CHARACTERIZATION OF THE POWER IN AN EXPERIMENTAL IRRADIATION
SUBASSEMBLY OF MIXED-OXIDE FUEL IN EBR-II

by

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ABSTRACT

Detailed transport analyses were carried out to determine the neutron and γ flux and the isotopic fission rates in EBR-II for run 48E, in which the experimental irradiation subassembly, X108, was irradiated. These results were used to compute the axial power distribution in each of the 19 experimental fuel pins in subassembly X108. Local and global variations in the neutron and gamma flux as well as transient effects were taken into consideration in the calculations.

I. INTRODUCTION

Since 1969, methods have been adapted, developed, and tested by the EBR-II Project to analyze the detailed spatial variations in neutron and gamma flux that occur in heterogeneous fast reactors for application in characterizing the irradiation environment in EBR-II.

Experimental irradiation subassembly X108 was irradiated in run 48E to determine the effect of fuel-cladding gap on the heat rating required to cause incipient fuel melting in mixed-oxide fuel elements. The subassembly, a standard Mark-A19 type, contained 19 fuel elements composed of 25% plutonium oxide and 75% uranium oxide. The uranium was enriched to 93% ^{235}U and the plutonium was enriched to 88% ^{239}Pu and ^{241}Pu .

The subassembly was loaded into position 2B1 in the EBR-II reactor grid. The reactor was brought up to power over a four-hour period and held at 62.5 MWt for about 11 min. The subassembly was then removed from the reactor, disassembled, and returned to the experimenter (HEDL) for examination and evaluation.

To evaluate and interpret the results from the experiment, the power in each of the 19 elements of the subassembly was predicted. The most sophisticated calculational techniques available were applied to determine the power in each element as accurately as possible, because errors in element power significantly affect estimates of linear heat rating for melting and subsequent determination of gap conductances. Neutron- and gamma-transport analyses were carried out with the exact composition and position of each subassembly in run 48E taken into consideration. The accumulated burnup in each subassembly was considered in determining the atom densities used in the calculation. Global flux tilt, local flux depressions, and central flux peaking are all included in the transport-theory analysis. Decay of γ precursors between the shutdown of run 48D and the start of run 48E, and buildup of these precursors during run 48E, were considered in a separate transient analysis.

The axial power distribution in each of the 19 fuel elements was carefully determined from the results of the neutron- and γ -transport analysis. These power distributions are given in Section V.

II. NEUTRON-TRANSPORT CALCULATIONS

The basis for determining the power in subassembly X108 was a detailed transport analysis of the neutron and γ flux in run 48E.

Detailed spatial analysis has been carried out for previous loadings of the extremely heterogeneous core of EBR-II with considerable success, as indicated by comparison of theoretical results with empirical values of space-dependent fission rates and control-rod worths. The precise geometry and atomic densities of the reactor are used in the mathematical model for the transport analysis, except that the hexagonal fuel elements are approximated as rectangles. The exact weights of fissile and fertile isotopes in each subassembly of the reactor are determined at the time of fabrication. Changes in isotopic abundance due to burnup are accounted for, and the precise atom densities in each subassembly are used to define a detailed mathematical model of the core.

The arrangement of the core in run 48E is shown in Fig. 1. Two-dimensional, XY-geometry, 29-group, transport-theory calculations were

B — DEPLETED URANIUM
 BETH — BERYLLIUM THIMBLE
 C — CONTROL ROD
 D — DRIVER FUEL
 MK-II — Mark-II FUEL

OSC — OSCILLATOR ROD
 P — 1/2 DRIVER FUEL -- 1/2 STAINLESS STEEL
 S — SAFETY ROD
 SSCR — STAINLESS STEEL CONTROL ROD
 SSTH — STAINLESS STEEL THIMBLE

— EXPERIMENTAL SUBASSEMBLY

Fig. 1. Loading Pattern for Run 48E

performed to obtain the relative distribution of flux and fission rate as a function of space and energy in this core loading at the reactor midplane. The 29-group cross sections used in the calculation were generated by using the MC² code and ENDF/B (Version I) cross-section data.

The axial power distribution was determined by performing a two-dimensional transport-theory calculation in which the independent variables were the radial and axial distances from the core center. The geometric model for this representation of the EBR-II core is shown in Fig. 2. For this calculation, the subassemblies in each row of the reactor were homogenized, and azimuthal symmetry was assumed. This RZ calculation determined the fission rate in the three-dimensional reactor with azimuthal symmetry and an arbitrary power level being assumed. The fission rate was integrated over the reactor volume and the total power generated at the arbitrary level of the calculation was determined by using 202.6 MeV per fission as the total energy deposited in the reactor per fission. This value includes the energy produced as the result of neutron capture and subsequent γ emission but excludes neutrino energy. The fission-rate distribution is then renormalized to correspond to a total reactor power of 62.5 MWt.

The normalized fission rate was integrated over a 1-cm height at the reactor midplane. The fission-rate distribution computed in the XY analysis was then integrated over the reactor midplane and renormalized so that the integral of the fission rate from the XY problem agrees with the integral of the fission rate over the reactor midplane of the correctly normalized R,Z fission distribution. The neutron fluxes and the fission rates of the individual isotopes were then normalized to correspond to a reactor power of 62.5 MWt by using the normalization factors computed on the basis of the total fission rates.

Four mesh points were used in each subassembly in the XY representation. The fission rates at other points in the subassembly were then determined from the fission rates at the mesh points. Figure 3 shows the fission rate of ²³⁵U at each of the mesh points in subassembly X108 and the six surrounding subassemblies. The fission rates for ²³⁸U, ²³⁹Pu, and ²⁴⁰Pu are similarly shown in Figs. 4, 5, and 6. Figure 7 shows axial variations of the fission rates in ²³⁵U, ²³⁸U, ²³⁹Pu, and ²⁴⁰Pu in row 2 of EBR-II. In

1 BLANKET	4 - 9 CORE, ROWS 1-6
2 LOWER REFLECTOR	10 - 15 PIN TOPS, ROWS 1-6
3 PIN GRID	16 - 21 UPPER REFLECTOR, ROWS 1-6
22 - 27 INNER BLANKET	

Fig. 2. Geometric Model of EBR-II for Two-dimensional R,Z Calculations

	4.43	4.51	4.52	4.46	
	4.61	4.69	4.71	4.68	
4.60	4.73	4.78	4.80	4.80	4.72
4.68	4.82	4.87	4.90	4.89	4.78
	4.87	4.98	5.01	4.94	
	4.84	4.96	5.01	4.95	

