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IRRADIATION OF NEUTRON DETECTORS AND ELECTRICAL COMPONENTS

by

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IRRADIATION OF NEUTRON DETECTORS AND ELECTRICAL COMPONENTS

Larry L. Yarger and Arnold M. Plummer

INTRODUCTION

Under the direction of the Pratt and Whitney Aircraft Division, CANEL, and as part of an instrumentation development program for space nuclear propulsion, Battelle irradiated a number of neutron sensors, electrical components, and miscellaneous items at the Battelle Research Reactor (BRR). The items were irradiated within specified temperature ranges and nuclear environments to determine the effects of radiation on either the operating characteristics or the structure of the components, or both. The irradiation conditions simulated the environment to be encountered in actual operation of the components.

In general, the experiments consisted of the following phases:

- (1) Reactor mapping to determine flux distributions and gamma exposure rates
- (2) Preirradiation checkout of the experiment at the BRR
- (3) Conduct of experiment, including continuous specimen-temperature monitoring and output monitoring to obtain performance data
- (4) Removal of experiment from the operating position and subsequent shipment of the irradiated experiment to CANEL.

All the components which were irradiated were supplied by Pratt and Whitney suitably encapsulated for operation in the BRR pool. Pratt and Whitney also supplied the instrumentation required to operate and monitor the components during the irradiations. Battelle fabricated adjustable mounting arrangements for the capsules so that the nuclear environment could be varied for any component.

This report summarizes the operating history and radiation measurements for the various experiments. Figure 1 summarizes the initiation and termination dates and the total testing time for each unit irradiated at the BRR.

DESCRIPTION OF BATTELLE RESEARCH REACTOR

The Battelle Research Reactor is a modified pool-type reactor operating at a power of 2 megawatts. The core is composed of MTR-type fuel elements suspended from a bridge into a large pool, where the pool walls form a stall area. Initially, six beam tubes and a thermal column partially covered three faces of the core as shown in Figure 2. However, three beam tubes were removed for the purpose of better accommodating the electrical units. Figures 3 and 4 show top and overall views of the pool, respectively.

RADIATION MEASUREMENTS

Table 1 lists each unit irradiated for Pratt and Whitney at the BRR and the target conditions for irradiation. The appropriate reactor locations to meet these conditions were determined from measurements made in capsule mockups. The measurements included thermal- and fast-neutron flux, cadmium ratio, and gamma dose rate at various locations in each capsule position. Thermal flux was measured by cobalt wires and the fast-neutron flux and energy spectrum were measured by using the activation reactions listed in Table 2. The fast-neutron spectrum is modified somewhat from the normal fission spectrum by the water between the core and the experiments, and this "hardening" is taken into account in the spectrum measurements. It should be understood that wherever fast-neutron results are listed in this report, they have been corrected for hardening and are values above 1.0-Mev neutron energy.

Gamma dose rate was measured with a 10-cc graphite-walled ionization chamber calibrated at the Battelle gamma facility. All gamma results listed in this report therefore describe the intensity of the gamma radiation in terms of the absorbed dose in carbon.

The dosimetry data for the neutron sensor units are listed in Tables 3 through 10 and shown in Figures 5 through 12. The in-pile dosimeter wires from four units (PW-392-1, PW-390-1, PW-388-2, and PW-401-1) were counted and analyzed at the BRR. The data reported in conjunction with these four units has had all the necessary corrections taken into account and is considered complete. The dosimeter wires in the remaining sensor units and the electrical units were to be analyzed by Pratt and Whitney personnel and were therefore returned to CANEL intact with the experiments. However, the necessary dosimetry correction data is included in this report to assist in obtaining the final dosimetry results for those units. The estimated total exposures received by the two ion chambers which are still operating at the BRR is included. These values are based on preliminary dosimetry measurements and in-pile monitoring.

The electrical units were irradiated in the four different positions around the BRR core as shown in Figure 13. Dosimetry data corresponding to each position are listed in Tables 11 and 12 and shown in Figures 14 through 22. These measurements were made in a mockup capsule of identical dimensions as the actual experiment capsules. The mockup capsule was air filled and the measurements were made along the axis in each of the four positions.

Each electrical unit capsule was wrapped with a 6-mil cadmium cover in order to lower the thermal-neutron flux to values near those listed in the specifications.

Preamplifier dosimetry is listed in Table 13 and shown in Figure 23. The gamma dose rate averaged over the length of each preamplifier was 3×10^5 rep/hr, and each received a total gamma dose of 4.2×10^8 rep.

