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PRE-EXPERIMENT ANALYSIS
FOR MSBR-1 EXPERIMENT.

E. P. LIPPINCOTT
E. C. DAVIS

authors

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Pre-Experiment Analysis for MSBR-1 Experiment

by

E. P. Lippincott and E. C. Davis

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Description of Experiment

A reactor lattice physics experiment is currently being prepared for the High Temperature Lattice Test Reactor (HTLTR) in support of the Molten Salt Breeder Reactor (MSBR) program. The lattice to be measured will utilize solid fuel in lieu of actual molten salt fuel. The dimensions of the fuel channels and the composition of the fuel mixture are designed to provide physics parameters close to those of the MSBR design.

The standard lattice is being constructed of graphite blocks 3-3/4-inch square with four fuel channels 0.786-inch in diameter. The fuel channels are filled with a mixture of graphite particles, ThO_2 particles and $^{233}\text{UO}_2$ - ThO_2 pyrocarbon coated microspheres. The mixing of the fuel blend and loading into the blocks is carried out with similar materials and methods as were used in loading the blocks for the HTGR lattices previously measured in the HTLTR. The completed blocks have a C/ ^{233}U atom ratio of about 9700 and C/Th ratio of about 150.

The central cells to be used in the MSBR experiment are shown in Figure 1. The results to be obtained from measurements on these cells are listed in Table I. The standard central cell will be used to measure k_{∞} for the lattice. Perturbations of the standard central cell design will be used to determine other coefficients necessary to predict the reactor physics behavior of an actual MSBR.

A. STANDARD

B. 1-9/16" DIA.

C. 2-37/64" DIA.

D. 4" DIA.

E. 6" DIA.

F. CRUCIFORM

FIGURE 1: MSBR CENTRAL CELLS

TABLE I

MSBR Experimental Measurements in HTLTR

Standard Lattice k_{∞}

Th Resonance Integral

Fuel Density Coefficient of Reactivity

Effects of Fuel Geometry

Graphite Control Rod Worth

Shutdown Rod Worth

Material Worth Measurements

Copper	^{233}U
Graphite	^{235}U
Beryllium	^{239}Pu
Lithium	INOR-8 (Hastelloy N)
Fluorine	^{233}U - Th - C Fuel Mixture
Thorium	

Three cells will be constructed as shown in Figure 1A: the standard cell, a cell with V_2O_3 in place of ThO_2 to determine the thorium resonance integral, and a reduced density cell for the density coefficient. The cells in Figure 1B and 1F have the same volume of fuel as the standard cell and will provide information on fuel geometry effects. Other effects of geometry with different amounts of fuel will be measured by cells illustrated in Figure 1C, 1D, and 1E, and replacement of these cells with a solid graphite block will indicate graphite control rod worths. A second block with design similar to Figure 1F will be constructed with hastelloy N in place of the fuel to measure shutdown rod worth. The sample position in the cruciform block will be used to measure material worths by substitution of various elements that would be used in an MSBR. The lithium and fluorine worths will be measured using LiF and teflon.

Measurements will be made at room temperature, $300^{\circ}C$, $627^{\circ}C$, and $1000^{\circ}C$, except for the teflon (to $300^{\circ}C$ only) and the LiF and Be (to $627^{\circ}C$ only). The $627^{\circ}C$ measurements will provide important data at the MSBR design operating temperature. The $300^{\circ}C$ and $1000^{\circ}C$ measurements will provide data for evaluation of temperature coefficients at the operating temperature. Measurements between room temperature and $627^{\circ}C$ will provide data useful in design of the control system for startup.

Lattice Parameter Calculations

Preliminary calculations have been carried out using EGGNIT for the epithermal region (above .683 ev) and GRANIT for the thermal region. These calculations are similar to ones reported previously for the HTGR lattices. The loading used in the calculations is the design loading described in Table II. The actual loading will differ only slightly from these values. The calculation ignored the end caps and thus is for an infinite fuel channel length.

The results of the calculations at room temperature and at 1000°C are presented in Table III. Included are the lattice parameters and the value of k_{∞} for fundamental mode fluxes by the equation:

$$k_{\infty} = \frac{v_1 \Sigma_1^f \phi_1 + v_2 \Sigma_2^f \phi_2}{\Sigma_1^a \phi_1 + \Sigma_2^a \phi_2}$$
$$= \frac{\eta_2 f_2 p + \eta_1 f_1 (1-p)(1+L^2 B^2)}{1+(1-p)L^2 B^2}$$

The results indicate a decrease in k_{∞} between room temperature and 1000°C of 0.043 which the experiment can measure to an accuracy of 5%.