Fig. 3. Fission Rate (fissions per atom of $^{235}\text{U} \times 10^{-9}$) in Subassembly X108 and the Six Surrounding Subassemblies in Run 48E

	3.00	3.03	2.92	2.76	
	3.07	3.09	3.04	3.03	
3.13	3.12	2.92	2.89	3.06	3.11
3.18	3.15	2.94	2.93	3.04	2.96
	3.17	3.19	3.20	3.00	
	3.02	3.06	3.12	2.97	

Fig. 4. Fissions per Atom of $^{238}\text{U} (x 10^{-10})$ in Subassembly X108 and the Six Surrounding Subassemblies in Run 48E

	5.26	5.35	5.33	5.24	
	5.46	5.56	5.57	5.52	
5.46	5.61	5.63	5.64	5.67	5.59
5.56	5.71	5.73	5.76	5.76	5.63
	5.77	5.88	5.91	5.81	
	5.71	5.83	5.90	5.82	

Fig. 5. Fissions per Atom of ^{239}Pu ($\times 10^{-9}$) in Subassembly X108 and the Six Surrounding Subassemblies in Run 48E

	2.13	2.16	2.12	2.05	
	2.20	2.23	2.22	2.20	
2.21	2.25	2.21	2.20	2.25	2.24
2.25	2.28	2.24	2.24	2.27	2.20
	2.30	2.34	2.35	2.27	
	2.24	2.29	2.32	2.26	

Fig. 6. Fissions per Atom of ^{240}Pu ($\times 10^{-9}$) in Subassembly X108 and the Six Surrounding Subassemblies in Run 48E

Fig. 7. Axial Variation of Fission Rates in Row 2 of EBR-II

Fig. 7, X is the distance above the bottom of the core and l is the axial length of the core. These fission-rate distributions formed the basis for characterizing the power distribution in the individual fuel elements in X108, as described in Section V.

III. GAMMA-TRANSPORT CALCULATIONS

It can often be assumed in reactor-design calculations that the energy released in fission is converted to heat at the point of fission. However, because the power in subassembly X108 must be determined as accurately as possible, γ transport and the emission absorption of γ rays far from the point of fission had to be considered. Transport-theory methods were applied to determine the distribution of γ rays and γ deposition in the reactor loading for run 48E. By using the neutron-flux distribution computed as described in Section II, the rate of production of γ rays by fission, neutron capture, inelastic scattering of neutrons, and decay of fission products was calculated as a function of subassembly position in run 48E. Then, a photon-transport calculation was performed with the known rate of production of γ rays as a function of space being used as a fixed-source input to the calculation. Finally, the rate of heat production was determined by multiplying the photon-flux vector at each space point by the cross-section vector for γ -energy absorption. The distributions of rates of γ -heat production were normalized by requiring that the total γ energy deposited in the reactor per second equal the total energy of all the γ rays produced in the reactor per second. The correctly normalized γ -heating rate in each subassembly in run 48E is shown in Fig. 8. These rates were computed by assuming that the reactor had reached steady state with respect to concentration of delayed- γ precursors. The effect of the buildup and decay of these precursors is discussed in Section IV.

IV. TRANSIENT EFFECTS

In run 48E the reactor was at full power only about 11 min. Therefore, the fission products that emit β and γ rays from 10^1 to 10^5 min after fission did not reach equilibrium concentration during the run. The effect

Fig. 8. Rates of Gamma-energy Deposition in Run 48E, W/cm³

of the transient character of the concentration of β and γ emitters was determined from the analytical formulas derived in this section.

After a scram following infinite reactor operating time, the fraction of steady-state power due to β and γ emission ($P_{\beta\gamma}$) remaining at time, $t(\text{hr})$, after shutdown may be represented as

$$P_{\beta\gamma}(-\infty, 0) = ae^{-\lambda t}, \quad (1)$$

where $a = 0.3$ and $\lambda = 1.609$ for $10^{-4} \text{ hr} < t < 0.35 \text{ hr}$; and
 $a = 1.0$ and $\lambda = 2.813$ for $0.35 \text{ hr} < t < 10 \text{ hr}$.

If the reactor is operated at constant power from time $t = -T_1$ to $t = 0$ and then scrammed, the fraction of steady-state β and γ power remaining at time $t(\text{hr})$ after the scram is

$$P_{\beta\gamma}(-T_1, 0) = aP_0[e^{-\lambda t} - e^{-\lambda(t+T_1)}], \quad (2)$$

where P_0 is the fraction of full power at which the reactor is operated. As $T_1 \rightarrow 0$, Eq. (2) reduces to

$$P_{\beta\gamma}(-T_1, 0) = aP_0[1 - e^{-\lambda T_1}]e^{-\lambda t} = aP_0[\lambda T_1]e^{-\lambda t}. \quad (3)$$

If the reactor is operated at variable power $P(t)$, where P is the fraction of steady-state power, for the time $t = -T_2$ to $t = -T_1$, and then scrammed, the fraction of steady-state β and γ power at time t is

$$P_{\beta\gamma}(-T_2, -T_1) = \int_{-T_2}^{-T_1} P(\tau) a\lambda e^{-\lambda(t-\tau)} d\tau = \int_{T_2}^{T_1} P(\tau) a\lambda e^{-\lambda(t+\tau)} d\tau \quad (4)$$

In the special case in which power is increased linearly with time,

$$P(t) = P_0 + bt, \quad (5)$$

Eq. (4) reduces to

$$\begin{aligned} P_{\beta\gamma}(-T_2, -T_1) &= \int_{T_2}^{T_1} (P_0 + b\tau) \lambda e^{-\lambda(t+\tau)} d\tau \\ &= \left[P_0 a - \frac{ab}{\lambda} (\lambda\tau + 1) \right] e^{-\lambda(t+\tau)} \bigg|_{T_2}^{T_1}. \end{aligned} \quad (6)$$

The power history during the irradiation of subassembly X108 consisted of approximately linear increases to constant power levels. The power history can be divided into four domains described by the following equations:

- (1) $P(t) = 0.112 t$ for $-9.1 < t < -1.35$ hr
- (2) $P(t) = 0.872$ for $-1.35 < t < -0.35$ hr
- (3) $P(t) = 0.872 + 0.83t$ for $-0.35 < t < -0.2$ hr
- (4) $P(t) = 1.0$ for $-0.2 < t < 0$

The β and γ power in X108 continued to build up until reactor shutdown.

