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Handbook of Critical Experiments Benchmarks

by

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Introduction

Data from critical experiments have been collected together for use as benchmarks in evaluating calculational techniques and nuclear data. These benchmarks have been selected from the numerous experiments performed on homogeneous plutonium systems. No attempt has been made to reproduce all of the data that exists. The primary objective in the collection of these data is to present representative experimental data defined in a concise, standardized format that can easily be translated into computer code input.

The selected benchmarks cover the following kinds of systems:

1. Unreflected spheres of plutonium metal containing 4.5 and 20 wt% ^{240}Pu .
2. Unreflected spherical steel vessel filled with plutonium nitrate solution.
3. Spherical steel vessels filled with plutonium nitrate solution of low ^{240}Pu content and reflected by:
 - a) full water with and without a Cd interface
 - b) different thicknesses of concrete some with and without a Cd interface
 - c) additional steel and full water
 - d) different thicknesses of paraffin.
4. Water reflected steel cylindrical vessels containing plutonium nitrate solution having 8.4, 13.5 and 42.9 wt% ^{240}Pu in the plutonium.
5. Unreflected and reflected annular steel cylindrical vessels containing plutonium nitrate solution.
6. Unreflected and reflected steel slab vessels containing plutonium nitrate solution.

7. Unreflected and reflected PuO_2 solids covering an H/Pu atomic ratio range from 0 to 50.
8. Metal plutonium sphere reflected by natural uranium.

Material properties for each experimental assembly are given on the first page of each benchmark while geometric descriptions are given on the second page. Diagrams are presented for each of experiments excepting those cases where the geometry is very simple and a short description suffices. Any available experimentally determined correction factors for reducing experiment complexity are also included with the pertinent benchmark.

It is the authors' hope that the data presented in this manner will better facilitate its use in code validation.

CRITICAL EXPERIMENTS - Pu BENCHMARK 1

GENERAL DESCRIPTION:

Infinite homogeneous critical solution of ^{239}Pu atoms in water

DATA SOURCE:

R. H. Masterson, J. D. White and T. J. Powell, 'The Limiting Critical Concentration for ^{239}Pu and ^{235}U in Aqueous Solutions', HW-77089, Hanford Atomic Products Operations (1963)

C. R. Richey, 'Reexamination of the Value for the Minimum Critical Concentration of Plutonium-239 in Water', Nucl Sci & Eng., 55, 244-247, (1974)

COMPOSITION OF FUEL:

Nuclide	Wt%	10^{30} Atoms/ m^3
Pu-239	0.7132	1.8113×10^{-5}
O	88.1765	3.3459×10^{-2}
H	11.1103	6.6918×10^{-2}
Solution Density, kg/m^3	1008.14	
Plutonium Concentration, kg/m^3	7.19 ± 0.15	
H : Pu, Atom Ratio	3694.5	

CRITICAL EXPERIMENTS - Pu BENCHMARK 2

GENERAL DESCRIPTION:

Stainless steel (type 304L) sphere, unreflected and filled with a homogeneous aqueous solution of Pu (4.57) (NO₃)₄ at 125 H: Pu.

DATA SOURCE:

R.C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R.C. Lloyd, C.R. Richey, E.D. Clayton and D.R. Skeen, "Criticality Studies with Plutonium Solutions," N.S.&E 25, 165-173, (1966).

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-238	0.0000 ± ———	—————
Pu-239	11.4689 ± 0.0572	4.1307 x 10 ⁻⁴
Pu-240	0.5507 ± 0.0027	1.9752 x 10 ⁻⁵
Pu-241	0.0371 ± 0.0002	1.3251 x 10 ⁻⁶
Pu-242	0.0007 ± ———	2.4899 x 10 ⁻⁸
N	7.6827 ± 0.0280	4.7224 x 10 ⁻³
O	73.8935 ± 0.2561	3.9764 x 10 ⁻²
H	6.3433 ± 0.0299	5.4182 x 10 ⁻²
Fe	0.0231 ± 0.0001	3.5612 x 10 ⁻⁶

Solution Density, kg / m ³	1429.00 ± 5.72
Plutonium Concentration, kg / m ³	172.30 ± 0.86
Excess Nitrate Concentration, Molarity	4.96 ± 0.12
H: Pu, Atom Ratio	124.8 ± 0.9

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

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^{a)} 304L Stainless Steel at 7.93 mg / m³

COMPOSITION OF REFLECTOR:

None

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, mm	193.18 ± 0.02
Vessel Wall Thickness, mm	$1.22 \pm \text{---}$

DELAYED CRITICAL CONFIGURATION:

Unreflected assembly^{a)}

Core Temperature, K	299.8 ± 2
Room Temperature, K	297.0 ± 2

a) Experimentally determined corrections for the vessel and piping increases the spherical critical volume for this solution to 0.0311 m^3 .

Reflected assembly

None

CRITICAL EXPERIMENTS - Pu BENCHMARK 3

GENERAL DESCRIPTION:

Stainless steel (Type 347) sphere, reflected with at least 300 mm of water and filled with a homogeneous aqueous solution of Pu (0.54) (NO₃)₄ at 980 H: Pu.

DATA SOURCE:

F.F. Kruesi J.O. Erkman and D.D. Lanning, "Critical Mass Studies of Plutonium Solutions," HW-24514 DEL, p 67, 1952.

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-238		
Pu-239	2.4493 ± 0.0245	6.6004 x 10 ⁻⁵
Pu-240	0.0133 ± 0.0009	3.5692 x 10 ⁻⁷
Pu-241		
Pu-242		
N	1.6332 ± 0.0217	7.5114 x 10 ⁻⁴
O	85.7193 ± 0.0746	3.4514 x 10 ⁻²
H	10.1715 ± 0.0077	6.5006 x 10 ⁻²
Fe	0.0134 ± 0.0002	1.5457 x 10 ⁻⁶

Solution Density, kg / m ³	1069.2 ± 0.3
Plutonium Concentration, kg / m ³	26.3 ± 0.3
Excess Nitrate, Concentration, Molarity	0.806 ± 0.009
H: Pu, Atom Ratio	979.6 ± 9.9

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

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	72.0	6.175 x 10 ⁻²
Cr	18.0	1.658 x 10 ⁻²
Ni	10.0	8.158 x 10 ⁻³

^{a)} 347 Stainless Steel at 7.95 mg / m³

COMPOSITION OF REFLECTOR^{a)}:

Nuclide	Wt%	10 ³⁰ Atoms / m ³
H	11.19	6.663 x 10 ⁻²
O	88.81	3.332 x 10 ⁻²

^{a)} Water at 299.8 ± 0.3 K

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere, mm	177.80 ± 1.59
Vessel Wall Thickness, mm	$1.27 \pm \text{—}$

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, K	299.8 ± 0.3
Room temperature, K	$297.0 \pm \text{—}$

a) The vessel neck increases the critical mass by a maximum of 50 mg of Pu.

CRITICAL EXPERIMENTS - Pu BENCHMARK 4

GENERAL DESCRIPTION:

Stainless steel (Type 304L) sphere, reflected with 6.604 mm of Type 304L steel and filled with a homogeneous aqueous solution of Pu (4.57) (NO₃)₄ at 758 H: Pu.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352
R. C. Lloyd, C. R. Richey, E. D. Clayton and D. R. Skeen, "Criticality Studies with Plutonium Solutions," N. S. & E 25, 165-173 (1966).

COMPOSITION OF FUEL^{a)}:

Nuclide	Wt%	10^{30} Atoms / m ³
Pu-238	—	—
Pu-239	3.0322 ± 0.0152	8.2232 x 10 ⁻⁵
Pu-240	0.1456 ± 0.0007	3.9321 x 10 ⁻⁶
Pu-241	0.0098 ± —	2.6356 x 10 ⁻⁷
Pu-242	0.0002 ± —	5.3567 x 10 ⁻⁹
N	1.3856 ± 0.0754	6.4132 x 10 ⁻⁴
O	85.2334 ± 0.3727	3.4536 x 10 ⁻²
H	10.1872 ± 0.0460	6.5520 x 10 ⁻²
Fe	0.0060 ± 0.0003	6.9650 x 10 ⁻⁷

Solution Density, kg / m ³	1076.0 ± 4.3
Plutonium Concentration, kg / m ³	34.3 ± 0.2
Excess Nitrate Concentration, Molarity	0.49 ± 0.02
H: Pu, Atom Ratio	758.0 ± 0.2

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

COMPOSITION OF EXPERIMENTAL VESSEL^{a)}:

Nuclide	Wt%	10^{30} Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^{a)} 304L Stainless Steel at 7.93 mg / m³

COMPOSITION OF REFLECTOR:

Same as experimental vessel.

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, mm	193.18 ± 0.02
Vessel Wall Thickness, mm	$1.22 \pm \text{---}$

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Steel Reflected Assembly^{a)}

Reflector and core temperature, K	299.8 ± 2
Room Temperature, K	297.0 ± 2

a) Same as unreflected Pu-Benchmark 2 except 6.604 mm of 304L steel added to vessel wall

CRITICAL EXPERIMENTS-Pu BENCHMARK 5

GENERAL DESCRIPTION:

Rectangular parallelipeds of homogeneous Pu (2.2) O₂ - polystyrene at 15 H : Pu atom ratio. Critical sizes given for assemblies both bare and reflected with at least 15 cm of plexiglas. Fuel used in the experiments was in the form of 51.16 mm compacts having different thicknesses and clad with 0.279 mm thick rubberized plastic.

