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FAST REACTOR PHYSICS CALCULATIONS

by
Robert Avery

Reactor Engineering Division

January 1956

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FAST REACTOR PHYSICS CALCULATIONS

by
Robert Avery

ABSTRACT

Multigroup diffusion theory calculations performed in connection with the fast power breeder reactor development program at Argonne are summarized. The problems investigated relate to: (1) steady-state properties; (2) long-term changes; (3) reactivity coefficients associated with temperature changes; (4) effectiveness of various control methods; (5) evaluation of neutron lifetime; (6) various methods of radial power flattening; (7) various parametric studies to determine optimum design points; (8) accuracy of diffusion theory for systems under consideration; and (9) analysis of experimental results.

I. INTRODUCTION

This report summarizes some of the reactor physics calculations performed as part of the PBR-EBR-II development program at Argonne.

As presently envisaged, PBR (Power Breeder Reactor) is a fast, 800-megawatt, sodium-cooled reactor using Pu^{239} fuel and U^{238} diluent. The core has a volume of 800 liters and is surrounded by a blanket consisting primarily of depleted uranium.

EBR-II is to be a prototype of PBR having a 50-liter core volume but probably using U^{235} , at least initially, as the fuel.

The problems investigated related to the steady-state properties of reference designs, long-term changes, reactivity coefficients, neutron lifetime, methods of radial power flattening, and effects of various composition and structure changes. The method used was multigroup diffusion theory. Solutions to the multigroup equations were obtained on the UNIVAC at the AEC Computing Facility at New York University.

Some of the problems were solved in cylindrical (axially bare) geometry, others in spherical geometry. A code for the slab geometry case is also available but none of these calculations are reported here.

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The large number of different assemblies studied results partially from the fact that both Pu^{239} and U^{235} fuel were considered for the full-scale reactor and for the pilot plant. Also, many different cases were investigated for parametric studies and in determining the effects of various changes. The accuracy obtained in the numerical solutions is sufficient to determine directly the effects of small perturbations which preserve the symmetry of the assembly.

As a test on the reliability of the results, fast assemblies for which experimental results have been obtained were analyzed.

The adequacy of multigroup diffusion theory as a framework for the calculations was also investigated. By comparison of the diffusion theory results with those given by a more accurate approximation to the transport equation, an estimate of the error introduced by the use of diffusion theory was obtained.

Even though there are large gaps and uncertainties in knowledge of the cross sections, the use of a fairly large number of energy groups seems to be indicated for the calculation of fast dilute systems. Some of the calculations were performed with seven energy groups, others with ten.

The calculations represent a more or less preliminary phase; therefore, the problem parameters should not be interpreted as design specifications. As the designs become fixed and as best estimates of cross sections change, it will probably become necessary to repeat many of the calculations. However, it is hoped that the present results will be useful, at least qualitatively, in indicating general trends and magnitudes of various quantities.

II. MULTIGROUP DIFFUSION THEORY EQUATIONS

The multigroup diffusion equations that are to be solved in each region are

$$\frac{1}{3\Sigma_{tr}^j} \nabla^2 \phi^j - \Sigma_a^j \phi^j + \sum_{i=1}^{j-1} \frac{\bar{\Sigma}_i^j}{\Sigma_j^j} \phi^i + \beta_j \sum_{i=1}^G \frac{\bar{\nu} \Sigma_f^i}{\Sigma_f^j} \phi^i = 0$$

for $j = 1, \dots, G$ ($j=1$, highest energy group; G , total number of groups),

where

ϕ^j is the total neutron flux (track length per unit volume) in the j 'th energy group,

$\bar{\Sigma}_i^j$ is the average cross section for the region and group,

Σ_{tr} is the transport cross section,

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Σ_a includes all processes for removal from group (fission, capture, and removal by inelastic and elastic scattering),

Σ_{ij} is cross section for transfer by scattering from the i 'th group to the j 'th group and includes both elastic and inelastic transfer,

β_j is the fraction of fission neutrons born in the j 'th group,

and

$\nu\Sigma_f$ is the product of the average number of neutrons released per fission and the fission cross section.

The equations are solved subject to the usual boundary conditions of flux and current continuity across boundaries, the vanishing of the flux at outer surface, and those imposed by the symmetry of the system.

The method of solution is based on the source iterative technique developed by KAPL.¹ The fission source term is treated as an inhomogeneous source term and the resulting flux is then determined; this, in turn, specifies a new fission source term. This procedure is repeated until the shapes of successive source terms agree within specified limits. Criticality, which corresponds to the magnitude of successive fission source terms also agreeing within specified limits, is obtained by varying the composition of certain regions (denoted as "core" regions). In the input information for a problem, one gives the volume fractions of the various materials for the various regions. For each core region one must give two such sets of volume fractions, $v_{F\ell}$ and $v_{D\ell}$, where the subscript ℓ labels the core region. One also gives for each core region a number, s_ℓ , between 0 and 1. The initial composition in the ℓ 'th core region is

$$s_\ell v_{F\ell} + (1 - s_\ell) v_{D\ell}.$$

For criticality, one then determines a number, c , such that the composition

$$cs_\ell v_{F\ell} + (1 - cs_\ell)v_{D\ell}$$

corresponds to a critical system.

In some cases, one may not be interested in obtaining criticality, but only in determining the reactivity of a specified system. The guesses of initial composition are then made to correspond to the specified system, and the convergence criterion on the magnitude of successive fission sources

¹R. Ehrlich and H. Hurwitz, Jr., "Multigroup Methods for Neutron Diffusion Problems," *Nucleonics*, 12, No. 2, 23 (1954).

is made very large. The problem is then solved as soon as the shape of successive fission source terms agree. The ratio, f , of the magnitude of the fission source to the magnitude of the preceding fission source gives

$$k_{\text{effective}} = f,$$

or

$$\frac{\Delta k}{k} = \frac{f-1}{f}$$

III. CROSS SECTIONS

A. Seven-Group Set

Many of the multigroup diffusion theory calculations were performed with the seven-group set of cross sections given in Table I.

The fission spectrum used was the normalized Watt formula

$$f(E) = \sqrt{\frac{2}{\pi e}} \sinh \sqrt{2E} e^{-E},$$

where E is the energy in mev.

The probability that a neutron is born with energy $>E$ is given by:

$$\begin{aligned} g(E) &= \int_E^{\infty} f(E') dE' \\ &= 1 + \sqrt{\frac{2}{\pi e}} \sinh \sqrt{2E} e^{-E} - \frac{1}{\sqrt{\pi}} \left[I\left(\frac{\sqrt{2E}-1}{\sqrt{2}}\right) + I\left(\frac{\sqrt{2E}+1}{\sqrt{2}}\right) \right], \end{aligned}$$

where

$$I(X) = \int_0^X e^{-t^2} dt.$$

The group inelastic cross sections given do not include inelastic collisions which do not remove a neutron from the group.

The seven-group inelastic scattering matrix is given in Table II. $X_{j \rightarrow k}$ is defined as the probability that a neutron suffering an inelastic collision in group j will have a final energy in group k . It is assumed to be the same for all materials.

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Table I

SEVEN-GROUP CROSS SECTIONS
(in barns)

Group No.	u Interval (in 10/E)	E_L , mev	β Fission Spectrum	$Pu^{239}(\nu = 2.9)$				$U^{235}(\nu = 2.5)$				$U^{238}(\nu = 2.5)$			
				σ_{tr}	σ_f	α	σ_{in}	σ_{tr}	σ_f	α	σ_{in}	σ_{tr}	σ_f	σ_c	σ_{in}
1	0-1.5	2.231 - 10	0.346	4.5	1.85	0.03	1.8	4.5	1.25	0.1	1.8	4.0	0.56	0.02	2.4
2	1.5-2	1.353 - 2.231	0.229	5.0	1.85	0.05	1.5	5.0	1.25	0.12	1.5	4.5	0.42	0.055	2.0
3	2-3	0.4979 - 1.353	0.301	6.0	1.80	0.07	1.0	6.0	1.20	0.15	1.0	5.5	0.03	0.12	1.6
4	3-4	0.1832 - 0.4979	0.091	7.5	1.75	0.12	0.5	7.5	1.35	0.2	0.5	7.0	0	0.175	1.0
5	4-5	0.0674 - 0.1832	0.025	8.5	2.05	0.2	0	8.5	1.90	0.25	0	8.5	0	0.25	0
6	5-6	0.0248 - 0.0674	0.006	10.	2.25	0.3	0	10.	2.50	0.3	0	10.	0	0.35	0
7	6-	0 - 0.0248	0.002	12.	2.60	0.4	0	12.	3.10	0.35	0	12.	0	0.55	0
(atoms/cm ³) $\times 10^{-24}$				0.0403				0.0482				0.0482			

Group No.	u Interval (in 10/E)	E_L , mev	β Fission Spectrum	Fe			Na		K			C		B ¹⁰	
				σ_{tr}	σ_c	σ_{in}	σ_{tr}	σ_c	σ_{tr}	σ_c	σ_{in}	σ_{tr}	σ_c	σ_{tr}	σ_c
1	0-1.5	2.231 - 10	0.346	2.5	0.03	1.0	3.0	0.0002	3.0	0.02	0.08	1.5	0	2.4	0.4
2	1.5-2	1.353 - 2.231	0.229	2.5	0.03	1.0	3.0	0.0005	2.5	0.02	0.04	1.75	0	2.6	0.6
3	2-3	0.4979 - 1.353	0.301	3.0	0.03	0.5	4.0	0.0008	2.0	0.02	0.04	2.5	0	2.7	0.7
4	3-4	0.1832 - 0.4979	0.091	3.5	0.03	0	4.0	0.0008	2.0	0.02	0	3.5	0	3.6	1.6
5	4-5	0.0674 - 0.1832	0.025	3.5	0.03	0	3.5	0.0008	2.0	0.02	0	4.25	0	5.2	3.2
6	5-6	0.0248 - 0.0674	0.006	3.5	0.03	0	5.5	0.0008	2.0	0.02	0	4.5	0	7.8	5.8
7	6-	0 - 0.0248	0.002	3.5	0.03	0	5.0	0.0008	1.5	0.02	0	4.5	0	10.5	8.5
(atoms/cm ³) $\times 10^{-24}$				0.0847			0.0220		0.0134			0.0838		0.1411	

Table II
SEVEN-GROUP INELASTIC SCATTERING MATRIX

j	$X_{j \rightarrow k}$					
	k = 2	3	4	5	6	7
1	0.6322	0.3180	0.0431	0.0058	0.0008	0.0001
2	-	0.8646	0.1171	0.0159	0.0021	0.0003
3	-	-	0.8646	0.1171	0.0159	0.0024
4	-	-	-	0.8646	0.1171	0.0183

The inelastic scattering law on which the matrix is based is:

$$\sigma(E_0 \rightarrow E) = (\text{const.})E.$$

The method for evaluating elastic transfer is discussed in Section IV, page 23.

The macroscopic constants for the various materials that enter formally into the diffusion theory equations are given in Table III.

In analyzing the multigroup results, the macroscopic fission and capture cross sections of the various materials are used to a considerable extent; for convenience they are listed in Table IV.

B. Ten-Group Set

The ten-group cross sections, given in Table V, incorporate a number of suggested improvements made by Professor H. A. Bethe on the seven-group set of cross sections. They were prepared prior to publication of BNL-250² and BNL-325³ and, consequently, do not include the downward revisions of the Pu²³⁹ and U²³⁵ fission cross sections.

The same fission spectrum and energy groups were used as in the seven-group set, except that three lower energy groups were added.

The ten-group inelastic scattering matrix is given in Table VI.

²Goldberg, M. D., et al., Neutron Cross Sections, BNL-250 (August 1, 1954).

³Hughes, D. J. and J. A. Harvey, Neutron Cross Sections, BNL-325 (July 1, 1955).

Table III
SEVEN-GROUP MACROSCOPIC CONSTANTS

Material	Group	ω_a	3^*_{tr}	ν^*_{ef}	Scattering Transfer Matrix					
					Σ^j_{-1}	Σ^j_{+2}	Σ^j_{-3}	Σ^j_{+4}	Σ^j_{+5}	Σ^j_{+6}
Pu239	1	0.150	0.544	0.216	0.0462	0.0231	0.00313	0.000421	0.000053	0.00000725
	2	0.140	0.605	0.216	0.0532	0.00708	0.000961	0.000127	0.0000181	-
	3	0.119	0.725	0.210	0.0359	0.00472	0.000641	0.0000967	-	-
	4	0.101	0.907	0.205	0.0191	0.00236	0.000369	-	-	-
	5	0.101	1.028	0.240	0.00205	-	-	-	-	-
	6	0.120	1.209	0.263	0.00240	-	-	-	-	-
	7	0.147	1.451	0.304	-	-	-	-	-	-
Pu235	1	0.154	0.651	0.151	0.0556	0.0276	0.00374	0.000503	0.0000694	0.00000868
	2	0.141	0.723	0.151	0.0641	0.00874	0.00115	0.000152	0.0000217	-
	3	0.116	0.868	0.145	0.0431	0.00564	0.000766	0.000116	-	-
	4	0.104	1.085	0.163	0.0230	0.00282	0.000441	-	-	-
	5	0.117	1.229	0.229	0.00248	-	-	-	-	-
	6	0.159	1.446	0.301	0.00273	-	-	-	-	-
	7	0.202	1.735	0.374	-	-	-	-	-	-
Pu238	1	0.144	0.578	0.0675	0.0737	0.0368	0.00499	0.000671	0.0000925	0.0000116
	2	0.121	0.651	0.0506	0.0849	0.0113	0.00153	0.000202	0.0000289	-
	3	0.0859	0.795	0.00362	0.0682	0.00903	0.00123	0.000185	-	-
	4	0.0590	1.012	-	0.0440	0.00564	0.000882	-	-	-
	5	0.0154	1.229	-	0.00334	-	-	-	-	-
	6	0.0208	1.446	-	0.00391	-	-	-	-	-
	7	0.0265	1.735	-	-	-	-	-	-	-
Fe	1	0.0421	0.635	-	0.0585	0.0269	0.00365	0.000491	0.0000678	0.00000847
	2	0.0941	0.635	-	0.0799	0.00992	0.00135	0.000178	0.0000254	-
	3	0.0515	0.762	-	0.0433	0.00496	0.000673	-	-	-
	4	0.0122	0.869	-	0.00968	-	-	-	-	-
	5	0.0122	0.889	-	0.00968	-	-	-	-	-
	6	0.0122	0.889	-	0.00968	-	-	-	-	-
	7	0.0025	0.889	-	-	-	-	-	-	-
Na	1	0.00768	0.198	-	0.00768	-	-	-	-	-
	2	0.0104	0.198	-	0.0103	-	-	-	-	-
	3	0.00751	0.264	-	0.00750	-	-	-	-	-
	4	0.00751	0.264	-	0.00750	-	-	-	-	-
	5	0.00658	0.231	-	0.00656	-	-	-	-	-
	6	0.0103	0.363	-	0.0103	-	-	-	-	-
	7	0.0000176	0.330	-	-	-	-	-	-	-
K	1	0.00403	0.121	-	0.00337	0.000341	0.0000462	0.00000622	0.000000086	0.000000011
	2	0.00434	0.101	-	0.00393	0.000126	0.0000179	0.00000225	0.00000032	-
	3	0.00212	0.0804	-	0.00178	0.0000628	0.00000852	0.00000129	-	-
	4	0.00161	0.0804	-	0.00135	-	-	-	-	-
	5	0.00161	0.0804	-	0.00135	-	-	-	-	-
	6	0.00161	0.0804	-	0.00135	-	-	-	-	-
	7	0.000268	0.0603	-	-	-	-	-	-	-
C	1	0.0273	0.377	-	0.0273	-	-	-	-	-
	2	0.0429	0.440	-	0.0429	-	-	-	-	-
	3	0.0333	0.629	-	0.0333	-	-	-	-	-
	4	0.0466	0.830	-	0.0466	-	-	-	-	-
	5	0.0566	1.068	-	0.0566	-	-	-	-	-
	6	0.0599	1.131	-	0.0599	-	-	-	-	-
	7	-	1.131	-	-	-	-	-	-	-
B10	1	0.129	1.016	-	0.0721	-	-	-	-	-
	2	0.182	1.101	-	0.0973	-	-	-	-	-
	3	0.152	1.143	-	0.0539	-	-	-	-	-
	4	0.279	1.524	-	0.0529	-	-	-	-	-
	5	0.504	2.201	-	0.0529	-	-	-	-	-
	6	0.871	3.302	-	0.0529	-	-	-	-	-
	7	1.199	4.445	-	-	-	-	-	-	-

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Table IV

SEVEN-GROUP MACROSCOPIC FISSION AND CAPTURE CROSS SECTIONS

Group	$\Sigma_f^{Pu^{239}}$	$\Sigma_c^{Pu^{239}}$	$\Sigma_f^{U^{235}}$	$\Sigma_c^{U^{235}}$	$\Sigma_f^{U^{238}}$	$\Sigma_c^{U^{238}}$	Σ_c^{Fe}	Σ_c^{Na}	Σ_c^K	Σ_c^C	$\Sigma_c^{B^{10}}$
1	0.07448	0.00260	0.06040	0.00608	0.02700	0.00073	0.0025	0.000004	0.00027	0	0.0569
2	0.07448	0.00413	0.06040	0.00671	0.02024	0.00280	0.0025	0.000011	0.00027	0	0.0847
3	0.07241	0.00523	0.05800	0.00838	0.00145	0.00580	0.0025	0.000018	0.00027	0	0.0991
4	0.07069	0.00848	0.06520	0.01254	0	0.00848	0.0025	0.000018	0.00027	0	0.2261
5	0.08276	0.01619	0.09160	0.02292	0	0.01206	0.0025	0.000018	0.00027	0	0.4511
6	0.09069	0.02691	0.12040	0.03587	0	0.01689	0.0025	0.000018	0.00027	0	0.8181
7	0.10483	0.04217	0.14960	0.05240	0	0.02650	0.0025	0.000018	0.00027	0	1.199

Table V

TEN-GROUP CROSS SECTIONS

Group No.	Interval (ln 10/E)	E _L , mev	β Fission Spectrum	Pu ²³⁹ (ν = 2.9)				U ²³⁵ (ν = 2.5)				U ²³⁸ (ν = 2.5)							
				σ _{tr}	σ _f	α	σ _{in}	σ _{tr}	σ _f	α	σ _{in}	σ _{tr}	σ _f	σ _c	σ _{in}				
1	0-1.5	2.231	0.346	4.5	2.00	0.03	1.2	4.5	1.25	0.1	2.0	4.5	0.56	0.02	2.7				
2	1.5-2	1.353	0.229	5.0	2.00	0.05	1.1	5.0	1.25	0.12	1.8	4.8	0.42	0.055	2.5				
3	2-3	0.4979	0.301	5.5	1.95	0.07	0.7	5.5	1.20	0.15	1.0	5.0	0.03	0.12	1.0				
4	3-4	0.1832	0.091	7.0	1.90	0.12	0.5	7.0	1.35	0.2	0.5	6.5	0	0.175	0.5				
5	4-5	0.0674	0.025	9.5	2.2	0.2	0	9.5	1.90	0.25	0	9.0	0	0.25	0				
6	5-6	0.0248	0.006	12.0	2.4	0.3	0	12.0	2.50	0.3	0	12.0	0	0.35	0				
7	6-7	0.00912	0.002	13.0	2.7	0.35	0	13.0	3.10	0.32	0	13.0	0	0.5	0				
8	7-8	0.00335	0	16.0	3.0	0.4	0	18.0	3.9	0.35	0	13.0	0	0.7	0				
9	8-9	0.001234	0	16.0	4.0	0.45	0	23.0	5.5	0.38	0	13.5	0	0.9	0				
10	9-	0	0	16.0	6.0	0.5	0	28.0	10.0	0.4	0	13.5	0	1.0	0				
(Atoms/cm ³) x 10 ⁻²⁴				0.0400				0.480				0.0480							
				Fe			Na			K			C		B ¹⁰		Ti		
				σ _{tr}	σ _c	σ _{in}	σ _{tr}	σ _c	σ _{in}	σ _{tr}	σ _c	σ _{in}	σ _{tr}	σ _c	σ _{tr}	σ _c	σ _{tr}	σ _c	σ _{in}
1	0-1.5	2.231	0.346	2.0	0.006	1.0	2.0	0.0002	0.1	2.0	0.02	0.3	1.2	0	2.0	0.2	2.0	0.01 0.8	
2	1.5-2	1.353	0.229	2.0	0.006	0.7	2.0	0.0005	0.05	2.0	0.02	0.2	1.5	0	2.0	0.4	2.0	0.01 0.55	
3	2-3	0.4979	0.301	2.0	0.006	0.3	3.0	0.001	0	1.5	0.02	0.1	2.0	0	3.0	0.3	2.0	0.01 0.25	
4	3-4	0.1832	0.091	3.0	0.006	0	3.0	0.001	0	1.5	0.02	0	3.0	0	4.5	0.9	3.0	0.01 0	
5	4-5	0.0674	0.025	3.0	0.006	0	3.0	0.001	0	1.5	0.02	0	4.0	0	4.5	1.9	5.0	0.01 0	
6	5-6	0.0248	0.006	3.0	0.006	0	5.0	0.001	0	2.0	0.02	0	4.4	0	5.5	3.1	15.0	0.01 0	
7	6-7	0.00912	0.002	3.0	0.006	0	5.0	0.001	0	1.3	0.02	0	4.4	0	8.8	5.2	30.0	0.01 0	
8	7-8	0.00335	0	7.0	0.006	0	15.0	0.001	0	1.5	0.02	0	4.4	0	12.1	8.5	10.0	0.01 0	
9	8-9	0.001234	0	7.0	0.010	0	10.0	0.002	0	1.5	0.02	0	4.4	0	17.6	14.0	6.0	0.02 0	
10	9-	0	0	10.0	0.015	0	4.0	0.003	0	1.5	0.02	0	4.4	0	26.6	23.0	6.0	0.03 0	
(Atoms/cm ³) x 10 ⁻²⁴				0.0847			0.0220			0.0134			0.0838		0.1411		0.0566		

Table VI
TEN-GROUP INELASTIC SCATTERING MATRIX

$X_{j \rightarrow k}$						
j	k = 2	3	4	5	6	7
1	0.3799	0.4402	0.1318	0.0366	0.0089	0.0026
2	-	0.7098	0.2126	0.0591	0.0143	0.0042
3	-	-	0.7324	0.2037	0.0493	0.0146
4	-	-	-	0.7612	0.1841	0.0547

The ten-group macroscopic constants entering formally into the diffusion equations are given in Table VII. The macroscopic fission and capture cross sections are given in Table VIII. The capture cross section of a $\frac{1}{V}$ absorber, which is useful for neutron lifetime calculation, is included in Table VIII.