The fraction of steady-state β and γ power in X108 at the time of shutdown due to each of the four reactor operating power domains can be calculated separately as follows:

- (1) $P(t) = 0.112t$ for $-9.1 < t < -1.35$ hr

The values of the symbols in Eq. (6) are:

$a = 1.0$, $b = 0.112$, $\lambda = 2.813$, $t = 0$, $T_1 = 1.35$, $T_2 = 9.1$; therefore,

$$P_{\beta\gamma}(-9.1, -1.35) = 0.0043.$$

- (2) $P(t) = 0.872$

The values of the symbols in Eq. (2) are:

$a = 1.0$, $\lambda = 2.813$, $t+T_1 = 1.35$, $t = 0.35$, $P_0 = 0.872$; therefore

$$P_{\beta\gamma}(-1.35, -0.35) = 0.306.$$

- (3) $P(t) = 0.872 + 0.83t$

The values of the symbols in Eq. (6) are:

$a = 0.3$, $\lambda = 1.609$, $P_0 = 0.872$, $b = 0.83$, $T_1 = 0.2$, $T_2 = 0.35$, $t = 0$; therefore

$$P_{\beta\gamma}(-0.35, -0.2) = 0.030.$$

- (4) $P(t) = 1$

The values of the symbols in Eq. (2) are:

$a = 0.3$, $\lambda = 1.609$, $T_1 = 0.2$, $t = 0$

Therefore, $P_{\beta\gamma}(-0.2, 0) = 0.083$.

The fraction of steady-state β and γ power that was reached in subassembly X108 at the time of shutdown is the total of the fractions due to

the four power-history domains, i.e., total $P_{\beta\gamma} = 0.0043 + 0.306 + 0.030 + 0.083 = 0.41$.

The delayed- γ emitters contribute 7.2 MeV per fission to the total reactor power. However, a subassembly of highly enriched fuel in EBR-II does not absorb as much γ energy per fission as it produces. The production rate is approximately proportional to the total number of fissile and fertile atoms. A subassembly of 90%-enriched fuel in the 52%-enriched core, therefore, absorbs only 5/9 of the γ energy it produces.

The β energy, on the other hand, remains in the subassembly where it was produced because of the short range of β particles.

Subassembly X108, therefore, would absorb 3.9 MeV per fission of delayed- γ energy and 7.0 MeV per fission of delayed- β energy during steady-state operation. At the end of run 48E, 59% of this total energy, or 6.4 MeV/fission, was not present, as shown above. This energy is equivalent to 3.3% of the total power in X108.

The same effect occurs in the reactor as a whole. The delayed- β and γ energy present at the end of run 48E was 41% of the steady-state value. The fraction of the steady-state delayed- β and γ energy not present was equivalent to 14.2 MeV/fission, or 4.1% of the total reactor power.

Reactor power, however, is maintained by measuring thermal power, not neutron flux. The fraction of power due to delayed- β and γ radiation that is not present is automatically compensated for by an increase in the neutron-flux level. This level was, therefore, 4.1% higher than it would have been during steady-state operation at full power.

The transient effect in subassembly X108 was a 4.1% increase in the fission rate accompanied by a 3.3% decrease in the energy absorbed per fission. The net transient effect was, therefore, to increase the power production in subassembly X108 by 0.8%.

V. CHARACTERIZATION OF POWER IN INDIVIDUAL FUEL ELEMENTS

The hexagonal subassemblies in EBR-II were represented as rectangles for the transport calculations, as shown in Fig. 9. The four mesh points

Fig. 9. Rectangular Representation of EBR-II Hexagon

in the subassembly at which the fission rates are calculated are shown in Fig. 9 along with the positions of the 19 fuel elements in subassembly X108. The fission rates in the elements were determined by interpolating between the fission rates computed at the four points in X108 and the eight nearest points in the six surrounding subassemblies, parts of which are shown.

Each element was arbitrarily subdivided into 20 axial nodes of equal height, and the weight of each isotope associated with each node was calculated from the isotopic weights in each element, supplied by HEDL, as given in Table I. The power in each node was then calculated by the following equation:

$$P_j = C \sum_i W_{ij} N_i F_i A_{ij},$$

where

P_j = power in node j (Btu/hr)

C = 3.246×10^{-11} W-sec/fission

W_{ij} = weight of isotope i in node j (g in Table I)

N_i = atoms/g of isotope i

F_i = fissions/atom of isotope i at core midplane/sec

A_{ij} = ratio of fission rate of isotope i at node j to fission rate of isotope i at midplane.

The number of ^{235}U fissions per second at each axial node of elements 1-19 is shown in column 2 of Table II, which also shows, in columns 3, 4, and 5, the number of fissions due to ^{238}U , ^{239}Pu , and ^{240}Pu . The total number of fissions per second and the total power at each axial node of elements 1-19 are shown in columns 6 and 7, respectively.

The conversion factor from total fissions to power was determined by combining the steady-state rate of power production in one element due to deposition of fission-fragment and neutron kinetic energy, β -particle energy, and γ energy. The total power produced from these sources was 193 MeV per fission, which is less than the energy per fission deposited in the reactor (202.6 MeV/fission) because some of the energy deposited in the reactor comes from neutron capture in the blanket and because highly enriched fuel elements, such as those in subassembly X108, produce more gamma energy than they absorb, as explained in Section IV.

