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PART IV, TASK 1.³

Quarterly Technical Report,
April-June 1975

by

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 during the second calendar quarter of 1975. The work performed during the first quarter is reported in reference 1, and completed phases of the program are summarized in references 2 through 8. The program is jointly supported by Babcock & Wilcox and the Energy Research and Development Administration (ERDA).

2. DESCRIPTION OF FACILITY

2.1. Facility

The CX-10 facility is located at B&W's Lynchburg Research Center. The critical assembly is erected in a 5-foot-diameter by 6.5-foot-high core tank having 0.5-inch-thick aluminum walls. The facility is described further in reference 1.

2.2. Fuel Rods

The fuel rods are 0.475 inch in outside diameter by approximately 71.5 inches long. The cladding is 0.016-inch-thick type 304 stainless steel, and the UO_2 fuel is enriched to 4.02 wt % ^{235}U . The fuel is described further in reference 1.

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&W⁶⁻⁹ but are restated here and in Table 2-1 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 linear density of 1.07 g/cm³.

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.

Table 2-1. 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	
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	6161 Al	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 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 3-6. 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. Numerical Adjustment of Boron Concentration

The moderator boron concentration of each core was adjusted (as described in reference 1) to produce a just-critical condition at a moderator height of 160.0 cm. Adjusted values are presented in Table 3-2 for each loading studied during the quarter.

3.4. Power Profile Measurements

The midplane relative power densities over each of two one-eighth sections of the central 15 by 15 array of core XV-C were obtained and compared. Relative power density is determined 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.

Axial relative power densities over each of two one-eighth sections of cores XV-D2 and XV-D3 were also obtained and compared. The measured values are presented in Tables 3-4, 3-5, 3-7, and 3-8. The symmetric locations are compared in terms of standard deviations from the average in Tables 3-6 and 3-9.

Table 3-1. Core Loadings Studied During Second Quarter

Core	Run	Moderator boron conc, ppm	Moderator height, 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-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

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

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

Core	No. of fuel rods	No. of positions					Moderator boron conc, ppm
		Water-filled	Al ₂ O ₃ -filled	Pyrex-filled	Vicor-filled	Zone-filled	
XV-2	1408	25	0	0	0	0	1743 ^(a)
XV-A1	1400	25	0	8	0	0	1584
XV-B1	1392	25	0	16	0	0	1440
XV-C1	1388	25	0	20	0	0	1377
XV-D1	1384	25	0	24	0	0	1315
XV-D2	1384	25	0	0	0	24	1336
XV-E2	1236	73	96	28	0	0	1349
XV-E1	1236	73	0	28	96	0	1129

(a) This is a repeat run of a core reported last quarter and is indicative of the repeatability of a core loading.

