CRITICAL EXPERIMENTS - BENCHMARKS
(Pu-U SYSTEMS)

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INTRODUCTION

Because of the great number of parameters involved in a multigroup nuclear criticality calculation, extensive experimental benchmarks are required to test calculational results. The calculation of just one experimental system yields information on the ability of a computational method to calculate that particular system but gives little assurance as to the accuracy on a system with different physical characteristics. (Good answers can be obtained fortuitously from chance combinations of physical characteristics which mask, e.g., inaccurate basic data or poor cross section averaging.) Calculations on experiments involving a wide range of fuel materials and neutron spectra increase the ability to identify cross section errors according to the material and energy range in which they occur. For example, the properties of small, low moderation, bare assemblies essentially depend only on the high-energy data. Overmoderated assemblies, on the other hand, essentially depend only on the thermal data.

The accuracy of a calculation is a function of the multigroup cross section data used and of a (generally large) number of approximations and input options characteristic of the individual codes. In addition, the multigroup cross sections are a function of the fundamental nuclear data for each isotope involved and of a (again generally large) number of approximations and input options characteristic of the individual data handling and group reduction codes.

Figure 1 is provided to illustrate some of the options available for processing ENDF/B cross sections for use in multigroup calculations. A point of concern is the difference in results that may be had from using group-averaged cross sections from two different processing codes in the same criticality calculation.

CODE VALIDATION

A recently proposed ANSI Standard, No. N16.9, entitled, Validation of Calculational Methods for Nuclear Criticality Safety, sets forth requirements on code validation for establishing the validity and area of applicability of any calculational method used in assessing nuclear

criticality safety. The Standard is being prepared by Work Group 11 of Subcommittee 8 (Fissionable Materials Outside Reactors) of the American Nuclear Society Standards Committee. It is stated that bias shall be established through correlating the results of criticality experiments with results obtained by the method being validated. The concentration ranges and geometries for which experimental data currently exists on homogeneous mixtures of plutonium-uranium are listed in Table I.

BENCHMARKS

To provide data in a useful format for code validation, fourteen benchmarks have been assembled from the currently available experimental data listed in Table I. The data sources and references are identified on each benchmark separately. All the data presented are for homogeneous, hydrogenous assemblies; however, additional benchmarks, which extend the range of systems covered, are to be included in revised issues of this report.

The primary purpose of the format used in each benchmark is to completely define an experiment on a single piece of paper, in the hope this will better facilitate its use as a benchmark for code validation. Each is limited to a single fuel composition and a single geometry. Some of the benchmarks are limited to a single dimension, also. However, for the experimental data that permit it, multiple dimensions are reported for each fuel composition and geometry. Except for the assemblies having a rectangular geometry, descriptive diagrams are presented for each of the experiments. Any experimentally-determined correction factors available for reducing the complexity of the experimental setups are also included in the benchmarks.

ACKNOWLEDGEMENT

This report is based on work performed under U. S. Atomic Energy Commission Contract AT(45-1)-1830.

**TYPICAL SCHEMATIC DIAGRAM FOR PROCESSING ENDF/B
CROSS SECTIONS FOR USE IN MULTIGROUP TRANSPORT
OR DIFFUSION THEORY**

FIGURE 1

EXPERIMENTAL DATA HOMOGENEOUS Pu-U MIXTURES

CONCENTRATION g (Pu+U)/ℓ	²⁴⁰ Pu WT% IN Pu	GEOMETRY AND REFLECTION	SOURCE
<u>~ 30 WT% PLUTONIUM ENRICHMENT</u>			
42 TO 298	5.58	WATER-REFLECTED, 61cm DIAMETER CYLINDER	LLOYD, <u>ANS TRANS.</u> , VOL. 17
57, 61, 103, 330	5.63	WATER-REFLECTED, 50.7cm DIAMETER CYLINDER	LANE, AWRE O 58173, 1973
61, 103, 330	5.63	WATER-REFLECTED, 38cm DIAMETER CYLINDER	LANE, AWRE O 58173, 1973
103, 330	5.63	WATER-REFLECTED, 30.6cm DIAMETER CYLINDER	LANE, AWRE O 58173, 1973
330	5.63	WATER-REFLECTED, 25.4cm DIAMETER CYLINDER	LANE, AWRE O 58173, 1973
111	4.66	WATER-REFLECTED, 19.3cm RADIUS SPHERE	LLOYD, <u>ANS TRANS.</u> , VOL. 15, NO. 2
228	4.66	WATER-REFLECTED, 17.9cm RADIUS SPHERE	LLOYD, <u>ANS TRANS.</u> , VOL. 15, NO. 2
529	8.0	BARE AND PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, <u>NUC. SCI. ENG.</u> , <u>50</u> , 1973
3973	5.9	POLYTHENE-REFLECTED PARALLELEPIPEDS	LANE, AWRE O 32/68, 1968
4807	11.5	BARE AND PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, <u>ANS TRANS.</u> , VOL. 15, NO. 1
<u>~ 15 WT% PLUTONIUM ENRICHMENT</u>			
311	4.65	WATER-REFLECTED, 19.3cm RADIUS SPHERE	LLOYD, <u>ANS TRANS.</u> , VOL. 15, NO. 2
783	8.0	BARE AND PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, <u>NUC. SCI. ENG.</u> , <u>50</u> , 1973
5000	11.5	BARE AND PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, IN PROGRESS, 1974
<u>~ 8 WT% PLUTONIUM ENRICHMENT</u>			
304 to 421	22.8	WATER-REFLECTED, 61cm DIAMETER CYLINDER ^(a)	LLOYD, <u>ANS TRANS.</u> , VOL. 15, NO. 2
484	8.0	PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, <u>NUC. SCI. ENG.</u> , <u>50</u> , 1973
1198	23.0	PLEXIGLAS-REFLECTED PARALLELEPIPEDS	BIERMAN, <u>ANS TRANS.</u> , VOL. 15, NO. 2

(a) EXPERIMENTS WERE PERFORMED, ALSO, BY DILUTING THIS SOLUTION WITH 477 g U/ℓ UO₂(NO₃)₂ SOLUTION. WT% Pu VARIED FROM 7.3 TO 5.5.

