217	0.015
148 77	GH	2.104	0.015	GH	1.985	0.013	1.749	0.013
148 78	GH	1.774	0.013	GH	1.643	0.012	1.469	0.011
148 79	TC	1.756	0.014					
148 80	TC	1.394	0.011					
148 81	TC	0.866	0.008					

TABLE 16.1 (contd)

Matrix	Loc ^a	z=51.6 mm ^b		Loc ^a	z=178.6 mm ^b		z=280.2 mm ^b	
Basic Data for ²³⁵ U(n,f) ^c on the 45° Radial								
146 52	HI	8.042	0.055	FG	6.957	0.044	6.608	0.047
145 53	HI	8.172	0.048	GH	7.076	0.040	6.664	0.038
145 54	HI	8.248	0.048	FG	7.117	0.044	6.702	0.051
144 54	HI	8.294	0.045	GH	7.268	0.047	6.880	0.044
143 55	HI	8.717	0.045	FG	7.469	0.054	7.037	0.044
143 56	HI	8.839	0.053	GH	7.681	0.045	7.044	0.048
142 56	HI	9.057	0.061	GH	7.796	0.046	7.134	0.046
142 57	HI	9.064	0.043	FG	7.842	0.042	7.180	0.041
141 57	HI	9.287	0.063	GH	7.856	0.041	7.214	0.037
141 58	HI	9.408	0.057	GH	8.029	0.045	7.343	0.045
140 58	HI	9.289	0.055	FG	7.981	0.041	7.362	0.045
140 59	HI	9.522	0.057	GH	8.203	0.046	7.464	0.053
139 59	HI	9.405	0.048	FG	8.099	0.044		
138 60	HI	9.511	0.051	GH	8.404	0.043	7.659	0.041
138 61	HI	9.367	0.055	GH	8.557	0.048	7.830	0.085
138 63	GH	8.828	0.074	GH			7.428	0.061
137 63	GH	8.656	0.055	GH	8.249	0.054	7.399	0.055
136 63	FG	8.373	0.052	FG	7.809	0.046	7.109	0.039
135 63	GH	8.005	0.048	GH	7.420	0.040	6.693	0.042
135 64	GH	7.538	0.039	GH	7.039	0.041	6.305	0.035
134 64	FG	7.086	0.038	FG	6.666	0.046	5.874	0.035
133 65	FG	6.005	0.037	FG	5.593	0.036	4.999	0.040
133 66	FG	5.394	0.034	FG	5.001	0.034	4.509	0.037
132 66	GH	4.847	0.031	GH	4.469	0.027	4.049	0.030
132 67	GH	4.276	0.022	GH	3.977	0.020	3.541	0.018
131 67	GH	3.712	0.019	GH	3.464	0.018	3.051	0.020
130 68	GH	2.690	0.016	GH	2.457	0.015	2.241	0.014
130 69	GH	2.277	0.014	GH	2.138	0.014	1.905	0.014
129 69	GH	2.004	0.014	GH	1.869	0.012	1.660	0.012

^aIn-drawer column which designates the foil location in the drawer. The ^{235}U foils were centered 13.8 mm above and the ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10^{-18} fissions per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.2 Basic Data for $^{238}\text{U}(n,f)$ and
 $^{238}\text{U}(n,\gamma)$ Radial Distributions
 in ZPPR-17B

Matrix	Loc ^a	²³⁸ U(n,f) ^c		²³⁸ U(n,γ) ^c	
Basic Data at z = 51.6 mm ^b					
147 50	HI	0.0459	0.0015	0.8813	0.0055
147 51	HI	0.0413	0.0016	0.8855	0.0059
148 52	HI	0.0422	0.0015	0.8832	0.0057
148 53	HI	0.0432	0.0015	0.8879	0.0057
148 54	HI	0.0418	0.0014	0.8901	0.0053
148 55	HI	0.0450	0.0017	0.9077	0.0058
148 56	HI	0.0431	0.0017	0.9509	0.0057
147 56	HI	0.0444	0.0015	0.9500	0.0056
147 57	HI	0.0444	0.0015	0.9612	0.0056
147 58	HI	0.0476	0.0018	0.9804	0.0058
147 59	HI	0.0485	0.0017	1.0069	0.0058
148 59	HI	0.0483	0.0017	1.0106	0.0064
148 60	HI	0.0466	0.0016	1.0132	0.0059
148 61	HI	0.0504	0.0018	1.0393	0.0067
148 62	HI	0.0574	0.0018	1.0676	0.0061
148 63	HI	0.0632	0.0019	1.0839	0.0062
148 64	HI	0.0807	0.0020	1.1113	0.0059
148 65	HI	0.1113	0.0025	1.0991	0.0064
148 66	FG	0.2103	0.0037	1.2539	0.0067
148 67	GH	0.2233	0.0032	1.2047	0.0063
148 68	GH	0.2307	0.0035	1.1627	0.0066
148 69	FG	0.2443	0.0039	1.1130	0.0061
148 71	GH	0.1803	0.0029	0.9466	0.0053
148 72	FG	0.1660	0.0030	0.8172	0.0047
148 73	GH	0.1220	0.0024	0.7140	0.0043
148 74	GH	0.0549	0.0019	0.5195	0.0034
148 75	GH	0.0273	0.0014	0.4089	0.0028
148 76	GH	0.0172	0.0016	0.3114	0.0024
148 77	GH	0.0114	0.0011	0.2363	0.0021
148 78	GH	0.0071	0.0012	0.1847	0.0019
Basic Data at z = 178.6 mm ^b					
147 50	FG	0.1469	0.0024	1.0449	0.0060
147 51	GH	0.1384	0.0022	1.0204	0.0059
148 52	GH	0.1401	0.0022	1.0136	0.0064
148 53	GH	0.1367	0.0023	1.0094	0.0058
148 54	FG	0.1492	0.0029	1.0297	0.0067
148 55	GH	0.1345	0.0022	1.0556	0.0061
148 56	GH	0.1352	0.0022	1.0936	0.0062
147 56	FG	0.1484	0.0022	1.0780	0.0061
147 57	GH	0.1374	0.0023	1.1389	0.0065
147 58	GH	0.1423	0.0027	1.1640	0.0065
147 59	FG	0.1569	0.0027	1.1407	0.0065
148 59	GH	0.1436	0.0024	1.1789	0.0065

TABLE 16.2 (contd)

Matrix	Loc ^a	²³⁸ U(n,f) ^c		²³⁸ U(n,γ) ^c	
148 60	FG	0.1627	0.0028	1.1542	0.0066
148 61	GH	0.1634	0.0026	1.1671	0.0066
148 62	GH	0.1610	0.0026	1.1973	0.0066
148 63	FG	0.1847	0.0028	1.1951	0.0070
148 64	GH	0.1809	0.0034	1.2288	0.0070
148 65	GH	0.1941	0.0032	1.2155	0.0068
148 66	FG	0.2273	0.0033	1.1661	0.0062
148 67	GH	0.2264	0.0032	1.1438	0.0065
148 68	GH	0.2265	0.0035	1.1058	0.0060
148 69	FG	0.2240	0.0032	1.0486	0.0057
148 72	FG	0.1587	0.0028	0.7785	0.0045
148 73	GH	0.1078	0.0023	0.6719	0.0049
148 74	GH	0.0480	0.0018	0.4816	0.0034
148 75	GH	0.0249	0.0016	0.3810	0.0029
148 76	GH	0.0147	0.0015	0.2889	0.0023
148 77	GH	0.0108	0.0011	0.2179	0.0020
148 78	GH	0.0057	0.0010	0.1700	0.0017

Basic Data at Z = 280.2 mm^b

147 50	FG	0.1750	0.0024	0.9635	0.0056
147 51	GH	0.1688	0.0026	0.9277	0.0056
148 52	GH	0.1667	0.0025	0.9276	0.0055
148 53	GH	0.1713	0.0024	0.9267	0.0055
148 54	FG	0.1784	0.0033	0.9467	0.0062
148 55	GH	0.1697	0.0031	0.9669	0.0073
148 56	GH	0.1596	0.0025	0.9973	0.0058
147 56	FG	0.1756	0.0026	0.9915	0.0059
147 57	GH	0.1624	0.0024	1.0229	0.0065
147 58	GH	0.1699	0.0028	1.0396	0.0060
147 59	FG	0.1839	0.0025	1.0309	0.0060
148 59	GH	0.1724	0.0024	1.0599	0.0073
148 60	FG	0.1949	0.0031	1.0284	0.0061
148 61	GH	0.1878	0.0027	1.0354	0.0059
148 62	GH	0.1974	0.0030	1.0549	0.0061
148 63	FG	0.2074	0.0027	1.0697	0.0062
148 64	GH	0.2023	0.0030	1.0890	0.0058
148 65	GH	0.2064	0.0032	1.0897	0.0058
148 66	FG	0.2233	0.0034	1.0708	0.0058
148 67	GH	0.2126	0.0033	1.0460	0.0058
148 68	GH	0.2049	0.0033	1.0055	0.0060
148 69	FG	0.2057	0.0030	0.9437	0.0066
148 71	GH	0.1545	0.0026	0.7855	0.0045
148 72	FG	0.1396	0.0025	0.6934	0.0045
148 73	GH	0.0980	0.0022	0.6051	0.0037
148 74	GH	0.0450	0.0018	0.4278	0.0030
148 75	GH	0.0231	0.0013	0.3371	0.0025
148 76	GH	0.0128	0.0012	0.2575	0.0021
148 77	GH	0.0091	0.0010	0.1951	0.0019

TABLE 16.2 (contd)

Matrix	Loc ^a	$^{238}\text{U}(n,f)^c$	$^{238}\text{U}(n,\gamma)^c$
148 78	GH	0.0055 0.0010	0.1503 0.0016

^aIn-drawer column which designates the foil location in the drawer. The ^{238}U foils were centered on the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10^{-18} fissions or captures per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.3 Basic Reaction Rate Data for Axial Distributions in ZPPR-17B

z, mm^a	Loc ^b	$^{239}\text{Pu}(n,f)^c$	$^{235}\text{U}(n,f)^c$	$^{238}\text{U}(n,f)^c$	$^{238}\text{U}(n,\gamma)^c$
Axial Traverse in Position 148 51					
26.2	HI	7.078 0.039	8.228 0.043	0.0428 0.0017	0.9003 0.0050
49.6	HI	7.082 0.041	8.174 0.049	0.0483 0.0021	0.9032 0.0052
77.0	HI	7.023 0.042	8.057 0.048	0.0503 0.0017	0.8946 0.0052
100.4	HI	6.909 0.039	7.765 0.053	0.0551 0.0016	0.8831 0.0048
127.8	HI	6.800 0.039	7.702 0.042	0.0712 0.0020	0.8788 0.0049
178.6	GH	6.211 0.036	7.036 0.038	0.1456 0.0023	1.0305 0.0055
229.4	GH	6.153 0.035		0.1633 0.0024	0.9834 0.0053
280.2	GH	6.201 0.042	6.614 0.038	0.1710 0.0025	0.9556 0.0052
331.0	GH	5.958 0.042	6.326 0.034	0.1760 0.0025	0.8951 0.0049
432.6	GH	5.266 0.033	5.677 0.032	0.1460 0.0024	0.8209 0.0047
483.4	GH	4.751 0.031	5.259 0.031	0.1159 0.0021	0.7636 0.0043
534.2	GH	4.594 0.031	5.127 0.031	0.0530 0.0015	0.7302 0.0042
585.0	GH	4.170 0.030	4.802 0.030	0.0317 0.0014	0.7027 0.0050
635.8	GH	3.878 0.028	4.359 0.028	0.0209 0.0013	0.6342 0.0040
686.6	GH	3.573 0.030	4.018 0.025	0.0141 0.0010	0.5856 0.0038
737.4	GH	3.423 0.027	3.828 0.034	0.0106 0.0009	0.5422 0.0033
825.2	TC		4.008 0.021		
876.0	TC		3.771 0.020		
933.1	TC		3.008 0.016		
983.9	TC		2.168 0.014		
1034.7	TC		1.383 0.011		
Axial Traverse in Position 138 62					
51.6	FG		8.967 0.046	0.1881 0.0030	1.3151 0.0067
102.4	FG		8.821 0.047	0.1992 0.0028	1.2780 0.0065
178.6	FG		8.481 0.045	0.2057 0.0033	1.2045 0.0063
229.4	FG		8.063 0.041	0.2108 0.0032	1.1514 0.0062
280.2	FG		7.740 0.041	0.2038 0.0030	1.0826 0.0058
331.0	FG		7.248 0.039	0.1912 0.0030	1.0260 0.0056
381.8	FG		6.668 0.043	0.1750 0.0032	0.9443 0.0053
432.6	FG		6.018 0.041	0.1548 0.0027	0.8589 0.0052
483.4	FG		5.338 0.033	0.1191 0.0024	0.7795 0.0045
534.2	GH		5.068 0.030	0.0565 0.0020	0.7241 0.0046
585.0	GH		4.547 0.030	0.0338 0.0014	0.6540 0.0039
635.8	GH		4.030 0.026	0.0217 0.0014	0.5824 0.0036
686.6	GH		3.545 0.023	0.0136 0.0011	0.5124 0.0032
737.4	GH		3.228 0.025	0.0098 0.0010	0.4780 0.0031
825.2	TC		3.227 0.018		
876.0	TC		2.957 0.017		
Axial Traverse in Position 148 70					
51.6	GH		7.408 0.068	0.2038 0.0030	1.0312 0.0061
102.4	GH		7.054 0.083	0.2036 0.0029	1.0154 0.0055
178.6	GH		6.952 0.040	0.1894 0.0030	0.9775 0.0054
229.4	GH		6.675 0.045	0.1838 0.0026	0.9358 0.0051

TABLE 16.3 (contd)

z, mm^a	Loc^b	$^{239}\text{Pu}(n, f)^c$	$^{235}\text{U}(n, f)^c$	$^{238}\text{U}(n, f)^c$	$^{238}\text{U}(n, \gamma)^c$
280.2	GH		6.262 0.042	0.1767 0.0026	0.8776 0.0049
331.0	GH		5.781 0.039	0.1581 0.0026	0.8104 0.0046
381.8	GH		5.220 0.037	0.1381 0.0025	0.7426 0.0047
432.6	GH		4.713 0.030	0.1181 0.0023	0.6671 0.0040
483.4	GH		4.152 0.028	0.0941 0.0020	0.6063 0.0041
534.2	GH		3.813 0.028	0.0439 0.0015	0.5392 0.0034
585.0	GH		3.303 0.030	0.0284 0.0015	0.4846 0.0036
635.8	GH		2.915 0.022	0.0165 0.0014	0.4269 0.0029
686.6	GH		2.548 0.022	0.0110 0.0010	0.3695 0.0026
737.4	GH		2.274 0.030	0.0081 0.0010	0.3323 0.0024

^aDistance from the reactor interface to the center of the foil.

