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PART IV, TASK 1

Quarterly Technical Report

December 1974-March 1975

by

M. N. Baldwin

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M. N. Baldwin

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ABSTRACT

The reactivity and power perturbation effects of poison and neutral pins in mockups of 15 by 15 fuel assemblies are being measured. The experimental facility - a water-moderated, 4% enriched UO_2 lattice - is arranged to mock up the fuel assemblies of the Consolidated Nuclear Steam Generator (CNSG) core.

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1. INTRODUCTION

In December of 1974, Babcock & Wilcox (B&W) initiated Part IV of the Physics Verification Program. The objective of Part IV is to generate accurate experimental data for use in verifying the calculational techniques that will be used to design the Consolidated Nuclear Steam Generator (CNSG) core.

This report presents the experimental results obtained through the first calendar quarter of 1975. Completed tasks of the program are summarized in references 1 through 7. The program is jointly supported by Babcock & Wilcox and the Energy Research and Development Administration (ERDA).

2. DESCRIPTION OF FACILITY

2.1. Facility

The facility, located at B&W's Lynchburg Research Center, is a critical assembly within a 5-foot-diameter by 6.5-foot-high core tank with 0.5-inch-thick aluminum walls. The core tank is located inside a steel tank 9 feet in diameter and is supported on a skirt which holds it about 2.5 feet above the base of the larger tank. A 2-inch thick aluminum base plate one inch above the bottom on the core tank supports the fuel rods. All moderator heights are referenced to the top of the base plate.

2.2. Fuel Rods

The physical and chemical properties of the fuel rods have been analyzed in prior experimental programs at B&W.^{8,9} These properties are summarized in Table 2-1. The uncertainties are standard deviations of the mean obtained from vendor quality control data and check measurements on randomly selected samples. The impurities are given as the summation of $N_i \sigma_i$, where N_i is the concentration of each impurity per cm^3 of the oxide fuel and σ_i is its microscopic absorption cross section.

Since the fuel rods were swaged, and thus have no fuel gap, the fuel diameter was obtained by measuring the outside diameter and wall thickness. Although the OD was constant, the wall thickness measured by a conductivity method was appreciably larger near the ends.⁹ The average cladding thickness between 40 and 140 cm was 15.9 ± 0.5 mils, but the average between 10 and 170 cm was 16.6 ± 0.6 mils. The value listed in Table 2-1 is the $\cos^2$ -weighted average between 10 and 170 cm.

The top and bottom end caps of the fuel rods are each approximately 2.35 inches long and consist of stainless steel thimbles filled with either aluminum or stainless steel plugs. Approximately 20% are stainless steel. No distinction is being made in the experiments since the reactivity differences have been shown to be negligible.⁹

2.3. Perturbing Pins

Poison pins, neutral pins, and vacant water-filled positions within the core lattice will be used to produce lattice heterogeneities for study. The physical and chemical properties of these pins have been reported in prior experimental programs at B&W.^{5,6,10}

Only neutral pins were used during the first quarter. They consist of reagent grade, anhydrous Al_2O_3 powder in 0.438-inch OD by 0.035-inch wall, 6061 aluminum tubes. Each tube is sealed at the bottom by a 0.4-inch thick aluminum plug (welded in place) and at the top by a cork plug. The Al_2O_3 is packed in the tube to a linear density of 1.31 g/cm.

Table 2-1. Physical Properties of Fuel Rods

<u>Item</u>	<u>Value</u>
Outer diameter, in.	0.4755 ± 0.0015
Wall thickness, in.	$0.0160 \pm 0.0005^{(a)}$
Wall material	Type 304 stainless steel
Fuel diameter, in.	0.444 ± 0.002
Active fuel length, in.	66.7 ± 0.3
Total length, in.	~ 71.5
Weight of fuel, g/rod	1600 ± 2
Weight of uranium, g/rod	1408 ± 2
Weight of ^{235}U , g/rod	56.61 ± 0.10
Enrichment, wt 25/wt U, %	4.020 ± 0.005
Fuel density, g/cm ³	9.46 ± 0.10
$\sum N_i \sigma_i$ (summation of impurities), cm ² /cm ³ oxide	$< 5 \times 10^{-4}$

^(a) Cos²-weighted average

3. MEASUREMENTS

3.1. Task Description

Accurate experimental data suitable for verifying and/or improving the calculational techniques that will be used to design the CNSG core are generated under this task. Unclad Pyrex glass rods, aluminum-clad Vicor glass rods, aluminum-clad B_4C powder, aluminum-clad zone-loaded rods, aluminum-clad Al_2O_3 powder (neutral rods), and water holes are spaced on selected patterns in an otherwise uniform clean lattice to study their effects on reactivity and power shape.

Two kinds of data are being determined:

1. The moderator boron concentration required to give a critical condition at a known moderator height of 160 cm.
2. Power maps in selected regions of a portion of the core loadings.

