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MASTER

STUDY NO. II-105-1

THERMAL AND TOTAL EPITHERMAL
NEUTRON FLUX DISTRIBUTIONS
IN THE
EXPERIMENTAL GAS-COOLED REACTOR

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N O T I C E

This report summarizes as of the date of the study the status of this phase of the design of the Experimental Gas Cooled Reactor under construction in the Oak Ridge Area. Since the data was developed prior to completion of all design, fabrication and construction, the information is subject to modification during the evolution of the complete design of the entire facility and no attempt has been made to revise, rewrite, edit or otherwise modify the study to maintain the data current with related research and development programs or subsequent design revisions. Users are cautioned to avoid interpretations and conclusions based on the incomplete data contained herein.

THERMAL AND TOTAL EPITHERMAL
NEUTRON FLUX DISTRIBUTIONS
IN THE
EXPERIMENTAL GAS COOLED REACTOR

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Thermal and Total Epithermal
Neutron Flux Distributions

I. OBJECTIVE

The objective of this report is to determine the thermal and total epithermal neutron flux distributions in the EGCR from the center of the core through the biological shield. This will provide data for Kaiser Engineers' calculations of biological shielding against neutron and gamma radiation. It will further provide data for neutron and gamma heating calculations for reactor components and for structures external to the reactor.

II. SUMMARY AND CONCLUSIONS

1. The maximum values of the neutron flux distribution are presented in Figures 1 through 8. The difference in the shielding effectiveness of ordinary concrete in the radial biological shield and the heavy concrete in the axial biological shield may be seen by examining these figures. The ordinary concrete permits a thermal flux buildup, similar to that found in the graphite reflector. In heavy concrete there is no such buildup as the thermal flux is attenuated through the complete shield.

2. It should be noted that the fast flux is a total epithermal flux and should be used with caution. For example, the radiation damage to steel is caused by fast flux, but only by that flux above energies of approximately 1 Mev, which is not the fast flux reported here. The fast flux distribution is given in Study No. II-105-2.

III. GIVEN DATA

The mock-ups of the reactor structure in the radial and axial directions are based on the description given below:

Radial Structure

Core radius	66.3 in.
Reflector thickness	26.67 in.
Void space	21.95 in.
Temperature barrier insulation	4 in.
Temperature barrier (thickness)	1 in.
Pressure vessel (thickness)	2.75 in.
Pressure vessel external insulation	4 in.
(this is assumed to be only 1/16 in. steel)	
Biological shield coolant gap	107.5 in.
Shield coolant baffle (thickness)	3/16 in.
Biological shield (thickness)	10 ft

Axial Structure

Core height	14 ft 6 in.
Reflector thickness	2 ft 3.75 in.
Top plate (thickness)	1 in.
Temperature barrier insulation	4 in.
(this is assumed to be only 1/16 in. steel)	
Temperature barrier (thickness)	1 in.

Pressure vessel (thickness) 4 in.
Pressure vessel external insulation . . . 4 in.
(this is assumed to be only 1/16 in. steel)
Biological shield 10 ft 6 in.

Ordinary concrete is used in radial biological shield.
Heavy (ferrophosphorous) concrete was used in the axial biological shield.
Reactor thermal power = 84.3 Mw.
Additional data used here were derived in A-C Title I Study No. 116 and are referenced in the section of this report covering calculations.

IV. ASSUMPTIONS

1. All assumptions inherent in the Val Prod code are made here.
2. The assumptions made in A-C Title I Study No. 116, which derive the data used in that report, are also made here.
3. In calculating the radial neutron flux distribution, the axial maximum-to-average ratio of the thermal flux was assumed to be 1.62.
4. In determining both the axial and radial flux distribution, the core was assumed to be made of a homogeneous mixture of materials, i.e., no fuel rotation scheme was mocked-up. Fuel was assumed to be made up of the core average of isotopes present in an equilibrium core.
5. Heavy concrete contains water in the amount of 3.3% by weight.

V. METHOD OF ANALYSIS

A Val Prod code utilizing multigroup-diffusion theory was used to calculate neutron flux distributions. Two energy groups were used to calculate a thermal and total epithermal flux. The basic cross-sectional data were obtained from A-C Title I Study No. 116. These cross sections included all isotopes built up in an equilibrium core. Core average values of these cross sections were used in a mock-up of a homogeneous core. The axial distribution was mocked up in semi-infinite slab geometry; spatial attenuation of flux outside the reflector was not calculated.