^bIn-drawer column which designates the foil location in the drawer. The ^{235}U foils were centered 13.8 mm above, the ^{238}U foils were centered on, and the ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

^cExperimental results in units of 10^{-18} fissions or captures per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.4 Basic Data for $^{239}\text{Pu}(n,f)$ Radial
Distributions in ZPPR-17C

<u>Matrix</u>	<u>Loc^a</u>	<u>z=51.6 mm^b</u>	<u>Loc^a</u>	<u>z=178.6 mm^b</u>	<u>z=280.2 mm^b</u>
Data on the X Axis ^c					
247 50	HI	4.047 0.028	JK	3.350 0.025	3.359 0.024
247 51	HI	4.949 0.031	IJ	4.061 0.029	3.977 0.030
248 52	HI	5.436 0.033	IJ	4.503 0.029	4.290 0.029
248 53	HI	6.012 0.034	IJ	4.981 0.032	4.734 0.032
248 54	HI	6.300 0.036	JK	5.199 0.033	5.019 0.030
248 55	HI	6.615 0.039	JK	5.532 0.034	5.263 0.031
248 56	HI	7.030 0.040	IJ	5.788 0.034	5.418 0.032
247 56	HI	6.924 0.037	JK	5.752 0.033	5.417 0.032
247 57	HI	7.174 0.040	IJ	6.008 0.033	5.647 0.033
147 50	HI	5.919 0.035	FG	6.517 0.037	
147 51	HI	6.152 0.035	GH	6.653 0.037	
148 52	HI	6.285 0.035	GH	6.531 0.036	
148 53	HI	6.550 0.034	GH	6.633 0.035	
148 54	HI	6.695 0.038	FG	6.705 0.038	
148 55	HI	7.078 0.039	FG	6.820 0.038	
148 56	HI	7.426 0.043	GH	7.135 0.038	
147 56	HI	7.270 0.039	FG	6.986 0.039	
147 57	HI	7.583 0.041	GH	7.335 0.042	

^aIn-drawer column which designates the foil location in the drawer. The ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10^{-18} fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.5 Basic Data for $^{235}\text{U}(n,f)$ Radial
Distributions in ZPPR-17C

Matrix	Loc ^a	Z=51.6 mm ^b		Loc ^a	Z=178.6 mm ^b		Z=280.2 mm ^b	
Data on the X Axis ^c								
247 50	HI	5.520	0.026	JK	4.359	0.022	4.034	0.021
247 51	HI	6.089	0.030	IJ	4.761	0.024	4.368	0.024
248 52	HI	6.398	0.033	IJ	5.065	0.028	4.659	0.025
248 53	HI	6.901	0.032	IJ	5.529	0.027	5.051	0.026
248 54	HI	7.249	0.035	JK	5.854	0.027	5.339	0.027
248 55	HI	7.549	0.032	JK	6.115	0.028	5.515	0.029
248 56	HI	7.951	0.038	IJ	6.530	0.032	5.835	0.029
247 56	HI	7.820	0.037	JK	6.327	0.029	5.714	0.030
247 57	HI	8.038	0.038	IJ	6.591	0.032	5.903	0.030
247 58	HI	8.126	0.039	JK	6.604	0.034	5.885	0.031
247 59	HI	8.203	0.035	JK	6.599	0.030	5.886	0.030
248 59	HI	8.242	0.037	IJ	6.802	0.033	6.043	0.029
248 60	HI	8.139	0.036	JK	6.550	0.029	5.881	0.028
248 61	HI	8.009	0.038	IJ	6.528	0.030	5.730	0.027
248 62	HI	7.889	0.038	IJ	6.323	0.032	5.612	0.028
248 63	HI	7.793	0.036	JK	6.155	0.032	5.448	0.028
248 64	HI	7.532	0.035	JK	6.085	0.029	5.243	0.025
248 65	HI	7.236	0.035	IJ	5.926	0.031	5.130	0.025
248 66	JK	7.004	0.032	JK	5.899	0.029	5.027	0.027
248 67	JK	7.014	0.032	JK	5.951	0.030	5.139	0.025
248 68	IJ	7.036	0.034	IJ	6.079	0.029	5.184	0.029
248 69	JK	6.996	0.034	JK	6.047	0.030	5.125	0.027
248 71	IJ	6.101	0.030	IJ	5.406	0.028	4.587	0.025
248 72	JK	5.476	0.028	JK	4.798	0.026	4.099	0.023
248 73	JK	4.761	0.025	JK	4.145	0.022	3.538	0.021
248 74	IJ	4.015	0.022	IJ	3.521	0.020	2.977	0.018
248 75	IJ	3.234	0.020	IJ	2.877	0.017	2.473	0.016
248 76	IJ	2.578	0.018	IJ	2.308	0.016	1.941	0.015
248 77	IJ	2.019	0.013	IJ	1.799	0.011	1.518	0.010
248 78	IJ	1.664	0.012	IJ	1.465	0.012	1.270	0.009
248 79	TC	1.652	0.011					
248 80	TC	1.347	0.009					
248 81	TC	0.839	0.007					
147 50	HI	6.969	0.033	FG	7.194	0.032	7.335	0.033
147 51	HI	7.195	0.033	GH	7.254	0.034	7.224	0.033
148 52	HI	7.333	0.035	GH	7.319	0.034	7.293	0.033
148 53	HI	7.562	0.034	GH	7.363	0.034	7.368	0.036
148 54	HI	7.803	0.033	FG	7.418	0.033	7.373	0.033
148 55	HI	8.148	0.037	FG	7.595	0.036	7.497	0.034
148 56	HI	8.518	0.036	GH	7.984	0.035	7.701	0.037
147 56	HI	8.355	0.036	FG	7.737	0.034	7.608	0.035
147 57	HI	8.584	0.036	GH	8.012	0.035	7.794	0.036
147 58	HI	8.741	0.038	FG	8.080	0.036	7.866	0.035
147 59	HI	8.788	0.041	FG	8.048	0.037	7.899	0.039
148 59	HI	8.796	0.041	GH	8.331	0.039	8.081	0.035

TABLE 16.5 (contd)

Matrix	Loc ^a	Z=51.6 mm ^b	Loc ^a	Z=178.6 mm ^b	Z=280.2 mm ^b
148 60	HI	8.720 0.040	FG	8.177 0.037	8.017 0.036
148 61	HI	8.675 0.039	GH	8.291 0.037	8.074 0.036
148 62	HI	8.567 0.040	GH	8.376 0.040	8.099 0.037
148 63	HI	8.520 0.038	FG	8.300 0.040	8.194 0.040
148 64	HI	8.367 0.040	FG	8.471 0.041	8.225 0.039
148 65	HI	8.160 0.039	IJ	8.424 0.040	8.220 0.038
148 66	FG	7.848 0.038	FG	8.288 0.040	8.150 0.038
148 67	FG	7.799 0.036	FG	8.233 0.040	8.007 0.038
148 68	GH	7.722 0.035	GH	8.063 0.037	7.643 0.039
148 69	FG	7.638 0.038	FG	7.719 0.036	7.269 0.034
148 71	GH	6.485 0.032	GH	6.572 0.034	6.096 0.033
148 72	FG	5.807 0.030	FG	5.791 0.029	5.335 0.030
148 73	FG	4.997 0.027	FG	4.931 0.027	4.530 0.026
148 74	GH	4.179 0.024	GH	4.110 0.023	3.744 0.021
148 75	GH	3.410 0.021	GH	3.342 0.020	3.025 0.019
148 76	GH	2.683 0.017	GH	2.616 0.017	2.403 0.016
148 77	GH	2.087 0.013	GH	2.042 0.012	1.857 0.012
148 78	GH	1.744 0.011	GH	1.679 0.012	1.551 0.011
148 79	TC	1.720 0.011			
148 80	TC	1.372 0.010			
148 81	TC	0.855 0.007			

Data on the 45° Radial

246 52	HI	6.906 0.033	JK	5.546 0.026	5.054 0.024
245 53	HI	7.376 0.032	IJ	5.997 0.029	5.357 0.028
245 54	HI	7.588 0.034	JK	6.166 0.028	5.578 0.026
244 54	HI	7.745 0.035	IJ	6.393 0.029	5.715 0.027
243 55	HI	7.984 0.036	JK	6.526 0.030	5.779 0.028
243 56	HI	7.997 0.037	IJ	6.481 0.031	5.761 0.028
242 56	HI	8.005 0.033	IJ	6.597 0.030	5.879 0.027
242 57	HI	8.127 0.037	JK	6.532 0.032	5.770 0.028
241 57	HI	8.054 0.037	IJ	6.597 0.033	5.734 0.029
241 58	HI	8.115 0.038	IJ	6.615 0.030	5.714 0.029
240 58	HI	7.899 0.036	JK	6.318 0.031	5.603 0.028
240 59	HI	7.918 0.036	IJ	6.391 0.029	5.586 0.026
239 59	HI	7.621 0.034	JK	6.111 0.028	5.334 0.027
238 60	HI	6.669 0.031	IJ	5.331 0.025	4.622 0.024
238 61	HI	5.496 0.028	IJ	4.533 0.025	3.927 0.023
238 63	IJ	6.096 0.029	IJ	5.068 0.024	4.347 0.023
237 63	JK	5.391 0.027	JK	4.413 0.023	3.786 0.019
236 63	JK	5.499 0.025	JK	4.534 0.023	3.829 0.021
235 63	IJ	5.854 0.030	IJ	4.839 0.026	4.116 0.022
235 64	JK	5.994 0.027	JK	5.063 0.024	4.292 0.022
234 64	JK	5.860 0.027	JK	4.982 0.024	4.217 0.021
233 65	JK	5.192 0.026	JK	4.511 0.025	3.774 0.022
233 66	JK	4.711 0.024	JK	4.177 0.021	3.489 0.021
232 66	IJ	4.273 0.024	IJ	3.730 0.020	3.163 0.019
232 67	IJ	3.885 0.020	IJ	3.414 0.019	2.912 0.017

TABLE 16.5 (contd)

Matrix	Loc ^a	Z=51.6 mm ^b	Loc ^a	Z=178.6 mm ^b	Z=280.2 mm ^b
231 67	IJ	3.369 0.019	IJ	2.954 0.017	2.523 0.016
230 68	IJ	2.482 0.015	IJ	2.194 0.014	1.847 0.013
230 69	IJ	2.057 0.011	IJ	1.824 0.010	1.578 0.009
229 69	IJ	1.820 0.010	IJ	1.617 0.009	1.386 0.010
146 52	HI	7.476 0.035	FG	7.216 0.033	7.221 0.034
145 53	HI	7.838 0.035	GH	7.403 0.033	7.357 0.033
145 54	HI	7.984 0.036	FG	7.462 0.034	7.414 0.035
144 54	HI	8.195 0.034	GH	7.652 0.032	7.496 0.035
143 55	HI	8.590 0.036	FG	7.909 0.034	7.696 0.033
143 56	HI	8.575 0.036	GH	7.981 0.033	7.693 0.032
142 56	HI	8.666 0.036	GH	7.985 0.033	7.749 0.034
142 57	HI	8.657 0.038	FG	8.019 0.036	7.831 0.036
141 57	HI	8.670 0.036	GH	8.102 0.034	7.806 0.033
141 58	HI	8.721 0.036	GH	8.155 0.036	7.934 0.033
140 58	HI	8.622 0.036	FG	8.086 0.034	7.945 0.033
140 59	HI	8.527 0.038	GH	8.175 0.034	7.921 0.035
139 59	HI	8.483 0.036	FG	8.132 0.036	7.936 0.036
138 60	HI	7.888 0.035	GH	8.143 0.036	7.893 0.035
138 61	HI	7.628 0.035	GH	8.218 0.037	7.979 0.036
138 63	GH	7.332 0.035	GH	8.025 0.036	7.764 0.036
137 63	FG	7.077 0.033	FG	7.851 0.038	7.583 0.035
136 63	FG	6.938 0.032	FG	7.591 0.036	7.292 0.034
135 63	GH	6.794 0.032	GH	7.275 0.034	6.904 0.032
135 64	FG	6.655 0.030	FG	6.960 0.032	6.592 0.030
134 64	FG	6.390 0.030	FG	6.493 0.030	6.120 0.030
133 65	FG	5.570 0.027	FG	5.510 0.027	5.150 0.025
133 66	FG	5.007 0.025	FG	5.000 0.025	4.636 0.023
132 66	GH	4.540 0.023	GH	4.465 0.023	4.124 0.022
132 67	IJ	4.064 0.021	IJ	4.019 0.021	3.668 0.020
131 67	IJ	3.538 0.019	IJ	3.470 0.019	3.178 0.018
130 68	IJ	2.515 0.013	IJ	2.461 0.013	2.233 0.012
130 69	IJ	2.146 0.012	IJ	2.122 0.012	1.956 0.011
129 69	IJ	1.906 0.012	IJ	1.836 0.011	1.679 0.010

