FZK-184-3
13 SEPTEMBER 1964

NERVA COMPONENTS IRRADIATION PROGRAM

Volume 3: GTR Test 13

Prepared for
Space Nuclear Propulsion Office
of the
National Aeronautics and Space Administration
Cleveland, Ohio

Contract No. AF 29(601)-6213
Supplement 1

NUCLEAR AEROSPACE RESEARCH FACILITY

operated by

GENERAL DYNAMICS | FORT WORTH

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Volume 3: GTR Test 13

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15/W002	Control Drum Plate Section
23/A406	Developmental Strain Gages
23/A407	Strain Gages
23/L302	High-Temperature Thermocouples
23/W003	Piezoelectric Ceramic Discs

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GENERAL DYNAMICS | FORT WORTH

FOREWORD

The test described in this document is designated SNPO-C, GTR-13. This is the thirteenth in a series of tests of NERVA components being performed by the Nuclear Aerospace Research Facility (NARF) of General Dynamics/Fort Worth for the Space Nuclear Propulsion Office, Cleveland, Ohio (SNPO-C). The 3-Mw Ground Test Reactor (GTR) and the 10-Mw Aerospace Systems Test Reactor (ASTR) are being used for these tests. Results of the first eight tests, performed under Contract AF33(657)-7201, may be found in GD/FW Report FZK-170, Volumes 1 through 8. Subsequent tests are being performed under Supplement 1 of Contract AF29(601)-6213 and are reported in GD/FW Report FZK-184, starting with the GTR-11 test as Volume 1.

SUMMARY

The tenth in the series of irradiation tests using the Ground Test Reactor at the Nuclear Aerospace Research Facility (NARF) to determine the effects of reactor radiation on candidate NERVA engine components was concluded on 12 June 1964. The items in the test, designated GTR-13, include strain gages, thermocouples, a control drum plate section, and piezoelectric ceramic discs.

The results of the test are described briefly in the following paragraphs (except where noted, all integrated fluxes are for neutron with E > 2.9 Mev).

<u>Developmental Strain Gages</u>

<u>East reactor position</u>. Sixteen Microdot strain gage pairs, which had been previously irradiated for 150 Mw-hours in GTR-12A, were to have been irradiated while immersed in liquid nitrogen; however, all gage pairs failed before reactor startup so no irradiation data were acquired.

<u>West reactor position</u>. Twenty Microdot full bridge strain gages were exposed to integrated neutron fluxes ranging from 9.3×10^{15} to 1.1×10^{16} n/cm^2 and gamma doses ranging from 6.3×10^{10} to 6.6×10^{10} ergs/gm(C). The gages were mounted in a fixture which was immersed in liquid nitrogen throughout the test. The output voltages were recorded when the gages were periodically flexed. There was little evidence of null (zero) shifts. Two gages showed decreases in sensitivity, the greater value being 50%. Of utmost significance was the failure of nine gages during the laboratory preirradiation temperature cycle, the failure of eight gages during the laboratory postirradiation temperature cycle, and the failure of only two gages during irradiation. It is apparent that this high failure rate is due to some cause other than irradiation.

Thermocouples

Two thermocouples were tested at temperatures to 2500°F. The thermocouples, one tungsten versus tungsten with 26% rhenium (W/W-26Re) and one tungsten with 5% rhenium versus tungsten with 26% rhenium (W-5Re/W-26Re), were exposed to integrated neutron fluxes ranging from 6.1×10^{16} to 7.4×10^{16} n/cm^2 and gamma doses ranging from 2.1×10^{11} to 2.4×10^{11} ergs/gm(C). The ratio of thermocouple output to heater input power was calculated at the beginning and end of the test. The percent deviation of these calculations is shown below.

Thermocouple	Deviation (%)
W/W-26Re	-10.9
W-5Re/W-26Re	-31.3

Control Drum Plate Section

A boron-aluminum control drum plate section and eight tensile test specimens of the same material were irradiated at LN_2 temperatures. The tensile specimens were irradiated under no load conditions. The control drum plate section was irradiated under tensile load of 500 lb in a special test fixture.

