Subcontract NP-1

WANL-TME-1758
January 1968

Westinghouse Astronuclear Laboratory

WESTINGHOUSE ASTRONUCLEAR EXPERIMENTAL FACILITY

**FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES
AT THE PAX PRESSURE VESSEL AND NOZZLE FLANGES**

MASTER

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1. INTRODUCTION

Measurements have been made in the region of the nozzle-pressure vessel flange, and especially in the associated bolt holes, of the PAX-E4 reactor mockup (Figure 1) in response to a test request* by Aerojet-General Corporation. Fast and thermal neutron flux and gamma dose rate have been measured using passive detectors of sulfur pellets, dysprosium-aluminum foil, and thermoluminescent dosimeters.

2. SUMMARY

A table of results is presented showing the thermal and fast neutron flux and the gamma dose rate in the region of the nozzle and pressure vessel flanges and bolt holes. A few additional points corresponding to NRX-A5 dosimeter locations in the region of the nozzle throat, which were requested by Aerojet to provide a comparison with the A5 test, as well as data obtained during a fast fission chamber calibration** are also reported.

3. EXPERIMENTAL DETAILS

3.1 GENERAL

For this experiment, the Aerojet stainless steel mockup nozzle was

* NRO/WANEF Test Specification Number 002, "Measurement of the Fast Neutron and Thermal Neutron and Gamma Dose Rates at the Nozzle and Closure Flanges, June 12, 1967".

** WANEF-487-67, "Calibration of U^{238} (2 ppm U^{235}) Fast Fission Chambers WX-30748)", November 1967.

placed on top of the PAX-E4 reactor assembly. Figure 1 diagrams the PAX-E4 assembly configuration. Passive dosimetry detectors were located at three different reactor angle locations spaced 30 degrees apart around the flanges. All nozzle flange bolt holes within 12 degrees of any of the passive dosimetry were filled with bolts. This can be seen in Figure 2 which shows a photograph of some of the dosimetry in place on the nozzle and pressure vessel. Dosimeters were also located at the nozzle throat and approximately 10" above it and below it at points corresponding to NRX-A5 dosimeter locations. The mounting hardware for the 2 ppm U^{238} fast fission detector was also in place at the nozzle throat for a simultaneous experiment in support of NTO. The passive dosimetry used in the detector calibration is also reported here as it was exposed during the same runs, counted in the same batch and data reduced with the flange dosimeters.

3.2 DOSIMETERS

The passive dosimeters used included dysprosium-aluminum foils, sulfur pellets, and thermoluminescent dosimeters. The dysprosium-aluminum foils were 1/4 inch in diameter and 0.010 inches thick. Each weighed approximately 23.2 milligrams and contained, by x-ray fluorescent analysis, 5.87 weight percent of dysprosium to an estimated accuracy of $\pm 6\%$. These foils were exposed both bare and cadmium-covered. The cadmium covers were 0.020 inches thick and formed of two interlocking parts so that their edges were twice as thick. The whole packet was approximately 3/8 inches in diameter and 0.11 inches thick. The sulfur pellets were discs of pressed sulfur approximately 0.43 inches in diameter and 0.275 inches thick, weighing approximately 1.1 grams. The

thermoluminescent dosimeters were hot-pressed chips of CaF_2 manufactured by Edgerton, Germeshausen & Grier, Inc., and approximately $1/8$ inch square by $1/16$ inch thick. Each chip was inserted into a piece of vinyl plastic tubing approximately 0.020 inches thick in order to help provide a condition of electron equilibrium during exposure. The detector calibration dosimetry also included U^{238} foils (190 ppm U^{235}), approximately 0.435 inches in diameter x 0.005 inches thick, weighing approximately 0.26 grams each.