The inelastic scattering matrix for all materials was derived from a differential inelastic scattering law of the form

$$\sigma(E_0 \rightarrow E) = (\text{const}) E \sigma_c(E) e^{-E/T},$$

where $\sigma_c(E)$ is proportional to the cross section for formation of the compound nucleus and was taken to be

$$\begin{aligned} \sigma_c(E) &= 1, \quad E \geq E' \\ &= \frac{\sqrt{E'}}{\sqrt{E}}, \quad E < E'. \end{aligned}$$

It was assumed that

$$T = 1 \text{ mev},$$

$$E' = 0.4979 \text{ mev } (\mu = 3).$$

For $E_2 > E_1 \geq E'$, we obtain

$$\int_{E_1}^{E_2} \sigma(E_0 \rightarrow E) dE = \text{Const.} \left[e^{-E_1} (E_1 + 1) - e^{-E_2} (E_2 + 1) \right].$$

100
015

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Table VII

TEN-GROUP MACROSCOPIC CONSTANTS

Material	Group	Σ_a	$3 \Sigma_{tr}$	$\nu \Sigma_f$	$\Sigma_j + 1$	$\Sigma_j + 2$	$\Sigma_j + 3$	$\Sigma_j + 4$	$\Sigma_j + 5$	$\Sigma_j + 6$
Pu ²³⁹	1	0.130965	0.54	0.232	0.01880	0.02113	0.006326	0.001757	0.0004272	0.0001248
	2	0.129108	0.6	0.232	0.03234	0.009354	0.002600	0.0006292	0.0001848	0
	3	0.1123728	0.66	0.2262	0.02142	0.005704	0.001380	0.0004088	0	0
	4	0.106586	0.84	0.2204	0.01669	0.003682	0.001094	0	0	0
	5	0.107905	1.14	0.2552	0.002305	0	0	0	0	0
	6	0.127784	1.44	0.2784	0.002984	0	0	0	0	0
	7	0.148943	1.56	0.3132	0.003143	0	0	0	0	0
	8	0.171965	1.92	0.348	0.003965	0	0	0	0	0
	9	0.235427	1.92	0.464	0.003427	0	0	0	0	0
	10	0.36	1.92	0.696	0	0	0	0	0	0
U ²³⁵	1	0.162618	0.648	0.15	0.03709	0.04226	0.01265	0.003514	0.0008544	0.0002496
	2	0.1549349	0.72	0.15	0.06266	0.01837	0.005106	0.001236	0.0003629	0
	3	0.1154948	0.792	0.144	0.03641	0.009778	0.002366	0.0007008	0	0
	4	0.103731	1.008	0.162	0.02024	0.004418	0.001313	0	0	0
	5	0.116873	1.368	0.228	0.002873	0	0	0	0	0
	6	0.159528	1.728	0.300	0.003528	0	0	0	0	0
	7	0.200012	1.872	0.372	0.003592	0	0	0	0	0
	8	0.257855	2.592	0.468	0.005135	0	0	0	0	0
	9	0.370513	3.312	0.660	0.006213	0	0	0	0	0
	10	0.672	4.032	1.2	0	0	0	0	0	0
U ²³⁸	1	0.158113	0.648	0.0672	0.04991	0.05705	0.01708	0.004743	0.001153	0.0003370
	2	0.144152	0.6912	0.0504	0.08653	0.02551	0.007092	0.001716	0.0005040	0
	3	0.0567548	0.72	0.0036	0.03671	0.009778	0.002366	0.0007008	0	0
	4	0.034751	0.936	0	0.02062	0.004418	0.001313	0	0	0
	5	0.015528	1.296	0	0.003528	0	0	0	0	0
	6	0.021497	1.728	0	0.004697	0	0	0	0	0
	7	0.02904	1.872	0	0.00504	0	0	0	0	0
	8	0.038559	1.872	0	0.004959	0	0	0	0	0
	9	0.04828	1.944	0	0.005080	0	0	0	0	0
	10	0.048	1.944	0	0	0	0	0	0	0

Table VII (Cont'd)

Material	Group	Σ_a	$3 \Sigma_{tr}$	$\nu \Sigma_f$	$\Sigma_j + 1$	$\Sigma_j + 2$	$\Sigma_j + 3$	$\Sigma_j + 4$	$\Sigma_j + 5$	$\Sigma_j + 6$
Na	1	0.00706562	0.132	0	0.005697	0.0009684	0.0002900	0.00008052	0.00001958	0.00000572
	2	0.00783526	0.132	0	0.007505	0.0002339	0.00006501	0.00001573	0.00000462	0
	3	0.005643	0.198	0	0.005621	0	0	0	0	0
	4	0.005643	0.198	0	0.005621	0	0	0	0	0
	5	0.005643	0.198	0	0.005621	0	0	0	0	0
	6	0.009392	0.330	0	0.009370	0	0	0	0	0
	7	0.009392	0.330	0	0.009370	0	0	0	0	0
	8	0.028132	0.99	0	0.02811	0	0	0	0	0
	9	0.018784	0.66	0	0.01874	0	0	0	0	0
	10	0.000066	0.264	0	0	0	0	0	0	0
Fe	1	0.0893022	0.5082	0	0.03628	0.03728	0.01116	0.003100	0.0007538	0.0002202
	2	0.0669990	0.5082	0	0.04928	0.01261	0.003504	0.0008478	0.0002490	0
	3	0.0310382	0.5082	0	0.02373	0.005176	0.001253	0.0003710	0	0
	4	0.0095622	0.7623	0	0.009054	0	0	0	0	0
	5	0.0095622	0.7623	0	0.009054	0	0	0	0	0
	6	0.0095622	0.7623	0	0.009054	0	0	0	0	0
	7	0.0095622	0.7623	0	0.009054	0	0	0	0	0
	8	0.0216582	1.7787	0	0.02115	0	0	0	0	0
	9	0.021987	1.7787	0	0.02114	0	0	0	0	0
	10	0.00127	2.541	0	0	0	0	0	0	0
K	1	0.00584613	0.0804	0	0.003085	0.001770	0.0005248	0.0001471	0.00003578	0.00001045
	2	0.00517278	0.0804	0	0.004127	0.0005698	0.0001584	0.00003832	0.00001126	0
	3	0.00254562	0.0603	0	0.001919	0.0002730	0.00006606	0.00001956	0	0
	4	0.001273	0.0603	0	0.001005	0	0	0	0	0
	5	0.001273	0.0603	0	0.001005	0	0	0	0	0
	6	0.001613	0.0804	0	0.001345	0	0	0	0	0
	7	0.0011376	0.05226	0	0.0008696	0	0	0	0	0
	8	0.001273	0.0603	0	0.001005	0	0	0	0	0
	9	0.001273	0.0603	0	0.001005	0	0	0	0	0
	10	0.000268	0.0603	0	0	0	0	0	0	0

Table VII (Cont'd)

Material	Group	Σ_a	$3 \Sigma_{tr}$	$\nu \Sigma_f$	$\Sigma_j^j + 1$	$\Sigma_j^j + 2$	$\Sigma_j^j + 3$	$\Sigma_j^j + 4$	$\Sigma_j^j + 5$	$\Sigma_j^j + 6$
C	1	0.02182	0.3018	0	0.02182	0	0	0	0	0
	2	0.03675	0.3771	0	0.03675	0	0	0	0	0
	3	0.02663	0.5028	0	0.02663	0	0	0	0	0
	4	0.03995	0.7542	0	0.03995	0	0	0	0	0
	5	0.05326	1.0056	0	0.05326	0	0	0	0	0
	6	0.05859	1.1061	0	0.05859	0	0	0	0	0
	7	0.05859	1.1061	0	0.05859	0	0	0	0	0
	8	0.05859	1.1061	0	0.05859	0	0	0	0	0
	9	0.05859	1.1061	0	0.05859	0	0	0	0	0
	10	0	1.1061	0	0	0	0	0	0	0
B ¹⁰	1	0.09315	0.8466	0	0.06493	0	0	0	0	0
	2	0.13424	0.8466	0	0.07780	0	0	0	0	0
	3	0.11369	1.2699	0	0.07136	0	0	0	0	0
	4	0.22215	1.905	0	0.09515	0	0	0	0	0
	5	0.33682	1.905	0	0.06872	0	0	0	0	0
	6	0.50082	2.328	0	0.06342	0	0	0	0	0
	7	0.82890	3.726	0	0.09520	0	0	0	0	0
	8	1.29415	5.121	0	0.09515	0	0	0	0	0
	9	2.07015	7.449	0	0.09515	0	0	0	0	0
	10	3.245	11.259	0	0	0	0	0	0	0
Ti	1	0.0496617	0.3396	0	0.02102	0.01993	0.005968	0.001657	0.0004030	0.0001177
	2	0.0379199	0.3396	0	0.02832	0.006618	0.001840	0.0004452	0.0001307	0
	3	0.0188022	0.3396	0	0.01445	0.002882	0.0006975	0.0002065	0	0
	4	0.007589	0.5094	0	0.007023	0	0	0	0	0
	5	0.012286	0.849	0	0.01172	0	0	0	0	0
	6	0.035776	2.547	0	0.03521	0	0	0	0	0
	7	0.071006	5.094	0	0.07044	0	0	0	0	0
	8	0.024036	1.598	0	0.02347	0	0	0	0	0
	9	0.015182	1.0188	0	0.01405	0	0	0	0	0
	10	0.001698	1.0188	0	0	0	0	0	0	0

Table VIII

TEN-GROUP MACROSCOPIC FISSION AND CAPTURE CROSS SECTIONS

Group	$\Sigma_f^{Pu^{239}}$	$\Sigma_c^{Pu^{239}}$	$\Sigma_f^{U^{235}}$	$\Sigma_c^{U^{235}}$	$\Sigma_f^{U^{238}}$	$\Sigma_c^{^{238}Pu}$	Σ_c^{Fe}	Σ_c^{Na}	Σ_c^K	Σ_c^C	$\Sigma_c^{B^{10}}$	Σ_c^{Ti}	$\Sigma_c^{1/v}$
1	0.080	0.00240	0.0600	0.00600	0.02688	0.00096	0.0005082	0.0000044	0.000268	0	0.02822	0.000566	0.0391
2	0.080	0.00400	0.0600	0.00720	0.02016	0.00264	0.0005032	0.0000110	0.000268	0	0.05644	0.000566	0.0543
3	0.078	0.00546	0.0576	0.00864	0.00144	0.00576	0.0005082	0.0000220	0.000268	0	0.04233	0.000566	0.0806
4	0.076	0.00912	0.0648	0.01296	0	0.00840	0.0005082	0.0000220	0.000268	0	0.1270	0.000566	0.1330
5	0.088	0.01760	0.0912	0.02280	0	0.01200	0.0005082	0.0000220	0.000268	0	0.2681	0.000566	0.2190
6	0.096	0.02880	0.1200	0.03600	0	0.01680	0.0005082	0.0000220	0.000268	0	0.4374	0.000566	0.3610
7	0.108	0.03780	0.1488	0.04762	0	0.02400	0.0005082	0.0000220	0.000268	0	0.7337	0.000566	0.5960
8	0.120	0.04800	0.1872	0.06552	0	0.03360	0.0005082	0.0000220	0.000268	0	1.199	0.000566	0.9820
9	0.160	0.07200	0.2640	0.10030	0	0.04320	0.000847	0.0000440	0.000268	0	1.975	0.001132	1.6200
10	0.240	0.12000	0.4800	0.19200	0	0.04800	0.00127	0.0000660	0.000268	0	3.245	0.001698	2.6700

For $E_1 < E_2 \leq E'$, we obtain

$$\int_{E_1}^{E_2} \sigma(E_0 \rightarrow E) dE = \text{Const.} \sqrt{E'} \left[I(\sqrt{E_2}) - I(\sqrt{E_1}) - \sqrt{E_2} e^{-E_2} + \sqrt{E_1} e^{-E_1} \right].$$

It was assumed that no inelastic scattering occurred to energies below group 7 (but the value assigned to group 7 included all scattering to below group 7 as evaluated by the formula).

IV. TREATMENT OF ELASTIC MODERATION

In both the seven- and ten-group sets, the cross section for transfer by elastic moderation from group j to $j+1$ was assumed to be

$$\alpha_j \bar{\xi} \Sigma_{\text{el tr}}^j$$

where

α_j is a constant which gives the ratio of the flux per unit u interval at E_{jL} (low energy end of the group) to the total flux in the j th energy group,

$\bar{\xi}$ is the average logarithmic loss per (spherically symmetric in center of mass system) elastic collision,

and

$$\Sigma_{\text{el tr}} = \Sigma_{\text{tr}} - \Sigma_f - \Sigma_c - \Sigma_{\text{in}}.$$

In groups 1 and 2 it was assumed that the flux shape was the same as in a fission spectrum, yielding

$$\alpha_1 = \frac{E_{1L} f(E_{1L})}{g(E_{1L})} = 1.37$$

$$\alpha_2 = \frac{E_{2L} f(E_{2L})}{g(E_{1L}) - g(E_{2L})} = 1.84$$

where $f(E)$ denotes the fission spectrum and

$$g(E) = \int_E^{\infty} f(E') dE'.$$

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In the remaining groups it was assumed that the flux per unit u interval was constant over the group; therefore,

$$\left. \begin{aligned} \alpha_j &= 1 \text{ for } j = 3 \text{ to } 6 \text{ (seven-group set)} \\ &= 3 \text{ to } 9 \text{ (ten-group set)} \end{aligned} \right\} \text{since } \Delta u = 1 \text{ for these groups.}$$

V. SUMMARY OF DIFFUSION THEORY STEADY-STATE PROPERTIES

Table IX lists the steady-state properties of the full-scale reactor and the pilot plant when calculated in cylindrical geometry with the seven-group set of cross sections. Both Pu^{239} and U^{235} are considered for the fuel. The fluxes and number of various events are normalized to one fission neutron in the core.

The full-scale reactor and the pilot plant are to have the same composition except for fuel enrichment. Table X lists the steady-state properties of spherical assemblies with four different Pu^{239} enrichments and two U^{235} enrichments. The Pu^{239} enrichments include one assembly more concentrated than EBR-II and one intermediate between EBR-II and PBR, as well as those corresponding to PBR and EBR-II. These calculations were performed with the ten-group cross sections.

The normalization is again one fission neutron in the core.

The blanket breeding ratios, breeding gains, and escape are listed only for the spherical assemblies, since the assumption of an axially bare reactor made in the cylindrical calculations causes too great an error in the direct evaluation of these quantities.

The fast fission bonus is determined primarily by what the fission neutrons see in their first collisions. If all the collisions above the U^{238} fission threshold are with U^{238} atoms, then the fast fission bonus is at a maximum. In general, however, the neutron may be degraded below the fission threshold by collisions with atoms other than U^{238} . The probability of this is determined essentially by the composition. The problem is complicated by the fact that neutrons may escape the core above the U^{238} fission threshold. For the assemblies we have been considering, the blanket has a higher density of U^{238} atoms than the core; for small concentrated assemblies, the fast fission bonus in the core is small. However, the increased fast leakage into the higher U^{238} density blanket just about compensates for it, and in practice the fast fission bonus is relatively independent of core dilution for the assemblies we are considering. This conclusion, of course, does not hold if one dilutes with a material other than U^{238} .

Table IX

SUMMARY OF STEADY-STATE PROPERTIES OF PBR AND EBR-II IN CYLINDRICAL GEOMETRY

	For All Assemblies:							
	Core Volume Fraction				Blanket Volume Fraction			
	Fuel+U ²³⁸	Fe	Na		U ²³⁵	U ²³⁸	Fe	Na
	0.335	0.148	0.517		0.0014	0.6986	0.1	0.2
	PBR				EBR-II			
Core Volume, liters	800				50			
Core Radius, cm	52.7				20.96			
Core Height, cm	91.44				36.32			
Equivalent Bare Core Height, cm	121.44				60.72			
Blanket thickness, cm	60				60			
	Pu ²³⁹ Fuel		U ²³⁵ Fuel		Pu ²³⁹ Fuel		U ²³⁵ Fuel	
	Pu ²³⁹	U ²³⁸	U ²³⁵	U ²³⁸	Pu ²³⁹	U ²³⁸	U ²³⁵	U ²³⁸
Core Volume Fractions	0.03882	0.29618	0.04848	0.28652	0.10722	0.22778	0.1511	0.1839
Critical Mass, kg	495		727		86		142	
Flux Integral for:	Core	Blanket	Core	Blanket	Core	Blanket	Core	Blanket
Group: 1	4.718	0.389	4.697	0.392	3.572	1.112	3.549	1.102
2	6.021	0.619	5.999	0.623	4.085	1.668	4.051	1.649
3	13.972	1.669	13.924	1.679	8.504	4.191	8.395	4.132
4	19.085	3.122	18.729	3.110	8.899	6.757	8.399	6.538
5	28.410	10.162	25.542	9.690	8.733	16.214	6.986	14.841
6	10.805	3.895	8.762	3.561	2.564	5.336	1.740	4.682
7	5.905	1.674	3.984	1.398	0.906	1.795	0.489	1.477
Pu ²³⁹ fissions	0.2760	0	0	0	0.3072	0	0	0
Pu ²³⁹ captures	0.0494	0	0	0	0.0424	0	0	0
U ²³⁵ fissions	0	0.0028	0.3231	0.0026	0	0.0045	0.3651	0.0042
U ²³⁵ captures	0	.00073	.0741	.00068	0	.0011	.0714	.0010
U ²³⁸ fissions	0.0798	.0178	.0769	.0179	0.0436	.0488	.0349	.0483
U ²³⁸ captures	.2799	.1893	.2353	.1762	.0711	.2936	.0479	.2669
Na+Fe captures	.0337	.0055	.0309	.0052	.0141	.0094	.0127	.0087
Total Fissions	0.3559	0.0206	0.4	0.0205	0.3508	0.0533	0.4	0.0525
Internal Breeding Ratio	0.860		0.592		0.203		0.110	
α = (fuel captures/fuel fissions)	0.179		0.229		0.138		0.196	
f = (U ²³⁸ fissions/fuel fissions)	0.354		0.293		0.301		0.228	
Max/average core power	1.60		1.58		1.31		1.28	

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Table X

SURVEY OF STEADY-STATE PROPERTIES OF ASSEMBLIES OF EBR-II-PBR
COMPOSITION WITH VARIOUS ENRICHMENTS

For All Assemblies:

	Core Volume Fraction						Blanket Volume Fraction					
	Fuel + U ²³⁵		Ti	Na	U ²³⁵		U ²³⁸	Ti	Na			
	0.32		0.14	0.54	0.0014		0.6986	0.1	0.2			
	Concentrated Pu ²³⁹ Assembly		EBR-II Pu ²³⁹ Fuel		EBR-II U ²³⁵ Fuel		Intermediate Pu ²³⁹ Fuel		PBR Pu ²³⁹ Fuel		PBR U ²³⁵ Fuel	
Core Volume (liters)	12.5		50		50		200		800		800	
Core Radius (cm)	14.4		22.85		22.85		36.28		57.59		57.59	
Blanket Thickness (cm)	45		45		45		45		45		45	
	Pu ²³⁹	U ²³⁸	Pu ²³⁹	U ²³⁸	U ²³⁵	U ²³⁸	Pu ²³⁹	U ²³⁸	Pu ²³⁹	U ²³⁸	U ²³⁵	U ²³⁸
Volume Fractions in Core	0.2170	0.1030	0.1043	0.2157	0.1606	0.1594	0.0551	0.2639	0.0351	0.2849	0.0475	0.2725
Critical Mass	43.1 kg Pu ²³⁹		82.7 kg Pu ²³⁹		150 kg U ²³⁵		178 kg Pu ²³⁹		446 kg Pu ²³⁹		712 kg U ²³⁵	
Flux Integral for:	Core	Blanket	Core	Blanket	Core	Blanket	Core	Blanket	Core	Blanket	Core	Blanket
Group 1	2.60	2.55	3.58	1.78	3.45	1.71	4.40	1.11	4.99	0.62	4.89	0.61
2	2.32	2.91	3.45	2.11	3.34	2.04	4.51	1.36	5.31	0.77	5.23	0.77
3	5.33	13.42	9.43	10.72	8.94	10.19	14.33	7.51	18.84	4.55	18.40	4.48
4	4.11	20.29	8.59	17.34	8.04	16.37	15.25	13.15	22.72	8.54	22.09	8.37
5	3.09	31.03	7.26	27.63	5.95	25.15	14.55	22.23	24.14	15.37	21.84	14.61
6	0.95	11.00	2.41	9.86	1.71	8.81	5.18	8.03	9.08	5.63	7.59	5.26
7	0.34	4.03	0.94	3.65	0.57	3.21	2.20	3.02	4.09	2.16	3.13	1.97
8	0.097	1.38	0.32	1.29	0.15	1.09	0.88	1.11	1.81	0.83	1.21	0.73
9	0.028	0.39	0.12	0.38	0.040	0.31	0.41	0.36	0.99	0.30	0.54	0.24
10	0.005	0.094	0.031	0.099	0.005	0.072	0.15	0.11	0.46	0.11	0.16	0.067
Pu ²³⁹ Fissions	0.3337	0	0.3115	0	0	0	0.2925	0	0.2790	0	0	0
Pu ²³⁹ Captures	0.0399	0	0.0431	0	0	0	0.0453	0	0.0491	0	0	0
U ²³⁵ Fissions	0	0.0106	0	0.0091	0.3724	0.0084	0	0.0073	0	0.0050	0.3282	0.0047
U ²³⁵ Captures	0	0.0026	0	0.0023	0.0748	0.0021	0	0.0019	0	0.0013	0.0758	0.0012
U ²³⁸ Fissions	0.0128	0.1023	0.0387	0.0740	0.0276	0.0711	0.0607	0.0476	0.0764	0.0271	0.0718	0.0268
U ²³⁸ Captures	0.0144	0.6842	0.0662	0.6037	0.0402	0.5472	0.1572	0.4831	0.2805	0.3334	0.2307	0.3127
Na + Ti Captures	0.0017	0.0054	0.0033	0.0044	0.0029	0.0042	0.0056	0.0036	0.0085	0.0024	0.0097	0.0023
Total Fissions	0.3465	0.1129	0.3503	0.0831	0.4	0.0795	0.3532	0.0549	0.3554	0.0321	0.4	0.0315
Internal Breeding Ratio	0.039		0.187		0.090		0.464		0.855		0.571	
Blanket Breeding Ratio	1.831		1.702		1.224		1.426		1.016		0.774	
Breeding Ratio	1.870		1.889		1.314		1.890		1.871		1.345	
$\alpha = \frac{\text{fuel captures}}{\text{fuel fissions}}$	0.120		0.138		0.201		0.158		0.176		0.231	
$f = \frac{\text{U}^{238} \text{ fissions}}{\text{fuel fissions}}$	0.345		0.352		0.265		0.370		0.371		0.300	
Max/Average Core Power	1.27		1.40		1.36		1.61		1.87		1.84	
Escape	0.0746		0.0515		0.0484		0.0318		0.0174		0.0170	
Buckling (cm ⁻²)	0.01190		0.00655		---		0.00346		0.00173		---	
Reflector Savings (cm)	14.4		16.0		---		17.1		17.9		---	

VI. COMPARISON OF RESULTS OF DIFFUSION THEORY AND S_4 METHOD

Carlson⁴ at Los Alamos has developed the " S_n Method" for numerically solving the Boltzmann Equation in a form suitable for high-speed computing machines. In this method, the angular variable, μ (cosine of angle between neutron direction and radius vector), is divided into n equal regions between -1 and 1 , and in each region the flux per unit μ interval is assumed to be linear with μ .