TABLE II

Basic ^{233}U Fuel Design Specifications for MSBR-1

	Can 20	Can 22	Eff Value
Kernel particle size	279 μ	319 μ	301.5 μ
Weight of microsphere	209.0 gm	268.93 gm	477.93 gm
Weight of ^{233}U	28.6243 gm	35.2054 gm	63.8297 gm

$$\frac{\text{C in moderator over 23-inches length}}{^{233}\text{U in fuel channel}} = 9000$$

$$\frac{\text{Total C over 23-inches}}{^{233}\text{U over 23-inches}} = 9680.2$$

$$\frac{\text{C in moderator over 23-inches length}}{\text{Th in fuel channel}} = 138.5$$

$$\frac{\text{Total C over 23-inches}}{\text{Thorium 23-inches}} = 149.0$$

Weighted average for
Isotopic Rates:

$$^{233}\text{U}; ^{234}\text{U}; ^{235}\text{U}; ^{236}\text{U}; \text{ and } ^{238}\text{U}$$

$$0.97444; 0.01047; 0.00092; 0.00007$$

$$\text{and } 0.01413$$

$$\text{Density of graphite in fuel rod} = 0.9272 \text{ gm/cm}^2$$

$$\text{Density of graphite in moderator} = 1.6171 \text{ gm/cm}^3$$

$$\text{Radius of fuel rod} = 0.99219 \text{ cm}; \text{ total volume fuel} = 2890.82 \text{ cm}^3$$

$$\text{Effective cell radius} = 2.68695 \text{ cm}; \text{ total volume moderator region} = 18309.88 \text{ cm}^3$$

$$VF_1^R = 0.136355$$

$$VF_2^R = 0.863645$$

$$\frac{\text{Volume of Graphite powder and PyC}}{\text{Volume of fuel}} = 0.834897$$

$$\frac{\text{Volume of Kernel (U,Th)O}_2}{\text{Volume of Fuel}} = 0.0099283$$

TABLE II, continued

$$\frac{\text{Volume of ThO}_2 \text{ Powder}}{\text{Volume of Fuel}} = 0.1551747$$

Basic Data Used for Room Temperature Calculations

		GRANIT*	EGGNIT*
Mix #1	Graphite N(C)	0.0565094	0.0388305
Mix #3	ThO ₂		
	N(Th)	0.0228184	
	N(O)	0.0456368	
Mix #4	Kernel (U,Th)O ₂		
	N(Th)	0.0169334	0.00370896
	N(O)	0.0456679	0.0075350817
	N(233U)	0.00574976	0.0000570853
	N(234U)	0.000061779	0.0000006134
	N(235U)	0.0000054285	0.0000000539
	N(236U)	0.0000004130	0.0000000041
	N(238U)	0.0000833751	0.0000008278
Mix #2	Graphite		
	Moderator N(C)	0.08111552	0.08111552

*Atoms/Barn-Cm

TABLE III

Lattice Parameters and k_{∞}

	$\frac{20^{\circ}\text{C}}{312.2}$	$\frac{1000^{\circ}\text{C}}{303.1}$
τ		
$\eta_1 f_1$	0.7262	0.6011
p	0.7079	0.6631
L^2	182.3	276.6
$\eta_2 f_2$	1.1773	1.2039
B^2	1.0×10^{-4}	1.5×10^{-6}
k_{∞}	1.044	1.001

Reactor Calculations

To determine an acceptable HTLTR loading and to predict the flux match, calculations have been carried out using the two-dimensional diffusion theory code 2-DB. The HTLTR model used for HTGR lattice calculations was used. MSBR lattice blocks were arranged in a 6 x 6 array (the geometry is identical to the HTGR lattices) and one row of lattice blocks surrounded the array making a total 8 x 8 array. In the HTGR-2 and HTGR-3 experiments, ^{235}U blocks from HTGR-1 were left in this outer row. A comparison was made of the effect of keeping the ^{235}U blocks in this row or replacing them with HTGR-3 blocks or MSBR-1 blocks. The effect of this substitution with the same driver and shim loading as for HTGR-2 and HTGR-3 is presented in TABLE IV. For the best flux match, the ratio in the last column should be 1.0. It is seen that the best match is obtained with the ^{235}U blocks in this row and the mismatch at room temperature with this loading is calculated to be only 0.5%.