DATA SOURCE:

C. R. Richey, J. D. White, E. D. Clayton and R. C. Lloyd, "Criticality of Homogeneous Plutonium Oxide-Plastic Compacts at H : Pu = 15", Nucl. Sci & Engr, 23, 150-158, (1965)

COMPOSITION OF FUEL

Nuclide	Wt%	10^{30} Atoms / m ³
Am-241	—	—
Pu-238	—	—
Pu-239	49.9430 ± 0.8921	2.756 x 10 ⁻³
Pu-240	1.1228 ± 0.0286	6.172 x 10 ⁻⁵
Pu-241	0.0548 ± 0.0100	3.010 x 10 ⁻⁶
Pu-242	-	-
H	3.2546 ± 0.0600	4.260 x 10 ⁻²
O	6.8419 ± 0.1532	5.642 x 10 ⁻³
C	38.7829 ± 0.7159	4.260 x 10 ⁻²
Fuel Density, kg / m ³	2190.9 ± 26.4	
Plutonium, kg / m ³	1120.0 ± 20	
H : Pu, Atom Ratio	15.1	
Particle Sizes, μm		
Plutonium Oxide	150 (MAX)	
Polystyrene	150 (MAX)	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	10^{30} Atoms / m ³
H		5.666 x 10 ⁻²
C	60.0	3.570 x 10 ⁻²
O	32.0	1.428 x 10 ⁻²
Reflector Density, kg / m ³	1185	

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assembly^{a)}

<u>LENGTH (mm)</u>	<u>WIDTH (mm)</u>	<u>HEIGHT^{a)} (mm)</u>
306.8	306.8	344.9 ± 5.1

Temperature at core center, K	328 ± 5
Room temperature, K	293 ± 2

Assembly Fully Reflected with 15 cm of Plexiglass

<u>LENGTH (mm)</u>	<u>WIDTH (mm)</u>	<u>HEIGHT^{a)} (mm)</u>
230.1	230.1	201.2 ± 1.8

Core center temperature, K	328 ± 5
Room temperature, K	293 ± 2

^{a)} Experimentally determined corrections applied to data to account for reactivity effects of stacking voids and cladding material.

CRITICAL EXPERIMENTS - Pu BENCHMARK 6

GENERAL DESCRIPTION:

Homogeneous sphere of unreflected Pu (4.5) metal.

DATA SOURCE:

G.E. Hanson and H.C. Paxton, "Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems," LA-4208, (1969)

G.A. Jarvis, G. A. Linenberger, J. D. Orndoff and H.C. Paxton, "Two Plutonium-Metal Critical Assemblies," NS & E 8, 525-531, (1960)

COMPOSITION OF FUEL :

<u>Nuclide</u>	<u>Wt %</u>	<u>10^{30} Atoms/m³</u>
Pu-239	94.21	3.7046×10^{-2}
Pu-240	4.47	1.7504×10^{-3}
Pu-241	0.30	1.1699×10^{-4}
Ga	1.02	6.0975×10^{-4}

Alloy Density, kg/m³ 15610.0 ± 31

CRITICAL DIMENSION^{a)}:

Radius, mm 63.85

^{a)} Experimental critical mass of 16.784 kg corrected to a 17.02 kg (±0.6%) perfect sphere of 15610 kg/m³ pure alloy in a vacuum at 273 K.

CRITICAL EXPERIMENTS-Pu BENCHMARK 7

GENERAL DESCRIPTION:

Stainless steel (Type 304L) cylinder, unreflected and partially filled with a homogeneous aqueous solution of Pu (13.8) (NO₃)₄ at 910H : Pu

DATA SOURCE:

F. Abbey, P. J. Hemmings, and E. R. Woodlock, "Data Checks on Plutonium Systems", HSRC/CSC/p. 24, (UK)

J. C. Smith, (Title unknown), HSRC/CSC/p. 30 (1964) (UK)

COMPOSITION OF FUEL:

Nuclide	Wt%	10^{30} Atoms / m ³
Pu-239	2.308	6.1822×10^{-5}
Pu-240	0.369	9.8429×10^{-6}
N	1.354	6.1898×10^{-4}
O	85.703	3.4300×10^{-2}
H	10.266	6.5215×10^{-2}
Solution Density, kg / m ³		1063.3
Plutonium Concentration, kg / m ³		28.5
Excess Nitrate Concentration, Molarity		0.55
H : Pu, Atom Ratio		910

COMPOSITION OF EXPERIMENTAL VESSEL ^{a)}:

Nuclide	Wt%	10^{30} Atoms / m ³
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 7930 kg / m³

COMPOSITION OF REFLECTOR:

None

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, mm	227.33 a)
Inside Height, mm	b)
Side Wall Thickness, mm	1.626
End Thicknesses, mm	1.626

- a) It is not clear whether the vessel radius is internal or external.
- b) Not given.

Critical height of solution, mm	364.03 a)
Reflector and core temperature, K	b)
Room temperature, K	b)

- a) It is not clear whether a correction has been made for the effects of the feed pipe. The correction might amount to 2.5 mm (max.) in the critical height.
- b) Not given

REFLECTED ASSEMBLY

None

CRITICAL EXPERIMENTS - Pu BENCHMARK 8

GENERAL DESCRIPTION:

Rectangular parallelepipeds of homogeneous Pu (18.35)O₂ - polystyrene at 49.6 H: Pu atom ratio. Critical heights given, as a function of base dimensions, for bare assemblies and assemblies fully reflected with at least 150 mm of Plexiglas. Fuel in the form of 50.9 x 50.9 mm compacts having different thicknesses and clad with 0.18 mm thick tape.

DATA SOURCE:

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

S.R. Bierman and E.D. Clayton, "Critical Experiments With Homogeneous PuO₂ - Polystyrene at 50 H: Pu", Nuc Tech, 15, 5-13, (1972).

COMPOSITION OF FUEL:

Nuclide	WT%	10^{30} Atoms / m ³
Am-241	0.208	7.272×10^{-6}
Pu-238	0.061	2.123×10^{-6}
Pu-239	19.846	6.996×10^{-4}
Pu-240	4.842	1.700×10^{-4}
Pu-241	1.126	3.936×10^{-5}
Pu-242	0.300	1.044×10^{-5}
H	5.470	4.573×10^{-2}
O	3.977	2.095×10^{-3}
C	64.170	4.502×10^{-2}
Fuel Density, kg/m ³	1399.4 ± 12.9	
Plutonium, kg/m ³	366.3 ± 3.8	
H: Pu, Atom Ratio	49.62 ± 0.65	
Mean Particle Sizes, μm		
Plutonium Oxide	1.2	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	WT%	10^{30} Atoms / m ³
H	55.3	4.489×10^{-2}
C	6.7	3.111×10^{-2}
Cl	38.0	7.240×10^{-3}
Cladding Density, kg/m ³	1120	

COMPOSITION OF REFLECTOR:

Nuclide	WT%	10^{30} Atoms / m ³
H	8.0	5.666×10^{-2}
C	60.0	3.570×10^{-2}
O	32.0	1.428×10^{-2}
Reflector Density, kg/m ³	1185	

DIMENSIONS OF FUEL:

	Unclad	Clad	Stacked ^{a)}
Length, mm	50.90 ± 0.05	51.14 ± 0.05	51.90 ± 0.05
Width, mm ^{b)}	50.90 ± 0.05	51.14 ± 0.05	51.90 ± 0.05
Heights, mm ^{b)}	50.89 ± 0.14	51.37 ± 0.14	51.60 ± 0.14
	13.51 ± 0.18	13.75 ± 0.18	13.84 ± 0.18

a) Average Dimension of Space occupied by compacts.

b) Compacts rotated 90° in unreflected assembly.

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

Number of Fuel Compacts				Corrected Height ^{b)} (50.90 mm) ^{a)}
Length (50.90 mm) ^{a)}	Width (50.89 mm) ^{a)}	Height		
		(50.90 mm) ^{a)}	(13.51 mm) ^{a)}	
9	8	9	2.599 ± 0.369	9.650 ± 0.098
Temperature at core center, K		328 ± 5		
Room temperature, K		293 ± 2		

Assemblies Fully Reflected with 15 cm of Plexiglass

Number of Fuel Compacts				Corrected Height ^{b)} (50.89 mm) ^{a)}
Length (50.90 mm) ^{a)}	Width (50.90 mm) ^{a)}	Height		
		(50.89 mm) ^{a)}	(13.51 mm) ^{a)}	
8	8	4	2.467 ± 0.075	4.634 ± 0.020
10	10	3	2.592 ± 0.060	3.671 ± 0.016
12	10	3	1.695 ± 0.038	3.434 ± 0.010
12	12	3	0.859 ± 0.045	3.213 ± 0.012
∞	∞	2	0.550 ± 0.105	2.136 ± 0.028 ^{c)}
Core center temperature, K		328 ± 5		
Room temperature, K		293 ± 2		

a) Length, width or thickness of unclad fuel.

b) Critical Mass of reflected systems decreased by experimentally determined 0.46% to account for reactivity effects of stacking voids and cladding material. Critical Mass of unreflected systems similarly reduced 0.41% to account for voids, cladding material, and reflection.