Table 3-3. Midplane Power Profile - Core XV-C1

Northwest segment				Southeast segment				Avg of symmetric locations	Standard deviation, %
Location	Runs 2081 and 2082	Runs 2080 and 2083	Average	Location	Runs 2081 and 2082	Runs 2080 and 2083	Average		
N1	1.466	1.442	1.454	S1	1.527	1.513	1.520	1.487	2.3
N1W1	1.429	1.425	1.427	S1E1	1.421	1.415	1.418	1.423	0.4
N2W1	1.500	1.498	1.499	S2E1	1.533	1.480	1.507	1.503	0.3
N3	1.458	1.435	1.446	S3	1.465	1.450	1.458	1.452	0.4
N3W1	1.570	1.559	1.565	S3E1	1.572	1.546	1.559	1.562	0.2
N3W2	1.562	1.562	1.562	S3E2	1.562	1.567	1.565	1.564	0.1
N4	1.681	1.649	1.665	S4	1.646	1.659	1.653	1.659	0.4
N4W2	1.596	1.564	1.580	S4E2	1.576	1.564	1.570	1.575	0.3
N4W3	1.533	1.480	1.507	S4E3	1.543	1.497	1.520	1.514	0.5
N4W4	1.524	1.526	1.525	S4E4	1.514	1.509	1.512	1.519	0.5
N5	1.481	1.458	1.470	S5	1.458	1.423	1.441	1.456	1.0
N5W1	1.523	1.524	1.524	S5E1	1.538	1.480	1.509	1.516	0.5
N5W2	1.558	1.554	1.556	S5E2	1.588	1.549	1.569	1.563	0.4
N5W4	1.684	1.660	1.672	S5E4	1.707	1.650	1.679	1.676	0.2
N6	1.289	1.301	1.295	S6	1.272	1.281	1.277	1.286	0.7
N6W2	1.337	1.389	1.363	S6E2	1.357	1.430	1.394	1.379	1.2
N6W3	1.465	1.510	1.488	S6E3	1.496	1.520	1.508	1.498	0.7
N6W4	1.477	1.431	1.454	S6E4	1.462	1.441	1.452	1.453	0.1
N6W5	1.444	1.420	1.432	S6E5	1.501	1.501	1.501	1.466	2.4
N7	1.246	1.281	1.264	S7	1.263	1.273	1.268	1.266	0.2
N7W1	1.271	1.228	1.250	S7E1	1.301	1.308	1.305	1.277	2.2
N7W2	1.264	1.311	1.288	S7E2	1.318	1.344	1.331	1.310	1.7
N7W3	1.305	1.337	1.321	S7E3	1.349	1.381	1.365	1.343	1.7
N7W4	1.309	1.350	1.330	S7E4	1.339	1.318	1.329	1.329	0.1
N7W5	1.342	1.322	1.332	S7E5	1.295	1.275	1.285	1.308	1.8
N7W6	1.300	1.320	1.310	S7E6	1.187	1.260	1.224	1.267	3.5
N7W7	1.227	1.325	1.276	S7E7	1.227	1.244	1.236	1.256	1.6

Table 3-4. Relative Power Profile Within Northwest
Quadrant of Core XV-D2

Distance from base plate, cm	Distance from core center, pin pitches north and west								
	N1W0	N3W0	N5W0	N9W0	N13W0	N18W0	N3W2	N5W2	N5W4
154.58	0.538	0.549	0.507	0.427	0.359	0.225	0.565	0.547	0.555
144.42	0.955	0.951	0.901	0.746	0.630	0.398	0.989	0.950	0.982
134.26	1.256	1.224	1.193	0.993	0.824	0.528	1.292	1.242	1.313
124.10	1.382	1.325	1.316	1.133	0.969	0.632	1.416	1.373	1.481
113.94	1.404	1.313	1.324	1.225	1.044	0.691	1.418	1.385	1.549
103.78	1.444	1.374	1.394	1.265	1.096	0.731	1.467	1.446	1.618
93.62	1.447	1.406	1.406	1.289	1.116	0.741	1.494	1.465	1.642
83.46	1.419	1.399	1.383	1.267	1.096	0.728	1.467	1.446	1.608
73.30	1.365	1.330	1.306	1.196	1.041	0.699	1.391	1.366	1.525
63.14	1.261	1.251	1.220	1.120	0.956	0.649	1.307	1.278	1.418
52.98	1.129	1.116	1.097	1.001	0.847	0.575	1.159	1.152	1.315
42.82	0.963	0.946	0.936	0.856	0.717	0.489	0.990	0.982	1.106
32.66	0.762	0.744	0.740	0.675	0.563	0.380	0.750	0.783	0.889
22.50	0.533	0.520	0.520	0.469	0.401	0.269	0.523	0.547	0.626

