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figure. The problem centers on how large an area, i.e., limits for the ordinate and abscissa, can be utilized to define storage systems known to be subcritical.

Note that the inconsistent treatment of the metal cube data suggests the critical mass value should not be the unreflected cube but that for the condition with associated reflector. The solution data reported by Odegaarden and Stevenson[4] appear to associate well with the data for U(93) metal spheres. The sphere data also represent the 44 different fissile materials given in the ANSI Standard[5] N16.5. It is clear that an area of applicability can be defined. However, the effect on the criticality of these systems of introducing interstitial low-density hydrogenous moderation needs to be examined before firm limits are proposed.

1. ANSI Standard N16.9, "Validation of Calculational Methods for Nuclear Criticality Safety" (1975).
2. J. T. THOMAS, *Trans. Am. Nucl. Soc.*, 22, 299 (1975).
3. H. C. PAXTON, "Criticality Control in Operations with Fissile Materials," LA-3366 (rev.), Los Alamos Scientific Laboratory (1972).
4. R. L. STEVENSON and R. H. ODEGAARDEN, "Studies on Surface Density Spacing Criteria Using KENO Calculations," *Trans. Am. Nucl. Soc.*, 12, 890 (1969).
5. ANSI Standard N16.5, "Guide for Nuclear Criticality Safety in the Storage of Fissile Materials" (1975).

5. Effect of Boron and Gadolinium on the Criticality of Plutonium-Uranium Systems, *R. C. Lloyd, E. D. Clayton (Battelle-Northwest)*

Experiments were performed to substantiate the effectiveness of soluble nuclear poisons on the criticality of plutonium-uranium nitrate solutions and to determine their effectiveness for criticality control on a heterogeneous assembly of mixed-oxide fuel pins immersed in plutonium-uranium nitrate solutions containing the soluble poisons.

Calculations indicate the most effecive use of soluble poisons may involve mixtures of several different elements, such as a mixture of boron and gadolinium, since one nuclide is more effective than another in absorbing neutrons from different portions of the neutron spectrum as the fuel concentration, or H/X ratio, is varied. As these are the first data known to be reported on boron-gadolinium mixtures, the data provide the only validation points for calculations of the mixed absorber effects.

Heterogeneous System: The lattice contained 301 fuel pins in a 55.5-cm-i.d. cylindrical vessel with 0.079-cm wall thickness. Pu+U nitrate solution was pumped into the vessel, using the critical approach method to determine the critical height. The Pu+U solution contained about 80 g Pu/liter. The ^{240}Pu content of the Pu was 6.3%, and the ^{235}U content of the U was 0.66%. The Pu made up about 30% of the total Pu+U by weight. The solution

TABLE I

Effect of Boron and Gadolinium on Criticality of Heterogeneous Lattice Assembly

Date	Exp No.	Critical Height (cm)	Pu Conc (g/liter)	U Conc (g/liter)	Acid Molarity	Total NO_3 (g/liter)	Specific Gravity	Gd (g/liter)	B (g/liter)
5-7-76	141R	21.20	84.5	182.1	1.75	296	1.438	0.13	0.27
5-9-75	142	25.37	84.0	183.2	1.88	302	1.442	0.235	0.6
5-13-75	143	30.49	82.7	180.6	2.01	308	1.444	0.309	0.9
5-30-75	148	43.86	81.2	180.0	2.18	321	1.447	0.424	1.35
6-3-75	149	51.97	81.0	180.4	2.09	316	1.451	0.519	1.5
7-17-75	152	55.18	81.0	180.3	2.21	318	1.452	0.537	1.548
7-18-75	153	65.42	80.5	180.5	2.24	321	1.454	0.541	1.662

Fuel Pin Dimensions	o.d. (cm)	Length (cm)
Fuel column	0.495	69.22
Cladding (316-SS)	0.584	72.90

Fuel Per Pin
PuO_2-U (nat)O_2: 138.4 ± 1.3 g
Pu: 30.75 ± 0.03 g U: 91.16 ± 1.03 g O: 16.49 ± 0.17 g

Fuel Enrichment
25.2 wt% Pu

Fuel Density
10.35 ± 0.09 g/cm^3 (93.34 ± 0.79% theoretical)

Isotopic Composition of Pu in Pins
^{238}Pu: 0.04 ± 0.01 at.% ^{239}Pu: 86.19 ± 0.06 at.% ^{240}Pu: 11.88 ± 0.06 at.% ^{241}Pu: 1.73 ± 0.01 at.% ^{242}Pu: 0.16 ± 0.01 at.%

Lattice
Triangular spacing = 3.048 cm

TABLE II

Effect of Boron and Gadolinium on Criticality of Homogeneous Systems (U + Pu Solutions in 61-cm-diam Water-Reflected Cylinder)