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

CRITICAL EXPERIMENTS - Pu BENCHMARK 9

GENERAL DESCRIPTION:

Stainless steel (Type 347) cylinder reflected with at least 200 mm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of Pu (8.4)(NO₃)₄ at 210 H:Pu.

DATA SOURCE:

R. C. Lloyd, E. D. Clayton, and L. E. Hansen "Criticality of Plutonium Nitrate Solution Containing Soluble Gadolinium", Nucl Sci & Engr 48, 300-304, (1972).

COMPOSITION OF FUEL: ^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-238	0.0004	1.2701 x 10 ⁻⁸
Pu-239	8.3833	2.6508 x 10 ⁻⁴
Pu-240	0.7747	2.4394 x 10 ⁻⁵
Pu-241	0.0787	2.4679 x 10 ⁻⁶
Pu-242	0.0045	1.4053 x 10 ⁻⁷
N	4.2995	2.3202 x 10 ⁻³
O	78.2964	3.6991 x 10 ⁻²
H	8.1625	6.1211 x 10 ⁻²
Solution Density, kg/m ³	1255.2	
Plutonium Concentration, kg/m ³	116	
Excess Nitrate, Concentration, Molarity	1.91	
H:Pu, Atom Ratio	209.6	

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

COMPOSITION OF EXPERIMENTAL VESSEL: ^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	72.0	6.175 x 10 ⁻²
Cr	18.0	1.658 x 10 ⁻²
Ni	10.0	8.158 x 10 ⁻³

^(a)347 Stainless Steel at 7950 kg/m³

COMPOSITION OF REFLECTOR: ^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²

^(a)Water at 296 ± 2K

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, mm	305.14
Inside Height, mm	1057.3
Side Wall Thickness, mm	0.79
End Thicknesses, mm	9.5

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, mm	154.4
Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

CRITICAL EXPERIMENTS - Pu BENCHMARK 10

GENERAL DESCRIPTION:

Rectangular parallelepipeds of homogeneous Pu (18.35)O₂-water at 0.04 H:Pu atom ratio. Critical heights given, as a function of base dimensions, for bare assemblies and assemblies fully reflected with at least 150 mm of Plexiglas. Fuel in the form of 51.3x51.3 cm compacts having different thicknesses and clad with a polyolefin plastic.

DATA SOURCE:

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

S. R. Bierman and E. D. Clayton, "Critical Experiments With Unmoderated Plutonium Oxide", Nuc Tech, 11, 185-190, (1971).

COMPOSITION OF FUEL:

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-238	0.203 ± 0.001	3.3806 x 10 ⁻⁵
Pu-239	65.840 ± 0.519	1.0918 x 10 ⁻²
Pu-240	16.064 ± 0.220	2.6528 x 10 ⁻³
Pu-241	4.418 ± 0.170	7.2658 x 10 ⁻⁴
Pu-242	0.996 ± 0.148	1.6312 x 10 ⁻⁴
H	0.014 ± —	5.5061 x 10 ⁻⁴
O	12.466 ± 0.088	3.0888 x 10 ⁻²
Fuel Density, kg/m ³	6583 ± 44	
Plutonium, kg/m ³	5762 ± 39	
H: Pu Atom Ratio	0.04	
Mean Particle Sizes,		
Plutonium Oxide	7.4	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	Wt%	10 ³⁰ Atoms/m ³
H	6.08	4.613 x 10 ⁻²
C	45.62	2.905 x 10 ⁻²
O	48.30	2.309 x 10 ⁻²
Cladding Density, kg/m ³	1270	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	10 ³⁰ Atoms/m ³
H	8.0	5.666 x 10 ⁻²
C	60.0	3.570 x 10 ⁻²
O	32.0	1.428 x 10 ⁻²
Reflector Density, kg/m ³	1185	

DIMENSIONS OF FUEL:

	<u>Unclad</u>	<u>Clad</u>	<u>Stacked^(a)</u>
Length, mm	51.30 ± 0.05	55.10 ± 0.06	55.40 ± 0.06
Width, mm	51.30 ± 0.05	55.10 ± 0.06	55.40 ± 0.06
Heights, mm	38.10 ± 0.20	40.79 ± 0.40	40.90 ± 0.40
	12.65 ± 0.13	15.25 ± 0.15	15.36 ± 0.15

^(a) Average Dimension of Space occupied by compacts.

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

<u>Number of Fuel Compacts</u>			
<u>Length</u> <u>(51.30 mm)^(a)</u>	<u>Width</u> <u>(51.30 mm)^(a)</u>	<u>Height</u> <u>(38.10 mm)^(a)</u>	<u>(12.65 mm)^(a)</u>
6	6	5	1.464 ± 0.271
6	6	5	1.635 ± 0.181

Temperature at core center, K $323^{(b)}$

Room temperature, K 293 ± 2

Assemblies Fully Reflected with 15 cm of Plexiglass

<u>Number of Fuel Compacts</u>			
<u>Length</u> <u>(51.30 mm)^(a)</u>	<u>Width</u> <u>51.30 mm)^(a)</u>	<u>Height</u> <u>(38.10 mm)^(a)</u>	<u>(12.65 mm)^(a)</u>
5	5	2	1.909 ± 0.008
5	6	2	1.078 ± 0.008
6	6	2	0.271 ± 0.024
6	8	1	2.409 ± 0.079
8	8	1	$1.858 \pm \text{---}$
∞	∞	$0.877 \pm 0.079^{(c)}$	---

Core center temperature, K $323^{(b)}$

Room temperature, K 293 ± 2

^(a) Length, width or thickness of unclad fuel.

^(b) Critical sizes corrected to 323K. Temperatures varied ± 20 degrees of 323K during critical approaches.

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

CRITICAL EXPERIMENT - BENCHMARK 11

GENERAL DESCRIPTION:

Rectangular parallelepipeds of homogeneous Pu(11.5)O₂-polystyrene at 5H:Pu Atom Ratio. Critical heights given, as a function of base dimensions for bare assemblies and assemblies fully reflected with at least 150 mm of Plexiglas. Fuel in the form of 51 x 51 mm compacts having different thicknesses and clad with approximately 0.18 mm thick tape.

DATA SOURCE:

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

S. R. Bierman and E. D. Clayton, "Critical Experiments with Homogeneous PuO₂-Polystyrene at 5 H/Pu", Nuc Appl, 6, 23-26 (1968).

COMPOSITION OF FUEL:

Nuclide	Wt%	10^{30} Atoms/m ³
Pu-239	61.05	4.986×10^{-3}
Pu-240	8.14	6.623×10^{-4}
Pu-241	1.71	1.382×10^{-4}
Pu-242	0.13	1.026×10^{-5}
H	1.51	2.920×10^{-2}
O	9.50	1.159×10^{-2}
C	17.96	2.920×10^{-2}
Fuel Density, kg/m ³	3.241	
Plutonium, kg/m ³	2.302	
H:Pu, Atom Ratio	5.0	
Mean Particle Sizes, μ m		
Plutonium Oxide	9	
Polystyrene	150	

COMPOSITION OF CLADDING:

Nuclide	Wt%	10^{30} Atoms/m ³
H	55.3	4.489×10^{-2}
C	6.7	3.111×10^{-2}
Cl	38.0	7.240×10^{-3}
Cladding Density, kg/m ³	1120	

COMPOSITION OF REFLECTOR:

Nuclide	Wt%	10^{30} Atoms/m ³
H	8.0	5.666×10^{-2}
C	60.0	3.570×10^{-2}
O	32.0	1.428×10^{-2}
Reflector Density, kg/m ³	1185	

DIMENSIONS OF FUEL:

	<u>Unclad</u>	<u>Clad</u>	<u>Stacked^{a)}</u>
Length, mm	51.20	51.74	52.07
Width, mm	51.20	51.56	51.59
Heights, mm	38.10	38.46	38.81
	13.04	13.55	14.00

a) Average Dimension of Space occupied by compacts

DELAYED CRITICAL CONFIGURATIONS:

Unreflected Assemblies

<u>Number of Fuel Compacts</u>				
<u>Length</u> <u>(51.20 mm) ^{a)}</u>	<u>Width</u> <u>(51.20 mm) ^{a)}</u>	<u>Height</u> <u>(38.10 mm) ^{a)}</u>	<u>Height</u> <u>(13.04 mm) ^{a)}</u>	<u>Corrected</u> <u>Height ^{b)}</u> <u>(38.10 mm) ^{a)}</u>
7	7	7	1.692 ± 0.039	7.564 ± 0.013
Temperature at core center, K		333 ± 10		
Room temperature, K		293 ± 2		

Assemblies Fully Reflected with 15 cm of Plexiglass

<u>Number of Fuel Compacts</u>				
<u>Length</u> <u>(51.20 mm) ^{a)}</u>	<u>Width</u> <u>(51.20 mm) ^{a)}</u>	<u>Height</u> <u>(38.10 mm) ^{a)}</u>	<u>Height</u> <u>(13.04 mm) ^{a)}</u>	<u>Corrected</u> <u>Height ^{b)}</u> <u>(38.10 mm) ^{a)}</u>
5	5	4	2.434 ± 0.004	4.811 ± 0.002
6	6	3	2.164 ± 0.012	3.721 ± 0.004
8	8	2	2.338 ± 0.006	2.779 ± 0.002
10	10	2	1.118 ± 0.002	2.373 ± 0.001
∞	∞		-	1.543 ± 0.055(c)

Core center temperature, K 333 ± 10
Room temperature, K 293 ± 2

a) Length, width or thickness of unclad fuel

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

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

CRITICAL EXPERIMENTS - Pu BENCHMARK 12

GENERAL DESCRIPTION:

HOMOGENEOUS SPHERE OF UNREFLECTED Pu (20) metal.

