WANL-TME-1759
August 1968

Subcontract NP-1

Westinghouse Astronuclear Laboratory

WESTINGHOUSE ASTRONUCLEAR EXPERIMENTAL FACILITY

FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES
ON THE PAX DOME AND PRESSURE VESSEL

MASTER

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

WANL-TME-1759
August 1968

Subcontract NP-1

Westinghouse Astronuclear Laboratory

WESTINGHOUSE ASTRONUCLEAR EXPERIMENTAL FACILITY

FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES
ON THE PAX DOME AND PRESSURE VESSEL

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared by:

W. D. Rankin
G. E. Kubancsek

Approved by:

H. C. Woodsum
H. C. Woodsum
Supervisor, Experimental Physics

W. P. Kovacic
W. P. Kovacic
Manager, WANEF

INFORMATION CATEGORY

Unclassified
W. P. Kovacic 8/8/68
Authorized Classifier Date

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

56

1. INTRODUCTION

Neutron flux and gamma dose rate measurements have been made on the dome and pressure vessel of the PAX mockup of the NRX-A6 reactor, in response to a test request by the WANL Radiation and Shielding Analysis Group. Fast and thermal neutron flux and gamma dose rates were measured using passive detectors of sulfur pellets, Uranium-238 foils, dysprosium-aluminum foils and thermoluminescent dosimeters.

The particular version of the NRX-A6 mockup in PAX during these measurements is known as the E4 assembly. Assemblies E2, E3 and E4 were identical and a plan view is shown in Figure 1. For a description of the E2, see WANEF Quarterly Report, WANL-TME-1739, "WANEF Critical Experiments in Support of NERVA, Quarterly Report - 3rd Quarter CY'67", Sections 3.1 and 3.3.

2. SUMMARY

The results of the dosimetry measurements on the PAX dome and pressure vessel are presented in the form of tables of data. Selected portions are also presented in graphical format. The data tabulated comprise saturated activities of bare and cadmium-covered dysprosium and the resultant thermal neutron flux, saturated activities of sulfur and Uranium-238 and the resultant fast neutron fluxes above 2.9 and 1.4 MeV, respectively, and the gamma dose rate from TLD measurements.

3. EXPERIMENTAL DETAILS

3.1 GENERAL

This experiment was carried out with the PAX-E4 reactor assembly as diagrammed in Figure 1. The Aerojet mockup stainless steel nozzle was in place for other simultaneous experiments. During the last run, the XE detector canister assembly mockup* was also in place in the test cell at a distance of 9 feet from the reactor centerline. This item, however, cannot be expected to have a significant influence on the results obtained.

The data herein reported was taken concurrently with that for several other experiments involving passive dosimetry and was reduced at the same time as the other data. These other measurements include the passive dosimetry measurements in the nozzle flange region and at the fast neutron fission counter location at the nozzle throat which have been documented in WANL-TME-1758, "Fast and Thermal Neutron Fluxes and Gamma Dose Rates at the PAX Pressure Vessel and Nozzle Flanges". Other measurements, not yet reported in final form, are those with the XE-2 detector canister mockup and those performed on a control drum vane.

3.2 DOSIMETERS

The passive dosimeters used included dysprosium-aluminum foils, sulfur pellets, Uranium-238 foils and thermoluminescent dosimeters. The dysprosium-aluminum foils were 1/4 inch in diameter and 0.010 inches thick. Each weighed approximately 23 milligrams and contained, by x-ray fluorescent

*WANL-TME-1771, "Westinghouse Astronuclear Experimental Facility Annual Operations Report - 1967", dated April 17, 1968.

analysis, 5.87 weight percent of dysprosium to an estimated accuracy of $\pm 6\%$. These foils were exposed both bare and with cadmium covers. The cadmium covers were 0.020 inches thick, formed of two interlocking parts so that their edges were twice as thick. The whole packet was $3/8$ inches in diameter and 0.11 inches thick. The sulfur pellets were discs of pressed sulfur 0.43 inches in diameter and 0.275 inches thick, weighing approximately 1.1 grams. The Uranium-238 foils were 0.005 inches thick and 0.435 inches in diameter and weighed approximately 0.26 grams each. The uranium is reported to contain 190 parts per million of Uranium-235. The thermoluminescent dosimeters were hot-pressed chips of CaF_2 manufactured by Edgerton, Germeshausen & Grier, Inc., and $1/8$ inch square by $1/16$ inch thick. Each chip was inserted into a piece of vinyl plastic tubing 0.020 inches thick in order to help provide a condition of electron equilibrium during exposure.