VI. DISCUSSION

The flux values calculated are the maximum values since they are given along the axis of the reactor where the radial distribution is a maximum, and in a radial plane where the axial distribution is a maximum. Values of the fluxes in the axial

direction out in the pressure vessel and biological shield have not been attenuated for the spatial dispersion of the flux emanating from the reactor.

The calculations were made on the assumption that the reactor core is homogeneous. The final flux distribution will depend on the fuel rotation program, the method of operating control rods, and the contents of the experimental loops. Since none of these were determined, it was necessary to make the above assumption about the core contents. It is obvious, if one examines Figures 1 and 5, that the absolute flux values at the core center are not the same for the axial and radial distributions. These values were based on assumptions which would give conservative (high) values of neutron flux. In calculating the radial distribution, a maximum-to-average ratio of the core axial thermal flux distribution was assumed to be 1.62. This value was determined in A-C Title I Study No. 116, and is assumed to give a relatively high radial flux value. In calculating the axial flux distribution, the maximum-to-average ratio of 1.335 for the core radial thermal flux distribution was used. This value was calculated for the radial distribution and is higher than the value obtained from a calculation of a detailed core mock-up done by ORNL which included the effects of the experimental tubes, and is therefore assumed to be conservative. The calculated value of the ratio of the maximum-to-average core axial flux distribution is 1.23. This is a relatively small value, but because of this the core flux at the reflector core interface will have a relatively high value, and the flux values in the reflector and out to the biological shield will tend to be high. Therefore, even if the actual core operating flux distribution cannot be determined at this time, the values reported here should be conservative.

The mock-up used in Val Prod to calculate the axial flux distribution included a 2.75-in. thick pressure vessel. The curves of the axial flux distribution through the pressure vessel have been extrapolated to give the distribution through a 4.0-in. vessel.

Neutron cross-sectional values for concrete are not precise but are the best values obtainable. Some of these values are taken from ANL-5800 where representative values are listed for several types of concrete. The slowing-down cross section of heavy concrete for the fast group was calculated on the basis that the water constituent causes almost all the slowing down of neutrons. Water content of the concrete was obtained from Kaiser Engineers as 3.3% of the total weight.

CALCULATIONS

A Method

B Radial Flux Distribution

1. Geometrical Mock Up
2. Tabulation of Val Prod Input Data
3. Calculation of Val Prod Input Data
4. Val Prod Output
5. Neutron Flux Normalization Factor

C Axial Flux Distribution

1. Geometrical Mock Up
2. Tabulation of Val Prod Input Data
3. Calculation of Val Prod Input Data
4. Val Prod Output
5. Neutron Flux Normalization Factor

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CALCULATION OF NEUTRON FLUX DISTRIBUTION FROM CORE CENTER TO BIOLOGICAL SHIELD (RADIAL DISTRIBUTION) (*AXIAL DISTRIBUTION)

A) Method

The Val-Pro code, which incorporates multigroup-diffusion theory, is used on the 650 IBM digital computer. Only two energy groups are used in these calculations. Both the radial and axial distributions are determined. Data is taken from ~~the~~ A-C study 116 to approximate an equilibrium core.

B) RADIAL FLUX DISTRIBUTION

① Geometrical Mock Up

The geometrical mock up is shown below. The material in each insulation region is mocked up as $\frac{1}{16}$ inch steel, the shield coolant baffle as $\frac{3}{16}$ inch steel, the temperature barrier and pressure vessel as 3.75 inches of steel, and the biological shield as ordinary concrete.