DATA SOURCE:

G. E. Hanson and H. C. Paxton, "Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems", LA-4208, (1969)

G. A. Jarvis, G. A. Linenberger, J. D. Orndoff and H. C. Paxton, "Two Plutonium-Metal Critical Assemblies", NS & E 8, 525-531, (1960)

COMPOSITION OF FUEL:

<u>Nuclide</u>	<u>Wt%</u>	<u>10^{30} Atoms/m³</u>
Pu-239	75.54	2.9933×10^{-2}
Pu-240	19.96	7.8764×10^{-3}
Pu-241	3.09	1.2143×10^{-3}
Pu-242	0.40	1.5654×10^{-4}
Ga	1.01	1.3722×10^{-3}
Alloy Density, kg/m ³	15730	

CRITICAL DIMENSION: (a)

Radius, mm 66.60

(a) Experimental critical mass of 19.173 kg corrected to a 19.46 kg ($\pm 0.8\%$) perfect sphere of 15730 kg/m³ pure alloy in vacuum at 273 K.

CRITICAL EXPERIMENTS - Pu BENCHMARK 13

GENERAL DESCRIPTION:

Stainless steel (type 304L) cylinder reflected with at least 200 mm of water on sides and bottom, and partially filled with a homogeneous aqueous solution of $\text{Pu}(42.9)(\text{NO}_3)_4$ at 623 H:Pu.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352
R. C. Lloyd and E. D. Clayton "The Criticality of High Burnup Plutonium", Nucl. Sci & Engr, 52, 73-75 (1973).

COMPOSITION OF FUEL: ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
Am-241	0.0394	1.0946×10^{-6}
Pu-238	0.0073	2.0537×10^{-7}
Pu-239	1.5114	4.2342×10^{-5}
Pu-240	1.5662	4.3694×10^{-5}
Pu-241	0.3943	1.0955×10^{-5}
Pu-242	0.1716	4.7478×10^{-6}
N	2.6918	1.2870×10^{-3}
O	84.0564	3.5184×10^{-2}
H	9.5613	6.3526×10^{-2}
Gd	0.0003	1.2776×10^{-8}

Solution Density, kg/m ³	1112.09
Plutonium, kg/m ³	40.6
Excess Nitrate, Molarity	1.46
H:Pu, Atom Ratio	623.1

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

COMPOSITION OF EXPERIMENTAL VESSEL: ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
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 7930 kg/m³

COMPOSITION OF REFLECTOR: ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
H	11.19	6.668×10^{-2}
O	88.81	3.334×10^{-2}

^(a) Water at 296K

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius, mm	305.14
Inside Height, mm	1057.3
Side Wall Thickness, mm	0.79
End Thicknesses, mm	9.5

DELAYED CRITICAL CONFIGURATION

Unreflected Assembly

None

Water Reflected Assembly

Critical height of solution, mm	809.2
Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

CRITICAL EXPERIMENTS - Pu BENCHMARK 14

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 320 mm water. Completely filled with a homogeneous aqueous solution of $\text{Pu(4.6) (NO}_3)_4$ at 1067 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et. al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
Pu-239	2.190 ± 0.014	5.848×10^{-5}
Pu-240	0.105 ± 0.0007	2.79×10^{-6}
Pu-241	0.0070 ± 0.0001	1.9×10^{-7}
Pu-242	0.0002 ± 0.0001	5.0×10^{-9}
N	1.236 ± 0.019	5.633×10^{-4}
O	86.09 ± 0.51	3.435×10^{-2}
H	10.36 ± 0.06	6.561×10^{-2}
Fe	0.0044 ± 0.0002	5.0×10^{-7}
Solution Density kg/m ³	1060 ± 4	
Plutonium Density kg/m ³	24.4 ± 0.1	
Excess Nitrate Molarity	0.53 ± 0.01	
H:Pu Atom Ratio	1067 ± 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%	10^{30} Atoms/m ³
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 7930 kg / m³

COMPOSITION OF REFLECTOR ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
H	11.19	6.668×10^{-2}
O	88.81	3.334×10^{-2}

^(a) Water at 296K

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	193.18 ± 0.16 mm
Vessel Wall Thickness	1.22 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

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

CRITICAL EXPERIMENTS - Pu BENCHMARK 15

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with an additional 2 mm of stainless steel and 320 mm water. Completely filled with a homogeneous aqueous solution of $\text{Pu}(4.6)(\text{NO}_3)_4$ at 1031 H: Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et. al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966)

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
Pu-239	2.261 ± 0.014	6.038×10^{-5}
Pu-240	0.109 ± 0.0007	2.90×10^{-6}
Pu-241	0.0073 ± 0.0001	1.9×10^{-7}
Pu-242	0.0002 ± 0.0001	5.0×10^{-9}
N	1.278 ± 0.020	5.824×10^{-4}
O	86.02 ± 0.51	3.432×10^{-2}
H	10.33 ± 0.06	6.542×10^{-2}
Fe	0.0045 ± 0.0002	5.1×10^{-7}
Solution Density kg / m ³	1060 ± 4	
Plutonium Density kg / m ³	25.2 ± 0.1	
Excess Nitrate Molarity	0.55 ± 0.02	
H : Pu Atom Ratio	1031 ± 7	

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

COMPOSITION OF EXPERIMENTAL VESSEL AND ADDITIONAL STAINLESS STEEL SHELL^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
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 7930 kg / m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
H	11.19	6.668×10^{-2}
O	88.81	3.334×10^{-2}

^(a) Water at 296K

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	$193.18 \pm 0.16 \text{ mm}$
Vessel Wall Thickness	3.25 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Water Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

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

CRITICAL EXPERIMENTS - BENCHMARK 16

GENERAL DESCRIPTION:

Sphere of homogeneous aqueous solution of Pu (4.6) (NO₃)₄ 193 mm radius, fully water reflected.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	2.130 ± 0.011	5.656 x 10 ⁻⁵
Pu-240	0.102 ± 0.0005	2.70 x 10 ⁻⁶
Pu-241	0.0069 ± 0.0001	1.8 x 10 ⁻⁷
Pu-242	0.0002 ± 0.0001	5 x 10 ⁻⁹
N	1.176 ± 0.018	5.329 x 10 ⁻⁴
O	86.22 ± 0.11	3.421 x 10 ⁻²
H	10.40 ± 0.01	6.550 x 10 ⁻²
Fe	0.0043 ± 0.0002	4.9 x 10 ⁻⁷
Solution density kg / m ³	1054 ± 1	
Plutonium density, kg / m ³	23.6 ± 0.1	
Excess nitrate molarity	0.49 ± 0.01	
H : Pu atom ratio	1102 ± 6	

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

COMPOSITION OF REFLECTOR ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²
Reflector and core temperature, K	296 ± 2	
Room temperature, K	294 ± 2	

(a) Water at 296K

Experimental corrections applied to account for the effects of vessel wall, neck and column supports.

