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REACTIVITY MEASUREMENTS OF VARIOUS TARGET
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REACTIVITY MEASUREMENTS OF VARIOUS TARGET ELEMENTS

W. A. BLYCKERT

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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REACTIVITY MEASUREMENTS OF VARIOUS TARGET ELEMENTS

INTRODUCTION

The amount of enriched uranium to support various type of target elements was determined in the Hanford Test Reactor. This report describes the measurement of separate and striped loadings for canned thorium oxide, bismuth, lithium-aluminum, and, in addition, bare depleted uranium. This experiment was undertaken to provide information needed to estimate the E-metal requirements in a production reactor when replacing natural uranium with target material. The amount of enriched uranium which is required to maintain the reactivity in support of target materials must be known to properly predict total reactor reactivity. Danger coefficient measurements were made during original startup tests to provide this information. However, fuel dimensions have changed and new target materials have been introduced which have not been tested in this manner. The target of particular interest at this time is thorium oxide.

SUMMARY

The length ratios of standard I&E canned E-metal (O3E) to various target materials required to provide the same reactivity as standard I&E natural fuel (O3N) in the Hanford Test Reactor (dry condition) were found to be 13.5, 4.80, 3.10, and 0.33 for striped loadings of lithium-aluminum, thorium oxide, depleted uranium, and bismuth, respectively. The measured length ratios for separate fuel and target column loadings were 13.7, 4.66, 2.83, and 0.54, respectively, for the same target materials. These results should aid in the prediction of fuel-target ratios in the production reactors. However, because of the limited test size and lattice differences between the dry HTR and the wet production reactor lattices, the values should not be used directly. Specifically, the test in the dry oversized HTR lattice underestimates the enrichment required to support low cross-section targets.

DISCUSSION

Test Details

The materials measured consisted of canned thorium oxide, bismuth, lithium-aluminum, and bare depleted uranium. The target materials were solid cylinders and the depleted uranium was in I&E form. Pertinent information on the test material is given in Table I.

The reactivity testing was conducted in the Hanford Test Reactor (dry condition) using the period technique¹. The four-inch canned uranium standards were used as the base. The reactivity of canned natural uranium (O3N) was measured and the reactivity of various combinations of striped loadings of E-metal (0.947 per cent U-235 by weight) (O3E) and target material were measured. By varying the ratio of E-metal to target, the reactivity of natural uranium was bracketed. The reactivity of target material by itself and of E-metal by itself were also determined. The position of each test piece in the metal stringer was carefully noted to allow subsequent analysis. Details are recorded in Appendix A.

1. E. E. Fitch, Jr. Hanford Test Reactor Operating Manual, HW-59085. February 3, 1959. (Secret).

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TABLE 1
TEST MATERIAL CHARACTERISTICS

<u>Test Material</u>	<u>Bare Core Dimensions</u>			<u>Density (g/cc)</u>	<u>Enrichment (w/o)</u>
	<u>OD (In.)</u>	<u>ID (In.)</u>	<u>Length (In.)</u>		
ThO ₂	1.345	--	8.458	8.00	--
Bi	1.343	--	6.000	10.0	--
LiAl ^a	1.341	--	5.70	2.46	40.5 Li-6
Depleted U	1.356	0.423	7.378	18.9	0.2 U-235
Natural U	1.356	0.423	8.378	18.9	0.711 U-235
E Metal	1.356	0.423	6.053	18.9	0.947 U-235

a Contains three per cent by weight Li in Al

Test Analysis

The analysis of the results of the measurements was dependent upon the accuracy of the observation of the reactor period and on the location of the test pieces in the stringer. It was assumed that the flux shape remained unperturbed in a cosine shaped distribution. The square of the flux factors of each test piece were summed to give the total flux factor squared weighting of the test pieces. The results were adjusted to an equivalent full-length test column. The change in reactivity for striped columns as compared to a full-length natural uranium column was noted and plotted in Figure 1 through 4. The ratios of E-metal to target material required for the striped loadings and for loadings of separate columns are given in Table 2 (dry condition).