SUMMARY OF IRRADIATIONS

Neutron Sensors

The neutron sensors which were irradiated consisted of four ionization chambers and four fission counters. The ion-chamber and fission-counter housings are shown in Figure 24. Photographs of the sensors during operation are shown in Figure 25, where the four fission counters are in the foreground and those remaining are the ion chambers. Figures 26 through 28 show the various positions of the sensors during their testing period. All changes in position are described in the summary for each particular unit.

The instrumentation for the sensors was situated in a separate control room. Figure 29 shows the sensor instrumentation. Recorders were provided to monitor the temperatures and output current of each sensor. The sensors were operated at temperatures near 400 F. Daily readings on each unit were taken by BRR personnel and then summarized every 2 weeks in a letter report to CANEL. Each type of sensor had a log book assigned to it for checkout notes, operational troubles, and other pertinent remarks. These have also been returned to CANEL. Following is a brief irradiation history of each sensor.

PW-392-1

Unit PW-392-1, a Reuter-Stokes ion chamber, was the first experiment to be irradiated for Pratt and Whitney at the BRR under this program. It was inserted for operation on January 25, 1963, at the onset of Reactor Cycle 123. It operated successfully for a total of 2156.2 hr after which time it was dismantled and returned to CANEL. The date of removal from the BRR core was May 14, 1963.

PW-392-2

Ion chamber PW-392-2 was identical to Unit PW-392-1 and was inserted for operation on January 31, 1963. After it had performed successfully for 2303.3 hr in its original position, it was repositioned in a thermal-neutron flux which was about 1/50 the original. This change took place on May 28, 1963. It continued to operate without difficulty for the remainder of its testing period, which essentially ended on July 6, 1964, after 10,283.5 hr in pile. At that time, it was again repositioned in a still lower flux where it will continue to operate indefinitely on a loan basis from CANEL. Only the output current will be monitored for the remainder of the operation.

PW-391-1

This ion chamber was manufactured by General Electric and operated under conditions similar to those of Unit PW-392-2. Unit PW-391-1 was inserted for operation on February 6, 1963, and performed successfully to the completion of its exposure. It was also repositioned in a lower flux on May 28, 1963 after it had operated for 2231.9 hr. On July 6, 1964, it was again repositioned in still lower flux conditions and will operate indefinitely on a loan basis. As of July 6, 1964, it had operated for 10,213.1 hr.

PW-402-1

This ion chamber was also manufactured by General Electric. It was inserted for operation on February 13, 1963, and operated successfully to completion on July 6, 1964. It was then returned to CANEL for inspection. It had been repositioned on May 28, 1963, after 2086.2 hr in pile and completed its total operational time of 10,066.4 hr in a lower flux position.

PW-388-1

Fission Counter PW-388-1 was manufactured by Reuter-Stokes and was inserted for testing on February 24, 1963. It, along with the other three fission counters subsequently inserted, was repositioned on April 17, 1963, to provide more reactor space. Trouble developed in the experiment during Reactor Cycle 130, and on May 7, 1963, the unit was removed from the BRR core. After a suitable "cooling" period, the unit was opened; it was found that moisture had condensed inside the capsule and caused the pre-amplifier cable to short out. The cable was replaced, and the unit was reinserted on May 22. The unit was repositioned in a lower flux on July 8, 1963, after it had operated for 2485.1 hr. On August 3, 1964, when it had been exposed a total of 10,123.0 hr, it was removed from the core and returned to CANEL. During the several thousand hours of operation in the lower flux position, the chamber did not always function properly. The output was quite erratic at times, and on a few occasions, there was no output. These difficulties are all described in the log book for the fission counters.

PW-388-2

Fission Counter PW-388-2 was also manufactured by Reuter-Stokes. The unit was inserted on March 4, 1963, and was removed from the core on June 24, 1963, after successfully operating for 2258.6 hr.

PW-390-1

Unit PW-390-1 was a General Electric fission counter. During the preirradiation checkout, difficulties were experienced with the unit, and it was necessary to substitute another preamplifier. The unit was then inserted for operation on March 20, 1963. After operating successfully for 2273.5 hr, it was repositioned in a lower flux, where it was to continue operation for an additional 8000 hr. However, on August 13, 1963, a malfunction developed in the preamplifier, and the unit was removed from the core and eventually returned to CANEL. The experiment had operated for a total of 2978.0 hr.

PW-401-1

This General Electric fission counter was inserted for operation on March 20, 1963. It operated successfully for 2284.1 hr and was then removed from the core (July 8, 1963) and returned to CANEL.