TABLE I

CRITICAL EXPERIMENTS - BENCHMARK 1

GENERAL DESCRIPTION:

Stainless steel sphere, reflected with at least 15 cm of water and filled with a homogeneous aqueous solution of $\text{Pu}(4.66)(\text{NO}_3)_4 + \text{U}(0.66)\text{O}_2(\text{NO}_3)_2$ containing 31.1 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.

R. C. Lloyd, E. D. Clayton, and S. R. Bierman, "Criticality of Plutonium-Uranium Nitrate Mixtures," *Trans. Am. Nucl. Soc.*, **15**, 803 (1972).

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0007	2.5316×10^{-8}
Pu-239	4.7204	1.7000×10^{-4}
Pu-240	0.2310	8.2845×10^{-6}
Pu-241	0.0112	4.0000×10^{-7}
Pu-242	0.0007	2.4897×10^{-8}
U-235	0.0727	2.6628×10^{-6}
U-236	0.0007	2.5530×10^{-8}
U-238	10.9210	3.9496×10^{-4}
N	5.7624	3.5418×10^{-3}
O	71.6305	3.8544×10^{-2}
H	6.5891	5.6278×10^{-2}
Gd	0.0036	2.1909×10^{-7}
Fe	0.0560	8.6327×10^{-6}

Solution Density, g/cm^3 1.4289

Plutonium Concentration, g/cm^3 0.0709

Uranium Concentration, g/cm^3 0.1571

Excess Nitrate Concentration, Molarity 3.4

H:Pu+U, Atomic 97.6

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm^3 .

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atom/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere, cm	17.87
Vessel Wall Thickness, cm	0.112

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

- a) The vessel neck and the support column increases the critical volume by ~0.4% (Reference: R. C. Lloyd, et al, "Criticality Studies With Plutonium Solutions," NS&E, 25, 171 (1966))

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 1

GENERAL DESCRIPTION:

Stainless steel sphere, reflected with at least 15 cm of water and filled with a homogeneous aqueous solution of $\text{Pu}(4.66)(\text{NO}_3)_4 + \text{U}(0.66)\text{O}_2(\text{NO}_3)_2$ containing 31.1 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, E. D. Clayton, and S. R. Bierman, "Criticality of Plutonium-Uranium Nitrate Mixtures," *Trans. Am. Nucl. Soc.*, 15, 803 (1972).

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Pu-239	4.7204	1.7000×10^{-4}
Pu-240	0.2310	8.2845×10^{-6}
Pu-241	0.0112	4.0000×10^{-7}
Pu-242	0.0007	2.4897×10^{-8}
U-235	0.0727	2.6628×10^{-6}
U-236	0.0007	2.5530×10^{-8}
U-238	10.9210	3.9496×10^{-4}
N	5.7624	3.5418×10^{-3}
O	71.6305	3.8544×10^{-2}
H	6.5891	5.6278×10^{-2}
Gd	0.0036	2.1909×10^{-7}
Fe	0.0560	8.6327×10^{-6}
Solution Density, g/cm ³	1.4289	
Plutonium Concentration, g/cm ³	0.0709	
Uranium Concentration, g/cm ³	0.1571	
Excess Nitrate Concentration, Molarity	3.4	
H:Pu+U, Atomic	97.6	

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atom/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere, cm	17.87
Vessel Wall Thickness, cm	0.112

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

a) The vessel neck and the support column increases the critical volume by ~0.4% (Reference: R. C. Lloyd, et al, "Criticality Studies With Plutonium Solutions," NS&E, 25, 171 (1966))

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 2

GENERAL DESCRIPTION:

Stainless steel sphere reflected with at least 15 cm of water and filled with a homogeneous aqueous solution of $\text{Pu}(4.66)(\text{NO}_3)_4 + \text{U}(0.66)\text{O}_2(\text{NO}_3)_2$ containing 31.6 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352

R. C. Lloyd, E. D. Clayton, and S. R. Bierman, "Criticality of Plutonium-Uranium Nitrate Mixtures," Trans. Am. Nucl. Soc., 15, 80B (1972).

COMPOSITION OF FUEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0003	9.2239×10^{-9}
Pu-239	2.7436	8.4012×10^{-5}
Pu-240	0.1344	4.1150×10^{-6}
Pu-241	0.0063	2.0040×10^{-7}
Pu-242	0.0003	9.0715×10^{-9}
U-235	0.0411	1.2798×10^{-6}
U-236	0.0006	1.8604×10^{-8}
U-238	6.1898	1.9031×10^{-4}
N	3.3788	1.7656×10^{-3}
O	78.9447	3.6114×10^{-2}
H	8.5234	6.1891×10^{-2}
Gd	0.0021	9.7744×10^{-8}
Fe	0.0346	4.4533×10^{-6}

Solution Density, g/cm ³	1.2148
Plutonium Concentration, g/cm ³	0.0351
Uranium Concentration, g/cm ³	0.0757
Excess Nitrate Concentration, Molarity	1.7
H:Pu+U, Atomic	221.1

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR ^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C.

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	19.31
Vessel Wall Thickness, cm	0.122

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, °C	23±2
Room temperature, °C	21±2

a) The vessel neck and the support column increases the critical volume by ~ 0.4%. (Reference: R. C. Lloyd, et al., "Criticality Studies With Plutonium Solutions," NS&E, 25, p. 171 (1966))

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 3

GENERAL DESCRIPTION:

Stainless steel sphere reflected with at least 15 cm of water and filled with a homogeneous aqueous solution of $\text{Pu}(4.66)(\text{NO}_3)_4 + \text{U}(0.66)(\text{NO}_3)_2$ containing 14.7 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352

R. C. Lloyd, E. D. Clayton, and S. R. Bierman, "Criticality of Plutonium-Uranium Nitrate Mixtures," *Trans. Am. Nucl. Soc.*, **15**, 808 (1972).

