**Critical Experiments
Measuring the Reactivity
Worths of Materials Commonly
Encountered as Fixed
Neutron Poisons**

by
**S. R. Bierman
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October 1976

Prepared for the Nuclear Regulatory Commission

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SUMMARY

There is a continuing interest in the use of fixed neutron absorbers (poisons) for criticality control, since their use would permit safely handling larger quantities of nuclear materials with reduced probability of criticality. The effectiveness of such absorbers as neutron poisons depends on self-shielding effects which in turn are determined by the magnitude of the absorption cross sections and their variation with energy, the thickness of material, and the neutron energy spectrum. Experiments were previously performed, and reported on,^(1,2) which provided data on the reactivity worths of copper and copper containing 1 wt% cadmium at several thicknesses and in two different neutron energy spectrums. The results from similar experiments using

- 304-L steel,
- 304-L steel containing 1.1 wt% Boron
- 304-L steel containing 1.6 wt% Boron
- Uranium depleted to 0.2 wt% ²³⁵U
- Boral
- Cadmium
- Lead

as fixed poisons are presented in this report and provide sets of clean, well defined, poisoned critical assemblies that can be used to check calculational techniques and cross section data in two different neutron energy spectrums.

The measurement data, currently being reported, are limited to a single region of a given absorber material in each critical assembly. Combinations of absorber materials or multi-regions were not investigated; however, material thicknesses were varied from zero up to about 60 mm.

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MATERIALS COMMONLY ENCOUNTERED AS FIXED NEUTRON POISONS

S. R. Bierman, B. M. Durst and E. D. Clayton

INTRODUCTION

Shipping casks, storage facilities, and process vessels involved in handling fissile materials contain neutron absorbing materials - either for their neutron absorbing properties or for structural and biological shielding reasons. These types of systems can be fully utilized, safely, only if the neutron absorbers are properly accounted for in the criticality analyses. The results from measurements on two such materials, copper and copper containing 1 wt% cadmium, were reported on previously.^(1,2) Since that time, the reactivity worths of several other materials, commonly considered for use as either fixed neutron poisons or biological shields, have been measured. The results of these latter measurements are presented in this report and provide a set of clean, well defined, poisoned critical assemblies that can be used to check calculational techniques and cross section data.

As in the earlier measurements, two different fuels were utilized in these measurements to provide data on the relative worths of the following materials in systems of differing neutron energy spectrum:

304-L Steel
304-L Steel Containing 1.1 wt% Boron
304-L Steel Containing 1.6 wt% Boron
Uranium Depleted to 0.2 Wt% ²³⁵U
Boral
Cadmium
Lead

Both sets of fuel were homogeneous mixtures of PuO₂-UO₂-polystyrene having Pu concentrations typical of the LMFBR fuels. One set had an atomic H:Pu+U ratio

of 30.6 and contained 14.6 wt% PuO_2 in the oxide. The second set had an atomic H:Pu+U ratio of 2.8 and contained 29.3 wt% PuO_2 in the oxide.

GENERAL DESCRIPTION OF EXPERIMENTS

Critical approach neutron multiplication measurements were made with each of the two fuels containing no poison material, and with several thicknesses of each of the previously listed materials. In each case, the critical assemblies consisted of rectangular parallelepipeds of closely packed fuel, fully reflected with at least 150 mm of Plexiglas (a methacrylate plastic). The geometry of these experimental assemblies is typified, graphically, in Figure 1. All of the assemblies had a constant base of 8 fuel compacts on a side. Criticality was approached by adding fuel compacts to the top face.

The fuels were in the form of compacts about 51 mm on a side, having thicknesses of about 51 mm and 14 mm, and containing a homogeneous mixture of PuO_2 - UO_2 -polystyrene, clad in about 0.12 mm thick tape. A detailed description of the two fuels and the reflector material is given in Table I.

The fixed poisons were in the form of plates having essentially the same length and width dimensions as the critical assemblies. Plate thicknesses varied from about 1 mm for the cadmium plates up to a maximum of about 13 mm for the uranium and lead plates. The plates were positioned in a single region parallel to, and at a fixed distance from, the bottom face of each assembly. The thickness of the poison region was varied, in each case, by stacking plates one on top of the other. The composition of each plate is given in Table II. The different thicknesses at which measurements were made, and the poison region location, can be obtained from Tables III and IV.