3.5 REACTOR RUNS

Two runs were required for this experiment. In the first, bare dysprosium-aluminum foils were placed at a reactor angle of $247-1/2$ degrees, cadmium-covered dysprosium-aluminum foils at an angle of $277-1/2$ degrees and TLD's at $217-1/2$ degrees. The reactor was run for 30 minutes at a power level determined to be 204 watts with the drum bank at 84.2 degrees. In the second reactor run, sulfur pellets were placed at a reactor angle of $247-1/2$ degrees. The reactor was run for 90 minutes at 765 watts with the drum bank angle at 84.2 degrees. All of the above reactor angles for dosimeter placement correspond approximately to the peaks in the circumferential thermal neutron scalloping around the pressure vessel. The location of the foils in the vicinity of the nozzle throat were at azimuths $7-1/2$ degrees less (i.e., 240, 270 and 210 degrees). The U^{238} foils on the chamber mounting hardware were irradiated on a separate run at 534 watts for 60 minutes.

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 into place. (Additional tape had been used to label the cadmium packets and

the TLD chip packets.) The dosimeters which were placed in the bolt holes were spaced apart with solid cylinders of steel 1/2 inches in diameter to mockup sections of the bolt. For each hole, there were four cylinders with dosimeters between each and at each end of the stack so that they approximately filled the 5/8 x 18 bolt hole with the topmost dosimeters just above the top of the hole. The stack of dosimeters and cylinders was taped together prior to insertion in the bolt hole. The cylinders were of different lengths for the different types of dosimeters. Those for the dysprosium-aluminum foils were 0.870 inches long. Those for the cadmium-covered foils were 0.750 inches long. Those for the TLD packets were 0.735 inches long. Those for the sulfur pellets were 0.595 inches long. Accuracy of positioning of any dosimeter is estimated at $\pm 1/8$ inch.

Figure 2 is a photograph showing the dosimeters in place for the first run. Figure 3 is a sketch of the reactor showing nozzle, core, and pressure vessel. Figure 4 shows the 22 positions at which dosimeters in the flange region were located.

3.5 POWER CALIBRATION

A calibration of the reactor power level had previously been established enabling the determination of reactor power levels to an estimated accuracy of ± 4 percent for successive runs with the same reactor configuration. Intercalibration of the various reactor runs is accomplished by placing three one-inch long gold wires in the center cluster of the reactor at the core mid-plane during each reactor run. Gamma counting of the resultant activities then establishes the reactor power level through the power calibration to the above estimated accuracy.

3.6 DOSIMETER CALIBRATIONS

The calibration of the thermoluminescent dosimeters was accomplished by exposing a representative sample of them to a Co^{60} source of known activity at various distances. The accuracy of the determination including problems of reproducibility is then estimated at ± 10 percent.

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 $\pm 5\%$.

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 the calibration was ± 5 percent.

The dysprosium-aluminum foils had been supplied as having a nominal content of 5% 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% to an estimated accuracy of $\pm 6\%$.

The U^{235} 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 the determination was $\pm 5\%$.

3.7 DATA REDUCTION

The data from the dysprosium-aluminum and sulfur foils was 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 was 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 universal constants used in the data reduction are given in Table 1.

The calculated fast flux in the U^{238} measurements was corrected for the contribution to the activity resulting from thermal fissions in the 190 ppm U^{235} impurity in the foil. This was accomplished by subtracting 19.75% of the measured thermal flux (from the dysprosium measurements) from the calculated fast flux in order to arrive at the value reported. The value of 19.75% was calculated by ratioing the thermal U^{235} cross-section to the fast U^{238} cross-section and multiplying by the U^{235} fractional content in the foil, i.e.,

$$\frac{577 \text{ barns}}{0.555 \text{ barns}} \times .000190 = 19.75\%$$

4. RESULTS

The results of the measurements in the flange area are presented in Table 2. The results of the measurements at the NRX-A5 locations are presented in Table 3. The results of the measurements at the fast fission chamber location are presented in Table 4. The radius, station and reactor angle are also indicated. The results of the dysprosium measurement are given in terms of bare and cadmium-covered activity as well as in thermal flux. The results of the sulfur and U^{238} measurements are given in terms of both activity and fast flux. The TLD measurements are given in terms of absolute dose rate.