COMPOSITION OF FUEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0003	1.1321×10^{-8}
Pu-239	2.9085	1.0930×10^{-4}
Pu-240	0.1426	5.3364×10^{-6}
Pu-241	0.0067	2.4969×10^{-7}
Pu-242	0.0003	1.1134×10^{-8}
U-235	0.1173	4.4830×10^{-6}
U-236	0.0018	6.8502×10^{-8}
U-238	17.6476	6.6597×10^{-4}
N	4.5922	2.9452×10^{-3}
O	68.1179	3.8246×10^{-2}
H	6.4276	5.7284×10^{-2}
Gd	0.0002	1.1426×10^{-8}
Fe	0.0370	5.9516×10^{-6}

Solution Density, g/cm ³	1.4910
Plutonium Concentration, g/cm ³	0.0456
Uranium Concentration, g/cm ³	0.2649
Excess Nitrate Concentration, Molarity	1.9
H:Pu+U, Atomic	72.9

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR ^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C.

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	19.31
Vessel Wall Thickness, cm	0.122

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, °C	23±2
Room temperature, °C	21±2

a) The vessel neck and the support column increases the critical volume by ~ 0.4%. (Reference: R. C. Lloyd, et al., "Criticality Studies With Plutonium Solutions," NS&E, 25, p. 171 (1966))

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 3

GENERAL DESCRIPTION:

Stainless steel sphere reflected with at least 15 cm of water and filled with a homogeneous aqueous solution of $\text{Pu}(4.66)(\text{NO}_3)_4 + \text{U}(0.66)(\text{NO}_3)_2$ containing 14.7 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352

R. C. Lloyd, E. D. Clayton, and S. R. Bierman, "Criticality of Plutonium-Uranium Nitrate Mixtures," *Trans. Am. Nucl. Soc.*, **15**, 808 (1972).

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Nuclide	Wt%	Atoms/barn cm
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Pu-239	2.9085	1.0930×10^{-4}
Pu-240	0.1426	5.3364×10^{-6}
Pu-241	0.0067	2.4969×10^{-7}
Pu-242	0.0003	1.1134×10^{-8}
U-235	0.1173	4.4830×10^{-6}
U-236	0.0018	6.8502×10^{-8}
U-238	17.6476	6.6597×10^{-3}
N	4.5922	2.9452×10^{-2}
O	68.1179	3.8246×10^{-2}
H	6.4276	5.7284×10^{-8}
Gd	0.0002	1.1426×10^{-6}
Fe	0.0370	5.9516×10^{-6}

Solution Density, g/cm ³	1.4910
Plutonium Concentration, g/cm ³	0.0456
Uranium Concentration, g/cm ³	0.2649
Excess Nitrate Concentration, Molarity	1.9
H:Pu+U, Atomic	72.9

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C.

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	19.31
Vessel Wall Thickness, cm	0.122

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, °C	23±2
Room temperature, °C	21±2

a) The vessel neck and the support column increases the critical volume by ~ 0.4%. (Reference: R. C. Lloyd, et al., "Criticality Studies With Plutonium Solutions," NS&E, 25, p. 171 (1966))

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 4

GENERAL DESCRIPTION:

Rectangular parallelipeds of homogeneous $\text{Pu}(8)\text{O}_2 - \text{U}(0.15)\text{O}_2$ - polystyrene containing 14.6 wt% PuO_2 in the oxide. Critical heights given, as a function of base dimensions, for bare assemblies and assemblies fully reflected with at least 15 cm of Plexiglas. Fuel in the form of 5.09 x 5.09 cm compacts having different thicknesses and clad with approximately 6 mil thick tape.

DATA SOURCE:

S. R. Bierman, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352

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", NS&E, 50, 115-126 (1973).

COMPOSITION OF FUEL:

Nuclide	Wt%	Atoms/barn cm
Am-241	0.012 ± ---	4.843×10^{-7}
Pu-238	0.000 ± ---	0.0
Pu-239	4.797 ± 0.002	1.953×10^{-4}
Pu-240	0.420 ± 0.001	1.702×10^{-5}
Pu-241	0.080 ± 0.001	1.211×10^{-6}
Pu-242	0.002 ± ---	8.040×10^{-8}
U-235	0.046 ± 0.005	1.904×10^{-6}
U-238	30.619 ± 0.007	1.252×10^{-3}
H	4.646 ± 0.035	4.485×10^{-2}
O	4.964 ± 0.002	3.019×10^{-2}
C	54.464 ± 0.410	4.412×10^{-2}
Fuel Density, g/cm ³	1.615 ± 0.017	
Plutonium Concentration, g/cm ³	0.085 ± 0.001	
Uranium Concentration, g/cm ³	0.495 ± 0.005	
H:Pu+U, Atomic	30.57 0.49	
Mean Particle Sizes, Microns		
Plutonium Oxide	5	
Uranium Oxide	9	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	Wt%	Atoms/barn cm
H	55.3	4.489×10^{-2}
C	6.7	3.111×10^{-2}
Cl	38.0	7.240×10^{-3}
Cladding Density, g/cm ³	1.120	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	Atoms/barn cm
H	8.0	5.666×10^{-2}
C	60.0	3.570×10^{-2}
O	32.0	1.428×10^{-2}
Reflector Density, g/cm ³	1.185	

DIMENSIONS OF FUEL:

	Unclad	Clad	Stacked ^{a)}
Length, cm	5.090 ± 0.005 ^{b)}	5.121 ± 0.005 ^{c)}	5.130 ± 0.010
Width, cm	5.090 ± 0.025 ^{b)}	5.137 ± 0.025 ^{c)}	5.190 ± 0.025
Heights, cm	5.090 ± 0.005	5.121 ± 0.005	5.130 ± 0.010
	1.384 ± 0.039	1.415 ± 0.039	1.424 ± 0.043

a) Average Dimension of Space occupied by compacts in the critical assemblies.

