March 1976

PHYSICS VERIFICATION PROGRAM

PART IV, TASK 1

— Summary Report —

by

M. N. Baldwin

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Physics Verification Program, Part IV,
Task 1 - Summary Report

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 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 was 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, issued in lieu of a fourth-quarter report, summarizes all of the experimental results obtained under the task. In several instances, data previously reported in quarterly technical reports have been reanalyzed, and the results given here may differ slightly from those reported earlier.¹⁻³ References 4 through 10 summarize other completed tasks.

The program is jointly supported by Babcock & Wilcox and the U. S. 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 supported on a skirt that 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.^{11,12} 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.¹² 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% of the end caps are stainless steel. No distinction is being made in the experiments since the reactivity differences have been shown to be negligible.¹²

2.3. Perturbing Pins

Poison pins, neutral pins, and vacant water-filled positions within the core lattice are being used to produce lattice heterogeneities for study. The physical and chemical properties of these pins have been reported in previous experimental programs at B&W^{8,9,10,13} but are restated here and in Table 2-2 for the convenience of the reader.

The neutral pins consist of reagent grade, anhydrous Al_2O_3 powder in 0.437-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 density of 1.07 g/cm^3 .

The Pyrex pins are smaller in diameter than the fuel pins and contain 12.6 wt % B_2O_3 . These rods are used in an unclad condition and are centered at the top and bottom grid plates with spacers.

The Vicor pins contain about 3 wt % B_2O_3 in pure silica and are approximately the same diameter as the Pyrex pins. The Vicor pins are standard 3-foot lengths. Two of these short pins are loaded in 6061 aluminum tubes (6 feet long by 0.439-inch OD by 0.035-inch wall), each of which has one end sealed with a 0.4-inch-thick aluminum plug.

The zone-loaded pins consist of 4 feet of Pyrex below 2 feet of Vicor loaded into aluminum tubes 6 feet long by 0.439-inch OD by 0.035-inch-wall, which are sealed on the bottom with an aluminum plug 0.4 inch thick.

2.4. Core Description

Top and bottom plates align the fuel rods in the core tank. The top and bottom egg-crate grid plates are 1-inch wide, slotted aluminum strips, which are interlocked to form a square matrix. The 0.160-inch-thick strips are spaced on centers of 0.644 ± 0.001 inch.

The fuel rods are supported on a 2-inch-thick aluminum base plate, which is raised about 1 inch above the bottom of the 5-foot-diameter tank. The intervening space is filled with moderator. Moderator levels are measured from a reference plane at the top of the base plate. The fuel rods and perturbing pins are uniformly spaced at intervals of the lattice pitch and are loaded to approximately a cylindrical geometry.

The safety blades are 8-inch-wide boral. Each blade is thin enough to pass between rows of fuel rods, so that uniform lattice spacing can be maintained. During measurements, the safety blades are held in a cocked position to minimize their contribution to core perturbations. Criticality is achieved by raising the level of the moderator. Boric acid in the moderator controls excess reactivity.

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

Table 2-2. Physical Properties of Perturbing Pins

Parameter	Vicor	Pyrex	Zoned		B ₄ C	Al ₂ O ₃
			Bottom section	Top section		
<u>Perturbing medium</u>						
Material	Vicor glass	Pyrex glass	Pyrex glass	Vicor glass	B ₄ C	Al ₂ O ₃
Diameter, cm	0.825 ± 0.002	0.830 ± 0.001	0.830 ± 0.001	0.825 ± 0.002	0.935 ± 0.001	0.933 ± 0.001
Length, cm	183.0 ± 0.3	188.0 ± 0.1	122.0 ± 0.1	61.0 ± 0.1	177.5 ± 2.0	177.8 ± 1.6
Mass, g	214.5 ± 0.5	225.4 ± 0.5	146.3 ± 0.3	71.5 ± 0.2	156.0 ± 0.1	130.0 ± 0.2
Analysis, wt %						
B ₂ O ₃	3.035	12.615 ± 0.007	12.615 ± 0.007	3.035	--	--
Boron	0.943	3.919	3.919	0.943	77.8	--
Carbon	--	--	--	--	20.8	--
Anhydrous B ₂ O ₃	--	--	--	--	0.1	--
Particle size, % 30-50 mesh	--	--	--	--	91.2	--
Al ₂ O ₃	--	--	--	--	--	>99
Water-soluble substances	--	--	--	--	--	<0.64
Alkalies and earths	--	--	--	--	--	<0.14
Loss on ignition	--	--	--	--	--	<0.3
<u>Cladding</u>						
Material	6061 Al	None	6061 Al		6061 Al	6061 Al
Diameter, cm	1.115 ± 0.001		1.115 ± 0.001		1.113 ± 0.001	1.111 ± 0.001
Thickness, cm	0.090 ± 0.000		0.090 ± 0.000		0.089 ± 0.001	0.089 ± 0.000

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 CNSC core were 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 were spaced according to selected patterns in an otherwise uniform clean lattice to study their effects on reactivity and power shape.