PHYSICAL MODEL OF PuO_2 - UO_2 -POLYSTYRENE ASSEMBLIES
SINGLE NEUTRON POISON PLATE

FIGURE 1

TABLE I

DESCRIPTION OF EXPERIMENTAL FUEL AND REFLECTOR MATERIAL

	2.8 H: Pu + U FUELED EXPERIMENTS			30.6 H: Pu + U FUELED EXPERIMENTS		
• CLADDING MATERIAL PER COMPACT, g	2.432			3.175		
• CLADDING DENSITY, kg/m ³	1120			1120		
• COMPOSITION OF CLADDING, 10 ³⁰ atoms/m ³						
H	4.489 x 10 ⁻²			4.489 x 10 ⁻²		
C	3.110 x 10 ⁻²			3.110 x 10 ⁻²		
Cl	0.724 x 10 ⁻²			0.724 x 10 ⁻²		
• COMPOSITION OF REFLECTOR, 10 ³⁰ atoms/m ³						
H	5.666 x 10 ⁻²			5.666 x 10 ⁻²		
C	3.570 x 10 ⁻²			3.570 x 10 ⁻²		
O	1.428 x 10 ⁻²			1.428 x 10 ⁻²		
• COMPOSITION OF FUEL COMPACTS, 10 ³⁰ atoms/m ³						
²⁴¹ Am	1.019 x 10 ^{-5(a)}			4.843 x 10 ^{-7(b)}		
²³⁹ Pu	2.203 x 10 ⁻³			1.953 x 10 ⁻⁴		
²³⁸ Pu	1.833 x 10 ⁻⁶			0.0		
²⁴⁰ Pu	2.931 x 10 ⁻⁴			1.702 x 10 ⁻⁵		
²⁴¹ Pu	4.934 x 10 ^{-5(a)}			1.211 x 10 ⁻⁶		
²⁴² Pu	5.636 x 10 ⁻⁶			8.040 x 10 ⁻⁸		
O	1.869 x 10 ⁻²			3.019 x 10 ⁻³		
²³⁸ U	6.172 x 10 ⁻³			1.252 x 10 ⁻³		
²³⁵ U	9.401 x 10 ⁻⁶			1.904 x 10 ⁻⁶		
H	2.417 x 10 ⁻²			4.485 x 10 ⁻²		
C	2.666 x 10 ⁻²			4.412 x 10 ⁻²		
• PuO ₂ PARTICLE SIZE, μm						
95%	< 20			< 20		
50%	< 8			< 5		
5%	< 2			< 0.5		
• UO ₂ PARTICLE SIZE, μm						
95%	< 40			< 40		
50%	< 9			< 9		
5%	< 2			< 3		
• POLYSTYRENE PARTICLE SIZE, μm						
95%	< 225			< 225		
50%	< 150			< 150		
5%	< 50			< 50		
• URANIUM DENSITY, kg/m ³	2438 ± 23			495 ± 5		
• PLUTONIUM DENSITY, kg/m ³	1012 ± 10			85 ± 1		
• FUEL COMPACT DENSITY, kg/m ³	4520 ± 43			1615 ± 17		
• DIMENSIONS OF FUEL COMPACTS, mm						
	LENGTH	WIDTH	THICKNESSES	LENGTH	WIDTH	THICKNESSES
UNCLAD COMPACTS	50.90 ± 0.05	50.83 ± 0.26	50.90 ± 0.05; 13.39 ± 0.26	50.90 ± 0.05	50.95 ± 0.21	50.90 ± 0.05; 13.84 ± 0.39
CLAD COMPACTS	51.14 ± 0.09	51.70 ± 0.26	51.14 ± 0.06; 13.63 ± 0.26	51.21 ± 0.05	51.42 ± 0.21	51.21 ± 0.05; 14.15 ± 0.39
CLAD COMPACTS + VOIDS	51.18 ± 0.15	51.74 ± 0.30	51.18 ± 0.15; 13.67 ± 0.26	51.30 ± 0.10	51.90 ± 0.25	51.30 ± 0.10; 14.85 ± 0.75

(a) ISOTOPIC ANALYSIS MADE ON 12-2-71. EXPERIMENTS PERFORMED MAY 1976.