b) 5.095 ± 0.021 cm for 5.090 cm high compacts

c) 5.142 ± 0.021 cm for 5.121 cm high clad compacts

DELAYED CRITICAL CONFIGURATIONS

Unreflected Assemblies

Number of Fuel Compacts				Corrected Height ^{b)} (5.090 cm) ^{a)}
Length (5.090 cm) ^{a)}	Width (5.095 cm) ^{a)}	Height (5.090 cm) ^{a)}	(1.384 cm) ^{a)}	
8	8	10	1.993 ± 0.033	10.293 ± 0.009
9	8	9	0.276 ± 0.040	8.860 ± 0.011
10	9	7	1.633 ± 0.018	7.268 ± 0.005
Temperature at core center, °C		30 ± 2		
Room temperature		20 ± 2		

Assemblies Fully Reflected with 15 cm of Plexiglas

Number of Fuel compacts				Corrected Height ^{b)} (5.095 cm) ^{a)}
Length (5.090 cm) ^{a)}	Width (5.090 cm) ^{a)}	Height (5.095 cm) ^{a)}	(1.384 cm) ^{a)}	
6	8	6	0.331 ± 0.055	5.851 ± 0.014
8	8	4	3.196 ± 0.007	4.678 ± 0.002
9	10	4	0.184 ± 0.048	3.891 ± 0.012
10	10	3	3.185 ± 0.022	3.714 ± 0.006
12	10	3	2.295 ± 0.029	3.482 ± 0.008
12	12	3	1.464 ± 0.033	3.265 ± 0.009
∞	∞	-	----	2.269 ± 0.018 ^{c)}
Core center temperature, °C		30 ± 1		
Room temperature, °C		20 ± 2		

a) Length, Width or Thickness of Unclad Fuel.

b) Critical Mass of reflected systems decreased by experimentally determined 3.92% to account for reactivity effects of stacking voids and cladding material. Critical Mass of unreflected systems similarly reduced 2.36% to account for voids, cladding material, and reflection.

c) Obtained from linear extrapolation of data from finite systems.

ADDITIONAL DATA:

Unreflected 9x8x8.860 Assembly

β/l , Sec ⁻¹ a)	182 ± 3
Prompt Critical - Delayed Critical, ΔH_{cm} a)	0.65 ± 0.04

a) From pulse neutron source measurements.

Dated:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 5

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.58)(\text{NO}_3)_4 + \text{U}(0.66)\text{O}_2(\text{NO}_3)_2$ containing 32.7 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.

R. C. Lloyd and E. D. Clayton "Criticality of Plutonium-Uranium Nitrate Solutions Containing 30 wt% Pu", Trans. Am. Nucl. Soc., 17, 269 (1973)

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0017	6.7208×10^{-8}
Pu-239	5.8532	2.3043×10^{-4}
Pu-240	0.3479	1.3639×10^{-5}
Pu-241	0.0219	8.5502×10^{-7}
Pu-242	0.0045	1.7496×10^{-7}
U-235	0.0846	3.3873×10^{-6}
U-236	0.0015	5.9803×10^{-8}
U-238	12.7436	5.0380×10^{-4}
N	7.0576	4.7420×10^{-3}
O	68.1601	4.0093×10^{-2}
H	5.6175	5.2449×10^{-2}
Gd	0.0015	8.9715×10^{-8}
Fe	0.1043	1.7577×10^{-5}

Solution Density, g/cm³ 1.5620

Plutonium Concentration, g/cm³ 0.0973

Uranium Concentration, g/cm³ 0.2004

Excess Nitrate Concentration, Molarity 4.6

H:Pu+U, Atomic 69.7

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	30.48
Inside Height, cm	105.73
Side Wall Thickness, cm	0.079
End Thicknesses, cm	0.95

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, cm	19.96
Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 6

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.58)(\text{NO}_3)_4 + \text{U}(0.66)(\text{NO}_3)_2$ containing 29.9 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.

R. C. Lloyd and E. D. Clayton "Criticality of Plutonium-Uranium Nitrate Solutions Containing 30 wt% Pu", Trans. Am. Nucl. Soc., 17, 269 (1973)

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0012	4.2186×10^{-8}
Pu-239	4.2686	1.4944×10^{-4}
Pu-240	0.2537	8.8446×10^{-6}
Pu-241	0.0160	5.5549×10^{-7}
Pu-242	0.0033	1.1410×10^{-7}
U-235	0.0701	2.4958×10^{-6}
U-236	0.0018	6.3816×10^{-8}
U-238	10.5617	3.7130×10^{-4}
N	5.2856	3.1580×10^{-3}
O	75.5666	3.7957×10^{-2}
H	6.8945	5.7242×10^{-2}
Gd	0.0011	5.8541×10^{-8}
Fe	0.0758	1.1359×10^{-5}

Solution Density, g/cm³ 1.3890

Plutonium Concentration, g/cm³ 0.0631

Uranium Concentration, g/cm³ 0.1477

Excess Nitrate Concentration, Molarity 2.9

H:Pu+U, Atomic 107.4

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	30.48
Inside Height, cm	105.73
Side Wall Thickness, cm	0.079
End Thicknesses, cm	0.95

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, cm	18.72
Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 7

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(\text{NO}_3)_4 + \text{U}(\text{NO}_3)_2$ containing 29.3 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.