^aIn-drawer column which designates the foil location in the drawer. The ²³⁵U foils were centered 13.8 mm above the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10⁻¹⁸ fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.6 Basic Data for $^{238}\text{U}(n,f)$ and
 $^{238}\text{U}(n,\gamma)$ Radial Distributions
 in ZPPR-17C

Matrix	Loc ^a	²³⁸ U(n,f) ^c		²³⁸ U(n,γ) ^c	
Data at Z = 51.6 mm ^b					
247 50	HI	0.0347	0.0014	0.6057	0.0044
247 51	HI	0.0364	0.0015	0.6711	0.0045
248 52	HI	0.0388	0.0018	0.7207	0.0047
248 53	HI	0.0394	0.0018	0.7751	0.0046
248 54	HI	0.0393	0.0015	0.8178	0.0054
248 55	HI	0.0409	0.0016	0.8530	0.0048
248 56	HI	0.0442	0.0015	0.8882	0.0053
247 56	HI	0.0418	0.0015	0.8800	0.0054
247 57	HI	0.0441	0.0017	0.8965	0.0060
247 58	HI	0.0456	0.0018	0.9121	0.0056
247 59	HI	0.0456	0.0018	0.9139	0.0055
248 59	HI	0.0453	0.0017	0.9349	0.0058
248 60	HI	0.0470	0.0016	0.9176	0.0064
248 61	HI	0.0471	0.0016	0.9160	0.0055
248 62	HI	0.0521	0.0019	0.9290	0.0052
248 63	HI	0.0578	0.0018	0.9159	0.0052
248 64	HI	0.0680	0.0020	0.8996	0.0054
248 65	HI	0.0944	0.0022	0.8736	0.0054
248 66	JK	0.1778	0.0029	1.0051	0.0055
248 67	JK	0.2071	0.0034	0.9863	0.0055
248 68	IJ	0.2114	0.0030	0.9854	0.0055
248 69	JK	0.2248	0.0039	0.9686	0.0055
248 71	IJ	0.1866	0.0035	0.8537	0.0050
248 72	JK	0.1693	0.0030	0.7686	0.0050
248 73	JK	0.1307	0.0025	0.6727	0.0040
248 74	IJ	0.0557	0.0018	0.4857	0.0037
248 75	IJ	0.0296	0.0014	0.3891	0.0032
248 76	IJ	0.0172	0.0017	0.3020	0.0037
248 77	IJ	0.0092	0.0011	0.2279	0.0024
248 78	IJ	0.0072	0.0018	0.1754	0.0021
147 50	HI	0.0425	0.0015	0.7879	0.0046
147 51	HI	0.0450	0.0018	0.8137	0.0047
148 52	HI	0.0446	0.0015	0.8272	0.0047
148 53	HI	0.0439	0.0017	0.8513	0.0048
148 54	HI	0.0456	0.0015	0.8788	0.0049
148 55	HI	0.0475	0.0016	0.9135	0.0052
148 56	HI	0.0463	0.0015	0.9451	0.0060
147 56	HI	0.0475	0.0015	0.9314	0.0062
147 57	HI	0.0487	0.0015	0.9558	0.0056
147 58	HI	0.0529	0.0020	0.9714	0.0054
147 59	HI	0.0510	0.0020	0.9836	0.0060
148 59	HI	0.0497	0.0020	0.9892	0.0055
148 60	HI	0.0507	0.0021	0.9845	0.0055
148 61	HI	0.0501	0.0024	0.9775	0.0054

TABLE 16.6 (contd)

Matrix	Loc ^a	²³⁸ U(n,f) ^c		²³⁸ U(n,γ) ^c	
148 62	HI	0.0544	0.0021	0.9911	0.0060
148 63	HI	0.0630	0.0020	0.9910	0.0055
148 64	HI	0.0783	0.0024	0.9940	0.0056
148 65	HI	0.1080	0.0026	0.9798	0.0055
148 66	FG	0.2016	0.0032	1.1238	0.0061
148 67	FG	0.2344	0.0035	1.0972	0.0065
148 68	GH	0.2314	0.0033	1.0702	0.0063
148 69	FG	0.2426	0.0033	1.0420	0.0061
148 71	GH	0.1964	0.0030	0.9026	0.0055
148 72	FG	0.1805	0.0033	0.8124	0.0052
148 73	FG	0.1394	0.0028	0.7042	0.0047
148 74	GH	0.0609	0.0018	0.5133	0.0038
148 75	GH	0.0310	0.0013	0.4074	0.0033
148 76	GH	0.0176	0.0012	0.3175	0.0028
148 77	GH	0.0102	0.0011	0.2425	0.0028
148 78	GH	0.0063	0.0010	0.1862	0.0023

Data at Z = 178.6 mm^b

247 50	JK	0.0947	0.0023	0.5809	0.0041
247 51	IJ	0.1023	0.0020	0.6627	0.0049
248 52	IJ	0.1055	0.0024	0.7279	0.0044
248 53	IJ	0.1094	0.0024	0.8112	0.0048
248 54	JK	0.1285	0.0025	0.8543	0.0049
248 55	JK	0.1351	0.0023	0.8983	0.0050
248 56	IJ	0.1216	0.0022	0.9560	0.0058
247 56	JK	0.1345	0.0023	0.9367	0.0052
247 57	IJ	0.1231	0.0023	0.9804	0.0058
247 58	JK	0.1384	0.0026	0.9892	0.0054
247 59	JK	0.1405	0.0026	0.9687	0.0057
248 59	IJ	0.1267	0.0026	1.0065	0.0060
248 60	JK	0.1444	0.0028	0.9475	0.0057
248 61	IJ	0.1299	0.0024	0.9482	0.0057
248 62	IJ	0.1321	0.0025	0.9385	0.0052
248 63	JK	0.1461	0.0025	0.9116	0.0051
248 64	JK	0.1482	0.0026	0.8793	0.0050
248 65	IJ	0.1487	0.0023	0.8639	0.0053
248 66	JK	0.1745	0.0030	0.8433	0.0053
248 67	JK	0.1883	0.0033	0.8417	0.0052
248 68	IJ	0.1864	0.0029	0.8355	0.0048
248 69	JK	0.1970	0.0032	0.8307	0.0049
248 71	IJ	0.1531	0.0029	0.7788	0.0046
248 72	JK	0.1466	0.0027	0.6818	0.0042
248 73	JK	0.1120	0.0024	0.5988	0.0040
248 74	IJ	0.0495	0.0018	0.4252	0.0034
248 75	IJ	0.0250	0.0017	0.3430	0.0030
248 76	IJ	0.0162	0.0012	0.2765	0.0027
248 77	IJ	0.0085	0.0011	0.2024	0.0024
248 78	IJ	0.0069	0.0010	0.1574	0.0019

TABLE 16.6 (contd)

Matrix	Loc ^a	$^{238}\text{U}(n,f)^c$	$^{238}\text{U}(n,\gamma)^c$
147 50	FG	0.1556 0.0027	1.0675 0.0058
147 51	GH	0.1508 0.0026	1.0511 0.0057
148 52	GH	0.1532 0.0029	1.0506 0.0061
148 53	GH	0.1526 0.0026	1.0633 0.0057
148 54	FG	0.1671 0.0028	1.0762 0.0058
148 55	FG	0.1704 0.0025	1.1014 0.0063
148 56	GH	0.1583 0.0026	1.1575 0.0066
147 56	FG	0.1729 0.0027	1.1401 0.0065
147 57	GH	0.1636 0.0029	1.1856 0.0063
147 58	FG	0.1663 0.0030	1.2103 0.0065
147 59	FG	0.1810 0.0028	1.1745 0.0063
148 59	GH	0.1610 0.0030	1.2543 0.0068
148 60	FG	0.1794 0.0029	1.1830 0.0068
148 61	GH	0.1773 0.0029	1.1866 0.0064
148 62	GH	0.1833 0.0033	1.1992 0.0064
148 63	FG	0.1982 0.0031	1.2010 0.0068
148 64	FG	0.2078 0.0033	1.2056 0.0064
148 65	IJ	0.2180 0.0035	1.1885 0.0065
148 66	FG	0.2451 0.0038	1.1728 0.0069
148 67	FG	0.2569 0.0044	1.1573 0.0071
148 68	GH	0.2369 0.0033	1.1154 0.0072
148 69	FG	0.2461 0.0031	1.0640 0.0069
148 71	GH	0.1906 0.0031	0.9464 0.0058
148 72	FG	0.1757 0.0030	0.8096 0.0048
148 73	FG	0.1345 0.0025	0.7106 0.0043
148 74	GH	0.0592 0.0017	0.4952 0.0037
148 75	GH	0.0297 0.0014	0.3993 0.0034
148 76	GH	0.0162 0.0012	0.3076 0.0028
148 77	GH	0.0129 0.0013	0.2276 0.0026
148 78	GH	0.0083 0.0014	0.1802 0.0024

Data at Z = 280.2 mm^b

247 50	JK	0.1159 0.0023	0.5330 0.0035
247 51	IJ	0.1220 0.0021	0.5871 0.0041
248 52	IJ	0.1247 0.0023	0.6414 0.0045
248 53	IJ	0.1344 0.0022	0.7042 0.0049
248 54	JK	0.1480 0.0027	0.7544 0.0045
248 55	JK	0.1591 0.0025	0.7852 0.0050
248 56	IJ	0.1447 0.0025	0.8233 0.0051
247 56	JK	0.1580 0.0027	0.8318 0.0053
247 57	IJ	0.1482 0.0023	0.8483 0.0053
247 58	JK	0.1615 0.0027	0.8677 0.0055
247 59	JK	0.1613 0.0026	0.8449 0.0058
248 59	IJ	0.1442 0.0025	0.8678 0.0058
248 60	JK	0.1607 0.0027	0.8392 0.0060
248 61	IJ	0.1547 0.0024	0.8174 0.0052
248 62	IJ	0.1506 0.0028	0.7985 0.0047
248 63	JK	0.1560 0.0029	0.7730 0.0046

TABLE 16.6 (contd)

Matrix	Loc ^a	²³⁸ U(n,f) ^c		²³⁸ U(n,γ) ^c	
248 64	JK	0.1596	0.0028	0.7401	0.0045
248 65	IJ	0.1456	0.0024	0.7258	0.0052
248 66	JK	0.1687	0.0029	0.7139	0.0048
248 67	JK	0.1728	0.0028	0.7070	0.0047
248 68	IJ	0.1580	0.0031	0.7177	0.0043
248 69	JK	0.1674	0.0031	0.7112	0.0046
248 71	IJ	0.1334	0.0028	0.6346	0.0041
248 72	JK	0.1266	0.0028	0.5737	0.0038
248 73	JK	0.0989	0.0025	0.5055	0.0035
248 74	IJ	0.0395	0.0014	0.3623	0.0030
248 75	IJ	0.0219	0.0016	0.2873	0.0027
248 76	IJ	0.0140	0.0011	0.2248	0.0024
248 77	IJ	0.0088	0.0010	0.1730	0.0021
248 78	IJ	0.0061	0.0012	0.1349	0.0018
147 50	FG	0.1953	0.0032	1.0536	0.0059
147 51	GH	0.1910	0.0028	1.0266	0.0057
148 52	GH	0.1965	0.0033	1.0230	0.0056
148 53	GH	0.1957	0.0031	1.0405	0.0062
148 54	FG	0.2179	0.0032	1.0512	0.0058
148 55	FG	0.2199	0.0035	1.0662	0.0059
148 56	GH	0.1981	0.0029	1.0905	0.0063
147 56	FG	0.2165	0.0032	1.0887	0.0060
147 57	GH	0.1999	0.0031	1.1173	0.0060
147 58	FG	0.2170	0.0034	1.1469	0.0063
147 59	FG	0.2182	0.0033	1.1328	0.0061
148 59	GH	0.1979	0.0033	1.1554	0.0063
148 60	FG	0.2252	0.0033	1.1358	0.0062
148 61	GH	0.2142	0.0034	1.1399	0.0062
148 62	GH	0.2266	0.0033	1.1356	0.0062
148 63	FG	0.2460	0.0033	1.1456	0.0067
148 64	FG	0.2506	0.0036	1.1569	0.0063
148 65	IJ	0.2390	0.0036	1.1468	0.0063
148 66	FG	0.2511	0.0036	1.1348	0.0065
148 67	FG	0.2528	0.0036	1.1056	0.0061
148 68	GH	0.2277	0.0030	1.0586	0.0062
148 69	FG	0.2349	0.0038	1.0132	0.0068
148 71	GH	0.1773	0.0030	0.8359	0.0052
148 72	FG	0.1615	0.0031	0.7380	0.0044
148 73	FG	0.1241	0.0025	0.6396	0.0039
148 74	GH	0.0515	0.0017	0.4498	0.0043
148 75	GH	0.0295	0.0014	0.3654	0.0031

TABLE 16.6 (contd)

Matrix	Loc ^a	²³⁸ U(n,f) ^c	²³⁸ U(n,γ) ^c
148 76	GH	0.0138 0.0013	0.2749 0.0026
148 77	GH	0.0081 0.0011	0.2126 0.0026
148 78	GH	0.0080 0.0013	0.1623 0.0020

^aIn-drawer column which designates the foil location in the drawer. The ²³⁸U foils were centered on the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10⁻¹⁸ fissions or captures per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 16.7 Basic Reaction Rate Data for Axial Distributions in ZPPR-17C