Two kinds of data were 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 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 year, the exact moderator boron concentration for the just-critical condition was established for the core loadings diagrammed in Figures 3-1 through 3-11. Data from these loadings are presented in Table 3-1. All measurements reported were taken with all safety blades fully withdrawn.

3.3. Effect of Moderator Boron Concentration on Critical Moderator Height

The $\Delta\rho/\Delta H$ data from Table 3-1, which corresponds to an average moderator height below 150 cm, have been fitted to a linearized form of the equation

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

For Core XV, c and λ have been determined to have values of 5.54×10^6 cents/cm² and 11.8 cm, respectively. A similar fit of Core XVI data gives 8.11×10^6 cents/cm² and -5.6 cm.

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

$$\rho = \frac{c/2}{(H - \lambda)^2} \bigg|_{H_1}^{H_2} = 91 \pm 4 \text{ cents}. \quad (2)$$

Three percent of the estimated uncertainty on this value is attributed to uncertainty in the experimental measurements of $\delta\rho/\delta H$. The additional 1% is for error in the least-squares fit.

Since the only other difference between runs 2001 and 2003 is 77 ± 4 ppm of moderator boron, we conclude that $\delta\rho/\delta B$ is 1.18 ± 0.08 cents/ppm for Core XV.

Similar calculations show the reactivity difference between runs 2189 and 2193 of Core XVI is 47 ± 2 cents or 29 ± 4 ppm of moderator boron. Thus, we conclude that $\delta\rho/\delta B$ is 1.62 ± 0.23 cents/ppm for Core XVI. The difference between this value and the value obtained for Core XV is probably not statistically significant since the two values lie well within two standard deviations.

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, $\delta B/\delta H$ averages about 1.3 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 cm. Adjusted values are presented in Table 3-2.

3.5. Power Profile Measurements

Midplane relative power profiles were measured and compared in each of two symmetric one-eighth sections of the central 15 by 15 arrays of cores XV-C1, XV-C2, XVI-B1, XVI-B2, XVI-D1, and XVI-D2. Axial power profiles were measured in selected symmetric locations of cores XV-D2 and XV-D3. Results of the power profile measurements are tabulated in Tables 3-3 through 3-7. The percentages listed in the tables are standard deviations from the averages of symmetric locations. The deviations from the average generally varied from about 0.1 to 2%; however, deviations up to about 8% did occur, especially near the extremes of the fuel rods. These probably resulted from variations in the fuel loading and end caps of the rods being scanned.

The relative power profiles within the cores were determined by counting collimated fission product gammas from activated fuel rods with a NaI(Tl) scintillation counter. Gamma photons with less than 250 KeV were discriminated out. The collimator consisted of a 0.5-inch-wide by 1-inch-long slot in a 2.5-inch-thick lead shield placed between the fuel rod and the detector so that only the gammas from a 0.5-inch segment of the rod were counted. The detector was surrounded by at least 4 inches of lead, and other portions of the fuel rod were shielded from the detector by at least another 5 inches of lead. The rods were rotated while being counted to provide data that were independent of rod orientation.

So that all fuel rod activations could be performed at a constant moderator height, the boron concentration was adjusted to make the assembly critical at a moderator height of about 156 cm. Activations were then made on an exponential period obtained by raising the moderator height to 159.7 ± 0.1 cm. The integrated exposure was approximately 1 kW-minute. Counting time varies from 8 to 50 seconds, and the total count collected at each rod position varies from 60,000 to 80,000 counts. Background activity is kept low by always loading essentially unirradiated fuel rods in the positions to be studied.

Decay corrections were obtained from a "master" fuel rod, irradiated simultaneously with the rods to be scanned and then counted in a second counting system. The second system was identical to the first in collimation and electronics. Counts were taken on the two systems simultaneously, and the master rod was never moved during the data acquisition of a given run. A

standard fuel rod, recounted at frequent intervals, provided data to correct for any small changes in either system.