TABLE 2
ENRICHMENT REQUIREMENT TO SUPPORT TARGET MATERIAL

<u>Target Material</u>	<u>E-Metal/Target Material (Dry Condition)</u>					
	<u>Striped Loading</u>			<u>Separate Columns</u>		
	<u>Length Ratio</u>	<u>Volume Ratio</u>	<u>Piece Ratio</u>	<u>Length Ratio</u>	<u>Volume Ratio</u>	<u>Piece Ratio</u>
ThO ₂	4.80	4.40	6.71	4.66	4.28	6.51
Bi	0.334	0.307	0.331	0.536	0.493	0.531
LiAl	13.5	12.5	13.4	13.7	12.6	13.6
Depleted U	3.10	3.10	3.78	2.83	2.83	3.45

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LENGTH RATIO OF E-METAL TO THORIA VS REACTIVITY (DRY)

Nat.
0

$\Delta \rho (\Delta ih)$

10
5
0
-5
-10
-15
-20
-25
-30
-35
-40

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Identifying numbers refer to specific test numbers of Appendix A.

FIGURE 2 - LENGTH RATIO OF E-METAL TO BISMUTH VS REACTIVITY (DEY)

Identifying numbers refer to specific Test Numbers of Appendix A.

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FIGURE 3
LENGTH RATIO OF E-METAL TO LITHIUM-ALUMINUM VS REACTIVITY (DRY)

Identifying numbers refer to fig. 1. Test Numbers of Appendix A.

FIGURE 4

LENGTH RATIO OF E-METAL TO DEPLETED URANIUM VS REACTIVITY (DRY)

A correlation was made between the amount of E-metal to support target material (for full-length columns) and the thermal blackness of the material. The successive generations method of Stuart and Woodruff² was used. The thermal blackness and absorptivity (assumed proportional to A_{∞}) of an equivalent full length column in the HTR are given in Table 3 and plotted in Figure 5.

TABLE 3
THERMAL BLACKNESS AND NEUTRON ABSORPTIVITY

<u>Test Material</u>	<u>Blackness (ρ)</u>	<u>Absorptivity Change (Δk)</u>
ThO ₂	0.30	190.
Bi	0.038	21.9
LiAl	0.97	561.

It may be seen that there is an approximate correlation between blackness and the absorptivity of the target material. This correlation should be useful in estimating E-metal requirements for new applications where separate column loadings are used.

The measurements made in the HTR were compared with those wet, danger coefficient measurements previously made in the C and K Reactor startups^{3,4,5}. The measured reactivity worths of target materials were used to balance the worth of E-metal and normalized to wet, I&E, natural-uranium fuel for the C Reactor and wet, solid, natural-uranium fuel for the K Reactor. These length ratios are tabulated in Table 4. Bailey's⁶ values for E-metal worths were used in this analysis.

The thermal blacknesses of the target materials are plotted in Figure 6 against the length ratio of E-metal to target material for the HTR, C, and K Reactor determinations.

The calculation of the target blackness did not account for the effect of the water surrounding the material. The effect of the water would be to decrease the blackness, thus moving the calculated points for the wet experiments in Figure 6 closer to the dry experimental determination.