Estimates of the accuracy of the measurements have been made. Table 5 summarizes the principal sources of uncertainty. Since these are 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 ± 9.2 , ± 8.5 and $\pm 11.5\%$ for the dysprosium, sulfur and U^{238} activities, respectively. For the flux determinations, the uncertainties are $\pm 13.4\%$ for the thermal flux, $\pm 13.1\%$ for the fast flux above 2.9 MeV as determined with sulfur, and $\pm 29.2\%$ for the fast flux above 1.4 MeV as determined with U^{238} . The gamma dose rate uncertainty is $\pm 14.8\%$.

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 - FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES

DOSIMETER LOCATION			DYSPROSIUM MEASUREMENTS			SULFUR MEASUREMENTS		TLD MEASUREMENTS
POSITION NUMBER ^{1/}	RADIUS (INCHES)	STATION (INCHES)	SATURATED ACTIVITY (DPM/gram/watt)		THERMAL ^{2/} FLUX (nv/watt)	SATURATED ACTIVITY (DPM/gram/watt) (AT 247.5°)	FAST FLUX ^{3/} (nv/watt)	DOSE RATE (mRad/hr/watt) (AT 217.5°)
			BARE (AT 247.6°)	Cd-COVERED (AT 277.5°)				
1	24.67	57.37	130.8 x 10 ³	9.1 x 10 ³	12.36 x 10 ³	2.57 x 10 ³	7.97 x 10 ³	434
2	24.26	58.32	138.7	9.1	13.17	2.89	8.97	467
3	23.79	59.23	135.1	9.1	12.80	3.06	9.51	538
4	23.20	60.07	132.9	8.4	12.64	3.20	9.92	490
5	22.67	60.89	125.1	9.5	11.75	3.18	9.87	538
6	22.04	61.67	121.0	9.5	11.33	3.20	9.92	443
7	22.04	62.59	101.7	9.1	9.40	2.78	8.62	449
8	23.04	63.37	92.4	6.5	8.72	2.41	7.49	386
9	23.04	64.30	51.5	3.4	4.88	1.40	4.33	212
10	22.17	64.96	35.6	3.2	3.29	1.57	4.86	197
11	20.36	65.20	33.1	3.1	3.05	2.09	6.49	226
12	19.61	65.78	33.9	3.8	3.06	2.44	7.58	266
13	18.86	66.52	37.9	3.9	3.45	3.07	9.54	353
14	18.17	67.27	41.9	4.6	3.78	3.95	12.26	449
15	17.45	68.00	48.4	4.9	4.41	4.26	13.23	478
16	16.72	68.72	47.6	5.7	4.25	4.43	13.76	526
17	16.04	69.46	49.8	4.9	4.56	4.41	13.70	487
18	21.11	61.4	156.0	12.8	14.55	4.17	12.96	712
19	21.11	62.3	87.3	10.0	7.86	3.53	10.97	544
20	21.11	63.2	72.7	9.8	6.39	3.42	10.61	508
21	21.11	64.1	52.4	8.2	4.48	2.90	9.01	434
22	21.11	64.9	34.6	3.8	3.13	1.97	6.13	241

^{1/} See Figure 4.

^{2/} Assuming: 1) (Thermal Activity) = (Bare Activity) - (Cd-Covered Activity)

2) Thermal Cross-section = 2700 barns ± 7.4%.

^{3/} Assuming: Fast cross-section = 300 millibarns; Effective Threshold = 2.9 MeV.

TABLE 3 - FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES
IN THE NOZZLE THROAT REGION

DOSIMETER LOCATION			DYSPROSIUM MEASUREMENTS			SULFUR		TLD
POSITION KEY 1/	RADIUS (INCHES)	STATION (INCHES)	SATURATED ACTIVITY 2/ BARE (AT 240°)	Cd-COVERED (AT 270°)	THERMAL 3/ FLUX (nv/w)	SATURATED 2/ ACTIVITY (AT 240°)	FAST 4/ FLUX (nv/w)	DOSE RATE mRad/hr-w (AT 210°)
SN3	8.5	92.2	44.1×10^3	2.8×10^3	4.20×10^3	1.69×10^3	5.25×10^3	181
SN5	5.5	81.3	46.7×10^3	4.8×10^3	4.25×10^3	3.51×10^3	10.91×10^3	365
SN7	14.5	71.7	48.0×10^3	5.5×10^3	4.32×10^3	4.56×10^3	14.14×10^3	478

1/ NRX-A5 position terminology.