TABLE I. Fissile Content of Elements in Subassembly X108^a

Element No.	Content, g						
	Pu	²³⁹ Pu	²⁴⁰ Pu	²⁴¹ Pu	U	²³⁵ U	²³⁸ U
P-19-1R	13.284	11.466	1.525	0.260	40.276	37.509	2.376
2	13.570	11.712	1.558	0.266	41.142	38.316	2.427
3R	16.237	14.014	1.864	0.318	49.082	45.700	2.945
5	14.022	12.102	1.610	0.275	42.515	39.594	2.508
6	14.208	12.263	1.631	0.278	43.077	40.118	2.542
7R	16.933	14.615	1.944	0.332	51.185	47.658	3.071
8	13.382	11.550	1.536	0.262	40.572	37.785	2.394
9	13.920	12.014	1.598	0.273	42.205	39.306	2.490
11R	16.591	14.320	1.905	0.325	50.151	46.696	3.009
12R	17.261	14.898	1.982	0.338	52.179	48.584	3.131
13	13.760	11.876	1.580	0.270	41.720	38.854	2.435
14	14.409	12.436	1.654	0.282	43.687	40.686	2.578
15R	16.516	14.255	1.896	0.324	49.926	46.486	2.996
17R	16.256	14.031	1.866	0.319	49.139	45.753	2.948
18R	17.019	14.689	1.954	0.334	51.446	47.901	3.087
19R	17.277	14.012	1.983	0.339	52.172	48.577	3.130
20	13.404	11.569	1.539	0.263	40.640	37.848	2.398
21	13.648	11.780	1.567	0.268	41.381	38.538	2.415
22	14.012	12.094	1.609	0.275	42.483	39.564	2.506
23	14.157	12.219	1.625	0.277	42.924	39.975	2.533
24R	16.244	14.020	1.865	0.318	49.104	45.721	2.946
25R	16.574	14.305	1.903	0.325	50.101	46.649	3.006
26R	16.942	14.623	1.945	0.332	51.214	47.685	3.073
27R	17.353	14.977	1.992	0.340	52.456	48.842	3.147

^aData supplied by HEDL.

TABLE II. Power Distribution in Elements 1-19 of Subassembly X108

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
	<u>Element 1</u>					
1 ^a	19.05	0.053	6.24	0.271	25.61	2703.0
2	19.86	0.063	6.73	0.307	26.96	2845.0
3	20.55	0.071	7.09	0.344	28.06	2961.0
4	21.43	0.077	7.45	0.368	29.33	3095.0
5	22.07	0.083	7.55	0.395	30.10	3176.0
6	22.74	0.087	7.98	0.411	31.22	3294.0
7	23.28	0.090	8.19	0.424	31.98	3375.0
8	23.65	0.092	8.34	0.434	32.52	3431.0
9	23.89	0.093	8.45	0.439	32.87	3469.0
10	23.96	0.093	8.49	0.442	32.99	3481.0
11	23.92	0.093	8.48	0.441	32.93	3475.0
12	23.74	0.092	8.41	0.436	32.68	3448.0
13	23.40	0.091	8.30	0.430	32.22	3400.0
14	22.93	0.088	8.11	0.418	31.55	3329.0
15	22.32	0.085	7.87	0.405	30.68	3238.0
16	21.68	0.081	7.58	0.386	29.73	3137.0
17	20.94	0.076	7.25	0.363	28.63	3021.0
18	20.11	0.069	6.87	0.332	27.38	2889.0
19	19.25	0.061	6.46	0.300	26.07	2751.0
20	18.34	0.052	6.04	0.267	24.70	2606.0

^aBottom

Element 2

1	19.78	0.054	6.47	0.280	26.58	2805.0
2	20.62	0.064	6.97	0.317	27.97	2952.0
3	21.34	0.073	7.34	0.356	29.11	3072.0
4	22.26	0.079	7.70	0.380	30.42	3210.0
5	22.92	0.085	7.82	0.408	31.23	3296.0
6	23.61	0.089	8.27	0.425	32.39	3418.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
7	24.17	0.092	8.49	0.438	33.19	3502.0
8	24.55	0.094	8.64	0.448	33.73	3560.0
9	24.81	0.095	8.75	0.454	34.11	3599.0
10	24.88	0.096	8.80	0.456	34.23	3612.0
11	24.83	0.096	8.79	0.456	34.17	3606.0
12	24.65	0.094	8.72	0.451	33.92	3579.0
13	24.30	0.093	8.60	0.444	33.44	3529.0
14	23.81	0.091	8.41	0.432	32.74	3455.0
15	23.17	0.088	8.16	0.418	31.84	3360.0
16	22.51	0.083	7.86	0.400	30.85	3256.0
17	21.74	0.078	7.52	0.375	29.71	3136.0
18	20.88	0.071	7.12	0.344	28.42	2999.0
19	19.98	0.063	6.69	0.310	27.04	2853.0
20	19.04	0.054	6.26	0.276	25.63	2705.0

Element 3

1	22.61	0.063	7.43	0.323	30.43	3211.0
2	23.57	0.075	8.01	0.366	32.02	3379.0
3	24.39	0.085	8.44	0.410	33.33	3517.0
4	25.44	0.092	8.84	0.438	34.81	3684.0
5	26.20	0.099	8.99	0.470	35.76	3774.0
6	26.98	0.103	9.51	0.490	37.08	3913.0
7	27.63	0.107	9.75	0.505	37.99	4009.0
8	28.06	0.109	9.93	0.517	38.62	4076.0
9	28.36	0.110	10.06	0.524	39.05	4121.0
10	28.44	0.111	10.11	0.526	39.19	4136.0
11	28.39	0.111	10.10	0.526	39.13	4129.0
12	28.18	0.110	10.01	0.520	38.82	4097.0
13	27.77	0.108	9.88	0.512	38.27	4039.0
14	27.22	0.105	9.66	0.500	37.49	3956.0
15	26.49	0.102	9.37	0.482	36.44	3845.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
16	25.73	0.097	9.03	0.461	35.32	3727.0
17	24.86	0.091	8.64	0.432	34.02	3590.0
18	23.86	0.083	8.18	0.400	32.52	3432.0
19	22.84	0.073	7.69	0.358	30.96	3267.0
20	21.76	0.062	7.19	0.318	29.33	3095.0

Element 4

1	22.50	0.070	7.75	0.299	30.62	3231.0
2	23.46	0.083	8.36	0.339	32.24	3402.0
3	24.28	0.095	8.80	0.380	33.56	3541.0
4	25.32	0.103	9.22	0.406	35.05	3699.0
5	26.08	0.110	9.37	0.436	36.00	3799.0
6	26.86	0.115	9.91	0.454	37.34	3940.0
7	27.50	0.119	10.17	0.469	38.26	4037.0
8	27.93	0.122	10.36	0.479	38.89	4104.0
9	28.22	0.123	10.49	0.486	39.32	4149.0
10	28.31	0.124	10.54	0.488	39.46	4164.0
11	28.25	0.124	10.53	0.488	39.39	4157.0
12	28.05	0.122	10.44	0.482	39.09	4125.0
13	27.64	0.121	10.30	0.475	38.54	4067.0
14	27.09	0.117	10.08	0.462	37.75	3984.0
15	26.36	0.113	9.77	0.447	36.69	3872.0
16	25.61	0.108	9.42	0.427	35.57	3753.0
17	24.74	0.101	9.01	0.401	34.25	3614.0
18	23.75	0.092	8.53	0.367	32.74	3455.0
19	22.74	0.081	8.02	0.332	31.17	3289.0
20	21.66	0.069	7.50	0.295	29.52	3116.0