2. G. W. Stuart and R. W. Woodruff. "Method of Successive Generations," Nuclear Sci. and Eng., VOL3, pp. 339-373. 1958.
3. D. K. McDaniels and G. C. Fullmer. C Pile Startup Technical Data, HW-29034. September 1, 1953. (Secret)
4. C. L. Miller. K Pile Startup Experiments, Part III, Reactivity Effects of Fuel and Target Materials, HW-37158 PT3. April 2, 1956. (Secret)
5. D. E. Simpson and W. H. Wolf. Reanalysis of Lattice Parameter and Danger Coefficient Measurements from Start-up Data - C and K Piles, HW-58149. November 7, 1958. (Secret)
6. G. F. Bailey. An Operational Reactivity Accounting System Based on One-Group Diffusion Theory, HW-70780. April 1, 1962. (Secret)

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FIGURE 5 - TARGET THERMAL BLACKNESS VS CHANGE IN ABSORPTIVITY
 (DRY SEPARATE COLUMNS) RL-REA-220

FIGURE 6 - E-MEAL REQUIREMENTS FOR VARIOUS TARGET MATERIALS

TABLE 4

TARGET-SUPPORTING
E-METAL REQUIREMENTS TO MATCH REACTIVITY OF NATURAL URANIUM

<u>Target Material</u>	<u>Column E-Metal/Column Target</u>			<u>Thermal Blackness (Dry)</u>
	<u>C Reactor^a</u>	<u>K Reactor^b</u>	<u>HTR^c</u>	
Bi	1.17	0.826	0.536	0.038
Th	6.05	5.39	--	0.49
ThO ₂	--	--	4.66	0.30
LiAl (3.5 w/o Li) ^d	8.92	7.65 ^f	--	0.79
LiAl (3.0 w/o Li) ^e	--	--	13.7	0.97

- a. Wet measurement; normalized to wet natural uranium I&E fuel
b. Wet measurement; normalized to wet natural uranium solid fuel
c. Dry measurement; normalized to dry O3N fuel
d. Continuing naturally occurring lithium
e. Containing lithium enriched to 40.5 w/o lithium-6
f. Calculated from C Reactor measurements

CONCLUSIONS

The results of dry measurements of the E-metal requirements to support various target materials indicate that the requirements are approximately the same for either the stripe or separate column loadings, except for bismuth, where one would expect a difference because of its small blackness. The comparison with previous wet danger coefficient measurements indicate that while dry measurement correlation may be used to approximate E-metal requirements, improvement in the calculation of the effect of water on blackness will be necessary before direct application of the dry experimental results may be made to the wet condition. It might also be noted that the reactivity of natural uranium is not sufficient to operate the production reactors now and that enrichment must be added to provide additional reactivity. Enrichment requirements to support target materials would therefore be in excess of those reported here.

ACKNOWLEDGMENTS

The assistance of G. F. Owsley in conducting the experiment and the personnel of the Hanford Test Reactor in operating the equipment is gladly acknowledged with thanks.

