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CRITICALITY EXPERIMENTS WITH FAST FLUX TEST FACILITY FUEL PINS

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ABSTRACT

A United States Department of Energy program was initiated during the early seventies at the Hanford Critical Mass Laboratory to obtain experimental criticality data in support of the Liquid Metal Fast Breeder Reactor Program. The criticality experiments program was to provide basic physics data for clean well defined conditions expected to be encountered in the handling of plutonium-uranium fuel mixtures outside reactors. One task of this criticality experiments program was concerned with obtaining data on PuO_2-UO_2 fuel rods containing 20 - 30wt% plutonium. To obtain this data a series of experiments were performed over a period of about twelve years. The experimental data obtained during this time are summarized and the associated experimental assemblies are described.

INTRODUCTION

In the early seventies, the United States Department of Energy's (USDOE) Critical Mass Laboratory at Hanford began a criticality experiments program to provide data in support of the Liquid Metal Fast Breeder Reactor Program. This criticality experiments program was to provide basic physics data for clean, well defined conditions expected to be encountered in the handling of plutonium-uranium fuel mixtures outside reactors.

Primarily, the experiments were designed to provide data for validating calculations used in criticality safety analyses. One task of this criticality experiments program was concerned with obtaining data on PuO_2-UO_2 fuel rods containing 20 - 30wt% plutonium. To obtain this data, a series of experiments with Fast Flux Test Facility (FFTF) fuel pins were performed over a period of about twelve years. These experiments covered a range of neutron moderation from near optimum to very undermoderated (H/Pu ratio varied from about 20 to 250) and involved water, organic and nitrate solution moderators. The experimental assemblies were either reflected with these moderators or with concrete. Measurements were also performed in selected assemblies to determined reaction rates, the reactivity effect of solid (Cd, Gd and B) and soluble neutron poisons (Gd) and neutron kinetic parameters. A complete listing of the experiments is given in Table 1. Each will be covered in greater detail in the sections that follow. The fuel pins used in the experiments are described in Figures 1 and 2.

WATER MODERATED ASSEMBLIES

One series of experiments involved single lattices of water moderated FFTF fuel pins. In each experimental assembly, the fuel was uniformly arranged in a rectangular geometry to obtain data over a range of neutron moderation from near optimum to very undermoderated. Except for the top and bottom surfaces, each assembly was fully reflected by either water or a combination of water and concrete. As will be discussed later, essentially only Type 3.2 fuel pins were used in the water moderated assemblies. Consequently the top and bottom reflector regions of each assembly consisted of at least 150mm of water uniformly perforated by fuel pin hardware (see Figure 1) that extends above and below the fuel region of these pins. The number of fuel pins required for delayed criticality were determined at moderator-to-fuel volume ratios of 1.67, 3.33, 3.49, 6.87, 10.88, and 17.53. At four, near identical, moderator-to-fuel volume ratios in this range (3.24, 6.92, 10.99, 17.55) similar measurement data were obtained with the assemblies reflected by 406mm of concrete on the four sides as indicated in Figure 3. Composition of the concrete in given in Table 2. The results obtained in these series of measurements are summarized in graphically in Figure 4. All of the data were obtained with assemblies of Type 3.2 fuel pins except for the very undermoderated case shown in Table 1. At a moderator-to-fuel volume ratio of 1.67, there was insufficient fuel of any one type to achieve delayed criticality. Consequently, in this assembly, some Type 3.1 fuel pins were on either side of a lattice of