Table 3-5. Relative Power Profile Within Southeast
Quadrant of Core XV-D2

Distance from base plate, cm	Distance from core center, pin pitches south and east								
	S1E0	S3E0	S5E0	S9E0	S13E0	S18E0	S3E2	S5E2	S5E4
154.58	0.540	0.538	0.520	0.421	0.358	0.226	0.576	0.546	0.583
144.42	0.949	0.929	0.915	0.742	0.617	0.397	0.995	0.952	1.017
134.26	1.253	1.229	1.195	0.977	0.812	0.525	1.310	1.246	1.326
124.10	1.370	1.361	1.324	1.133	0.947	0.627	1.414	1.376	1.485
113.94	1.367	1.368	1.351	1.216	1.043	0.691	1.409	1.381	1.571
103.78	1.425	1.415	1.397	1.242	1.108	0.734	1.452	1.457	1.637
93.62	1.450	1.437	1.421	1.274	1.135	0.741	1.489	1.486	1.657
83.46	1.430	1.428	1.400	1.261	1.140	0.726	1.454	1.464	1.623
73.30	1.367	1.361	1.324	1.195	1.068	0.696	1.390	1.390	1.539
63.14	1.268	1.247	1.219	1.110	0.994	0.642	1.273	1.278	1.419
52.98	1.143	1.123	1.098	0.996	0.900	0.572	1.139	1.160	1.265
42.82	0.969	0.952	0.929	0.842	0.774	0.483	0.965	0.977	1.088
32.66	0.757	0.741	0.727	0.662	0.604	0.377	0.757	0.769	0.853
22.50	0.533	0.515	0.501	0.464	0.429	0.258	0.533	0.536	0.593

Table 3-6. Comparison of Symmetrical Locations Within
Core XV-D2 - % Standard Deviation From
Average

Distance from base plate, cm	Distance from core center, pin pitches north and west or south and east								
	<u>1,0</u>	<u>3,0</u>	<u>5,0</u>	<u>9,0</u>	<u>13,0</u>	<u>18,0</u>	<u>3,2</u>	<u>5,2</u>	<u>5,4</u>
154.58	0.2	1.0	1.3	0.7	0.1	0.2	1.0	0.1	2.5
144.42	0.3	1.2	0.8	0.3	1.1	0.1	0.3	0.1	1.8
134.26	0.1	0.2	0.1	0.8	0.7	0.3	0.7	0.2	0.5
124.10	0.4	1.4	0.3	0.0	1.2	0.4	0.1	0.1	0.1
113.94	1.4	2.1	1.0	0.4	0.0	0.0	0.3	0.1	0.7
103.78	0.7	1.5	0.1	0.9	0.5	0.2	0.5	0.4	0.6
93.62	0.1	1.1	0.5	0.6	0.9	0.0	0.2	0.7	0.5
83.46	0.4	1.0	0.6	0.2	2.0	0.1	0.4	0.6	0.5
73.30	0.1	1.2	0.7	0.0	1.3	0.2	0.0	0.9	0.8
63.14	0.3	0.2	0.0	0.5	2.0	0.5	1.3	0.0	0.0
52.98	0.6	0.3	0.0	0.3	3.1	0.3	0.9	0.3	2.0
42.82	0.3	0.3	0.4	0.8	4.0	0.6	1.3	0.3	0.8
32.66	0.3	0.2	0.9	1.0	3.6	0.4	0.5	0.9	2.1
22.50	0.0	0.5	1.9	0.5	3.5	2.1	1.0	1.0	2.8

Table 3-7. Relative Power Profile Within Southeast
Quadrant of Core XV-D3

Distance from base plate, cm	Distance from core center, pin pitches south and east								
	<u>S1E0</u>	<u>S3E0</u>	<u>S5E0</u>	<u>S9E0</u>	<u>S13E0</u>	<u>S18E0</u>	<u>S3E2</u>	<u>S5E2</u>	<u>S5E4</u>
154.58	0.461	0.466	0.437	0.304	0.238	0.163	0.494	0.471	0.469
144.42	0.824	0.838	0.775	0.561	0.448	0.287	0.872	0.828	0.833
134.26	1.152	1.161	1.075	0.785	0.634	0.401	1.210	1.157	1.158
124.10	1.435	1.430	1.327	0.980	0.788	0.493	1.501	1.427	1.446
113.94	1.663	1.663	1.558	1.135	0.928	0.571	1.730	1.659	1.682
103.78	1.830	1.820	1.725	1.266	1.018	0.628	1.888	1.820	1.833
93.62	1.950	1.910	1.830	1.342	1.104	0.666	1.992	1.926	1.921
83.46	1.976	1.930	1.865	1.379	1.138	0.686	2.030	1.962	1.953
73.30	1.923	1.887	1.822	1.356	1.123	0.678	1.959	1.912	1.916
63.14	1.803	1.752	1.735	1.270	1.058	0.639	1.845	1.818	1.796
52.98	1.637	1.610	1.590	1.184	0.995	0.573	1.688	1.656	1.634
42.82	1.407	1.362	1.330	1.018	0.862	0.491	1.435	1.420	1.385
32.66	1.123	1.096	1.092	0.828	0.701	0.395	1.120	1.135	1.110
22.50	0.801	0.780	0.767	0.602	0.511	0.275	0.794	0.797	0.775