Table II (contd)

Table 11 (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
<u>Element 5</u>						
1	19.10	0.051	6.21	0.268	25.63	
2	19.92	0.060	6.70	0.304	26.98	2848.0
3	20.60	0.069	7.05	0.340	28.06	2961.0
4	21.49	0.074	7.39	0.364	29.32	3094.0
5	22.13	0.079	7.51	0.390	30.11	3177.0
6	22.80	0.083	7.94	0.406	31.23	3296.0
7	23.34	0.086	8.15	0.419	31.98	3374.0
8	23.71	0.088	8.30	0.429	32.53	3433.0
9	23.96	0.089	8.40	0.435	32.88	3470.0
10	24.03	0.090	8.45	0.437	33.01	3483.0
11	23.98	0.090	8.44	0.436	32.95	3477.0
12	23.81	0.089	8.37	0.431	32.70	3451.0
13	23.47	0.087	8.26	0.425	32.24	3402.0
14	23.00	0.085	8.07	0.414	31.57	3331.0
15	22.38	0.082	7.83	0.400	30.39	3207.0
16	21.74	0.078	7.55	0.383	29.75	3140.0
17	21.00	0.073	7.22	0.359	28.65	3024.0
18	20.16	0.066	6.84	0.329	27.40	2891.0
19	19.30	0.059	6.43	0.300	26.09	2753.0
20	18.39	0.050	6.01	0.264	24.71	2608.0
<u>Element 6</u>						
1	19.63	0.053	6.41	0.277	26.37	2783.0
2	20.47	0.063	6.91	0.315	27.76	2929.0
3	21.18	0.071	7.28	0.353	28.88	3048.0
4	22.09	0.077	7.63	0.377	30.17	3184.0
5	22.75	0.083	7.76	0.404	31.00	3271.0
6	23.43	0.087	8.20	0.421	32.14	3391.0
7	23.99	0.090	8.42	0.434	32.93	3475.0
8	24.37	0.092	8.57	0.444	33.48	3533.0
9	24.62	0.093	8.68	0.450	33.84	3571.0
10	24.70	0.094	8.72	0.453	33.97	3584.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
11	24.65	0.093	8.71	0.452	33.91	3578.0
12	24.47	0.092	8.64	0.447	33.65	3551.0
13	24.11	0.091	8.52	0.440	33.16	3499.0
14	23.63	0.089	8.34	0.428	32.49	3428.0
15	23.00	0.086	8.09	0.414	31.59	3334.0
16	22.34	0.082	7.80	0.396	30.62	3231.0
17	21.58	0.076	7.45	0.372	29.48	3111.0
18	20.72	0.070	7.06	0.341	28.19	2975.0
19	19.83	0.061	6.64	0.308	26.84	2832.0
20	18.90	0.052	6.21	0.273	25.44	2684.0

Element 7

1	23.38	0.066	7.66	0.335	31.44	3318.0
2	24.38	0.078	8.26	0.380	33.10	3493.0
3	25.22	0.089	8.70	0.426	34.44	3634.0
4	26.31	0.096	9.11	0.455	35.97	3796.0
5	27.09	0.103	9.26	0.488	36.94	3898.0
6	27.91	0.108	9.80	0.508	38.33	4045.0
7	28.57	0.112	10.05	0.525	39.26	4143.0
8	29.02	0.114	10.23	0.537	39.90	4211.0
9	29.32	0.116	10.36	0.544	40.34	4257.0
10	29.41	0.116	10.42	0.547	40.49	4273.0
11	29.35	0.116	10.41	0.546	40.42	4265.0
12	29.14	0.115	10.32	0.540	40.12	4234.0
13	28.72	0.113	10.18	0.532	39.55	4174.0
14	28.15	0.110	9.96	0.517	38.74	4088.0
15	27.39	0.106	9.66	0.501	37.66	3974.0
16	26.60	0.101	9.31	0.479	36.49	3851.0
17	25.70	0.095	8.90	0.449	35.14	3708.0
18	24.68	0.086	8.43	0.411	33.61	3547.0
19	23.62	0.076	7.93	0.372	31.20	3292.0
20	22.50	0.065	7.41	0.330	30.31	3199.0

Table II (contd)

Node	Fissions/Node (x 10 ⁻¹²)				Total Fissions/ Node (x 10 ⁻¹²)	Power, Btu/hr
	²³⁵ U	²³⁸ U	²³⁹ Pu	²⁴⁰ Pu		
Element 8						
1	18.87	0.051	6.17	0.266	25.36	2676.0
2	19.67	0.061	6.65	0.302	26.68	2816.0
3	20.36	0.069	7.00	0.338	27.77	2931.0
4	21.23	0.074	7.34	0.362	29.01	3061.0
5	21.87	0.080	7.46	0.388	29.80	3145.0
6	22.52	0.084	7.89	0.404	30.90	3261.0
7	23.06	0.086	8.10	0.417	31.66	3341.0
8	23.43	0.088	8.24	0.426	32.18	3396.0
9	23.67	0.090	8.35	0.432	32.54	3434.0
10	23.74	0.090	8.39	0.434	32.65	3446.0
11	23.69	0.090	8.38	0.434	32.59	3439.0
12	23.52	0.089	8.31	0.429	32.35	3414.0
13	23.18	0.088	8.20	0.423	31.89	3365.0
14	22.72	0.085	8.02	0.411	31.24	3297.0
15	22.11	0.082	7.78	0.398	30.37	3205.0
16	21.48	0.078	7.50	0.380	29.44	3107.0
17	20.75	0.074	7.17	0.357	28.35	2992.0
18	19.92	0.067	6.79	0.327	27.10	2860.0
19	19.07	0.059	6.38	0.295	25.80	2723.0
20	18.17	0.050	5.97	0.262	24.45	2580.0
Element 9						
1	19.29	0.051	6.30	0.271	25.91	2734.0
2	20.12	0.061	6.79	0.307	27.28	2879.0
3	20.81	0.069	7.15	0.344	28.37	2994.0
4	21.71	0.075	7.50	0.368	29.65	3129.0
5	22.36	0.080	7.62	0.394	30.45	3213.0
6	23.03	0.084	8.06	0.411	31.59	3334.0
7	23.58	0.087	8.27	0.424	32.36	3415.0
8	23.95	0.089	8.42	0.433	32.89	3471.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
9	24.20	0.090	8.52	0.439	33.25	3509.0
10	24.27	0.090	8.57	0.442	33.37	3522.0
11	24.22	0.090	8.56	0.441	33.31	3515.0
12	24.05	0.089	8.49	0.436	33.07	3490.0
13	23.70	0.088	8.37	0.430	32.59	3439.0
14	23.23	0.085	8.19	0.418	31.92	3369.0
15	22.60	0.083	7.94	0.404	31.03	3275.0
16	21.96	0.079	7.65	0.387	30.08	3174.0
17	21.21	0.074	7.32	0.363	28.97	3057.0
18	20.36	0.067	6.93	0.332	27.69	2922.0
19	19.49	0.059	6.52	0.300	26.37	2783.0
20	18.57	0.051	6.10	0.267	24.99	2637.0