	Core	Reflector	Insul- ation	Temp. Barrier and Pressure Vessel	Barrier Vessel	Insul- ation	Shield Coolant Baffle	Biol. Shield	
<i>m</i>	0	20	30	35	49	55	60	65	90
Δr	8.42	6.78	.508	.9538	.5295	.508	.09525	6.096	
<i>r</i>	0	168.4	236.2	238.74	246.09	248.27	260.81	251.29	403.69
region width	168.4	6.78	2.54	6.353	3.177	2.54	.47625	152.4	

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B/ ② Tabulation of Val-Prod Input Data

Region	D_1	D_2	ΣA_1	ΣA_2	Σd_1	$\epsilon \Sigma f$
1	1.325	1.228	.002529	.006873	.002170	.003886
2	1.14	.8879	.003363	.0002609	.003330	0
3	6.403	6.403	.00009938	.0114	.00009938	0
4	.400	.400 .00159	.00159	.18243	.00159	0
5	.400	.400 .00159	.00159	.18243	.00159	0
6	6.403	6.403	.00009938	.0114	.00009938	0
7	.400	.400	.00159	.19991	.00159	0
8	1.98	.858	.022	.0071	.022	0

B/ ③ Calculation of Val Prod Input Data

Most of the data used is taken from A-C Study 116 with some changes made as given below. Other data is taken from various references as indicated.

CORE CONSTANTS

$D_1 = 1.11$ for density of graphite = 1.6 gm/cc (reference 1)

$D_1 = 1.11 \times 1.65 / 1.6 = 1.14$ for graphite density = 1.65 gm/cc

$D_{1,L} = D_1 \alpha_{1,L}$ where $\alpha_{1,L}$ is the radial streaming correction.

$D_{1,H} = D_1 \alpha_{1,H}$ " " " " axial " "

$D_{1,L} = 1.14 \sqrt{1.351} = 1.14 \times 1.162 = 1.325$ α values are

$D_{1,H} = 1.14 \sqrt{1.45} = 1.14 \times 1.204 = 1.373$

obtained from AC
Job Report 1-135-4.3

$$\bar{D}_1 = \frac{D_{1,L} B_L^2 + D_{1,H} B_H^2}{B_L^2 + B_H^2} = \frac{1.325 \times 1.355 \times 10^{-4} + 1.373 \times 2.897 \times 10^{-4}}{1.355 \times 10^{-4} + 2.897 \times 10^{-4}}$$

$$= 1.333$$

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$$D_2 = \frac{1}{3 \Sigma a} = \frac{1}{3 \times \frac{.319}{.319}} = 1.045$$

$$D_{2,I} = 1.045 \alpha_{2,I} = 1.045 \sqrt{1.3799} = 1.228$$

$$D_{2,II} = 1.045 \alpha_{2,II} = 1.045 \sqrt{1.5078} = 1.283$$

$$\bar{D}_2 = \frac{1.228 \times 1.355 + 1.283 \times .2897}{1.355 + .2897} = 1.253$$

$$\Sigma \lambda_{2,I} = \frac{D_{2,I}}{\tau} + D_{2,II} B_{II}^2 = \frac{1.253}{\tau} + 1.373 \times .2897 \times 10^{-4}$$

$$\tau_1 = 497.03, \quad \tau_{II} = 533.46$$

$$\bar{\tau} = \frac{497.03 \times 1.355 + 533.46 \times .2897}{1.355 + .2897} = 503.4$$

$$\Sigma \lambda_{2,I} = \frac{1.253}{503.4} + 1.373 \times .2897 \times 10^{-4} = .002529$$

$$\Sigma \lambda_{2,I} = \rho \frac{D_{2,I}}{\tau} = \frac{.81961 \times 1.333}{503.4} = .00217$$

$$\Sigma \lambda_{2,2} = \Sigma \lambda + D_{2,II} B_{II}^2$$

$$\text{From study 116, } \Sigma \lambda_{2,2} = .01277$$

$$\therefore \Sigma \lambda = \Sigma \lambda_{2,2} - D_{2,II} B_{II}^2 = .01277 - 1.283 \times .2897 \times 10^{-4} = .01273$$

A correction is applied here :

$$\text{In study 116, } \bar{\Sigma} \text{ is defined as } \sum_i \frac{\Sigma_i V_i d_i}{V_{\text{tot}}}$$

where d_i = disadvantage factor; Σ_i = total reaction rate cross section when used with Maxwell Boltzmann flux.

$$\text{In this calculation we will use } \bar{\Sigma} = \frac{\sum_i \Sigma_i V_i d_i}{\sum_i V_i d_i}$$

where Σ_i is the cross section for only thermal reaction rate.