The boral shield, normally used to attenuate thermal neutrons, was removed from the reactor face. In addition polyethylene was positioned in front of the specimens for maximum thermalization of the fast neutron flux.

The plate section and tensile specimen were exposed to integrated neutron fluxes ranging from 1.2×10^{16} to 2.1×10^{16} n/cm^2 ($E > 2.9$ Mev) and from 2.3×10^{16} to 6.5×10^{16} n/cm^2 ($E < 0.48$ ev). The gamma dose ranged from 1.0×10^{11} to 1.3×10^{11} ergs/gm(C).

Preirradiation tests were conducted at WANL by Westinghouse personnel. The specimens were returned to WANL after the irradiation so that postirradiation tests could be performed. Only temperature data were taken during the radiation.

Hardness, dimension, weight, dye penetrant and metallography tests are being performed on the control drum plate section. Conventional tensile tests are being performed on the tensile test specimens.

Piezoelectric Ceramic Discs

Thirty-four piezoelectric ceramic discs were irradiated in the reactor core. They were exposed to an integrated neutron flux of 7.3×10^{17} n/cm^2 and a gamma dose of 1.5×10^{12} ergs/gm(C). Gaseous nitrogen was used for the cooling agent. However, the temperature of the discs became excessive during irradiation at the 3 Mw power level. It is believed that these discs are depolarized when and if a specific temperature is surpassed. Postirradiation analysis indicates that the discs are depolarized. Therefore, a comparison of the pre- and postirradiation data cannot be presented.

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I. INTRODUCTION

A series of tests is being performed at the Nuclear Aerospace Research Facility (NARF) of General Dynamics/ Fort Worth to determine the effects of nuclear radiation on components proposed for application in the NERVA engine. The Aerojet-General Corporation has prime responsibility for development of the NERVA engine; the nuclear reactor in the engine is being developed by the Westinghouse Electric Corporation.

This report deals with the tenth irradiation, designated GTR 13, of the series performed with the Ground Test Reactor (GTR). This test was performed in accordance with test specifications submitted by the Aerojet-General Corporation (AGC), Azusa, California (Ref. 1). Test components and assemblies were furnished by AGC and the Westinghouse Astronuclear Laboratory (WANL), Large, Pennsylvania.

The GTR 13 test included developmental strain gages, thermocouples, control drum plate section, and piezoelectric ceramic discs. The developmental strain gages were tested in two assemblies. However, all gages on one assembly failed prior to start of irradiation.

Section II contains general information pertaining to the components that were tested and the manner in which the tests were performed. In Sections III through VI, the test components are discussed individually. Each section contains a description of the test method, data presented in graphic and tabular form, and a brief discussion of the effects observed by NARF personnel.

II. EXPERIMENTAL ARRANGEMENT AND PROCEDURE

2.1 Experimental Arrangement

This test was performed with the Radiation Effects Testing System. This system consists primarily of (1) the 3-Mw Ground Test Reactor contained in a closet, (2) a test cell adjacent to the closet, (3) environmental control equipment, (4) equipment for moving test assemblies into the three irradiation positions around the reactor closet, and (5) safety and emergency equipment. These facilities are described briefly in Appendix A. A detailed description is given in Reference 2.

The reactor core and all three irradiation positions (the north, the east, and the west) were utilized in this experiment. Modified NASA-type dewars were installed in the east and west positions and a specially-designed test fixture was installed in the north position. A dummy fuel element containing test specimens was installed in the reactor core.

The west dewar contained a developmental strain gage fixture, while the east dewar contained a developmental strain gage fixture, a control drum plate section, and static material specimens. The control drum plate section was irradiated in a stressed condition by means of a spring-clamp arrangement, while the static material specimens were mounted in aluminum holders and attached to the assembly framework. The developmental strain gages were tested dynamically by flexing the beams upon which they were installed.

The boral shield was removed from the east reactor face and a 1/2-in. polyethylene shield placed in front of the control drum plate section and static material specimens to obtain maximum thermalization of the fast-neutron flux.

Both dewars were filled with liquid nitrogen (LN_2) during the experiment and the specimens were maintained at -320°F.