Date	Exp No.	Critical Height (cm)	Pu Conc (g/liter)	U Conc (g/liter)	Acid Molarity	Total NO_3 (g/liter)	Specific Gravity	Gd (g/liter)	B (g/liter)
4-7-75	137R	18.13	85.0	182.5	1.55	320	1.433	0.04	0.0
4-9-75	138	18.65	84.9	182.2	1.61	311	1.434	0.04	0.1
4-11-75	139R	19.68	84.8	182.6	1.67	290	1.433	0.04	0.3
4-17-75	140	21.13	84.5	182.1	1.75	296	1.438	0.128	0.27
5-20-75	145	32.16	82.8	180.6	1.95	309	1.443	0.293	0.9
5-22-75	146	43.03	82.2	179.5	2.12	319	1.446	0.388	1.2
5-26-75	147	52.12	81.2	180.0	2.18	321	1.447	0.424	1.35
5-16-75	150	67.83	81.0	180.4	2.09	316	1.451	0.519	1.5
7-11-75	151	75.44	81.0	180.3	2.21	318	1.452	0.537	1.54

contained a combination of B and Gd in the ratio ~3-to-1 by weight. The data from these experiments are summarized in Table I.

Homogeneous System: The experiments were performed on a water-reflected, stainless-steel cylindrical vessel of 61.03-cm i.d. and wall thickness 0.079 cm. Critical experiment data on the homogeneous Pu+U solutions containing various concentrations of B and Gd are given in Table II. The variation in critical height with added quantity of neutron poison can be seen from the value given in the table. Several of the Pu+U solutions are the same solutions as used in the heterogeneous system.

The results of theory-experiment comparisons utilizing ENDF/B cross sections and the KENO Monte Carlo code will be presented and discussed.

6. Critical Experiments with Low-Moderated Homogeneous Mixtures of Plutonium and Uranium Oxides Containing 8 and 15 wt% Plutonium, *S. R. Bierman, E. D. Clayton (Battelle-Northwest)*

Data from the latest in a series of experiments to define the criticality parameters of undermoderated, homogeneous oxide mixtures of plutonium and uranium are presented in this paper. Data from preceding experiments have been reported in Ref. 1-3. These latest measurements were carried out with fuel mixtures containing about 8 and 15 wt% Pu in the Pu+U and having H/(Pu+U) atomic ratios of about 7 and 3, respectively. As in the past, with this high a concentration of oxide, the experiments were performed with solid compacts of PuO_2-UO_2-polystyrene 5.09 cm square and having thicknesses of about 5.09 and 1.3 cm. Each compact was clad with MM&M #471 tape. A complete description is given in Table I for each of the two fuels, the cladding material, and the Plexiglas reflector used in the experiments. In both fuel mixtures the plutonium contained about 11.5 wt% ^{240}Pu and the uranium was depleted to about 0.2 wt% ^{235}U.

Neutron multiplication measurements were made on fully reflected parallelepipeds of each fuel. For the 8 wt% Pu-enriched fuel mixture, the geometry ranged from the near cubic to a relatively thin slab. However, because of the prohibitively large volume required for criticality with the 15 wt% Pu fuel, the experiments were limited to a single near-cubic assembly. The critical sizes obtained from these measurements are shown in Table II. Also shown in Table II are computed k_{eff} values for each of these critical assemblies. The calculations were performed with the averaged cross sections that had been processed from ENDF/B-III with the FLANGE and ETOG codes.

With two exceptions, the data covered in this paper, along with the data previously published,[1-3] provide sufficient experimental data for validating calculations on undermoderated LMFBR homogeneous plutonium-uranium mixtures containing up to 30 wt% Pu. Criticality data are still needed on dry or moist oxide mixtures and on mixtures having 25 to 40 wt% ^{240}Pu in the plutonium.

1. S. R. BIERMAN, E. D. CLAYTON, and L. E. HANSEN, "Critical Experiments with Homogeneous Mixtures of Plutonium and Uranium Oxides Containing 8, 15, and 30 wt% Plutonium," *Nucl. Sci. Eng.*, **50**, 115 (1973).

2. S. R. BIERMAN and E. D. CLAYTON, "Critical Experiments with Mixed Oxides of Pu and U Containing 8 and 30 wt% Plutonium," *Trans. Am. Nucl. Soc.*, **15**, 307 (1972).

3. R. C. LLOYD, S. R. BIERMAN, and E. D. CLAYTON, "Criticality of Plutonium-Uranium Mixtures Containing 5 to 8 wt% Plutonium," *Nucl. Sci. Eng.*, **55**, 51 (1974).