TABLE 1. Summary of Criticality Experiments with FFTF Fuel Pins

Moderator	Reflector	Neutron Absorbers	Experimental Assembly: Geometry	Lattice Pitch (mm)	Moderator To Fuel Ratio (Vol)	Fuel Pins (Type)	References
Water	Water	None	Rectangular	7.67	1.67	3.1 & 3.2 (a)	1 (b)
				9.52	3.33	3.2	1 (b)
				9.68	3.49	3.2	1 (b)
				12.59	6.87	3.2	1
				15.34	10.88	3.2	1 (b)
				19.05	17.53	3.2	1 (b)
Water	Water	Gd Pins, Cd Plates and Boral Plates	Rectranglar	9.68	3.49	3.2	2
				12.42	6.65	3.2	2
				15.37	10.88	3.2	2
				19.35	18.13	3.2	2
				24.87	30.87	3.2	2
Water	Concrete	None	Rectangular	9.53	3.24	3.2	3 (b)
				12.64	6.92	3.2	3 (b)
				15.41	10.99	3.2	3 (b)
				19.06	17.55	3.2	3
Organic(c)	Organic(c)	None	Rectangular	7.61	1.66	3.1 & 3.2 (d)	4 (b)
				9.68	3.49	3.2	4
				12.42	6.65	3.2	4
				15.37	10.88	3.2	4
				19.35	18.13	3.2	4
Pu-U Nitrate Solutions	Water	Soluable Gd Soluable Gd-B Mixtures	Hexagonal	30.48	—	Special Drivers	5,6
Pu-U Nitrate Solution	Water	Soluable Gd	Hexagonal	30.48	—	Special Drivers	7 (e)

(a) Includes 65 type 3.1 FTR fuel pins on a 15.342 mm lattice pitch positioned on either side (36 on one side and 29 on the other) of a 27 x 36 fuel pin array of type 3.2 FTR fuel pins at a 7.671 mm square lattice pitch
(b) Includes reaction rate measurement using solid state track recorders
(c) Normal paraffin hydrocarbon containing 38 wt% tributyl phosphate
(d) Includes type 3.1 FTR fuel pins on a 1.532 cm lattice pitch positioned on either side (36 one side) of a 27 x 36 fuel pin array of type 3.2 FTR fuel pins on a 0.767 cm lattice pitch
(e) Subcritical reactivity measurements as Gd concentration is increased

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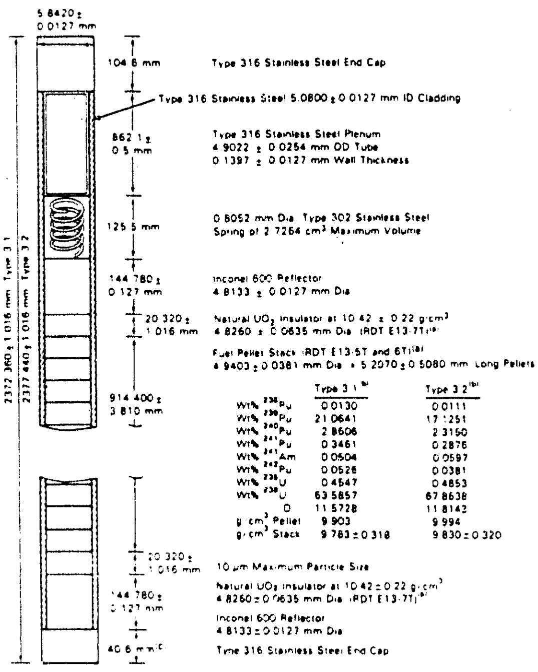


(a) Referenced Division of Reactor Development and Technology standard
(b) Isotopics based on measured data from pellet lots. Americium 241 contents as of January 1, 1976 based on plutonium-241 half life of 14.35 yrs
(c) 35.6 mm for type 3.1 fuel pins

FIGURE 1. Simplified Description of Fast Flux Test Facility Fuel Pin Types 3.1 and 3.2

primarily Typed 3.2 pins. Detailed information on each experimental assembly can be found in the references(1),(2),(3). Briefly, however, the fuel region of each assembly consisted of only fuel pins and moderator or material having similar neutronic properties. A sketch showing the relative elevations of components (when present) in an experimental assembly is given in Figure 5.

As indicated in Table 1, reaction rate measurements were made over the entire range of neutron moderation from near optimum to very undermoderated. Solid state tract recorders positioned in the moderator regions between fuel pins were used to determine fission rates for 235U, 238U, 239Pu, 237Np, and 232Th axially and radially in the assemblies indicated. The measurements and data result are presented in detail in Reference 2.