The north position was occupied by the thermocouple test. The thermocouples were mounted in heaters that were operated during data cycles to a temperature of approximately 2500°F.

The piezoelectric ceramic discs were located in a dummy fuel element. The element was positioned in the northwest corner of the reactor core. Gaseous nitrogen was purged through the dummy fuel element as a cooling medium. However, with maximum permissible gas flow, the specimen temperature exceeded the expected value.

The test assemblies were connected to instrumentation located within the control room with electrical harnesses and pneumatic lines approximately 120 feet in length.

2.2 Experimental Procedures

Before moving the items to the reactor area, data were recorded at ambient temperatures and at test temperatures using the same harnesses and instrumentation used in the test.

Only temperature data were taken on the piezoelectric ceramic discs and the control drum plate section during the irradiation.

In order to detect any dose-rate effect at the start of the test, data were recorded at reactor power levels of 10 kw, 100 kw, and 1 Mw before reaching the 3-Mw power level. Data were also recorded from the thermocouples during a manual shutdown after approximately 75 Mw-hr. This was done to determine if a sudden power level change would affect the thermocouple output.

The irradiation period for the items located in the irradiation cell was 290 Mw-hr while the irradiation time for the ceramic discs located in the core was 295 Mw-hr. GTR irradiation profiles are shown in Figures 2-1 and 2-2 for the irradiation cell and the reactor core, respectively.

Standard dosimetry techniques were used in measuring the integrated neutron fluxes and gamma doses to which the test items were exposed. The application of these techniques in determining the radiation exposures is discussed in Appendix B.

In the sections dealing with strain gages and thermocouples, will be found data that have been plotted to show the test parameters as a function of radiation exposure. The form, which is standard throughout this report, includes a small block for preirradiation data, a block for data recorded at each of the logarithmic increases in reactor power level, a large block for data taken during the 3-Mw irradiation, and a small block for postirradiation data. Data taken at the 3-Mw irradiation were plotted as a function of integrated power in thousands of megawatt-minutes (Mw-min x 10^{-3}). This scale

