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WESTINGHOUSE ASTRONUCLEAR EXPERIMENTAL FACILITY

R-1 PARAMETRIC SHIELD STUDIES ON PAX:
REACTIVITY WORTH OF MOCKUP BORATED
ALUMINUM-TITANIUM HYDRIDE SHIELDS (U)

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R-1 PARAMETRIC SHIELD STUDIES ON PAX:
REACTIVITY WORTH OF MOCKUP BORATED
ALUMINUM-TITANIUM HYDRIDE SHIELDS (U)

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1. INTRODUCTION

One of the several objectives of the R-1 parametric shield⁽¹⁾ experiments performed on PAX-E5⁽²⁾ was to determine the effects on core reactivity produced by the addition of shield materials in slab form. Measurements were made on PAX by adding the material to the nozzle end of the reactor and mocking up the inlet region thereon. In particular, reactivity effects for the following simulated material regions⁽³⁾ were measured:

- a. Cluster plate
- b. Item a. + core support plate
- c. Item b. + inlet plena and dome pressure vessel (Configuration 4)
- d. Same as Item c. but with a flight shield mockup consisting of six standard modules⁽⁴⁾ of BATH materials located between the cluster plate and the support plate. (Configuration 7A)
- e. Same as Item c. but with a flight shield mockup consisting of six standard modules⁽⁴⁾ of BATH materials located between the support plate and the plena regions. (Configuration 7C)
- f. Same as Item d. but with a 1/4" layer of Boral added between the dome plena and pressure vessel regions. (Configuration 7B)
- g. Same as Item e. but with a 1/4" layer of Boral added between the dome plena and pressure vessel regions. (Configuration 7D)

(1) See Section IV of WANL-TME-1677, "WANEF Experimental Program CY'68"

(2) PAX-E5 is physically identical to PAX-E4 as described in WANL-TME-1739 (4) and WANL-TME-1758 (5).

(3) Drawing Numbers 939J300, 340 and 520, "R-1 Reactor Study Layout and Conceptual Shield Design Layouts".

(4) See Figure 5 for a description of a standard shield mockup module of BATH (borated aluminum-titanium hydride) material.

It is important to note that aluminum spacers 1/4" thick were placed at certain locations within the slab configurations. A typical spacer arrangement is shown in Figure 10 for Configuration 7A. The void content for other configurations is given in Table 1. Reactivity measurements were made by the period-pickoff technique. Detailed experimental run conditions are given in Table 2.

A summary of experimental results follows in Section 2. Section 3 gives more explanation of the experimental details and methods. Section 4 shows how the reported results were obtained from the measurements. Appendix 1 gives a more detailed breakdown of some intermediate configuration results.

This transmittal is in partial fulfillment of the required parametric data for preliminary R-1 shield mockup measurements. Other transmittals to follow will include radiation dosimetry data results and power distribution and calibration data.

2. SUMMARY OF RESULTS AND CONCLUSIONS

Several different arrangements of the above mentioned simulated shielding regions are designated as Configurations 1, 4, 4B, 7A, 7B and 7C (see Figures 6 through 9). The increases in reactivity for Configurations 4 through 7C relative to Configuration 1 (the bare core) are 49.45¢, 50.35¢, 45.74¢, 46.89¢ and 48.23¢, respectively. The uncertainty is about $\pm 0.6\%$ for all configurations. The detailed calculations by which these results were obtained are shown in Appendix 1.