CRITICAL EXPERIMENTS - Pu BENCHMARK 17

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 25.4 mm paraffin. Completely filled with a homogeneous aqueous solution of Pu (4.6) (NO₃)₄ at 434.4 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et. al., "Criticality Studies with Plutonium Solutions", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-239	4.182 ± 0.028	1.284 x 10 ⁻⁴
Pu-240	0.2010 ± 0.0014	6.144 x 10 ⁻⁶
Pu-241	0.0134 ± 0.0001	4.08 x 10 ⁻⁷
Pu-242	0.0003 ± 0.0001	9.1 x 10 ⁻⁹
N	5.989 ± 0.095	3.139 x 10 ⁻³
O	81.57 ± 0.51	3.743 x 10 ⁻²
H	8.052 ± 0.043	5.865 x 10 ⁻²
Fe	0.0082 ± 0.0004	1.1 x 10 ⁻⁶
Solution Density kg/m ³	1219 ± 6	
Plutonium Density kg/m ³	53.6 ± 0.3	
Excess Nitrate Molarity	4.31 ± 0.08	
H:Pu Atom Ratio	434.4 ± 2.6	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) 304L Stainless Steel 7930 kg / m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
H	14.37	7.734 x 10 ⁻²
C	85.63	3.867 x 10 ⁻²

^(a) Paraffin at 900 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Paraffin Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

a) The vessel neck and the support column decrease the critical volume by ~0.6% (Reference: R. C. Lloyd, et al, "Criticality Studies With Plutonium Solutions," NS&E, 25, 171 (1966))

CRITICAL EXPERIMENTS - Pu BENCHMARK 18

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 12.7 mm paraffin. Completely filled with a homogeneous aqueous solution of $\text{Pu}(4.6) (\text{NO}_3)_4$ at 459.4 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solutions", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
Pu-239	4.418 ± 0.026	1.284×10^{-4}
Pu-240	0.212 ± 0.001	6.14×10^{-6}
Pu-241	0.0142 ± 0.0001	4.09×10^{-7}
Pu-242	0.0003 ± 0.0001	9×10^{-9}
N	3.718 ± 0.057	1.845×10^{-3}
O	82.64 ± 0.33	3.590×10^{-2}
H	8.995 ± 0.031	6.202×10^{-2}
Fe	0.0088 ± 0.0005	1.1×10^{-6}
Solution Density kg/m ³	1154 ± 3	
Plutonium Density kg/m ³	53.6 ± 0.3	
Excess Nitrate Molarity	2.19 ± 0.05	
H:Pu Atom Ratio	459.4 ± 2.4	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
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 7930 kg/m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
H	14.86	7.995×10^{-2}
C	85.14	3.844×10^{-2}

^(a) Paraffin at 900 kg/m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Paraffin Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

- a) The vessel neck and the support column decrease the critical volume by $\sim 0.6\%$ (Reference: R. C. Lloyd, et al, "Criticality Studies With Plutonium Solutions," NS&E, 25, 171 (1966))

CRITICAL EXPERIMENT - Pu BENCHMARK 19

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 25.4 mm paraffin. Completely filled with a homogeneous aqueous solution of $\text{Pu}(4.6) (\text{NO}_3)_4$ at 223.4 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solutions" Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
Pu-239	6.912 ± 0.054	2.339×10^{-4}
Pu-240	0.332 ± 0.003	1.12×10^{-5}
Pu-241	0.0222 ± 0.0002	7.45×10^{-7}
Pu-242	0.0005 ± 0.0001	2.0×10^{-8}
N	7.952 ± 0.129	4.592×10^{-3}
O	77.94 ± 0.67	3.940×10^{-3}
H	6.839 ± 0.052	5.488×10^{-2}
Fe	0.0138 ± 0.0007	2.0×10^{-6}
Solution Density kg/m ³	1343 ± 8	
Pu Density kg/m ³	97.6 ± 0.5	
Excess Nitrate Molarity	6.0 ± 0.11	
H:Pu Atom Ratio	223.4 ± 1.5	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
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 7930 kg / m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
H	14.37	7.734×10^{-2}
C	85.63	3.867×10^{-2}

(a) Paraffin at 900 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Paraffin Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

- a) The vessel neck and the support column decrease the critical volume by $\sim 0.6\%$ (Reference: R. C. Lloyd, et al, "Criticality Studies With Plutonium Solutions," NS&E, 25, 171 (1966))

CRITICAL EXPERIMENTS - Pu BENCHMARK 20

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 254 mm concrete. Completely filled with a homogeneous aqueous solution of Pu (4.6) (NO₃)₄ at 684.3 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-239	2.879 ± 0.018	8.769 x 10 ⁻⁵
Pu-240	0.138 ± 0.001	4.19 x 10 ⁻⁶
Pu-241	0.0093 ± 0.0001	2.81 x 10 ⁻⁷
Pu-242	0.0002 ± 0.0001	6 x 10 ⁻⁹
N	5.790 ± 0.090	3.010 x 10 ⁻³
O	82.87 ± 0.66	3.771 x 10 ⁻²
H	8.306 ± 0.071	6.000 x 10 ⁻²
Fe	0.0058 ± 0.0003	7.6 x 10 ⁻⁷
Solution Density kg/m ³	1209 ± 5	
Plutonium Density kg/m ³	36.6 ± 0.2	
Excess Nitrate Molarity	4.39 ± 0.08	
H:Pu Atom Ratio	650.8 ± 5.9	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻²

^(a) 304L Stainless Steel at 7930 kg/m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Mg	1.309	7.620 x 10 ⁻⁴
Al	6.393	3.353 x 10 ⁻³
Ca	7.390	2.609 x 10 ⁻³
Fe	5.295	1.342 x 10 ⁻³
K	1.204	4.358 x 10 ⁻³
Mn	0.107	2.756 x 10 ⁻⁵
Si	25.662	1.293 x 10 ⁻²
H	1.237	1.737 x 10 ⁻²
Na	0.186	1.145 x 10 ⁻⁴
O	51.207	4.529 x 10 ⁻²

^(a) Concrete at 2350 kg/m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Concrete Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 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))

CRITICAL EXPERIMENTS - Pu BENCHMARK 21

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 101.6 mm concrete. Completely filled with a homogeneous aqueous solution of Pu (4.6) (NO₃)₄ at 684.3 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-239	2.954 ± 0.019	8.506 x 10 ⁻⁵
Pu-240	0.142 ± 0.001	4.07 x 10 ⁻⁶
Pu-241	0.0095 ± 0.0001	2.7 x 10 ⁻⁷
Pu-242	0.0002 ± 0.0001	6.0 x 10 ⁻⁹
N	4.269 ± 0.066	2.098 x 10 ⁻³
O	83.70 ± 0.59	3.601 x 10 ⁻²
H	8.959 ± 0.066	6.118 x 10 ⁻²
Fe	0.0059 ± 0.0003	7.3 x 10 ⁻⁷
Solution Density kg/m ³	1143 ± 5	
Plutonium Density kg/m ³	35.5 ± 0.2	
Excess Nitrate Molarity	2.89 ± 0.05	
H:Pu Atom Ratio	684.3 ± 5.5	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻²

^(a) 304L Stainless Steel at 7930 kg / m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Mg	1.309	7.620 x 10 ⁻⁴
Al	6.393	3.353 x 10 ⁻³
Ca	7.390	2.609 x 10 ⁻³
Fe	5.295	1.342 x 10 ⁻³
K	1.204	4.358 x 10 ⁻³
Mn	0.107	2.756 x 10 ⁻⁵
Si	25.662	1.293 x 10 ⁻²
H	1.237	1.737 x 10 ⁻²
Na	0.186	1.145 x 10 ⁻⁴
O	51.207	4.529 x 10 ⁻²

^(a) Concrete at 2350 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Concrete Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 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))

CRITICAL EXPERIMENTS - Pu BENCHMARK 22

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 101.6 mm concrete. Completely filled with a homogeneous aqueous solution of Pu (4.6) (NO₃)₄ at 496 H : Pu

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et. al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-239	3.431 ± 0.022	1.083 x 10 ⁻⁴
Pu-240	0.165 ± 0.001	5.19 x 10 ⁻⁶
Pu-241	0.0110 ± 0.0001	3.44 x 10 ⁻⁷
Pu-242	0.0003 ± 0.0001	9.0 x 10 ⁻⁹
N	7.390 ± 0.115	3.981 x 10 ⁻³
O	81.48 ± 0.75	3.843 x 10 ⁻²
H	7.543 ± 0.086	5.647 x 10 ⁻²
Fe	0.0068 ± 0.0004	9.2 x 10 ⁻⁷
Solution Density kg/m ³	1253 ± 5	
Plutonium Density kg/m ³	45.2 ± 0.2	
Excess Nitrate Molarity	5.86 ± 0.10	
H:Pu Atom Ratio	496 ± 6.0	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) 304L Stainless Steel at 7930 kg/m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Mg	1.309	7.620 x 10 ⁻⁴
Al	6.393	3.352 x 10 ⁻³
Ca	7.390	2.609 x 10 ⁻³
Fe	5.295	1.342 x 10 ⁻³
K	1.204	4.358 x 10 ⁻³
Mn	0.107	2.756 x 10 ⁻⁵
Si	25.662	1.293 x 10 ⁻²
H	1.237	1.737 x 10 ⁻²
Na	0.186	1.145 x 10 ⁻⁴
O	51.207	4.529 x 10 ⁻²

^(a) Concrete at 2350 kg/m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Concrete Reflected Assembly^{a)}

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))

CRITICAL EXPERIMENTS - Pu BENCHMARK 23

GENERAL DESCRIPTION:

Stainless Steel sphere reflected uniformly with 101.6 mm concrete and 0.762 mm cadmium. Completely filled with a homogeneous aqueous solution of Pu(4.6) (NO₃)₄ at 454.5 H : Pu.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL (a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Pu-239	2.854 ± 0.018	1.220 x 10 ⁻⁴
Pu-240	0.137 ± 0.001	5.82 x 10 ⁻⁶
Pu-241	0.0092 ± 0.0001	3.88 x 10 ⁻⁷
Pu-242	0.0002 ± 0.0001	9.0 x 10 ⁻⁹
N	2.443 ± 0.038	3.268 x 10 ⁻³
O	84.81 ± 0.53	3.755 x 10 ⁻²
H	9.762 ± 0.060	5.827 x 10 ⁻²
Fe	0.0057 ± 0.0003	1.0 x 10 ⁻⁶
Solution Density kg/m ³	1222 ± 6	
Plutonium Density kg/m ³	50.9 ± 0.3	
Excess Nitrate Molarity	4.57 ± 0.08	
H:Pu Atom Ratio	454.5 ± 2.7	