3.2. Critical Parameters

The change in the moderator boron concentration is being used as a measure of reactivity change, since this quantity can be readily compared with computer calculations. Excess reactivity is 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.

During the quarter, the exact moderator boron concentration for the just-critical condition was established for the six core loadings diagrammed in Figures 3-1 through 3-5. Data from these loadings are presented in Table 3-1. All measurements reported were taken with all safety blades fully withdrawn. Moderator height measurements are referenced to the top of the base plate.

3.3. Effect of Moderator Boron Concentration on Critical Moderator Height

Extensive $\delta\rho/\delta H$ data have been accumulated previously.¹⁰ Below a moderator height of 150 cm, these data have been fitted to a linearized form of the equation

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

where c and λ were determined¹⁰ to have the values 8.05×10^6 cents/cm² and 6.0 cm, respectively. While some adjustment of these constants may be justified when all data have been collected, $\Delta\rho/\Delta H$ values calculated using these constants agree to within 8% with similar data taken to date in the present program (see Figure 3-6).

The reactivity difference between runs 2001 and 2003 of Table 3-1, which is attributable to moderator height, can be evaluated by the integral form of equation 3-1. Thus,

$$\Delta\rho = \frac{C/2}{(H + \lambda)^2} \left| \begin{array}{l} 119.80 \\ 149.42 \end{array} \right. = 88 \pm 7\text{c}. \quad (3-2)$$

Since the only difference between these two runs is 78 ± 4 ppm of moderator boron, we conclude that $\delta\rho/\delta B$ is 1.1 ± 0.1 cents/ppm.

The numerical value of $\delta\rho/\delta H$ at a 160 cm moderator height is about 1.7 cents/cm (from Table 3-1). Thus, $\delta B/\delta H \approx 1.5$ ppm/cm at the 160 cm moderator height.

3.4. Numerical Adjustment of Boron Concentration

$\delta B/\delta H$ obtained above is used to adjust the moderator boron concentration of each core to that required when the critical moderator height is 160.0 cm. Adjusted values are presented in Table 3-2 for each loading studied during the quarter.

3.5. Power Profile Measurements

The midplane relative power densities over each of two one-eighth sections of the central 15×15 array of Core XV-C2 were obtained and

compared. Relative power density is determined by using a sodium iodide (thallium-activated) scintillation counter to count collimated fission product gammas from activated fuel rods. The Lynchburg Research Center has used this method extensively. Results are presented in Table 3-3.

Table 3-1. Core Loadings Studied During Quarter

Core	Run	Moderator boron conc, ppm	Moderator ht, cm		Doubling time, s	$\Delta\rho$, %	ΔH , cm	$\bar{H}$, cm	$\Delta\rho/\Delta H$	$(\Delta\rho/\Delta H)^{-1/3}$
			Critical	Super- critical						
XV-1	1996	1897.6	159.35	165.22	77	8.5	5.87	162.3	1.45	0.884
XV-1	1998	1866.0	143.05	146.29	89	7.6	3.24	144.7	2.35	0.752
XV-1	1999	1862.3	140.20	143.88	70	9.2	3.68	142.0	2.50	0.737
XV-1	2000	1836.5	129.44	132.17	70	9.2	2.73	130.8	3.37	0.667
XV-1	2001	1805.4	119.80	121.92	73	8.9	2.12	120.9	4.20	0.620
XV-1	2002	1874.3	144.78	148.26	78	8.4	3.48	146.5	2.41	0.746
XV-1	2003	1882.5	149.42	153.02	88	7.6	3.60	151.2	2.11	0.780
XV-2	2016	1750.0	159.72	165.84	69	9.3	6.12	162.8	1.52	0.870
XV-A2	2022	1714.3	159.65	166.02	66	9.6	6.37	162.8	1.51	0.872
XV-B2	2023	1685.4	159.45	165.52	72	9.0	6.07	162.5	1.48	0.877
XV-C2	2027	1670.3	159.84	165.30	78	8.4	5.46	162.6	1.54	0.866
XV-D3	2053	1651.9	160.08	166.30	68	9.4	6.22	163.2	1.51	0.872

Table 3-2. Core Loadings Adjusted to 160.0-cm
Critical Moderator Height

<u>Core</u>	<u>No. fuel rods</u>	<u>No. of positions</u>		<u>Moderator boron conc, ppm</u>
		<u>Water</u>	<u>Al₂O₃</u>	
XV-1	1433	0	0	1899
XV-2	1408	25	0	1750
XV-A2	1400	25	8	1715
XV-B2	1392	25	16	1686
XV-C2	1388	25	20	1671
XV-D3	1384	25	24	1652