3. EXPERIMENTAL METHODS AND DETAILS

The R-1 dome end mockup consists of several regions. They include the cluster plate, core support plate, inlet plenum, pressure vessel and the six standard modules of BATH material. The cluster plate was mocked up by two Boral discs 36" in diameter surrounded by two Boral rings of 36 inches I.D. and 48 inches O.D. with a total thickness of $3/8$ inch (see Figure 1), the core support plate and hydrogen coolant was mocked up by three $1-1/2$ inch thick aluminum plates and two $1/4$ inch thick polyethylene sheets (see Figure 2). The dome plenum region was mocked up by two $1/4$ inch plus two $1/8$ inch thick stainless steel plates, followed by three $1/4$ inch polyethylene sheets (see Figure 3). The pressure vessel was represented by ten $1/16$ inch thick aluminum sheets. Six standard modules were also employed to represent a typical R-1 shield region. Each module consists of one $1/8$ inch thick Inconel, two $1/8$ inch thick titanium, five $1/16$ inch thick aluminum, one $1/8$ inch thick Boral, one $1/4$ inch thick polyethylene, five $1/16$ inch thick aluminum and one $1/4$ inch thick Boral sheets (see Figure 5). The lateral dimensions for each piece of these materials are 52 inches square. In order to measure neutron flux and dose rate inside the shield mockup using passive dosimeters, small aluminum spacer bars were placed between those shielding materials of interest. Two aluminum bars ($3' \times 1/2" \times 1/4"$) or rods ($3' \times 1/4"$ diameter) two inches apart were sandwiched centrally between two sheets of material in order to leave a quarter inch gap for the passive dosimeters. In addition, small aluminum bars one inch square and a quarter inch thick and/or rods of the above mentioned

dimension were also inserted at some of the corners and edges of these layers so that the shielding materials may be kept as flat as possible. In all, a maximum of twenty-two sets of spacers were used, and their locations are shown for Configuration 7A in Figure 10. Before neutron and gamma radiation measurements were to be made, it was important to measure the reactivity worth of these shielding materials as they were piled on top of the reactor. The worth is measured by the period-pickoff technique which is accurate to about $\pm 0.2\%$.*

The standard procedure in measuring changes in reactivity is as follows:

- 1) Establish a critical configuration and then determine the delayed critical drum positions.
- 2) Insert or add the material of interest and run the drums to their previously determined delayed critical positions. The difference in reactivity (in cents) between these two runs will be the worth of the added material.

To determine the reactivity worth of a large amount of poison, one would need to know the delay critical positions and the total drum bank worth. A sample problem is worked out in Appendix 2.

* The accuracy of the period-pickoff technique is assumed to be the same in the FCX and the PAX. It is shown in Appendix 1 of the Analysis of FCX Base Point Reactivity Measurements** that σ_p (from period-pickoff) and σ_c (from computer) are $\pm 0.17\%$ and $\pm 0.23\%$, respectively; hence, the quoted $\pm 0.2\%$ accuracy.

** WANL-TME-1794, in preparation.

The maximum permissible reactivity insertion without poison compensation is fifty cents based on safety regulations (see References 1-3). It was also desirable to keep the delay critical angle at about 89° to conform with a typical Nevada Test Site configuration. Therefore, poison wires were inserted before the shielding materials were added, and the sequence of operations is summarized in Table 2.

4. RESULTS AND ANALYSIS

The reactivity worth of Configuration 4 is 49.45¢. This is obtained by summing up its components as they are piled on top of the bare PAX core (see Appendix 1). The worth of the Boral discs and rings is 8.53¢ from Runs 44 and 45; the first 1-1/2 inch aluminum plate is 15.99¢ from Runs 27 and 28, the next 3 inch aluminum plate is 17.63¢ from Runs 28 and 29, and the rest of the pressure vessel and plenum region is 7.30¢ from Runs 29 and 30. Hence, Configuration 4 is worth the sum of these, or 49.45¢. The worth of the other configurations is obtained similarly using data in Table 2. Since the worth of each configuration is a result of six to nine independent measurements, each of which carries an uncertainty of $\pm 0.2\%$, the total uncertainty is, therefore, about $\pm 0.6\%$.

The difference between Configurations 4 and 4B is merely an insertion of a 1/4 inch Boral sheet between the upper dome plenum and pressure vessel mockup, and the change in reactivity is only 0.90¢. Similarly, the same change between Configurations 7A and 7B is noted while a change of reactivity of 1.15¢ is measured (see Appendix 1). These differences are within the

absolute uncertainty, and therefore they are not very significant. However, these small differences may indicate that the inserted 1/4 inch Boral sheet is reflecting some fast neutrons back into the core.

Going from Configuration 4 to 7A, one sees that the addition of six standard modules actually reduces the reactivity of PAX by 3.7¢. This shows that the six shield modules are better neutron absorbers than scatterers. The effectiveness in attenuating fast and thermal neutrons will be reported in the future.