Matrix	z, mm ^a	Loc ^b	²³⁹ Pu(n,f) ^c	²³⁵ U(n,f) ^c	²³⁸ U(n,f) ^c	²³⁸ U(n,γ) ^c
248 51	1034.7	TC		0.900 0.006		
248 51	983.9	TC		1.356 0.009		
248 51	933.1	TC		1.787 0.010		
248 51	875.9	TC		2.043 0.012		
248 51	825.1	TC		2.022 0.012		
248 51	737.4	IJ	1.306 0.024	1.480 0.008	0.0057 0.0012	0.2233 0.0021
248 51	686.6	IJ	1.415 0.016	1.648 0.010	0.0100 0.0009	0.2415 0.0021
248 51	635.8	IJ	1.593 0.016	1.891 0.010	0.0125 0.0011	0.2760 0.0020
248 51	585.0	IJ	1.860 0.016	2.146 0.011	0.0201 0.0012	0.3161 0.0024
248 51	534.2	IJ	2.161 0.019	2.472 0.012	0.0342 0.0014	0.3491 0.0026
248 51	483.4	JK	2.510 0.019	2.732 0.013	0.0718 0.0019	0.3906 0.0028
248 51	432.6	JK	2.885 0.021	3.053 0.015	0.0919 0.0021	0.4347 0.0034
248 51	381.8	JK	3.182 0.021	3.408 0.016	0.1046 0.0021	0.4755 0.0036
248 51	331.0	JK	3.420 0.024	3.642 0.017	0.1117 0.0020	0.5020 0.0036
248 51	280.2	JK	3.515 0.024	3.770 0.038	0.1132 0.0022	0.5285 0.0034
248 51	229.4	JK	3.582 0.023	3.850 0.018	0.1103 0.0020	0.5477 0.0034
248 51	178.6	JK	3.561 0.023	4.080 0.036	0.0920 0.0018	0.5791 0.0039
248 51	127.8	HI	3.909 0.024	4.540 0.021	0.0498 0.0017	0.5371 0.0035
248 51	100.4	HI	4.020 0.025	4.778 0.022	0.0420 0.0014	0.5607 0.0035
248 51	77.0	HI	4.170 0.025	4.968 0.022	0.0363 0.0014	0.5806 0.0039
248 51	49.6	HI	4.375 0.025	5.255 0.034	0.0347 0.0014	0.6126 0.0040
248 51	26.2	HI	4.735 0.027	5.607 0.025	0.0333 0.0016	0.6473 0.0042
148 51	26.2	HI	5.625 0.032	6.548 0.032	0.0383 0.0014	0.7550 0.0043
148 51	49.6	HI	5.924 0.031	6.885 0.040	0.0437 0.0014	0.7872 0.0048
148 51	77.0	HI	6.267 0.034	7.103 0.034	0.0525 0.0016	0.8236 0.0050
148 51	100.4	HI	6.482 0.034	7.260 0.031	0.0593 0.0016	0.8501 0.0047
148 51	127.8	HI	6.596 0.035	7.316 0.031	0.0761 0.0018	0.8598 0.0051
148 51	178.6	FG	6.486 0.035	7.158 0.049	0.1598 0.0027	1.0616 0.0057
148 51	229.4	FG	6.711 0.036	7.116 0.030	0.1888 0.0027	1.0447 0.0056
148 51	280.2	FG	6.892 0.036	7.267 0.097	0.1998 0.0028	1.0459 0.0056
148 51	331.0	FG	6.769 0.035	7.081 0.029	0.2058 0.0030	1.0143 0.0061
148 51	381.8	FG	6.535 0.035	6.833 0.028	0.1914 0.0025	0.9875 0.0054
148 51	432.6	FG	6.100 0.032	6.487 0.026	0.1718 0.0025	0.9395 0.0055
148 51	483.4	FG	5.585 0.031	6.016 0.025	0.1415 0.0025	0.8945 0.0050
148 51	534.2	GH		5.863 0.026	0.0631 0.0020	0.8571 0.0049
148 51	585.0	GH		5.434 0.025	0.0396 0.0017	0.8125 0.0047
148 51	635.8	GH		5.035 0.027	0.0267 0.0015	0.7457 0.0048
148 51	686.6	GH		4.601 0.022	0.0182 0.0015	0.6800 0.0041
148 51	737.4	GH		4.244 0.021	0.0102 0.0012	0.6324 0.0049
148 51	825.1	TC		4.668 0.021		
148 51	875.9	TC		4.350 0.024		
148 51	933.1	TC		3.453 0.023		
148 51	983.9	TC		2.550 0.013		
148 51	1034.7	TC		1.597 0.009		
238 62	875.9	TC		1.290 0.010		
238 62	825.1	TC		1.232 0.009		
238 62	737.4	IJ		1.061 0.009	0.0066 0.0012	0.1846 0.0020

TABLE 16.7 (contd)

Matrix	z, mm ^a	Loc ^b	²³⁹ Pu(n,f) ^c	²³⁵ U(n,f) ^c	²³⁸ U(n,f) ^c	²³⁸ U(n,γ) ^c
238 62	686.6	IJ		1.197 0.010	0.0112 0.0009	0.1999 0.0018
238 62	635.8	IJ		1.415 0.011	0.0149 0.0010	0.2357 0.0022
238 62	585.0	IJ		1.696 0.011	0.0205 0.0013	0.2820 0.0026
238 62	534.2	IJ		2.041 0.014	0.0337 0.0013	0.3213 0.0024
238 62	483.4	JK		2.350 0.015	0.0690 0.0018	0.3678 0.0031
238 62	432.6	JK		2.777 0.017	0.0958 0.0023	0.4253 0.0030
238 62	381.8	JK		3.165 0.017	0.1124 0.0023	0.4748 0.0032
238 62	331.0	JK		3.488 0.018	0.1257 0.0026	0.5288 0.0035
238 62	280.2	JK		3.783 0.024	0.1325 0.0024	0.5797 0.0040
238 62	229.4	JK		4.067 0.020	0.1419 0.0029	0.6206 0.0039
238 62	178.6	JK		4.335 0.015	0.1397 0.0026	0.6720 0.0040
238 62	102.4	JK		4.838 0.024	0.1351 0.0025	0.7597 0.0045
238 62	51.6	JK		5.322 0.025	0.1429 0.0028	0.8378 0.0048
138 62	51.6	FG		7.382 0.023	0.1713 0.0026	1.0795 0.0058
138 62	102.4	FG		7.916 0.033	0.1898 0.0030	1.1477 0.0061
138 62	178.6	FG		8.158 0.048	0.2185 0.0027	1.1662 0.0066
138 62	229.4	FG		8.146 0.035	0.2291 0.0030	1.1574 0.0061
138 62	280.2	FG		7.998 0.035	0.2336 0.0031	1.1305 0.0060
138 62	331.0	FG		7.670 0.033	0.2169 0.0029	1.0798 0.0057
138 62	381.8	FG		7.173 0.031	0.2057 0.0028	1.0183 0.0055
138 62	432.6	FG		6.551 0.030	0.1781 0.0032	0.9328 0.0052
138 62	483.4	FG		5.912 0.028	0.1392 0.0025	0.8572 0.0049
138 62	534.2	GH		5.544 0.025	0.0640 0.0020	0.7899 0.0051
138 62	585.0	GH		5.031 0.024	0.0354 0.0017	0.7310 0.0053
138 62	635.8	GH		4.477 0.022	0.0245 0.0016	0.6596 0.0043
138 62	686.6	GH		4.005 0.020	0.0165 0.0013	0.5925 0.0038
138 62	737.4	GH		3.621 0.019	0.0117 0.0012	0.5321 0.0036
138 62	825.1	TC		3.601 0.020		
138 62	875.9	TC		3.378 0.018		
248 70	737.4	IJ		1.406 0.009	0.0072 0.0010	0.2120 0.0019
248 70	686.6	IJ		1.597 0.009	0.0077 0.0010	0.2366 0.0020
248 70	635.8	IJ		1.875 0.010	0.0127 0.0011	0.2808 0.0022
248 70	585.0	IJ		2.167 0.012	0.0195 0.0011	0.3276 0.0025
248 70	534.2	IJ		2.538 0.014	0.0348 0.0013	0.3707 0.0029
248 70	483.4	JK		2.894 0.015	0.0784 0.0019	0.4244 0.0032
248 70	432.6	JK		3.367 0.016	0.1036 0.0020	0.4811 0.0036
248 70	381.8	JK		3.895 0.018	0.1245 0.0023	0.5523 0.0037
248 70	331.0	JK		4.380 0.019	0.1431 0.0027	0.6221 0.0038
248 70	280.2	JK		4.908 0.046	0.1539 0.0027	0.6870 0.0036
248 70	229.4	JK		5.290 0.027	0.1729 0.0026	0.7535 0.0044
248 70	178.6	JK		5.755 0.046	0.1904 0.0028	0.8002 0.0050
248 70	102.4	JK		6.226 0.027	0.2070 0.0031	0.8785 0.0050
248 70	51.6	JK		6.631 0.059	0.2138 0.0029	0.9227 0.0055
148 70	51.6	FG		7.069 0.064	0.2331 0.0029	0.9860 0.0054
148 70	102.4	FG		7.161 0.033	0.2362 0.0033	0.9922 0.0057
148 70	178.6	FG		7.188 0.026	0.2289 0.0030	0.9948 0.0055

TABLE 16.7 (contd)

Matrix	z, mm ^a	Loc ^b	²³⁹ Pu(n,f) ^c	²³⁵ U(n,f) ^c	²³⁸ U(n,f) ^c	²³⁸ U(n,γ) ^c
148 70	229.4	FG		6.966 0.029	0.2242 0.0029	0.9738 0.0053
148 70	280.2	FG		6.712 0.034	0.2157 0.0031	0.9362 0.0052
148 70	331.0	FG		6.232 0.026	0.2009 0.0030	0.8761 0.0050
148 70	381.8	FG		5.696 0.024	0.1844 0.0026	0.8007 0.0045
148 70	432.6	FG		5.122 0.022	0.1547 0.0027	0.7305 0.0044
148 70	483.4	FG		4.551 0.020	0.1153 0.0022	0.6562 0.0044
148 70	534.2	GH		4.155 0.020	0.0539 0.0016	0.6127 0.0038
148 70	585.0	GH		3.702 0.017	0.0291 0.0012	0.5503 0.0037
148 70	635.8	GH		3.244 0.019	0.0204 0.0011	0.4830 0.0031
148 70	686.6	GH		2.827 0.015	0.0108 0.0011	0.4244 0.0029
148 70	737.4	GH		2.548 0.013	0.0091 0.0010	0.3752 0.0029

^aDistance from the reactor interface to the center of the foil.

^bIn-drawer column which designates the foil location in the drawer. The ²³⁵U foils were centered 13.8 mm above, the ²³⁸U foils were centered on, and the ²³⁹Pu foils were centered 13.8 mm below the mid-height of the drawer.

^cExperimental results in units of 10⁻¹⁸ fissions or captures per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

17. IN-CELL REACTION RATE MEASUREMENTS AND CELL FACTORS FOR ZPPR-17B AND ZPPR-17C (J. M. Gasidlo and D. W. Maddison)

17.1 Introduction

Reaction rate maps are measured by placing foils in matrix positions chosen to measure specific distributions as a radial map or an axial distribution. These "mapping" foils are always placed in the same location in a drawer for a specific type of cell. Then, cell factors are used to convert the reaction rates measured in the mapping foil to reaction rates averaged over the materials used to construct the cell.

17.2 Description of the In-Cell Measurements

Cell factors were measured in special experiments where the ordinary plates used to build the reactor were replaced with special plates. Ordinary ZPPR fuel plates were replaced with two half-thickness fuel plates for which the sum of the fuel alloy is equal to one ordinary fuel plate. Foils were placed between and on the outer surfaces of the two half-thickness fuel plates. The 6.35 mm U_3O_8 and 3.175 mm depleted uranium metal plates were replaced with special plates that have slots machined across the width of the plates in which special foils can be placed to measure the integral of the reaction rate across the width of the plate. Because the number of special plates is limited, the 6.35 mm U_3O_8 plates were sometimes replaced with two 3.175 mm U_3O_8 plates (the 3.175 mm depleted uranium metal plates with 1.588 mm plates) and the plate average was measured by a foil placed between the two plates.

The foils were first placed in stainless steel or aluminum holders, or in the slots of the special plates. The foil holders were then placed between the vertical columns* of materials in the drawers. The

*ZPPR drawers are divided into sixteen 3.175 mm (1/8 in.) wide vertical columns designated by letters A through P. The letter A denotes the column at the left as one faces the drawer. The letters FG, for example, indicate the foil is between columns F and G, and is centered 19.050 mm (0.750 in.) from the left side of the drawer.

special plates replaced the normal plates used in the drawers. (These plates are designated by a negative sign in front of the in-drawer column location.) Foils were placed in, between or on the surface of any plates containing the foil material: ^{239}Pu foils are used only at fuel plates whereas ^{235}U and ^{238}U foils are used at fuel plates, depleted uranium metal plates and depleted uranium oxide plates. In all cells at least one foil of each type was placed in the "mapping foil" location.

In ZPPR-17B the cell studies were directed towards measuring cell factors in those cells with environments different from the ZPPR-17A cells. These were the matrix positions immediately adjacent to the control rod positions (CRPs). The ZPPR-17A cell factors (see ANL-ZPR-481, Section 8) were used in all matrix positions not immediately adjacent to CRPs. In ZPPR-17C the cell studies were directed towards matrix positions immediately adjacent to control rods (CRs) and to the central blanket adjacent to CRPs immediately opposite CRs. The ZPPR-17A and -17B cell factors were used in all other matrix positions.

