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CALCULATIONS OF THE POWER DISTRIBUTIONS IN THE
TOWER SHIELDING REACTOR II*

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The power distribution and heat flux of the TSR-II fuel plates have been calculated for the final core configuration which includes the fuel-bearing cover shell on the control mechanism housing. Calculations for the clean-cold condition of the reactor were based on gold foil activation measurements of the thermal-neutron density distribution in the core and those for high-power operation were based on GNU-II code calculations for the thermal-neutron density distribution. The data are presented for operation of the reactor at 1 MW.

*This work was performed in 1961.

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Introduction

Preliminary calculations of the power distribution and heat flux of the Tower Shielding Reactor II fuel plates, based upon the results of a Cornwash code calculation of the radial distribution of thermal neutrons born in the core for 5-MW operation, were published in 1959.¹ Since then, the radial power distribution in the core has been changed by the addition of a fuel-bearing spherical shell which surrounds the control-mechanism housing, making it necessary to recompute the power distribution and heat flux in the fuel plates. These calculations were based on gold foil activation measurements of the thermal-neutron distribution in the core for clean cold operation and on GNU-II² code calculations of the thermal-neutron density distribution in the core for high-power operation. The results of the new power distribution calculations and the methods used in the calculations are reported here. Since the maximum permissible power may be different for different operating conditions, the data are presented for operation at 1 MW.

Fuel Elements

A detailed description of the TSR-II core assembly is contained elsewhere,¹ and the fuel elements (see Fig. 1) are briefly described here to acquaint the reader with the fuel plate numbering system. The spherical annular fuel region is comprised of 21 fuel elements. In addition, a fuel-bearing spherical shell composed of four equal parts compactly surrounds the control-mechanism housing and is separated from the core annulus by 1/4 in. of water and 1/4 in. of water and aluminum. Each point in the surface of the cover plates is equidistant from the core center, an arrangement which is quite different from the vertical geometry of the fuel plates of the main fuel region.

Each of eight central elements, which are positioned in the upper and lower sections of the core, contains 40 concentric fuel plates that are of

¹L. B. Holland and C. E. Clifford, Description of the Tower Shielding Reactor II and Proposed Preliminary Experiments, ORNL-2747 (1959).

²C. L. Davis, J. N. Bookston, and B. E. Smith, GNU-II, A Multigroup One-Dimension-Diffusion Program, GMR-101 (1957).

Fig. 1. Fuel Element Arrangement in TSR-II.

varying lengths and are numbered 1 through 40 radially outward from the vertical axis of the core. The cylindrical fuel annulus portion of the fuel region is composed of 12 annular elements, each containing 31 fuel-bearing plates of varying lengths that are numbered 41 through 71 radially outward from the reactor vertical axis also. A single cylindrical plug element consisting of six concentric fuel plates of equal lengths, numbered 2 through 7 radially outward, is centered in the lower central elements.

Power Generation in Fuel-Bearing Spherical Shell

Since the fuel-bearing spherical shell for the control-mechanism housing is separated from the main fuel annulus, the power generation in the shell was calculated separately.

The percent of power generated in the fuel-bearing shell was calculated both for the clean-cold operation and the high-power operation by considering the cover shell as making a complete spherical shell. The calculations were based on machine-code-calculated relative power density distributions over both the shell cover region and the main fuel region weighted by volume shell intervals in each region. The fuel-bearing spherical shell accounts for approximately 2.25% of the power generated in the reactor core for the clean-cold condition and for 2.5% of the power generated at the end of the core life.

The power generated in the fuel-bearing shell was obtained by multiplying the power as determined in a complete spherical shell by 0.700, the ratio of the measured approximate fuel area (4.22 ft^2) to the total area of a complete shell. The power generation distribution was assumed to be uniform over the fuel area; the values obtained were $18,300 \text{ Btu hr}^{-1} \text{ ft}^{-2}$ for clean cold operation and $20,220 \text{ Btu hr}^{-1} \text{ ft}^{-2}$ for high-power operation.