(b) ISOTOPIC ANALYSIS MADE ON 5-28-70. EXPERIMENTS 081 THRU 152 PERFORMED SEPTEMBER, NOVEMBER, 1975. EXPERIMENTS 153 THRU 166 PERFORMED MAY, 1976.

TABLE II
COMPOSITION OF NEUTRON POISON PLATES

ELEMENT (a)	BORAL CORE (b) (2530 kg/m ³)	ALUMINUM (2692 kg/m ³)	STEEL			LEAD	URANIUM	CADMIUM
	WT%	WT%	NO BORON (7930 kg/m ³) WT%	1.1% B (7900 kg/m ³) WT%	1.6 % B (7770 kg/m ³) WT%	(11340 kg/m ³) WT%	(18700 kg/m ³) WT%	(8650 kg/m ³) WT%
B	27.40	--	--	1.05 ± 0.08	1.62 ± 0.10	--	--	--
Cd	--	--	--	--	--	--	--	99.40 ± 0.5
C	7.61	--	--	--	--	--	0.009	--
Al	63.68	97.98	--	--	--	--	0.003	--
Cu	0.09	0.14	--	--	--	< 0.01	0.001	--
Zn	0.16	0.25	--	--	--	--	--	--
Fe	0.45	0.70	74.0	73.22	72.80	<0.03	0.003	--
Cr	0.10	0.15	18.0	17.81	17.71	--	0.001	--
Ni	--	--	8.0	7.92	7.87	--	0.002	--
Mn	0.10	0.15	--	--	--	--	0.001	--
Mg	0.05	0.08	--	--	--	--	--	--
Ti	0.10	0.15	--	--	--	--	--	--
Ca	--	--	--	--	--	--	0.001	--
Li	0.26	0.40	--	--	--	--	0.005	--
Pb	--	--	--	--	--	99.30 ± 0.5	0.001	--
Bi	--	--	--	--	--	0.01	--	--
²³⁸ U	--	--	--	--	--	--	99.776	--
²³⁶ U	--	--	--	--	--	--	0.002	--
²³⁵ U	--	--	--	--	--	--	0.194	--
²³⁴ U	--	--	--	--	--	--	0.001	--