For the cell studies adjacent to CRPs and CRs, half of the cell was measured on one side of the CRP (or CR) and half on the other side. Even then, there was not sufficient room in the cell to contain the necessary foils and foil holder. In that case, the column of 6.35 mm U_3O_8 plates on the side of the cell away from the cell studies was replaced with a 3.18 mm column of U_3O_8 plates and a 1.59 mm column of alternating depleted uranium metal and stainless steel plates. This substitution made room for the cell study foils and changed the uranium content in that column by 0.2%.

The basic data for the cell studies in ZPPR-17B are given in Tables 17.1 - 17.3 and for ZPPR-17C in Tables 17.5 - 17.7. The data are given in units of 10^{-18} fission or captures per second per atom in the irradiated foil at an estimated reactor power of one watt. The second number associated with each reaction is one standard deviation estimate of the uncertainty. As described in Section 17.4 the uncertainties given in the tables are solely due to counting statistics and data reduction. They

include the effects of peak integration, interference peak corrections, corrections for other reactions in the foils, irradiation history and foil positioning in the counter system.

17.3 Derivation of Cell-Averaging Factors

The results of special experiments (see Brumbach and Gasidlo ANL-85-44) were used to convert the data from the special plate measurements to in-plate or plate-averaged reaction rates. These plate-averaged reaction rates were divided by calculated values to remove the effects of the gross reactor flux distribution, atom-weighted plate-by-plate to determine the cell-averaged reaction rate, and divided by the mapping foil value to determine the cell factor. This process is described in greater detail in ANL-85-44.

17.4 Discussion of Cell Factors and Uncertainties

The cell factors for ZPPR-17B are given in Table 17.4 and for ZPPR-17C in Table 17.8. The second number associated with each cell factor is a one standard deviation estimate of the uncertainty. The uncertainties in the cell factors are solely due to propagation of the uncertainties in the basic data tables. They are systematic for the use of a single cell factor, but they are random when applied to the cell-averaged reaction rates for different cell factors. The listed uncertainties do not include systematic uncertainties such as deriving plate-averaged reaction rates from half-thickness plate data or other uncertainties such as those due to detector calibrations. See ANL-85-44 for a discussion of these additional uncertainties.

Under the heading "ENVIRONMENT" is listed the reactor region in which the cell factor can be used, and the type of cell and cell environment for which the cell factor is applicable. The key for reactor regions is: IC is a fueled drawer containing an internal blanket region, OC is a fueled drawer not containing an internal blanket region, RB is a radial blanket drawer and RR is a radial reflector drawer. For the second part, the mapping foil is always located in the center drawer, the center drawer has

the two indicated drawers on either side, and the mapping foil is located closer to the left-hand drawer. (See Section 16.2 on the method used for specifying the in-drawer location of mapping foils.) The key is: SC is a drawer with one fuel column, DC is a drawer with two fuel columns, and F is any fueled drawer. The code OC F/SC/RB means that the cell factor is used in the outer core for a drawer with one fuel column that has any fueled drawer on one side and a radial blanket drawer on the other with the mapping foil closer to the fueled drawer.

The cell factors for drawers immediately adjacent to CRPs or CRs and for axial traverses are listed for the matrix position in which they were used. Cell factors were not measured for every position listed in the table, for example $z = 229.4$ or 331.0 mm. These cell factors were derived by averaging the cell factors and uncertainties from the axial positions on either side, i.e., the cell factor at 229.4 mm is the average of the cell factors at 178.6 and 280.2 mm.

One limitation on the use of cell factors must be discussed. Note that the cell factors for $^{239}\text{Pu}(n,f)$ in all blanket regions and $^{235}\text{U}(n,f)$ in the radial reflector are given as unity. Also note that the "measured" cell factors for ^{235}U are nearly unity everywhere. As foil positions in the blankets and reflectors are displaced farther from the fueled regions, neutron self-shielding can vary from $\sim 1\%$ near the core to $>5\%$ at the blanket and reflector boundaries. Hence, cross sections self-shielded for the mapping foils must be used in these regions. This is true even for the "cell-averaged" $^{235}\text{U}(n,f)$ mapping foils. (Since the cell factor is a ratio of measured reaction rates, the self-shielding will cancel.) Note that for ^{238}U measurements in the blankets, the mapping foils are self-shielded by the blanket materials. Hence, neutron self-shielding in the ^{238}U mapping foils will be much smaller than for ^{239}Pu and ^{235}U foils.

TABLE 17.1 Basic Data for ^{239}Pu Cell Studies in ZPPR-17B

Matrix	Loc ^a	z, mm ^b	$^{239}\text{Pu}(n, f)^c$	z, mm ^b	$^{239}\text{Pu}(n, f)^c$
Measurements in Cells with One Fuel Column					
148 56	GH	178.6	6.581 0.034	229.4	6.476 0.031
148 56	HI	178.6	6.407 0.032	229.4	6.334 0.032
148 56	IJ	178.6	6.694 0.039	229.4	6.565 0.030
148 56	GH	280.2	6.350 0.030		
148 56	HI	280.2	6.317 0.033		
148 56	IJ	280.2	6.518 0.034		
Measurements in Cells with Two Fuel Columns					
249 51	LM	178.6	6.288 0.029	280.2	6.147 0.031
249 51	KL	178.6	5.997 0.034	280.2	6.076 0.030
249 51	JK	178.6	6.257 0.031	280.2	6.112 0.030
148 51	JK	178.6	6.130 0.032	280.2	6.130 0.031
148 51	KL	178.6	5.979 0.030	280.2	5.966 0.031
148 51	LM	178.6	6.202 0.029	280.2	6.071 0.028
249 48	LM	381.8	5.642 0.029	483.4	4.676 0.026
249 48	KL	381.8	5.571 0.028	483.4	4.590 0.023
249 48	JK	381.8	5.633 0.030	483.4	4.672 0.027
148 48	JK	381.8	5.578 0.031	483.4	4.743 0.025
148 48	KL	381.8	5.530 0.030	483.4	4.593 0.025
148 48	LM	381.8	5.740 0.032	483.4	4.787 0.025

^aIn-drawer column which designates the foil location in the drawer. The ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10^{-18} fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.2 Basic Data for ^{235}U Cell Studies in ZPPR-17B

Matrix	Loc ^a	z,mm ^b	$^{235}\text{U}(n,f)^c$	z,mm ^b	$^{235}\text{U}(n,f)^c$
Measurements in Cells with One Fuel Column					
149 56	AB	178.6	7.467 0.030	229.4	7.076 0.029
148 56	GH	178.6	7.350 0.030	229.4	7.023 0.028
148 56	HI	178.6	7.309 0.033	229.4	7.019 0.030
148 56	IJ	178.6	7.506 0.030	229.4	7.166 0.028
149 56	OP	178.6	7.920 0.031	229.4	7.519 0.030
149 56	AB	280.2	6.862 0.028		
148 56	GH	280.2	6.895 0.028		
148 56	HI	280.2	6.841 0.027		
148 56	IJ	280.2	6.979 0.027		
149 56	OP	280.2	7.192 0.029		
Measurements in Cells with Two Fuel Columns					
Central Blanket Cells					
249 51	OP	26.2	8.311 0.035	77.0	8.203 0.035
249 51	II	26.2	8.070 0.034	77.0	7.994 0.035
248 51	HI	26.2	8.002 0.032	77.0	7.896 0.032
149 51	HI	26.2	8.097 0.032	77.0	7.868 0.031
148 51	II	26.2	8.023 0.032	77.0	7.889 0.031
148 51	OP	26.2	8.095 0.031	77.0	7.979 0.036
249 51	OP	127.8	7.829 0.034		
249 51	II	127.8	7.626 0.033		
248 51	HI	127.8	7.589 0.031		
149 51	HI	127.8	7.598 0.031		
148 51	II	127.8	7.568 0.031		
148 51	OP	127.8	7.575 0.030		
Core Cells					
248 51	OP	178.6	7.181 0.029	280.2	6.675 0.028
249 51	LM	178.6	7.062 0.033	280.2	6.647 0.030
249 51	KL	178.6	6.820 0.030	280.2	6.458 0.030
249 51	JK	178.6	6.961 0.032	280.2	6.572 0.031
148 51	JK	178.6	6.907 0.028	280.2	6.519 0.027
148 51	KL	178.6	6.801 0.030	280.2	6.405 0.027
148 51	LM	178.6	6.855 0.030	280.2	6.463 0.027
149 51	OP	178.6	6.948 0.030	280.2	6.484 0.027
248 48	OP	381.8	5.900 0.026	483.4	5.191 0.025
249 48	LM	381.8	5.926 0.028	483.4	5.164 0.026
249 48	KL	381.8	5.878 0.028	483.4	5.045 0.024
249 48	JK	381.8	5.971 0.028	483.4	5.141 0.024
148 48	JK	381.8	6.057 0.029	483.4	5.181 0.026
148 48	KL	381.8	5.949 0.028	483.4	5.114 0.025

TABLE 17.2 (contd)

Matrix	Loc ^a	z, mm ^b	²³⁵ U(n,f) ^c	z, mm ^b	²³⁵ U(n,f) ^c
148 48	LM	381.8	6.068 0.028	483.4	5.223 0.026
149 48	OP	381.8	6.115 0.028	483.4	5.320 0.023

Axial Blanket Cells

249 51	OP	534.2	5.110 0.023	585.0	4.736 0.023
249 51	JJ	534.2	4.964 0.024	585.0	4.592 0.021
248 51	IJ	534.2	5.041 0.023	585.0	4.661 0.020
248 51	GH	534.2	4.942 0.021	585.0	4.593 0.020
149 51	GH	534.2	4.976 0.021	585.0	4.684 0.021
149 51	IJ	534.2	4.979 0.021	585.0	4.626 0.020
148 51	JJ	534.2	4.913 0.021	585.0	4.538 0.019
148 51	OP	534.2	4.992 0.022	585.0	4.628 0.021
249 51	OP	635.8	4.305 0.022	686.6	3.994 0.019
249 51	JJ	635.8	4.233 0.021	686.6	3.867 0.024
248 51	IJ	635.8	4.264 0.020	686.6	3.861 0.018
248 51	GH	635.8	4.218 0.019	686.6	3.820 0.017
149 51	GH	635.8	4.284 0.019	686.6	3.913 0.018
149 51	IJ	635.8	4.219 0.019	686.6	3.852 0.017
148 51	JJ	635.8	4.144 0.018	686.6	3.771 0.017
148 51	OP	635.8	4.190 0.019	686.6	3.820 0.018
249 51	OP	737.4	3.727 0.020		
249 51	JJ	737.4	3.576 0.018		
248 51	IJ	737.4	3.577 0.017		
248 51	GH	737.4	3.539 0.017		
149 51	GH	737.4	3.667 0.017		
149 51	IJ	737.4	3.577 0.017		
148 51	JJ	737.4	3.512 0.016		
148 51	OP	737.4	3.556 0.017		

^aIn-drawer column which designated the foil location in the drawer. The ²³⁵U foils were centered 13.8 mm above the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10⁻¹⁸ fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.3 Basic Data for ^{238}U Cell Studies in ZPPR-17B

Matrix	z, mm^a	Loc ^b	$^{238}\text{U}(n, f)^c$	$^{238}\text{U}(n, \gamma)^c$
Measurements in Cells with One Fuel Column				
148 56	178.6	-AB	0.1069 0.0019	0.9741 0.0054
148 56	178.6	GH	0.1283 0.0020	1.0930 0.0053
148 56	178.6	HI	0.1385 0.0017	0.9674 0.0048
148 56	178.6	IJ	0.1314 0.0018	1.1303 0.0054
148 56	178.6	-OP	0.1038 0.0020	1.0783 0.0056
148 56	229.4	-AB	0.1298 0.0019	0.9421 0.0049
148 56	229.4	GH	0.1499 0.0018	1.0399 0.0050
148 56	229.4	HI	0.1575 0.0019	0.9343 0.0046
148 56	229.4	IJ	0.1458 0.0020	1.0686 0.0052
148 56	229.4	-OP	0.1236 0.0020	1.0467 0.0053
148 56	280.2	-AB	0.1353 0.0020	0.9152 0.0052
148 56	280.2	GH	0.1549 0.0020	0.9989 0.0052
148 56	280.2	HI	0.1655 0.0021	0.9032 0.0049
148 56	280.2	IJ	0.1516 0.0022	1.0232 0.0055
148 56	280.2	-OP	0.1295 0.0020	0.9953 0.0051
Measurements in Cells with Two Fuel Columns				
Central Blanket Cells				
249 51	26.2	OP	0.0447 0.0014	1.0641 0.0059
249 51	26.2	II	0.0400 0.0015	0.9153 0.0049
248 51	26.2	HI	0.0400 0.0012	0.8900 0.0046
149 51	26.2	HI	0.0400 0.0012	0.8988 0.0048
148 51	26.2	II	0.0401 0.0013	0.9151 0.0049
148 51	26.2	OP	0.0414 0.0012	1.0033 0.0052
249 51	77.0	OP	0.0520 0.0013	1.0434 0.0058
249 51	77.0	II	0.0476 0.0014	0.9014 0.0052
248 51	77.0	HI	0.0496 0.0013	0.8839 0.0050
149 51	77.0	HI	0.0481 0.0012	0.8920 0.0044
148 51	77.0	II	0.0478 0.0014	0.9001 0.0045
148 51	77.0	OP	0.0508 0.0014	0.9871 0.0048
249 51	127.8	OP	0.0732 0.0016	1.0178 0.0057
249 51	127.8	II	0.0688 0.0016	0.8820 0.0047
248 51	127.8	HI	0.0692 0.0013	0.8750 0.0051
149 51	127.8	HI	0.0696 0.0013	0.8686 0.0043
148 51	127.8	II	0.0704 0.0015	0.8827 0.0044
148 51	127.8	OP	0.0703 0.0016	0.9640 0.0047
Core Cells				
249 51	178.6	-OP	0.1171 0.0019	0.9651 0.0053
249 51	178.6	LM	0.1358 0.0017	0.9755 0.0051