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

COMPOSITION OF EXPERIMENTAL VESSEL (a)

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

(a) 304L Stainless Steel at 7930 kg/m³

COMPOSITION OF REFLECTORS

Nuclide	Wt%	10 ³⁰ Atoms/m ³
Mg	1.309	7.620 x 10 ⁻⁴
Al	6.393	3.353 x 10 ⁻³
Ca	7.390	2.609 x 10 ⁻³
Fe	5.295	1.342 x 10 ⁻³
K (a)	1.204	4.358 x 10 ⁻³
Mn	0.107	2.756 x 10 ⁻⁵
Si	25.662	1.293 x 10 ⁻²
H	1.237	1.737 x 10 ⁻²
Na	0.186	1.145 x 10 ⁻⁴
O	51.207	4.529 x 10 ⁻²
Cd (b)	100.00	4.633 x 10 ⁻²

(a) Concrete at 2350 kg/m³

(b) Natural cadmium at 8648 kg/m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

Concrete Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 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))

CRITICAL EXPERIMENTS - Pu BENCHMARK 24

GENERAL DESCRIPTION:

Stainless steel sphere reflected uniformly with 320 mm water and 0.762 mm cadmium.
Completely filled with a homogeneous aqueous solution of $\text{Pu(4.6) (NO}_3)_4$ at 540.2 H : Pu.

DATA SOURCE:

R. C. Lloyd, Battelle, Pacific Northwest Laboratories, Richland, Washington 99352.
R. C. Lloyd, et al., "Criticality Studies with Plutonium Solution", Nuclear Science and Engineering 25, 165-173, (1966).

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
Pu-239	3.962 ± 0.025	1.124×10^{-4}
Pu-240	0.190 ± 0.001	5.37×10^{-6}
Pu-241	0.0127 ± 0.0001	3.57×10^{-7}
Pu-242	0.0003 ± 0.0001	8.0×10^{-9}
N	2.726 ± 0.042	1.320×10^{-3}
O	83.61 ± 0.54	3.544×10^{-2}
H	9.487 ± 0.065	6.38×10^{-2}
Fe	0.0079 ± 0.0004	9.6×10^{-7}
Solution Density kg / m ³	1126 ± 4.5	
Plutonium Density kg / m ³	46.9 ± 0.2	
Excess Nitrate Molarity	1.41 ± 0.03	
H : Pu Atom Ratio	540.2 ± 4.0	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
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 7930 kg / m³

COMPOSITION OF REFLECTORS

Nuclide	Wt%	10^{30} Atoms / m ³
H	11.19	6.668×10^{-2}
O (a)	88.81	3.334×10^{-2}
Cd (b)	100.00	4.633×10^{-2}

(a) Water at 296K

(b) Natural cadmium at 8648 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL:

Inside Radius of Sphere	178.7 ± 0.15 mm
Vessel Wall Thickness	1.12 mm

DELAYED CRITICAL CONFIGURATION:

Unreflected Assembly

None

WATER Reflected Assembly^{a)}

Reflector and core temperature, K	296 ± 2
Room temperature, K	294 ± 2

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

CRITICAL EXPERIMENTS - Pu BENCHMARK 25

GENERAL DESCRIPTION:

Bare plutonium metal alloy sphere, uniformly reflected with 196.09 mm of natural uranium.

DATA SOURCE:

G. E. Hansen and H. C. Paxton, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

G. E. Hansen and H. C. Paxton, "Reevaluated Critical Specifications of Some Los Alamos Fast-Neutron Systems," Report LA-4208, June 1969

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
Pu-239	94.90	3.713×10^{-2}
Pu-240	4.80	1.870×10^{-3}
Pu-241	0.30	1.164×10^{-4}
Ga	1.10	1.476×10^{-3}

Alloy density of 15530 kg / m³

COMPOSITION OF REFLECTOR^(a)

Nuclide	Wt%	10^{30} Atoms / m ³
U-235	0.71	3.456×10^{-4}
U-238	99.29	4.772×10^{-2}

(a) Natural uranium at a density of 19,000 kg / m³

GEOMETRY DESCRIPTION:^(a)

Plutonium alloy radius (mm)	90.66
Air gap between sphere and reflector (mm)	0.114 ± 0.013
Natural uranium reflector thickness (mm)	196.09

(a) Experiment error in critical volume of 0.495 vol%

CRITICAL EXPERIMENTS - Pu BENCHMARK 26

GENERAL DESCRIPTION:

Stainless steel annular cylinder reflected on the outside by water and on the inside by air. Annular ring completely filled with a homogeneous aqueous solution of Pu(18.88)(NO₃)₄ at 148.3 H: Pu.

DATA SOURCE:

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucléaires de Saclay, Département de Sûreté Nucleaire, "Criticité de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu), " (1974)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	8.140 ± 0.120	2.842 x 10 ⁻⁴
Pu-240	2.071 ± 0.031	7.201 x 10 ⁻⁵
Pu-241	0.634 ± 0.010	2.195 x 10 ⁻⁵
Pu-242	0.125 ± 0.002	4.31 x 10 ⁻⁶
Fe	0.183 ± 0.010	2.74 x 10 ⁻⁵
Am-241	0.053 ± 0.003	1.8 x 10 ⁻⁶
Cr	0.055	8.8 x 10 ⁻⁶
Ni	0.044	6.3 x 10 ⁻⁶
W	0.011	5.0 x 10 ⁻⁷
Mo	0.0038	3.3 x 10 ⁻⁷
Co	0.0017	2.4 x 10 ⁻⁷
V	0.0002	3.0 x 10 ⁻⁸
Ti	0.0001	2.0 x 10 ⁻⁸
N	6.753 ± 0.068	4.024 x 10 ⁻³
H	6.847 ± 0.037	5.670 x 10 ⁻²
O	75.09 ± 0.40	3.917 x 10 ⁻²
Solution Density, kg / m ³	1386 ± 1.4	
Plutonium Density, kg / m ³	152 ± 2.3	
Excess Nitrate Molarity	4.14 ± 0.08	
H : Pu atom ratio	148.3 ± 2.4	

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

COMPOSITION OF EXPERIMENTAL VESSEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) Z3CN18/ 10 Stainless Steel

COMPOSITION OF REFLECTOR ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²

^(a) Water at 296K

DIMENSIONS OF EXPERIMENTAL VESSEL^(a)

Inside diameter of cylinder	194 mm
Outside diameter of cylinder	500 mm
Vessel inside and outside wall thickness	3 mm

DELAYED CRITICAL CONFIGURATION

Unreflected assembly

None

Water and air reflected assembly^(a)

Reflector and core temperature, K	294
Critical solution height, mm	368.8 ± 0.4

(a) No corrections have been made in the critical height for slightly conical bottom and minor variations in temperature

CRITICAL EXPERIMENTS - Pu BENCHMARK 27

GENERAL DESCRIPTION:

Stainless steel annular cylinder reflected on the outside by water and on the inside by air. Annular ring completely filled with a homogeneous aqueous solution of Pu (18.88) (NO₃)₄ at 877 H: Pu.

DATA SOURCE:

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucléaires de Saclay, Département de Sécurité Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu)," (1974)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	1.912 ± 0.029	5.366 x 10 ⁻⁵
Pu-240	0.486 ± 0.007	1.36 x 10 ⁻⁵
Pu-241	0.149 ± 0.002	4.15 x 10 ⁻⁶
Pu-242	0.0294 ± 0.0004	8.15 x 10 ⁻⁷
Fe	0.0430 ± 0.0022	5.17 x 10 ⁻⁶
Am-241	0.0124 ± 0.0006	3.45 x 10 ⁻⁷
Cr	0.0129	1.66 x 10 ⁻⁶
Ni	0.0103	1.18 x 10 ⁻⁶
W	0.0026	9.5 x 10 ⁻⁸
Mo	0.0009	6.0 x 10 ⁻⁸
Co	0.0004	5.0 x 10 ⁻⁸
V	<0.0001	-
Ti	<0.0001	-
N	3.107 ± 0.031	1.488 x 10 ⁻³
H	9.515 ± 0.022	6.333 x 10 ⁻²
O	84.72 ± 0.20	3.552 x 10 ⁻²
Solution density, kg / m ³	1114 ± 1.1	
Plutonium density, kg / m ³	28.7 ± 0.4	
Excess nitrate molarity	1.99 ± 0.03	
H : Pu atom ratio	877 ± 13	

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

COMPOSITION OF EXPERIMENTAL VESSEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

(a) Z3CN18/10 Stainless Steel

COMPOSITION OF REFLECTOR ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²

(a) Water at 296 K

DIMENSIONS OF EXPERIMENTAL VESSEL^(a)

Inside diameter of cylinder	194 mm
Outside diameter of cylinder	500 mm
Vessel inside and outside wall thickness	3 mm

DELAYED CRITICAL CONFIGURATION

Unreflected assembly

None

Water and air reflected assembly

Reflector and core temperature, K	294
Critical solution height, mm	933.4 ± 0.2

(a) No corrections have been made in the critical height for slightly conical bottom and minor variations in temperature

CRITICAL EXPERIMENTS - Pu BENCHMARK 28

GENERAL DESCRIPTION:

Stainless steel annular cylinder reflected on the outside by water and on the inside by 0.8 mm cadmium and an entirely filled inner region of paraffin. Annular ring completely filled with a homogeneous aqueous solution of Pu (18.88)(NO₃)₄ at 139.7 H: Pu.