Element 10

1	21.85	0.067	7.51	0.290	29.72	3136.0
2	22.78	0.080	8.10	0.329	31.29	3302.0
3	23.57	0.091	8.53	0.369	32.56	3436.0
4	24.59	0.098	8.94	0.394	34.02	3590.0
5	25.32	0.105	9.08	0.423	34.93	3686.0
6	26.08	0.110	9.61	0.440	36.24	3824.0
7	26.70	0.114	9.86	0.454	37.13	3918.0
8	27.12	0.117	10.04	0.464	37.74	3983.0
9	27.41	0.118	10.16	0.471	38.16	4027.0
10	27.49	0.119	10.22	0.473	38.30	4042.0
11	27.43	0.119	10.20	0.473	38.22	4033.0
12	27.24	0.117	10.12	0.467	37.94	4004.0
13	26.84	0.116	9.98	0.460	37.40	3947.0
14	26.31	0.113	9.76	0.448	36.63	3866.0
15	25.60	0.109	9.47	0.433	35.61	3758.0
16	24.87	0.104	9.13	0.414	34.52	3643.0
17	24.02	0.097	8.73	0.389	33.24	3508.0
18	23.06	0.088	8.27	0.356	31.77	3353.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
19	22.08	0.078	7.77	0.321	30.25	3192.0
20	21.03	0.067	7.27	0.286	28.65	3023.0

Element 11

1	23.07	0.064	7.58	0.328	31.04	3276.0
2	24.05	0.076	8.17	0.372	32.67	3448.0
3	24.88	0.086	8.60	0.417	33.98	3586.0
4	25.95	0.093	9.01	0.446	35.50	3746.0
5	26.73	0.010	9.16	0.478	36.38	3839.0
6	27.53	0.104	9.69	0.498	37.82	3991.0
7	21.19	0.108	9.94	0.514	31.75	3351.0
8	28.63	0.110	10.12	0.525	39.39	4157.0
9	28.93	0.112	10.25	0.533	39.83	4203.0
10	29.02	0.113	10.30	0.535	39.97	4218.0
11	28.96	0.112	10.29	0.535	39.90	4211.0
12	28.75	0.111	10.21	0.529	39.60	4179.0
13	28.33	0.109	10.07	0.521	39.03	4119.0
14	27.77	0.107	9.85	0.507	38.23	4034.0
15	27.03	0.103	9.55	0.490	37.17	3923.0
16	26.25	0.098	9.20	0.469	36.02	3801.0
17	25.36	0.092	8.80	0.440	34.69	3661.0
18	24.35	0.084	8.34	0.403	33.18	3501.0
19	23.30	0.074	7.84	0.364	31.58	3333.0
20	22.20	0.063	7.33	0.323	29.92	3157.0

Element 12

1	23.84	0.067	7.85	0.341	32.10	3387.0
2	24.86	0.080	8.46	0.387	33.79	3566.0
3	25.72	0.091	8.91	0.434	35.16	3710.0
4	26.83	0.098	9.34	0.464	36.73	3876.0
5	27.63	0.105	9.49	0.498	37.72	3981.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
6	28.46	0.110	10.04	0.519	39.13	4129.0
7	29.13	0.114	10.30	0.535	40.08	4230.0
8	29.59	0.117	10.49	0.547	40.74	4299.0
9	29.90	0.118	10.62	0.555	41.19	4347.0
10	29.99	0.119	10.67	0.557	41.34	4363.0
11	29.93	0.119	10.66	0.557	41.27	4355.0
12	29.72	0.117	10.57	0.551	40.96	4322.0
13	29.29	0.116	10.43	0.543	40.38	4261.0
14	28.70	0.112	10.20	0.528	39.54	4173.0
15	27.93	0.109	9.90	0.510	38.45	4058.0
16	27.13	0.104	9.53	0.488	37.25	3931.0
17	26.21	0.097	9.12	0.458	35.89	3787.0
18	25.16	0.088	8.64	0.419	34.31	3621.0
19	24.09	0.078	8.12	0.379	32.67	3448.0
20	22.95	0.067	7.60	0.337	30.95	3266.0

Element 13

1	19.15	0.052	6.28	0.271	25.75	2717.0
2	19.96	0.062	6.77	0.307	27.10	2860.0
3	20.65	0.070	7.13	0.344	28.19	2975.0
4	21.54	0.076	7.47	0.367	29.45	3108.0
5	22.19	0.081	7.59	0.394	30.26	3193.0
6	22.85	0.085	8.03	0.411	24.15	2549.0
7	23.40	0.088	8.24	0.424	32.15	3393.0
8	23.77	0.090	8.39	0.433	32.68	3449.0
9	24.01	0.091	8.50	0.440	33.04	3487.0
10	24.09	0.092	8.54	0.441	33.16	3499.0
11	24.04	0.092	8.53	0.441	33.10	3493.0
12	23.87	0.091	8.46	0.436	32.86	3468.0
13	23.52	0.089	8.35	0.430	32.39	3418.0
14	23.05	0.087	8.16	0.418	31.72	3347.0
15	22.43	0.084	7.92	0.404	30.84	3254.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
16	21.79	0.080	7.63	0.386	29.89	3154.0
17	21.05	0.075	7.30	0.363	28.79	3038.0
18	20.21	0.068	6.91	0.332	27.52	2904.0
19	19.34	0.060	6.50	0.300	26.20	2765.0
20	18.43	0.051	6.08	0.266	24.83	2620.0