An auxiliary experiment was performed to determine whether activation of the stainless steel fuel rod cladding would significantly interfere with profile measurements made as outlined above. For this determination, an aluminum-clad fuel rod was irradiated along with a stainless steel-clad rod, and the activities of both were followed simultaneously following shutdown with the two identical counting systems. Measurements were taken over the interval of 30 minutes to 4 hours following shutdown. The ratio of activity recorded by the two counting systems remained within 1% of its average over the entire counting interval, thus proving interference from cladding activation to be negligible.

Table 3-1. Core Loading Studied

Core	Run	Moderator boron conc, ppm	Moderator ht, cm		Doubling time, s	Δp , c	ΔH cm	$\bar{H}$, cm	$\Delta p/\Delta H$	$(\Delta p/\Delta H)^{-1/3}$
			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
XV-2	2068	1743.1	159.90	165.88	71	9.1	5.98	162.9	1.52	0.870
XV-A1	2073	1583.8	159.68	165.18	73	8.9	5.50	162.4	1.62	0.851
XV-B1	2077	1438.6	159.16	164.86	69	9.3	5.70	162.0	1.63	0.850
XV-C1	2079	1376.6	159.76	165.87	56.5	10.8	6.11	162.8	1.77	0.827
XV-D1	2085	1314.6	159.76	165.18	73	8.9	5.42	162.5	1.64	0.848
XV-D2	2089	1336.2	159.85	164.56	37	14.8	4.71	162.2	3.14 ^(a)	0.683 ^(a)
XV-E2	2101	1348.5	159.60	165.10	70	9.2	5.50	162.4	1.67	0.843
XV-E1	2106	1128.7	159.58	164.39	84	7.9	4.81	162.0	1.64	0.848
XVI-A2	2127	1932.5	160.16	166.85	68	9.4	6.69	163.5	1.41	0.892
XVI-A1	2134	1824.9	159.52	167.78	50.5	11.8	8.26	163.6	1.43	0.888
XVI-B2	2139	1645.5	159.61	165.15	78	8.4	5.54	162.4	1.52	0.870
XVI-B1	2155	1551.4	159.70	167.48	51.5	11.7	7.78	163.6	1.50	0.874
XVI-C2	2166	1513.5	159.29	167.00	53	11.3	7.71	163.1	1.47	0.879
XVI-C1	2164	1439.3	159.77	167.59	49.5	11.9	7.82	163.7	1.52	0.870
XVI-D2 ^(b)	2169	1385.2	159.90	166.55	62	10.1	6.65	163.2	1.52	0.870
XVI-D1	2180	1334.4	159.38	167.26	50	11.9	7.88	163.3	1.51	0.872
XVI-D1	2189	1317.9	150.16	154.93	65.5	9.7	4.77	152.5	2.03	0.790
XVI-D1	2190	1304.9	140.74	145.33	52.5	11.4	4.59	143.0	2.48	0.739
XVI-D1	2192	1266.3	121.85	124.29	69	9.3	2.44	123.1	3.81	0.640
XVI-D1	2193	1288.7	131.96	134.51	87	7.7	2.55	133.2	3.02	0.692
XVI-E1	2199	1081.4	160.36	167.54	61	10.2	7.18	164.0	1.42	0.890
XVI-D1	2201	1328.4	159.55	167.30	54.5	11.1	7.75	163.4	1.43	0.888
XVI-B2	2207	1641.4	160.36	167.54	61	10.2	7.18	164.0	1.42	0.890

(a) The large difference from similar measurements results from zone-loaded pins.

(b) Also designated XVI-E2.