Also, as indicated Table 1, the poisoning effects of various neutron absorbers were measured at essentially each of the moderator-to-fuel ratios cover by the water reflected assemblies. In these measurements either individual fuel pins were replaced with gadolinium pins or complete rows of fuel pins were replaced by absorber plates in the assemblies and the change in critical size, with and without the absorbers was determined. A multitude of configurations were investigated. A description of each experimental assembly and the measurement results are covered in Reference 2.

FUEL PIN DIMENSIONS (cm)

	ID	OD	LENGTH
FUEL COLUMN	--	0.495	69.22
CLADDING (316-SS)	0.513	0.584	72.90
LOWER END CAP	--	--	0.356
UPPER END SPACER	--	--	0.635
UPPER AIR GAP	--	--	1.773
UPPER END CAP	--	--	0.563

FUEL ENRICHMENT

25.2 WT% Pu

FUEL PER PIN

PuO_2-U(NAT)O_2: 138.4 ± 1.23 g

Pu: 30.75 ± 0.03 g
U: 91.16 ± 1.03 g
O: 16.49 ± 0.17 g

FUEL DENSITY

10.35 ± 0.09 g/cm^3
(93.34 ± 0.79% THEORETICAL)

ISOTOPIC COMPOSITION OF Pu IN PINS

^{238}Pu: 0.04 ± 0.01 AT%
^{239}Pu: 86.19 ± 0.06 AT%
^{240}Pu: 11.88 ± 0.06 AT%
^{241}Pu: 1.73 ± 0.01 AT%
^{242}Pu: 0.16 ± 0.01 AT%

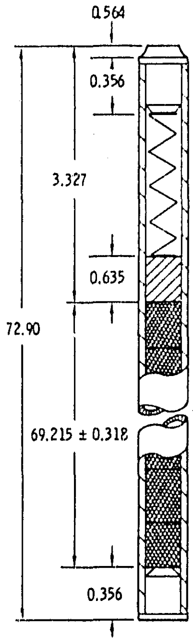
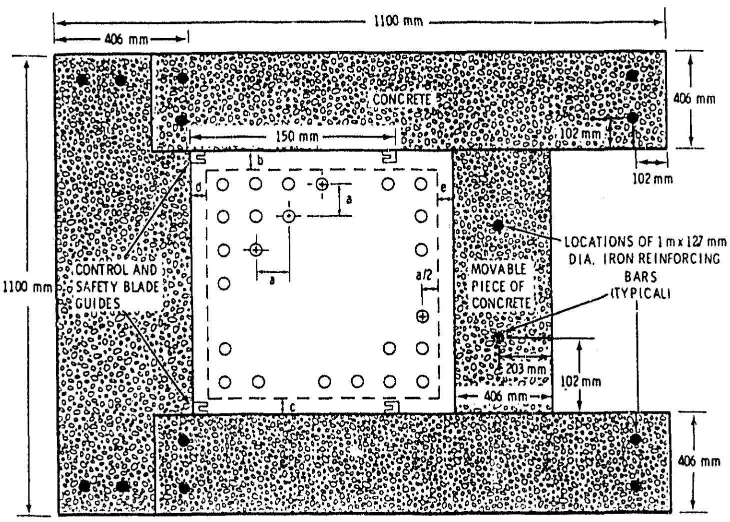


FIGURE 2. Simplified Description of Fast Flux Test Facility Special Driver Fuel



VARIABLE DIMENSIONS, mm

a	b	c	d	e
9.53 ± 0.13	20.22 ± 0.34	21.48 ± 0.87	20.22 ± 0.65	20.33 ± 0.24
12.63 ± 0.13	19.09 ± 0.18	15.94 ± 0.22	18.67 ± 0.65	18.78 ± 0.24
15.41 ± 0.13	32.00 ± 0.15	22.06 ± 0.24	17.28 ± 0.65	17.39 ± 0.24
19.06 ± 0.18	23.49 ± 0.47	21.48 ± 0.87	15.45 ± 0.65	15.56 ± 0.26

FIGURE 3. Plan View - Critical Experiments with Concrete-Reflected FTR Fuel Pins in Water

TABLE 2. Composition of Concrete Reflector Critical Experiments - FTR Fuel Pins in Water