3.3 REACTOR RUNS

Three reactor runs were required for this experiment. In the first, bare dysprosium-aluminum foils were placed along the dome end and lateral surface of the pressure vessel at reactor angles of 247.5° and its diagonal opposite of 67.5° , both of which correspond approximately to an azimuthal peak of the thermal neutron flux scalloping around the pressure vessel drum produced by shadowing effects. Dysprosium-aluminum foils were also placed at an angle of 262.5° which corresponds approximately to a scalloping minimum. TLD chips were placed at reactor angles of 277.5° , corresponding to another thermal flux scalloping peak and at 292.5° , corresponding to a scalloping minimum.. The reactor was run for 30 minutes at a power level determined to be 204 ± 18 watts with the drum bank at 84.2° .

In the second reactor run, sulfur pellets were placed at reactor angles of 247.5° , corresponding to a thermal flux scalloping maximum and at 262.5° , corresponding to a scalloping minimum. The reactor was run for 90 minutes at 765 ± 69 watts with the drum bank at 84.1° .

In the third reactor run, cadmium-covered dysprosium-aluminum foils were placed at reactor angles of 247.5° and 262.5° , duplicating a portion of the locations at which bare dysprosium-aluminum measurements had been performed in the first run. Uranium-238 foils were placed at a reactor angle of 277.5° , corresponding to another thermal flux scalloping maximum. The reactor was run for 60 minutes at a power level of 500 ± 45 watts with the drum bank at 84.6° .

3.4 DOSIMETER PLACEMENT

In placing the dosimeters in position, the locations were first marked on the nozzle and pressure vessel and then the dosimeters were taped in place with a cloth-base tape. (Additional tape was used to label the cadmium packets and the TLD chip packets.) Accuracy of positioning of any dosimeter is estimated at $\pm 1/8$ inch.

Figure 2 consists of two photographs showing the dosimeters in place for the first run. Figure 3 is a sketch of the reactor showing nozzle, core and pressure vessel with the indicated reference coordinates. Figure 4 shows the positions at which dosimeters were located on the dome and at the dome flange region of the pressure vessel.

3.5 POWER CALIBRATION

A calibration of the reactor power levels in the PAX-E4 assembly had previously been established based on measured power distributions in one 60° sector of the reactor core centered on the region of the NRX-A6 Build 2 fuel. A report on this calibration is in preparation. The estimated accuracy was $\pm 4\%$ for successive runs with the same reactor configuration, using the established techniques of inter-run normalization by means of gold wires inserted into the center of the reactor. The results are reported herein using this calibration.

Subsequent measurements on the reactor during the PAX-E5 series of experiments revealed a significant asymmetry in the power generation in the different core sectors. It is now estimated that the total power in the core was 5.2 percent greater than that assumed in the calculations used for the data in this report. However, since most of the data was taken on the side of the core near the NRX-A6 sector in which the original power calibration was performed and since that sector most closely represents the reactor in which one is interested, it is not clear that the results should be corrected for the core asymmetry. The reported uncertainty in reactor power has, therefore, been increased to ± 9 percent and the data left as originally calculated.

3.6 DOSIMETRY CALIBRATIONS

The calibration of the thermoluminescent dosimeters was accomplished by exposing a representative sample of them at various distances from a Co^{60} source of known activity. The known activity was obtained by the manufacturer through reference to a National Bureau of Standards calibration. The accuracy of this calibration, including problems of reproducibility, is thus estimated at $\pm 10\%$.