R. C. Lloyd and E. D. Clayton "Criticality of Plutonium-Uranium Nitrate Solutions Containing 30 wt% Pu", Trans. Am. Nucl. Soc., 17, 269 (1973)

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0005	1.4604×10^{-8}
Pu-239	1.6529	4.8075×10^{-5}
Pu-240	0.0982	2.8443×10^{-6}
Pu-241	0.0062	1.7883×10^{-7}
Pu-242	0.0013	3.7342×10^{-8}
U-235	0.0279	8.2529×10^{-7}
U-236	0.0007	2.0618×10^{-8}
U-238	4.2088	1.2293×10^{-4}
N	3.0929	1.5353×10^{-3}
O	81.8212	3.5557×10^{-2}
H	9.0596	6.2492×10^{-2}
Gd	0.0004	1.7686×10^{-8}
Fe	0.0294	3.6602×10^{-6}

Solution Density, g/cm³ 1.1540

Plutonium Concentration, g/cm³ 0.0203

Uranium Concentration, g/cm³ 0.0489

Excess Nitrate Concentration, Molarity 1.8

H:Pu+U, Atomic 357.3

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	30.48
Inside Height, cm	105.73
Side Wall Thickness, cm	0.079
End Thicknesses, cm	0.95

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, cm	29.92
Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 8

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.58)(\text{NO}_3)_4 + \text{U}(0.66)\text{O}_2(\text{NO}_3)_2$ containing 29.3 wt% plutonium in the plutonium-uranium mixture.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd and E. D. Clayton "Criticality of Plutonium-Uranium Nitrate Solutions Containing 30 wt% Pu", Trans. Am. Nucl. Soc., 17, 269 (1973)

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-238	0.0003	8.3767×10^{-9}
Pu-239	1.0563	2.9365×10^{-5}
Pu-240	0.0628	1.7386×10^{-6}
Pu-241	0.0039	1.0752×10^{-7}
Pu-242	0.0008	2.1964×10^{-8}
U-235	0.0179	5.0609×10^{-7}
U-236	0.0005	1.4077×10^{-8}
U-238	2.6924	7.5163×10^{-5}
N	2.2938	1.0883×10^{-3}
O	84.1608	3.4957×10^{-2}
H	9.6914	6.3896×10^{-2}
Gd	0.0003	1.2678×10^{-8}
Fe	0.0188	2.2371×10^{-6}

Solution Density, g/cm ³	1.1030
Plutonium Concentration, g/cm ³	0.0124
Uranium Concentration, g/cm ³	0.0299
Excess Nitrate Concentration, Molarity	1.3
H:Pu+U, Atomic	597.6

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} 304L Stainless Steel at 7.93 g/cm³.

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	Atoms/barn cm
H	11.19	6.672×10^{-2}
O	88.81	3.336×10^{-2}

^{a)} Water at 23°C

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, cm	30.48
Inside Height, cm	105.73
Side Wall Thickness, cm	0.079
End Thicknesses, cm	0.95

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, cm	95.20
Reflector and core temperature, °C	23 ± 2
Room temperature, °C	21 ± 2

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 9

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.63)(\text{NO}_3)_4 + \text{U}(0.71)\text{O}_2(\text{NO}_3)_2$ containing 30.7 wt% plutonium in the plutonium-uranium mixture. Cylinders filled with a 15 cm thick polythene plug above the solution.

DATA SOURCE:

R. C. Lane, AWRE, Aldermaston, Berkshire, U. K.

R. C. Lane and C. Parker "Measurements of the Critical Size of Solution of Plutonium and Natural Uranium Nitrates with $\text{Pu/U}=0.3$," AWRE Report No. 0 58/73, December 1973.

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-239	6.2448	$2.3987 \pm 0.06 \times 10^{-6}$
Pu-240	0.3742	1.4313×10^{-5}
Pu-241	0.0279	1.0628×10^{-6}
U-235	0.1065	4.1604×10^{-6}
U-238	14.8870	$5.7422 \pm 0.2 \times 10^{-5}$
N	4.7284	$3.0997 \pm 0.03 \times 10^{-4}$
O	67.3406	$3.8647 \pm 1.0 \times 10^{-4}$
H	6.2906	$5.7304 \pm 2.0 \times 10^{-4}$
Fe	-----	2.0×10^{-8}
Solution Density, g/cm^3		1.524 ± 0.001
Plutonium Concentration, g/cm^3		0.1013 ± 0.0002
Uranium Concentration, g/cm^3		0.2285 ± 0.001
Excess Nitrate Concentration, Molarity		1.54 ± 0.03
H:Pu+U, Atomic		68.7 ± 0.3

a) Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

a) Type of Stainless Steel not given by data source. Composition shown for 304L at 7.93 g/cm^3 .

COMPOSITION OF REFLECTOR:

Nuclide	Water		Polythene Plug ^{a)}	
	Wt%	Atoms/barn cm	Wt%	Atoms/barn cm
H	11.19	6.666×10^{-2}	14.37	7.902×10^{-2}
O	88.81	3.333×10^{-2}	---	---
C	---	---	85.63	3.951×10^{-2}

a) Composition taken from AWRE 0 32/60, Reference 1 of Data Source.

DIMENSIONS OF EXPERIMENTAL VESSELS:

Inside Radius, cm	25.36	18.995	15.31	12.713
Inside Heights, cm	91.5	107.5	107.5	107.5
Side Wall Thicknesses, cm	0.25	0.25	0.25	0.20
Bottom Thicknesses, cm	0.10	0.10	0.10	0.10

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

None

Water Reflected Assemblies^{a)}

Cylinder Inside Radius (cm)	Critical Height of Solution	
	Experiment (cm)	Corrected ^{b)} (cm)
12.713 ± 0.003	56.31 ± 0.06	51.80 ± 0.2
25.360 ± 0.005	16.05 ± 0.04	14.94 ± 0.2
18.995 ± 0.020	21.17 ± 0.04	20.05 ± 0.2
15.310 ± 0.005	29.89 ± 0.05	28.64 ± 0.2

Reflector and core temperature, °C 26 ± 2

a) The dump valve assembly increased the critical weight by ~0.05%.

b) Measured corrections applied to experimental critical height to obtain "clean" cylinder of solution fully reflected by an infinite amount of water.

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 10

GENERAL DISCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.63)(\text{NO}_3)_4 + \text{U}(0.71)\text{O}_2(\text{NO}_3)_2$ containing 30.7 wt% plutonium in the plutonium-uranium mixture. Cylinders filled with a 15 cm thick polythene plug above the solution.