Chemical Element	wt%[a]
Aluminum	2.32 ± 0.01
Calcium	7.27 ± 0.28
Iron	0.28 ± 0.02
Silicon	34.68 ± 0.39
Magnesium	1.45 ± 0.05
Potassium	0.75 ± 0.15
Sodium	0.17 ± 0.01
Oxygen	52.26 ± 0.58
Helium	0.82 ± 0.07

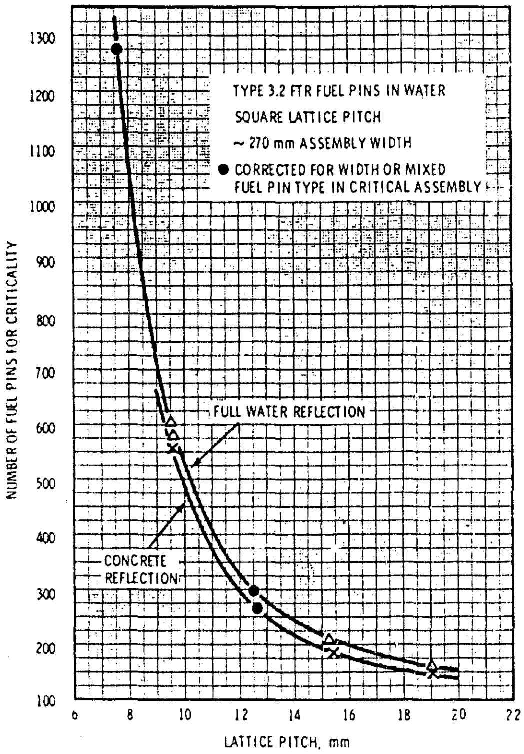


FIGURE 4. FTR Fuel Pins Required for Criticality as a Function of Lattice Pitch

ORGANIC MODERATED ASSEMBLIES

The most recent series of experiments to be performed in this program with FFTF fuel pins involved single lattices of fuel pins in an organic mixture similar to that used in the solvent extraction stage of fuel reprocessing. The experiments were partially funded by the Power Reactor and Nuclear Fuel Development Corporation of Japan as part of a joint program on criticality data development with the USDOE.

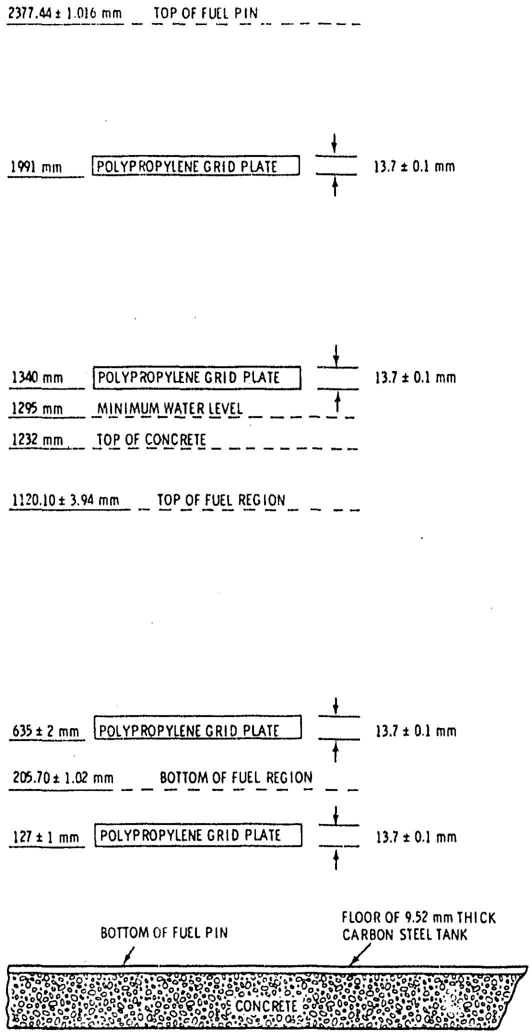


FIGURE 5. Relative Elevations--Critical Experiments with Concrete-Reflected FTR Fuel Pins in Water