Finally, when the same shielding materials are rearranged from Configuration 7A to 7C, i.e., the shield mockup is placed above rather than below the support plate, the worth goes up 2.5¢ (from 45.74¢ to 48.23¢). This is reasonable since the 4-1/2 inch aluminum plates are not as effective a neutron absorber as the standard shield modules, and so the net number of neutrons reflected from the shield mockup to the reactor core are increased. The reduction in thermal current may be determined in a later foil dosimetry transmittal.

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FIGURE 1 - THE CLUSTER PLATE MOCKUP

FIGURE 2 - CORE SUPPORT PLATE MOCKUP

FIGURE 3 - PLENUM REGION MOCKUP

FIGURE 4 - THE PRESSURE VESSEL MOCKUP

FIGURE 5 - DETAIL STANDARD MODULE TYPICAL SHIELD MATERIAL
(Designated as BATH material - boron aluminum,
titanium hydride)

FIGURE 6 - CONFIGURATION 1 CONSISTING OF THE BARE PAX
AND ITS R-1 ADAPTER RING ON WHICH SHIELDING
MATERIALS ARE TO REST.

FIGURE 7 - CONFIGURATION 4. WITH INSERTION OF A 1/4" BORAL SHEET BETWEEN THE PRESSURE VESSEL AND THE PLENUM REGION, THE NEW CONFIGURATION IS 4B.

FIGURE 8 - CONFIGURATION 7A. WITH INSERTION OF A 1/4" BORAL SHEET BETWEEN THE PRESSURE VESSEL AND THE PLENUM REGION, THE NEW CONFIGURATION IS 7B.

FIGURE 9 - CONFIGURATION 7C

PAX CORE

FIGURE 10

Arrows indicate 1/4" thick gaps created by the spacers in
 Configuration 7A.

TABLE 1 - VOID CONTENT FOR VARIOUS CONFIGURATIONS
CREATED BY 1/4" THICK ALUMINUM SPACERS

<u>CONFIGURATION</u>	<u>MATERIAL THICKNESS (In)</u>	<u>VOID THICKNESS (In)</u>	<u>TOTAL THICKNESS (In)</u>
4	7.125	2.000	9.125
4B	7.375	2.000	9.375
7A	16.875	5.500	22.375
7B	17.125	5.500	22.625
7C	16.875	5.500	22.375

TABLE 2 - MAJOR SEQUENCE OF RUNS. RUN NUMBERS NOT LISTED ARE ENTIRELY DEVOTED TO ACTIVE AND/OR PASSIVE RADIATION MEASUREMENTS WITHOUT CORE CHANGES

<u>RUN NO.</u> <u>PAX-85</u>	<u>DATE</u>	<u>PERIOD</u> <u>ANGLE</u>	<u>DELAY CRITICAL</u> <u>ANGLE</u>	<u>REACT.</u> <u>(ϵ)</u>	<u>PERIOD</u> <u>(sec)</u>	<u>DESCRIPTION</u>
25	1/24/68	89.00°	85.86°	21.30	32.05	Base point with shutdown can
26	1/24/68	106.00°	103.10°	18.60	39.83	Base point with shutdown can and 90 poison wires (approximately 1½ wires/cluster) which are worth about - 1.13\$.
27	1/24/68	103.10°	101.83°	8.67	114.73	With 3/8" Boral discs and rings but no shutdown can and Run 26.
28	1/25/68	101.83°	99.42°	15.99	50.56	With 1½" aluminum and Run 27
29	1/25/68	99.42°	96.82°	17.63	43.24	With additional 3" aluminum and Run 28
30	1/25/68	96.82°	95.80°	7.30	141.5	With additional 2/4" polyethylene, 3/4" steel, 3/4" polyethylene, 5/8" aluminum and Run 29
31	1/26/68	97.00°	93.58°	23.28	27.61	Remove shielddings and 50 poison wires, insert shutdown can and do drum worths
32	1/26/68	88.00°	86.90°	7.67	133.7	Replace shielddings, add 3 wires, remove PASS* but leave can in Drum 12. There are now 43 poison wires.
44	2/6/68	96.00°		11.70	77.65	Base point to remeasure Boral discs and rings with shutdown can.
45	2/6/68	96.00°		20.23	34.83	With Boral discs and rings and shutdown can
43	2/5/68	90.00°		21.26	30.15	Configuration 4, base point for first module in Configuration 7A.
46	2/6/68	90.00°		19.61	36.65	First module of 7A from 4 is - 1.65\$.
47	2/8/68	90.00°	86.20°	17.55	43.54	Five additional modules in 7A is - 2.06\$.
79	3/7/68	89.00°	85.96°	22.11	30.12	Configuration 1
80	3/8/68	89.00°	86.78°	14.90	55.50	Configuration 1 to 7C after inserting 43 poison wires back to core
81	3/8/68	90.00°	86.83°	21.84	30.75	No change
84	3/12/68	89.00°		14.58	57.25	Configuration 7C is changed to 4 plus Boral housing
85	3/13/68	90.00°		21.04	32.70	No change
86	3/13/68	90.00°		21.88	30.64	Run 85 plus curved Boral sheet
88	3/14/68	90.00°		20.87	33.15	Back to Configuration 4
89	3/14/68	90.00°		21.77	30.93	From Configuration 4 to 4B
91	3/18/68	90.00°		18.31	40.84	From Configuration 4B to 7B