Electrical Units

There were six electrical units irradiated at the BRR: two limit switches, two scram motors, and two shim motors. Figure 30 shows, in general, a representation of an electrical unit and the placement of the 6-mil cadmium cover. Figure 13 shows the placement of the various electrical units with respect to the reactor core. Photographs of the electrical units during operation are shown in Figure 31.

The control panels for the electrical units were placed on the third floor of the BRR. A photograph of these instruments is shown in Figure 32. The electrical units performed successfully throughout their entire exposure, with the exception of Shim Motor PW-389-1. Midway in its testing period the motor current became higher for one direction of the motor's rotation than for the other, and it remained such throughout the remainder of the test.

All the electrical units were operated so that the temperature in the center of each experiment was near 600 F.

PW-387-2

The first limit switch was inserted for operation on December 11, 1963, and was removed on April 13, 1964, after 2618.7 hr in pile.

PW-387-3

The second limit switch was inserted on January 9, 1964, and was removed on April 13, 1964, after 1961.1 hr in pile.

PW-386-1

The first scram motor was inserted on January 9, 1964, and removed after 1998.4 hr of operation on April 13, 1964.

PW-386-3

The second scram motor was inserted for operation on January 22, 1964 and was removed on April 27, 1964. It operated for 2007.1 hr.

PW-389-1 and PW-389-2

Both shim motors were inserted for operation on April 15, 1964. Unit PW-389-2 was removed from the core on August 3, 1964, after 2222.1 hr of operation and Unit PW-389-1 was removed on August 17, 1964, after 2508.7 hr of operation.

Miscellaneous Items

The miscellaneous items which were irradiated under this program were two preamplifiers, a scram-motor rotor, carbon brushes, beryllium and beryllium oxide samples, and a control-motor winding.

Figure 33 gives a representation of a preamplifier housing and Figure 34 shows the preamplifiers during operation. Figure 35 shows the preamplifier instrument panel to the right of a sensor panel. The preamplifiers were operated at temperatures near 250 F. Figure 36 shows the preamplifier placement, and Figure 37 shows the placement of all the remaining samples with respect to the BRR core.

Preamplifiers

The preamplifiers were irradiated in the shielding pool located adjacent to the BRR thermal column. They were inserted on April 1, 1964, and removed on June 8, 1964. They both performed without fault for 1395.0 hr before being returned to CANEL.

Scram-Motor Rotor and Carbon Brushes

The scram motor rotor and carbon brushes were attached together and irradiated from February 1, 1963 to April 29, 1963 for a total of 1707.3 hr. Temperature readings were to have been taken in the scram-motor-rotor capsule during the irradiation, but a short developed in the thermocouple and no readings were obtained.

Control-Motor Winding

The control-motor winding was inserted near the reactor-core face on February 20, 1963, and was removed on April 1, 1963 after a 793.1 hr irradiation.

Beryllium and Beryllium Oxide Samples

These samples were irradiated together in a test cell of the BRR for 571.7 hr beginning on April 3, 1963, and ending on April 29, 1963.

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FIGURE 1. INITIATION AND TERMINATION DATES AND TOTAL TESTING TIME FOR EACH UNIT IRRADIATED AT THE BRR