DATA SOURCE:

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucléaires de Saclay, Département de Sécurité Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu), " (1974)

COMPOSITION OF FUEL^(a)

Nuclide	Wt %	10 ³⁰ Atoms/m ³
Pu-239	8.789 ± 0.132	3.084 x 10 ⁻⁴
Pu-240	2.236 ± 0.034	7.814 x 10 ⁻⁵
Pu-241	0.685 ± 0.010	2.384 x 10 ⁻⁵
Pu-242	0.135 ± 0.002	4.679 x 10 ⁻⁶
Fe	0.198 ± 0.010	2.974 x 10 ⁻⁵
Am-241	0.057 ± 0.003	2.0 x 10 ⁻⁶
Cr	0.059	9.5 x 10 ⁻⁶
Ni	0.047	6.7 x 10 ⁻⁶
W	0.011	5.0 x 10 ⁻⁷
Mo	0.0042	3.7 x 10 ⁻⁷
Co	0.0018	2.6 x 10 ⁻⁷
V	0.0002	3.0 x 10 ⁻⁸
Ti	0.0001	2.0 x 10 ⁻⁸
N	6.202 ± 0.062	3.714 x 10 ⁻³
H	6.966 ± 0.039	5.798 x 10 ⁻²
O	74.61 ± 0.37	3.912 x 10 ⁻²
Solution density kg/m ³	1393 ± 1.4	
Plutonium density kg/m ³	165 ± 2.5	
Excess Nitrate Molarity	3.41 ± 0.07	
H:Pu atom ratio	139.7 ± 2.2	

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	wt %	10 ³⁰ Atoms/m ³
Fe	74.0	3.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

(a) Z3CN18/10 Stainless Steel

COMPOSITION OF INNER REFLECTOR^(a)

Nuclide	Wt %	10 ³⁰ Atoms/m ³
Paraffin H	14.86	7.995 x 10 ⁻²
Paraffin C	85.14	3.844 x 10 ⁻²
Natural Cadmium Cd	100	4.635 x 10 ⁻²

(a) Paraffin at 900 kg/m³
Natural Cadmium at 8648 kg/m³

COMPOSITION OF OUTER REFLECTOR^(a)

Nuclide	Wt %	10 ³⁰ Atoms/m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²

(a) Water at 296 K

DIMENSIONS OF EXPERIMENTAL VESSEL^(a)

Inside diameter of cylinder	194 mm
Outside diameter of cylinder	500 mm
Vessel inside and outside wall thickness	3 mm

DELAYED CRITICAL CONFIGURATION

Unreflected assembly

None

Water, cadmium and paraffin reflected assembly

Reflector and core temperature, K	294
Critical solution height, mm	607.2 ± 0.2 mm

(a) No corrections have been made in the critical height for slightly conical bottom and minor variations in temperature

CRITICAL EXPERIMENTS - Pu BENCHMARK 29

GENERAL DESCRIPTION:

Stainless steel annular cylinder reflected on the outside by water and on the inside by 0.8 mm cadmium and an entirely filled inner region of paraffin. Annular ring completely filled with a homogeneous aqueous solution of Pu (18.88) (NO₃)₄ at 462.7 H: Pu.

DATA SOURCE:

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucléaires de Saclay, Département de Sécurité Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu), " (1974)

COMPOSITION OF FUEL (a)

Nuclide	Wt %	10 ³⁰ Atoms / m ³
Pu-239	3.423 ± 0.051	1.004 x 10 ⁻⁴
Pu-240	0.871 ± 0.013	2.54 x 10 ⁻⁴
Pu-241	0.266 ± 0.004	7.73 x 10 ⁻⁶
Pu-242	0.0525 ± 0.0008	1.52 x 10 ⁻⁶
Fe	0.077 ± 0.004	9.7 x 10 ⁻⁶
Am-241	0.022 ± 0.001	6.4 x 10 ⁻⁷
Cr	0.023 ± ---	3.1 x 10 ⁻⁶
Ni	0.018 ± ---	2.1 x 10 ⁻⁶
W	0.0046 ± ---	1.7 x 10 ⁻⁷
Mo	0.0016 ± ---	1.2 x 10 ⁻⁷
Co	0.0007 ± ---	8.0 x 10 ⁻⁸
V	0.0001 ± ---	1.0 x 10 ⁻⁸
Ti	< 0.0001 ± ---	
N	3.741 ± 0.041	1.872 x 10 ⁻⁴
H	8.972 ± 0.025	6.240 x 10 ⁻²
O	82.51 ± 0.24	3.615 x 10 ⁻²
Solution density, kg / m ³	1164 ± 1.4	
Plutonium density, kg / m ³	53.7 ± 0.8	
Excess Nitrate Molarity	2.21 ± 0.03	
H:Pu atom ratio	462 ± 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 %	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

(a) Z3CN18/10 Stainless Steel

COMPOSITION OF INNER REFLECTOR (a)

Nuclide	Wt %	10 ³⁰ Atoms / m ³
Paraffin H	14.86	7.995 x 10 ⁻²
C	85.14	3.844 x 10 ⁻²
Natural Cadmium Cd	100	4.635 x 10 ⁻²

(a) Paraffin at 900 kg / m³
Natural Cadmium at 8648 kg / m³

COMPOSITION OF OUTER REFLECTOR (a)

Nuclide	Wt %	10 ³⁰ Atoms / m ³
H	11.19	6.668 x 10 ⁻²
O	88.81	3.334 x 10 ⁻²

(a) Water at 296 K

DIMENSIONS OF EXPERIMENTAL VESSEL ^(a)

Inside diameter of cylinder	194 mm
Outside diameter of cylinder	500 mm
Vessel inside and outside wall thickness	3 mm

DELAYED CRITICAL CONFIGURATION

Unreflected assembly

None

Water, cadmium and paraffin reflected assembly

Reflector and core temperature, K	294
Critical solution height, mm	920.9 ± 0.4

(a) No corrections have been made in the critical height for slightly conical bottom and minor variations in temperature

CRITICAL EXPERIMENTS - Pu BENCHMARK 30

GENERAL DESCRIPTION:

Stainless steel parallelepiped filled with a homogeneous aqueous solution of Pu (18.88) (NO₃)₄ at 1916 H : Pu.

DATA SOURCE

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucleaires de Saclay, Departement de Surete Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu)," (1974)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	0.899 ± 0.013	2.469 x 10 ⁻⁵
Pu-240	0.229 ± 0.003	6.26 x 10 ⁻⁶
Pu-241	0.0700 ± 0.0010	1.91 x 10 ⁻⁶
Pu-242	0.0138 ± 0.0002	3.74 x 10 ⁻⁷
Fe	0.0202 ± 0.0010	2.37 x 10 ⁻⁶
Am-241	0.0074 ± 0.0004	2.0 x 10 ⁻⁷
Cr	0.0061 ± ---	7.7 x 10 ⁻⁷
Ni	0.0049 ± ---	5.5 x 10 ⁻⁷
W	0.0012 ± ---	4.3 x 10 ⁻⁸
Mo	0.0004 ± ---	3.0 x 10 ⁻⁸
Co	0.0002 ± ---	2.0 x 10 ⁻⁸
V	<0.0001 ± ---	--
Ti	<0.0001 ± ---	--
N	2.930 ± 0.029	1.373 x 10 ⁻³
H	9.769 ± 0.021	6.362 x 10 ⁻²
O	86.06 ± 0.19	3.531 x 10 ⁻²

Solution Density, kg / m³ 1090.0 ± 1.1
 Plutonium Density, kg / m³ 13.2 ± 0.2
 Excess Nitrate Molarity 2.06 ± 0.02
 H : Pu atom ratio 1916.0 ± 29

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

COMPOSITION OF EXPERIMENTAL VESSEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) Z3CN18/10 Stainless Steel

COMPOSITION OF REFLECTOR

	Nuclide	Wt%	10 ³⁰ Atoms / m ³
WATER	H	11.19	6.668 x 10 ⁻²
	O ^(a)	88.81	3.334 x 10 ⁻²
LUCOFLEX	H ^(b)	4.84	4.105 x 10 ⁻²
	C	38.44	2.737 x 10 ⁻²
	Cl	56.72	1.368 x 10 ⁻²

^(a) Water at 296 K

^(b) Lucoflex at 1420 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL (a)

Inside length and width of solution tank	1300 mm x 1300 mm
Solution tank wall thickness	5 mm
Thickness of solution tank bottom	5 mm
Solution critical height	701.3 ± 0.2 mm

Solution temperature, K	300.5
Reflector temperature, K	296

- (a) No corrections have been made in the critical height for minor variations in temperature. Vessel deformity results in a volume error correction of $+ 0.0005 \text{ m}^3$.
- (b) Two 8 mm thick steel braces 440 mm apart. One 8 mm steel horizontal brace around the experimental vessel is not shown. The exact positions of the braces is not known.