Element 14

1	19.72	0.053	6.44	0.278	26.49	2795.0
2	20.56	0.063	6.95	0.315	27.89	2943.0
3	21.27	0.071	7.32	0.353	29.01	3061.0
4	22.19	0.077	7.67	0.377	30.31	3199.0
5	22.85	0.083	7.79	0.405	31.13	3285.0
6	23.53	0.087	8.24	0.422	32.28	3406.0
7	24.09	0.090	8.46	0.435	33.08	3491.0
8	24.48	0.092	8.61	0.445	36.63	3866.0
9	24.73	0.093	8.72	0.451	33.99	3587.0
10	24.81	0.094	8.76	0.453	34.12	3601.0
11	24.76	0.093	8.75	0.453	34.06	3594.0
12	24.58	0.092	8.68	0.448	33.80	3567.0
13	24.22	0.091	8.56	0.441	33.31	3515.0
14	23.74	0.088	8.38	0.429	32.64	3445.0
15	23.10	0.086	8.12	0.415	31.72	3347.0
16	22.44	0.081	7.83	0.397	30.75	3245.0
17	21.68	0.076	7.49	0.372	29.62	3126.0
18	20.81	0.070	7.09	0.341	28.31	2988.0
19	19.92	0.061	6.67	0.308	26.96	2845.0
20	18.98	0.052	6.24	0.274	25.55	2696.0

Table II (contd)

Node	Fissions/Node (x 10 ⁻¹²)				Total Fissions/ Node (x 10 ⁻¹²)	Power, Btu/hr
	²³⁵ U	²³⁸ U	²³⁹ Pu	²⁴⁰ Pu		
	Element 15					
1	22.79	0.063	7.46	0.324	30.70	3240.0
2	23.76	0.074	8.05	0.367	32.25	3403.0
3	24.58	0.084	8.47	0.412	33.55	3541.0
4	25.64	0.091	8.88	0.440	35.05	3699.0
5	26.40	0.098	9.03	0.472	36.00	3799.0
6	27.20	0.102	9.55	0.492	37.34	3940.0
7	27.84	0.106	9.80	0.507	38.25	4036.0
8	28.28	0.108	9.97	0.519	38.88	4103.0
9	28.58	0.110	10.10	0.526	39.32	4149.0
10	28.67	0.110	10.15	0.528	39.46	4164.0
11	28.61	0.110	10.14	0.528	39.39	4157.0
12	28.40	0.109	10.06	0.522	39.09	4125.0
13	27.99	0.107	9.93	0.514	38.54	4067.0
14	27.43	0.104	9.70	0.500	37.73	3982.0
15	26.70	0.101	9.41	0.484	36.70	3873.0
16	25.93	0.096	9.07	0.463	35.56	3753.0
17	25.05	0.090	8.67	0.434	34.24	3613.0
18	24.05	0.082	8.21	0.398	32.74	3455.0
19	23.02	0.072	7.72	0.359	31.17	3289.0
20	21.93	0.062	7.22	0.319	29.53	3116.0

Element 16

1	22.88	0.073	7.90	0.309	31.16	3288.0
2	23.86	0.087	8.51	0.350	32.81	3462.0
3	24.68	0.099	8.97	0.393	34.14	3603.0
4	25.75	0.107	9.39	0.420	35.67	3764.0
5	26.51	0.114	9.55	0.450	36.62	3865.0
6	27.31	0.120	10.10	0.469	38.00	4010.0
7	27.96	0.124	10.36	0.484	38.93	4108.0
8	28.40	0.127	10.55	0.495	39.57	4176.0
9	28.70	0.128	10.68	0.502	40.01	4222.0
10	28.79	0.129	10.74	0.504	40.16	4238.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
11	28.73	0.129	10.73	0.504	40.09	4231.0
12	28.52	0.127	10.64	0.498	39.79	4199.0
13	28.11	0.126	10.50	0.491	39.23	4140.0
14	27.55	0.122	10.26	0.477	38.41	4053.0
15	26.81	0.118	9.96	0.462	37.35	3941.0
16	26.04	0.112	9.59	0.441	36.18	3818.0
17	25.15	0.105	9.17	0.414	34.84	3677.0
18	24.15	0.096	8.69	0.379	33.32	3516.0
19	23.12	0.085	8.17	0.343	31.72	3347.0
20	22.03	0.072	7.64	0.304	30.05	3171.0

Element 17

1	22.37	0.062	7.34	0.319	30.09	3175.0
2	23.32	0.074	7.92	0.361	31.68	3343.0
3	24.13	0.084	8.34	0.405	32.96	3478.0
4	25.17	0.091	8.74	0.433	34.43	3633.0
5	25.92	0.097	8.88	0.464	35.36	3731.0
6	26.70	0.102	9.39	0.483	36.68	3871.0
7	27.34	0.105	9.64	0.499	37.58	3966.0
8	27.77	0.107	9.81	0.510	38.20	4031.0
9	28.06	0.109	9.94	0.517	38.63	4077.0
10	28.14	0.109	9.99	0.520	38.76	4090.0
11	28.09	0.109	9.98	0.519	38.70	4084.0
12	27.88	0.107	9.90	0.513	38.40	4052.0
13	27.48	0.107	9.76	0.506	37.85	3994.0
14	26.93	0.104	9.55	0.492	37.08	3913.0
15	26.21	0.100	9.26	0.476	36.05	3804.0
16	25.46	0.095	8.92	0.455	34.93	3686.0
17	24.59	0.089	8.53	0.427	33.64	3550.0
18	23.61	0.081	8.08	0.391	32.16	3394.0
19	22.60	0.072	7.60	0.353	30.63	3232.0
20	21.53	0.061	7.11	0.314	29.02	3062.0

Table II (contd)

Node	Fissions/Node (x 10 ⁻¹²)				Total Fissions/ Node (x 10 ⁻¹²)	Power, Btu/hr
	²³⁵ U	²³⁸ U	²³⁹ Pu	²⁴⁰ Pu		
	Element 18					
1	23.67	0.165	7.62	0.332	31.69	3344.0
2	24.68	0.078	8.22	0.377	33.36	3520.0
3	25.54	0.088	8.65	0.422	34.70	3662.0
4	26.64	0.096	9.07	0.451	36.26	3826.0
5	27.43	0.102	9.21	0.484	37.23	3929.0
6	28.25	0.107	9.75	0.504	38.61	4074.0
7	28.93	0.111	10.00	0.520	39.56	4175.0
8	29.38	0.113	10.18	0.532	40.21	4243.0
9	29.69	0.115	10.31	0.539	40.65	4290.0
10	29.78	0.115	10.36	0.542	40.80	4306.0
11	29.72	0.115	10.35	0.541	40.73	4298.0
12	29.51	0.114	10.27	0.535	40.43	4267.0
13	29.08	0.112	10.13	0.527	39.85	4206.0
14	28.50	0.109	9.91	0.513	39.03	4119.0
15	27.43	0.106	9.61	0.496	37.94	4004.0
16	26.94	0.101	9.26	0.475	36.78	3881.0
17	26.02	0.094	8.85	0.445	35.41	3737.0
18	24.99	0.086	8.39	0.408	33.87	3574.0
19	23.92	0.076	7.89	0.368	32.25	3403.0
20	22.79	0.065	7.38	0.327	30.24	3191.0