TABLE 17.3 (contd)

Matrix	z, mm^a	Loc ^b	$^{238}\text{U}(n, f)^c$		$^{238}\text{U}(n, \gamma)^c$	
249 51	178.6	KL	0.1463	0.0018	0.8855	0.0047
249 51	178.6	JK	0.1413	0.0019	1.0302	0.0057
148 51	178.6	JK	0.1427	0.0020	1.0287	0.0050
148 51	178.6	KL	0.1546	0.0018	0.8742	0.0044
148 51	178.6	LM	0.1395	0.0018	0.9425	0.0050
148 51	178.6	-OP	0.1205	0.0019	0.9039	0.0048
249 51	280.2	-OP	0.1446	0.0021	0.8947	0.0051
249 51	280.2	LM	0.1628	0.0019	0.9059	0.0048
249 51	280.2	KL	0.1750	0.0019	0.8530	0.0046
249 51	280.2	JK	0.1704	0.0021	0.9583	0.0051
148 51	280.2	JK	0.1726	0.0020	0.9500	0.0047
148 51	280.2	KL	0.1817	0.0022	0.8394	0.0043
148 51	280.2	LM	0.1689	0.0018	0.8762	0.0043
148 51	280.2	-OP	0.1522	0.0023	0.8463	0.0051
249 48	381.8	-OP	0.1404	0.0021	0.7741	0.0048
249 48	381.8	LM	0.1604	0.0018	0.7975	0.0043
249 48	381.8	KL	0.1698	0.0021	0.7602	0.0042
249 48	381.8	JK	0.1623	0.0020	0.8556	0.0046
148 48	381.8	JK	0.1581	0.0021	0.8550	0.0046
148 48	381.8	KL	0.1630	0.0020	0.7734	0.0042
148 48	381.8	LM	0.1517	0.0018	0.8292	0.0048
148 48	381.8	-OP	0.1347	0.0019	0.8322	0.0052
249 48	483.4	-OP	0.0990	0.0018	0.6694	0.0041
249 48	483.4	LM	0.1128	0.0018	0.6984	0.0039
249 48	483.4	KL	0.1196	0.0016	0.6601	0.0040
249 48	483.4	JK	0.1148	0.0018	0.7619	0.0042
148 48	483.4	JK	0.1135	0.0016	0.7556	0.0040
148 48	483.4	KL	0.1153	0.0016	0.6665	0.0038
148 48	483.4	LM	0.1101	0.0016	0.7182	0.0040
148 48	483.4	-OP	0.0952	0.0017	0.7202	0.0043
Axial Blanket Cells						
249 51	534.2	OP	0.0580	0.0015	0.6695	0.0042
249 51	534.2	JJ	0.0528	0.0011	0.6025	0.0034
248 51	534.2	IJ	0.0542	0.0013	0.7329	0.0041
248 51	534.2	GH	0.0533	0.0012	0.7363	0.0041
149 51	534.2	GH	0.0526	0.0013	0.7404	0.0038
149 51	534.2	IJ	0.0547	0.0013	0.7325	0.0038
148 51	534.2	JJ	0.0531	0.0015	0.5974	0.0035
148 51	534.2	OP	0.0555	0.0012	0.6288	0.0033
249 51	585.0	OP	0.0347	0.0011	0.6106	0.0036
249 51	585.0	JJ	0.0321	0.0011	0.5446	0.0032
248 51	585.0	IJ	0.0346	0.0012	0.6860	0.0041
248 51	585.0	GH	0.0324	0.0011	0.6862	0.0041

TABLE 17.3 (contd)

Matrix	z, mm ^a	Loc ^b	²³⁸ U(n, f) ^c		²³⁸ U(n, γ) ^c	
149 51	585.0	GH	0.0314	0.0010	0.6898	0.0036
149 51	585.0	IJ	0.0323	0.0011	0.6869	0.0036
148 51	585.0	JJ	0.0339	0.0011	0.5399	0.0030
148 51	585.0	OP	0.0337	0.0011	0.5659	0.0031
249 51	635.8	OP	0.0218	0.0011	0.5432	0.0035
249 51	635.8	JJ	0.0226	0.0010	0.4842	0.0031
248 51	635.8	IJ	0.0194	0.0009	0.6310	0.0039
248 51	635.8	GH	0.0217	0.0014	0.6360	0.0040
149 51	635.8	GH	0.0203	0.0010	0.6438	0.0034
149 51	635.8	IJ	0.0210	0.0010	0.6319	0.0034
148 51	635.8	JJ	0.0217	0.0010	0.4804	0.0027
148 51	635.8	OP	0.0219	0.0009	0.5062	0.0028
249 51	686.6	OP	0.0152	0.0009	0.4869	0.0030
249 51	686.6	JJ	0.0143	0.0009	0.4293	0.0027
248 51	686.6	IJ	0.0139	0.0009	0.5822	0.0033
248 51	686.6	GH	0.0120	0.0010	0.5821	0.0035
149 51	686.6	GH	0.0141	0.0010	0.5899	0.0035
149 51	686.6	IJ	0.0122	0.0009	0.5754	0.0033
148 51	686.6	JJ	0.0137	0.0010	0.4164	0.0025
148 51	686.6	OP	0.0133	0.0009	0.4482	0.0028
249 51	737.4	OP	0.0105	0.0008	0.4317	0.0028
249 51	737.4	JJ	0.0091	0.0009	0.3766	0.0025
248 51	737.4	IJ	0.0068	0.0010	0.5364	0.0031
248 51	737.4	GH	0.0100	0.0008	0.5315	0.0032
149 51	737.4	GH	0.0082	0.0009	0.5426	0.0032
149 51	737.4	IJ	0.0095	0.0008	0.5353	0.0029
148 51	737.4	JJ	0.0101	0.0008	0.3721	0.0025
148 51	737.4	OP	0.0091	0.0009	0.3964	0.0023

^aDistance from the reactor interface to the center of the foil.

^bIn-drawer column which designates the foil location in the drawer. The ²³⁸U foils were centered on the mid-height of the drawer. A negative sign designates a plate-spanning averaging foil.

^cExperimental results in units of 10⁻¹⁸ fissions or captures per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.4 Cell-Averaging Factors for ZPPR-17B

$^{239}\text{Pu}(n,f)^a$	$^{235}\text{U}(n,f)^a$	$^{238}\text{U}(n,f)^a$	$^{238}\text{U}(n,\gamma)$	Environment ^b	z, mm^c
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	IC 147-50	51.6
0.9853 .0056	0.9985 .0046	0.987 .015	0.8610 .0051	IC 147-50	178.6
0.9914 .0054	0.9948 .0048	0.990 .013	0.8826 .0052	IC 147-50	280.2
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	IC 148-56	51.6
0.9885 .0058	1.0132 .0047	0.933 .016	0.9003 .0052	IC 148-56	178.6
1.0021 .0056	1.0010 .0044	0.967 .015	0.9201 .0056	IC 148-56	280.2
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	IC 147-57,58	51.6
0.9826 .0061	1.0066 .0066	0.933 .016	0.8886 .0051	IC 147-57,58	178.6
0.9910 .0112	0.9980 .0044	0.967 .015	0.9116 .0057	IC 147-57,58	280.2
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	IC 148-59	51.6
0.9768 .0063	1.0000 .0044	0.933 .015	0.8768 .0050	IC 148-59	178.6
0.9798 .0059	0.9950 .0044	0.967 .016	0.9032 .0057	IC 148-59	280.2
1.0 .006	0.9988 .0051	0.998 .022	1.0664 .0078	IC F/SC/F	0-51.6
0.9772 .0046	0.9996 .0069	0.938 .013	0.8858 .0057	IC F/SC/F	178.6
0.9916 .0058	0.9998 .0052	0.953 .012	0.9172 .0061	IC F/SC/F	280.2
1.0 .006	0.9988 .0051	0.998 .022	1.0664 .0078	IC SC/DC/SC	0-51.6
0.9888 .0060	0.9974 .0050	0.980 .014	0.8640 .0055	IC SC/DC/SC	178.6
0.9895 .0055	0.9961 .0055	0.985 .013	0.8799 .0059	IC SC/DC/SC	280.2
	0.9950 .0044			OC 137-63	0-280.2
	0.9921 .0050			OC 136-63	0-280.2
0.9903 .0057	0.9984 .0049	0.974 .013	0.8935 .0061	OC SC/DC/SC	0-280.2
0.9890 .0061	0.9975 .0059	0.957 .011	0.9272 .0054	OC F/SC/F	0-280.2
0.9850 .0059	1.0020 .0057	0.978 .019	0.9020 .0051	OC F/SC/RB	0-280.2
0.9929 .0047	0.9926 .0042	0.962 .013	0.8762 .0048	OC CB/DC/SC	0-51.6
0.9888 .0060	0.9974 .0050	0.980 .014	0.8640 .0055	OC CB/DC/SC	178.6
0.9895 .0055	0.9961 .0055	0.985 .013	0.8799 .0059	OC CB/DC/SC	280.2
1.0 .008	1.0022 .0063	0.912 .026	1.0229 .0058	RB SC/RB/RB	ALL
1.0 .008	0.9949 .0074	0.988 .071	1.0170 .0071	RB RB/RB/RB	ALL
1.0 .008	0.9791 .0085	0.838 .100	1.0508 .0090	RB RB/RB/RR	ALL
	1.0 .010			RR	ALL
1.0 .006	1.0064 .0046	1.017 .026	1.0744 .0060	148-51	26.2
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	148-51	49.6
1.0 .006	1.0064 .0046	1.017 .026	1.0645 .0056	148-51	77.0
1.0 .006	1.0064 .0046	1.017 .026	1.0625 .0053	148-51	100.4
1.0 .006	1.0064 .0046	1.015 .018	1.0604 .0049	148-51	127.8
0.9762 .0054	1.0018 .0049	0.985 .015	0.8631 .0053	148-51	178.6
0.9848 .0052	0.9985 .0050	0.988 .013	0.8718 .0059	148-51	229.4

TABLE 17.4 (contd)

$^{239}\text{Pu}(n,f)^a$	$^{235}\text{U}(n,f)^a$	$^{238}\text{U}(n,f)^a$	$^{238}\text{U}(n,\gamma)$	Environment ^b	z, mm^c
0.9933 .0054	0.9952 .0050	0.990 .014	0.8805 .0053	148-51	280.2
0.9935 .0056	0.9921 .0050	0.985 .014	0.8886 .0054	148-51	331.0
0.9937 .0058	0.9890 .0050	0.980 .013	0.8968 .0055	148-51	381.8
0.9941 .0060	0.9956 .0066	0.980 .015	0.8836 .0056	148-51	432.6
0.9945 .0062	1.0022 .0051	0.980 .017	0.8704 .0056	148-51	483.4
1.0 .008	0.9947 .0055	1.012 .019	0.8410 .0045	148-51	534.2
1.0 .008	0.9947 .0055	1.047 .038	0.8145 .0040	148-51	585.0
1.0 .008	0.9947 .0055	1.047 .042	0.7839 .0061	148-51	635.8
1.0 .008	0.9947 .0055	1.047 .063	0.7551 .0052	148-51	686.6
1.0 .008	0.9947 .0055	1.047 .101	0.7262 .0042	148-51	737.4
1.0 .006	0.9985 .0065	0.987 .021	0.8610 .0072	138-62	51.6
1.0 .006	0.9985 .0065	0.987 .021	0.8610 .0072	138-62	102.4
1.0 .006	0.9966 .0068	0.988 .020	0.8718 .0073	138-62	178.6
1.0 .006	0.9942 .0069	0.991 .020	0.8812 .0075	138-62	229.4
1.0 .006	0.9919 .0069	0.994 .020	0.8906 .0076	138-62	280.2
1.0 .006	0.9904 .0060	0.996 .017	0.8947 .0066	138-62	331.0
1.0 .006	0.9890 .0050	0.997 .014	0.8988 .0055	138-62	381.8
1.0 .006	0.9946 .0052	0.988 .015	0.8874 .0056	138-62	432.6
1.0 .006	1.0001 .0053	0.980 .016	0.8761 .0057	138-62	483.4
1.0 .008	0.9947 .0055	1.012 .019	0.8410 .0045	138-62	534.2
1.0 .008	0.9947 .0055	1.047 .038	0.8145 .0040	138-62	585.0
1.0 .008	0.9947 .0055	1.047 .042	0.7839 .0061	138-62	635.8
1.0 .008	0.9947 .0055	1.047 .063	0.7551 .0052	138-62	686.6
1.0 .008	0.9947 .0055	1.047 .101	0.7262 .0042	138-62	737.4
0.9890 .0061	0.9975 .0059	0.957 .011	0.9272 .0054	148-70	0-381.8
0.9892 .0064	0.9980 .0067	0.955 .013	0.9224 .0054	148-70	432.6
0.9920 .0065	1.0007 .0076	0.953 .014	0.9175 .0054	148-70	483.4
1.0 .008	1.0005 .0059	1.081 .031	0.8815 .0061	148-70	534.2
1.0 .008	1.0005 .0059	1.081 .053	0.8521 .0064	148-70	585.0
1.0 .008	1.0005 .0070	1.081 .077	0.8340 .0060	148-70	635.8
1.0 .008	1.0005 .0073	1.081 .16	0.8053 .0058	148-70	686.6
1.0 .008	1.0005 .0074	1.081 .14	0.7817 .0064	148-70	734.4

^aThe second number for each cell factor is a one standard deviation uncertainty. See text for details.