The calibration of the sulfur dosimeters in terms of absolute disintegration rate was established by radiochemical means involving chemical separation of the P-32 activity of an irradiated pellet and absolute counting techniques. This was then used as a reference to establish the absolute efficiency of the beta counters in which the samples were counted. The accuracy of the calibration was ± 5 percent.

The calibration of the dysprosium-aluminum foils was accomplished by gamma spectrometry of three irradiated foils to establish absolute disintegration rates which were then used to determine the efficiency of the beta counting system used for the experiment. The accuracy of this calibration was estimated to be ± 5 percent.

The dysprosium-aluminum foils had been supplied as having a nominal content of 5 percent dysprosium by weight. A representative sample of the foils was analyzed by x-ray fluorescence techniques which compared them with a known standard of dysprosium-aluminum. The results indicated a content of 5.87 percent to an estimated accuracy of ± 6 percent.

The U-238 foils were calibrated by performing a radiochemical separation of the Mo-99 activity in an irradiated foil and then using absolute counting techniques to establish the total number of fissions in the foil. Accuracy of this determination was ± 5 percent.

3.7 DATA REDUCTION

The data from the dysprosium-aluminum and sulfur foils were first reduced to the form of saturated activity per gram of foil material per watt

of reactor power where the activity was expressed in disintegrations per minute. The data from the U-238 foils were first reduced to the form of total fissions per gram of foil per watt. Corrections were made in the data reduction for counter background, resolving time and absolute efficiency as well as for reactor power, buildup to saturation, and foil decay. Corrections were also made for the individual weight of each foil as determined on a precision balance. These results were then converted to neutron flux per watt of reactor power. In doing this, it was assumed that the dysprosium thermal activity was the difference of the bare and cadmium-covered activities. The physical constants used in the data reduction are given in Table 1.

The activity of the U-238 foils was first reduced to an equivalent fast flux with the assumption that the activity arose solely from fast fissions in the U-238. This flux was then corrected for the contribution to the activity resulting from thermal fissions in the 190 ppm U-235 impurity in the foil. If ϕ is the equivalent fast flux, ϕ_f the true fast flux, and ϕ_t the thermal flux and if F_{235} and F_{238} are the fractional contents of U-238 and U-235 in the foil, and if Σ_f is the U-238 fast fission cross-section, Σ_t the U-235 thermal fission cross-section, then:

$$\phi \cdot \Sigma_f = \phi_f \cdot \Sigma_f \cdot F_{238} + \phi_t \cdot \Sigma_t \cdot F_{235}$$

or, since $F_{238} \approx 1$

$$\phi - \phi_f = \phi_t \cdot \frac{\Sigma_t}{\Sigma_f} \cdot F_{235}$$

$$= \phi_t \left(\frac{577 \text{ barns}}{0.555 \text{ barns}} \right) \quad 0.000190$$

$$= .1975 \phi_t$$

$$\text{or, } \phi_f = \phi - .1975 \phi_t$$

It should be noted that the above neglects any resonance or epithermal fissions

in the U-235 since it is assumed that these are much less than thermal fissions. Therefore, the equivalent fast flux at each location was reduced by 19.75 percent of the thermal flux as measured with the Dy foils. The magnitude of this correction ranged from 7 percent at the center of the dome to 40 percent at Station 15.

4. RESULTS

The results are presented in Tables 2 and 3. In each table, the dosimeter position number corresponding to the locations shown in Figure 4 is given. The radius, station and reactor angle are also indicated. Table 2 presents the results of the dysprosium measurement in terms of bare and cadmium-covered activity as well as the thermal neutron flux obtained as the difference of these two measurements. Table 3 presents the results of the sulfur and U-238 measurements in terms of both saturated activity and equivalent fast neutron flux. Table 3 also presents the results of the TLD measurements in terms of absolute dose rate.