(a) ALL ELEMENTS ARE NATURAL EXCEPT URANIUM WHICH HAS THE INDICATED NUCLIDE DISTRIBUTIONS

(b) DOES NOT INCLUDE 1.02 mm THICK ALUMINUM CLADDING ON EITHER SIDE OF CORE MATERIAL

TABLE III

EXPERIMENTALLY DETERMINED CRITICAL HEIGHTS

PLEXIGLAS REFLECTED 8x8 ASSEMBLIES OF 30.6 H:Pu + U PuO₂-UO₂-POLYSTYRENE COMPACTS

LAYERS OF FUEL (a) (50.9 mm)	NEUTRON POISON PLATE				LAYERS OF FUEL (c)		TOTAL LAYERS OF FUEL (d) (50.9 mm)	RSTM EXPERIMENT NUMBER	CALCULATED k _{eff} (e)
	TYPE	PLATE MASS (kg)	PLATE THICKNESS (mm)	PLATE + VOID THICKNESS (b) (mm)	(50.9 mm)	(13.84 mm)			
3	NONE	0	0	-	1	3.578	4.921 ± 0.006 (f)	0.97, 150, 153	0.997 ± 0.005
3	STEEL (g)	3.902 ± 0.010	3.10 ± 0.05	3.5 ± 0.5	2	0.781	5.201 ± 0.002	085	
3	STEEL (g)	7.804 ± 0.014	6.20 ± 0.07	6.9 ± 0.8	2	1.655	5.426 ± 0.002	086	
3	STEEL (g)	19.510 ± 0.022	15.50 ± 0.11	15.9 ± 0.5	2	3.667	5.944 ± 0.505	090	
3	STEEL (g)	31.216 ± 0.028	24.80 ± 0.14	25.2 ± 0.5	3	1.317	6.339 ± 0.003	087	1.020 ± 0.006
3	STEEL (g)	46.824 ± 0.034	37.20 ± 0.17	38.0 ± 1.0	3	2.770	6.713 ± 0.003	089	
3	STEEL (g)	62.432 ± 0.040	49.60 ± 0.19	51.2 ± 0.8	4	0.012	7.003 ± 0.004	088	
3	1.1 WT% B-STEEL (g)	3.908 ± 0.028	2.98 ± 0.06	3.8 ± 0.9	3	1.251	6.322 ± 0.004	084	
3	1.1 WT% B-STEEL (g)	7.816 ± 0.040	5.95 ± 0.08	7.0 ± 0.8	3	2.937	6.756 ± 0.006	081	
3	1.1 WT% B-STEEL (g)	15.632 ± 0.056	11.91 ± 0.11	13.2 ± 0.7	4	0.866	7.223 ± 0.006	082	
3	1.1 WT% B-STEEL (g)	23.448 ± 0.069	17.86 ± 0.14	18.9 ± 0.6	4	1.663	7.428 ± 0.002	083	
3	1.1 WT% B-STEEL (g)	42.988 ± 0.094	32.75 ± 0.18	35.1 ± 0.5	4	2.813	7.724 ± 0.006	095	1.023 ± 0.005
3	1.6 WT% B-STEEL (g)	3.834 ± 0.008	2.98 ± 0.05	3.4 ± 0.5	3	2.074	6.534 ± 0.004	093	
3	1.6 WT% B-STEEL (g)	3.834 ± 0.008	2.98 ± 0.05	3.4 ± 0.5	3	2.024	6.521 ± 0.005 (h)	094	
3	1.6 WT% B-STEEL (g)	15.336 ± 0.017	11.94 ± 0.11	12.8 ± 1.0	4	1.336	7.344 ± 0.003	091	
3	1.6 WT% B-STEEL (g)	30.672 ± 0.024	23.87 ± 0.15	25.6 ± 1.9	4	2.661	7.685 ± 0.005	092	1.013 ± 0.005
3	URANIUM (i)	20.165 ± 0.021	6.58 ± 0.13	6.7 ± 0.2	2	1.445	5.372 ± 0.002	163	
3	URANIUM (i)	61.370 ± 0.030	19.53 ± 0.18	20.2 ± 0.5	2	3.586	5.923 ± 0.002	164	0.994 ± 0.005
3	URANIUM (i)	141.195 ± 0.042	45.05 ± 0.24	46.5 ± 0.7	3	2.762	6.711 ± 0.003	165	0.990 ± 0.007
3	URANIUM (i)	182.370 ± 0.047	57.99 ± 0.30	60.1 ± 1.5	4	0.109	7.028 ± 0.004	166	
3	BORAL (j)	1.552 ± 0.002	3.68 ± 0.06	4.2 ± 0.6	4	0.967	7.249 ± 0.005	151	
3	BORAL (j)	3.142 ± 0.002	7.52 ± 0.08	8.2 ± 0.7	4	2.479	7.638 ± 0.005	152	
3	BORAL (j)	7.840 ± 0.002	18.71 ± 0.12	19.5 ± 0.8	5	0.047	8.012 ± 0.006	155	
3	BORAL (j)	10.907 ± 0.002	25.98 ± 0.15	26.8 ± 0.8	5	0.548	8.141 ± 0.006	157	
3	BORAL (j)	15.393 ± 0.002	36.60 ± 0.18	38.2 ± 0.8	5	3.885	8.246 ± 0.006	156	1.021 ± 0.005
3	CADMIUM	1.441 ± 0.001	1.058 ± 0.005	1.28 ± 0.2	3	1.736	6.447 ± 0.004	096	
3	CADMIUM	2.847 ± 0.001	2.079 ± 0.005	2.30 ± 0.2	3	2.350	6.605 ± 0.005	154	
3	LEAD	12.231 ± 0.021	6.44 ± 0.03	6.5 ± 0.1	2	0.190	5.049 ± 0.002	158	
3	LEAD	30.496 ± 0.030	16.02 ± 0.02	16.1 ± 0.1	2	0.921	5.237 ± 0.002	162	
3	LEAD	61.386 ± 0.036	32.00 ± 0.02	32.8 ± 0.5	2	1.989	5.512 ± 0.003	160	1.019 ± 0.005
3	LEAD	86.136 ± 0.042	44.86 ± 0.02	45.7 ± 0.8	2	2.984	5.768 ± 0.003	159	
3	LEAD	110.896 ± 0.047	57.71 ± 0.03	58.0 ± 0.3	3	0.062	6.016 ± 0.002	161	