The four, spherical geometry, Pu^{239} fuel assemblies given in Table X were sent to Los Alamos and solved by the S_4 method with the same ten-group cross sections. The transport cross sections in the diffusion theory were interpreted as total cross sections with spherically symmetric scattering (i. e., the transport approximation) in the S_4 calculations. For each assembly, the critical composition as determined by diffusion theory was specified and the critical core radius was then determined. The blanket thickness was kept fixed at 42.75 cm (approximately an extrapolation length less than in the diffusion theory calculations). The results, and a comparison with diffusion theory, are given in Figure 1 and Table XI.

Table XI

COMPARISON OF RESULTS OF DIFFUSION THEORY WITH S_4 METHOD

	PER		Intermediate		EBR-II		Concentrated	
	D.T.	S_4	D.T.	S_4	D.T.	S_4	D.T.	S_4
Pu^{239} volume fraction in core	0.03511	0.03511	0.05611	0.05611	0.1043	0.1043	0.2169	0.2169
Critical radius, cm	57.59	57.59	36.28	35.94	22.85	22.18	14.40	13.48
Critical mass, kg Pu^{239}	446	446	178	173	82.7	75.6	43.1	35.3
$\frac{\Delta M}{M_{S_4}}$, fixed composition	0	-	0.029	-	0.094	-	0.221	-
$\frac{\Delta M}{M_{S_4}}$, fixed radius	0	-	0.015	-	0.05	-	0.12	-

⁴Carlson, B. G. "Solution of the Transport Equation by S_n Approximations," LA-1891 (February, 1955).

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VII. CRITICAL MASS

The critical masses for various full-scale and pilot plant designs are summarized in Table XII. The results represent calculations in both spherical and cylindrical geometry, Pu^{239} fuel and U^{235} fuel, seven-group and ten-group cross sections, and also for slightly varying reference compositions and dimensions. For convenience, the effects on critical mass resulting from various methods of radial power flattening are included.

(A large number of such calculations are discussed in Section XIII.)

The critical masses were all calculated for the clean assembly. Estimates of the increases in critical mass required to compensate for fuel burnup and fission poisons are included; they are based on results discussed in Section IX.

From the results of the diffusion theory and the S_4 method, it appears that diffusion theory is satisfactory for critical mass calculations on the full-scale reactor. As the assemblies get smaller and more enriched, the relative error introduced by the use of diffusion theory increases. For EBR-II, diffusion theory overestimates the critical mass by about 5% if the radius is specified and the critical composition then determined.

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Table XII

CRITICAL MASSES OF VARIOUS ASSEMBLIES

Argonne Problem No.	UNIVAC Tape Prob. No.	Critical Mass, kg	Reference* Composition	Remarks
<u>PBR - Pu²³⁹ Fuel</u>				
1	02008	495	1	Cylindrical reference design (Table IX), using seven-group cross sections.
80	04143	464	1	Same as Problem 1, but using ten-group cross sections.
13	02103.	543	1	Same as Problem 1, with radial flattening of power by variation of enrichment in 5 rings in core (see Section XIII, page 41).
84	04147	459	2	Cylindrical reference design. Cylindrical counterpart of Problem S1.
92	04127	594	2 (active part of core only)	Same core composition as Problem 122 (see Appendix A), with central blanket (see Section XIII).
S1	04A01	446	2	Spherical reference design (Table X). S_4 method gives same critical mass.
S80	04B69	468	2	Same as Problem S1 with estimated additional fuel to compensate for 2% core alloy burnup. With 446 kg Pu ²³⁸ , $k_{eff} = 0.980$ (see Section IX, page 33).
<u>PBR - U²³⁵ Fuel</u>				
31	02019	727	1	Same as Problem 1 but with U ²³⁵ fuel.
81	04144	745	1	Same as Problem 31, but using ten-group cross sections.
S67	04A38	712	2	Same as Problem S1, but with U ²³⁵ fuel.
<u>EBR-II - Pu²³⁹ Fuel</u>				
37	02020	86	1	Cylindrical pilot plant reference design (Table IX). Seven-group cross sections.
82	04145	85	1	Same as Problem 37, but using ten-group cross sections.
40	02098	89	1	Same as Problem 37, with radial flattening of power by variation of enrichment in 5 rings in core (see Section XIII).
85	04151	89	2	Cylindrical Pilot Plant reference design. Cylindrical counterpart of Problem S2.
S2	04A02	83	2	Spherical Pilot Plant reference design (Table X). S_4 method gives 79 kg Pu ²³⁹ for same dimensions.
S86	04B64	87	2	Same as Problem S2 with estimated additional fuel to compensate for 2% core alloy burnup. With 83 kg Pu ²³⁹ , $k_{eff} = 0.974$ (see Section IX, page 33).
<u>EBR-II - U²³⁵ Fuel</u>				
47	02022	142	1	Same as Problem 37, but with U ²³⁵ fuel.
83	04146	155	1	Same as Problem 47, but using ten-group cross sections.
S68	04A39	150	2	Same as Problem S2, but with U ²³⁵ fuel.
<u>EBR-II - Pu²³⁹-U²³⁵ Fuel</u>				
110	04109	Pu ²³⁹ 25.4 U ²³⁵ 145.7	2 (active part of core only)	Same core composition as Problem 123, using both Pu ²³⁹ and U ²³⁵ fuel with central blanket (see Section XIII).

*Core Height, cm

Equivalent Bare Core Height, cm

		<u>PBR</u>	<u>EBR-II</u>								
*Core Height, cm		91.44	36.32								
Equivalent Bare Core Height, cm		121.44	60.72								
						<u>Composition 2</u>					
		<u>Composition 1 (Cylindrical Geometry)</u>				<u>(Cylindrical and Spherical Geometry)</u>					
		<u>Pu²³⁹</u>	<u>U²³⁵</u>	<u>U²³⁸</u>	<u>Fe</u>	<u>Na</u>	<u>Pu²³⁹</u>	<u>U²³⁵</u>	<u>U²³⁸</u>	<u>Ti</u>	<u>Na</u>
Core Volume Fractions		← 0.335 →			0.148	0.517	← 0.32 →			0.14	0.54
Blanket Volume Fraction	0	0.0014	0.6986		0.1	0.2	0	0.0014	0.6986	0.1	0.2
Blanket Thickness, cm			60						45		

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VIII. FLUX DISTRIBUTION

In Figures 2 to 5 cylindrical and spherical geometry diffusion theory flux distributions are given for PBR and EBR-II.

The fluxes are all normalized to an average of one fission neutron/cm³ of core. However, in the cylindrical case, the values given are for the mid-plane. The radial average of these values over the core is thus $\frac{\pi}{2}$, since the axial average of $\cos \frac{\pi z}{H}$ introduces a factor $\frac{2}{\pi}$.

To convert the fluxes to operating conditions, one multiplies by:

$$3.125 \times 10^{13} \times \left(\frac{\text{megawatts}}{\text{liter}} \right)_{\text{average over core}} \times \left(\frac{\text{fission neutrons}}{\text{fissions}} \right)_{\text{average over core}}$$

The energy spectra of the flux integrals over the cores of various assemblies are compared in Table XIII. To facilitate the comparison, the fluxes have been renormalized to a sum over the groups of unity.

In Table XIV, the energy distribution of neutrons causing fissions in the core are given for the four spherical assemblies of varying Pu²³⁹ enrichment described in Table X. The median fission energies are also given. The fraction of fissions occurring in the highest energy groups passes through a slight minimum. This results from the competition, as one goes to higher dilutions, between degradation of the spectrum and increased U²³⁸ fast fission.

The power distributions for PBR and EBR-II in cylindrical geometry are given in Figures 6 to 9. In Figures 8 and 9 the power distributions of the Pu²³⁹ fuel cylindrical reference designs of Table IX are compared with the distributions obtained when the power is flattened by varying the enrichment in radial rings in the core. The power distributions obtained when the power is flattened by the use of a central blanket are shown in Figures 10 and 11. The flattened assemblies are discussed in detail in Section XIII.

The changes in blanket power distribution due to buildup of Pu²³⁹ are discussed in detail in the following section.

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Table XIII

ENERGY SPECTRA OF FLUX INTEGRALS OVER CORE

Group No.	PBR-Pu ²³⁹ Fuel			PBR-U ²³⁵ Fuel		Intermediate- Pu ²³⁹ Fuel
	1 (02008)	84 (04147)	S1 (04A01)	31 (02019)	S67 (04A38)	S5 (04A04)
1	0.053	0.056	0.054	0.058	0.057	0.071
2	.068	.060	.057	.073	.062	.073
3	.157	.210	.204	.171	.216	.232
4	.215	.248	.246	.229	.260	.246
5	.319	.254	.261	.313	.257	.235
6	.122	.095	.098	.107	.089	.084
7	0.066	.043	.044	0.049	.037	.036
8	-	.019	.020	-	.014	.014
9	-	.010	.011	-	.0063	.0066
10	-	0.0048	0.0050	-	0.0019	0.0024

Group No.	EBR-Pu ²³⁹ Fuel			EBR-II - U ²³⁵ Fuel		Concentrated Pu ²³⁹ Fuel
	37 (02020)	85 (04151)	S2 (04A02)	47 (02022)	S68 (04A39)	S4 (04A05)
1	0.096	0.110	0.099	0.106	0.107	0.138
2	.109	.105	.095	.120	.104	.123
3	.227	.277	.261	.250	.277	.282
4	.241	.236	.238	.250	.250	.218
5	.234	.179	.201	.208	.185	.164
6	.069	.059	.067	.052	.053	.050
7	0.024	.023	.026	0.014	.018	.018
8	-	.0076	.0088	-	.0046	.0052
9	-	.0027	.0033	-	.0012	.0015
10	-	0.0007	0.0009	-	0.0002	0.0003

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Table XIV

ENERGY DISTRIBUTION OF NEUTRONS
CAUSING FISSIONS IN CORE

(f_j is the fraction of fissions occurring in the j 'th group)

Group j	E_j Lower	PBR f_j	Inter- mediate f_j	EBR-II f_j	Concen- trated f_j
1	2.231	0.147	0.144	0.145	0.151
2	1.353	0.128	0.125	0.125	0.130
3	0.4979	0.167	0.193	0.227	0.262
4	0.1832	0.170	0.184	0.194	0.196
5	0.0674	0.210	0.203	0.190	0.170
6	0.0248	0.086	0.079	0.069	0.057
7	0.00912	0.044	0.038	0.030	0.023
8	0.00335	0.021	0.017	0.012	0.007
9	0.001234	0.016	0.011	0.006	0.003
10	0	0.011	0.006	0.002	0.001
Median Fission Energy, mev		0.36	0.41	0.49	0.59

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IX. LONG-TERM CHANGES

The long-term changes investigated were:

- (1) Buildup, burnup, and fission product distribution
- (2) Power distribution changes
- (3) Effect of fission product capture on breeding gain
- (4) Reactivity effects.

These effects all depend on the details of the unloading cycles which in practice probably would be very complicated, involving the unloading of various segments of the reactor at different times. In order to obtain an estimate of the magnitude of the effects involved, the long-term changes were determined between the initial clean reactor and conditions after a 2% average burnup by fission of the core alloy ($\text{Pu}^{239} + \text{U}^{238}$) atoms.

Calculations were performed on the following initially clean PBR and EBR-II reference design assemblies in spherical geometry using the ten-group set of cross sections.

	Core Radius, cm	Blanket Thickness, cm	Core Volume Fraction			
			Pu^{239}	U^{238}	Ti	Na
PBR	57.59	45	0.03511	0.28489	0.14	0.54
EBR-II	22.85	45	0.10425	0.21575	0.14	0.54

The blanket volume fractions for the PBR and the EBR-II were: 0.0014 U^{235} ; 0.6986 U^{238} ; 0.1 Ti; and 0.2 Na.

The flux distributions obtained for the initial clean reactor were used to determine the buildup, burnup, and fission product distribution under the assumption that the flux shapes did not vary with time. The continuously varying compositions after 2% burnup were approximated by five core and five blanket regions each of constant composition equal to the average value for the region. Tables XV and XVI list the various distributions that result for PBR and EBR-II.

In order to determine the remainder of the long-term changes, solutions were obtained for the reactors of these new compositions.

The blanket power distributions before and after the 2% burnup are shown in Figures 12 and 13.

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Table XV

BURNUP, BUILDUP, AND FISSION PRODUCT DISTRIBUTION FOR PBR AFTER 2% CORE ALLOY BURNUP

(Calculation made in spherical geometry)

Region	Outer Radius, cm	Original Volume Fraction Pu ²³⁹	Volume Fraction Pu ²³⁹ Destroyed	Volume Fraction Pu ²³⁹ Added	Fraction Original Pu ²³⁹ Remaining	Fissions
						Pu ²³⁹ atoms destroyed
1	11.518	0.03511	0.01204	0.01016	0.9463	1.103
2	23.036	0.03511	0.01146	0.00967	0.9491	1.102
3	34.554	0.03511	0.00982	0.00830	0.9568	1.100
4	46.072	0.03511	0.00757	0.00644	0.9678	1.093
5	57.59 (core radius)	0.03511	0.00509	0.00441	0.9807	1.060
6	59.59	0	0	0.007959	--	--
7	62.59	0	0	0.006580	--	--
8	66.59	0	0	0.004948	--	--
9	72.59	0	0	0.003190	--	--
10	102.59	0	0	0.000636	--	--

Assuming uniform changes in core:

57.59	0.03511	0.00696	0.00595	0.9712	1.084
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Table XVI

BURNUP, BUILDUP, AND FISSION PRODUCT DISTRIBUTION FOR EBR-II AFTER 2% CORE ALLOY BURNUP

(Calculation made in spherical geometry)

Region	Outer Radius, cm	Original Volume Fraction Pu ²³⁹	Volume Fraction Pu ²³⁹ Destroyed	Volume Fraction Pu ²³⁹ Added	Fraction Original Pu ²³⁹ Remaining	<u>Fissions</u>
						Pu ²³⁹ atoms destroyed
1	4.57	0.10425	0.00993	0.00175	0.9215	1.015
2	9.14	0.10425	0.00950	0.00168	0.9250	1.013
3	13.71	0.10425	0.00872	0.00156	0.9313	1.007
4	18.28	0.10425	0.00765	0.00140	0.9401	0.995
5	22.85 (core radius)	0.10425	0.00639	0.00122	0.9504	0.971
6	24.85	0	0	0.003481	--	--
7	27.85	0	0	0.002946	--	--
8	31.85	0	0	0.002239	--	--
9	37.85	0	0	0.001433	--	--
10	67.85	0	0	0.000241	--	--

Assuming uniform changes in core:

22.85	0.10425	0.00732	0.00136	0.9428	0.988
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The flux and power distribution changes calculated for the core are small and probably not too meaningful. A useful calculation would have to explicitly take into account the effect of the control mechanism which is used to compensate for long-term reactivity effects. Since the control would probably be in the form of a localized perturbation, its effect on the flux distribution would probably be larger than that resulting from burnup and buildup; however, the changes given for the blanket should be reliable. The fairly large increase in blanket power and flux is an indication that an accurate calculation would require that it be made in several steps, with the resulting flux in each step used to determine the conditions for the next step. The present calculation should give a rough estimate of the effect.

The long-term change in breeding gain would involve the behavior and influence of the control system; however, the effect of fission product absorption on breeding gain should not be too dependent on control details.

The fission product capture cross section for the sum of the two fission products was assumed to vary as $\frac{1}{v}$ and to equal 0.4 barn in group 5 (0.0674 - 0.1832 mev) of the ten-energy groups. This gives an effective cross section of about 0.4 barn in PBR and 0.3 barn in EBR-II. With these values the breeding gain reduction due to fission product capture at the end of the 2% burnup cycle is 0.04 for PBR and 0.01 for EBR-II. The average loss for the cycle would be approximately half as large.

The long-term reactivity effects resulting from 2% burnup are given in Table XVII. The various effects of Pu^{239} removal from core, Pu^{239} added to blanket, and fission product formation were evaluated separately. The fission product scattering was accounted for by assuming that each fission product had the same scattering as an atom of Fe. As a numerical check, all the effects were also evaluated simultaneously and the result agreed with the individual sum.

Table XVII

LONG-TERM REACTIVITY EFFECTS IN PBR AND EBR-II
IN CYCLE OF 2% CORE ALLOY BURNUP

	$\frac{\Delta k}{k}$	
	PBR	EBR-II
Pu^{239} removed from core	-0.0186	-0.0328
Pu^{239} added to blanket	0.0098	0.0084
Fission product formation	-0.0104	-0.0018
Total of all effects	-0.0192	-0.0262
Core changes only	-0.0290	-0.0346
Core changes only - assumed uniform	-0.0238	-0.0332

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To investigate the effect of non-uniform core changes, the long-term reactivity change assuming uniform core changes equal to the average value over the core were also evaluated. The difference in PBR amounted to an underestimate of about 15% of the reactivity loss due to core changes when calculated on a uniform basis. For EBR-II the underestimate is only about 5%. This, of course, is a consequence of much flatter distributions in the EBR-II core than in the PBR core.

One can also express the results in terms of the extra loading of fuel needed to compensate for the net long-term reactivity loss. In both PBR and EBR-II

$$\frac{\Delta k}{k} \sim \frac{1}{2} \left(\frac{\Delta M}{M} \right),$$

so that the burnup allowance is approximately 4% of the clean critical mass for the PBR and approximately 5% for the EBR-II. For the reference designs considered this would raise the Pu^{239} critical mass from 446 kg to 468 kg for the PBR, and from 83 kg to 87 kg for the EBR-II. These changes are considerably smaller than the uncertainties in calculations of the critical mass.

X. REACTIVITY COEFFICIENTS ASSOCIATED WITH TEMPERATURE CHANGES

Calculations were made to determine reactivity coefficients associated with temperature changes, particularly to obtain an estimate of the amount of control needed on changing from "cold" to "hot" operation. The specific effects considered were expansion of entire assembly and Na density changes. Other effects, e.g., Doppler effect, were not considered. The calculations were made in both spherical and cylindrical geometry and with both the seven- and ten-group set of cross sections.

For PBR, the reactivity change associated with a uniform expansion is given by:

$$\frac{\Delta k/k}{\Delta V/V} \sim -0.3.$$

In going from "cold" to "hot" operation, the volume might increase by 1 to 2%, yielding a reactivity loss of ~ 0.3 to 0.6%.

For EBR-II,

$$\frac{\Delta k/k}{\Delta V/V} \sim -0.5$$

yielding a reactivity loss of ~ 0.5 to 1%.

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In PBR, the effect of Na density on reactivity is given by:

$$\frac{\Delta k/k}{(\Delta \rho/\rho)_{\text{Na}}} \sim 0.02$$

and in EBR-II by:

$$\frac{\Delta k/k}{(\Delta \rho/\rho)_{\text{Na}}} \sim 0.05 .$$

The Na density will increase by 10 or 15% in going from "cold" to "hot" operation, giving a reactivity loss of $\sim 0.2\%$ in the PBR and $\sim 0.5\%$ in the EBR-II.

The description of the assemblies and exact values obtained are given in Table XVIII.