FIGURE 2. SKETCH OF REACTOR POOL AND FACILITIES

FIGURE 3. VIEW LOOKING DOWN AT TOP OF POOL

N33923

N69406

FIGURE 4. PHOTOGRAPH OF EXTERIOR OF POOL

TABLE 1. TARGET CONDITIONS FOR EACH UNIT IRRADIATED AT THE BRR FOR PRATT AND WHITNEY

Experiment	Capsule	Test Hr	Total Fast- Neutron Exposure ^(a) , n/cm ²	Thermal-Neutron Flux ^(b) , n/(cm ²)(sec)	Fast-Neutron Flux ^(a) , n/(cm ²)(sec)	Gamma Dose Rate, roentgens/ hr
Ion chamber	PW-392-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^6 to 10^8
Ion chamber	PW-392-2	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^6 to 10^8
		8,000		5×10^8	3×10^8	10^5 to 10^7
Ion chamber	PW-391-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^6 to 10^8
		8,000		5×10^8	3×10^8	10^5 to 10^7
Ion chamber	PW-402-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^6 to 10^8
		8,000		5×10^8	3×10^8	10^5 to 10^7
Fission counter	PW-388-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^5 to 10^7
		8,000		1×10^7	3×10^6	10^4 to 10^5
Fission counter	PW-388-2	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^5 to 10^7
Fission counter	PW-390-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^3 to 10^5
		8,000		1×10^7	3×10^6	10^3 to 10^5
Fission counter	PW-401-1	2,000		1×10^9 to 2×10^{10}	1×10^9 to 2×10^{10}	10^5 to 10^7
Scram-motor brushes	PW-100-D		1×10^{19}			
Scram-motor brushes	PW-100-E		1×10^{19}			
Scram-motor brushes	PW-100-F		1×10^{19}			
Scram-motor brushes	PW-100-G		1×10^{19}			
Scram-motor brushes	PW-101-1		1×10^{19}			
BeO sample	PW-103-5	500	Minimum of 1×10^{19}		Minimum of 5×10^{12}	
BeO sample	PW-103-6	500	1×10^{19}		5×10^{12}	
BeO sample	PW-103-7	500	Minimum of 1×10^{19}		Minimum of 5×10^{12}	
BeO sample	PW-103-8	500	1×10^{19}		5×10^{12}	
Be sample	PW-104-1	500	1×10^{19}		5×10^{12}	
Be sample	PW-104-2	500	1×10^{19}		5×10^{12}	
Be sample	PW-104-3	500	1×10^{19}		5×10^{12}	
Be sample	PW-104-4	500	1×10^{19}		5×10^{12}	
Limit switches	PW-387-2	2,000		5×10^{11}	1×10^{12}	5×10^7
Limit switches	PW-387-3	2,000		5×10^{11}	1×10^{12}	5×10^7
Scram motor	PW-386-1	2,000		5×10^{11}	1×10^{12}	5×10^7
Scram motor	PW-386-3	2,000		5×10^{11}	1×10^{12}	5×10^7
Shim motor	PW-389-1	2,000		5×10^{11}	1×10^{12}	5×10^7
Shim motor	PW-389-2	2,000		5×10^{11}	1×10^{12}	5×10^7
Preamplifier	PW-455-1	10,000		1×10^6 to 1×10^7	3×10^5 to 3×10^6	2×10^3
Preamplifier	PW-455-2	10,000		1×10^6 to 1×10^7	3×10^5 to 3×10^6	2×10^3

(a) Greater than 1.0 Mev.

(b) Less than 0.4 ev.

TABLE 2. FAST-NEUTRON THRESHOLD DETECTORS

Detector	Threshold Energy, Mev	Cross Section, mb
$\text{In}^{115}(n, n')\text{In}^{115m}$	1.4	229
$\text{Ni}^{58}(n, p)\text{Co}^{58}$	2.5	226
$\text{S}^{32}(n, p)\text{P}^{32}$	2.9	278
$\text{Al}^{27}(n, \alpha)\text{Na}^{24}$	6.9	40

TABLE 3. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURES FOR IONIZATION CHAMBER PW-392-1

Distance From Bottom of Chamber, in.	Total Thermal Exposure, 10^{17} n/cm^2	Total Fast Exposure, 10^{15} n/cm^2
0.5	1.46	8.15
1.5	1.52	8.90
2.5	1.46	8.78
3.5	1.36	8.29
4.5	1.22	7.61
5.5	1.03	6.70
6.5	0.830	5.60
7.5	0.713	4.80
8.5	0.574	3.99
9.5	0.470	3.23
10.5	0.367	2.71
11.5	0.293	2.35
Average	0.940	5.93

TABLE 4. GAMMA DOSE RATE AND TOTAL GAMMA DOSE FOR IONIZATION CHAMBERS(a)

Unit	Gamma Dose Rate(b)		Total Gamma Dose(c)	
	10^5 REP/Hr	10^{-3} W/G	10^9 REP	W-Hr/G
PW-392-1	7.4	1.7	1.6	3.7
PW-392-2	5.9	1.4	6.0	14.0
PW-391-1	8.6	2.0	8.8	20.2
PW-402-1	3.6	0.83	3.6	8.4

(a) Averaged over length of each ion chamber.

(b) Averaged over total time in pile.

(c) Carbon dose.

TABLE 5. CADMIUM-RATIO MEASUREMENTS FOR IONIZATION CHAMBERS(a)

Unit	Cobalt-Cadmium Ratio
PW-392-1	71.5(b)
PW-392-2	54.5
PW-391-1	54.8
PW-401-1	74.7

(a) Averaged over length of each ion chamber.

(b) Taken into account in dosimetry results listed in Table 3.