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$$\frac{V_{tot}}{\sum_i V_i d_i} = \frac{(8 \text{ in} \times 2.54)^2}{V_0 + V_1 \frac{\bar{\phi}_1}{\bar{\phi}_0} + V_2 \frac{\bar{\phi}_2}{\bar{\phi}_0} + V(\text{void})}$$

$$= \frac{(8 \times 2.54)^2}{16.185 + 3677 \times 1.491 + 2.87 \times 1.064 + 26.15} = .6956$$

• This data is taken from AC Job Report 3-135-4.3

In order to change Σ from total reaction rate cross section to thermal reaction rate cross section one multiplies by

$$(1 - b\lambda) = 1.0 - 1.341 \times .17 = .772 \quad \text{Data taken from AC Job Report 3-135-4.3}$$

$$\text{The total correction factor} = .772 \times .6956 = .537$$

$$\therefore \Sigma_{0,2} = .01273 \times .537 = .006836$$

$$\Sigma_{1,2} = .006836 + .000037 = .006873$$

From study 116 :

$$\epsilon \Sigma_f \approx .007282 \quad \text{for axial calculation}$$

$$\text{for radial calculation: } \epsilon \Sigma_f = \epsilon \Sigma_f(\text{axial}) \times \frac{\Sigma_{1,2}(\text{radial})}{\Sigma_{1,2}(\text{axial})}$$

$$\epsilon \Sigma_f = .007237$$

Applying a correction factor:

$$.007237 \times .537 = .003886$$

Reflector Constants

$$D_1 = 1.14 \quad \text{as shown above}$$

$$\tau = 364 \quad \text{for graphite of density } 1.6 \text{ gm/cc}$$

$$\tau = 364 \left(\frac{1.6}{1.65} \right)^2 = 342.3 \quad \text{for density of } 1.65 \text{ gm/cc}$$

$$\Sigma_{R,1} = \frac{D_1}{\tau} + D_1 B_H^2 = \frac{1.14}{342.3} + 1.14 \times .2897 \times 10^{-4} = .003363$$

$$\Sigma_{R,2} = \Sigma_R + D_2 B_H^2$$

$$\text{For graphite, } \sigma_R = .0045, \quad N = \frac{1.65 \times .6023}{12} = .08282$$

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$$\Sigma_0 = .0045 \times .08282 \frac{\sqrt{293/578}}{1.128} = .0002352$$

$$\Sigma u = .37542$$

$$D_2 = \frac{1}{3\Sigma u} = \frac{1}{3 \times .37542} = .8879$$

$$\Sigma_{A,2} = .0002352 + .8879 \times .2897 \times 10^{-4} = .0002609$$

$$\Sigma_{d,1} = \frac{D_1}{T} = \frac{1.14}{342.3} = .00333$$

Insulation (stainless steel)

$$\left. \begin{array}{l} \Sigma_{A,2} = .2540 \text{ at } 20^\circ\text{C} \\ \Sigma_{u,2} = .8329 \end{array} \right\} \text{ (see R\&D Report 102)}$$

$$\Sigma_{u,1} \text{ assume } \approx .833$$

$$D_1 = \frac{1}{3\Sigma_{u,1}} = .4008$$

$$D_2 = \frac{1}{3\Sigma_{u,2}} = .4002$$

$$\Sigma_{d,1} = \frac{D_1}{T} = \frac{.400}{251.5} = .00159$$

$$\Sigma_{d,1} = .00159$$

$$\Sigma_{A,2} = \frac{D_2}{T} \Sigma_{A,2} \text{ at } T = 300^\circ\text{C} = .254 \sqrt{\frac{293}{578}} = .18243$$

$$\text{at } T = 180^\circ\text{C}, \Sigma_{A,2} = .254 \sqrt{\frac{293}{453}} = .19991$$

Since the mock up width of insulation is 2.54 cm
and the actual thickness of material = $\frac{1}{16}$ inch;
all cross sections should be reduced by

$$\frac{2.54}{16} \times \frac{1}{2.54} = .0625$$

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Temperature Barrier
Pressure Vessel
Shield Coolant Baffle

} all use stainless steel cross sections
as given above

Biological Shield (Ordinary concrete)

This data has been taken from ANL 5800, and
also from personal communication with P. Wood. of AEC.

$$D_1 = 1.98$$

$$D_2 = .858$$

$$\Sigma A_1 = .022$$

$$\Sigma A_{s1} = .022$$

$$\Sigma A_{s2} = .0071$$

B) ④ VAL PROD Output

The space points, radii, fast and thermal fluxes are listed below as obtained from Val Prod output, corresponding to the reactor mock up. To account for the large void spaces not shown in the mock-up, the real radii, and the corrected flux values are also shown below. The fluxes have already been multiplied by a factor to normalize them to reactor full power operation.

