CRITICAL EXPERIMENTS SUPPORTING CLOSE PROXIMITY WATER STORAGE OF POWER REACTOR FUEL

TECHNICAL PROGRESS REPORT
FOR THE PERIOD
JANUARY 1, 1978-MARCH 31, 1978

M. N. Baldwin
G. S. Hoovler

July 1978

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Critical Experiments Supporting Close Proximity
Water Storage of Power Reactor Fuel
Technical Progress Report

By: M. N. Baldwin, G. S. Hoovler

ABSTRACT

Experimental measurements are being conducted on critical configurations of clusters of fuel rods mocking up LWR-type fuel elements in close proximity water storage. Results will serve to benchmark the computer codes used in the design of nuclear power reactor fuel storage racks.

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CONTENTS

	Page
1. INTRODUCTION	1-1
2. DESCRIPTION OF FACILITY	2-1
2.1. Facility	2-1
2.2. Fuel Rods	2-1
2.3. B ₄ C Pins	2-1
3. MEASUREMENTS	3-1
4. ANALYSIS	4-1
5. REFERENCES	5-1
DISTRIBUTION	A-1

List of Tables

Table

1. Certified Chemical Analysis of B ₄ C	2-1
2. Core Loadings Established With Full Top Grid	3-3
3. Benchmark Core Loadings Adjusted to 145-cm Moderator Height	4-3

List of Figures

Figure

1. Core I Loading Diagram — Cylindrical Base Case	3-4
2. Core II Loading Diagram — Nine Arrays With 0 Pin Pitch Separation	3-5
3. Core III Loading Diagram — Nine Arrays With 1 Pin Pitch Separation	3-6
4. Core IV Loading Diagram — Nine Arrays With 1 Pin Pitch Separation and 84 B ₄ C Pins	3-7

Figures (Cont'd)

Figure		Page
5.	Core V Loading Diagram — Nine Arrays With 2 Pin Pitch Separation and 64 B ₄ C Pins	3-8
6.	Core VI Loading Diagram — Nine Arrays With 2 Pin Pitch Separation and 64 B ₄ C Pins	3-9
7.	Core VII Loading Diagram — Nine Arrays With 3 Pin Pitch Separation and 34 B ₄ C Pins	3-10
8.	Core VIII Loading Diagram — Nine Arrays With 3 Pin Pitch Separation and 34 B ₄ C Pins	3-11
9.	Core IX Loading Diagram — Nine Arrays With 4 Pin Pitch Separation	3-12
10.	$(\partial\rho/\partial H)^{-1/3}$ Vs Moderator Height for Cores I Through IX	4-4
11.	Excess Reactivity to 145 cm Vs Moderator Height for Cores I Through IX	4-5

1. INTRODUCTION

In July of 1977, The Babcock & Wilcox Company was awarded a contract by the U. S. Department of Energy (DOE) to conduct critical experiments supporting close proximity water storage of nuclear power reactor fuel. The need for this program resulted from delays in increasing the nuclear fuel reprocessing capability in the United States, which have greatly increased the amount of fuel to be stored and have placed a premium on optimum use of storage capacity.

Experimental measurements are being conducted on critical configurations of clusters of fuel rods mocking up LWR-type fuel elements in close proximity water storage. The square clusters with 14 rods on each side are arranged in 3x3 arrays. Both the spacing between the fuel clusters and the intervening material are being varied to provide a variety of benchmark loadings.

The KENO IV code and the PDQ07 code (in selected cases) are being used to analyze each benchmark loading to determine the calculated k_{eff} of each configuration.

All pertinent data will be documented in the final report in sufficient detail to permit use of the benchmark loadings in validating calculational methods according to ANSI Standard N16.9-1975.

Quarterly reports are being issued during the experimental measurements of the contract.

This report, the second of the quarterly series, presents the experimental results obtained during the first calendar quarter of 1978. Work during the previous quarter is reported in reference 1.

2. DESCRIPTION OF FACILITY

2.1. Facility

The facility, located at B&W's Lynchburg Research Center, is a critical assembly within a core tank 152.4 cm in diameter by 198 cm high with aluminum walls 1.27 cm thick. The facility is further described in reference 1.

2.2. Fuel Rods

The fuel rods are 1.206 cm in OD by 156.4 cm long. The cladding is 0.081 cm thick, type 6061 aluminum; and the UO_2 fuel is enriched to 2.46 wt % ^{235}U . The fuel is further described in reference 1.

2.3. B_4C Pins

The B_4C pins are 1.113 cm in OD by 0.089 cm wall, aluminum tubes filled with natural B_4C powder ranging from 30 to 50 mesh. The bottom ends are sealed with welded aluminum plugs 0.952 cm long, and the tops are sealed with removable cork plugs. The pins contain 156 g of B_4C , which constitutes a column long enough to span the full core height. The B_4C within the tubes extends about 30 cm above the moderator level. The B_4C is compacted to 0.879 ± 0.001 g/cm. A certified chemical analysis of the B_4C powder is given in Table 1.