(a) LAYERS OF 50.9 mm THICK FUEL BELOW NEUTRON POISON PLATE

(b) INCLUDES THE 0.09 mm VOID PRESENT BETWEEN LAYERS OF FUEL

(c) LAYERS OF 50.9 mm AND 13.84 mm THICK FUEL ABOVE NEUTRON POISON PLATE

(d) TOTAL LAYERS OF FUEL COMPACTS EXPRESSED AS EQUIVALENT 50.9 mm THICK COMPACTS. MULTIPLY BY 0.9608 TO CORRECT FOR STACKING VOIDS AND CLADDING

(e) KENO CALCULATIONS USING 18 GROUP EGGNIT AVERAGED CROSS SECTIONS FROM FLANGE-ETOG PROCESSED ENDF/B-3 DATA. ONE SIGMA LIMITS ON THE MONTE CARLO CALCULATION

(f) AVERAGE OF THREE MEASUREMENTS, 4.928, 4.916 AND 4.918, PERFORMED DURING COURSE OF EXPERIMENTS

(g) TYPE 304L STEEL

(h) REPEAT OF RSTM EXPERIMENT NO. 093 WITH DIFFERENT NEUTRON POISON PLATES

(i) URANIUM DEPLETED TO 0.194 ± 0.002 WT% ²³⁵U

(j) IN DESCENDING ORDER, POISON REGION CONSISTS OF 1, 2, 5, 7 AND 10 BORAL PLATES EACH CLAD IN 1.02 mm THICK ALUMINIUM

TABLE IV

EXPERIMENTALLY DETERMINED CRITICAL HEIGHTS

PLEXIGLAS REFLECTED 8x8 ASSEMBLIES OF 2.8 H:Pu + U PuO₂-UO₂-POLYSTYRENE COMPACTS WITH DRIVER REGION OF 30.6 H:Pu + U FUEL