Figure 5, 6 and 7 present some of the results in a graphical form. For each of the dosimeter types used, the distribution at that reactor angle in which the most detailed data was taken is plotted as a function of reactor station. Thus in Figure 5, the bare and cadmium-covered dysprosium activities as well as the thermal neutron flux are plotted; in Figure 6, the fast neutron flux from the sulfur and U-238 measurements is plotted; and in Figure 7, the results of the TLD measurements are plotted. Note that these are not axial distributions since the radial location of the points is varying with the axial position.

Estimates of the accuracy of the measurements have been made.

Table 4 summarizes the principal sources of uncertainty. Since these are assumed independent in nature, the total uncertainty is taken to be the square root of the sum of the squares of the individual uncertainties. The resultant uncertainties, on a one-sigma basis, are ± 12.3 , ± 11.7 and $\pm 14.0\%$ for the dysprosium, sulfur and U-238 activities, respectively. For the flux determinations, the uncertainties are $\pm 15.7\%$ for the thermal flux, $\pm 15.4\%$ for the fast flux above 2.9 MeV as determined with sulfur, and $\pm 19.9\%$ for the fast flux above 1.4 MeV as determined with U-238. The gamma dose rate uncertainty is $\pm 16.9\%$.

Table 1. Constants Used in Data Reduction

	$\text{Dy}^{164} \longrightarrow \text{Dy}^{165}$		$\text{S}^{32} \longrightarrow \text{P}^{32}$		U^{238}
Atomic Number	66	66	16	15	92
Isotopic Weight ¹⁾	163.9392		31.97207		238.0508
Abundance ¹⁾	0.2818		0.950		
Half Life ¹⁾		141 min.		14.3 days	
Decay Constant		$4.9159 \times 10^{-3} \text{ min.}^{-1}$		$3.3661 \times 10^{-5} \text{ min.}^{-1}$	
Thermal Cross-Section ²⁾	2700 barns + 7.4%				
Fast Cross-Section			0.300 barns		0.555 barns ³⁾
Effective Threshold Energy			2.9 Mev		1.4 Mev ³⁾

1. Chart of Nuclides, July 1966
2. BNL 325, 2nd Edition, Supp. 2
3. ANL-5800, 2nd Edition, Reactor Physics Constants, July 1963