The experiments were specifically designed to provide data for direct comparison with the water moderated measurements discussed above. The same lattice arrangements and FFTF fuel pins were used in these organic moderated assemblies as were used in the water moderated experiments. As discussed above for the water moderated/reflected assemblies, the organic moderated assemblies were fully reflected with the organic mixture. The organic moderator was a mixture of 38wt% tributylphosphate in a normal paraffin hydrocarbon mixture of $C_{11}H_{24}$ to $C_{15}H_{32}$ molecules. As indicated in Table 1, the number of fuel pins required for delayed criticality was determined at moderator-to-fuel volume ratios of 1.66, 3.49, 6.65, 10.88 and 18.13. A comparison between these organic moderated assemblies and the corresponding water moderated assemblies is shown in Figure 6. The experimental results and assemblies

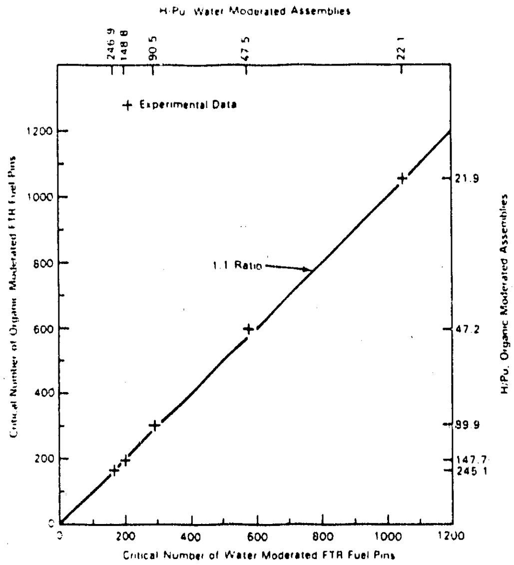


FIGURE 6. Critical Size Comparison of Organic and Water Moderated FTR Fuel Pin Lattices

are described in greater detail in Reference 4. Reaction rate measurements were made using solid state tract recorders to obtain absolute fission rates for 235U, 238U, 239Pu, 237Np, and 232Th in the neutron energy spectrum of the fuel pins and the organic moderator of the very undermoderated experimental assembly having a moderator-to-fuel volume ratio of 1.66. Also the absolute fission rate in the fuel and 238U capture in both the fuel pins and in the moderator region between the pins were measured. In addition epi-cadimium fission and capture rates were measured in the moderator region between pins. The measurements were made near the center at midplane of the assembly fuel region. Additional details and measurement results are given in Reference 5.

NITRATE MODERATED ASSEMBLIES

The earliest series of experiments in this program with FFTF fuel pins were performed with the special driver fuel pins described in Figure 2. These experiments consisted of a single lattice of fuel pins uniformly arranged in a hexagonal pattern on a 3.048cm center-to-center spacing. The lattice was contained in a cylindrical vessel. Measurements were performed by incrementally adding mixed plutonium-uranium solutions to the lattice assembly to achieve criticality. The Pu-U mixture remained essentially constant at 30wt% Pu and critical heights were determined for solutions having up to 257.6gPu+U/liter. At concentrations near 260gPu+U/liter, the effect that gadolinium and mixtures of gadolinium-boron dissolved in the solution had on the critical height was also measured. A sketch of the experimental assembly is shown in Figure 7. A complete description of the experimental and the measurement results are given in references 6 and 7.