XI. EFFECTIVENESS OF VARIOUS CONTROL METHODS

The amounts of reactivity obtained by various control methods are given in Table XVIII.

The methods of control investigated were interchange of fuel (Pu^{239}) with U^{238} , insertion of poison (B^{10}), and the use of various reflectors.

The worth of fuel was obtained at the center of the core, midway out to the edge of the core, at the core-blanket interface, and also uniformly over the core. The calculation, made in cylindrical geometry, assumed that the change was made uniformly over the axial direction. The results are given in terms of the change of the reactivity per fraction of the core critical mass interchanged with an equal volume of U^{238} .

The reactivity loss associated with the replacement of a kilogram of U^{238} with an equal volume of B^{10} was evaluated for various locations.

The reactivity changes resulting from the replacement of the first part of the blanket by either Na or Fe were also obtained. The much greater effectiveness (loss of reactivity) of a Na blanket in EBR-II than in PBR should be noted.

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Table XVIII

SUMMARY OF REACTIVITY CHANGES IN PBR AND EBR-II

Description of Assembly	PBR Sphere		PBR Cylinder		EBR-II Sphere		EBR-II Cylinder	
	Core	Blanket	Core	Blanket	Core	Blanket	Core	Blanket
Volume Fraction Pu^{239}	0.03511	0	0.0388	0	0.10425	0	0.1072	0
U^{235}	0	0.0014	0	0.0014	0	0.0014	0	0.0014
U^{238}	0.28489	0.6986	0.2962	0.6986	0.21575	0.6986	0.2278	0.6986
Ti	0.14	0.1	0.148	0.1	0.14	0.1	0.148	0.1
Na	0.54	0.2	0.517	0.2	0.54	0.2	0.517	0.2
Radius, cm	57.59	102.59	52.7	112.7	22.85	67.85	20.96	80.96
Critical Mass	446 kg Pu^{239}		495 kg Pu^{239}		83 kg Pu^{239}		86 kg Pu^{239}	
<u>Reactivity Changes in 2% Core Alloy Burnup</u>								
Pu^{239} removed from core by burnup minus buildup, $\Delta k/k$	-0.0186				-0.0328			
Pu^{239} added to blanket by buildup, $\Delta k/k$	0.0098				0.0084			
Fission products, $\Delta k/k$	-0.0104				-0.0018			
Total	-0.0192				-0.0262			
<u>Reactivity Coefficients</u>								
<u>Expansion</u>								
Core and blanket uniformly, $(\Delta k/k)/(\Delta V/V)$	-0.30		-0.29		-0.50		-0.56	
Core - No change in blanket, $(\Delta k/k)/(\Delta V/V)$	-0.28				-0.36			
<u>Na Density</u>								
Core and blanket uniformly, $(\Delta k/k)/(\Delta \rho/\rho)_{\text{Na}}$	0.023		0.021		0.046		0.070	
<u>Effectiveness of Control Methods</u>								
<u>$\text{U}^{238} \rightarrow \text{Pu}^{239}$</u>								
At core-blanket interface, $(\Delta k/k)/(\Delta M/M_C)_{\text{Pu}^{239}}$	0.087		0.121		0.235		0.235	
Midway in core, $(\Delta k/k)/(\Delta M/M_C)_{\text{Pu}^{239}}$			0.91					
Center of core, $(\Delta k/k)/(\Delta M/M_C)_{\text{Pu}^{239}}$			1.32					
Uniformly over core, $(\Delta k/k)/(\Delta M/M_C)_{\text{Pu}^{239}}$	0.52		0.53		0.50		0.51	
<u>$\text{U}^{238} \rightarrow \text{B}^{10}$</u>								
Per kg $\text{U}^{238} \rightarrow \text{B}^{10}$ (equal volume) at interface, $\Delta k/k$	-0.00017		-0.00014		-0.0021		-0.0022	
Per kg $\text{U}^{238} \rightarrow \text{B}^{10}$ (equal volume) midway in core, $\Delta k/k$			-0.0014					
Per kg $\text{U}^{238} \rightarrow \text{B}^{10}$ (equal volume) center of core, $\Delta k/k$			-0.0015					
<u>Various Reflectors</u>								
9 cm Na, $\Delta k/k$			-0.0075				-0.12	
9 cm Fe, $\Delta k/k$			0.011				0.017	
18 cm Na, $\Delta k/k$			-0.011					
18 cm Fe, $\Delta k/k$			0.017					

XII. NEUTRON LIFETIME

The neutron lifetime, ℓ , can be evaluated from

$$\ell = \frac{(\Delta\nu/\nu)}{C},$$

where $(\Delta\nu/\nu)$ is the loss of reactivity associated with the uniform insertion of a $\frac{1}{\nu}$ -absorber with macroscopic cross section $\frac{C}{\nu}$.

The average neutron velocities for each of the ten energy groups are given in Table XIX. They were obtained by taking the reciprocal of the average $\frac{1}{\nu}$ for the flux in the group under the assumption that the neutron flux in groups 1 and 2 was that of a fission spectrum, while for all lower groups the flux per unit u interval was constant. It was assumed that the lowest group extended from $u = 9$ to 10. The energies corresponding to these velocities are also included.

Table XIX

NEUTRON VELOCITIES FOR LIFETIME CALCULATIONS

<u>Group</u>	<u>ν, cm/10^{-8}sec</u>	<u>E, mev</u>	<u>$1/\nu$</u>
1	25.59	3.42	0.0391
2	18.26	1.74	0.0548
3	12.40	0.804	0.0806
4	7.522	0.296	0.133
5	4.562	0.109	0.219
6	2.772	0.0402	0.361
7	1.677	0.0147	0.596
8	1.018	0.00542	0.982
9	0.6174	0.00199	1.62
10	0.3746	0.000734	2.67

Figure 14, curve (a), gives the neutron lifetime as a function of enrichment (and thus of size) for the Pu^{239} spherical assemblies described in Table X, page 26.

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The calculated lifetime is 0.8×10^{-7} sec for EBR-II and 1.7×10^{-7} sec for PBR. In order to determine the influence of the blanket, the lifetimes were also evaluated for the bare cores as a function of enrichment and are shown in Figure 14, curve (b).

The effect of the blanket on the lifetime decreases with core size. This result is perfectly reasonable, physically, since for the larger core size a smaller fraction of the neutrons causing fissions have spent part of their lifetime diffusing in the blanket.

There are several experimental values of the neutron lifetime for bare uranium assemblies of various dilutions and also for Topsy, a natural uranium-reflected, 94% enriched uranium assembly. These assemblies were evaluated in order to test the method and the cross sections. The curve of calculated lifetime versus enrichment for the bare assemblies is given in Figure 15 along with the experimental values. The agreement is quite good and thus lends some confirmation to the values obtained for EBR-II. The experimental points do not go to sufficiently low enrichments to give a good test of the low energy cross sections and thus of the PBR value.

For Topsy the agreement was (probably fortuitously) very good: 2.03×10^{-8} sec calculated versus 2.05×10^{-8} sec experimentally.

XIII. CENTRAL BLANKET RADIAL POWER FLATTENING

One method of flattening the radial power distribution is to introduce a cylindrical region in the center of the core with composition similar to that of the blanket. A series of calculations were performed both for PBR and EBR-II in order to determine the optimum size and composition of such central blankets. The calculations were all done in cylindrical geometry with the ten-group cross sections. The assemblies consisted of concentric cylindrical annuli in the following order:

- (1) Central blanket containing either 0.45, 0.55, or 0.65 volume fraction depleted uranium, 0.1 Ti for structural material, and the remainder Na.
- (2) Active region of core of the usual reference composition: 0.32 core alloy, 0.14 Ti, and 0.54 Na.
- (3) Inner blanket of same composition as central blanket (1).
- (4) Outer blanket: 0.8 depleted uranium, 0.1 Ti, and 0.1 Na.

For most of the calculations the inner blanket was 9 cm thick. For all of the calculations the total thickness of inner and outer blanket was 45 cm.

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For PBR, Pu^{239} fuel was used. For EBR-II, a mixture of Pu^{239} and U^{235} was used. The volume fraction of Pu^{239} was always 0.032 (10% of core alloy volume); the amount of U^{235} was determined by criticality.

The equivalent bare core heights:

PBR - 121.44 cm.
EBR-II - 60.72 cm.

were based on an assumption 2 x 15 cm axial reflector savings for PBR and 2 x 12.2 cm for EBR-II.

The problem parameters and results are given in Table XX for PBR and Table XXI for EBR-II. The following notations are used in the tables:

R_{CB}	Radius of central blanket, cm.
R_C	Outer radius of core, cm.
R_{IB}	Outer radius of inner blanket, cm.
R_B	Outer radius of outer blanket, cm.
V_{CB}	Volume of central blanket, liter
V_{AC}	Volume of active region of core, liter
V_C	Volume of core (active region and central blanket), liter
v_B^U	Volume fraction of depleted uranium in central and inner blankets
$v_{AC}^{\text{Pu}^{239}}, v_{AC}^{\text{U}^{235}}$	Volume fraction of Pu^{239} , U^{235} in active region of core
$v_{AC}^{\text{U}^{238}}$	Volume fraction of U^{238} in active region of core
$M(\text{Pu}^{239}), M(\text{U}^{235})$	Amount of Pu^{239} , U^{235} in active region of core, kg.
$M^*(\text{U}^{235})$	For EBR-II assemblies where a mixture of U^{235} and Pu^{239} is used; this is the estimated critical mass if only U^{235} were used.

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P_{CB}	Ratio of power generated in central blanket to sum of power generated in central blanket and active region of core.
$(M/A)_C$	Ratio of maximum power generated to average power generated in both central blanket and active region of core.
$(M/A)_{AC}$	Ratio of maximum power generated to average power generated in active region of core only.
α^{fuel}	Average capture-to-fission ratio of fuel (includes both U^{235} and Pu^{239} in EBR-II where mixture is used).
f_{CB}	U^{238} fast fission bonus in central blanket (ratio of U^{238} fission in central blanket to fuel fissions in active region of core).
f_{AC}	U^{238} fast fission bonus in active region of core.
f_{IB}	U^{238} fast fission bonus in inner blanket.
$f = f_{CB} + f_{AC} + f_{IB}$	Total fast fission bonus except for contribution from outer blanket. Since the latter is almost constant among the various assemblies, f can be used for comparative purposes.
Advantage Factor of Flattened Assembly	Ratio of critical mass of an unflattened assembly generating same total power as flattened assembly to critical mass of flattened assembly. It is assumed that the maximum power density is the limiting quantity and is thus the same in the two assemblies.

It can be seen that as the size of the assembly increases, the advantage factor with optimum central blanket increases. In the smaller PBR designs of Table XX, which correspond to a higher permissible maximum power generation since the specified core power is fixed at 800 megawatts, it is doubtful whether the use of a central blanket is justified. However, it appears that present heat transfer limitations might force one into even larger assemblies than those considered in the table and where the advantage factor might be slightly larger. Therefore, the central blanket feature is being included in present EBR-II and PBR reference design. In EBR-II, it is being included strictly as a prototype feature, since it is clearly not advantageous for EBR-II in itself.

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Table XX

ANALYSIS OF CENTRAL BLANKET POWER FLATTENING IN PBR

UNIVAC Problem No.	R _{CB} , cm	R _C , cm	R _{IB} , cm	R _B , cm	V _{CB} , liters	V _{AC} , liters	V _C , liters	U v _B	Pu ²³⁹ v _{AC}	U ²³⁸ v _{AC}	M(Pu ²³⁹), kg	P _{CB}	(M/A) _C	(M/A) _{AC}	α^{fuel}	f _{CB}	f _{AC}	f _{IB}	f	Advantage Factor
04123	0	52.7	61.7	97.7	0	797.8	797.8	0.55	0.03643	0.28357	461.3	0	1.537	1.537	0.173	0	0.275	0.043	0.318	1.000
04124	21.08	52.7	61.7	97.7	127.6	670.2	797.8	0.55	0.04935	0.27065	524.9	0.0342	1.337	1.162						0.987
04125	31.62	52.7	61.7	97.7	287.2	510.6	797.8	0.55	0.06804	0.25196	551.4	0.0600	1.600	1.082						0.939
04126	23.04	57.6	62.1	102.6	152.5	800.6	953.1	0.55	0.04667	0.27333	592.9	0.0318	1.346	1.168						1.016
04127	23.04	57.6	66.6	102.6	152.5	800.6	953.1	0.55	0.04672	0.27328	593.6	0.0320	1.346	1.168	0.167	0.036	0.229	0.053	0.318	1.015
04128	23.04	57.6	71.1	102.6	152.5	800.6	953.1	0.55	0.04673	0.27327	593.7	0.0320	1.346	1.168						1.015
04129	34.56	57.6	66.6	102.6	343.1	610.0	953.1	0.55	0.06361	0.25639	615.8	0.0571	1.614	1.095						0.834
04130	0	62.1	71.1	107.1	0	1107.8	1107.8	0.55	0.03363	0.28637	591.3	0	1.576	1.576						1.000
04131	24.84	62.1	71.1	107.1	177.2	930.6	1107.8	0.55	0.04458	0.27542	658.5	0.0315	1.350	1.171						1.049
04132	37.26	62.1	71.1	107.1	398.8	709.0	1107.8	0.55	0.06048	0.25952	680.5	0.0550	1.621	1.098	0.159	0.061	0.189	0.066	0.316	0.858
04133	21.08	52.7	61.7	97.7	127.6	670.2	797.8	0.45	0.04888	0.27112	519.9	0.0315	1.350	1.171						0.988
04134	23.04	57.6	66.6	102.6	152.5	800.6	953.1	0.45	0.04630	0.27370	588.2	0.0297	1.355	1.173	0.167	0.034	0.229	0.046	0.309	1.020
04135	34.56	57.6	66.6	102.6	343.1	610.0	953.1	0.45	0.06318	0.25682	611.7	0.0548	1.618	1.095						0.838
04136	24.84	62.1	71.1	107.1	177.2	930.6	1107.8	0.45	0.04429	0.27571	654.2	0.0291	1.358	1.175						1.049
04137	21.08	52.7	61.7	97.7	127.6	670.2	797.8	0.65	0.04977	0.27023	529.3	0.0362	1.328	1.158						0.985
04138	23.04	57.6	66.6	102.6	152.5	800.6	953.1	0.65	0.04708	0.27292	598.2	0.0338	1.340	1.165	0.167	0.038	0.229	0.059	0.326	1.012
04139	34.56	57.6	66.6	102.6	343.1	610.0	953.1	0.65	0.06395	0.25605	619.1	0.0600	1.607	1.094						0.833
04140	24.84	62.1	71.1	107.1	177.2	930.6	1107.8	0.65	0.04483	0.27517	662.1	0.0333	1.343	1.167						1.048

Table XXI

ANALYSIS OF CENTRAL BLANKET POWER FLATTENING IN EBR-II

UNIVAC Problem No.	R_{CB} , cm	R_C , cm	R_{IB} , cm	R_B , cm	V_{CB} , liters	V_{AC} , liters	V_C , liters	v_B	$v_{AC}^{U^{235}}$	$v_{AC}^{U^{238}}$	$M(Pu^{239})$	$M(U^{235})$	$M(U^{238})$	P_{CB}	$(M/A)_C$	$(M/A)_{AC}$	ϵ^{fuel}	ϵ_{CB}	ϵ_{AC}	ϵ_{IB}	ϵ	Advantage Factor
04105	0	20.96	29.96	65.96	0	50.13	50.13	0.55	0.12905	0.15895	25.46	121.17	168.3	0	1.255	1.255	0.179	0	0.0803	0.0824	0.163	1.000
04106	8.384	20.96	29.96	65.96	8.02	42.11	50.13	0.55	0.17399	0.11401	21.38	137.23	176.8	0.0330	1.326	1.152						0.920
04107	12.576	20.96	29.96	65.96	18.05	32.08	50.13	0.55	0.25879	0.02921	16.29	155.50	185.6	0.0586	1.609	1.094						0.773
0.4108	9.14	22.85	27.35	67.85	9.53	50.04	59.57	0.55	0.15312	0.13488	25.41	143.51	190.5	0.0333	1.325	1.151						0.949
0.4109	9.14	22.85	31.85	67.85	9.53	50.04	59.57	0.55	0.15594	0.13206	25.41	145.73	192.7	0.0334	1.332	1.158	0.184	0.0361	0.0547	0.0843	0.175	0.935
04110	9.14	22.85	36.35	67.85	9.53	50.04	59.57	0.55	0.15720	0.13080	25.41	147.34	194.3	0.0334	1.335	1.160						0.925
04111	13.71	22.85	31.85	67.85	21.45	38.12	59.57	0.55	0.23745	0.05055	19.36	169.54	205.4	0.0584	1.610	1.094						0.781
04112	0	24.61	33.61	69.61	0	69.10	69.10	0.55	0.10406	0.18394	35.09	134.68	199.6	0	1.297	1.297						1.000
04113	9.844	24.61	33.61	69.61	11.06	58.04	69.10	0.55	0.14454	0.14346	29.47	157.13	211.6	0.0331	1.332	1.157						0.928
04114	14.766	24.61	33.61	69.61	24.88	44.22	69.10	0.55	0.22112	0.06688	22.45	183.14	224.7	0.0580	1.610	1.094	0.186	0.0616	0.0210	0.0888	0.171	0.781
04115	8.384	20.96	29.96	65.96	8.02	42.11	50.13	0.45	0.18144	0.10656	21.38	143.11	182.7	0.0286	1.334	1.154						0.886
04116	9.14	22.85	31.85	67.85	9.53	50.04	59.57	0.45	0.16207	0.12593	25.41	151.90	198.9	0.0291	1.341	1.160	0.184	0.0316	0.0547	0.0737	0.160	0.903
04117	13.71	22.85	31.85	67.85	21.45	38.12	59.57	0.45	0.24712	0.04088	19.36	176.44	212.3	0.0522	1.627	1.099						0.752
04118	9.844	24.61	33.61	69.61	11.06	58.04	69.10	0.45	0.14950	0.13850	29.47	162.52	217.0	0.0291	1.346	1.165						0.897
04119	8.384	20.96	29.96	65.96	8.02	42.11	50.13	0.65	0.16612	0.12188	21.38	131.02	170.6	0.0370	1.317	1.149						0.956
04120	9.14	22.85	31.85	67.85	9.53	50.04	59.57	0.65	0.15186	0.13614	25.41	142.33	189.3	0.0369	1.322	1.153	0.184	0.0399	0.0547	0.0933	0.188	0.957
04121	13.71	22.85	31.85	67.85	21.45	38.12	59.57	0.65	0.23099	0.05701	19.36	164.92	200.7	0.0635	1.595	1.090						0.803
04122	9.844	24.61	33.61	69.61	11.06	58.04	69.10	0.65	0.14099	0.14701	29.47	153.27	207.8	0.0367	1.326	1.156						0.946
04141 (U^{235} fuel)	0	20.96	29.96	65.96	0	50.13	50.13	0.55	0.17973	0.14027	0	168.75	168.8	0	1.249	1.249	0.193		0.0671			1.000
04142 (Pu^{239} fuel)	0	20.96	29.96	65.96	0	50.13	50.13	0.55	0.11482 ($v_{AC}^{Pu^{239}}$)	0.20518	91.35	0	168.8	0	1.272	1.272	0.129		0.1222			1.000

The relatively constant values of α and of the fast fission bonus indicate that the breeding gain is relatively independent of the central blanket design and is approximately the same as for the unflattened assembly. The reduced fast fission bonus in active cores of higher enrichments is compensated by increased central and inner blanket U^{238} fast fissions which result from increased leakage from the active core.

A typical power distribution with a central blanket is shown in Figure 6 for PBR (Prob. 04127) and in Figure 7 for EBR-II (Prob. 04109).

Another method of flattening the radial power distribution is to vary the enrichment of the fuel radially.

The power distribution that results when the enrichment is varied in five concentric cylindrical annuli of equal radial intervals in the core is shown in Figure 8 for PBR and in Figure 9 for EBR-II. The enrichments were varied so that the peak powers in each ring were equal. For comparison, the unflattened power distributions are also shown.

The Pu^{239} critical mass is increased from 495 kg to 543 kg for PBR and from 86 kg to 89 kg for EBR-II. The relative enrichments in the five rings are 1, 1.021, 1.091, 1.255, 1.632 in PBR, and 1, 1.020, 1.077, 1.203, 1.423 in EBR-II.

The effect on breeding gain of flattening in this manner is essentially negligible. $\alpha^{Pu^{239}}$ (Pu^{239} capture/ Pu^{239} fission) increases from 0.179 to 0.180 in PBR when the system is flattened, and from 0.138 to 0.139 in EBR-II. The fast fission bonus (U^{238} fissions/ Pu^{239} fissions) increases from 0.354 to 0.362 in PBR and from 0.301 to 0.305 in EBR-II.

The maximum-to-average power generation ratio in the core is reduced from 1.601 to 1.120 in PBR and from 1.311 to 1.072 in EBR-II. The advantage factor for the flattened assemblies as previously defined is 1.24 for PBR and 1.09 for EBR-II.

The above calculations were made with a slightly different reference composition. The core volume fractions were 0.335 core alloy, 0.148 Fe and 0.517 Na. The blanket composition was 0.0014 U^{235} , 0.6986 U^{238} , 0.1 Fe, and 0.2 Na, and the blanket thickness was 60 cm.

XIV. PARAMETRIC STUDY OF CORE COMPOSITION

In order to determine the effects of quite large departure from the reference design of PBR, a series of twenty-seven assemblies of varying core composition and size were investigated. The problem parameters and results are given in Table XXII and in Appendix A.