^bReactor region and local environment. See Text for key and discussion.

^cAxial position to which this cell factor applies.

TABLE 17.5 Basic Data for ^{239}Pu Cell Studies in ZPPR-17C

Matrix	Loc ^a	z, mm ^b	$^{239}\text{Pu}(n, f)^c$	z, mm ^b	$^{239}\text{Pu}(n, f)^c$
248 51	LM	178.6	3.321 0.025	280.2	3.335 0.026
248 51	KL	178.6	3.438 0.025	280.2	3.419 0.029
248 51	JK	178.6	3.650 0.025	280.2	3.538 0.025
248 48	JK	178.6	3.763 0.027	280.2	3.728 0.024
248 48	KL	178.6	3.810 0.028	280.2	3.723 0.025
248 48	LM	178.6	4.020 0.028	280.2	3.872 0.025
249 51	LM	381.8	3.209 0.024	483.4	2.499 0.021
249 51	KL	381.8	3.277 0.030	483.4	2.540 0.021
249 51	JK	381.8	3.360 0.026	483.4	2.663 0.023
249 48	JK	381.8	3.506 0.025	483.4	2.779 0.026
249 48	KL	381.8	3.605 0.031	483.4	2.809 0.030
249 48	LM	381.8	3.654 0.025	483.4	2.914 0.024

^aIn-drawer column which designates the foil location in the drawer. The ^{239}Pu foils were centered 13.8 mm below the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10^{-18} fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.6 Basic Data for $^{235}\text{U}(\text{n},\text{f})$ Cell
Studies in ZPPR-17C

Matrix	Loc ^a	z,mm ^b	$^{235}\text{U}(\text{n},\text{f})^{\text{c}}$	z,mm ^b	$^{235}\text{U}(\text{n},\text{f})^{\text{c}}$
Central Blanket Cells					
249 51	OP	26.2	4.566 0.021	77.0	3.929 0.019
249 51	II	26.2	5.253 0.025	77.0	4.579 0.022
249 51	HI	26.2	5.337 0.024	77.0	4.677 0.022
249 48	HI	26.2	5.375 0.024	77.0	4.708 0.022
249 48	II	26.2	5.497 0.025	77.0	4.792 0.023
249 48	OP	26.2	6.031 0.026	77.0	5.394 0.023
249 51	OP	127.8	3.593 0.018		
249 51	II	127.8	4.154 0.021		
249 51	HI	127.8	4.298 0.021		
249 48	HI	127.8	4.281 0.022		
249 48	II	127.8	4.382 0.021		
249 48	OP	127.8	4.948 0.023		
149 51	AB	26.2	6.298 0.027	77.0	7.171 0.032
149 51	HH	26.2	6.498 0.030	77.0	7.111 0.031
149 51	HI	26.2	6.422 0.032	77.0	7.064 0.030
149 48	HI	26.2	6.437 0.028	77.0	7.095 0.031
149 48	HH	26.2	6.500 0.028	77.0	7.152 0.031
149 48	AB	26.2	6.798 0.029	77.0	7.336 0.031
149 51	AB	127.8	7.452 0.031		
149 51	HH	127.8	7.360 0.032		
149 51	HI	127.8	7.259 0.031		
149 48	HI	127.8	7.276 0.031		
149 48	HH	127.8	7.395 0.031		
149 48	AB	127.8	7.440 0.032		
Core Cells					
248 51	OP	178.6	3.665 0.018	280.2	3.407 0.017
248 51	LM	178.6	3.795 0.019	280.2	3.568 0.018
248 51	KL	178.6	3.861 0.019	280.2	3.642 0.018
248 51	JK	178.6	4.035 0.019	280.2	3.775 0.019
248 48	JK	178.6	4.217 0.021	280.2	3.911 0.020
248 48	KL	178.6	4.312 0.021	280.2	3.983 0.020
248 48	LM	178.6	4.437 0.022	280.2	4.092 0.020
248 48	OP	178.6	4.612 0.021	280.2	4.199 0.020
249 51	OP	381.8	2.836 0.016	483.4	2.235 0.013
249 51	LM	381.8	3.002 0.016	483.4	2.394 0.014
249 51	KL	381.8	3.088 0.016	483.4	2.488 0.015
249 51	JK	381.8	3.233 0.017	483.4	2.599 0.014
249 48	JK	381.8	3.448 0.018	483.4	2.777 0.015
249 48	KL	381.8	3.466 0.017	483.4	2.809 0.015
249 48	LM	381.8	3.638 0.018	483.4	2.938 0.016

TABLE 17.6 (contd)

Matrix	Loc ^a	z, mm ^b	²³⁵ U(n, f) ^c	z, mm ^b	²³⁵ U(n, f) ^c
249 48	OP	381.8	3.706 0.018	483.4	3.030 0.015
Axial Blanket Cells					
249 51	OP	534.2	2.008 0.012	585.0	1.732 0.011
248 51	JJ	534.2	2.629 0.016	585.0	2.315 0.014
248 51	IJ	534.2	2.685 0.015	585.0	2.380 0.014
248 48	IJ	534.2	2.388 0.014	585.0	2.078 0.013
248 48	JJ	534.2	2.400 0.014	585.0	2.122 0.014
249 48	OP	534.2	2.656 0.014	585.0	2.354 0.013
249 51	OP	635.8	1.477 0.010	686.6	1.273 0.009
248 51	JJ	635.8	2.025 0.013	686.6	1.805 0.012
248 51	IJ	635.8	2.085 0.013	686.6	1.853 0.013
248 48	IJ	635.8	1.808 0.012	686.6	1.578 0.011
248 48	JJ	635.8	1.815 0.012	686.6	1.598 0.011
249 48	OP	635.8	2.081 0.012	686.6	1.845 0.011
249 51	OP	737.4	1.163 0.009		
248 51	JJ	737.4	1.628 0.011		
248 51	IJ	737.4	1.686 0.012		
248 48	IJ	737.4	1.445 0.010		
248 48	JJ	737.4	1.449 0.011		
249 48	OP	737.4	1.698 0.010		

^aIn-drawer column which designates the foil location in the drawer. The ²³⁵U foils were centered 13.8 mm above the mid-height of the drawer.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10⁻¹⁸ fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.7 Basic Data for $^{238}\text{U}(\text{n},\text{f})$ and $^{238}\text{U}(\text{n},\gamma)$
Cell Studies in ZPPR-17C

Matrix	Loc ^a	z,mm ^b	²³⁸ U(n,f) ^c		²³⁸ U(n,γ)	
Central Blanket Cells						
249 51	OP	26.2	0.0337	0.0013	0.6281	0.0035
249 51	II	26.2	0.0326	0.0013	0.6434	0.0036
249 51	HI	26.2	0.0344	0.0015	0.6495	0.0040
249 48	HI	26.2	0.0343	0.0014	0.6356	0.0039
249 48	II	26.2	0.0353	0.0012	0.6673	0.0044
249 48	OP	26.2	0.0327	0.0013	0.7643	0.0045
249 51	OP	77.0	0.0369	0.0012	0.5540	0.0032
249 51	II	77.0	0.0356	0.0012	0.5766	0.0033
249 51	HI	77.0	0.0359	0.0016	0.5775	0.0036
249 48	HI	77.0	0.0372	0.0014	0.5711	0.0038
249 48	II	77.0	0.0360	0.0012	0.5936	0.0037
249 48	OP	77.0	0.0367	0.0013	0.6936	0.0042
249 51	OP	127.8	0.0490	0.0013	0.5045	0.0030
249 51	II	127.8	0.0501	0.0016	0.5349	0.0032
249 51	HI	127.8	0.0480	0.0015	0.5376	0.0035
249 48	HI	127.8	0.0503	0.0016	0.5271	0.0035
249 48	II	127.8	0.0475	0.0014	0.5459	0.0035
249 48	OP	127.8	0.0548	0.0016	0.6454	0.0041
149 51	AB	26.2	0.0397	0.0012	0.8427	0.0049
149 51	HH	26.2	0.0400	0.0015	0.7651	0.0042
149 51	HI	26.2	0.0387	0.0014	0.7577	0.0041
149 48	HI	26.2	0.0392	0.0015	0.7543	0.0050
149 48	HH	26.2	0.0407	0.0017	0.7716	0.0049
149 48	AB	26.2	0.0395	0.0014	0.8495	0.0052
149 51	AB	77.0	0.0536	0.0014	0.9420	0.0049
149 51	HH	77.0	0.0531	0.0015	0.8407	0.0045
149 51	HI	77.0	0.0485	0.0016	0.8257	0.0047
149 48	HI	77.0	0.0491	0.0016	0.8273	0.0048
149 48	HH	77.0	0.0516	0.0016	0.8319	0.0048
149 48	AB	77.0	0.0519	0.0016	0.9086	0.0052
149 51	AB	127.8	0.0767	0.0016	0.9809	0.0051
149 51	HH	127.8	0.0765	0.0018	0.8819	0.0050
149 51	HI	127.8	0.0775	0.0017	0.8639	0.0046
149 48	HI	127.8	0.0768	0.0018	0.8681	0.0050
149 48	HH	127.8	0.0743	0.0018	0.8584	0.0054
149 48	AB	127.8	0.0776	0.0018	0.9416	0.0058
Core Cells						
248 51	OP	178.6	0.0701	0.0017	0.4659	0.0029
248 51	LM	178.6	0.0881	0.0018	0.5095	0.0032

TABLE 17.7 (contd)

Matrix	Loc ^a	z, mm ^b	²³⁸ U(n, f) ^c		²³⁸ U(n, γ)	
248 51	KL	178.6	0.0983	0.0020	0.5066	0.0034
248 51	JK	178.6	0.0949	0.0020	0.5802	0.0034
248 48	JK	178.6	0.0938	0.0018	0.6001	0.0037
248 48	KL	178.6	0.0997	0.0017	0.5504	0.0037
248 48	LM	178.6	0.0978	0.0017	0.6060	0.0042
248 48	OP	178.6	0.0832	0.0017	0.5913	0.0041
248 51	OP	280.2	0.0920	0.0017	0.4380	0.0030
248 51	LM	280.2	0.1052	0.0020	0.4723	0.0030
248 51	KL	280.2	0.1128	0.0021	0.4742	0.0030
248 51	JK	280.2	0.1092	0.0019	0.5296	0.0035
248 48	JK	280.2	0.1119	0.0017	0.5478	0.0034
248 48	KL	280.2	0.1187	0.0018	0.5209	0.0036
248 48	LM	280.2	0.1136	0.0018	0.5529	0.0035
248 48	OP	280.2	0.1080	0.0018	0.5408	0.0036
249 51	OP	381.8	0.0841	0.0016	0.3923	0.0031
249 51	LM	381.8	0.0963	0.0021	0.4207	0.0027
249 51	KL	381.8	0.1047	0.0021	0.4199	0.0028
249 51	JK	381.8	0.1024	0.0019	0.4692	0.0030
249 48	JK	381.8	0.1087	0.0018	0.4873	0.0035
249 48	KL	381.8	0.1112	0.0017	0.4594	0.0034
249 48	LM	381.8	0.1076	0.0021	0.4942	0.0034
249 48	OP	381.8	0.0965	0.0018	0.4827	0.0036
249 51	OP	483.4	0.0555	0.0014	0.3130	0.0025
249 51	LM	483.4	0.0641	0.0018	0.3421	0.0023
249 51	KL	483.4	0.0724	0.0017	0.3392	0.0024
249 51	JK	483.4	0.0698	0.0019	0.3912	0.0029
249 48	JK	483.4	0.0737	0.0016	0.4024	0.0029
249 48	KL	483.4	0.0789	0.0017	0.3732	0.0028
249 48	LM	483.4	0.0758	0.0018	0.4039	0.0030
249 48	OP	483.4	0.0681	0.0016	0.4020	0.0029
Axial Blanket Cells						
249 51	OP	534.2	0.0326	0.0012	0.2827	0.0021
248 51	JJ	534.2	0.0359	0.0014	0.3274	0.0024
248 51	IJ	534.2	0.0365	0.0013	0.3694	0.0025
248 48	IJ	534.2	0.0356	0.0016	0.3163	0.0027
248 48	JJ	534.2	0.0334	0.0011	0.2984	0.0026
249 48	OP	534.2	0.0359	0.0013	0.3381	0.0026
249 51	OP	585.0	0.0203	0.0010	0.2415	0.0018
248 51	JJ	585.0	0.0225	0.0011	0.2830	0.0021
248 51	IJ	585.0	0.0223	0.0012	0.3323	0.0026
248 48	IJ	585.0	0.0209	0.0015	0.2774	0.0024
248 48	JJ	585.0	0.0204	0.0011	0.2552	0.0024
249 48	OP	585.0	0.0233	0.0011	0.2925	0.0024

TABLE 17.7 (contd)

Matrix	Loc ^a	z, mm ^b	²³⁸ U(n,f) ^c		²³⁸ U(n,γ)	
249 51	OP	635.8	0.0122	0.0010	0.2047	0.0018
248 51	JJ	635.8	0.0130	0.0012	0.2466	0.0021
248 51	IJ	635.8	0.0134	0.0010	0.2918	0.0023
248 48	IJ	635.8	0.0131	0.0010	0.2375	0.0024
248 48	JJ	635.8	0.0118	0.0009	0.2165	0.0019
249 48	OP	635.8	0.0134	0.0011	0.2728	0.0024
249 51	OP	686.6	0.0089	0.0009	0.1778	0.0015
248 51	JJ	686.6	0.0092	0.0011	0.2077	0.0020
248 51	IJ	686.6	0.0101	0.0009	0.2548	0.0021
248 48	IJ	686.6	0.0098	0.0014	0.2138	0.0021
248 48	JJ	686.6	0.0092	0.0011	0.1859	0.0018
249 48	OP	686.6	0.0105	0.0011	0.2336	0.0020
249 51	OP	737.4	0.0057	0.0010	0.1541	0.0016
248 51	JJ	737.4	0.0068	0.0009	0.1857	0.0018
248 51	IJ	737.4	0.0080	0.0009	0.2317	0.0019
248 48	IJ	737.4	0.0080	0.0010	0.1936	0.0020
248 48	JJ	737.4	0.0064	0.0011	0.1610	0.0018
249 48	OP	737.4	0.0084	0.0013	0.2070	0.0021

^aIn-drawer column which designates the foil location in the drawer. The ²³⁸U foils were centered on the mid-height of the drawer. A negative sign designates a plate-spanning averaging foil.