Table 1. Certified Chemical Analysis of B_4C

Total boron	77.8 wt %
Total carbon	20.8 wt %
Anhydrous B_2O_3	0.10 wt %
Boron plus carbon	98.6 wt %
Particle size, 30 to 50 mesh	91.2%

3. MEASUREMENTS

The experimental measurements are separated into two parts. In the first part of the program, the clusters are separated by water only, or water and B_4C -filled pins. Top and bottom "egg-crate" aluminum grids hold the fuel rods and B_4C pins in place. Critical configurations are obtained with the clusters separated by an integral number of pin pitches.

The top and bottom egg-crate grid plates consist of slotted aluminum strips 2.54 cm wide, interlocked to form a square matrix. The strips are 0.406 cm thick and are spaced on 1.636 ± 0.005 -cm centers. An aluminum base plate 5.08 cm thick and 2.54 cm above the bottom of the core tank supports the fuel rods. All moderator heights are referenced to the top of the base plate.

During the last quarter, three benchmark cores were established. The loading diagrams of these previously established cores are illustrated herein for the convenience of the reader (Figures 1 through 3). During the present reporting quarter, six additional benchmark cores were established, as diagrammed in Figures 4 through 9. Each small square shown in Figures 1 through 9 represents a grid position occupied by a fuel rod. The shaded circles between the fuel rod arrays represent B_4C pins used to partially isolate the arrays.

The planned core loadings utilizing B_4C pins are now complete and are all tabulated in Table 2. Loadings planned for the remainder of this program will utilize water, steel, or borated sheets for partial isolation of the fuel rod arrays.

The excess reactivity of Cores II and III was controlled by dissolving boric acid (H_2BO_3) in the moderator (demineralized water). The boron concentration in parts per million (ppm) is defined as the grams of natural boron per million cm^3 of moderator at 25C; it is determined by titration against a standard KOH solution. The measurements have an absolute standard deviation of ± 3 ppm.

$\Delta\rho/\Delta H$ measurements were taken by raising the moderator level a few centimeters above the critical moderator height, determining the stable reactor period

over several decades, and converting the reactor period to reactivity units (ρ/β) using the in-hour equation. Moderator height measurements were taken with a conductivity probe accurate to about ± 0.2 cm. Incremental changes in moderator level were measured to an accuracy of about ± 0.02 cm.

Table 2. Core Loadings Established With Full Top Grid

Core	Run	Load'g diagr figure No.	Spacing betw'n arrays, pin pitches	No. of B ₄ C pins	Mod'r temp, C	Mod'r boron conc, ppm (±3)	Critical mod'r ht, cm (±0.2)	Super- critical mod'r ht, cm (±0.2)	Doubling time, s	$\Delta\rho$, c	ΔH , cm (±.02)	$\frac{\Delta\rho}{\Delta H}$	$\bar{H}$, cm	$\left(\frac{\Delta\rho}{\Delta H}\right)^{-1/3}$
I	2245	1	--	--	21	0	143.88	147.12	98.5	6.95	3.24	2.15	145.5	0.775
II	2255	2	0	0	18.5	1037	144.29	--	--	--	--	--	--	--
III	2265	3	1	0	18	769	148.63	150.67	202	3.72	2.04	1.82	149.7	0.819
III	2266	3	1	0	18	764	144.88	149.88	64.5	9.70	5.00	1.94	147.4	0.802
III	2267	3	1	0	18	762	140.38	144.80	62.5	10.0	4.42	2.26	142.6	0.762
III	2268	3	1	0	18.5	753	131.32	133.80	95.0	7.20	2.48	2.90	132.6	0.701
III	2269	3	1	0	18	739	120.64	124.26	43.5	13.1	3.62	3.62	122.5	0.651
III	2270	3	1	0	18	721	110.04	111.84	78.0	8.40	1.80	4.67	110.9	0.598
III	2271	3	1	0	18.5	702	100.32	102.09	55.5	11.0	1.77	6.21	101.2	0.544
IV	2282	4	1	84	17	0	145.68	148.94	110	6.33	3.26	1.94	147.3	0.802
V	2295	5	2	64	17.5	0	144.75	149.27	72.0	8.95	4.52	1.98	147.0	0.796
VI	2297	6	2	64	17.5	0	107.67	109.92	49.5	11.9	2.25	5.29	108.8	0.574
VII	2314	7	3	34	17.5	0	146.15	149.80	96.5	7.09	3.65	1.94	148.0	0.802
VIIa	2315	--	3	34	17.5	0	122.92	125.89	59.4	10.4	2.97	3.50	124.4	0.659
VIIb	2316	--	3	34	17.5	0	116.59	118.79	75.7	8.64	2.20	3.93	117.7	0.634
VIII	2317	8	3	34	17.5	0	111.49	113.78	56.7	10.8	2.29	4.72	112.6	0.596
IX	2321	9	4	0	17.5	0	129.65	131.87	100	6.88	2.22	3.10	130.8	0.686
IXa	2323	--	4	2	17.5	0	139.36	144.96	43.8	13.0	5.60	2.32	142.2	0.755