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Table XXII

PARAMETRIC STUDY OF CORE COMPOSITION

UNIVAC Tape No.	$R_c(\text{cm})$	Volume Fractions in Core					Core Energy Spectrum								Fast Fission Bonus		
		v_c^{Na}	$v_c^{\text{Pu}^{239}}$	$v_c^{\text{U}^{238}}$	v_c^{Fe}	$M(\text{Pu}^{239})$	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	ϕ_7	$\alpha_c^{\text{Pu}^{239}}$	f_c	f_B	f_{total}
02057	20	0.8	0.08421	0.11579	0	154.7	5.23	5.70	11.03	10.13	11.14	3.68	1.77	0.142	0.099	0.307	0.406
02058	20	0.8	0.08560	0.05720	0.05720	157.3	5.48	5.86	11.52	10.70	10.82	3.70	1.89	0.141	0.049	0.305	0.354
02059	20	0.8	0.08721	0	0.11279	160.3	5.75	6.02	12.04	11.31	10.46	3.68	1.98	0.139	0	0.304	0.304
02060	20	0.5	0.08114	0.41886	0	149.1	3.37	4.11	8.53	9.36	13.33	3.83	1.28	0.153	0.281	0.215	0.496
02061	20	0.5	0.08216	0.20892	0.20892	151.0	3.78	4.43	9.71	11.42	12.77	4.24	1.76	0.152	0.140	0.215	0.355
02062	20	0.5	0.08366	0	0.41634	153.7	4.30	4.81	11.21	14.57	11.72	4.37	2.29	0.150	0	0.214	0.214
02063	20	0.2	0.08468	0.71532	0	155.6	2.47	3.15	6.79	8.14	14.10	3.47	0.814	0.157	0.388	0.157	0.545
02064	20	0.2	0.08362	0.35819	0.35819	153.7	2.85	3.49	8.11	11.04	13.80	4.48	1.48	0.159	0.193	0.157	0.350
02065	20	0.2	0.08195	0	0.71805	150.6	3.37	3.93	10.03	16.98	12.53	4.95	2.51	0.139	0	0.160	0.160
02066	50	0.8	0.03603	0.16397	0	413.8	7.70	9.29	19.17	20.39	25.47	9.94	7.46	0.168	0.245	0.142	0.387
02067	50	0.8	0.03604	0.08198	0.08198	413.9	8.52	9.96	21.46	24.07	25.01	10.41	9.24	0.169	0.122	0.142	0.264
02068	50	0.8	0.03664	0	0.16336	420.8	9.51	10.72	24.26	29.15	24.02	11.46	11.04	0.168	0	0.144	0.144
02069	50	0.5	0.04231	0.45769	0	485.9	4.12	5.39	11.84	14.75	26.72	8.58	3.47	0.173	0.431	0.081	0.512
02070	50	0.5	0.03940	0.23030	0.23030	452.5	4.82	6.06	14.50	21.03	27.88	11.24	6.84	0.180	0.216	0.080	0.296
02071	50	0.5	0.03452	0	0.46548	396.5	5.81	6.97	18.69	36.09	28.55	13.80	14.59	0.190	0	0.082	0.082
02072	50	0.2	0.05189	0.74811	0	596.0	2.80	3.76	8.42	11.10	24.29	6.30	1.53	0.170	0.511	0.051	0.562
02073	50	0.2	0.04620	0.37690	0.37690	530.6	3.33	4.30	10.69	17.31	26.53	10.14	4.28	0.181	0.256	0.050	0.306
02074	50	0.2	0.03532	0	0.76468	405.7	4.14	5.08	14.63	37.75	28.92	15.21	15.17	0.199	0	0.054	0.054
02075	80	0.8	0.02780	0.17220	0	817.3	8.42	10.45	22.06	24.60	32.62	13.50	11.82	0.180	0.294	0.082	0.376
02076	80	0.8	0.02696	0.08652	0.08652	792.7	9.47	11.38	25.37	30.51	32.89	14.70	16.22	0.184	0.148	0.082	0.230
02077	80	0.8	0.02628	0	0.17372	772.7	10.82	12.52	29.75	39.86	32.66	15.44	22.16	0.199	0	0.082	0.082
02078	80	0.5	0.03631	0.46369	0	1067.6	4.28	5.67	12.61	16.15	31.16	10.33	4.39	0.180	0.469	0.048	0.517
02079	80	0.5	0.03236	0.23382	0.23382	951.4	5.06	6.47	15.81	24.15	33.95	14.51	9.91	0.190	0.236	0.041	0.277
02080	80	0.5	0.02530	0	0.47470	743.8	6.21	7.56	21.06	46.08	37.75	19.87	28.12	0.211	0	0.043	0.043
02081	80	0.2	0.04697	0.75303	0	1381.0	2.86	3.86	8.72	11.69	26.84	7.06	1.73	0.173	0.538	0.031	0.569
02082	80	0.2	0.04108	0.37946	0.37946	1207.8	3.42	4.45	11.20	18.73	30.08	11.95	5.34	0.187	0.268	0.036	0.304
02083	80	0.2	0.02724	0	0.77276	800.9	4.31	5.34	15.79	45.53	35.98	20.65	26.34	0.217	0	0.027	0.027

The calculations were all made in cylindrical geometry with the seven-group set of cross sections. The equivalent bare height was 121.22 cm and for critical mass purposes it was assumed that the reflector savings were 2 x 15 cm. The blanket composition (volume fraction) was 0.0014 U²³⁵, 0.6986 U²³⁸, 0.1 Fe, and 0.2 Na, and the blanket thickness was 60 cm. Core radii of 20, 50, and 80 cm were investigated and, for each, Na volume fractions of 0.8, 0.5, and 0.2 were considered. For each of the resulting assemblies, it was assumed that the diluent for the Pu²³⁹ fuel was either all U²³⁸, half U²³⁸, and half Fe, or all Fe. The amount of fuel was determined by criticality.

XV. EBR CALCULATIONS

The flux distribution for EBR calculated in cylindrical geometry with the seven-group cross sections is given in Figure 10. The spherical geometry, ten-group flux distribution is given in Figure 11. The calculated values of Pu²³⁹ for the cylindrical assembly as a function of radial distance are given in Figure 16, and for the spherical assembly in Figure 17. The calculated values of Pu²³⁹ assuming no outer graphite reflector are also shown in Figure 17, as are the experimental values.

The discrepancies between calculation and measurement near the outer edge of the blanket may be due to an insufficient number of low energy groups (with high values of α) to adequately take into account the thermalizing action of the graphite reflector. Another possibility may be the assumption of incorrect cross sections.

The calculated critical mass for EBR is 61.6 kg in spherical geometry and 55.4 kg in cylindrical geometry, to be compared to an experimental critical mass of 52 kg U²³⁵. The cylindrical calculation is perhaps not too meaningful since an axial reflector savings must be assumed. In view of the overestimate of critical mass inherent in the use of diffusion theory for assemblies of this size and the geometrical approximations made, the agreement is close.

The calculated values of the reactivity changes resulting from the interchange of U²³⁸ and various materials at the edge of the EBR core are listed in Table XXIII. The calculations were made with the ten-group cross sections in spherical geometry, the interchange occurring in a spherical shell 2 cm thick just outside the core. These numbers may be of interest if such an experimental program is undertaken.

A calculation to determine the expansion coefficient of reactivity in EBR gives in cylindrical geometry:

$$\frac{\Delta k/k}{\Delta V/V} \sim -0.40 ,$$

where the expansion occurred in the radial direction only.

Table XXIII

CALCULATED EBR REACTIVITY CHANGES FOR INTERCHANGE OF VARIOUS MATERIALS
WITH U^{238} AT CORE EDGE

	Material							
	Pu ²³⁹	U ²³⁵	Void	Ti	NaK	Fe	C	B ¹⁰
Δk/k per kg U ²³⁸ inter- changed with equal volume of material	0.00485	0.00303	-0.00205	-0.00143	-0.00188	-0.00099	-0.00110	-0.00522

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FIG. 2
PBR FLUX DISTRIBUTION IN CYLINDRICAL GEOMETRY
(SEVEN-ENERGY GROUPS)
UNIVAC TAPE PROBLEM NO. 02008

16. 069

FIG. 3
EBR-II FLUX DISTRIBUTION IN CYLINDRICAL GEOMETRY
(SEVEN-ENERGY GROUPS)
UNIVAC TAPE PROBLEM NO. 02020

RE-7-17183-C

FIG. 4
PBR FLUX DISTRIBUTION IN SPHERICAL GEOMETRY (TEN-ENERGY GROUPS)
UNIVAC TAPE PROBLEM NO. 04A01

RE-7-17180-B

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FIG. 5
EBR-II FLUX DISTRIBUTION IN SPHERICAL GEOMETRY (TEN-ENERGY GROUPS)
UNIVAC TAPE PROBLEM NO. 040A2

RE-7-17182-B

037028J0370

037028J0370

FIG. 6
TYPICAL POWER DISTRIBUTION FOR THE
PBR WITH CENTRAL BLANKET
(PROBLEM NO. 04127)

ANL-FWT-15157-A

FIG. 7
TYPICAL POWER DISTRIBUTION FOR
EBR-II WITH CENTRAL BLANKET
(PROBLEM NO. 04109)

037229.030

FIG. 8
COMPARISON OF UNFLATTENED RADIAL POWER DISTRIBUTION IN PBR WITH FLATTENED DISTRIBUTION ACHIEVED WHEN FUEL ENRICHMENT IS VARIED IN FIVE CONCENTRIC ANNULI OF EQUAL RADIAL INTERVALS

ANL-FWT-15316-A

FIG. 9
COMPARISON OF UNFLATTENED RADIAL POWER
DISTRIBUTION IN EBR-II WITH FLATTENED
DISTRIBUTION ACHIEVED WHEN FUEL ENRICHMENT IS VARIED
IN FIVE CONCENTRIC ANNULI OF EQUAL RADIAL INTERVALS

ANL-FWT-15315-A

RE-7-17195-A

162 058

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FIG. II
EBR FLUX DISTRIBUTION IN SPHERICAL GEOMETRY
(TEN-ENERGY GROUPS)
UNIVAC TAPE PROBLEM NO. 04A34

RE-7-17196-B

0371228.0 CLASSIFIED

0371228.000 100 057

FIG. 12
POWER DISTRIBUTION IN PBR BLANKET
BEFORE AND AFTER 2% BURNUP OF CORE

ANL-FWT-15314-A

FIG. 13
POWER DISTRIBUTION IN EBR-II BLANKET
BEFORE AND AFTER 2% BURNUP OF CORE

ANL-FWT-15313-A

RE-7-14554-A

FIG. 15
NEUTRON LIFETIME OF BARE URANIUM
ASSEMBLIES VS U^{235} ENRICHMENT

RE-7-17181-A

FIG. 16
CALCULATED $\alpha_{Pu^{239}}$ IN EBR CYLINDRICAL GEOMETRY
(7-GROUPS) UNIVAC PROBLEM NO. 02023

FIG. 17
CALCULATED VS EXPERIMENTAL $\alpha_{Pu^{239}}$ IN EBR

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APPENDIX ATABULATION OF UNIVAC PROBLEM PARAMETERS
AND PARTIAL RESULTS

The following tabulation lists the specifications for the various UNIVAC problems along with some of the results. The notations used throughout the tables are described below.

PBR	Full-scale reactor - Pu^{239} fuel
CONV	Full-scale reactor - U^{235} fuel
PPB	Pilot plant (EBR-II) - Pu^{239} fuel
PPC	Pilot plant (EBR-II) - U^{235} fuel
PPM	Pilot plant (EBR-II) - mixed Pu^{239} - U^{235} fuel
M	Critical mass of Pu^{239} or U^{235} , in kilograms
E	Radial escape out of last region (normalized to one fission neutron in core)
R	Maximum-to-average radial power generation in the core
R*	Maximum-to-average radial power generation in active region of core
H_{EBC}	Equivalent bare core height (cm), i.e., actual height plus estimated reflector savings.
σ and ϵ	Allowable errors for the iterative solution; both are absolute quantities when the initial source is normalized to one fission neutron in the core. σ measures the difference in each region between two successive resultant source integrals for the region. ϵ measures the deviation from unity for the resultant source integral over the core. When σ is satisfied and ϵ is not, the volume fractions are changed in a specified manner.

037029.030

603

Reactivity For most of the problems (those marked C under Reactivity) criticality was obtained and the corresponding volume fractions are given. In some problems it was only desired to determine the deviation from criticality. In these cases ϵ was made very large, and the number of source neutrons, f , resulting from one source neutron was obtained. f corresponds to k_{eff} and $(f-1)/f$ to $(\Delta k/k)$ in the usual notation.

S Integral of source ($\approx$ power) over region.

To compute the mass of fuel in the core in the cylindrical problems, it is necessary to make an assumption as to the actual volume of the core. The following estimated reflector savings (R. S.) were used:

	<u>Axial R. S. (cm)</u>
PBR	2 x 15
CONV	2 x 15
PPB	2 x 12.2
PPC	2 x 12.2
PPM	2 x 12.2
EBR	2 x 8.75
Parametric Study Problems	2 x 15

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Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions										Reactivity	S
									Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	K	C	B ¹⁰				
CYLINDRICAL GEOMETRY - SEVEN-GROUP CROSS SECTIONS																				
1	02008	Reference PBR.	495.3	.001437	1.6014	121.44	1	52.7	.03882	----	.29618	.148	.517	----	----	----	.0001	.00001	C	.0515
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
2	02007	PBR. .035 U-Pu → .035 Na	483.1	.001535	1.5807	121.44	1	52.7	.03787	----	.26213	.148	.552	----	----	----	.001	.001	C	.0556
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
3	02039	PBR. .135 U-Pu → .135 Fe	468.3	.001632	1.5755	121.44	1	52.7	.03671	----	.16329	.283	.517	----	----	----	.001	.001	C	.0572
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
4	02038	PBR. .235 U-Pu → .235 Fe	443.2	.001844	1.5540	121.44	1	52.7	.03471	----	.06526	.383	.517	----	----	----	.001	.001	C	.0633
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
5	02040	PBR. U → Fe	422.2	.002018	1.5372	121.44	1	52.7	.03309	----	----	.44991	.517	----	----	----	.001	.001	C	.0679
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
6	02010	PBR. .048 Fe → .048 Na	486.3	.001514	1.5812	121.44	1	52.7	.03812	----	.29688	.1	.565	----	----	----	.001	.001	C	.0554
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
7	02011	PBR. .052 Na .052 Fe	504.2	.001366	1.6162	121.44	1	52.7	.03952	----	.29548	.2	.465	----	----	----	.001	.001	C	.0490
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
8	02012	PBR. .085 U-Pu void	474.5	.001766	1.5333	121.44	1	52.7	.03719	----	.21281	.148	.517	----	----	----	.001	.001	C	.0652
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
9	02013	PBR. .135 U-Pu void	468.2	.001993	1.4888	121.44	1	52.7	.03670	----	.16330	.148	.517	----	----	----	.001	.001	C	.0753
							2	112.7	----	.0014	.6986	.1	.2	----	----	----				
10	02043	PBR. Flat power by vary- ing enrichment, 5 rings	542.7	.001709	1.1213	121.44	1	10.54	.03129	----	.30371	.148	.517	----	----	----	.001	.001	C	.0426
							2	21.08	.03254	----	.30246	.148	.517	----	----	----				.1280
							3	31.62	.03536	----	.29944	.148	.517	----	----	----				.2120
							4	42.16	.04068	----	.29432	.148	.517	----	----	----				.2653
							5	52.7	.05257	----	.28243	.148	.517	----	----	----				.3316
							6	112.7	----	.0014	.6986	.1	.2	----	----	----				.0650
11	02044	PBR. Flat power by vary- ing enrichment, 5 rings	563.1	.001860	1.2804	121.44	1	10.54	.02741	----	.30759	.148	.517	----	----	----	.001	.001	C	.0341
							2	21.08	.02933	----	.30567	.148	.517	----	----	----				.1073
							3	31.62	.03344	----	.30156	.148	.517	----	----	----				.1918
							4	42.16	.03974	----	.29526	.148	.517	----	----	----				.2791
							5	52.7	.06030	----	.27870	.148	.517	----	----	----				.3877
							6	112.7	----	.0014	.6986	.1	.2	----	----	----				.0726
12	02097	PBR. Flat power by vary- ing enrichment, 5 rings	540.8	.001704	1.1280	121.44	1	10.54	.03252	----	.30248	.148	.517	----	----	----	.001	.001	C	.0447
							2	21.08	.03317	----	.30183	.148	.517	----	----	----				.1317
							3	31.62	.03545	----	.29955	.148	.517	----	----	----				.2135
							4	42.16	.04033	----	.29467	.148	.517	----	----	----				.2833
							5	52.7	.05203	----	.28297	.148	.517	----	----	----				.3268
							6	112.7	----	.0014	.6986	.1	.2	----	----	----				.0646
13	02103	PBR. Flat power by vary- ing enrichment, 5 rings	542.7	.001740	1.1196	121.44	1	10.54	.03224	----	.30276	.148	.517	----	----	----	.001	.001	C	.0438
							2	21.08	.03292	----	.30208	.148	.517	----	----	----				.1295
							3	31.62	.03517	----	.29983	.148	.517	----	----	----				.2110
							4	42.16	.04046	----	.29454	.148	.517	----	----	----				.2841
							5	52.7	.05261	----	.28239	.148	.517	----	----	----				.3316
							6	112.7	----	.0014	.6986	.1	.2	----	----	----				.0654
14	02009	PBR. 60-cm blanket → 90-cm blanket	495.8	.028469	1.5724	121.44	1	52.7	.03886	----	.29614	.148	.517	----	----	----	.001	.001	C	.0504
							2	82.7	----	.0014	.6986	.1	.2	----	----	----				
15	02090	PBR. 60-cm blanket → 45-cm blanket	495.8	.006672	1.5754	121.44	1	52.7	.03886	----	.29614	.148	.517	----	----	----	.001	.001	C	.0523
							2	97.7	----	.0014	.6986	.1	.2	----	----	----				
16	02005	PBR. Depleted U → Natural U in blanket	492.1	.002046	1.5852	121.44	1	52.7	.03857	----	.29643	.148	.517	----	----	----	.001	.001	C	.0790
							2	112.7	----	.005	.695	.1	.2	----	----	----				
17	02006	PBR. 100% depleted U blanket	495.6	.0083628	1.6039	121.44	1	52.7	.03885	----	.29615	.148	.517	----	----	----	.001	.001	C	.0618
							2	112.7	----	.002	.998	.1	.2	----	----	----				
18	02042	PBR. Varying coolant dis- tribution in blanket	495.3	.0007852	1.5729	121.44	1	52.7	.03882	----	.29618	.148	.517	----	----	----	.001	.001	C	.0460
							2	67.7	----	.0014	.6986	.1	.2	----	----	----				.0064
							3	82.7	----	.0018	.7984	.1	.1	----	----	----				.0009
							4	97.7	----	.0017	.8483	.1	.05	----	----	----				.0009
							5	112.7	----	.0018	.8782	.1	.02	----	----	----				.0001

Argonne JINRAC Tape	Prob. No.	Prob. No.	Problem Description	M(Pu ²³³)	E	R	H _{EP} cm	Region	Outer Boundary, cm	Pu ²³³	u ²³⁵	u ²³⁸	Fe	Ma	K	C	B ₁₀	λ	ε	Reactivity	S
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CYLINDRICAL GEOMETRY - SEVEN-GROUP CROSS SECTIONS (Cont'd.)