TABLE 6. ESTIMATED TOTAL THERMAL- AND FAST-NEUTRON EXPOSURES FOR IONIZATION CHAMBERS PW-391-1 AND PW-392-2

Unit	Total Thermal-Neutron Exposure, 10^{17} n/cm ²	Total Fast-Neutron Exposure, 10^{15} n/cm ²
PW-391-1(a)	0.83	5.1
PW-392-2(b)	1.1	4.5

(a) Based on 10,213.1 hr in pile.

(b) Based on 10,283.5 hr in pile.

TABLE 7. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURES FOR FISSION COUNTERS

Distance From Bottom of Chamber, in.	PW-388-2		PW-401-1		PW-390-1	
	Total Thermal Exposure, 10^{16} n/cm ²	Total Fast Exposure, 10^{15} n/cm ²	Total Thermal Exposure, 10^{16} n/cm ²	Total Fast Exposure, 10^{15} n/cm ²	Total Thermal Exposure, 10^{15} n/cm ²	Total Fast Exposure, 10^{15} n/cm ²
0.5	1.31	3.43	1.20	3.72	8.27	2.57
1.5	1.28	3.43	1.29	3.96	8.33	2.63
2.5	1.25	3.35	1.29	4.05	8.48	2.64
3.5	1.23	3.30	1.31	4.08	8.66	2.67
4.5	1.21	3.28	1.29	4.07	8.32	2.63
5.5	1.13	3.16	1.29	4.02	8.42	2.64
6.5	1.11	3.06	1.28	3.98	8.21	2.60
7.5	1.05	2.91	1.23	3.90	8.05	2.58
8.5	0.982	2.80	1.16	3.74	7.82	2.47
9.5	0.903	2.62	1.07	3.55	7.50	2.38
Average	1.14	3.13	1.24	3.91	8.21	2.58

TABLE 8. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURES FOR FISSION-COUNTER PREAMPLIFIERS

Unit	Average Total Thermal Exposure, 10^{13} n/cm ²	Average Total Fast Exposure, 10^{11} n/cm ²
PW-388-2	1.96	2.60
PW-401-1	3.84	5.10
PW-390-1	1.33	3.66
PW-388-1	(a)	(a)

(a) Dosimeter wires are to be analyzed at CANEL.

TABLE 9. GAMMA DOSE RATE AND TOTAL GAMMA DOSE FOR FISSION COUNTERS AND FISSION-COUNTER PREAMPLIFIERS^(a)

Unit	Gamma Dose Rate ^(b)		Total Gamma Dose ^(c)	
	REP/Hr	W/G	REP	W-Hr/G
PW-388-2	7.1×10^5	1.6×10^{-3}	1.6×10^9	3.8
PW-388-2 (preamp)	1.4×10^4	3.2×10^{-5}	3.1×10^7	0.072
PW-401-1	7.0×10^5	1.6×10^{-3}	1.6×10^9	3.7
PW-401-1 (preamp)	2.0×10^4	4.6×10^{-5}	4.5×10^7	0.11
PW-390-1	7.1×10^5	1.6×10^{-3}	2.1×10^9	5.0
PW-390-1 (preamp)	1.9×10^4	4.4×10^{-5}	5.8×10^7	0.14
PW-388-1	3.9×10^5	9.0×10^{-4}	3.9×10^9	8.95
PW-388-1 (preamp)	7.1×10^3	1.6×10^{-5}	7.2×10^7	0.17

(a) Averaged over lengths of fission counters or preamplifiers.

(b) Averaged over total time in pile.

(c) Carbon dose.

TABLE 10. COBALT-CADMIUM RATIO FOR FISSION COUNTERS

Unit	Cobalt-Cadmium Ratio
PW-388-1	>100
PW-388-1 (preamp)	>100
PW-388-2	37.5 ^(a)
PW-388-2 (preamp)	>100
PW-390-1	53.5 ^(a)
PW-390-1 (preamp)	>100
PW-402-1	33.0 ^(a)
PW-402-1 (preamp)	>100

(a) Taken into account in dosimetry results listed in Tables 7, 8, and 9.

TABLE 11. GAMMA DOSE RATE IN THE FOUR ELECTRICAL-UNIT IRRADIATION POSITIONS

Position	Gamma Dose Rate ^(a)	
	10^7 REP/Hr	10^{-2} W/G
1	2.8	6.5
2	3.0	7.0
3	2.0	4.7
4	3.0	7.0

(a) Carbon dose.