CORE

m	r mock-up	ϕ_1 (Fast)	ϕ_2 (Thermal)	r (real)	ϕ_1 (corrected)	ϕ_2 (corrected)
0	0	5.0289	1.5618	same as r-mock-up	9.3603×10^{13}	2.907×10^{13}
2	16.84	4.9959	1.5515		9.2989 "	2.8879 "
4	33.68	4.8972	1.5209		9.1152 "	2.8309 "
6	50.52	4.7348	1.4704		8.8129 "	2.7369 "
8	67.36	4.5114	1.4011		8.3971 "	2.6079 "
10	84.20	4.2311	1.3146		7.8753 "	2.4469 "
12	101.04	3.8981	1.2133		7.2565 "	2.2583 "
14	117.88	3.5147	1.1025		6.5419 "	2.0521 "
16	134.72	3.0726	.9983		5.7190 "	1.8581 "
18	151.56	2.5181	.95770		4.6869 "	1.7826 "
20	168.4	1.6116	1.2020		2.9997 "	2.2373 "

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REFLECTOR						
m	λ	ϕ_1	ϕ_2	λ (real)	ϕ_1 (corr)	ϕ_2 (corr)
20	168.4	1.6116	1.2020	same as λ	2.9997×10^{13}	2.2373×10^{13}
22	181.96	.74652	1.4613	mock-up	1.3895 "	2.7199 "
24	195.52	.34733	1.2635		.64648 "	2.3518 "
26	209.08	.16328	.90491		.30384 "	1.6843 "
28	222.64	.079401	.50330		.14778 "	.93679 "
30	236.2	.043746	.096798	↓	.081424 "	.18017 "

INSULATION						
30	236.2	.043746	.096798	287.02	6.7006×10^{11}	.14827 "
32	237.22	.043466	.092669	291.08	6.5934 "	.14057 "
34	238.23	.043188	.088727	295.15	6.4881 "	.13329 "
35	238.74	.043049	.086824	297.18	6.4371 "	.12983 "

TEMPERATURE BARRIER + PRESSURE VESSEL						
35	238.74	.043049	.086824	297.18	6.4371 "	.12983 "
37	239.75	.039177	.047200	298.09	5.8648 "	7.0658×10^{11}
39	240.56	.035447	.025710	299.00	5.3082 "	3.8501 "
41	241.46	.031847	.014053	299.90	4.7726 "	2.1060 "
43	242.37	.028365	.0077307	300.81	4.2539 "	1.1594 "
45	243.28	.024988	.0043058	301.72	3.7502 "	6.4621×10^{10}
47	244.19	.021706	.0024640	302.63	3.2600 "	3.7007 "
49	245.09	.018506	.0015052	303.53	2.7813 "	2.2622 "
51	246.15	.014868	.0010350	304.59	2.2358 "	1.5568 "
53	247.21	.011304	.0010453	305.65	1.7017 "	1.5736 "
55	248.27	.0078094	.0015557	306.71	1.1766 "	2.3440 "

INSULATION						
55	248.27	.0078094	.0015557	311.79	1.1574 "	2.3057 "
57	249.29	.0076021	.0016078	315.85	1.1168 "	2.3620 "
59	250.30	.0073958	.0016626	319.91	1.0771 "	2.4212 "
60	250.81	.0072930	.0016911	321.95	1.0575 "	2.4521 "

SHIELD COOLANT BAFFLE

m	L	ϕ_1	ϕ_2	L (vml)	ϕ (corr.)	ϕ_2 (corr.)
60	250.81	.0072930	.0016911	426.533	7.9822x10 ¹⁰	1.8509x10 ¹⁰
62	251.000	.0066773	.0018797	426.724	7.3103 "	2.0579 "
64	251.191	.0060632	.0021016	426.914	8.6404 "	2.3017 "
65	251.286	.0057566	.0022265	427.01	6.3052 "	2.4387 "