19	02024		PBR, 9-cm Na reflector	502.3	.002620	1.6336	121.44	1	52.7 61.7 112.7	.03857 --- ---	--- .0014 ---	.29563 .6936 ---	.148 --- ---	.517 1.0 .2	---	---	---	.001	.001		C	1 0 .0370
20	02025		PBR, 18-cm Na reflector	505.6	.004813	1.6516	121.44	1	52.7 70.7 112.7	.03963 --- ---	--- .0014 ---	.29537 .6936 ---	.148 .1 ---	.517 1.0 .2	---	---	---	.001	.001		C	1 0 .0268
21	02045		PBR, 9-cm Fe reflector	485.3	.001516	1.5370	121.44	1	52.7 61.7 112.7	.03804 --- ---	--- .0014 ---	.29696 .6936 ---	.148 1.0 .1	.517 1.0 .2	---	---	---	.001	.001		C	1 0 .0130
22	02046		PBR, 18-cm Fe reflector	479.4	.001841	1.5118	121.44	1	52.7 70.7 112.7	.03756 --- ---	--- .0014 ---	.29742 .6936 ---	.148 1.0 .1	.517 1.0 .2	---	---	---	.001	.001		C	1 0 .0047
23	02067		PBR, Higher density Na	495.3	.001224	1.6238	121.44	1	52.7 112.7	.03892 ---	.0014	.29818 .6936	.148 ---	.6915 .289636	---	---	---	.0001	∞	f = 1.0065		.0478
24	02068		PBR, 1/2 volume decrease	495.3	.001368	1.6013	121.0338	1	52.52375 112.4231	.0392085 ---	.0014141	.2991753 .7056568	.1489499 .1010101	.5222222 .2820202	---	---	---	.0001	∞	f = 1.0029		.0510
25	02028		PBR, Center control Pu → U	494.1	.001453	1.5537	121.44	1	2.535 52.7 112.7	.03882 --- ---	--- .0014 ---	.335 .29518 .6936	.148 .148 ---	.517 .517 .2	---	---	---	.0001	∞	f = .9967		.00095 .0015 .0523
26	02031		PBR, Mid-core control Pu → U	490.7	.001724	1.7251	121.44	1	21.08 26.35 52.7	.03882 --- ---	--- .0014 ---	.29618 .335 .29518	.148 .148 ---	.517 .517 .2	---	---	---	.0001	∞	f = .9244		.24584 .02384 .77762 .0662
27	02034		PBR, Outside core control U → Pu	495.3	.003843	1.2860	121.44	1	52.7 59.7 112.7	.03882 --- ---	.0014 .0014	.29518 .5996 .6936	.148 ---	.517 .2	---	---	---	.0001	∞	f = 1.0809		.3772 .0696
28	02029		PBR, Center control U → Pu	494.1	.001530	1.3811	121.44	1	2.535 52.7 112.7	.03882 --- ---	.0014	.29518 .6936	.148 ---	.517 .2	---	---	---	.0001	∞	f = .9715		.0564
29	02084		PBR, Mid-core control Pu → B ₁₀	490.7	.001970	1.6141	121.44	1	21.08 26.35 52.7	.03882 --- ---	--- .0014 ---	.29618 .335 .29518	.148 .148 ---	.517 .517 .2	---	---	---	.0001	∞	f = .8420		.2204 .2211 .7595 .0825
30	02035		PBR, Outside core control U → B ₁₀	495.3	.001285	1.6722	121.44	1	52.7 59.7 112.7	.03882 --- ---	.0014 .0014	.29618 .6736 .6936	.148 ---	.517 .2	---	---	---	.0001	∞	f = .9894		.0284 .0205
31	02019		Reference CONW	727.4*	.001403	1.5823	121.44	1	52.7 112.7	.03882 ---	.0014	.29652 .6936	.148 ---	.517 .2	---	---	---	.0001	.0001		C	1 0.0514
32	02089		Large CONW	990.6*	.001050	1.6528	121.44	1	64.6 124.6	.03882 ---	.0014	.29106 .6936	.148 ---	.517 .2	---	---	---	.001	.001		C	1 0.388
33	02100		CONV, Flat power by varying enrichment, 3 rings	789.9*	.001631	1.2304	121.44	1	31.62 42.16 52.7	.03882 --- ---	.0014	.29208 .29493 .27062	.148 .148 ---	.517 .517 .2	---	---	---	.001	.001		C	1 0.3390 .2799 .3622 .0623
34	02104		CONV, Flat power by varying enrichment, 3 rings	813.7*	.001736	1.0304	121.44	1	31.62 42.16 52.7	.03882 --- ---	.0014	.29636 .28077 .26527	.148 .148 ---	.517 .517 .2	---	---	---	.001	.001		C	1 0.3165 .2887 .3549 .0681
35	02102		CONV, Flat power by varying enrichment, 5 rings	796.0*	.001739	1.1216	121.44	1	10.54 21.08 31.62 42.16 52.7	.03882 --- ---	.0014	.29180 .29396 .29114 .28455 .28391 .28389	.148 .148 ---	.517 .517 ---	---	---	---	.001	.001		C	1 0.0445 .1308 .2115 .2823 .3549 .0681

*M(u²³⁵)

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions										Reactivity	s
									Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	K	C	B ¹⁰				
CYLINDRICAL GEOMETRY - SEVEN-GROUP CROSS SECTIONS (Cont'd.)																				
36	02101	Large CONV with central blanket	1092.5*	.001373	1.1961	121.44	1 2 3	25.84 84.6 124.6	--- --- ---	.0014 .05769 .0014	.6986 .27731 .6986	.148 .148 .1	.2 .517 .2	---	---	---	.001 .001 ---	.001 ---	C	.0654 .9346 .0536
37	02020	Reference PPB	85.95	.002547	1.311	60.72	1 2	20.96 80.96	.10722 ---	---	.22778 .6986	.148 .1	.517 .2	---	---	---	.0001 ---	.00001 ---	C	1 .1334
38	02048	PPB. Flat power by varying enrichment, 5 rings	89.02	.002791	1.1187	60.72	1 2 3 4 5 6	4.192 8.384 12.576 16.768 20.96 80.96	.09449 .09594 .09733 .10687 .12757 ---	---	.24051 .23956 .23767 .22533 .20743 .6986	.148 .148 .148 .148 .148 .1	.517 .517 .517 .517 .517 .2	---	---	---	.001 ---	.001 ---	C	.0443 .1235 .2041 .2786 .3435 .1394
39	02049	PPB. Flat power by varying enrichment, 5 rings	90.70	.002694	1.1684	60.72	1 2 3 4 5 6	4.192 8.384 12.576 16.768 20.96 80.96	.08616 .08702 .08961 .10770 .14216 ---	---	.24884 .24798 .24539 .22730 .19284 .6986	.148 .148 .148 .148 .148 .1	.517 .517 .517 .517 .517 .2	---	---	---	.001 ---	.001 ---	C	.0337 .1164 .1870 .2753 .3816 .1450
40	02098	PPB. Flat power by varying enrichment, 5 rings	89.20	.002636	1.072	60.72	1 2 3 4 5 6	4.192 8.384 12.576 16.768 20.96 80.96	.09068 .09250 .09763 .10912 .12907 ---	---	.24432 .24250 .23737 .22588 .20593 .6986	.148 .148 .148 .148 .148 .1	.517 .517 .517 .517 .517 .2	---	---	---	.001 ---	.001 ---	C	.0425 .1256 .2041 .2797 .3492 .1407
41	02051	PPB. 9-cm Na reflector	105.49	.003920	1.4547	60.72	1 2 3	20.96 29.96 80.96	.13159 ---	---	.20341 ---	.148 ---	.517 .2	---	---	---	.001 ---	.001 ---	C	1 0 .0846
42	02050	PPB. 9-cm Fe reflector	83.15	.002427	1.2918	60.72	1 2 3	20.96 29.96 80.96	.10373 ---	---	.23127 .6986	.148 1.0 .1	.517 ---	---	---	---	.001 ---	.001 ---	C	1 0 .0284
43	02086	PPB. Higher density Na	85.95	.002250	1.3302	60.72	1 2	20.96 80.96	.10722 ---	---	.22778 .6986	.148 .1	.6815 .263636	---	---	---	.0001 ∞	f = 1.0222	1	.1247
44	02089	PPB. 1% volume decrease	85.95	.002445	1.3118	60.5169	1 2	20.8899 80.6892	.1083065 ---	---	.2300773 .7056566	.1494949 .1010101	.5222222 .2020202	---	---	---	.0001 ∞	f = 1.0056	1	.1318
45	02053	PPB. Outside core control U → Pu	85.95	.003174	1.2448	60.72	1 2 3	20.96 23.96 80.96	.10722 ---	---	.22778 .5986 .6986	.148 .1 .1	.517 .2 .2	---	---	---	.0001 ∞	f = 1.0667	1	.23075 .11217
46	02054	PPB. Outside core control U → B ¹⁰	85.95	.002485	1.3383	60.72	1 2 3	20.96 23.96 80.96	.10722 ---	---	.22778 .6786 .6986	.148 .1 .1	.517 .2 .2	---	---	.02	.0001 ∞	f = .9789	1	.0452 .0871
47	02022	Reference PPC	142.44*	.002434	1.2814	60.72	1 2	20.96 80.96	---	.15110 .0014	.18390 .6986	.148 .1	.517 .2	---	---	---	.0001 .0001	.0001 ---	C	1 .1311
48	02023	EBR	55.41*	.0006837	1.2324	39.1	1 2 3 4	8.85 22.75 39.16 99.16	---	.55438 .0035 .006 ---	.03539 .4865 .821 ---	.11663 .06838 .175 .011	.06838 .257 .078 ---	.22522 ---	---	---	.0001 .0001	.0001 ---	C	1 .1281 .0454 0
49	02056	EBR. B ¹⁰ control	55.41*	.0006734	1.2449	39.1	1 2 3 4 5	8.85 10.85 22.75 39.16 99.16	---	.55438 .0035 .0035 .006 ---	.03539 .4565 .4865 .821 ---	.11663 .06838 .175 .175 .011	.06838 .257 .078 .257 ---	.22522 ---	---	.03	.0001 ∞	f = .9855	1	.0301 .0966 .0457 0
50	02021	EBR. Pu loading	34.59	.0007663	1.1938	39.1	1 2 3 4	8.85 22.75 39.16 99.16	.40697 ---	---	---	.16860 .09886 .175 .011	.32557 .257 .078 ---	---	---	---	.001 .001	.001 ---	C	1 .1458 .0518 0
51	02047	EBR. Without outer graphite	55.49*	.06292	1.2343	39.1	1 2 3	8.85 22.75 39.16	---	.55517 .0035 .006	.03544 .4865 .821	.11639 .06824 .175 .011	.06824 .22476 .257 ---	---	---	---	.001 .001	.001 ---	C	1 .12745 .03943

*M(U²³⁵)

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions										Reactivity	S
									Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	K	C	B ¹⁰	O	L		
CYLINDRICAL GEOMETRY - SEVEN-GROUP CROSS SECTIONS (Cont'd.)																				
52	02026	Snell Experiment				1000	1 2	60 300	.03060 ---	---	.30440 .9928	.148 ---	.517 ---	---	---	---	.001	.001	C	-.0889
53	02057	Parametric study	154.74	.006544	1.1847	121.44	1 2	20 80	.08421 ---	---	.11579 .6986	.1 ---	.8 .2	---	---	---	.001	.001	C	-.2434
54	02058	Parametric study	157.30	.006840	1.1751	121.44	1 2	20 80	.0856 ---	0 .0014	.0572 .6986	.0572 ---	.8 .2	---	---	---	.001	.001	C	-.2525
55	02059	Parametric study	160.26	.007086	1.1652	121.44	1 2	20 80	.08721 ---	---	---	.11279 .6986	.8 .2	---	---	---	.001	.001	C	-.2623
56	02060	Parametric study	149.10	.004620	1.3135	121.44	1 2	20 80	.08114 ---	---	.41886 .6986	.1 ---	.5 .2	---	---	---	.001	.001	C	-.1494
57	02061	Parametric study	150.98	.005138	1.2859	121.44	1 2	20 80	.08216 ---	---	.20892 .6986	.20892 ---	.5 .2	---	---	---	.001	.001	C	-.1654
58	02062	Parametric study	153.73	.005778	1.2535	121.44	1 2	20 80	.08366 ---	---	---	.41634 .6986	.5 .2	---	---	---	.001	.001	C	-.1845
59	02063	Parametric study	155.61	.003396	1.4220	121.44	1 2	20 80	.08468 ---	---	.71532 .6986	.1 ---	.2 .2	---	---	---	.001	.001	C	-.1014
60	02064	Parametric study	153.66	.003964	1.3849	121.44	1 2	20 80	.08362 ---	---	.35819 .6986	.35819 ---	.2 .2	---	---	---	.005	.005	C	-.1163
61	02065	Parametric study	150.59	.004843	1.3354	121.44	1 2	20 80	.08195 ---	---	---	.71805 .6986	.2 .2	---	---	---	.005	.005	C	-.1379
62	02066	Parametric study	413.8	.002472	1.4235	121.44	1 2	50 110	.03603 ---	---	.16337 .6986	.1 ---	.8 .2	---	---	---	.005	.005	C	-.1010
63	02067	Parametric study	413.9	.002719	1.4003	121.44	1 2	50 110	.03604 ---	---	.08198 .6986	.08198 ---	.8 .2	---	---	---	.005	.005	C	-.1108
64	02068	Parametric study	420.8	.003037	1.3691	121.44	1 2	50 110	.03684 ---	---	---	.16336 .6986	.8 .2	---	---	---	.005	.005	C	-.1239
65	02069	Parametric study	485.9	.001425	1.5483	121.44	1 2	50 110	.04231 ---	---	.45769 .6986	.1 ---	.5 .2	---	---	---	.005	.005	C	-.0511
66	02070	Parametric study	452.5	.001676	1.5471	121.44	1 2	50 110	.0394 ---	---	.2303 .6986	.2303 ---	.5 .2	---	---	---	.005	.005	C	-.0583
67	02071	Parametric study	396.5	.002125	1.5239	121.44	1 2	50 110	.03452 ---	---	---	.46548 .6986	.5 .2	---	---	---	.005	.005	C	-.0706
68	02072	Parametric study	596.0	.000896	1.6244	121.44	1 2	50 110	.05189 ---	---	.74811 .6986	.1 ---	.2 .2	---	---	---	.005	.005	C	-.0305
69	02073	Parametric study	530.6	.001098	1.6530	121.44	1 2	50 110	.04620 ---	---	.37690 .6986	.37690 ---	.2 .2	---	---	---	.005	.005	C	-.0354
70	02074	Parametric study	405.7	.001579	1.6333	121.44	1 2	50 110	.03532 ---	---	---	.76468 .6986	.2 .2	---	---	---	.005	.005	C	-.0446
71	02075	Parametric study	817.3	.001299	1.5456	121.44	1 2	80 140	.02780 ---	---	.17220 .6986	.1 ---	.8 .2	---	---	---	.005	.005	C	-.0585
72	02076	Parametric study	792.7	.001455	1.5394	121.44	1 2	80 140	.02896 ---	---	.08652 .6986	.08652 ---	.8 .2	---	---	---	.005	.005	C	-.0628
73	02077	Parametric study	772.7	.001673	1.5300	121.44	1 2	80 140	.02628 ---	---	---	.17372 .6986	.8 .2	---	---	---	.005	.005	C	-.0711
74	02078	Parametric study	1067.6	.0007469	1.5059	121.44	1 2	80 140	.03631 ---	---	.46369 .6986	.1 ---	.5 .2	---	---	---	.005	.005	C	-.0293

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions							S	Reactivity	S		
									Pu ²³³	U ²³⁵	U ²³³	Fe	Na	K	C				B ¹⁰	
CYLINDRICAL GEOMETRY - SEVEN-GROUP CROSS SECTIONS (Cont'd.)																				
75	02079	Parametric study	951.4	.0007852	1.6927	121.44	1 2	80 140	.03236 ---	--- .0014	.23382 .6986	.23382 .1	.5 .2	---	---	---	.005	.005	C	1 .0293
76	02080	Parametric study	743.8	.001072	1.6936	121.44	1 2	80 140	.02530 ---	--- .0014	--- .6986	.47470 .1	.5 .2	---	---	---	.005	.005	C	1 .0371
77	02081	Parametric study	1381.0	.0004929	1.4293	121.44	1 2	80 140	.04697 ---	--- .0014	.75303 .6986	--- .1	.2 .2	---	---	---	.005	.005	C	1 .0185
78	02082	Parametric study	1207.8	.0007032	1.5031	121.44	1 2	80 140	.04108 ---	--- .0014	.37946 .6986	.37946 .1	.2 .2	---	---	---	.005	.005	C	1 .0250
79	02083	Parametric study	800.9	.0007560	1.7840	121.44	1 2	80 140	.02724 ---	--- .0014	--- .6986	.77276 .1	.2 .2	---	---	---	.005	.005	C	1 .0234

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions											Reactivity	S
									Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	K	C	S ¹⁰	S	C			
CYLINDRICAL GEOMETRY - TEN-GROUP CROSS SECTIONS																					
80	04143	PBR. Corresponds to Problem 1.	464.1	0.001834	1.568	121.44	1	52.7	0.03666	0	0.29834	0.148	0.517	-	-	-	0.0001	0.0001	C	1	
								112.7	0	0.0014	0.6986	0.1	0.2	-	-	-			0.0469		
81	04144	CONV. Corresponds to Problem 31.	744.7*	.001800	1.540	121.44	1	52.7	-	0.04984	0.28516	0.148	0.517	-	-	-	0.0001	0.0001	C	1	
								112.7	-	0.0014	0.6986	0.1	0.2	-	-	-			0.0468		
82	04145	PPB. Corresponds to Problem 37.	85.30	.003108	1.285	60.72	1	20.96	0.10722	0	0.22778	0.148	0.517	-	-	-	0.0001	0.0001	C	1	
								80.96	0	0.0014	0.6986	0.1	0.2	-	-	-			0.1172		
83	04146	PPC. Corresponds to Problem 47.	155.19*	.002814	1.260	60.72	1	20.96	-	0.16529	0.16971	0.148	0.517	-	-	-	0.0001	0.0001	C	1	
								80.96	-	0.0014	0.6986	0.1	0.2	-	-	-			0.1117		
84	04147	PBR. Modified reference design.	459.48	.008556	1.550	121.44	1	52.7	0.036290	0	0.28371	0.14**	0.54	-	-	-	0.00001	0.00001	C	1	
								97.7	0	0.0014	0.6986	0.1*	0.2	-	-	-			0.0539		
85	04151	PPB. Modified reference design	89.0	.01452	1.262	60.72	1	20.96	0.11187	0	0.20813	0.14**	0.54	-	-	-	0.00001	0.00001	C	1	
								80.96	0	0.0014	0.6986	0.1**	0.2	-	-	-			0.1285		
86	04159	EBR. Corresponds to Problem 48.	58.40*	.0007087	1.245	39.1	1	8.85	-	0.58660	0.03744	0.10689	0.06267	0.20640	-	-	0.00001	0.00001	C	1	
								22.75	-	0.0035	0.4865	0.175	0.078	0.257	-	-			0.1085		
								39.16	-	0.006	0.821	0.011	0	-	-	-			0.0367		
								99.16	-	-	-	-	-	1.0	-			0			
87	04160	EBR. 2% radial expansion of core	58.40*	0.0007190	1.241	39.1	1	8.9381	-	0.57510	0.03671	0.10479	0.06144	0.20235	-	-	0.00001	∞	f = 0.9920	1	
								22.75	-	0.0035	0.4865	0.175	0.078	0.257	-	-			0.1098		
								39.16	-	0.006	0.821	0.011	-	-	-	-			0.0378		
								99.16	-	-	-	-	-	1.0	-			0			

*M(U²³⁵)

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Argonne Prob. No.	UNIVAC Tape Prob. No.	M(Pu ²³⁹)	M(U ²³⁵)	E	R	R*	H _{EBG} , cm	Region	Outer Boundary, cm	Material Volume Fractions						
										Pu ²³⁹	U ²³⁵	U ²³⁸	Ti	Na	S	
CENTRAL BLANKET - CYLINDRICAL GEOMETRY - TEN-GROUP CROSS SECTIONS																
(In all problems: $\delta = \epsilon = 0.005$ and problems run to criticality)																
88	04123	461.3	0	0.007127	1.537	1.537	121.44	1	52.7	0.03643	0	0.28357	0.14	0.54	1.0	
								2	61.7	0	0.0011	0.5489	0.1	0.35	0.0334	
								3	97.7	0	0.0016	0.7984	0.1	0.1	0.0199	
89	04124	524.9	0	0.008719	1.337	1.162	121.44	1	21.08	0	0.0011	0.5489	0.1	0.35	0.0302	
								2	52.7	0.04935	0	0.27065	0.14	0.54	0.9698	
								3	61.7	0	0.0011	0.5489	0.1	0.35	0.0443	
								4	97.7	0	0.0016	0.7984	0.1	0.1	0.0256	
90	04125	551.4	0	0.01052	1.600	1.082	121.44	1	31.62	0	0.0011	0.5489	0.1	0.35	0.0532	
								2	52.7	0.06804	0	0.25196	0.14	0.54	0.9468	
								3	61.7	0	0.0011	0.5489	0.1	0.35	0.0579	
								4	97.7	0	0.0016	0.7984	0.1	0.1	0.0326	
91	04126	592.9	0	0.007052	1.346	1.168	121.44	1	23.04	0	0.0011	0.5489	0.1	0.35	0.0281	
								2	57.6	0.04667	0	0.27333	0.14	0.54	0.9719	
								3	62.1	0	0.011	0.5489	0.1	0.35	0.0256	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0390	
92	04127	593.6	0	0.007879	1.346	1.168	121.44	1	23.04	0	0.0011	0.5489	0.1	0.35	0.0283	
								2	57.6	0.04672	0	0.27328	0.14	0.54	0.9717	
								3	66.6	0	0.011	0.5489	0.1	0.35	0.0404	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0230	
93	04128	593.7	0	0.008795	1.346	1.168	121.44	1	23.04	0	0.0011	0.5489	0.1	0.35	0.0283	
								2	57.6	0.04673	0	0.27327	0.14	0.54	0.9700	
								3	71.1	0	0.0011	0.5489	0.1	0.35	0.0490	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0138	
94	04129	615.8	0	0.009760	1.614	1.095	121.44	1	34.56	0	0.0011	0.5489	0.1	0.35	0.0506	
								2	57.6	0.06361	0	0.25639	0.14	0.54	0.9494	
								3	66.6	0	0.0011	0.5489	0.1	0.35	0.0537	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0305	
95	04130	591.3	0	0.005630	1.576	1.576	121.44	1	62.1	0.03363	0	0.28637	0.14	0.54	1.0	
								2	71.1	0	0.0011	0.5489	0.1	0.35	0.0268	
								3	107.1	0	0.0016	0.7984	0.1	0.1	0.0159	
96	04131	685.5	0	0.007522	1.350	1.171	121.44	1	24.84	0	0.0011	0.5489	0.1	0.35	0.0278	
								2	62.1	0.04458	0	0.27542	0.14	0.54	0.9722	
								3	71.1	0	0.0011	0.5489	0.1	0.35	0.0386	
								4	107.1	0	0.0016	0.7984	0.1	0.1	0.0238	
97	04132	680.5	0	0.009210	1.621	1.098	121.44	1	37.26	0	0.0011	0.5489	0.1	0.35	0.0487	
								2	62.1	0.06048	0	0.25952	0.14	0.54	0.9513	
								3	71.1	0	0.011	0.5489	0.1	0.35	0.0507	
								4	107.1	0	0.0016	0.7984	0.1	0.1	0.0296	
98	04133	519.9	0	0.009532	1.350	1.171	121.44	1	21.08	0	0.0009	0.4491	0.1	0.45	0.0278	
								2	52.7	0.04888	0	0.27112	0.14	0.54	0.9722	
								3	61.7	0	0.0009	0.4491	0.1	0.45	0.0386	
								4	97.7	0	0.0016	0.7984	0.1	0.1	0.0292	
99	04134	588.2	0	0.008608	1.355	1.173	121.44	1	23.04	0	0.0009	0.4491	0.1	0.45	0.0262	
								2	57.6	0.04630	0	0.27370	0.14	0.54	0.9738	
								3	66.6	0	0.0009	0.4491	0.1	0.45	0.0351	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0263	