DATA SOURCE:

R. C. Lane, AWRE, Aldermaston, Berkshire, U.K.

R. C. Lane and C. Parker "Measurements of the Critical Size of Solution of Plutonium and Natural Uranium Nitrates with PU/U=0.3," AWRE Report No. 0 58/73, December 1973.

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-239	2.5059	$7.4780 \pm 0.02 \times 10^{-5}$
Pu-240	0.1502	4.4635×10^{-6}
Pu-241	0.0111	3.2849×10^{-7}
U-235	0.0428	1.2990×10^{-6}
U-238	5.9792	$1.7918 \pm 0.005 \times 10^{-4}$
N	2.5184	$1.2826 \pm 0.01 \times 10^{-3}$
O	79.8370	$3.5597 \pm 0.01 \times 10^{-2}$
H	8.9554	$6.3379 \pm 0.01 \times 10^{-2}$
Fe	-----	7.0×10^{-9}
Solution Density, g/cm ³		1.184 ± 0.001
Plutonium Concentration, g/cm ³		0.03158 ± 0.00006
Uranium Concentration, g/cm ³		0.0713 ± 0.0002
Excess Nitrate Concentration, Molarity		1.1 ± 0.07
H:Pu+U, Atomic		243 ± 0.63

a) Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

a) Type of Stainless Steel not given by data source. Composition shown for 304L at 7.93 g/cm³.

COMPOSITION OF REFLECTOR:

Nuclide	Water		Polythene Plug ^{a)}	
	Wt%	Atoms/barn cm	Wt%	Atoms/barn cm
H	11.19	6.666×10^{-2}	14.37	7.902×10^{-2}
O	88.81	3.333×10^{-2}	---	---
C	---	---	85.63	3.951×10^{-2}

a) Composition taken from AWRE 0 32/60, Reference 1 of Data Source.

DIMENSIONS OF EXPERIMENTAL VESSELS:

Inside Radius, cm	25.36	18.995	15.31
Inside Heights, cm	91.5	107.5	107.5
Side Wall Thicknesses, cm	0.25	0.25	0.25
Bottom Thicknesses, cm	0.10	0.10	0.10

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

None

Water Reflected Assemblies^{a)}

Cylinder Inside Radius (cm)	Critical Height of Solution	
	Experiment (cm)	Corrected ^{b)} (cm)
25.360 ± 0.005	20.39 ± 0.03	19.94 ± 0.2
18.995 ± 0.020	28.24 ± 0.04	27.64 ± 0.2
15.310 ± 0.005	46.18 ± 0.05	43.20 ± 0.2

Reflector and core temperature, °C 26 ± 2

- a) The dump valve assembly decreased the critical weight by $\sim 0.8\%$.
- b) Measured corrections applied to experimental critical height to obtain "clean" cylinder of solution fully reflected by an infinite amount of water.

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 11

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.63)(\text{NO}_3)_4 + \text{U}(0.71)\text{O}_2(\text{NO}_3)_2$ containing 30.6 wt% plutonium in the plutonium-uranium mixture. Cylinders filled with a 15 cm thick polythene plug above the solution.

DATA SOURCE:

R. C. Lane, AWRE, Aldermaston, Berkshire, U.K.

R. C. Lane and C. Parker "Measurements of the Critical Size of Solution of Plutonium and Natural Uranium Nitrates with PU/U=0.3," AWRE Report No. 0 58/73, December 1973.

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-239	1.5632	$4.4068 \pm 0.02 \times 10^{-5}$
Pu-240	0.0937	2.6305×10^{-6}
Pu-241	0.0070	1.9570×10^{-7}
U-235	0.0268	7.6836×10^{-7}
U-238	3.7461	$1.0604 \pm 0.003 \times 10^{-4}$
N	1.9691	$9.4738 \pm 0.1 \times 10^{-4}$
O	82.9717	$3.4948 \pm 0.01 \times 10^{-2}$
H	9.6224	$6.4332 \pm 0.01 \times 10^{-2}$
Fe	-----	4.0×10^{-9}
Solution Density, g/cm ³		1.1185 ± 0.001
Plutonium Concentration, g/cm ³		0.01861 ± 0.00007
Uranium Concentration, g/cm ³		0.0422 ± 0.0001
Excess Nitrate Concentration, Molarity		0.01 ± 0.03
H:Pu+U, Atomic		419 ± 2

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} Type of Stainless Steel not given by data source. Composition shown for 304L at 7.93 g/cm³.

COMPOSITION OF REFLECTOR:

Nuclide	Water		Polythene Plug ^{a)}	
	Wt%	Atoms/barn cm	Wt%	Atoms/barn cm
H	11.19	6.666×10^{-2}	14.37	7.902×10^{-2}
O	88.81	3.333×10^{-2}	---	---
C	---	---	85.63	3.951×10^{-2}

^{a)} Composition taken from AWRE 0 32/60, Reference 1 of Data Source.

DIMENSIONS OF EXPERIMENTAL VESSELS:

Inside Radius, cm	25.36	18.995
Inside Heights, cm	91.5	107.5
Side Wall Thicknesses, cm	0.25	0.25
Bottom Thicknesses, cm	0.10	0.10

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

None

Water Reflected Assemblies^{a)}

Cylinder
Inside Radius
(cm)

25.360 ± 0.005
 18.995 ± 0.020

Critical Height of Solution
Experiment
(cm)

33.59 ± 0.03
 72.86 ± 0.07

Corrected^{b)}
(cm)

33.92 ± 0.3
 70.17 ± 0.3

Reflector and core temperature, °C 26 ± 2

- a) The dump valve assembly increased the critical weight by $\sim 0.01\%$.
b) Measured corrections applied to experimental critical height to obtain "clean" cylinder of solution fully reflected by an infinite amount of water.