LAYERS OF 2.8 H: Pu + U FUEL (a) (50.9 mm)	NEUTRON POISON PLATE				LAYERS OF FUEL (c)			TOTAL LAYERS OF FUEL (d) (50.9 mm)	RSTM EXP. NO.	CALCULATED k _{eff} (e)
	TYPE	PLATE MASS (kg)	PLATE THICKNESS (mm)	PLATE + VOID THICKNESS (b) (mm)	2.8H:Pu + U FUEL (50.9 mm)	30.6 H: Pu + U FUEL (50.9 mm)	30.6 H: Pu + U FUEL (13.84 mm)			
2	NONE	0	0	--	2	2	0.233	6.060 ± 0.003	025	1.026 ± 0.007
2	STEEL (f)	19.510 ± 0.022	15.50 ± 0.11	16.4 ± 0.5	2	2	1.309	6.337 ± 0.003	032	
2	STEEL (f)	42.922 ± 0.033	34.11 ± 0.16	34.8 ± 0.3	2	2	2.292	6.590 ± 0.003	031	1.010 ± 0.005
2	1.1 WT % B-STEEL (f)	3.908 ± 0.028	2.98 ± 0.06	3.1 ± 0.3	2	2	0.995	6.256 ± 0.003	030	
2	1.1 WT % B-STEEL (f)	19.540 ± 0.063	14.88 ± 0.12	15.8 ± 1.0	2	2	2.754	6.709 ± 0.003	029	
2	1.1 WT % B-STEEL (f)	42.988 ± 0.094	32.75 ± 0.18	34.7 ± 1.5	2	2	3.966	7.021 ± 0.003	028	1.023 ± 0.006
2	1.6 WT % B-STEEL (f)	3.834 ± 0.008	2.98 ± 0.05	3.2 ± 0.3	2	2	1.173	6.302 ± 0.003	026	
2	1.6 WT % B-STEEL (f)	30.672 ± 0.024	23.87 ± 0.15	25.2 ± 1.2	2	2	3.733	6.961 ± 0.003	027	1.016 ± 0.005
2	URANIUM (g)	20.165 ± 0.021	6.58 ± 0.13	7.1 ± 0.7	2	2	0.761	6.196 ± 0.003	022	
2	URANIUM (g)	61.370 ± 0.030	19.53 ± 0.18	20.1 ± 0.7	2	2	1.472	6.379 ± 0.003	023	1.005 ± 0.005
2	URANIUM (g)	182.370 ± 0.047	57.99 ± 0.30	59.8 ± 0.7	2	2	3.302	6.850 ± 0.003	024	
2	BORAL (h)	1.552 ± 0.002	3.68 ± 0.06	3.9 ± 0.3	2	2	2.300	6.592 ± 0.003	036	
2	BORAL (h)	4.747 ± 0.002	11.38 ± 0.10	11.7 ± 0.4	2	2	3.908	7.006 ± 0.004	037	
2	BORAL (h)	15.393 ± 0.002	36.60 ± 0.18	39.2 ± 1.9	2	3	1.670	7.430 ± 0.004	035	1.010 ± 0.006
2	CADMIUM	2.847 ± 0.001	2.079 ± 0.005	2.30 ± 0.21	2	2	1.049	6.270 ± 0.003	040	
2	LEAD	18.265 ± 0.021	9.58 ± 0.03	10.9 ± 1.4	2	2	0.719	6.185 ± 0.003	034	
2	LEAD	49.265 ± 0.030	25.55 ± 0.04	26.3 ± 0.8	2	2	1.395	6.359 ± 0.003	039	1.013 ± 0.006
2	LEAD	79.761 ± 0.042	41.58 ± 0.06	43.2 ± 1.4	2	2	1.872	6.482 ± 0.003	033	
2	ALUMINUM	11.910 ± 0.056	26.78 ± 0.06	27.1 ± 0.4	2	2	1.620	6.417 ± 0.003	038	1.009 ± 0.005

(a) LAYERS OF 50.9 mm THICK FUEL BELOW POISON PLATE

(b) INCLUDES 0.04 mm VOID PRESENT BETWEEN LAYERS OF FUEL

(c) LAYERS AND TYPE OF 50.9 mm AND 13.84 mm FUEL ABOVE POISON PLATE

(d) TOTAL LAYERS OF FUEL COMPACTS EXPRESSED AS EQUIVALENT 50.9 mm THICK COMPACTS. BOTTOM FOUR LAYERS ARE 2.8 H: Pu + U FUEL.

(e) KENO CALCULATIONS USING 18 GROUP EGGNIT AVERAGED CROSS SECTIONS FROM FLANGE-ETOG PROCESSED ENDF/B-3 DATA. ONE SIGMA LIMITS ON THE MONTE CARLO CALCULATION

(f) TYPE 304 L STEEL

(g) URANIUM DEPLETED TO 0.194 ± 0.002 WT % ²³⁵U

(h) IN DESCENDING ORDER, POISON REGION CONSISTS OF 1,3 AND 10 BORAL PLATES EACH CLAD IN 1.02 mm THICK ALUMINUM

DISCUSSION OF EXPERIMENTAL DATA

A detailed description is given in Table III for each critical assembly fueled with the 30.6 H:Pu+U compacts. The layers of fuel above and below the poison region are given along with the actual mass of poison material present in the respective assemblies. As mentioned earlier, the poison region in some of the assemblies is made up of several thinner plates stacked on top of one another to achieve the plate thickness that is indicated. The combined poison plate and void thickness of the poison region is shown for each assembly in addition to the total actual thickness of plate in the poison region.