BIOLOGICAL SHIELD

65	251.29	.0057566	.0022265	436.88	6.1630 "	2.3837 "
67	263.48	.0015886	.0033589	449.07	1.7349 "	3.6683 "
69	275.67	.00043886	.0018158	461.26	4.8819x10 ⁹	2.0199 "
71	287.86	.12133 ⁻³	.78860 ⁻³	473.46	1.3731 "	8.9246x10 ⁹
73	300.05	.3356 ⁻⁴	.30737 ⁻³	485.65	3.8594x10 ⁸	3.5348 "
75	312.25	.926 ⁻⁵	.11095 ⁻³	497.84	1.0810 "	1.2952 "
80	342.73	.34 ⁻⁶	.681 ⁻⁵	528.32	4.1855x10 ⁶	8.223x10 ⁹
84	367.11	.1 ⁻⁷	.70 ⁻⁶	552.70	1.2363x10 ⁵	8.654x10 ⁶
85	373.21		.38 ⁻⁶	558.80		4.7238x10 ⁶
89	397.59		.2 ⁻⁷	583.18		2.534x10 ⁵
90	403.69			589.28		

B/ (5) Normal Normalization Factor

A factor is computed that will convert VAL PROD output to flux values found in the reactor at full power operation.

Radial Thermal ^{core} flux ratio $\frac{\text{maximum}}{\text{average}} = 1.335$ From VAL PROD output

Axial " " " " = 1.62 From AC Study 116

The number of fissions to produce 84.3 megawatts (or full power operation) = $\sum_f \bar{\phi} V_{\text{core}} = 84.3 \times 10^6 \text{ watts} \times 3.16 \times 10^{10} \text{ fissions per watt} = 2.6639 \times 10^{18}$

$$\Sigma_f = \frac{.003886}{1.61} = \frac{.003886}{.772} = .005034$$

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$$V_{\text{core}} = \pi r^2 H = 3.1416 (168.4)^2 \times 441.96 = 3.9375 \times 10^7$$

$$\therefore \bar{\phi} \text{ (average core flux)} = \frac{2.6639 \times 10^8}{0.05034 \times 3.9375 \times 10^8} = 1.344 \times 10^{13}$$

Maximum thermal core flux =

$$= 1.335 \times 1.62 \times 1.344 \times 10^{13} = 2.907 \times 10^{13}$$

REFERENCE

1. Raymond L. Murray, "Nuclear Reactor Physics"
Prentice - Hall, Inc., 1957

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C/ AXIAL FLUX DISTRIBUTION

① Geometrical Mock up

The material in the Top Plate region is mocked up as 1 inch steel, the insulation regions as 1/6 inch steel in each, the Temperature barrier and pressure vessel as 3.75 inches steel, and the biological shield as heavy concrete (Pentaporphonous).

	Core	Reflector	Top Plate	Insulation	Temp. and Vessel	Barrier Pressure	Insulation	Biol. Shield	
n	0	30	45	52	55	63	68	71	91
Ag	7.366	4.6187	.38286	.84667	.79413	.6354	.84667	7.620	
z	0	220.98	290.26	292.8	295.34	301.7	304.87	307.41	459.81
region width	220.98	69.28	2.54	2.54	6.353	3.177	2.54	152.4	

C/ ② Tabulation of Vol Prod Input Data

Region	D_1	D_2	ΣA_{11}	ΣA_{12}	ΣA_{21}	$\epsilon \Sigma_f$
1	1.373	1.283	.002669	.0070058	.00217	.003886
2	1.373	1.0903	.00285	.0008407	.002848	0
3	.695	.695	.0009147	.1049	.0009147	0
4	6.403	6.403	.9938 ⁻⁴	.0114	.9938 ⁻⁴	0
5	.400	.400	.00159	.1824	.00159	0
6	.400	.400	.00159	.1899	.00159	0
7	6.403	6.403	.9938 ⁻⁴	.0114	.9938 ⁻⁴	0
8	.98	.42	.011	.0767	.011	0

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C) ③ Calculation of Val Prod Input Data

Input data is taken from part B) of these calculations.