Table 3-8. Relative Power Profile Within Northwest
Quadrant of Core XV-D3

Distance from base plate, cm	Distance from core center, pin pitches north and west								
	N1W0	N3W0	N5W0	N9W0	N13W0	N18W0	N3W2	N5W2	N5W4
154.58	0.468	0.468	0.444	0.304	0.278	0.161	0.474	0.476	0.404
144.42	0.836	0.836	0.797	0.561	0.486	0.284	0.876	0.837	0.775
134.26	1.151	1.154	1.101	0.785	0.672	0.400	1.214	1.168	1.100
124.10	1.423	1.430	1.373	0.980	0.829	0.500	1.506	1.442	1.389
113.94	1.652	1.649	1.591	1.135	0.958	0.581	1.742	1.666	1.612
103.78	1.813	1.813	1.747	1.266	1.045	0.640	1.923	1.837	1.775
93.62	1.927	1.910	1.836	1.342	1.109	0.676	2.019	1.939	1.897
83.46	1.971	1.938	1.855	1.379	1.115	0.690	2.051	1.974	1.947
73.30	1.926	1.880	1.790	1.356	1.088	0.680	1.988	1.915	1.915
63.14	1.830	1.814	1.693	1.270	1.023	0.651	1.890	1.817	1.820
52.98	1.662	1.646	1.524	1.284	0.933	0.586	1.720	1.661	1.671
42.82	1.423	1.400	1.311	1.018	0.799	0.503	1.478	1.412	1.440
32.66	1.112	1.114	1.054	0.828	0.635	0.405	1.178	1.105	1.151
22.50	0.778	0.794	0.747	0.602	0.451	0.284	0.840	0.786	0.828

Table 3-9. Comparison of Symmetrical Locations
Within Core XV-D3 - % Standard
Deviation From Average

Distance from base plate, cm	Distance from core center, pin pitches north and west or south and east								
	<u>1,0</u>	<u>3,0</u>	<u>5,0</u>	<u>9,0</u>	<u>13,0</u>	<u>18,0</u>	<u>3,2</u>	<u>5,2</u>	<u>5,4</u>
154.58	0.8	0.2	0.8	6.9	8.4	0.6	2.1	0.5	8.0
144.42	0.7	0.1	1.4	2.5	4.2	0.5	0.2	0.5	3.7
134.26	0.0	0.3	1.2	1.1	3.0	0.1	0.2	0.5	2.6
124.10	0.4	0.0	1.7	1.2	2.6	0.7	0.2	0.5	2.1
113.94	0.3	0.4	1.1	1.4	1.6	0.9	0.3	0.2	2.2
103.78	0.5	0.2	0.6	0.8	1.3	1.0	0.9	0.5	1.6
93.62	0.6	0.0	0.2	0.1	0.2	0.8	0.7	0.3	0.6
83.46	0.1	0.2	0.3	0.5	1.0	0.3	0.5	0.3	0.2
73.30	0.1	0.2	0.9	0.2	1.6	0.1	0.7	0.1	0.0
63.14	0.7	1.8	1.2	1.0	1.7	0.9	1.2	0.0	0.7
52.98	0.8	1.1	2.2	0.3	3.3	1.1	0.9	0.2	1.1
42.82	0.6	1.4	0.7	0.0	3.9	1.2	1.5	0.3	2.0
32.66	0.5	0.8	1.8	0.8	5.2	1.3	2.6	1.4	1.8
22.50	1.5	0.9	1.3	1.7	6.7	1.6	2.9	0.7	3.4

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

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