2/ In units of dpm/gram/watt.

3/ Assuming: a) (Thermal Activity) = (Bare Activity) - (Cadmium-Covered Activity)

b) Thermal Cross-Section = 2700 barns.

4/ Assuming Fast Cross-Section = 300 millibarns for Effective Threshold = 2.9 MeV.

TABLE 4 - FAST AND THERMAL NEUTRON FLUXES AND GAMMA DOSE RATES AT U²³⁸ CHAMBER

	<u>RADIUS</u> <u>(INCHES)</u>	<u>STATION</u> <u>(INCHES)</u>	<u>ANGLE</u> <u>(DEGREES)</u>	<u>SATURATED</u> <u>ACTIVITY</u> <u>dpm/gram/watt</u>	<u>THERMAL</u> <u>FLUX 1/</u> <u>nv/watt</u>	<u>FAST</u> <u>FLUX</u> <u>nv/watt</u>	<u>GAMMA DOSE</u> <u>mRad/hr/watt</u>	<u>COMMENTS</u>
Dy - Bare	10.4	81.3	182	6.36 x 10 ³	5.99 x 10 ³			{ Inside chamber clamp, chamber not in place, near center of chamber.
Dy - Cadmium-Covered	10.4	81.3	178	4.6 x 10 ³				
Dy - Bare	11.6	81.3	160	70.1 x 10 ³	6.63 x 10 ³			{ Outside chamber clamp, chamber not in place, near end of chamber.
Dy - Cadmium-Covered	10.9		158.5	4.8 x 10 ³				
Sulfur	10.9	80.3	165	3.20 x 10 ³	2/ 9.93 x 10 ³	8.26 x 10 ³		On bottom of chamber, 1-3/4 inches from end. On top of chamber near clamp.
Sulfur	10.6	82.3	188	2.66 x 10 ³				
Uranium-238	10.7	80.3	168.5	1.80 x 10 ⁵	2/ 34.5 x 10 ³	33.4 x 10 ³		On bottom of chamber, 2-1/2 inches from end. On bottom of chamber, 2-1/2 inches from end.
Uranium-238	10.9	80.3	195	1.75 x 10 ⁵				
TLD	11.2	81.3	182.5				255	Inside chamber clamp, chamber not in place, near center of chamber.
TLD	11.5	81.3	160.0				347	Outside chamber clamp, chamber not in place, near end of chamber.

1/ Assuming: a) (Thermal Activity) = (Bare Activity) - (Cadmium-Covered Activity)
b) Thermal Cross-Section = 2700 barns

2/ Assuming: Fast Cross-Section = 300 millibarns for Effective Threshold = 2.9 MeV

3/ Assuming: a) Fast 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 for foil activity resulting from thermal fissions in the U-235 impurity.

TABLE 5 - 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 Individual Variations between "Foil"	5	1	1	10
Absolute Efficiency Calibration	5	5	5	10
Power Calibration	4	4	4	4
Absolute Activity*	9.2	8.5	11.5	--
Subtraction of Activities	2	--	10	--
Cross-Section	7.4	10	10	--
"Foil" Content	6	--	--	--
Absolute Flux or Dose*	13.4	13.1	18.3	14.8

* Statistical sum of preceding numbers.

** In percent.

Note: Except for 21F clusters

Figure 1. PAX-E4 Assembly

Figure 2. Dosimeters in Place for Nozzle Flange Measurement

Figure 3. PAX Assembly with Nozzle in Place

Figure 4. Location of Dosimeters for Nozzle Flange Experiment