Thermal-Neutron Density; Distribution and Average

Measurements of the relative thermal-neutron density as a function of radial distance across the fuel region were made by gold foil activation measurements taken over several months during initial low-power reactor operation at room temperature (clean-cold operation). The curve for the clean-cold condition in Fig. 2 represents an approximate general fit to the

Fig. 2. Thermal-Neutron Flux Distribution in TSR-II.

accumulated data. Also shown in Fig. 2 is the calculated thermal-neutron density distribution for high-power operation near the end of the core life (i.e., with the shim-safety plates fully withdrawn to account for the temperature rise, xenon poisoning, fuel depletion, and samarium poisoning).

The average relative neutron density was determined from the curves of Fig. 2 by weighting points along intervals of the curves by the square of the radial distance at each interval:

$$n_{av} = \frac{\sum_{i=1}^{14} R_i^2 n_i}{\sum_{i=1}^{14} R_i^2},$$

where R_i = radial distance to center point of interval i , and n_i = relative neutron density from curve at interval i .

Average Power Generation in Fuel Annulus

The average power generation per unit area within the main fuel annulus was considered to be equal to the ratio of the power in that region (1 MW less the power generated in the fuel-bearing cover shells) to the total fuel area of all the fuel plates. From a total fuel area (considering only one side of a fuel plate) in the main fuel region of 328.7 ft², the average power generation per megawatt of reactor power was calculated to be 10,150 Btu hr⁻¹ ft⁻² for clean cold operation and 10,123 Btu hr⁻¹ ft⁻² for high-power operation.

Power Generation and Heat Flux Distribution in Main Fuel Annulus

The power generation for clean-cold operation was obtained from the gold foil activation measurements of the radial thermal-neutron density shown in Fig. 2 and the distribution for high-power operation (1-MW operation at the end of core life) was obtained from a calculated radial neutron density distribution. Since heat is removed from both sides of each fuel plate, the heat flux at any point is just one-half the value of the power generation.

To obtain a power generation distribution it was assumed that the power generation per unit area at each point in the fuel plates was proportional to the thermal-neutron density. Then the average power generated in the fuel annulus was normalized to the average thermal-neutron density in the core to obtain a distribution of power generation per unit area as a function of radial distance across the main fuel annulus as shown in Fig. 3.

With a knowledge of the power generation along any radial vector in the core region, the power generation and the heat flux along the length of a given fuel plate were determined from a series of right-triangle relationships as indicated in Fig. 4. The results of the power generation distributions for four plates in an annular fuel element are shown in Fig. 5. As indicated on the graph, the distribution along the fuel plates of the annular elements begins at their horizontal midplane. Results for three plates in a central fuel element are presented in Fig. 6.

Integration under the distribution curve for a given plate and the subsequent division by the fuel length of the plate gave the average power generation per unit area of the plate. The total power developed in each plate was then obtained by multiplying the average power generation per unit area by the fuel area of the plate. For clean-cold operation the total power developed in each fuel plate of an annular element is shown in Fig. 7, and that developed per fuel plate of a central element is presented in Fig. 8. The power developed per fuel plate of an annular element for 1-MW reactor operation both for clean-cold and high-power operation is listed in Table 1. Similar comparisons are made in Table 2 for a central element and in Table 3 for the cylindrical element.

A summation of the power developed in all fuel plates for all elements gave a total power of 972.6 kW for clean-cold operation and 975.0 kW for high-power operation. This value agreed within approximately 0.5% of that which should have been developed in the main fuel region, that is, 1 MW less the power developed in the fuel-bearing cover-shell region.

Fig. 3. Power Generation Distribution as a Function of Radial Distance Across TSR-II Fuel Region.

$$l_{i,j} = \sqrt{R_i^2 - r_j^2}, \quad j = 1, \dots, 71; \quad i = 1, \dots, 12$$

$$\Delta l = l_{i+1,j} - l_{i,j} = \sqrt{R_{i+1}^2 - r_j^2} - \sqrt{R_i^2 - r_j^2}$$

$$R_1 = 22.86 \text{ cm}; \quad R_{12} = 38.83 \text{ cm}$$

Fig. 4. Right-Triangle Relationships for Determining Incremental Length of TSR-II Fuel Plates in an Annulus of Nearly Constant Power Generation.