TABLE IV

^{233}U Refinements for MSBR-1 Loading with Variations
in Outer Ring #4 Based on Cadmium Ratios

Summary of Room Temperature Calculation for Cadmium Ratio at
Axial Position #5 which is 13.335 cm from Centerline of Core

Calculation	Outer Row	Radial #1*	Radial #13*	Ratio 13/1
2 DB #1	^{235}U ; HTGR-2,-3	1.5336	1.5417	1.0053
2 DB #2	HTGR-3	1.5555	1.6403	1.0545
2 DB #3	MSBR-1	1.5396	1.5740	1.0223

Summary of 1000°C Temperature Calculation for Cadmium Ratio of
Axial Position #5 which is 13.335 cm from Centerline of Core

2 DB #4	^{235}U ; HTGR-2,-3	1.7980	1.8176	1.0109
2 DB #5	HTGR-3	1.8443	1.9800	1.0736
2 DB #6	MSBR-1	1.8112	1.8691	1.0320

Summary of Adjoint Calculation for ϕ_2^+/ϕ_1^+
Axial Position #5 which is 13.335 cm from Centerline of Core

2 DB #7 Room Temp.	^{235}U ; HTGR-2,-3	1.1555	1.2222	1.0577
2 DB #8 1000°C	^{235}U ; HTGR-2,-3	1.2191	1.2715	1.0430

*Position #1 is at the reactor center (radially); Position #13 is at the edge of the MSBR lattice region.

In Table V, the flux ratios calculated by 2 DB are compared with the fundamental mode values derived from the EGGNIT and GRANIT results. The difference in the direct flux ratios is greater than indicated by the mismatch and is due to the perturbation caused by the end cap graphite. A similar effect was corrected for in the HTGR Lattices.

The flux ratios calculated for the MSBR-1 lattice are close to those for the HTGR-2 lattice. Therefore, it is expected that the temperature coefficient of the HTLTR will be close to the values measured in the HTGR-2 experiment, and the room temperature fuel loading will be based on this assumption to operate to 1000°C.

Reactivity Estimates

An estimate of the worth of the central cell gives a value of 4.0¢ not including end caps, based on an assumed worth of copper of .021¢/gm. Reactivity estimates for the central cells with similar amounts of fuel but different geometry have not been made but should be close to 4¢. Estimates for the solid graphite block, block with 6-inch diameter fuel and 4-inch diameter fuel are +16.5¢, -17.0¢, and +1.9¢, respectively.

An estimate of the reactivity worth of the hastelloy N block gave a value of \$2.70. Since measurement of reactivities of this magnitude presents problems, the block was redesigned to eliminate 60% of the metal. Further reduction was not possible if the original purpose of the measurement

TABLE V

DIRECT AND ADJOINT FLUX RATIOS COMPARED TO FUNDAMENTAL MODE VALUES

Center of Cell
(Radial #1, Axial #5)

Direct Flux ϕ_1/ϕ_2	Adjoint Flux ϕ_1^+/ϕ_2^+
-----------------------------------	--

ROOM TEMPERATURE COMPARISON

2 DB Flux Ratio	1.8740	.8654
Fundamental mode Flux Ratio	1.9342	.8648
% Error	3.2%	0.1%

1000°C TEMPERATURE COMPARISON

2 DB Flux Ratio	1.2531	.8203
Fundamental mode Flux Ratio	1.2880	.8310
% Error	2.8%	1.3%

was to be retained, i.e., to measure the worth of realistic safety blades in geometry similar to that to be used in a MSBR. The total worth of the hastelloy in the new block will be about \$1.60. An incremental procedure will be used to measure this reactivity and the measurement will also provide information on the interaction between the hastelloy pieces as they are loaded.

Estimates for reactivities of the samples used in the material worth measurements were also made at ORNL. These were used to determine the amount of material needed to give 5¢ reactivity when the amount of material that could be used was flexible. The results of this analysis are presented in Table VI.

TABLE VI

MATERIAL REACTIVITY ESTIMATES

Material	Estimated Reactivity*
Graphite Rod	0.0¢
Graphite Powder	-0.3¢
Void	-1.0¢
Copper Foil on Graphite Rod (212 gm.)	-4.5¢
Beryllium Rod	+2.0¢
Teflon Rod	-0.8¢
LiF in Tube	-2.2¢
ThO ₂ Powder** (250 gm)	-5¢
²³³ U + Th Particles** (7.5 gm ²³³ U)	+5¢
²³⁵ U Particles** (10.0 gm ²³⁵ U)	+5¢
²³⁹ Pu Coated Particles** (4.6 gm ²³⁹ Pu)	+5¢
Hastelloy N Foil on Graphite rod	-5.7¢
MSBR-1 Fuel Mixture	-7.1¢

*Reactivity change expected when solid graphite rod is replaced with tube containing material

**Material diluted with graphite powder

Conclusions

The pre-experiment analysis for the MSBR-1 experiment has determined that this experiment as designed, can be carried out safely and conveniently. The analysis indicates that a good measurement of the temperature coefficient of k_{∞} can be made. In addition, a close flux match should be achieved. The analysis pointed to some difficulty in measurement of the hastelloy block and the block was redesigned to lessen this difficulty.

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