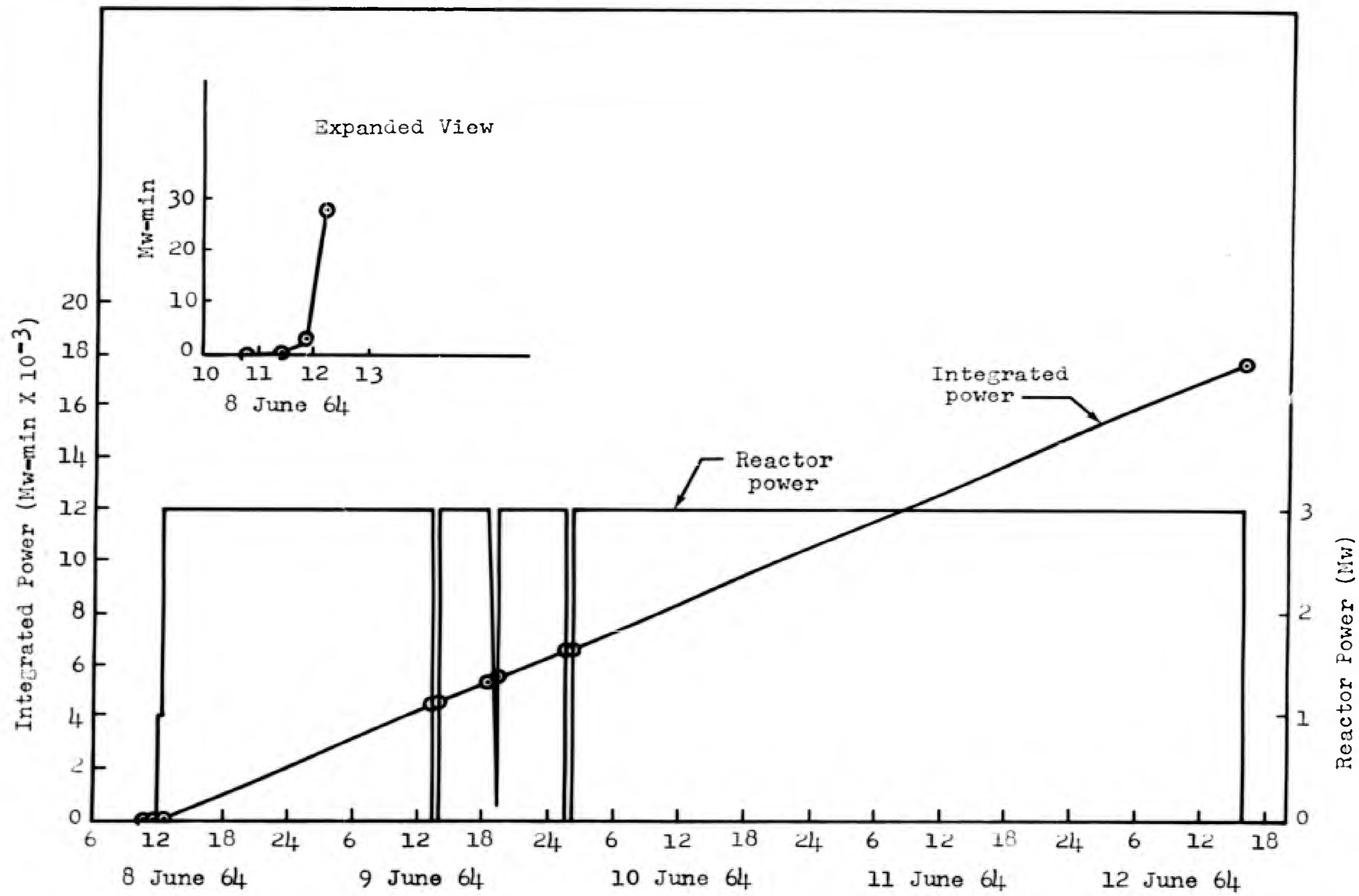

Figure 2-2 Reactor Power Profile: Reactor Core

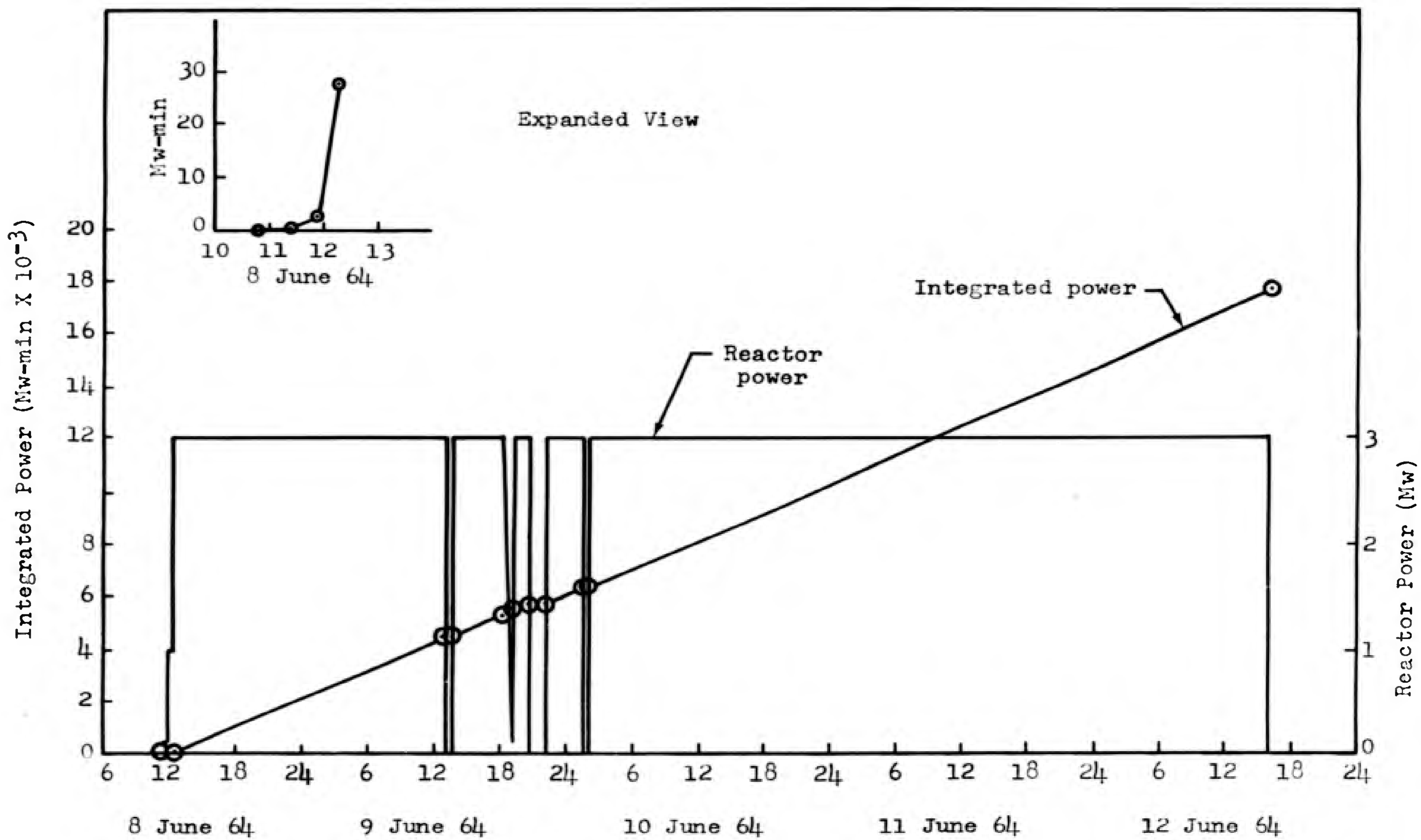

Figure 2-1 Reactor Power Profile: Irradiation Cell

appears above the top of the graph.

To relate the data to total irradiation exposure, integrated neutron flux and gamma dose scales have been placed at the bottom of the graph.

III. DEVELOPMENTAL STRAIN GAGES
(Tests 23/A406 and 23/A407)

3.1 Test Method

Twenty full-bridge weldable Microdot strain gages were irradiated at the west reactor position (Figs. 3-1 and 3-2). The gages tested along with the type beam to which each was attached are listed below:

- Ten Microdot SG 160/3 gages on five Inconel 750X beams (one on upper side of beam and one on lower);
- Ten Microdot SG 160/4 gages on five 6061 T6 aluminum alloy beams (one on upper side of beam and one on lower).

The beams were simultaneously flexed by two opposing bellows, each alternately pressurized with gaseous nitrogen. One bellows deflected the beams upward and the other bellows deflected the beams downward. Both bellows could be simultaneously vented to the atmosphere to provide a no-flexed (neutral) position.

Excitation of 10 v-dc was continuously applied to all bridges (Fig. 3-3). The output voltages were fed into a Hewlett-Packard Dymec 2010-D Digital Data Acquisition System. The Dymec recorded the data in two forms, printed tape and punched tape. The Dymec also sequentially provided a guard circuit to each bridge as its output was sampled (Fig. 3-3).

RCA Ultrasensitive Model WV-84C microammeters were used for insulation resistance and guard current measurements.