CRITICAL EXPERIMENTS - Pu BENCHMARK 31

GENERAL DESCRIPTION:

Stainless steel parallelepiped filled with a homogeneous aqueous solution of Pu (18.88) (NO₃)₄ at 1916 H:Pu. Reflected on bottom and sides by at least 200 mm of water.

DATA SOURCE

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucleaires de Saclay, Departement de Surete Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu)," (1974)

COMPOSITION OF FUEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	0.899 ± 0.013	2.469 x 10 ⁻⁵
Pu-240	0.229 ± 0.003	6.26 x 10 ⁻⁶
Pu-241	0.0700 ± 0.0010	1.91 x 10 ⁻⁶
Pu-242	0.0138 ± 0.0002	3.74 x 10 ⁻⁷
Fe	0.0202 ± 0.0010	2.37 x 10 ⁻⁶
Am-241	0.0074 ± 0.0004	2.0 x 10 ⁻⁷
Cr	0.0061 ± ---	7.7 x 10 ⁻⁷
Ni	0.0049 ± ---	5.5 x 10 ⁻⁷
W	0.0012 ± ---	4.3 x 10 ⁻⁸
Mo	0.0004 ± ---	3.0 x 10 ⁻⁸
Co	0.0002 ± ---	2.0 x 10 ⁻⁸
V	<0.0001 ± ---	--
Ti	<0.0001 ± ---	--
N	2.930 ± 0.029	1.373 x 10 ⁻³
H	9.769 ± 0.021	6.362 x 10 ⁻²
O	86.06 ± 0.19	3.531 x 10 ⁻²

Solution Density, kg/m ³	1090.0 ± 1.1
Plutonium Density, kg/m ³	13.2 ± 0.2
Excess Nitrate Molarity	2.06 ± 0.02
H : Pu atom ratio	1916.0 ± 29

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

COMPOSITION OF EXPERIMENTAL VESSEL ^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) Z3CN18/10 Stainless Steel

COMPOSITION OF REFLECTOR

	Nuclide	Wt%	10 ³⁰ Atoms / m ³
WATER	H	11.19	6.668 x 10 ⁻²
	O ^(a)	88.81	3.334 x 10 ⁻²
LUCOFLEX	H ^(b)	4.84	4.105 x 10 ⁻²
	C	38.44	2.737 x 10 ⁻²
	Cl	56.72	1.368 x 10 ⁻²

^(a) Water at 296 K

^(b) Lucoflex at 1420 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL (a)

Inside length and width of solution tank	1300 mm x 1300 mm
Solution tank wall thickness	5 mm
Thickness of solution tank bottom	5 mm
Solution critical height	677.3 ± 0.2 mm

Solution temperature, K	300.5
Reflector temperature, K	296

- (a) No corrections have been made in the critical height for minor variations in temperature. Vessel deformity results in a volume error correction of $+ 0.0005 \text{ m}^3$.
- (b) Two 8 mm thick steel braces 440 mm apart. One 8 mm steel horizontal brace around experimental vessel is not shown. The exact positions of the braces is not known.

CRITICAL EXPERIMENTS - Pu BENCHMARK 32

GENERAL DESCRIPTION:

Stainless steel parallelepiped filled with a homogeneous aqueous solution of Pu (18.88) (NO₃)₄ at 1916 H:Pu. Reflected on bottom and sides by at least 200 mm of water plus lucoflex.

DATA SOURCE

Guy Colomb, Daniel Mangin, Louis Maubert, Centre d'Etudes Nucleaires de Saclay, Departement de Surete Nucleaire, "Criticite de Solutions de Nitrate de Plutonium (19% ²⁴⁰Pu)," (1974)

COMPOSITION OF FUEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Pu-239	0.899 ± 0.013	2.469 x 10 ⁻⁵
Pu-240	0.229 ± 0.003	6.26 x 10 ⁻⁶
Pu-241	0.0700 ± 0.0010	1.91 x 10 ⁻⁶
Pu-242	0.0138 ± 0.0002	3.74 x 10 ⁻⁷
Fe	0.0202 ± 0.0010	2.37 x 10 ⁻⁶
Am-241	0.0074 ± 0.0004	2.0 x 10 ⁻⁷
Cr	0.0061 ± ---	7.7 x 10 ⁻⁷
Ni	0.0049 ± ---	5.5 x 10 ⁻⁷
W	0.0012 ± ---	4.3 x 10 ⁻⁸
Mo	0.0004 ± ---	3.0 x 10 ⁻⁸
Co	0.0002 ± ---	2.0 x 10 ⁻⁸
V	<0.0001 ± ---	- -
Ti	<0.0001 ± ---	- -
N	2.930 ± 0.029	1.373 x 10 ⁻³
H	9.769 ± 0.021	6.362 x 10 ⁻²
O	86.06 ± 0.19	3.531 x 10 ⁻²

Solution Density, kg / m³ 1090.0 ± 1.1
 Plutonium Density, kg / m³ 13.2 ± 0.2
 Excess Nitrate Molarity 2.06 ± 0.02
 H : Pu atom ratio 1916.0 ± 29

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

COMPOSITION OF EXPERIMENTAL VESSEL^(a)

Nuclide	Wt%	10 ³⁰ Atoms / m ³
Fe	74.0	6.331 x 10 ⁻²
Cr	18.0	1.654 x 10 ⁻²
Ni	8.0	6.510 x 10 ⁻³

^(a) Z3CN18/10 Stainless Steel

COMPOSITION OF REFLECTOR

	Nuclide	Wt%	10 ³⁰ Atoms / m ³
WATER	H	11.19	6.668 x 10 ⁻²
	O ^(a)	88.81	3.334 x 10 ⁻²
LUCOFLEX	H ^(b)	4.84	4.105 x 10 ⁻²
	C	38.44	2.737 x 10 ⁻²
	Cl	56.72	1.368 x 10 ⁻²

^(a) Water at 296 K

^(b) Lucoflex at 1420 kg / m³

DIMENSIONS OF EXPERIMENTAL VESSEL (a)

Inside length and width of solution tank	1300 mm x 1300 mm
Solution tank wall thickness	5 mm
Thickness of solution tank bottom	5 mm
Solution critical height	663.4 ± 0.2 mm

Solution temperature, K	300.5
Reflector temperature, K	296

- (a) No corrections have been made in the critical height for minor variations in temperature. Vessel deformity results in a volume error correction of $+0.0005 \text{ m}^3$.
- (b) Two 8 mm thick steel braces 440 mm apart. One 8 mm thick steel horizontal brace around experimental vessel is not shown. The exact positions of the braces is not known.

CRITICAL EXPERIMENTS - Pu BENCHMARK 33

GENERAL DESCRIPTION:

Unreflected homogeneous aqueous Pu (4.67) (NO₃)₄ solution at 422 H:Pu in slab geometry infinite in two dimensions.

DATA SOURCE:

R. C. Lloyd, E. D. Clayton, L. E. Hansen, and S. R. Bierman, "Criticality of Plutonium Nitrate Solutions in Slab Geometry" Nuc Tech, 18, 225-230, (1973)

COMPOSITION OF FUEL: ^(a)

Nuclide	Wt%	10^{30} Atoms/m ³
Pu-238	0.0003	8.8459×10^{-9}
Pu-239	4.7301	1.3889×10^{-4}
Pu-240	0.2324	6.7956×10^{-6}
Pu-241	0.0127	3.6982×10^{-7}
Pu-242	0.0005	1.4500×10^{-8}
N	3.9342	1.9716×10^{-3}
H	8.8611	6.1706×10^{-2}
O	82.2287	3.6075×10^{-2}
Solution Density, kg/m ³	1165.6	
Plutonium Density, kg/m ³	58.0	
Excess Nitrate Molarity	2.3	
H:Pu atom ratio	422.4	
Temperature, K	296 ± 1	

a) Hydrogen ion concentration adjusted to obtain total nitrate reported by data source. Water concentration calculated by:

$$\text{kgH}_2\text{O/m}^3 = 1000 - 0.3619 \text{ kg Pu/m}^3 - 33.1 \text{ H}^+$$

Errors in concentrations accounted for in standard deviation reported on critical size.

CRITICAL DIMENSION ^(a):

Thickness, mm 169.1 ± 4.0

a) Experimental critical thickness of egg crate reinforced 304L steel vessel used in experiments increased by:

3.26 mm for vessel wall reflection,
8.32 mm for support structures reflection,
10.5 mm for room reflection,

to obtain clean slab of solution.

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