Table 3-2. Core Loadings Adjusted to 160-cm Critical Moderator Height

Core	No. of fuel rods	No. of positions						Moderator boron conc, ppm	Change in boron conc, ppm
		Water- filled	Al ₂ O ₃ - filled	Pyrex- filled	Vicor- filled	Zone- filled	B ₄ C- filled		
XV-1	1433	0	0	0	0	0	0	1899	
XV-2	1408	0	0	0	0	0	0	1750, 1743	152.5
XV-A1	1400	25	0	8	0	0	0	1584	
XV-A2	1400	25	8	0	0	0	0	1715	131
XV-B1	1392	25	0	16	0	0	0	1440	
XV-B2	1392	25	16	0	0	0	0	1686	246
XV-C1	1388	25	0	20	0	0	0	1377	
XV-C2	1388	25	20	0	0	0	0	1671	294
XV-D1	1384	25	0	24	0	0	0	1315	
XV-D2	1384	25	0	0	0	24	0	1336	21
XV-D3	1384	25	24	0	0	0	0	1652	337
XV-E1	1236	73	0	28	96	0	0	1129	
XV-E2	1236	73	96	28	0	0	0	1349	220
XV1-A1	4204	201	0	72	0	0	24	1826	
XV1-A2	4204	225	0	72	0	0	0	1952	126
XV1-B1	4132	201	0	144	0	0	24	1552	
XV1-B2	4132	225	0	144	0	0	0	1646, 1642	92
XV1-C1	4096	201	0	180	0	0	24	1440	
XV1-C2	4096	225	0	180	0	0	0	1515	75
XV1-D1	4060	201	0	216	0	0	24	1335, 1328	
XV1-D2	4060	225	0	216	0	0	0	1385	53.5
XV1-E1	4060	129	0	216	0	0	96	1081, 1082	
XV1-E2	4060	225	0	216	0	0	0	1385	303.5

Table 3-3. Midplane Power Profile for Core XV-C
Relative to Fuel Rod in Location E15

Locations	Avg of symmetric locations in core XV-C1	Avg of symmetric locations in core XV-C2
N1, S1	1.487 ± 2.3%	1.996 ± 0.7%
N1W1, S1E1	1.423 ± 0.4%	1.869 ± 0.5%
N2W1, S2E1	1.503 ± 0.3%	2.004 ± 0.3%
N3, S3	1.452 ± 0.4%	1.931 ± 0.3%
N3W1, S3E1	1.562 ± 0.2%	1.988 ± 0.1%
N3W2, S3E2	1.564 ± 0.1%	2.040 ± 0.3%
N4, S4	1.659 ± 0.4%	2.050 ± 0.9%
N4W2, S4E2	1.575 ± 0.3%	1.939 ± 0.2%
N4W3, S4E3	1.514 ± 0.5%	1.989 ± 0.5%
N4W4, S4E4	1.519 ± 0.5%	1.834 ± 0.1%
N5, S5	1.456 ± 1.0%	1.807 ± 0.5%
N5W1, S5E1	1.516 ± 0.5%	1.953 ± 0.1%
N5W2, S5E2	1.563 ± 0.4%	1.868 ± 1.9%
N5W4, S5E4	1.676 ± 0.2%	1.932 ± 0.7%
N6, S6	1.286 ± 0.7%	1.806 ± 0.8%
N6W2, S6E2	1.379 ± 1.2%	1.720 ± 0.4%
N6W3, S6E3	1.498 ± 0.7%	1.748 ± 0.1%
N6W4, S6E4	1.453 ± 0.1%	1.656 ± 0.4%
N6W5, S6E5	1.466 ± 2.4%	1.783 ± 1.4%
N7, S7	1.266 ± 0.2%	1.584 ± 1.0%
N7W1, S7E1	1.277 ± 2.2%	1.644 ± 1.7%
N7W2, S7E2	1.310 ± 1.7%	1.566 ± 1.6%
N7W3, S7E3	1.343 ± 1.7%	1.513 ± 0.1%
N7W4, S7E4	1.329 ± 0.1%	1.469 ± 0.6%
N7W5, S7E5	1.308 ± 1.8%	1.514 ± 2.7%
N7W6, S7E6	1.267 ± 3.5%	1.556 ± 1.3%
N7W7, S7E7	1.256 ± 1.6%	1.390 ± 1.5%

Table 3-4. Axial Power Profile in Selected Locations of Core
XV-D2 — Average of Symmetric Locations