TABLE 12. VERTICAL DISTRIBUTION OF COBALT-CADMIUM RATIO IN ELECTRICAL-UNIT POSITIONS

Distance From Bottom of Capsule, in.	Cobalt-Cadmium Ratio			
	Position 1	Position 2	Position 3	Position 4
0.5	9.4	11.0	2.10	5.5
1.5	9.3	11.3	2.36	5.5
2.5	10.0	11.8	2.72	5.6
3.5	10.0	11.7	3.43	5.8
4.5	10.7	12.1	3.96	5.8
5.5	10.6	13.0	4.68	6.2
6.5	12.1	13.8	6.43	7.1
7.5	14.9	16.0	8.58	9.5
8.5	18.0	20.3	11.74	12.0

FIGURE 5. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURE IN ION CHAMBER PW-392-1

FIGURE 6. NEUTRON SPECTRUM FOR ION CHAMBER PW-392-2

FIGURE 7. NEUTRON SPECTRUM FOR ION CHAMBER PW-391-1

FIGURE 8. NEUTRON SPECTRUM FOR ION CHAMBER PW-402-1

FIGURE 9. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURE FOR FISSION COUNTER PW-388-2

FIGURE 10. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURE FOR FISSION COUNTER PW-401-1

FIGURE 11. TOTAL THERMAL- AND FAST-NEUTRON EXPOSURE FOR FISSION COUNTER PW-390-1

FIGURE 12. NEUTRON SPECTRUM FOR FISSION COUNTER PW-388-1

FIGURE 13. ELECTRICAL-UNIT POSITIONS

FIGURE 14. UNPERTURBED FAST-NEUTRON FLUX IN ELECTRICAL-UNIT POSITIONS AT REACTOR POWER OF 2 MEGAWATTS

FIGURE 15. NEUTRON SPECTRUM IN POSITION 1

FIGURE 16. NEUTRON SPECTRUM IN POSITION 2

FIGURE 17. NEUTRON SPECTRUM IN POSITION 3

FIGURE 18. NEUTRON SPECTRUM IN POSITION 4

FIGURE 19. COBALT-CADMIUM RATIO IN ELECTRICAL-UNIT POSITION 1

FIGURE 20. COBALT-CADMIUM RATIO IN ELECTRICAL-UNIT POSITION 2

FIGURE 21. COBALT-CADMIUM RATIO IN ELECTRICAL-UNIT POSITION 3

FIGURE 22. COBALT-CADMIUM RATIO IN ELECTRICAL-UNIT POSITION 4

TABLE 13. VERTICAL DISTRIBUTION OF COBALT-CADMIUM RATIO FOR PREAMPLIFIERS

Inches From Bottom of Capsule	Cobalt-Cadmium Ratio	
	PW-455-1	PW-455-2
1	49.7	51.8
2	48.9	53.7
3	49.1	68.6
4	49.4	54.7
5	50.4	65.3
6	50.8	68.8
7	46.1	67.4
8	45.7	66.1
9	48.3	68.7
10	46.6	83.1

FIGURE 23. NEUTRON SPECTRUM IN LOCATION OF PREAMPLIFIERS

A-48829

FIGURE 24. FLUX-SENSOR TEST UNITS

FIGURE 25. TWO VIEWS OF NEUTRON SENSORS DURING IRRADIATION

FIGURE 25. (CONTINUED)

FIGURE 26. INITIAL SENSOR POSITIONS

FIGURE 27. FISSION-COUNTER POSITIONS AS OF APRIL 17, 1963

FIGURE 28. FINAL LOW-FLUX SENSOR POSITIONS

14760

FIGURE 29. NEUTRON-SENSOR INSTRUMENT CONSOLE

FIGURE 29. (CONTINUED)

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FIGURE 30. OUTER HOUSING FOR ELECTRICAL UNIT

8013

FIGURE 31. TWO VIEWS OF ELECTRICAL UNITS DURING IRRADIATION

8012

FIGURE 31. (CONTINUED)

FIGURE 32. ELECTRICAL-UNIT INSTRUMENT CONSOLE

FIGURE 33. OUTER HOUSING FOR PREAMPLIFIERS

10711

FIGURE 34. PREAMPLIFIERS DURING IRRADIATION

FIGURE 35. PREAMPLIFIER
INSTRUMENT CONSOLE
(RIGHT)

FIGURE 36. PREAMPLIFIER LOCATION IN THE BRR

FIGURE 37. PLACEMENT OF MISCELLANEOUS ITEMS WITH RESPECT TO BRR CORE