Argonne Prob. No.	UNIVAC Tape Prob. No.	M(Pu ²³⁹)	M(U ²³⁵)	E	R	R*	H _{EBG} , cm	Region	Outer Boundary, cm	Material Volume Fractions						
										Pu ²³⁹	U ²³⁵	U ²³⁸	Ti	Na	S	
CENTRAL BLANKET - CYLINDRICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)																
(In all problems: $\delta = \epsilon = 0.005$ and problems run to criticality)																
100	04135	611.7	0	0.01088	1.618	1.095	121.44	1	34.56	0	0.0009	0.4491	0.1	0.45	0.0485	
								2	57.6	0.06318	0.	0.25682	0.14	0.54	0.9515	
								3	66.6	0	0.0009	0.4491	0.1	0.45	0.0475	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0369	
101	04136	654.2	0	0.008198	1.358	1.175	121.44	1	24.84	0	0.009	0.4491	0.1	0.45	0.0257	
								2	62.1	0.04429	0	0.27571	0.14	0.54	0.9743	
								3	71.1	0	0.0009	0.4491	0.1	0.45	0.0334	
								4	107.1	0	0.0016	0.7984	0.1	0.1	0.0270	
102	04137	529.3	0	0.007973	1.328	1.158	121.44	1	21.08	0	0.0013	0.6487	0.1	0.25	0.0320	
								2	52.7	0.04977	0	0.27023	0.14	0.54	0.9680	
								3	61.7	0	0.0013	0.6487	0.1	0.25	0.0493	
								4	97.7	0	0.0016	0.7984	0.1	0.1	0.0223	
103	04138	598.2	0	0.007208	1.340	1.165	121.44	1	23.04	0	0.0013	0.6487	0.1	0.25	0.0299	
								2	57.6	0.04708	0	0.27292	0.14	0.54	0.9701	
								3	66.6	0	0.0013	0.6487	0.1	0.25	0.0450	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0201	
104	04139	619.1	0	0.008904	1.607	1.094	121.44	1	34.56	0	0.0013	0.6487	0.1	0.25	0.0532	
								2	57.6	0.06395	0	0.25605	0.14	0.54	0.9468	
								3	66.6	0	0.0013	0.6487	0.1	0.25	0.0596	
								4	102.6	0	0.0016	0.7984	0.1	0.1	0.0266	
105	04140	662.1	0	0.006896	1.343	1.167	121.44	1	24.84	0	0.0013	0.6487	0.1	0.25	0.0293	
								2	62.1	0.04483	0	0.25717	0.14	0.54	0.9707	
								3	71.1	0	0.0013	0.6487	0.1	0.25	0.0431	
								4	107.1	0	0.0016	0.7984	0.1	0.1	0.0210	
106	04105	25.46	121.17	0.01219	1.255	1.255	60.72	1	20.96	0.12905	0	0.15895	0.14	0.54	1.0	
								2	29.96	0	0.0011	0.5489	0.1	0.35	0.0776	
								3	65.96	0	0.0016	0.7984	0.1	0.1	0.0428	
107	04106	21.38	137.23	0.01224	1.326	1.152	60.72	1	8.384	0	0.0011	0.5489	0.1	0.35	0.0330	
								2	20.96	0.17399	0	0.11401	0.14	0.54	0.9670	
								3	29.96	0	0.0011	0.5489	0.1	0.35	0.0836	
								4	65.96	0	0.0016	0.7984	0.1	0.1	0.0457	
108	04107	16.29	155.50	0.01297	1.609	1.094	60.72	1	12.576	0	0.0011	0.5489	0.1	0.35	0.0586	
								2	20.96	0.25879	0	0.02921	0.14	0.54	0.9414	
								3	29.96	0	0.0011	0.5489	0.1	0.35	0.0923	
								4	65.96	0	0.0016	0.7984	0.1	0.1	0.0502	
109	04108	25.41	143.51	0.01042	1.325	1.151	60.72	1	9.14	0	0.0011	0.5489	0.1	0.35	0.0333	
								2	22.85	0.15312	0	0.13488	0.14	0.54	0.9667	
								3	27.85	0	0.0011	0.5489	0.1	0.35	0.0503	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0762	
110	04109	25.41	145.73	0.01143	1.332	1.158	60.72	1	9.14	0	0.0011	0.5489	0.1	0.35	0.0334	
								2	22.85	0.15594	0	0.13206	0.14	0.54	0.9666	
								3	31.85	0	0.0011	0.5489	0.1	0.35	0.0789	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0434	
111	04110	25.41	147.34	0.01254	1.335	1.160	60.72	1	9.14	0	0.0011	0.5489	0.1	0.35	0.0334	
								2	22.85	0.1572	0	0.13080	0.14	0.54	0.9666	
								3	36.35	0	0.0011	0.5489	0.1	0.35	0.0951	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0250	
112	04111	19.36	169.54	0.01094	1.610	1.094	60.72	1	13.71	0	0.0011	0.5489	0.1	0.35	0.0584	
								2	22.85	0.23745	0	0.05055	0.14	0.54	0.9416	
								3	31.85	0	0.0011	0.5489	0.1	0.35	0.0877	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0471	

Argonne Prob. No.	UNIVAC Tape Prob. No.	M(Pu ²³⁹)	M(U ²³⁵)	E	R	R*	H _{EBC} , cm	Region	Outer Boundary, cm	Material Volume Fractions						
										Pu ²³⁹	U ²³⁵	U ²³⁸	Ti	Na	S	
CENTRAL BLANKET - CYLINDRICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)																
(In all problems: $\delta = \epsilon = 0.005$ and problems run to criticality)																
113	04112	35.09	134.68	0.009989	1.297	1.297	60.72	1	24.61	0.10406	0	0.18394	0.14	0.54	1.00	
								2	33.61	0	0.0011	0.5489	0.1	0.35	0.0669	
								3	69.61	0	0.0016	0.7984	0.1	0.1	0.0366	
114	04113	29.47	157.13	0.01149	1.332	1.157	60.72	1	9.844	0	0.0011	0.5489	0.1	0.35	0.0331	
								2	24.61	0.14454	0	0.14346	0.14	0.54	0.9669	
								3	33.61	0	0.0011	0.5489	0.1	0.35	0.0748	
								4	69.61	0	0.0016	0.7984	0.1	0.1	0.0432	
115	04114	22.45	183.14	0.01137	1.610	1.094	60.72	1	14.766	0	0.0011	0.5489	0.1	0.35	0.0580	
								2	24.61	0.22112	0	0.06688	0.14	0.54	0.9420	
								3	33.61	0	0.0011	0.5489	0.1	0.35	0.0637	
								4	69.61	0	0.0016	0.7984	0.1	0.1	0.0445	
116	04115	21.38	143.11	0.01435	1.334	1.154	60.72	1	8.384	0	0.0009	0.4491	0.1	0.45	0.0286	
								2	20.96	0.18144	0	0.10656	0.14	0.54	0.9714	
								3	29.96	0	0.0009	0.4491	0.1	0.45	0.0729	
								4	65.96	0	0.0016	0.7984	0.1	0.1	0.0529	
117	04116	25.41	151.90	0.01237	1.341	1.160	60.72	1	9.14	0	0.0009	0.4491	0.1	0.45	0.0291	
								2	22.85	0.16207	0	0.12593	0.14	0.54	0.9709	
								3	31.85	0	0.0009	0.4491	0.1	0.45	0.0688	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0501	
118	04117	19.36	176.44	0.01356	1.627	1.099	60.72	1	13.71	0	0.0009	0.4491	0.1	0.45	0.0522	
								2	22.85	0.24712	0	0.04068	0.14	0.54	0.9478	
								3	31.85	0	0.0009	0.4491	0.1	0.45	0.0768	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0567	
119	04118	29.47	162.52	0.01150	1.346	1.165	60.72	1	9.844	0	0.0009	0.4491	0.1	0.45	0.0291	
								2	24.61	0.14950	0	0.13850	0.14	0.54	0.9709	
								3	33.61	0	0.0009	0.4491	0.1	0.45	0.0647	
								4	69.61	0	0.0016	0.7984	0.1	0.1	0.0466	
120	04119	21.38	131.02	0.01141	1.317	1.149	60.72	1	8.384	0	0.0013	0.6487	0.1	0.25	0.0370	
								2	20.96	0.16612	0	0.12188	0.14	0.54	0.9630	
								3	29.96	0	0.0013	0.6487	0.1	0.25	0.0937	
								4	65.96	0	0.0016	0.7984	0.1	0.1	0.0407	
121	04120	25.41	142.33	0.01051	1.322	1.153	60.72	1	9.14	0	0.0013	0.6487	0.1	0.25	0.0369	
								2	22.85	0.15186	0	0.13614	0.14	0.54	0.9631	
								3	31.85	0	0.0013	0.6487	0.1	0.25	0.0876	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0375	
122	04121	19.36	164.92	0.01128	1.595	1.090	60.72	1	13.71	0	0.0013	0.6487	0.1	0.25	0.0635	
								2	22.85	0.23099	0	0.05701	0.14	0.54	0.9365	
								3	31.85	0	0.0013	0.6487	0.1	0.25	0.0969	
								4	67.85	0	0.0016	0.7984	0.1	0.1	0.0406	
123	04122	24.97	153.27	0.009758	1.326	1.156	60.72	1	9.844	0	0.0013	0.6487	0.1	0.25	0.0367	
								2	24.61	0.14099	0	0.14701	0.14	0.54	0.9633	
								3	33.61	0	0.0013	0.6487	0.1	0.25	0.0823	
								4	69.61	0	0.0016	0.7984	0.1	0.1	0.0348	
124	04141	0	168.75	0.01158	1.249	1.249	60.72	1	20.96	0.17973	0	0.14027	0.14	0.54	1.000	
								2	29.96	0	0.0011	0.5489	0.1	0.35	0.0768	
								3	65.96	0	0.0016	0.7984	0.1	0.1	0.0424	
125	04142	91.35	0	0.01236	1.272	1.272	60.72	1	20.96	0.11482	0	0.20518	0.14	0.54	1.00	
								2	29.96	0	0.0011	0.5489	0.1	0.35	0.0802	
								3	65.96	0	0.0016	0.7984	0.1	0.1	0.0449	

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary, cm	Material Volume Fractions												δ	ε	Reactivity	S
								Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	I/v	K	C	B ¹⁰						
								SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS															
S1	04A01	Reference PBR.	445.8	0.01738	1.8730	1	57.59	0.03511	0	0.28489	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	102.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.0902		
S2	04A02	Reference PPB.	82.68	0.05146	1.4041	1	22.85	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.2081		
S3	04A03	Reference assembly with 6.25-liter core.	31.76	-	-	1	11.43	0.32	-	-	-	0.54	0.14	-	-	-	-	0.0001	0	f = 0.9941	I		
						2	56.43	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0	f = 0.9941	-		
S4	04A05	Reference assembly with 12.5-liter core.	43.05	0.07463	1.2665	1	14.4	0.2169	0	0.1031	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	59.4	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.2824		
S5	04A04	Reference assembly with 200-liter core.	178.1	0.03178	1.6081	1	36.28	0.05611	-	0.26389	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	81.28	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.1370		
S6	04A06	Reference assembly with 500-liter core.	320.6	0.02165	1.7783	1	49.24	0.0404	-	0.2796	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	94.24	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.0975		
S7	04A07	Reference assembly with 1200-liter core.	601.5	0.01422	1.9593	1	65.92	0.03159	-	0.28841	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	I		
						2	110.92	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	0.0001	C	0.0671		
S8	04A08	PBR. Neutron lifetime.	445.8	0.01330	1.8953	1	57.59	0.03511	-	0.28489	-	0.54	0.14	0.01	-	-	-	0.0001	0	f = 0.8727	I		
						2	102.59	-	0.0014	0.6986	-	0.2	0.1	0.01	-	-	-	0.0001	0	f = 0.8727	0.0900		
S9	04B46	PBR. Neutron lifetime.	445.8	0.01689	1.8730	1	57.59	0.03511	-	0.28489	-	0.54	0.14	0.001	-	-	-	0.0001	0	f = 0.9831	I		
						2	102.59	-	0.0014	0.6986	-	0.2	0.1	0.001	-	-	-	0.0001	0	f = 0.9831	0.0815		
S10	04A09	PPB. Neutron lifetime.	82.68	0.04023	1.4264	1	22.85	0.10425	-	0.21575	-	0.54	0.14	0.01	-	-	-	0.0001	0	f = 0.9325	I		
						2	67.85	-	0.0014	0.6986	-	0.2	0.1	0.01	-	-	-	0.0001	0	f = 0.9325	0.2192		
S11	04B47	PPB. Neutron lifetime.	82.68	0.05011	1.4064	1	22.85	0.10425	-	0.21575	-	0.54	0.14	0.001	-	-	-	0.0001	0	f = 0.9921	I		
						2	67.85	-	0.0014	0.6986	-	0.2	0.1	0.001	-	-	-	0.0001	0	f = 0.9921	0.2093		
S12	04A10	6.25-liter core. Neutron lifetime.	31.76	0.06917	1.2330	1	11.43	0.32	-	-	-	0.54	0.14	0.01	-	-	-	0.0001	0	f = 0.9567	I		
						2	56.43	-	0.0014	0.6986	-	0.2	0.1	0.01	-	-	-	0.0001	0	f = 0.9567	0.3264		
S13	04A12	200-liter core. Neutron lifetime.	43.05	0.07096	1.2700	1	14.4	0.2169	-	0.1031	-	0.54	0.14	0.002	-	-	-	0.0001	0	f = 0.9899	I		
						2	59.4	-	0.0014	0.6986	-	0.2	0.1	0.002	-	-	-	0.0001	0	f = 0.9899	0.2842		
S14	04A11	200-liter core. Neutron lifetime.	178.1	0.03091	1.6105	1	36.28	0.05611	-	0.26389	-	0.54	0.14	0.001	-	-	-	0.0001	0	f = 0.9880	I		
						2	81.28	-	0.0014	0.6986	-	0.2	0.1	0.001	-	-	-	0.0001	0	f = 0.9880	0.1384		
S15	04A13	500-liter core. Neutron lifetime.	320.6	0.02109	1.7794	1	49.24	0.0404	-	0.2796	-	0.54	0.14	0.001	-	-	-	0.0001	0	f = 0.9849	I		
						2	94.24	-	0.0014	0.6986	-	0.2	0.1	0.001	-	-	-	0.0001	0	f = 0.9849	0.0988		
S16	04A14	1200-liter core. Neutron lifetime.	601.5	0.01376	1.9580	1	65.92	0.03159	0	0.28841	-	0.54	0.14	0.001	-	-	-	0.0001	0	f = 0.9818	I		
						2	110.92	-	0.0014	0.6986	-	0.2	0.1	0.001	-	-	-	0.0001	0	f = 0.9818	0.0683		
S17	04A15	PBR. 2% uniform expansion.	445.8	0.01876	1.8631	1	57.9714	0.03442	-	0.27931	-	0.529412	0.137255	-	-	-	-	0.0001	0	f = 0.9941	I		
						2	103.2695	-	0.001373	0.684902	-	0.196078	0.098039	-	-	-	-	0.0001	0	f = 0.9941	0.0823		
S18	04A16	PPB. 2% uniform expansion.	82.68	0.05518	1.3996	1	23.0013	0.10221	-	0.21152	-	0.529412	0.137255	-	-	-	-	0.0001	0	f = 0.9900	I		
						2	68.2992	-	0.001373	0.684902	-	0.196078	0.098039	-	-	-	-	0.0001	0	f = 0.9900	0.2132		
S19	04A17	6.25-liter core. 2% uniform expansion.	31.76	0.09335	1.2173	1	11.5057	0.31372	-	-	-	0.529412	0.137255	-	-	-	-	0.0001	0	f = 0.9822	I		
						2	56.8037	-	0.001373	0.684902	-	0.196078	0.098039	-	-	-	-	0.0001	0	f = 0.9822	0.3266		

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary, cm	Material Volume Fractions											δ	ε	Reactivity	S
								Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	I/v	K	C	B ¹⁰					
								SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)														
S20	04A18	PBR. 2% core expansion.	445.8	0.01809	1.8610	1	57.9714	0.03442	-	0.27931	-	0.529412	0.137255	-	-	-	-	0.0001	∞	f = 0.9945	1	
						2	102.7108	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	∞	f = 0.9928	1	
S21	04A19	PPB. 2% core expansion.	82.68	0.05259	1.3969	1	23.0013	0.10221	-	0.21152	-	0.529412	0.137255	-	-	-	-	0.0001	∞	f = 0.9928	1	
						2	67.8673	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	∞	f = 0.9928	1	
S22	04A20	6.25-liter core. 2% core expansion.	31.76	0.08834	1.2142	1	11.5057	0.31372	-	-	-	0.529412	0.137255	-	-	-	-	0.0001	∞	f = 0.9880	1	
						2	56.4331	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	0.0001	∞	f = 0.9880	1	
S23	04A21	PBR. Na density change.	445.8	0.01642	1.8920	1	57.59	0.03511	-	0.28489	-	0.623455	0.14	-	-	-	-	0.0001	∞	f = 1.0034	1	
						2	102.59	-	0.0014	0.6986	-	0.230909	0.1	-	-	-	-	0.0001	∞	f = 1.0034	1	
S24	04A22	PPB. Na density change.	82.68	0.04934	1.4175	1	22.85	0.10425	-	0.21575	-	0.623455	0.14	-	-	-	-	0.0001	∞	f = 1.0067	1	
						2	67.85	-	0.0014	0.6986	-	0.230909	0.1	-	-	-	-	0.0001	∞	f = 1.0067	1	
S25	04A23	6.25-liter core. Na density change.	31.76	0.08421	1.2270	1	11.43	0.32	-	-	-	0.623455	0.14	-	-	-	-	0.0001	∞	f = 1.0003	1	
						2	56.43	-	0.0014	0.6986	-	0.230909	0.1	-	-	-	-	0.0001	∞	f = 1.0003	1	
S26	04A25	Reference composition. 30-cm bare core.	339.3	0.6010	3.2882	1	30	0.18902	-	0.13098	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	1	
S27	04A26	Reference composition. 40-cm bare core.	414.6	0.5425	3.2880	1	40	0.09746	-	0.22254	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	1	
S28	04A27	Reference composition. 60-cm bare core.	671.4	0.4058	3.2882	1	60	0.04676	-	0.27324	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	1	
S29	04A28	Reference composition. 80-cm bare core.	1121.5	0.2927	3.2879	1	80	0.03295	-	0.28705	-	0.54	0.14	-	-	-	-	0.0001	0.0001	C	1	
S30	04A30	30-cm bare core. Neutron lifetime.	339.3	0.5987	3.2871	1	30	0.18902	-	0.13098	-	0.54	0.14	0.002	-	-	-	0.0001	∞	f = 0.9945	1	
S31	04A31	40-cm bare core. Neutron lifetime.	414.6	0.5385	3.2877	1	40	0.09746	-	0.22254	-	0.54	0.14	0.002	-	-	-	0.0001	∞	f = 0.9885	1	
S32	04A32	60-cm bare core. Neutron lifetime.	671.4	0.3994	3.2863	1	60	0.04676	-	0.27324	-	0.54	0.14	0.002	-	-	-	0.0001	∞	f = 0.9757	1	
S33	04A33	80-cm bare core. Neutron lifetime.	1121.5	-	-	1	80	0.03295	-	0.28705	-	0.54	0.14	0.002	-	-	-	0.0001	∞	f = 0.9671	1	
S34	04A34	EBR.	61.64*	0.08967	1.3459	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	0.0001	C	1	
						2	23	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	-	-	-	0.1507		
						3	40	-	0.006	0.821	0.011	-	-	-	-	-	-	-	0.1495			
						4	100	-	-	-	-	-	-	-	-	1	-	0				
S35	04A35	EBR. Pu ²³⁹ loading.	34.64	0.1071	1.2612	1	11.5	0.34256	-	-	0.18690	0.10959	-	-	0.36092	-	-	0.001	0.001	C	1	
						2	23	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	-	-	-	0.1877		
						3	40	-	0.006	0.821	0.011	-	-	-	-	-	-	-	0.1824			
						4	100	-	-	-	-	-	-	-	-	1	-	0				
S36	04A36	EBR. B ¹⁰ control.	61.64*	0.08851	1.3613	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9884	1	
						2	13.5	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	0.03	-	-	0.0328		
						3	23	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	-	-	-	0.1169		
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-	-	0.1504			
						5	100	-	-	-	-	-	-	-	-	1	-	0				

*M(U²³⁵)