Data similar to that given for the 30.6 H:Pu+U fuel in Table III is given for the 2.8 H:Pu+U fuel in Table IV. To achieve criticality with the assemblies containing the 2.8 H:Pu+U fuel, a driver region of the 30.6 H:Pu+U fuel had to be used. In these assemblies, the poison region was centered in the 2.8 H:Pu+U fuel at a distance from the reflector and driver region boundaries such that a neutron flux characteristic of the 2.8 H:Pu+U fuel existed over the poison region. Calculations on these two-region assemblies show that less than 30% of the fissions occur in the 30.6 H:Pu+U driver fuel. Also, calculations show that the spatial distribution of fissions in an assembly of only 2.8 H:Pu+U fuel is essentially identical with the fission distribution over the poison plate region of the two-region assemblies. The calculated spatial distribution of the fissions in each type assembly is shown in Figure 2.

As discussed previously, the approach-to-critical for each of the assemblies shown in Tables III and IV was made by incrementally loading fuel compacts to the top face of each assembly in a symmetrical manner with respect to the neutron flux. Consequently, the fractional layers given in Tables III and IV should be treated as full layers of thinner fuel compacts having a thickness equal to the fractional layer times the full sized compact. To provide a more simplified geometry, the

CALCULATED FISSION SPATIAL DISTRIBUTIONS

FIGURE 2

total number of fuel layers in terms of 50.9 mm thick compacts is also given for each assembly in Tables III and IV. A further simplification can be obtained by making corrections for the cladding and stacking voids in each assembly. The effect of these cladding and stacking voids was experimentally determined previously^(3,4) for each of these fuels. The fuel regions in each 30.6 H:Pu+U assembly can be expressed as homogeneous regions of PuO_2 - UO_2 -polystyrene fuel only, by reducing the mass 3.92%. For the 2.8 H:Pu+U, corrections are not needed. The negative reactivity effects caused by the stacking voids, and the reduced fuel density due to the cladding being present, are compensated for by the positive worth of the additional hydrogen and carbon introduced into each assembly by the cladding material.

The tabulated data presented in Tables III and IV are shown graphically in Fig.'s 3 and 4. Presenting the data graphically in this fashion permits comparisons to be made between different thicknesses of a given material, between different materials, and between a material and a void as represented by aluminum in each of these figures. However, it should be noted that the neutron importance in the vicinity of the plates is not the same in the assemblies. Consequently, the data as shown in Fig.'s 3 through 4 are intended to show only approximately the relative effectiveness of the plates as neutron absorbers in the two different fuels.

In previous experiments^(1,2) with aluminum simulating a void in these fuels, the critical height was observed to vary linearly with aluminum thickness. Consequently, for the two region assemblies containing 2.8 and 30.6 H:Pu+U fuel, experimental data was obtained for only a single thickness of aluminum in the 2.8 H:Pu+U fuel. This critical height, in conjunction with the unpoisoned critical height for these 2.8 H:Pu+U fueled assemblies, was used to construct the aluminum curve shown in Fig. 4. The aluminum data previously reported for the 30.6 H:Pu+U fuel was used to construct the aluminum curve shown in Fig. 3.

EFFECT OF POISON PLATES ON CRITICAL HEIGHT

FIGURE 3

EFFECT OF POISON PLATES ON CRITICAL HEIGHT

FIGURE 4

Effective multiplication constants were calculated for some of the experimental assemblies as indicated in Tables III and IV. The calculations were made with the Monte Carlo code KENO⁽⁵⁾ using 18-group EGGNIT⁽⁶⁾ averaged cross sections that had been processed from the ENDF/B-III with FLANGE-II⁽⁷⁾ and ETOG-I⁽⁸⁾ codes. The EGGNIT multigroup constants for the cladding, fuel, and poison plates were generated in the spectra characteristic of the fuel. The reflector multigroup constants were averaged in the spectra characteristic of the reflector material. The geometries for each assembly were input to KENO as described in Tables III and IV and as shown in Fig. 1. Stacking voids and cladding materials, as specified in Table I, were included in the calculational models. The mass of the plates was homogenized over the plate plus void space of the respective poison region. In all of the KENO calculations, 150 generations of 300 neutrons each were used and the average k_{eff} reported for each calculation was obtained from at least forty of these generations in succession.

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