Element 19

1	23.67	0.067	7.78	0.340	31.86	3362.0
2	24.68	0.083	8.39	0.386	33.54	3539.0
3	25.53	0.091	8.83	0.433	34.88	3681.0
4	26.63	0.098	9.26	0.462	36.45	3847.0
5	27.42	0.105	9.41	0.496	37.43	3950.0
6	28.25	0.110	9.95	0.516	38.83	4098.0
7	28.92	0.114	10.21	0.533	39.78	4198.0
8	29.38	0.117	10.39	0.545	40.43	4267.0
9	29.68	0.118	10.53	0.552	40.88	4314.0
10	29.78	0.119	10.58	0.555	41.03	4330.0

Table II (contd)

Node	Fissions/Node ($\times 10^{-12}$)				Total Fissions/ Node ($\times 10^{-12}$)	Power, Btu/hr
	^{235}U	^{238}U	^{239}Pu	^{240}Pu		
11	29.71	0.118	10.57	0.555	40.95	4321.0
12	29.50	0.117	10.48	0.548	40.65	4290.0
13	29.07	0.116	10.34	0.540	40.07	4229.0
14	28.49	0.112	10.11	0.526	39.24	4141.0
15	27.73	0.109	9.81	0.508	38.16	4027.0
16	26.94	0.103	9.45	0.486	36.98	3902.0
17	26.02	0.097	9.04	0.456	35.61	3758.0
18	24.98	0.088	8.56	0.418	34.05	3593.0
19	23.91	0.078	8.05	0.377	32.42	3421.0
20	22.78	0.066	7.57	0.335	30.71	3241.0

VI. REFERENCE MEASUREMENTS AND UNCERTAINTIES

The calculational methods used in this characterization study were developed since 1964, the methods were adapted and developed, the accuracy of the results was checked by comparison with actual measurements whenever possible. For example, the uncertainty in the relative flux distribution is indicated by comparing control-rod worths calculated by these methods with measured worths. Calculated and measured control-rod worths for EBR-II run 27A are plotted on polar coordinates in Fig. 10. The largest difference between the calculated and measured values--4.2%--occurs at control rod 7. Since the control-rod worth is approximately proportional to the square of the flux, the indicated maximum error in relative flux is 2.1%.

Some uncertainty is associated with the calculation of the local peaks and depressions of the flux in the highly heterogeneous EBR-II core. Experience has shown that this error can be minimized by using an S_n calculation of sufficiently high order. The flux peaking and depression computed by S_4 very closely approximate the peaking and depression computed by S_6 and S_8 , but differ substantially from results from S_2 calculations and diffusion theory. Therefore, the neutron-transport calculations described here were performed in the S_4 approximation.

In subassembly X108 there is only a small local effect. The ^{235}U fission rate shows only a radial gradient, while the rate for ^{238}U shows a depression of about 7%. Therefore, the uncertainty in the power produced in the fuel elements in X108 due to local effects is estimated to be less than 1%.

As shown in Section IV, the transient effect of buildup and decay of γ precursors is of the order of 1%. Transient effects, therefore, introduce an uncertainty of less than 1% in the computed power generation in the X108 elements.

The γ -energy deposition per fission varies by 10% from the center to the edge of subassembly X108. The rate of γ -energy deposition per gram of uranium is shown in Fig. 11 as a function of position in X108 and the six surrounding subassemblies. The rate varies from the center to the edge of subassembly X108 by about 10%. This variation does not occur in the fission rate (Section II), but is due to the imbalance between the γ energy produced

Fig. 10. Control-rod Worths for EBR-II Run 27A

		27.11	27.38	26.47	25.01	
		27.75	27.58	27.55	27.68	
28.05	27.98	30.88	30.84	28.08	28.79	
		X108				
28.48	28.30	31.05	31.08	27.61	27.14	
		28.85	29.07	29.28	27.41	
				CORE CENTER		
		27.44	27.47	28.10	26.85	

Fig. 11. Rate of Gamma-energy Deposition in Subassembly X108
and Surrounding Subassemblies (W/g)

and that absorbed in the highly enriched fuel of subassembly X108 (Section IV). The γ -energy deposition per fission is 5% above the average at the center and 5% below the average at the edge. If this effect were included in the calculation of the individual element powers, the calculated total power in the center element would be increased by 0.7% and that in the peripheral elements would be decreased by 0.7%.

The accuracy of characterization of the power in X108 is also limited by the uncertainty in determining total reactor power. There is an apparent discrepancy between the total power indicated by the primary-system thermal balance and that from the secondary system. This uncertainty is frequently of the order of 6%. Usually, it is a "directional" uncertainty suggesting a true power level between 59 and 62.5 MWt.

The combined uncertainties in the total neutron flux and fission rate are estimated to be of the order of 8%. The uncertainty in the γ -heating rate is estimated to be of the order of 20%. The total uncertainty in the computed power in the fuel pins in subassembly X108 is, therefore, estimated to be about 10%.

VII. SUMMARY

Detailed transport analyses were carried out to determine the neutron and γ flux and the isotopic fission rates in EBR-II for run 48E, in which experimental irradiation subassembly X108 was irradiated. These results were used to compute the axial power distribution in each of the 19 experimental fuel elements in subassembly X108. Local and global variations in the neutron and gamma flux as well as transient effects were taken into consideration in the calculations. The computed power distributions are given in Table II in Section V.

The analyses were based on methods which have been adapted, developed, and tested by the EBR-II Project since 1969. These methods have been checked by comparing computed physics parameters with measurements in the EBR-II reactor.

Uncertainties in the computed power distribution result from the finite accuracy of (1) the EBR-II thermal-power measurement, (2) calculation of local flux variations, and (3) transient- γ calculations. The total uncertainty is estimated to be about 10%.

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