Figure 1. Core I Loading Diagram —
Cylindrical Base Case

Figure 2. Core II Loading Diagram — Nine Arrays
With 0 Pin Pitch Separation

Figure 3. Core III Loading Diagram — Nine Arrays
With 1 Pin Pitch Separation

Figure 4. Core IV Loading Diagram — Nine Arrays With
1 Pin Pitch Separation and 84 B₄C Pins

Figure 5. Core V Loading Diagram — Nine Arrays With
2 Pin Pitch Separation and 64 B₄C Pins

Figure 6. Core VI Loading Diagram — Nine Arrays With
2 Pin Pitch Separation and 64 B₄C Pins

Figure 7. Core VII Loading Diagram — Nine Arrays With
3 Pin Pitch Separation and 34 B₄C Pins

Figure 8. Core VIII Loading Diagram — Nine Arrays With
3 Pin Pitch Separation and 34 B₄C Pins

Figure 9. Core IX Loading Diagram — Nine Arrays
With 4 Pin Pitch Separation

4. ANALYSIS

The results of all core loadings that utilize B₄C pins for partial isolation of the fuel rod arrays are summarized in Table 2. The $\Delta\rho/\Delta H$ data from Table 2 that correspond to an average moderator height below 140 cm have been fitted to a linearized form of the equation:

$$\frac{\delta\rho}{\delta H} = \frac{c}{(H + \lambda)^3} \quad (1)$$

The fit is shown in Figure 10, where C and λ have been determined to have values of 7.894×10^6 cents/cm² and 6.90 cm, respectively. Above 140 cm the curve is allowed to deviate from the analytical least-squares fit to follow the experimental values.

With the aid of Figure 10, one can determine the reactivity that a core critical at a moderator height of H_c would have if the moderator height were raised to 145 cm. The result of this integration is shown in Figure 11; the curve has an estimated uncertainty of $\pm 4\%$. Of this, 3% is attributed to uncertainty in the experimental measurement of $\delta\rho/\delta H$. The additional 1% is for error in the least-squares fit. Figure 11 is used along with β to adjust k_{eff} so that all cores may be specified at the common moderator height of 145 cm. Adjustments of this type are tabulated in Table 3 using a value of 0.0075 for β_{eff} . The limits of k_{eff} given in Table 3 assume an uncertainty of 0.0005 on the value of β_{eff} .

The reactivity difference between runs 2268 and 2271 of Core III, which is attributable to moderator height, can be evaluated by the integral form of equation 1. Thus

$$\rho = \frac{C/2}{(H + \lambda)^2} \Big|_{H_1}^{H_2} = 136.7 \pm 5.5 \text{ cents} \quad (2)$$

Since the only other difference between runs 2268 and 2271 is 51 ± 4 ppm of moderator boron, we conclude that $\delta\rho/\delta B$ is 2.7 ± 0.2 cents/ppm for Core III.

Table 3. Benchmark Core Loadings Adjusted to
145-cm Moderator Height

Core	Loading diagram figure No.	Spacing betw. arrays, pin pitches	No. of B ₄ C pins	Moderator boron conc, ppm	Reactivity(ρ) at 145-cm moderator ht, c	Moderator temp, C	k_{eff} at 145-cm moderator height
I	1	--	0	0	2.47	21	1.0002 $\pm$ 0.0000
II	2	0	0	1037	1.56	18.5	1.0001 $\pm$ 0.0000
III	3	1	0	764	0.33	18	1.0000 $\pm$ 0.0000
IV	4	1	84	0	-1.45	17	0.9999 $\pm$ 0.0000
V	5	2	64	0	0.55	17.5	1.0000 $\pm$ 0.0000
VI	6	2	64	0	129.41	17.5	1.0098 $\pm$ 0.0011
VII	7	3	34	0	-2.44	17.5	0.9998 $\pm$ 0.0000
VIII	8	3	34	0	110.32	17.5	1.0083 $\pm$ 0.0009
IX	9	4	0	0	40.40	17.5	1.0030 $\pm$ 0.0003

Figure 10. $(\partial\rho/\partial H)^{-1/3}$ Vs Moderator Height for Cores
I Through IX

Figure 11. Excess Reactivity to 145 cm Vs Moderator Height For Cores I Through IX

5. REFERENCES

- ¹ M. N. Baldwin and G. S. Hoovler, Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel, BAW-1484-1, Babcock & Wilcox, Lynchburg, Virginia, March 1978.

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