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 12

GENERAL DESCRIPTION:

Stainless steel cylinders reflected with at least 15 cm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(5.63)(\text{NO}_3)_4 + \text{U}(0.71)\text{O}_2(\text{NO}_3)_2$ containing 30.6 wt% plutonium in the plutonium-uranium mixture. Cylinders filled with a 15 cm thick polythene plug above the solution.

DATA SOURCE:

R. C. Lane, AWRE, Aldermaston, Berkshire, U. K.

R. C. Lane and C. Parker "Measurements of the Critical Size of Solution of Plutonium and Natural Uranium Nitrates with PU/U=0.3," AWRE Report No. 0 58/73, December 1973.

COMPOSITION OF FUEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Pu-239	1.4772	$4.1438 \pm 0.02 \times 10^{-5}$
Pu-240	0.0885	2.4723×10^{-6}
Pu-241	0.0066	1.8361×10^{-7}
U-235	0.0253	7.2179×10^{-7}
U-238	3.5327	$9.9515 \pm 0.003 \times 10^{-5}$
N	1.9220	$9.2017 \pm 0.1 \times 10^{-4}$
O	83.2647	$3.4899 \pm 0.01 \times 10^{-2}$
H	9.6830	$6.4419 \pm 0.01 \times 10^{-2}$
Fe	-----	4.0×10^{-9}
Solution Density, g/cm ³		1.1130 ± 0.001
Plutonium Concentration, g/cm ³		0.01750 ± 0.00008
Uranium Concentration, g/cm ³		0.0396 ± 0.0001
Excess Nitrate Concentration, Molarity		0.90 ± 0.03
H:Pu+U, Atomic		446 ± 2

^{a)} Water and hydrogen ion concentration adjusted to obtain density and total nitrate reported by data source.

COMPOSITION OF EXPERIMENTAL VESSEL ^{a)}:

Nuclide	Wt%	Atoms/barn cm
Fe	74.0	6.331×10^{-2}
Cr	18.0	1.654×10^{-2}
Ni	8.0	6.510×10^{-3}

^{a)} Type of Stainless Steel not given by data source. Composition shown for 304L at 7.93 g/cm³.

COMPOSITION OF REFLECTOR:

Nuclide	Water		Polythene Plug ^{a)}	
	Wt%	Atoms/barn cm	Wt%	Atoms/barn cm
H	11.19	6.666×10^{-2}	14.37	7.902×10^{-2}
O	88.81	3.333×10^{-2}	---	---
C	---	---	85.63	3.951×10^{-2}

^{a)} Composition taken from AWRE 0 32/60, Reference 1 of Data Source.

DIMENSIONS OF EXPERIMENTAL VESSELS:

Inside Radius, cm	25.36
Inside Heights, cm	91.5
Side Wall Thicknesses, cm	0.25
Bottom Thicknesses, cm	0.10

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

None

Water Reflected Assemblies

Cylinder
Inside Radius
(cm)

25.360 ± 0.005

Critical Height of Solution
Experiment
(cm)

37.16 ± 0.03

Corrected^{a)}
(cm)

37.50 ± 0.2

Reflector and core temperature, °C 26 ± 2

a) Measured corrections applied to experimental critical height to obtain "clean" cylinder of solution fully reflected by an infinite amount of water.

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 13

GENERAL DESCRIPTION:

Rectangular parallelepipeds of homogeneous $\text{Pu}(8)\text{O}_2 - \text{U}(0.15)\text{O}_2$ - polystyrene containing 30.0 wt% PuO_2 in the oxide. Critical heights given, as a function of base dimensions, for bare assemblies and assemblies fully reflected with at least 15 cm of Plexiglas. Fuel in the form of 5.09 x 5.09 cm compacts having different thicknesses and clad with approximately 6 mil thick tape.

DATA SOURCE:

S. R. Bierman, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352

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", NS&E, 50, 115-126 (1973).

COMPOSITION OF FUEL:

Nuclide	Wt%	Atoms/barn cm
Am-241	0.009 ± ---	3.161×10^{-7}
Pu-238	0.000 ± ---	0.000
Pu-239	7.270 ± 0.021	2.575×10^{-4}
Pu-240	0.651 ± 0.015	2.296×10^{-5}
Pu-241	0.049 ± 0.004	1.721×10^{-6}
Pu-242	0.003 ± ---	1.049×10^{-7}
U-235	0.028 ± ---	1.008×10^{-6}
U-238	18.567 ± 0.003	6.603×10^{-4}
H	5.320 ± 0.040	4.468×10^{-2}
O	3.731 ± 0.004	1.975×10^{-3}
C	64.370 ± 0.484	4.537×10^{-2}
Fuel Density, g/cm ³	1.405 ± 0.020	
Plutonium Concentration, g/cm ³	0.112 ± 0.002	
Uranium Concentration, g/cm ³	0.261 ± 0.004	
H:Pu+U, Atomic	47.35 ± 1.0	
Mean Particle Sizes, Microns		
Plutonium Oxide	5	
Uranium Oxide	9	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	Wt%	Atoms/barn cm
H	55.3	4.489×10^{-2}
C	6.7	3.111×10^{-2}
Cl	38.0	7.240×10^{-3}
Cladding Density, g/cm ³	1.120	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	Atoms/barn cm
H	8.0	5.666×10^{-2}
C	60.0	3.570×10^{-2}
O	32.0	1.428×10^{-2}
Reflector Density, g/cm ³	1.185	

DIMENSIONS OF FUEL:

	Unclad	Clad	Stacked ^{a)}
Length, cm	5.090 ± 0.005	5.122 ± 0.005	5.160 ± 0.010
Width, cm	5.090 ± 0.005	5.106 ± 0.005	5.160 ± 0.025
Heights, cm	5.100 ± 0.005	5.133 ± 0.005	5.190 ± 0.010
	1.300 ± 0.127	1.333 ± 0.039	1.390 ± 0.043

a) Average Dimension of Space occupied by compacts in the reflected critical assemblies. Add 0.01 cm for bare assemblies.