TABLE 2 - DYSPROSIUM ACTIVITY AND THERMAL NEUTRON FLUX

POSITION NUMBER 1/	RADIUS 4/ (INCHES)	STATION (INCHES) 4/	DYSPROSIUM-ALUMINUM					THERMAL FLUX 2/, 3/ (nv/watt)	
			ACTIVITY (DPM/watt/gram of foil)						
			BARE			CADMIUM-COVERED			
			$\theta = 67.9^\circ$	$\theta = 247.5^\circ$	$\theta = 262.5^\circ$	$\theta = 247.5^\circ$	$\theta = 262.5^\circ$	$\theta = 247.5^\circ$	$\theta = 262.5^\circ$
1	0.00	-29.38		31.2×10^3		5.8×10^3		2.58×10^3	
2	1.98	-29.33	33.3×10^3	30.2				(2.48)	
3	3.97	-29.26	35.0	30.0				(2.47)	
4	5.92	-29.00	35.0	29.1		5.6		2.39	
5	7.91	-28.79	37.5	29.1				(2.39)	
6	10.89	-28.41	38.3	30.6				(2.55)	
7	11.83	-27.94	40.8	31.5		5.6		2.64	
8	13.73	-27.41	42.5	32.9	31.5×10^3			(2.78)	$(2.64) \times 10^3$
9	15.63	-26.75	40.2	33.6				(2.85)	
10	16.64	-26.63	41.0	32.5	33.3	5.5	5.7×10^3	2.75	2.80
11	18.00	-26.19		32.5				(2.75)	
12	18.81	-25.63		35.0	33.9			(3.00)	(2.90)
13	20.56	-24.60		36.3		5.4		3.14	
14	22.16	-23.40		38.6	37.9		5.2	(3.37)	3.32
15	23.59	-22.00		40.3				(3.55)	
16	24.16	-21.19		43.1	42.7	5.2		3.85	(3.81)
17	24.72	-20.35		46.1				(4.16)	
18	24.97	-19.88		48.2	46.0	5.3	5.0	4.36	4.16
19	25.31	-19.41		49.3				(4.50)	
20	25.95	-19.41		43.2	38.1	4.7		3.91	(3.39)
21	26.45	-19.41		34.3				(3.06)	
22	26.95	-19.41		33.9	31.0	3.6	3.7	3.08	2.77
23	27.45	-19.41		32.2					
24	27.25	-17.88		104.8					
25	27.25	-17.38		103.4	100.1	7.6	7.9	9.73	9.36
26	27.25	-16.88		106.3				(10.02)	
27	27.25	-16.38		113.8	113.2	7.8	8.1	10.76	10.68
28	27.14	-15.88		122.4×10^3				$(11.61) \times 10^3$	
29	27.14	-15.38		125.8	122.0×10^3	8.4×10^3	8.6×10^3	11.92	11.52×10^3
30	27.14	-14.88		134.1		8.6		12.75	
31	26.73	-14.69		135.1	132.2	8.8	8.8	12.84	12.53
32	25.76	-14.00		126.5	124.3	8.5	8.6	11.99	11.75
33	25.70	-13.50		128.4		9.0		12.13	
34	25.67	-13.00		129.3	131.4	9.3	9.0	12.19	12.42
35	25.67	-12.50		137.0				(12.96)	
36	25.67	-12.00		138.4	134.1	9.6	9.7	13.08	13.63
37	25.67	- 9.00		164.3				(15.54)	
38	25.67	- 6.00		189.6	176.3	13.2	12.7	17.91	16.62
39	25.67	- 3.00		194.3				(18.37)	
40	25.67	0.00		290.8	242.2	12.7		28.24	(23.36)
41	25.67	4.00		640.0				(66.33)	
42	25.67	9.00		1026.2	669.3	31.7	24.1	101.20	65.54
43	25.67	15.00		1343.5	831.4	40.2		132.38	(81.47)
44	25.67	21.00		1384.0				(136.28)	
45	25.67	26.00		1384.7	838.4	42.9	32.0	136.30	81.92

1/ Position numbers correspond to locations shown in Figure 4.

2/ Thermal flux calculated assuming: a) (Thermal Activity) = (Bare Activity) - (Cadmium-Covered Activity).
b) Thermal Cross-section = 2700 barns.

3/ Flux numbers appearing in parenthesis were obtained by interpolating the cadmium-covered activity from adjacent positions.

4/ See Figure 3 for reference station and radius, Figure 4 for detector placement.