Distance from base plate, cm	N1W0, S1E0	N3W0, S3E0	N5W0, S5E0	N9W0, S9E0	N13W0, S13E0	N18W0, S18E0	N3W2, S3E2	N5W2, S5E2	N5W4, S5E4
154.58	0.539 (0.2%)	0.544 (1.0%)	0.514 (1.3%)	0.424 (0.7%)	0.358 (0.1%)	0.226 (0.2%)	0.570 (1.0%)	0.546 (0.1%)	0.569 (2.5%)
144.42	0.952 (0.3%)	0.940 (1.2%)	0.908 (0.8%)	0.744 (0.3%)	0.624 (1.1%)	0.398 (0.1%)	0.992 (0.3%)	0.951 (0.1%)	1.000 (1.8%)
134.26	1.254 (0.1%)	1.226 (0.2%)	1.194 (0.1%)	0.985 (0.8%)	0.818 (0.7%)	0.526 (0.3%)	1.301 (0.7%)	1.244 (0.2%)	1.320 (0.5%)
124.10	1.376 (0.4%)	1.343 (1.4%)	1.320 (0.3%)	1.133 (0.0%)	0.958 (1.2%)	0.630 (0.4%)	1.415 (0.1%)	1.374 (0.1%)	1.483 (0.1%)
113.94	1.386 (1.4%)	1.340 (2.1%)	1.338 (1.0%)	1.220 (0.4%)	1.044 (0.0%)	0.691 (0.0%)	1.414 (0.3%)	1.383 (0.1%)	1.560 (0.7%)
103.78	1.434 (0.7%)	1.394 (1.5%)	1.396 (0.1%)	1.254 (0.9%)	1.102 (0.5%)	0.732 (0.2%)	1.460 (0.5%)	1.452 (0.4%)	1.628 (0.6%)
93.62	1.448 (0.1%)	1.422 (1.1%)	1.414 (0.5%)	1.282 (0.6%)	1.126 (0.9%)	0.741 (0.0%)	1.492 (0.2%)	1.476 (0.7%)	1.650 (0.5%)
83.46	1.424 (0.4%)	1.414 (1.0%)	1.392 (0.6%)	1.264 (0.2%)	1.118 (2.0%)	0.727 (0.1%)	1.460 (0.4%)	1.455 (0.6%)	1.616 (0.5%)
73.30	1.366 (0.1%)	1.346 (1.2%)	1.315 (0.7%)	1.196 (0.0%)	1.054 (1.3%)	0.698 (0.2%)	1.390 (0.0%)	1.378 (0.9%)	1.527 (0.8%)
63.14	1.264 (0.3%)	1.249 (0.2%)	1.220 (0.0%)	1.115 (0.5%)	0.975 (2.0%)	0.646 (0.5%)	1.290 (1.3%)	1.278 (0.0%)	1.418 (0.0%)
52.98	1.136 (0.6%)	1.120 (0.3%)	1.098 (0.0%)	0.998 (0.3%)	0.874 (3.1%)	0.574 (0.3%)	1.149 (0.9%)	1.156 (0.3%)	1.290 (2.0%)
42.82	0.966 (0.3%)	0.949 (0.3%)	0.932 (0.4%)	0.849 (0.8%)	0.746 (4.0%)	0.486 (0.6%)	0.978 (1.3%)	0.980 (0.3%)	1.097 (0.8%)
32.66	0.760 (0.3%)	0.742 (0.2%)	0.734 (0.9%)	0.668 (1.0%)	0.584 (3.6%)	0.378 (0.4%)	0.754 (0.5%)	0.776 (0.9%)	0.871 (2.1%)
22.50	0.533 (0.0%)	0.518 (0.5%)	0.510 (1.9%)	0.466 (0.5%)	0.415 (3.5%)	0.264 (2.1%)	0.528 (1.0%)	0.542 (1.0%)	0.610 (2.8%)

Table 3-5. Axial Power Profile in Selected Locations of Core
XV-D3 - Average of Symmetric Locations