* PAX Auxiliary Shutdown System

APPENDIX 1 - CALCULATION OF WORTH OF EACH CONFIGURATION

CONFIGURATION	MATERIAL	REFERENCE RUN (IN TABLE 1)	WORTH (¢)
4	Boral Discs and Rings	44, 45	8.53
	First 1½" Aluminum	27, 28	15.99
	Next 3" Aluminum	28, 29	17.63
	Rest of material for Configuration 4	29, 30	7.30
	Total Worth of Configuration 4		<u>49.45</u>
7A	First Module of Configuration 7A	43, 46	- 1.65
	Rest of Modules of Configuration 7A	46, 47	- 2.06
	Total Worth of Configuration 7A	43,46,47, Configuration 4	<u>45.74</u>
7C	90 Poison Wires	25,26,6.55¢/degree	-113.00
	47 Poison Wires	30, 32	- 58.40
	43 Poison Wires	Net Difference	- 54.60
	Total Worth of Configuration 7C	79, 80, 43 Wires	<u>48.23</u>
4B	½" Boral	88, 89	0.90
	Configuration 4	Measured Above	49.45
	Total Worth of Configuration 4B	Net Difference	<u>50.35</u>
7B	Total Worth of Configuration 7B	88, 89, 91, 4B	<u>46.89</u>

* Total drum bank is about 6.55¢/degree in this neighborhood as shown in Appendix 2.

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APPENDIX 2

CALCULATION OF WORTH OF 90 POISON WIRES

It can be shown from the PAX Shutdown Determination Curve that delay critical at 103° (Run No. 26) corresponds to 62.1% of the normalized drum span and 85° (Run No. 25) to 46.2%. Taking the total drum bank to be 7.40\$ as measured on January 10, 1968, and the difference of the above, one finds readily the total drum bank is worth about

$$\frac{(.621 - .462) \times 740}{103 - 85} \text{ or } 6.55 \text{ cents per degree in this angular neighborhood.}$$

Hence, the 90 poison wires are worth $6.55 \times (103.10 - 85.86)$ or 113 cents.

REFERENCES:

1. Section 3 of WANEF Operating Limits, WANL-TME-1295, Revision C, January 1967.
2. Section 5 of WANEF Reactor Operations Manual, WANL-TME-267, Revision E, January 1967.
3. Section 7.4.5.3 of the Safety Report, WANL-TNR-099, January 1967.
4. WANL-TME-1739, "WANEF Critical Experiments in Support of NERVA Quarterly Report, 3rd Quarter CY'67", dated January 1968.
5. WANEF-TME-1758, "Fast and Thermal Neutron Fluxes and Gamma Dose Rates at the PAX Pressure Vessel and Nozzle Flanges", dated January 1968.

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