TABLE I

Description of Experimental Fuel and Reflector

	15.0 wt% Pu FUEL 2.86 H: (Pu + U), ATOMIC	8.1 wt% Pu FUEL 7.3 H: (Pu + U), ATOMIC
FUEL COMPOSITION, 10^{24} atoms/cm^3		
^{241}Am	2.765×10^{-5}	3.132×10^{-6}
^{238}Pu	5.737×10^{-7}	3.809×10^{-7}
^{239}Pu	1.118×10^{-3}	3.490×10^{-4}
^{240}Pu	1.478×10^{-4}	4.678×10^{-5}
^{241}Pu	2.221×10^{-5}	7.745×10^{-6}
^{242}Pu	2.370×10^{-6}	1.116×10^{-6}
^{235}U	1.365×10^{-5}	9.116×10^{-6}
^{238}U	7.549×10^{-3}	4.606×10^{-3}
O	1.840×10^{-2}	1.178×10^{-2}
C	2.653×10^{-2}	3.567×10^{-2}
H	2.534×10^{-2}	3.680×10^{-2}
CLADDING COMPOSITION, 10^{24} atoms/cm^3		
H	4.489×10^{-2}	4.489×10^{-2}
C	3.111×10^{-2}	3.111×10^{-2}
Cl	7.240×10^{-3}	7.240×10^{-3}
REFLECTOR COMPOSITION, 10^{24} atoms/cm^3		
H	5.666×10^{-2}	5.666×10^{-2}
C	3.510×10^{-2}	3.510×10^{-2}
O	1.428×10^{-2}	1.428×10^{-2}
PuO_2 PARTICLE SIZE, µm		
95%	<20	<20
50%	< 5	< 5
5%	< 1	< 1
UO_2 PARTICLE SIZE, µm		
95%	<18	<18
50%	< 5	< 5
5%	< 2	< 2
POLYSTYRENE PARTICLE SIZE, µm		
95%	<225	<225
50%	<150	<150
5%	<50	<50

	15.0 wt% Pu FUEL			8.1 wt% Pu FUEL		
FUEL COMPACT SIZES, cm	UNCLAD	CLAD	STACKED[a]	UNCLAD	CLAD	STACKED[a]
Length	5.090 ± 0.005	5.114 ± 0.005	5.129 ± 0.013	5.090 ± 0.005	5.114 ± 0.005	5.138 ± 0.089
Width	5.090 ± 0.005	5.114 ± 0.005	5.129 ± 0.013	5.090 ± 0.005	5.114 ± 0.005	5.138 ± 0.089
Heights	5.082 ± 0.066	5.170 ± 0.067	5.173 ± 0.037	5.081 ± 0.003	5.168 ± 0.003	5.170 ± 0.060
	1.265 ± 0.041	1.353 ± 0.044	1.395 ± 0.056	1.274 ± 0.008	1.361 ± 0.009	1.381 ± 0.064

[a] Average dimension of space occupied by compacts.

TABLE II

Critical Assembly Configurations and Calculated k_{eff} Values

CRITICAL NUMBER OF FUEL COMPACTS						
REFLECTOR	LENGTH (a)	WIDTH (a)	HEIGHT (b)	HEIGHT (c)	CORRECTED HEIGHT (d)	KENO k_{eff} (e)
8.1 WT% Pu, 7.3 H:(Pu + U) PuO_2-UO_2-POLYSTYRENE FUEL COMPACTS						
Plexiglas	10	9	9	1.135 ± 0.001	9.274 ± 0.003	1.025 ± 0.005
Plexiglas	10	11	7	3.239 ± 0.001	7.780 ± 0.002	1.027 ± 0.004
Plexiglas	12	12	6	2.526 ± 0.003	6.609 ± 0.007	1.021 ± 0.006
Plexiglas	14	13	5	3.733 ± 0.005	5.919 ± 0.008	1.021 ± 0.003
15.0 WT% Pu, 2.86 H:(Pu + U) PuO_2-UO_2-POLYSTYRENE FUEL COMPACTS						
Plexiglas	10	10	9	6.651 ± 0.016	10.749 ± 0.031	0.994 ± 0.002

a) Number of compacts in the length and width dimensions. Each dimension is 5.09 cm per compact.

b) Number of full sized compacts in the height dimension. Each compact is 5.081 cm high for the 8.1 wt % Pu fuel and 5.082 cm high for the 15 wt % Pu fuel.

c) Number of thin sized compacts in the height dimension. Each compact is 1.274 cm high for the 8.1 wt % Pu fuel and 1.265 cm high for the 15 wt % Pu fuel.

d) Critical height in terms of full sized compacts corrected for measured reactivity worth of smaller compacts.

e) 18 energy group EGGNIT averaged cross-sections using FLANGE-ETOG processed ENDF/B-III data.