Distance from base plate, cm	N1W0, S1E0	N3W0, S3E0	N5W0, S5E0	N9W0, S9E0	N13W0, S13E0	N18W0, S18E0	N3W2, S3E2	N5W2, S5E2	N5W4, S5E4
154.58	0.464 (0.8%)	0.467 (0.2%)	0.440 (0.8%)	0.325 (6.9)	0.258 (8.4)	0.162 (0.6%)	0.484 (2.1%)	0.474 (0.5%)	0.436 (8.0%)
144.42	0.830 (0.7%)	0.837 (0.1%)	0.786 (1.4%)	0.575 (2.5%)	0.467 (4.2%)	0.286 (0.5%)	0.874 (0.2%)	0.832 (0.5%)	0.804 (3.7%)
134.26	1.152 (0.0%)	1.158 (0.3%)	1.088 (1.2%)	0.794 (1.1%)	0.653 (3.0%)	0.400 (0.1%)	1.212 (0.2%)	1.162 (0.5%)	1.129 (2.6%)
124.10	1.429 (0.4%)	1.430 (0.0%)	1.350 (1.7%)	0.992 (1.2%)	0.808 (2.6%)	0.496 (0.7%)	1.504 (0.2%)	1.434 (0.5%)	1.418 (2.1%)
113.94	1.658 (0.3%)	1.656 (0.4%)	1.574 (1.1%)	1.150 (1.4%)	0.943 (1.6%)	0.576 (0.9%)	1.736 (0.3%)	1.662 (0.2%)	1.647 (2.2%)
103.78	1.822 (0.5%)	1.816 (0.2%)	1.736 (0.6%)	1.276 (0.8%)	1.032 (1.3%)	0.634 (1.0%)	1.906 (0.9%)	1.828 (0.5%)	1.804 (1.6%)
93.62	1.938 (0.6%)	1.910 (0.0%)	1.833 (0.2%)	1.344 (0.1%)	1.106 (0.2%)	0.671 (0.8%)	2.006 (0.7%)	1.932 (0.3%)	1.909 (0.6%)
83.46	1.974 (0.1%)	1.934 (0.2%)	1.860 (0.3%)	1.386 (0.5%)	1.126 (1.0%)	0.688 (0.3%)	2.040 (0.5%)	1.968 (0.3%)	1.950 (0.2%)
73.30	1.924 (0.1%)	1.884 (0.2%)	1.806 (0.9%)	1.359 (0.2%)	1.106 (1.6%)	0.679 (0.1%)	1.974 (0.7%)	1.914 (0.1%)	1.916 (0.0%)
63.14	1.816 (0.7%)	1.783 (1.8%)	1.714 (1.2%)	1.282 (1.0%)	1.040 (1.7%)	0.645 (0.9%)	1.868 (1.2%)	1.818 (0.0%)	1.808 (0.7%)
52.98	1.650 (0.8%)	1.628 (1.1%)	1.557 (2.2%)	1.187 (0.3%)	0.964 (3.3%)	0.580 (1.1%)	1.704 (0.9%)	1.658 (0.2%)	1.652 (1.1%)
42.82	1.415 (0.6%)	1.381 (1.4%)	1.320 (0.7%)	1.018 (0.0%)	0.830 (3.9%)	0.497 (1.2%)	1.456 (1.5%)	1.416 (0.3%)	1.412 (2.0%)
32.66	1.118 (0.5%)	1.105 (0.8%)	1.073 (1.8%)	0.822 (0.8%)	0.668 (5.2%)	0.400 (1.3%)	1.149 (2.6%)	1.120 (1.4%)	1.130 (1.8%)
22.50	0.790 (1.5%)	0.787 (0.9%)	0.757 (1.3%)	0.592 (1.7%)	0.481 (6.7%)	0.280 (1.6%)	0.817 (2.9%)	0.792 (0.7%)	0.802 (3.4%)

Table 3-6. Midplane Power Profile for Core XVI-B
Relative to Fuel Rod in Location E25

Locations	Avg of symmetric locations in core XVI-B1	Avg of symmetric locations in core XVI-B2
N1, S1	0.496 ± 1.1%	1.076 ± 1.9%
N1W1, S1E1	0.446 ± 0.6%	1.036 ± 0.7%
N2W1, S2E1	0.402 ± 1.0%	1.117 ± 0.3%
N3, S3	0.408 ± 1.0%	1.105 ± 0.3%
N3W1, S3E1	0.390 ± 1.0%	1.153 ± 0.4%
N3W2, S3E2	0.394 ± 0.4%	1.160 ± 1.3%
N4, S4	0.392 ± 0.4%	1.228 ± 0.6%
N4W2, S4E2	0.406 ± 0.0%	1.156 ± 1.1%
N4W3, S4E3	0.416 ± 0.6%	1.140 ± 1.2%
N4W4, S4E4	0.431 ± 2.1%	1.142 ± 1.5%
N5, S5	0.472 ± 0.7%	1.088 ± 0.6%
N5W1, S5E1	0.457 ± 0.7%	1.132 ± 0.2%
N5W2, S5E2	0.452 ± 1.3%	1.152 ± 0.1%
N5W4, S5E4	0.434 ± 0.7%	1.243 ± 0.2%
N6W1, S6E1	0.550 ± 0.0%	1.030 ± 0.1%
N6W2, S6E2	0.536 ± 0.1%	1.039 ± 0.8%
N6W3, S6E3	0.520 ± 1.6%	1.129 ± 1.0%
N6W4, S6E4	0.535 ± 0.6%	1.096 ± 1.2%
N6W5, S6E5	0.556 ± 0.4%	1.134 ± 1.2%
N7, S7	0.600 ± 0.7%	0.942 ± 0.3%
N7W1, S7E1	0.606 ± 0.2%	0.986 ± 0.3%
N7W2, S7E2	0.612 ± 0.6%	1.003 ± 0.1%
N7W3, S7E3	0.620 ± 1.4%	0.997 ± 0.3%
N7W4, S7E4	0.631 ± 1.0%	0.998 ± 2.9%
N7W5, S7E5	0.649 ± 2.0%	1.028 ± 1.1%
N7W6, S7E6	0.698 ± 3.9%	1.001 ± 1.2%
N7W7, S7E7	0.690 ± 1.7%	0.975 ± 1.2%