CORE

$$D_{1,11} = 1.373 \quad \overline{D}_1 = 1.333$$

$$D_{1,1} = 1.325$$

$$D_{2,11} = 1.283$$

$$\overline{D}_2 = 1.253$$

$$D_{2,1} = 1.228$$

$$\Sigma A_{1,1} = \frac{D_{1,1}}{r} + D_{1,1} B_1^2 = \frac{1.253}{503.4} + 1.325 \times 1.355 \times 10^{-4} = .002669$$

$$\Sigma A_{1,2} = \Sigma A + D_{2,1} B_1^2$$

$$= .006836 + 1.253 \times 1.355 \times 10^{-4} = .0070058$$

$$\Sigma A_{1,1} = p \frac{D_{1,1}}{r} = .002170$$

$$\epsilon \Sigma_f = .003886$$

REFLECTOR

$$D_{1,11} = 1.14 \alpha_{1,11} = 1.14 \times 1.204 = 1.373$$

$$D_{1,1} = 1.14 \alpha_{1,1} = 1.14 \times 1.162 = 1.325$$

$$\overline{D}_1 = 1.333$$

$$D_{2,11} = .8879 \alpha_{2,11} = .8879 \times 1.228 = 1.0903$$

$$D_{2,1} = .8879 \alpha_{2,1} = .8879 \times 1.175 = 1.0433$$

$$\overline{D}_2 = 1.0514$$

$$\Sigma A_{1,1} = \frac{D_{1,1}}{r} + D_{1,1}$$

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TOP PLATE
INSULATION
TEMPERATURE BARRIER
PRESSURE VESSEL

All data for the above regions was taken from part B

BIOLOGICAL SHIELD

Data for this region was taken from ANL 5800
 Material is ferro-phosphorous concrete.

3.3% of concrete by weight is due to H_2O

This number was obtained from W. Dodson (Kaiser)
 via phone call

From ANL 5800 :

D_{th} , Σ_a		D_{th}	Σ_a
	4.857% H_2O by weight	.348	.0781
	2.488% " " "	.463	.0759
	by interpolation, for 3.3% H_2O by weight		
		$D_{th} = .4236$	$\Sigma_a = .0767$

D_i As seen from ANL 5800 data, D_i is approximately proportional to D_{th} for various concretes. Then taking data for ordinary concrete (radial calculation)

$$D_i = 1.98, D_{th} = .858$$

then for heavy concrete

$$D_i = \frac{1.98}{.858} \times .4236 = .978$$

This number checks fairly well with other types of concrete listed in ANL 5800

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$\Sigma_{A,1}; \Sigma_{A,1}$ For our purposes $\Sigma_{A,1} = \Sigma_{A,1}$

$$\Sigma_{A,1} = \frac{\overline{D_1}}{\overline{\tau}} = \frac{\overline{D_1}}{\frac{\Delta U}{3 \overline{\Sigma_A} \overline{\xi \Sigma_s}}} = \frac{\overline{\xi \Sigma_s}}{\Delta U}$$

$\Sigma_{A,1}$ is dependent almost entirely on H content in concrete:

$$\xi(H) = 1.0$$

$$\rho(\text{concrete}) = 4.68 \text{ gm/cc} \quad \text{from 5800}$$

$$\rho(H) = .033 \times \frac{2}{18} \times 4.68 = .0172 \text{ gm/cc}$$

$$\overline{\Sigma_s} \approx \frac{.0172 \times .602 \times 20}{1.0} = .207$$

$$\Sigma_{A,1} = \frac{\overline{\xi \Sigma_s}}{\Delta U} \approx \frac{1.0 \times .207}{18} = .0115$$

$$\Sigma_{A,1} = .0115$$

C/ (4) VAL PROD Output

The space points, radii, fast and thermal fluxes are listed below as obtained from VAL PROD output

CORE

n	z	ϕ_1	ϕ_2
0	0	4.5427	1.4005
3	22.098	4.5146	1.3918
6	44.196	4.4301	1.3657
9	66.294	4.2895	1.3222
12	88.392	4.0932	1.2615
15	110.49	3.8420	1.1839