Table 3-3a. Midplane Power Profile for Core XV-C2

Northwest segment				Southeast segment				Avg of symmetric locations	Standard deviation, %
Location	Run 2041	Run 2043	Average	Location	Run 2045	Run 2046	Average		
N1	2.036	1.982	1.983	S1	1.961	2.057	2.009	1.996	0.7
N1W1	1.886	1.871	1.878	S1E1	1.822	1.897	1.860	1.869	0.5
N2W1	1.977	2.020	1.998	S2E1	1.983	2.036	2.010	2.004	0.3
N3	1.957	1.914	1.936	S3	1.903	1.948	1.926	1.931	0.3
N3W1	1.987	1.990	1.985	S3E1	1.948	2.031	1.990	1.988	0.1
N3W2	2.072	2.018	2.045	S3E2	2.007	2.062	2.034	2.040	0.3
N4	2.071	2.064	2.068	S4	2.025	2.041	2.033	2.050	0.9
N4W2	1.942	1.943	1.942	S4E2	1.878	1.995	1.936	1.939	0.2
N4W3	2.018	1.977	1.998	S4E3	1.944	2.015	1.980	1.989	0.5
N4W4	1.841	1.831	1.836	S4E4	1.825	1.841	1.833	1.834	0.1
N5	1.820	1.813	1.816	S5	1.746	1.849	1.798	1.807	0.5
N5W1	1.969	1.939	1.954	S5E1	1.929	1.974	1.952	1.953	0.1
N5W2	1.918	1.888	1.903	S5E2	1.804	1.862	1.833	1.868	1.9
N5W4	1.933	1.960	1.946	S5E4	1.873	1.965	1.919	1.932	0.7
N6	1.826	1.813	1.820	S6	1.783	1.799	1.791	1.806	0.8
N6W2	1.685	1.768	1.726	S6E2	1.669	1.758	1.714	1.720	0.4
N6W3	1.765	1.733	1.749	S6E3	1.727	1.765	1.746	1.748	0.1
N6W4	1.657	1.668	1.662	S6E4	1.623	1.676	1.650	1.656	0.4
N6W5	1.830	1.785	1.808	S6E5	1.720	1.796	1.758	1.783	1.4
N7	1.593	1.607	1.600	S7	1.549	1.587	1.568	1.584	1.0
N7W1	1.699	1.641	1.670	S7E1	1.583	1.651	1.617	1.644	1.7
N7W2	1.628	1.551	1.590	S7E2	1.523	1.559	1.541	1.566	1.6
N7W3	1.509	1.516	1.512	S7E3	1.470	1.559	1.514	1.513	0.1
N7W4	1.479	1.477	1.478	S7E4	1.448	1.471	1.460	1.469	0.6
N7W5	1.597	1.511	1.554	S7E5	1.467	1.481	1.474	1.514	2.7
N7W6	1.601	1.553	1.577	S7E6	1.538	1.533	1.536	1.556	1.3
N7W7	1.430	1.393	1.411	S7E7	1.374	1.366	1.370	1.390	1.5

Table 3-3b. Midplane Power Profile for Core XV-C2

		Distance ^{West} of Core Center, pin pitches East							
		0	1	2	3	4	5	6	7
Distance North of Core Center, South of Core Center	0	Water		Al ₂ O ₃					
	1	1.996	1.869			Water		Al ₂ O ₃	
	2	Al ₂ O ₃	2.004	Water					
	3	1.931	1.988	2.040	Al ₂ O ₃		Water		
	4	2.050	Water	1.939	1.989	1.834			
	5	1.807	1.953	1.868	Water	1.932	Water		
	6	1.806	Al ₂ O ₃	1.720	1.748	1.656	1.783	Al ₂ O ₃	
	7	1.584	1.644	1.566	1.513	1.469	1.514	1.556	1.390

Figure 3-1. Core XV Loading Diagram

X Positions where content is varied (25 total)

<u>Core</u>	<u>Content of X positions</u>
XV-1	Fuel
XV-2	Water

Figure 3-2. Core XV-A^(a) Loading Diagram

- O Water-filled positions (25 total).
- X Positions where content is varied (8 total).

(a) Designated Core XV-A2 when the X positions are filled with neutral pins.

Figure 3-3. Core XV-B^(a) Loading Diagram

- O Water-filled positions (25 total).
- X Positions where content is varied (16 total).

(a) Designated Core XV-B2 when the X positions are filled with neutral pins.

Figure 3-4. Core XV-C^(a) Loading Diagram

- O Water-filled positions (25 total).
- X Positions where content is varied (20 total).

(a) Designated Core XV-C2 when the X positions are filled with neutral pins.

Figure 3-5. Core XV-D^(a) Loading Diagram

- O Water-filled positions (25 total).
- X Positions where content is varied (24 total).

(a) Designated Core XV-D3 when the X positions are filled with neutral pins.

Figure 3-6. $(\Delta\rho/\Delta H)^{-1/3}$ Vs Moderator Height

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