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

Number of Fuel Compacts				Corrected Height ^{b)} (5.100 cm) ^{a)}
Length (5.090 cm) ^{a)}	Width (5.090 cm) ^{a)}	Height (5.100 cm) ^{a)} (1.300 cm) ^{a)}		
8	8	8	1.518 ± 0.024	8.282 ± 0.006
9	8	7	2.118 ± 0.031	7.447 ± 0.008
9	10	6	1.769 ± 0.020	6.370 ± 0.005
Temperature at core center, °C		30 ± 2		
Room temperature		20 ± 2		

Assemblies Fully Reflected with 15 cm of Plexiglas

Number of Fuel Compacts				Corrected Height ^{b)} (5.100 cm) ^{a)}
Length (5.090 cm) ^{a)}	Width (5.090 cm) ^{a)}	Height (5.100 cm) ^{a)} (1.300 cm) ^{a)}		
6	6	6	0.667 ± 0.016	6.057 ± 0.004
7	7	4	3.072 ± 0.094	4.696 ± 0.024
8	8	4	0.153 ± 0.067	3.965 ± 0.017
10	9	3	1.663 ± 0.059	3.361 ± 0.015
10	10	3	1.153 ± 0.027	3.233 ± 0.007
12	10	3	0.400 ± 0.082	3.045 ± 0.021
12	11	3	0.106 ± 0.016	2.972 ± 0.004
13	12	2	3.460 ± 0.078	2.829 ± 0.020
∞	∞	2	0.616 ± 0.086 ^{c)}	2.118 ± 0.022
Core center temperature, °C		30 ± 1		
Room temperature, °C		20 ± 2		

a) Length, Width or Thickness of Unclad Fuel.

b) Critical Mass of reflected systems decreased by experimentally determined 1.83% to account for reactivity effects of stacking voids and cladding material. Critical Mass of unreflected systems similarly reduced 1.24% to account for voids, cladding material, and reflection.

c) Obtained from linear extrapolation of data from finite systems.

DATED:

June 28, 1974

CRITICAL EXPERIMENTS - BENCHMARK 14

GENERAL DESCRIPTION:

Rectangular parallelipeds of homogeneous $\text{Pu}(8)\text{O}_2 - \text{U}(0.15)\text{O}_2$ - polystyrene containing 7.8 ~~30~~ wt% PuO_2 in the oxide. Critical heights given, as a function of base dimensions, for assemblies fully reflected with at least 15 cm of Plexiglas. Fuel in the form of 5.09 x 5.09 cm compacts having different thicknesses and clad with approximately 6 mil thick tape.

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COMPOSITION OF FUEL:

Nuclide	Wt%	Atoms/barn cm
Am-241	$0.005 \pm \text{---}$	1.740×10^{-7}
Pu-238	$0.000 \pm \text{---}$	0.0
Pu-239	1.858 ± 0.019	6.521×10^{-5}
Pu-240	0.166 ± 0.004	5.802×10^{-6}
Pu-241	0.012 ± 0.001	4.177×10^{-7}
Pu-242	$0.001 \pm \text{---}$	3.466×10^{-8}
U-235	$0.036 \pm \text{---}$	1.285×10^{-6}
U-238	23.763 ± 0.004	8.375×10^{-4}
H	5.670 ± 0.040	4.719×10^{-2}
O	3.489 ± 0.005	1.830×10^{-3}
C	65.000 ± 0.459	4.540×10^{-2}
Fuel Density, g/cm^3	1.392 ± 0.007	
Plutonium Concentration, g/cm^3	0.028 ± 0.001	
Uranium Concentration, g/cm^3	0.331 ± 0.002	
H:Pu+U, Atomic	51.85 ± 0.35	
Mean Particle Sizes, Microns		
Plutonium Oxide	5	
Uranium Oxide	9	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	Wt%	Atoms/barn cm
H	55.3	4.489×10^{-2}
C	6.7	3.111×10^{-2}
Cl	38.0	7.240×10^{-3}
Cladding Density, g/cm^3	1.120	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	Atoms/barn cm
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C	60.0	3.570×10^{-2}
O	32.0	1.428×10^{-2}
Reflector Density, g/cm^3	1.185	

DIMENSIONS OF FUEL:

	<u>Unclad</u>	<u>Clad</u>	<u>Stacked^{a)}</u>
Length	5.090 ± 0.005	5.114 ± 0.005	5.128 ± 0.010
Width, cm	5.080 ± 0.010	5.116 ± 0.010	5.189 ± 0.025
Heights, cm	5.090 ± 0.005	5.114 ± 0.005	5.128 ± 0.010
	1.324 ± 0.026	1.360 ± 0.026	1.438 ± 0.043

a) Average Dimension of Space occupied by compacts in the critical assemblies.

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

None

Assemblies Fully Reflected with 15 cm of Plexiglas

Number of Fuel Compacts				Corrected Height ^{b)} (5.090cm) ^{a)}
Length (5.090cm) ^{a)}	Width (5.080cm) ^{a)}	Height (5.090cm) ^{a)} (1.324cm) ^{a)}		
8	8	8	1.657 ± 0.012	7.156 ± 0.003
8	9	7	2.357 ± 0.019	6.462 ± 0.005
10	10	6	0.430 ± 0.012	5.188 ± 0.003
10	12	5	2.462 ± 0.031	4.787 ± 0.008
12	11	5	1.442 ± 0.012	4.562 ± 0.003
12	12	5	0.934 ± 0.012	4.429 ± 0.011
12	13	5	0.438 ± 0.158	4.340 ± 0.041
∞	∞	-	-----	2.914 ± 0.118 ^{c)}

Core center temperature, °C 30 ± 1

Room temperature, °C 20 ± 2

a) Length, Width or Thickness of Unclad Fuel

b) Critical Mass of reflected systems decreased by experimentally determined 15.125% to account for reactivity effects of stacking voids and cladding material.

c) Obtained from extrapolation of data from finite systems

DATED:

June 28, 1974

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