Table 3-7. Midplane Power Profile for Core XVI-D
Relative to Fuel Rod in Location E25

Locations	Avg of symmetric locations in core XVI-D1	Avg of symmetric locations in core XVI-D2
N1, S1	0.373 ± 0.3%	0.832 ± 2.5%
N1W1, S1E1	0.341 ± 0.6%	0.804 ± 0.3%
N2W1, S2E1	0.306 ± 1.3%	0.849 ± 0.4%
N3, S3	0.318 ± 0.8%	0.855 ± 2.4%
N3W1, S3E1	0.304 ± 1.5%	0.874 ± 0.7%
N3W2, S3E2	0.306 ± 0.7%	0.884 ± 0.7%
N4, S4	0.307 ± 0.7%	0.922 ± 1.4%
N4W2, S4E2	0.314 ± 1.8%	0.878 ± 2.2%
N4W3, S4E3	0.326 ± 0.0%	0.884 ± 1.4%
N4W4, S4E4	0.343 ± 1.2%	0.868 ± 1.2%
N5, S5	0.368 ± 1.0%	0.828 ± 3.2%
N5W1, S5E1	0.356 ± 0.1%	0.850 ± 1.1%
N5W2, S5E2	0.348 ± 2.5%	0.878 ± 0.5%
N5W4, S5E4	0.352 ± 1.6%	0.966 ± 0.1%
N6W1, S6E1	0.422 ± 0.1%	0.750 ± 2.5%
N6W3, S6E3	0.410 ± 0.9%	0.853 ± 0.0%
N6W4, S6E4	0.432 ± 0.1%	0.832 ± 0.0%
N6W5, S6E5	0.442 ± 0.3%	0.880 ± 0.9%
N7, S7	0.474 ± 1.8%	0.746 ± 0.0%
N7W1, S7E1	0.479 ± 0.2%	0.742 ± 1.1%
N7W2, S7E2	0.485 ± 0.6%	0.752 ± 0.0%
N7W3, S7E3	0.494 ± 0.1%	0.778 ± 0.4%
N7W4, S7E4	0.508 ± 0.7%	0.786 ± 0.5%
N7W5, S7E5	0.530 ± 1.0%	0.787 ± 0.4%
N7W6, S7E6	0.544 ± 0.3%	0.768 ± 1.3%
N7W7, S7E7	0.580 ± 0.4%	0.770 ± 1.9%

Figure 3-1. Core XV Loading Diagram

X indicates 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 Loading Diagram

o indicates water-filled positions (25 total).

X indicates positions where content is varied (8 total).

<u>Core</u>	<u>Content of X positions</u>
XV-A1	Pyrex
XV-A2	Neutral

Figure 3-3. Core XV-B Loading Diagram

o indicates water-filled positions (25 total).

X indicates positions where content is varied (16 total).

<u>Core</u>	<u>Content of X positions</u>
XV-B1	Pyrex
XV-B2	Neutral

Figure 3-4. Core XV-C Loading Diagram

o indicates water-filled positions (25 total).

X indicates positions where content is varied (20 total).

<u>Core</u>	<u>Content of X positions</u>
XV-C1	Pyrex
XV-C2	Neutral

Figure 3-5. Core XV-D Loading Diagram

o indicates water-filled positions (25 total).

X indicates positions where content is varied (24 total).

<u>Core</u>	<u>Content of X positions</u>
XV-D1	Pyrex
XV-D2	Zone-loaded
XV-D3	Neutral

Figure 3-6. Core XV-E Loading Diagram

- indicates pyrex-filled positions (28 total).
- indicates water-filled positions (73 total).
- X indicates positions where content is varied (96 total).