UNIVAC		Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary, cm	Material Volume Fractions										Reactivity	S		
Argonne Prob. No.	Tape Prob. No.							Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	I/v	K	C	B ¹⁰			∅	ε
SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)																					
S37	04A37	EBR. Without outer graphite.	62.33*	0.2687	1.3546	1	11.5	-	0.52233	0.03334	0.12632	0.07407	-	-	0.24394	-	-	0.001	0.001	C	1
						2	23	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	-				0.1487
						3	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1067
S38	04B30	EBR. Mixed U ²³⁵ and Pu ²³⁹ fuel.	13.78, 37.44*	0.09685	1.3033	1	11.5	0.13627	0.31373	-	0.1564	0.0917	-	-	0.3019	-	-	0.001	0.001	C	1
						2	23	-	0.0035	0.4865	0.175	0.078	-	-	0.257	-	-				0.1660
						3	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1627
						4	100	-	-	-	-	-	-	-	-	1	-				0
S39	04B39	EBR. U ²³⁸ →Pu ²³⁹ outside core.	61.64*	0.10175	1.3222	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 1.0329	1
						2	13.5	0.1	0.0035	0.3565	0.175	0.078	-	-	0.257	-	-				0.1482
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1255
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1681
						5	100	-	-	-	-	-	-	-	-	1	-				0
S40	04B40	EBR. U ²³⁸ →U ²³⁵ outside core.	61.64*	0.09908	1.335	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 1.0185	1
						2	13.5	-	0.1035	0.3565	0.175	0.078	-	-	0.257	-	-				0.1169
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1220
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1654
						5	100	-	-	-	-	-	-	-	-	1	-				0
S41	04B41	EBR. U ²³⁸ →void outside core.	61.64*	0.09620	1.3639	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9805	1
						2	13.5	-	0.0035	0.3565	0.175	0.078	-	-	0.257	-	-				0.02674
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1204
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1666
						5	100	-	-	-	-	-	-	-	-	1	-				0
S42	04B42	EBR. U ²³⁸ →Ti outside core.	61.64*	0.09484	1.3600	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9850	1
						2	13.5	-	0.0035	0.3565	0.175	0.0758	0.1	-	0.257	-	-				0.0265
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1177
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1631
						5	100	-	-	-	-	-	-	-	-	1	-				0
S43	04B43	EBR. U ²³⁸ →NaK outside core	61.64*	0.09590	1.3628	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9818	1
						2	13.5	-	0.0035	0.3565	0.175	0.1013	-	-	0.3337	-	-				0.0267
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1197
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1657
						5	100	-	-	-	-	-	-	-	-	1	-				0
S44	04B44	EBR. U ²³⁸ →Fe outside core.	61.64*	0.09412	1.3570	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9882	1
						2	13.5	-	0.0035	0.3565	0.275	0.078	-	-	0.257	-	-				0.0264
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1161
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1610
						5	100	-	-	-	-	-	-	-	-	1	-				0
S45	04B45	EBR. U ²³⁸ →C outside core.	61.64*	0.09448	1.3561	1	11.5	-	0.51655	0.03297	0.12807	0.07510	-	-	0.24731	-	-	0.0001	∞	f = 0.9874	1
						2	13.5	-	0.0035	0.3565	0.175	0.078	-	-	0.257	-	-				0.0266
						3	23	-	0.0035	0.4565	0.175	0.078	-	-	0.257	-	-				0.1177
						4	40	-	0.006	0.821	0.011	-	-	-	-	-	-				0.1625
						5	100	-	-	-	-	-	-	-	-	1	-				0
S46	04A94	Los Alamos PPC mockup.	93.4*	0.3580	1.387	1	19.31	-	0.1654	0.1406	0.145	1	-	-	-	-	-	0.001	∞	f = 0.9341	1
						2	34.5	-	0.0072	0.9928	-	-	-	-	-	-	-				0.2509
S47	04B02	15-cm U bare core.	154.8*	-	-	1	15	-	0.58473	0.41517	-	-	-	-	-	-	-	0.0001	0.0001	C	1
S48	04B04	30-cm U bare core.	320.0*	-	-	1	30	-	0.15106	0.84884	-	-	-	-	-	-	-	0.0001	0.0001	C	1
S49	04B05	50-cm U bare core.	881.9*	0.1718	3.2860	1	50	-	0.08993	0.91007	-	-	-	-	-	-	-	0.0001	0.0001	C	1

*M(U²³⁵)

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary, cm	Material Volume Fractions												δ	ε	Reactivity	S
								Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	I/v	K	C	B ¹⁰						
								SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)															
S50	04B07	15-cm U bare core. Neutron lifetime.	154.8*	0.5067	3.2849	1	15	-	0.58473	0.41517	-	-	-	0.01	-	-	-	0.0001	∞	f = 0.09886	1		
S51	04B09	30-cm U bare core. Neutron lifetime.	320.0*	0.3277	3.2838	1	30	-	0.15106	0.84884	-	-	-	0.005	-	-	-	0.0001	∞	f = 0.9805	1		
S52	04B10	50-cm U bare core. Neutron lifetime.	881.9*	0.1678	3.2742	1	50	-	0.08993	0.91007	-	-	-	0.005	-	-	-	0.0001	∞	f = 0.9707	1		
S53	04A78	Topsy.	16.10*	0.2859	1.3076	1	6.023	-	0.939	0.061	-	-	-	-	-	-	-	0.0001	∞	f = 0.8782	1		
						2	31	-	0.0072	0.9928	-	-	-	-	-	-	-				0.4420		
S54	04A79	Topsy. Neutron lifetime.	16.10*	0.2554	1.3210	1	6.023	-	0.939	0.061	-	-	-	0.01	-	-	-	0.0001	∞	f = 0.8607	1		
						2	31	-	0.0072	0.9928	-	-	-	0.01	-	-	-				0.4391		
S55	04B13	0.854 density en- riched U core, with natural U reflector.	19.72*	0.2872	1.2682	1	6.79	-	0.80276	0.05124	-	-	-	-	-	-	-	0.001	∞	f = 0.8910	1		
						2	31.2	-	0.0072	0.9928	-	-	-	-	-	-	-				0.4323		
S56	04B14	0.702 density en- riched U core, with natural U reflector.	25.33*	0.3016	1.2280	1	7.88	-	0.65988	0.04212	-	-	-	-	-	-	-	0.001	∞	f = 0.9028	1		
						2	31	-	0.0072	0.9928	-	-	-	-	-	-	-				0.4178		
S57	04B15	0.5 density enriched U core, with natural U reflector.	36.87*	0.3451	1.1705	1	10	-	0.47	0.03	-	-	-	-	-	-	-	0.001	∞	f = 0.9073	1		
						2	30.6	-	0.0072	0.9928	-	-	-	-	-	-	-				0.4061		
S58	04B16	0.805 enriched U core with natural U reflector.	18.32*	-	-	1	6.62	-	0.805	0.195	-	-	-	-	-	-	-	0.001	∞	f = 0.8936	1		
						2	31	-	0.0072	0.9928	-	-	-	-	-	-	-				-		
S59	04B17	0.676 enriched U core with natural U reflector.	20.72*	-	-	1	7.31	-	0.676	0.324	-	-	-	-	-	-	-	0.001	∞	f = 0.9014	1		
						2	31.1	-	0.0072	0.9928	-	-	-	-	-	-	-				-		
S60	04B18	0.473 enriched U core with natural U reflector.	27.06*	-	-	1	9	-	0.473	0.527	-	-	-	-	-	-	-	0.001	∞	f = 0.9151	1		
						2	30.9	-	0.0072	0.9928	-	-	-	-	-	-	-				-		
S61	04B19	Popsy	5.809	0.3405	1.2564	1	4.44	1	-	-	-	-	-	-	-	-	-	0.0001	∞	f = 0.8446	1		
						2	30.7	-	0.0072	0.9928	-	-	-	-	-	-	-				0.5854		
S62	04B20	Popsy. Neutron lifetime.	5.809	0.3037	1.2645	1	4.44	1	-	-	-	-	-	0.01	-	-	-	0.0001	∞	f = 0.8300	1		
						2	30.7	-	0.0072	0.9928	-	-	-	0.01	-	-	-				0.5794		
S63	04B21	Enriched U core with 4" Fe reflector.	26.48*	0.5888	1.5538	1	7.11	-	0.939	0.061	-	-	-	-	-	-	-	0.001	∞	f = 0.8572	1		
						2	20.11	-	-	-	1	-	-	-	-	-	-				0		
S64	04B22	Enriched U core with 2" C reflector.	29.61*	0.6415	1.7931	1	7.38	-	0.939	0.061	-	-	-	-	-	-	-	0.001	∞	f = 0.7654	1		
						2	14.38	-	-	-	-	-	-	-	-	1	-				0		
S65	04B23	Enriched U core with 6" C reflector.	21.85*	0.6252	1.4859	1	6.67	-	0.939	0.061	-	-	-	-	-	-	-	0.001	∞	f = 0.7917	1		
						2	23.67	-	-	-	-	-	-	-	-	1	-				0		
S66	04B24	Enriched U core with 17" C reflector.	17.21*	0.6043	1.2119	1	6.16	-	0.939	0.061	-	-	-	-	-	-	-	0.001	∞	f = 0.8172	1		
						2	51.16	-	-	-	-	-	-	-	-	1	-				0		
S67	04A38	Reference CONV	711.5*	0.01700	1.8367	1	57.59	-	0.04748	0.27252	-	0.54	0.14	-	-	-	-	0.001	0.001	C	1		
						2	102.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-				0.0789		

*M(235)

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary cm	Material Volume Fractions										Reactivity	S		
								Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	1/v	K	C	B ¹⁰			δ	ε
SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS(Cont'd.)																					
S68	04A39	Reference PPC.	150.3*	0.04844	1.3608	1	22.85	-	0.1606	0.1594	-	0.54	0.14	-	-	-	-	0.001	0.001	C	1
						2	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	-	0.1993
S69	04A40	Reference PPM.	25.38, 103.43*	0.04933	1.3729	1	22.85	0.032	0.1105	0.1775	-	0.54	0.14	-	-	-	-	0.001	0.001	C	1
						2	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	-	0.2017
S70	04A45	PBR outside core control U ²³⁵ →Pu ²³⁹	445.8	0.02029	1.8139	1	57.59	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 1.0124	1
						2	60.59	0.03	0.0014	0.6686	-	0.2	0.1	-	-	-	-	-	-	0.0919	
						3	102.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0659	
S71	04A46	PBR Outside core control U ²³⁸ →B ¹⁰	445.8	0.01676	1.9684	1	57.59	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 0.9875	1
						2	60.59	-	0.0014	0.6686	-	0.2	0.1	-	-	-	0.03	-	-	0.0254	
						3	102.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0527		
S72	04A43	PPB Outside core control U ²³⁸ →Pu ²³⁹	82.68	0.05565	1.3765	1	22.85	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 1.0312	1
						2	25.85	0.03	0.0014	0.6686	-	0.2	0.1	-	-	-	-	-	-	0.1482	
						3	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.1541	
S73	04A44	PPB Outside core control U ²³⁸ →B ¹⁰	82.68	0.05052	1.4375	1	22.85	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 0.9739	1
						2	25.85	-	0.0014	0.6686	-	0.2	0.1	-	-	-	0.03	-	-	0.0634	
						3	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.1457	
S74	04A41	PBR. Subdivided into ten regions.	445.8	0.01880	1.8780	1	11.518	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 0.9996	0.0140
						2	23.036	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.0935	
						3	34.554	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.2174	
						4	46.072	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.3248	
						5	57.59	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.3502	
						6	59.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0192	
						7	62.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0201	
						8	66.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0163	
						9	72.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0124	
						10	102.59	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0118	
S75	04A42	PPB. Subdivided into ten regions.	82.68	0.05503	1.4060	1	4.57	0.10425	-	0.215	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 0.9982	0.0111
						2	9.14	0.10425	-	0.215	-	0.54	0.14	-	-	-	-	-	-	0.0743	
						3	13.71	0.10425	-	0.215	-	0.54	0.14	-	-	-	-	-	-	0.1841	
						4	18.28	0.10425	-	0.215	-	0.54	0.14	-	-	-	-	-	-	0.3111	
						5	22.85	0.10425	-	0.215	-	0.54	0.14	-	-	-	-	-	-	0.4193	
						6	24.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0462	
						7	27.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0502	
						8	31.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0425	
						9	37.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0336	
						10	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	-	0.0343	
S76	04B65	PBR. Pu ²³⁹ removed and added to core in 2% core alloy burnup.	432.9	0.01926	1.8282	1	11.518	0.033223	-	0.28489	-	0.54	0.14	-	-	-	-	0.0001	∞	f = 0.9814	0.0137
						2	23.036	0.033320	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.0914	
						3	34.554	0.033591	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.2147	
						4	46.072	0.033972	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.3249	
						5	57.59	0.034430	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	0.3553	
						6	59.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	0.0198	
						7	62.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	0.0208	
						8	66.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	0.0169	
						9	72.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	0.0130	
						10	102.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	0.0127	
*M(U ²³⁵)																					

*M(U²³⁵)

Argonne Prob. No.	UNIVAC Tape Prob. No.	Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer Boundary, cm	Material Volume Fractions										Reactivity	S		
								Pu ²³⁹	U ²³⁵	U ²³⁸	Fe	Na	Ti	I/v	K	C	B ¹⁰			S	ε
								SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)													
S77	04866	PBR. Pu ²³⁹ added to blanket in 2% core alloy burnup.	445.8	0.02167	1.8453	1	11.518	0.03511	-	0.28489	-	0.54	0.14	-	-	-	0.0001	∞	f = 1.0095	0.0138	
						2	23.036	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	-	0.0921
						3	34.554	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	-	0.2149
						4	46.072	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	-	0.3238
						5	57.59	0.03511	-	0.28489	-	0.54	0.14	-	-	-	-	-	-	-	0.3555
						6	59.59	0.007959	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0312
						7	62.59	0.006580	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0341
						8	66.59	0.004948	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0288
						9	72.59	0.003190	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0223
						10	102.59	0.000636	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0174
S78	04867	PBR. Fission product capture in 2% core alloy burnup.	445.8	0.01898	1.8560	1	11.518	0.03511	-	0.28489	-	0.54	0.14	0.0001752	-	-	-	0.0001	∞	f = 0.9827	0.0139
						2	23.036	0.03511	-	0.28489	-	0.54	0.14	0.0001667	-	-	-	-	-	-	0.0927
						3	34.554	0.03511	-	0.28489	-	0.54	0.14	0.0001426	-	-	-	-	-	-	0.2163
						4	46.072	0.03511	-	0.28489	-	0.54	0.14	0.0001093	-	-	-	-	-	-	0.3248
						5	57.59	0.03511	-	0.28489	-	0.54	0.14	0.0000712	-	-	-	-	-	-	0.3523
						6	59.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0196
						7	62.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0205
						8	66.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0167
						9	72.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0128
						10	102.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0124
S79	04868	PBR. Fission product scattering in 2% core alloy burnup.	445.8	0.01874	1.8934	1	11.518	0.03511	-	0.28489	0.0014567	0.54	0.14	-	-	-	0.0001	∞	f = 0.9993	0.0191	
						2	23.036	0.03511	-	0.28489	0.0013853	0.54	0.14	-	-	-	-	-	-	-	0.0941
						3	34.554	0.03511	-	0.28489	0.0011858	0.54	0.14	-	-	-	-	-	-	-	0.2182
						4	46.072	0.03511	-	0.28489	0.0009084	0.54	0.14	-	-	-	-	-	-	-	0.3248
						5	57.59	0.03511	-	0.28489	0.0005919	0.54	0.14	-	-	-	-	-	-	-	0.3488
						6	59.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0190
						7	62.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0198
						8	66.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0161
						9	72.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0124
						10	102.59	-	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0120
S80	04869	PBR. All long term effects in 2% core alloy burnup.	432.9	0.02229	1.7654	1	11.518	0.033223	-	0.28489	0.0014567	0.54	0.14	0.0001752	-	-	-	0.0001	∞	f = 0.9739	0.0132
						2	23.036	0.033320	-	0.28489	0.0013853	0.54	0.14	0.0001667	-	-	-	-	-	-	0.0889
						3	34.554	0.033591	-	0.28489	0.0011858	0.54	0.14	0.0001426	-	-	-	-	-	-	0.2107
						4	46.072	0.033972	-	0.28489	0.0009084	0.54	0.14	0.0001093	-	-	-	-	-	-	0.3240
						5	57.59	0.034430	-	0.28489	0.0005919	0.54	0.14	0.0000712	-	-	-	-	-	-	0.3633
						6	59.59	0.007959	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0327
						7	62.59	0.006580	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0359
						8	66.59	0.004948	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0305
						9	72.59	0.003190	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0236
						10	102.59	0.000636	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0188
S81	04871	PBR. All effects assuming uniform core changes in 2% core alloy burnup.	432.92	0.02195	1.8451	1	11.518	0.034096	-	0.28489	0.007540	0.54	0.14	0.000907	-	-	-	0.0001	∞	f = 0.9801	0.0158
						2	23.036	0.034096	-	0.28489	0.007540	0.54	0.14	0.000907	-	-	-	-	-	-	0.0921
						3	34.554	0.034096	-	0.28489	0.007540	0.54	0.14	0.000907	-	-	-	-	-	-	0.2149
						4	46.072	0.034096	-	0.28489	0.007540	0.54	0.14	0.000907	-	-	-	-	-	-	0.3237
						5	57.59	0.034096	-	0.28489	0.007540	0.54	0.14	0.000907	-	-	-	-	-	-	0.3555
						6	59.59	0.007959	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0321
						7	62.59	0.006580	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0351
						8	66.59	0.004948	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0289
						9	72.59	0.003190	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0233
						10	102.59	0.000636	0.0014	0.6986	-	0.2	0.10	-	-	-	-	-	-	-	0.0183

Argonne Tape		UNIVAC		Problem Description	M(Pu ²³⁹)	E	R	Re- gion	Outer boundary, cm	Material Volume fractions										Reactivity	S
Prob. No.	Prob. No.	Pu ²³⁹	U ²³⁵							U ²³⁸	Fe	Na	Ti	I/v	K	C	β ¹⁰				
SPHERICAL GEOMETRY - TEN-GROUP CROSS SECTIONS (Cont'd.)																					
S82	04860	PPB, Pu ²³⁹ removed in 2% core alloy burnup.	76.87	0.05751	1.3625	1	4.57	0.094322	-	0.21575	-	0.54	0.14	-	-	-	0.0001	f	0.9586	0.0108	
						2	9.14	0.094753	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.0725		
						3	13.71	0.095535	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.1814		
						4	18.28	0.096603	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.3104		
						5	22.85	0.097861	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.4249		
						6	24.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0493		
						7	27.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0538		
						8	31.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0458		
						9	37.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0366		
						10	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0377		
S83	04861	PPB, Pu ²³⁹ added to blanket in 2% core alloy burnup.	82.68	0.05759	1.3985	1	4.57	0.10425	-	0.21575	-	0.54	0.14	-	-	-	0.0001	f = 1.0067	0.0111		
						2	9.14	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.0790		
						3	13.71	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.1836		
						4	18.28	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.3109		
						5	22.85	0.10425	-	0.21575	-	0.54	0.14	-	-	-	-	-	0.4205		
						6	24.85	0.003481	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0530		
						7	27.85	0.002946	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0591		
						8	31.85	0.002239	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0516		
						9	37.85	0.001433	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0414		
						10	67.85	0.000241	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0384		
S84	04862	PPB, Fission product capture in 2% core alloy burnup.	82.68	0.05515	1.4041	1	4.57	0.10425	-	0.21575	-	0.54	0.14	0.0012125	-	-	-	0.0001	f = 0.9934	0.0111	
						2	9.14	0.10425	-	0.21575	-	0.54	0.14	0.0011573	-	-	-	-	-	0.0742	
						3	13.71	0.10425	-	0.21575	-	0.54	0.14	0.0010559	-	-	-	-	-	0.1840	
						4	18.28	0.10425	-	0.21575	-	0.54	0.14	0.0009151	-	-	-	-	-	0.3111	
						5	22.85	0.10425	-	0.21575	-	0.54	0.14	0.0007467	-	-	-	-	-	0.4196	
						6	24.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0465		
						7	27.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0505		
						8	31.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0428		
						9	37.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0339		
						10	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0345		
S85	04863	PPB, Fission product scattering in 2% core alloy burnup.	82.68	0.05983	1.4118	1	4.57	0.10425	-	0.21575	0.010079	0.54	0.14	-	-	-	-	0.0001	f = 0.9992	0.0112	
						2	9.14	0.10425	-	0.21575	0.009620	0.54	0.14	-	-	-	-	-	0.0746		
						3	13.71	0.10425	-	0.21575	0.008777	0.54	0.14	-	-	-	-	-	0.1845		
						4	18.28	0.10425	-	0.21575	0.007607	0.54	0.14	-	-	-	-	-	0.3112		
						5	22.85	0.10425	-	0.21575	0.006207	0.54	0.14	-	-	-	-	-	0.4185		
						6	24.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0459		
						7	27.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0499		
						8	31.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0422		
						9	37.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0334		
						10	67.85	-	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0341		
S86	04864	PPB, All long term effects in 2% core alloy burnup.	77.95	0.05956	1.3650	1	4.57	0.096069	-	0.21575	0.010079	0.54	0.14	0.0012125	-	-	-	0.0001	f = 0.9707	0.0108	
						2	9.14	0.096431	-	0.21575	0.009620	0.54	0.14	0.0011573	-	-	-	-	-	0.0726	
						3	13.71	0.097092	-	0.21575	0.008777	0.54	0.14	0.0010559	-	-	-	-	-	0.1814	
						4	18.28	0.098004	-	0.21575	0.007607	0.54	0.14	0.0009151	-	-	-	-	-	0.3104	
						5	22.85	0.099083	-	0.21575	0.006207	0.54	0.14	0.0007467	-	-	-	-	-	0.4248	
						6	24.85	0.003481	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0557		
						7	27.85	0.002946	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0624		
						8	31.85	0.002239	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0546		
						9	37.85	0.001433	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0442		
						10	67.85	0.000241	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0415		
S87	04870	PPB, All effects assuming uniform core changes in 2% core alloy burnup.	77.95	0.05942	1.3975	1	4.57	0.098291	-	0.21575	0.007234	0.54	0.14	0.0008703	-	-	-	0.0001	f = 0.9724	0.0111	
						2	9.14	0.098291	-	0.21575	0.007234	0.54	0.14	0.0008703	-	-	-	-	-	0.0740	
						3	13.71	0.098291	-	0.21575	0.007234	0.54	0.14	0.0008703	-	-	-	-	-	0.1555	
						4	18.28	0.098291	-	0.21575	0.007234	0.54	0.14	0.0008703	-	-	-	-	-	0.3109	
						5	22.85	0.098291	-	0.21575	0.007234	0.54	0.14	0.0008703	-	-	-	-	-	0.4206	
						6	24.85	0.003481	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0555		
						7	27.85	0.002946	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0621		
						8	31.85	0.002239	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0545		
						9	37.85	0.001433	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0441		
						10	67.85	0.000241	0.0014	0.6986	-	0.2	0.1	-	-	-	-	-	0.0413		