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APPENDIX A

RECORDED TEST OBSERVATIONS

<u>Test No.</u>	<u>Period (sec)</u>	<u>Case</u>	<u>Material Locations^a</u>
1	24.7	Base - 4" Canned Standard	
2	25.0	9 Canned Nat. U	1' 10-1/8" to 8' 6" NU.
3	33.2	10 Bi	2' 5-1/4" to 7' 9-1/2" Bi.
4	21.6	5 Bi - 4 E	2' 6-1/4" to 3' 0-3/4" Bi; 3' 7-1/4" E; 4' 1-7/8" Bi; 4' 8-1/2" E; 5' 2-7/8" Bi; 5' 9-1/2" E; 6' 4" Bi; 6' 10-3/4" E; 7' 5" Bi.
5	23.0	6 Bi - 3 E	2' 6-1/2" to 3' 7-3/8" Bi; 4' 2" E; 4' 8-1/2" Bi; 5' 3" E; 5' 9-1/2" Bi; 6' 4-1/8" E; 7' 5" Bi.
6	25.4	7 Bi - 2 E	2' 6-7/8" to 3' 7-11/16" Bi; 4' 2-5/16" E; 5' 9-1/2" Bi; 6' 4-1/8" E; 7' 5" Bi.
7	24.9	7 Nat. U	2' 2-3/4" to 7' 5-1/8" NU.
8	47.8	3 ThO ₂ - 8 E	1' 10" to 2' 11-1/4" E; 3' 8-3/8" Th; 4' 9-1/2" E; 5' 6-5/8" Th; 6' 7-3/4" E; 7' 4-7/8" Th; 8' 6-1/8" E.
9	31.4	2 ThO ₂ - 9 E	1' 8-3/8" to 3' 4-1/8" E; 4' 1-1/4" Th; 5' 9" E; 6' 6" Th; 8' 1-7/8" E.
10	30.0	2 ThO ₂ - 9 E	1' 8-3/8" to 2' 9-1/2" E; 3' 6-5/8" Th; 6' 3-1/2" E; 7' 0-1/2" Th; 8' 1-7/8" E.
11	21.9	1 ThO ₂ - 10 E	1' 11-1/8" to 4' 7-7/8" E; 5' 4-7/8" Th; 8' 1-7/8" E.
12	15.5	10 E	2' 3-7/8" to 7' 9-1/2" E.
13	24.7	Standard	
14	24.1	Standard	
15	56.1	2 ThO ₂	4' 0-7/8" to 5' 7-3/8" Th.
16	23.9	1 ThO ₂ - 8 E	2' 3-1/2" to 4' 5-3/4" E; 5' 2-3/4" Th; 7' 5-1/8" E.
17	25.7	1 ThO ₂ - 6 E	3' 0-1/8" to 4' 7-7/8" E; 5' 5" ThO ₂ ; 7' 0-7/8" E.

a. Centerline was at the 5' mark.

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APPENDIX A (Cont'd)

<u>Test No.</u>	<u>Period (sec)</u>	<u>Case</u>	<u>Material Locations^a</u>
18	27.0	2 ThO ₂ - 9 E	1' 8-1/2" to 2' 5-1/2" Th; 7' 4-5/8" E; 8' 1-7/8" Th.
19	20.7	3 E	4' 4" to 5' 11-3/4" E.
20	28.0	1 ThO ₂ - 4 E	3' 4-5/8" to 4' 5-7/8" E; 5' 2-3/8" Th; 6' 4-1/8" E.
21	24.1	Standard	
22	37.5	1 LiAl - 6 E	3' 3-1/4" to 4' 10-3/4" E; 5' 5" Li; 7' 0-3/4" E.
23	31.2	1 LiAl - 10 E	2' 2" to 4' 10-3/4" E; 5' 5" Li; 8' 1-3/4" E.
24	29.4	1 LiAl - 10 E	2' 2" to 3' 3-1/4" E; 3' 9-3/8" Li; 8' 1-3/4" E.
25	26.1	1 LiAl - 10 E	2' 2-1/8" to 2' 8-1/4" Li; 8' 1-3/4" E.
26	24.1	Standard	
27	24.2	Standard	
28	21.5	6 E - 1 Depleted U	3' 1-7/8" to 4' 9-5/8" E; 5' 5" D; 7' 0-3/4" E.
29	24.0	4 E - 1 D	3' 6-1/4" to 4' 7-1/2" E; 5' 2-7/8" D; 6' 4-1/8" E.
30	26.2	2 E - 1 D	4' 3" to 4' 9-5/8" E; 5' 5" D; 5' 11-3/4" E.
31	29.6	8 E - 3 D	1' 10-3/4" to 3' 6-1/2" E; 4' 2" D; 4' 8-1/2" E; 5' 4" D; 5' 10-1/2" E; 6' 6" D; 8' 1-5/8" E.
32	27.0	8 E - 3 D	1' 11-1/8" to 2' 6-1/2" D; 4' 8-3/4" E; 5' 4" D; 7' 6-1/4" E; 8' 1-3/4" D.
33	23.2	9 E - 2 D	1' 11-1/2" to 3' 7-1/4" E; 4' 2-5/8" D; 5' 10-1/4" E; 6' 5-3/4" D; 8' 1-3/4" E.
34	24.4	Standard	

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