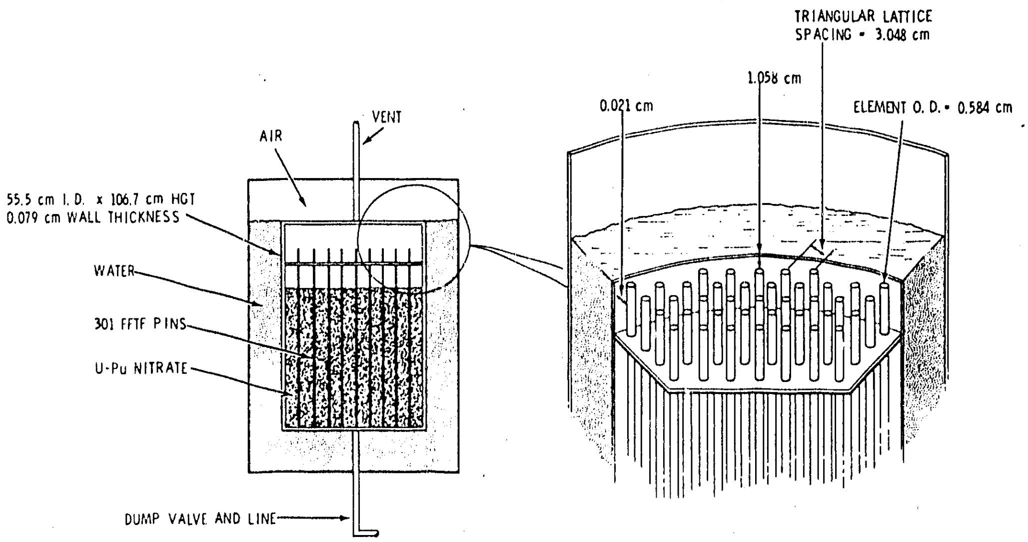


FIGURE 7. Experimental Arrangement for FFTF Fuel Pins in Pu-U Nitrate Solutions

In addition to the criticality measurements performed in this series of experiments, pulse neutron source measurements were made to determine k_{eff} values as Pu-U solution containing dissolved gadolinium was added in increments to the lattice assembly. In these measurements, the gadolinium concentrations varied up to 1.34g/liter and the subcritical conditions varied down to k_{eff} values of about 0.6. A complete description of these measurements is given in reference 8.

SUMMARY

The LMFBR Criticality Experiments Program with lattices of FFTF fuel pins provided experimental data over the primary neutron moderation range of interest from optimum to the very under-moderated condition. Data is available on assemblies moderated with water, organic and nitrate solutions, and reflected with either water or concrete. Data also exists on the reactivity effect of boron and gadolinium on these lattices. In addition, measurements were performed in this program to determine k_{eff} values as dissolved gadolinium was added to assemblies moderated with mixed Pu-U nitrate solutions. To provide basic physics, data reaction rate measurements were performed in selected assemblies to obtain thermal and epi-thermal fission rates for 235U, 238U, 239Pu, 232Th and 237Np in addition to capture rates in 238U. Except for measurement data on fuel pellets as they are being dissolved, the program has provided a complete criticality data base in support of FFTF fuel fabrication, handling and reprocessing.

REFERENCES

1. S. R. Bierman, et al. "Critical Experiments With Fast Test Reactor Fuel Pins in Water," *Nucl. Tech.* *44*:141. (1979)

2. B. M. Durst, et al. "Summary of Experimental Data for Critical Arrays of Water Moderated Fast Test Reactor Fuel," PNL-3313, Pacific Northwest Laboratory, Richland, Washington. (1981)

3. S. R. Bierman, et al. "Critical Experiments With Concrete Reflected Fast Test Reactor Fuel Pins in Water," *Nucl. Tech.* *49*:140. (1980)

4. S. R. Bierman, et al. "Experimental Criticality Data Comparing Organic with Water Moderation," *Trans. Am. Nucl. Soc.*, *54*:195. (1987)

5. S. R. Bierman and N. Fukumura. "Neutron Reaction Rate Measurements in an Organically Moderated Lattice of FTR Fuel Pins," *Trans. Am. Nucl. Soc.*, *54*:195. (1987)

6. R. C. Lloyd and E. D. Clayton. "Criticality Safety Data Applicable to Processing Liquid-Metal Fast Breeder Reactor Fuel," *N S & E*, *59*:21. (1976)

7. R. C. Lloyd and E. D. Clayton. "Effect of Fixed and Soluble Neutron Absorbers on the Criticality of Uranium-Plutonium Systems," *N S & E*, *62*:726. (1977)

8. S. R. Bierman. "Reactivity Measurements Under Conditions Typical to Fuel Element Dissolution," *Nucl. Tech.* *31*:339. (1976)

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