Fig. 5. Power Generation Distribution in Fuel Plates of a TSR-II Annular Element as a Function of the Distance from the Horizontal Midplane to the Edge of the Fuel.

Fig. 6. Power Generation Distribution in Fuel Plates of TSR-II Central Element as a Function of the Distance from the Inside Edge of the Fuel.

Fig. 7. Power Generated per Fuel Plate of an Annular Fuel Element of the TSR-II.

Fig. 8. Total Power Generated per Fuel Plate of a Central Fuel Element of the TSR-II as a Function of Plate Number.

Table 1. Power Generation in Fuel Plates of a TSR-II
Annular Element for Clean-Cold and High-Power
Reactor Operation

Plate No.	Power Generation (kW/1-MW Reactor Power)		Plate No.	Power Generation (kW/1-MW Reactor Power)	
	Clean Cold	High Power		Clean Cold	High Power
41	2.020	2.097	56	1.849	1.830
42	2.060	2.092	57	1.803	1.790
43	2.031	2.081	58	1.754	1.744
44	2.036	2.075	59	1.704	1.690
45	2.037	2.070	60	1.650	1.635
46	2.038	2.060	61	1.593	1.576
47	2.033	2.055	62	1.529	1.504
48	2.028	2.040	63	1.460	1.430
49	2.020	2.026	64	1.382	1.352
50	2.006	2.012	65	1.299	1.272
51	1.990	1.993	66	1.205	1.184
52	1.970	1.970	67	1.302	1.088
53	1.956	1.940	68	0.990	0.970
54	1.916	1.910	69	0.853	0.830
55	1.882	1.872	70	0.664	0.660
			71	0.443	0.433

Table 2. Power Generation in Fuel Plates of a TSR-II Central Fuel Element for Clean-Cold and High-Power Reactor Operation

Plate No.	Power Generation (kW/1-MW Reactor Power)		Plate No.	Power Generation (kW/1-MW Reactor Power)	
	Clean Cold	High Power		Clean Cold	High Power
1	0.2254	0.2266	21	1.006	1.010
2	0.2580	0.2600	22	1.058	1.060
3	0.2920	0.2940	23	1.106	1.110
4	0.3280	0.3300	24	1.158	1.164
5	0.3620	0.3640	25	1.210	1.217
6	0.3960	0.3980	26	1.266	1.275
7	0.4330	0.4360	27	1.322	1.332
8	0.4690	0.4730	28	1.380	1.390
9	0.5060	0.5100	29	1.440	1.454
10	0.5428	0.5464	30	1.505	1.518
11	0.5800	0.5850	31	1.574	1.586
12	0.6200	0.6250	32	1.649	1.659
13	0.6600	0.6640	33	1.726	1.735
14	0.6970	0.7040	34	1.808	1.824
15	0.7380	0.7440	35	1.909	1.930
16	0.7800	0.7860	36	2.010	2.044
17	0.8220	0.8300	37	2.122	2.176
18	0.8640	0.8720	38	2.240	2.320
19	0.9100	0.9160	39	2.390	2.484
20	0.9562	0.9594	40	2.592	2.660

Table 3. Power Generation in Fuel Plates of a TSR-II
Cylindrical Element for Clean-Cold and
High-Power Reactor Operation

Plate No.	Power Generation (kW/1-MW Reactor Power)	
	Clean Cold	High Power
2	0.310	0.315
3	0.442	0.450
4	0.574	0.581
5	0.708	0.714
6	0.840	0.846
7	0.970	0.979

Peak-to-Average Power

The ratio of the peak-to-average power generation calculated for the main fuel region was 1.20 for clean cold operation and 1.37 for high-power operation. The ratio of the power generation in the fuel-bearing cover shells to the average in the main fuel region was 1.80 for clean cold operation and was 2.00 for high-power operation.

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