<u>Core</u>	<u>Content of X positions</u>
XV-E1	Vicor
XV-E2	Neutral

Figure 3-7. Core XVI-A Loading Diagram

- Pyrex-filled positions (72 total)
- ◊ Water-filled positions (201 total)
- x Positions where content is varied (24 total)

<u>Core</u>	<u>Contents of x positions</u>
XVI-A1	B ₄ C
XVI-A2	Water

Figure 3-8. Core XVI-B Loading Diagram

- Pyrex-filled positions (144 total)
- Water-filled positions (201 total)
- x Positions where content is varied (24 total)

<u>Core</u>	<u>Contents of x positions</u>
XVI-B1	B ₄ C
XVI-B2	Water

Figure 3-9. Core XVI-C Loading Diagram

- Pyrex-filled positions (180 total)
- Water-filled positions (201 total)
- x Positions where content is varied (24 total)

<u>Core</u>	<u>Contents of x positions</u>
XVI-C1	B ₄ C
XVI-C2	Water

Figure 3-10. Core XVI-D Loading Diagram

- Pyrex-filled positions (216 total)
- o Water-filled positions (201 total)
- x Positions where content is varied (24 total)

<u>Core</u>	<u>Contents of x positions</u>
XVI-D1	B ₄ C
XVI-D2	Water

Figure 3-11. Core XVI-E Loading Diagram

- Pyrex-filled positions (216 total)
- Water-filled positions (129 total)
- × Positions where content is varied (96 total)

<u>Core</u>	<u>Contents of × positions</u>
XVI-E1	B ₄ C
XVI-E2	Water

REFERENCES

- ¹ M. N. Baldwin, Physics Verification Program - Part IV, Task 1, Quarterly Technical Report, December 1974 - March 1975, BAW-3647-34, Babcock & Wilcox, Lynchburg, Virginia, May 1975.
- ² M. N. Baldwin, Physics Verification Program - Part IV, Task 1, Quarterly Technical Report, April-June 1975, BAW-3647-35, Babcock & Wilcox, Lynchburg, Virginia, August 1975.
- ³ M. N. Baldwin, Physics Verification Program - Part IV, Task 1, Quarterly Technical Report, July-September 1975, BAW-3647-36, Babcock & Wilcox, Lynchburg, Virginia, January 1976.
- ⁴ R. H. Clark, et al., Physics Verification Program - Part I, Final Report, BAW-3647-3, Babcock & Wilcox, Lynchburg, Virginia, March 1967.
- ⁵ M. N. Baldwin, R. H. Clark, and J. E. Rogers, Physics Verification Program - Part II, Final Report, BAW-3647-7, Babcock & Wilcox, Lynchburg, Virginia, April 1968.
- ⁶ M. N. Baldwin and M. E. Stern, Physics Verification Program - Part III, Task 1, Final Report, BAW-3647-13, Babcock & Wilcox, Lynchburg, Virginia, July 1969.
- ⁷ M. N. Baldwin, et al., Physics Verification Program - Part III, Tasks 2 and 3, Final Report, BAW-3647-16, Babcock & Wilcox, Lynchburg, Virginia, April 1970.
- ⁸ M. N. Baldwin and M. E. Stern, Physics Verification Program - Part III, Task 4, Summary Report, BAW-3647-20, Babcock & Wilcox, Lynchburg, Virginia, March 1971.
- ⁹ M. N. Baldwin and G. T. Fairburn, Physics Verification Program - Part III Tasks 5, 6, and 7, Summary Report, BAW-3647-24, Babcock & Wilcox, Lynchburg, Virginia, March 1972.

- ¹⁰ M. N. Baldwin, et al., Physics Verification Program — Part III, Tasks 8, 9, 10, and 11, Summary Report, BAW-3647-33, Babcock & Wilcox, Lynchburg, Virginia, October 1975.
- ¹¹ R. M. Ball, et al., NMSR-MARTY Critical Experiments — Summary of 4% Enriched UO₂ Cores Studied, BAW-1216, Babcock & Wilcox, Lynchburg, Virginia, May 1961.
- ¹² T. C. Engelder, et al., SSCR Basic Physics — Critical Experiments on Lattices Moderated by D₂O-H₂O Mixtures, BAW-1231, Babcock & Wilcox, Lynchburg, Virginia, December 1961.
- ¹³ R. H. Clark, et al., Lumped Burnable Poison Program — Final Report, BAW-3492-1, Babcock & Wilcox, Lynchburg, Virginia, January 1966.

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