TABLE 3 - SULFUR AND URANIUM-238 ACTIVITY AND FAST NEUTRON FLUX AND GAMMA DOSE RATE

POSITION NUMBER ^{1/}	RADIUS ^{4/} (INCHES)	STATION ^{4/} (INCHES)	SULFUR				^{U238}		TLD	
			ACTIVITY (DPM/gram/watt)		FAST FLUX ^{2/} (nv/watt)		ACTIVITY (fiss/gm/w-hr)		DOSE RATE (mRad/hr/watt)	
			$\theta = 247.5^\circ$	$\theta = 262.5^\circ$	$\theta = 247.5^\circ$	$\theta = 262.5^\circ$	$\theta = 277.5^\circ$	$\theta = 277.5^\circ$	$\theta = 277.5^\circ$	$\theta = 292.5^\circ$
1	0.00	-29.38	207		643		3.50×10^4	6.44×10^3		
2	1.98	-29.33							63.4	
3	3.97	-29.26							60.4	
4	5.92	-29.00					2.79	5.07	62.2	
5	7.91	-28.79							64.0	
6	10.89	-28.41	193		601		3.21	5.86	61.0	56.2
7	11.83	-27.94							65.2	
8	13.73	-27.41					3.13	5.67	67.0	62.2
9	15.63	-26.75							66.4	
10	16.64	-26.63	197	191	612	593	3.13	5.67	68.2	58.6
11	18.00	-26.19							65.2	
12	18.81	-25.63					2.74	4.85	63.4	67.0
13	20.56	-24.60							75.3	
14	22.16	-23.40	221	224	687	695	2.87	5.03	71.2	74.1
15	23.59	-22.00							79.5	
16	24.16	-21.19					3.28	5.74	81.9	70.6
17	24.72	-20.35							69.4	
18	24.97	-19.88	274	275	852	855	3.37	5.82	88.5	75.3
19	25.31	-19.41							90.9	
20	25.95	-19.41					3.10	5.39	77.1	78.9
21	26.45	-19.41							75.9	
22	26.95	-19.41	180	172	558	534	2.93	5.21		67.0
23	27.45	-19.41							70.0	
24	27.25	-17.88							150	
25	27.25	-17.38					5.30	8.61	163	140
26	27.25	-16.88							147	
27	27.25	-16.38	436	402	1353	1249	5.19	8.18	159	155
28	27.14	-15.88							178	
29	27.14	-15.38					6.66	10.86	202	182
30	27.14	-14.88							232	
31	26.73	-14.69	703	729	2182	2263	6.98	11.32	207	213
32	25.76	-14.00					7.00	11.54	193	179
33	25.70	-13.50							205	
34	25.67	-13.00					8.71	14.88	227	207
35	25.67	-12.50							240	
36	25.67	-12.00	1074	1016	3334	3155	9.30	15.88	267	214
37	25.67	- 9.00							407	
38	25.67	- 6.00					20.75	37.66	550	526
39	25.67	- 3.00							574	
40	25.67	0.00					19.80	33.74	694	604
41	25.67	4.00							921	
42	25.67	9.00					28.84	37.27	1310	1180
43	25.67	15.00					33.35	40.08	1570	1610
44	25.67	21.00							1690	
45	25.67	26.00					39.50	51.51	1630	1730

^{1/} Position numbers correspond to locations shown in Figure 4.

^{2/} Fast flux calculated assuming: cross-section = 300 millibarns for Effective Threshold = 2.9 MeV.

^{3/} Fast flux calculated assuming: a) cross-section = 555 millibarns for Effective Threshold = 1.4 MeV.
b) A value of 0.198 times the thermal flux was subtracted from the gross fast flux to correct for foil activity resulting from thermal fissions in the U-235 impurity.

^{4/} See Figure 3 for reference station and radius, Figure 4 for detector placement.

TABLE 4 - ACCURACY ESTIMATES

	<u>ONE-SIGMA UNCERTAINTY ESTIMATES**</u>			
	<u>Dy-Al</u>	<u>S</u>	<u>U²³⁸</u>	<u>TLD</u>
Misc. Statistical and Systematic Errors	4.5	5.5	9.5	2
Unaccounted for Individual Variations between "Foil"	5	1	1	10
Absolute Efficiency Calibration	5	5	5	10
Power Calibration	9	9	9	9
Absolute Activity*	12.3	11.7	14.0	--
Subtraction of Activities	2	--	10	--
Cross-Section	7.4	10	10	--
"Foil" Content	6	--	--	--
Absolute Flux or Dose*	15.7	15.4	19.9	16.9

* Statistical sum of preceding numbers.

** In percent.

612253-6B

FIGURE 1 PAX-E4 ASSEMBLY

FIGURE 2 - TWO VIEWS OF DY-AL AND TLD DOSIMETERS ON DOME AND PRESSURE VESSEL

Figure 3. PAX Assembly with Nozzle in Place

FIGURE 4 - DOSIMETER LOCATIONS ON DOME AND PRESSURE VESSEL

FIGURE 5 - THERMAL NEUTRON MEASUREMENTS ALONG THE SURFACE OF PAX DOME AND PRESSURE VESSEL

WANT-TME-1759

FIGURE 6 - FAST NEUTRON FLUX ALONG THE SURFACE OF PAX DOME AND PRESSURE VESSEL

FIGURE 7 - GAMMA DOSE RATE ALONG THE SURFACE OF PAX DOME AND PRESSURE VESSEL