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m	z	ϕ_1	ϕ_2
18	132.59	3.5373	1.0901
21	154.69	3.1805	.98158
24	176.78	2.7685	.86512
27	198.88	2.2637	.77852
29	213.61		.82979
30	220.98	1.3951	.96070

REFLECTOR

30	220.98	1.3951	.96070
32	230.22	.91720	1.1423
34	239.45	.60358	1.1473
36	248.69	.39806	1.0468
38	257.93	.26382	.88432
40	267.17	.17683	.68596
42	276.40	.12150	.46601
44	285.64	.087936	.23109
45	290.26	.077308	.10859

TOP PLATE

45	290.26	.077308	.10859
47	290.985	.074569	.081959
49	291.711	.071881	.061824
51	292.44	.069243	.046580
52	292.80	.067942	.040399

INSULATION

52	292.80	.067942	.040399
53	293.65	.067615	.038959
54	294.49	.067288	.037568
55	295.34	.066962	.036225

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TEMPERATURE BARRIER + PRESSURE VESSEL

55	295.39	.066962	.036225
57	296.93	.057506	.012852
59	298.52	.048627	.004711
61	300.10	.040235	.0018632
63	301.69	.032248	.00088394
65	302.96	.026692	.00068345
67	304.23	.020105	.00088887
68	304.87	.017162	.0011946

INSULATION

68	304.87	.017162	.0011946
69	306.71	.016918	.0012297
70	306.56	.016674	.0012662
71	307.41	.016431	.0013042

BIOLOGICAL SHIELD

71	307.41	.016481	.0013042
73	322.65	.0034057	.5-1191 ⁻³
75	337.89	.70591 ⁻³	.10733 ⁻³
77	353.13	.1463 ⁻³	.2178 ⁻³
79	368.37	.3030 ⁻⁴	.373 ⁻⁵
81	383.61	.626 ⁻⁵	.13 ⁻⁶
83	398.85	.127 ⁻⁵	
85	414.09	.24 ⁻⁶	
87	429.33	.4 ⁻⁷	
89	444.57		
91	459.81		

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B/ (5) Normalization Factor

~~THE~~ A factor is calculated that will convert VAL PROD output to flux values found in the reactor at full power operation.

Axial Max. / Ave. ratio of thermal core flux = 1.2307

from VAL PROD output.

Radial " " of thermal core flux = 1.335

∴ Max. core flux

$$= 1.344 \times 10^{13} \times 1.2307 \times 1.335$$

$$= 2.208 \times 10^{13}$$

Conversion factor for VAL PROD output

$$= \frac{2.208 \times 10^{13}}{1.4005} = 1.577 \times 10^{13}$$

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Figure 1

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Figure 2

RADIAL NEUTRON FLUX VS
DISTANCE FROM CORE CENTER

Φ_1 - TOTAL EPITHERMAL FLUX

Φ_2 - THERMAL FLUX

CORE POWER = 84.3 MEGAWATTS

MAXIMUM RADIAL VALUES SHOWN

Figure 3

RADIAL NEUTRON FLUX VS DISTANCE FROM CORE CENTER

Φ_1 TOTAL EPITHERMAL FLUX

Φ_2 THERMAL FLUX

CORE POWER = 89.3 MEGAWATTS

MAXIMUM RADIAL
FLUX VALUES
SHOWN

Figure 9

RADIAL NEUTRON FLUX VS
DISTANCE FROM CORE CENTER

ϕ_1 TOTAL EPITHERMAL FLUX
 ϕ_2 THERMAL FLUX

CORE POWER = 84.3 MEGAWATTS
MAXIMUM RADIAL FLUX VALUES
SHOWN

Figura 5

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Figure 6

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Figure 7

AXIAL NEUTRON FLUX VS. DISTANCE FROM CORE CENTER

Φ_1 Total Epithermal Flux

Φ_2 Thermal Flux

CORE POWER = 89.3 Megawatts

Maximum Axial Flux Values Shown

Figure 8

AXIAL NEUTRON FLUX VS DISTANCE FROM
CORE CENTER Φ_0 Total Epithermal Flux Φ_T Thermal Flux

CORE POWER = 89.5 Megawatts

Maximum Axial Flux Values Shown