^bDistance from the reactor interface to the center of the foil.

^cExperimental results in units of 10⁻¹⁸ fissions per sec per atom at a reactor power of approximately one watt. The second number is one standard deviation uncertainty. See text for details.

TABLE 17.8 Cell-Averaging Factors for ZPPR-17C

$^{239}\text{Pu}(n,f)^a$	$^{235}\text{U}(n,f)^a$	$^{238}\text{U}(n,f)^a$	$^{238}\text{U}(n,\gamma)^a$	Environment ^b	z, mm^c
1.0 .006	1.0153 .0052	1.018 .020	1.0568 .0070	IC 147-50	51.6
0.9853 .0056	0.9985 .0046	0.987 .015	0.8610 .0051	IC 147-50	178.6
0.9914 .0054	0.9948 .0048	0.990 .013	0.8826 .0052	IC 147-50	280.2
1.0 .008	1.0114 .0054	1.004 .028	1.0583 .0119	IC 247-50,248-51	51.6
0.9900 .0173	1.0064 .0096	0.987 .022	0.8936 .0154	IC 247-50,248-51	178.6
0.9932 .0074	0.9999 .0105	0.987 .022	0.9134 .0132	IC 247-50,248-51	280.2
1.0 .006	1.0153 .0052	1.018 .020	1.0568 .0070	IC 148,248-56	51.6
0.9885 .0058	1.0132 .0047	0.933 .016	0.9003 .0052	IC 148,248-56	178.6
1.0021 .0056	1.0010 .0044	0.967 .015	0.9201 .0056	IC 148,248-56	280.2
1.0 .006	1.0153 .0052	1.018 .020	1.0568 .0070	IC 147,247-57	51.6
0.9826 .0061	1.0066 .0066	0.933 .016	0.8886 .0051	IC 147,247-57	178.6
0.9910 .0112	0.9980 .0044	0.967 .015	0.9116 .0057	IC 147,247-57	280.2
1.0 .006	1.0064 .0046	1.017 .026	1.0694 .0058	IC 147,247-58	51.6
0.9853 .0056	0.9985 .0046	0.987 .015	0.8610 .0051	IC 147,247-58	178.6
0.9914 .0054	0.9948 .0048	0.990 .013	0.8826 .0052	IC 147,247-58	280.2
1.0 .006	1.0153 .0052	1.018 .020	1.0568 .0070	IC 148,248-59	51.6
0.9768 .0063	1.0000 .0044	0.933 .015	0.8768 .0050	IC 148,248-59	178.6
0.9798 .0059	0.9950 .0044	0.967 .016	0.9032 .0057	IC 148,248-59	280.2
1.0 .006	1.0153 .0052	1.018 .020	1.0568 .0070	IC 138-61	51.6
1.0 .006	1.0066 .0066	0.933 .016	0.8886 .0051	IC 138-61	178.6
1.0 .006	0.9980 .0044	0.967 .015	0.9116 .0057	IC 138-61	280.2
1.0 .006	1.0114 .0054	1.004 .028	1.0607 .0097	IC 238-61	51.6
1.0 .006	1.0060 .0107	0.942 .022	0.9179 .0126	IC 238-61	178.6
1.0 .006	1.0062 .0096	0.957 .022	0.9504 .0132	IC 238-61	280.2
1.0 .006	0.9988 .0051	0.998 .022	1.0664 .0078	IC F/SC/F	0-51.6
0.9772 .0046	0.9996 .0069	0.938 .013	0.8858 .0057	IC F/SC/F	178.6
0.9916 .0058	0.9998 .0052	0.953 .012	0.9172 .0061	IC F/SC/F	280.2
1.0 .006	0.9988 .0051	0.998 .022	1.0664 .0078	IC SC/DC/SC	0-51.6
0.9888 .0060	0.9974 .0050	0.980 .014	0.8640 .0055	IC SC/DC/SC	178.6
0.9895 .0055	0.9961 .0055	0.985 .013	0.8799 .0059	IC SC/DC/SC	280.2
0.9863 .0098	1.0029 .0096	0.977 .026	0.8692 .0092	OC 148,248-73	0-280.2
	0.9950 .0044			OC CRP-SC-F	0-280.2
	0.9921 .0050			OC CRP-DC-F	0-280.2
0.9903 .0057	0.9984 .0049	0.974 .013	0.8935 .0061	OC SC/DC/SC	0-280.2
0.9890 .0061	0.9975 .0059	0.957 .011	0.9272 .0054	OC F/SC/F	0-280.2
0.9850 .0059	1.0020 .0057	0.978 .019	0.9020 .0051	OC F/SC/RB	0-280.2
0.9929 .0047	0.9926 .0042	0.962 .013	0.8762 .0048	OC CB/DC/SC	0-51.6

TABLE 17.8 (contd)

$^{239}\text{Pu}(n,f)^a$		$^{235}\text{U}(n,f)^a$		$^{238}\text{U}(n,f)^a$		$^{238}\text{U}(n,\gamma)^a$		Environment ^b	z, mm ^c
0.9888	.0060	0.9974	.0050	0.980	.014	0.8640	.0055	OC CB/DC/SC	178.6
0.9895	.0055	0.9961	.0055	0.985	.013	0.8799	.0059	OC CB/DC/SC	280.2
1.0	.008	1.0022	.0063	0.912	.026	1.0229	.0058	RB SC/RB/RB	ALL
1.0	.008	0.9949	.0074	0.988	.071	1.0170	.0071	RB RB/RB/RB	ALL
1.0	.008	0.9791	.0085	0.838	.100	1.0508	.0090	RB RB/RB/RR	ALL
		1.0	.010					RR	ALL
1.0	.006	1.0153	.0052	1.018	.020	1.0596	.0072	148-51	26.2
1.0	.006	1.0153	.0052	1.018	.020	1.0568	.0070	148-51	49.6
1.0	.006	1.0153	.0052	1.018	.020	1.0539	.0068	148-51	77.0
1.0	.006	1.0153	.0052	1.018	.020	1.0494	.0067	148-51	100.4
1.0	.006	1.0153	.0052	1.018	.020	1.0450	.0065	148-51	127.8
0.9762	.0054	1.0018	.0049	0.985	.015	0.8631	.0053	148-51	178.6
0.9848	.0052	0.9985	.0050	0.988	.013	0.8718	.0059	148-51	229.4
0.9933	.0054	0.9952	.0050	0.990	.014	0.8805	.0053	148-51	280.2
0.9935	.0056	0.9921	.0050	0.985	.014	0.8886	.0054	148-51	331.0
0.9937	.0058	0.9890	.0050	0.980	.013	0.8968	.0055	148-51	381.8
0.9941	.0060	0.9956	.0066	0.980	.015	0.8836	.0056	148-51	432.6
0.9945	.0062	1.0022	.0051	0.980	.017	0.8704	.0056	148-51	483.4
1.0	.008	0.9947	.0055	1.012	.019	0.8410	.0045	148-51	534.2
1.0	.008	0.9947	.0055	1.047	.038	0.8145	.0040	148-51	585.0
1.0	.008	0.9947	.0055	1.047	.042	0.7839	.0061	148-51	635.8
1.0	.008	0.9947	.0055	1.047	.063	0.7551	.0052	148-51	686.6
1.0	.008	0.9947	.0055	1.047	.101	0.7262	.0042	148-51	737.4
1.0	.006	1.0114	.0054	1.004	.028	1.0583	.0119	248-51	26.2
1.0	.006	1.0114	.0054	1.004	.028	1.0607	.0097	248-51	49.6
1.0	.006	1.0114	.0054	1.004	.028	1.0631	.0068	248-51	77.0
1.0	.006	1.0114	.0054	1.004	.028	1.0604	.0091	248-51	100.4
1.0	.006	1.0114	.0054	1.004	.028	1.0577	.0110	248-51	127.8
0.9900	.0173	1.0064	.0096	0.987	.022	0.8936	.0154	248-51	178.6
0.9916	.0133	1.0032	.0101	0.987	.022	0.9035	.0143	248-51	229.4
0.9932	.0074	0.9999	.0105	0.987	.022	0.9134	.0132	248-51	280.2
0.9983	.0079	0.9968	.0084	0.987	.022	0.9132	.0119	248-51	331.0
1.0034	.0084	0.9937	.0056	0.987	.022	0.9130	.0104	248-51	381.8
0.9979	.0091	0.9940	.0057	0.987	.022	0.9038	.0133	248-51	432.6
0.9924	.0098	0.9944	.0058	0.987	.022	0.8945	.0157	248-51	483.4
1.0	.008	0.9964	.0085	0.967	.034	0.9241	.0212	248-51	534.2
1.0	.008	0.9964	.0085	0.967	.052	0.8945	.0278	248-51	585.0
1.0	.008	0.9964	.0085	0.967	.067	0.8868	.0280	248-51	635.8
1.0	.008	0.9964	.0085	0.967	.097	0.8539	.0230	248-51	686.6
1.0	.008	0.9964	.0085	0.967	.100	0.8377	.0253	248-51	737.4
1.0	.006	0.9985	.0065	0.987	.021	0.8610	.0072	138-62	51.6
1.0	.006	0.9985	.0065	0.987	.021	0.8610	.0072	138-62	102.4
1.0	.006	0.9966	.0068	0.988	.020	0.8718	.0073	138-62	178.6
1.0	.006	0.9942	.0069	0.991	.020	0.8812	.0075	138-62	229.4

TABLE 17.8 (contd)

$^{239}\text{Pu}(n,f)^a$		$^{235}\text{U}(n,f)^a$		$^{238}\text{U}(n,f)^a$		$^{238}\text{U}(n,\gamma)^a$		Environment ^b	z, mm^c
1.0	.006	0.9919	.0069	0.994	.020	0.8906	.0076	138-62	280.2
1.0	.006	0.9904	.0060	0.996	.017	0.8947	.0066	138-62	331.0
1.0	.006	0.9890	.0050	0.997	.014	0.8988	.0055	138-62	381.8
1.0	.006	0.9946	.0052	0.988	.015	0.8874	.0056	138-62	432.6
1.0	.006	1.0001	.0053	0.980	.016	0.8761	.0057	138-62	483.4
1.0	.008	0.9947	.0055	1.012	.019	0.8410	.0045	148-51	534.2
1.0	.008	0.9947	.0055	1.047	.038	0.8145	.0040	148-51	585.0
1.0	.008	0.9947	.0055	1.047	.042	0.7839	.0061	148-51	635.8
1.0	.008	0.9947	.0055	1.047	.063	0.7551	.0052	148-51	686.6
1.0	.008	0.9947	.0055	1.047	.101	0.7262	.0042	148-51	737.4
1.0	.006	1.0064	.0136	0.987	.031	0.8936	.0218	238-62	51.6
1.0	.006	1.0064	.0136	0.987	.031	0.8936	.0218	238-62	102.4
1.0	.006	1.0032	.0143	0.987	.031	0.9035	.0202	238-62	178.6
1.0	.006	1.0000	.0129	0.987	.031	0.9084	.0185	238-62	229.4
1.0	.006	0.9968	.0114	0.987	.031	0.9132	.0167	238-62	280.2
1.0	.006	0.9952	.0090	0.987	.022	0.9131	.0139	238-62	331.0
1.0	.006	0.9937	.0056	0.987	.022	0.9130	.0104	238-62	381.8
1.0	.006	0.9940	.0057	0.987	.022	0.9038	.0133	238-62	432.6
1.0	.006	0.9944	.0058	0.987	.022	0.8945	.0157	238-62	483.4
1.0	.008	0.9964	.0085	0.967	.034	0.9241	.0212	238-62	534.2
1.0	.008	0.9964	.0085	0.967	.052	0.8945	.0278	238-62	585.0
1.0	.008	0.9964	.0085	0.967	.067	0.8868	.0280	238-62	635.8
1.0	.008	0.9964	.0085	0.967	.097	0.8539	.0230	238-62	686.6
1.0	.008	0.9964	.0085	0.967	.100	0.8377	.0253	238-62	737.4
0.9911	.0059	1.0007	.0043	0.974	.013	0.8935	.0061	148,248-70	0-381.8
0.9870	.0072	0.9982	.0043	0.958	.015	0.8822	.0067	148,248-70	432.6
0.9829	.0086	0.9957	.0042	0.942	.017	0.8709	.0073	148,248-70	483.4
1.0	.008	0.9986	.0059	1.064	.052	0.8627	.0057	148,248-70	534.2
1.0	.008	1.0005	.0059	1.081	.053	0.8361	.0064	148,248-70	585.0
1.0	.008	1.0005	.0070	1.081	.077	0.8340	.0060	148,248-70	635.8
1.0	.008	1.0005	.0073	1.081	.16	0.8053	.0058	148,248-70	686.6
1.0	.008	1.0005	.0074	1.081	.14	0.7817	.0064	148,248-70	734.4

^aThe second number for each cell factor is a one standard deviation uncertainty. See test for details.

^bReactor region and local environment. See text for key and discussion.

^cAxial position to which this cell factor applies.