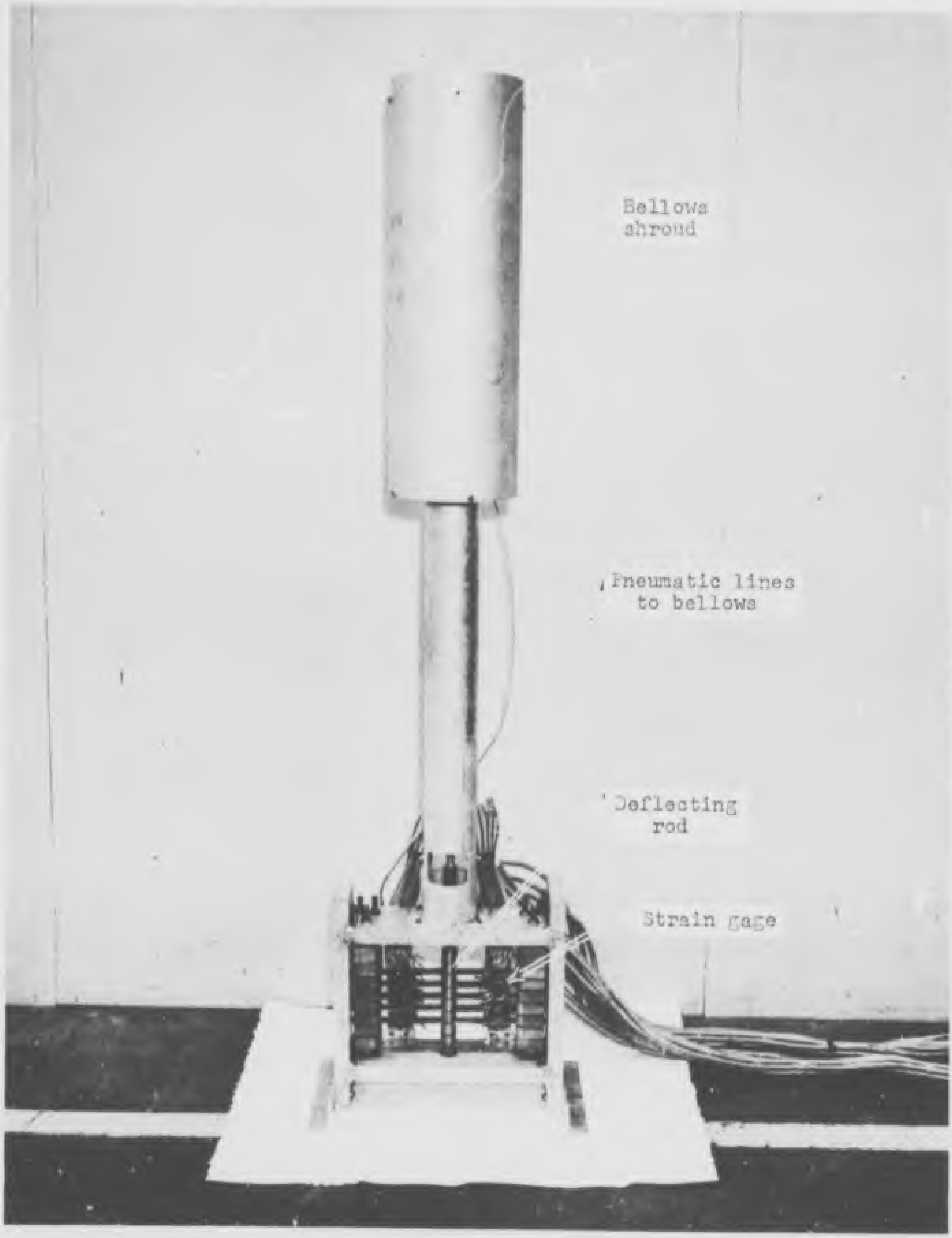

Figure 3-1 Developmental Strain Gage Fixture: West Dewar Position

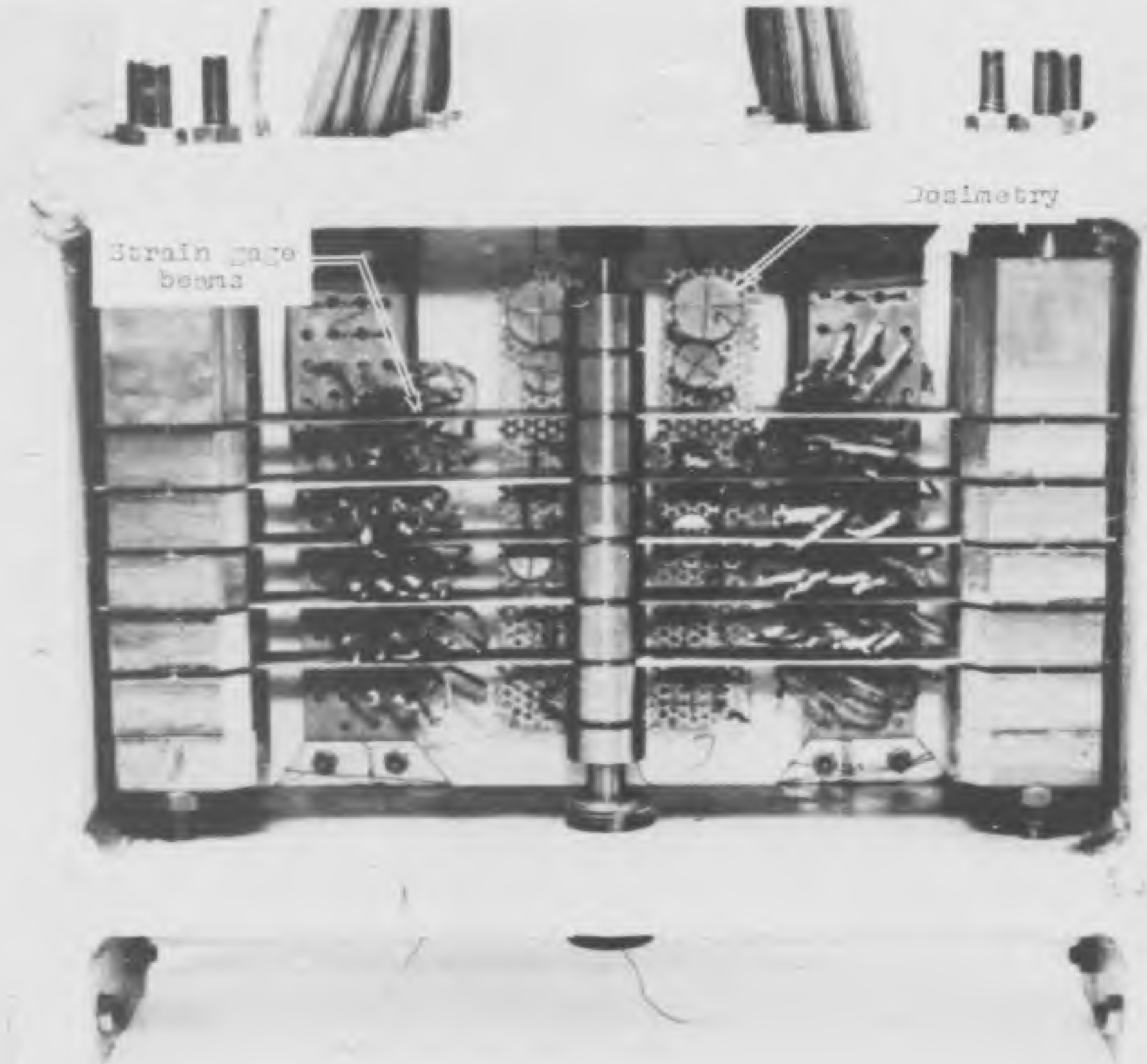

Figure 3-2 Developmental Strain Gages: West Dewar Position

C 21,446
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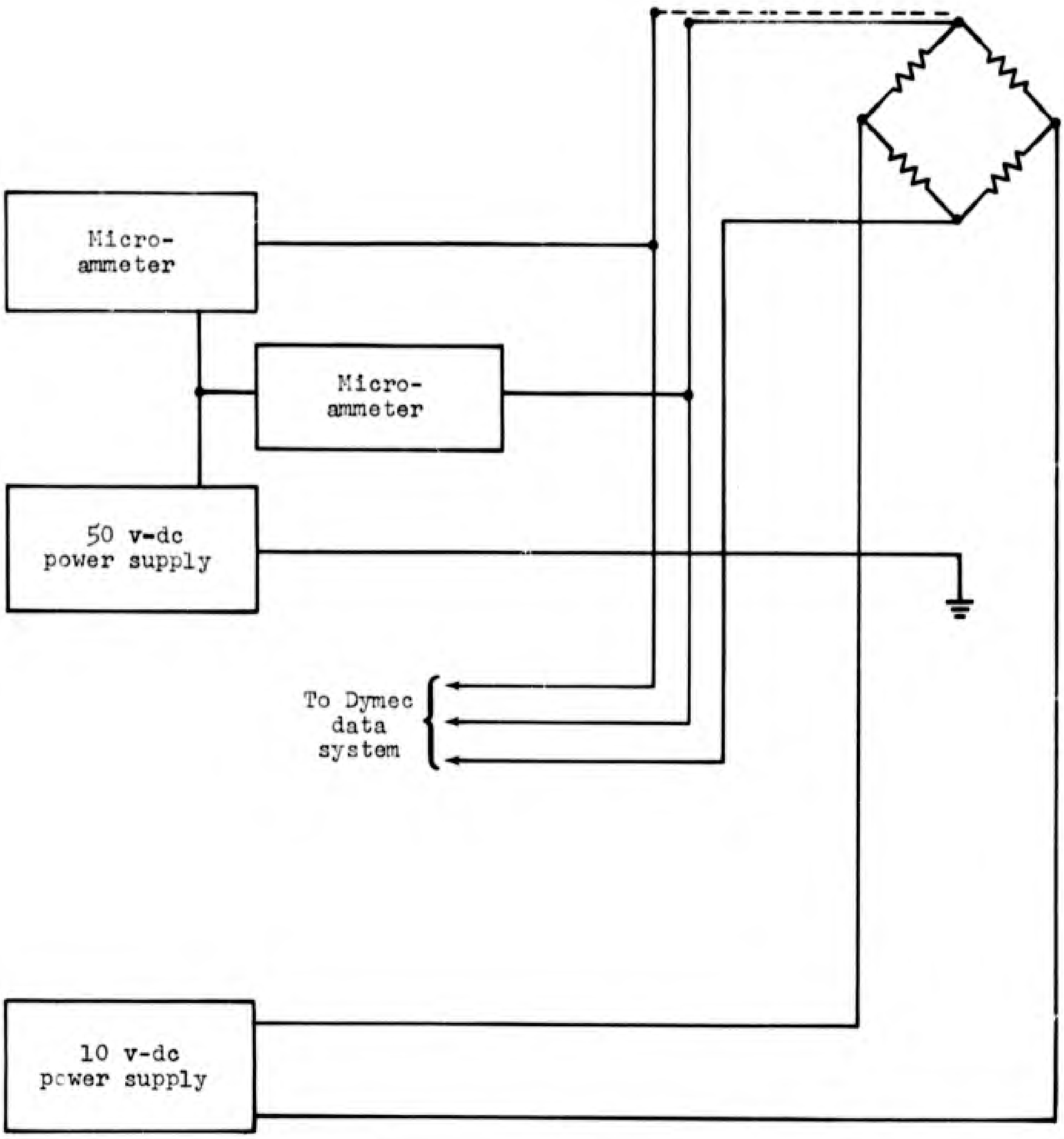

Figure 3-3 Electrical Schematic for GTR 13 Strain Gage Tests

Thirty-two (16 pairs) Microdot weldable strain gages were to have been irradiated at the east reactor position (Figs. 3-4 and 3-5). The gages along with the type of beams to which each was attached are listed below:

- Twelve Microdot SG 121 gages on six Inconel 750X beams (one on upper side of beam and one on lower);
- Ten Microdot SG 131 gages on five Inconel 750X beams (one on upper side of beam and one on lower);
- Ten Microdot SG 131 gages on five 6061 T6 aluminum alloy beams (one on upper side of beam and one on lower).

However, all gage pairs were inoperative before irradiation was initiated. All the right hand beams were removed at the direction of the resident AGC representative for the purpose of inspection and investigation into the cause of failure.

3.2 Data Presentation

East Irradiation Position

No data are presented for the strain gages scheduled for the east reactor position because all the gages were inoperative prior to reactor startup.

West Irradiation Position

The strain gage output voltages are plotted in Figures 3-6 through 3-19, directly from the "deflected up" and "deflected down" readings at each data point. This method of presentation was chosen to reflect any null shifts which might have occurred. The "beam neutral" data readings were unreliable for the determination of null shifts because no mechanical means were provided on the test fixture to obtain a repeatable neutral (null) position.

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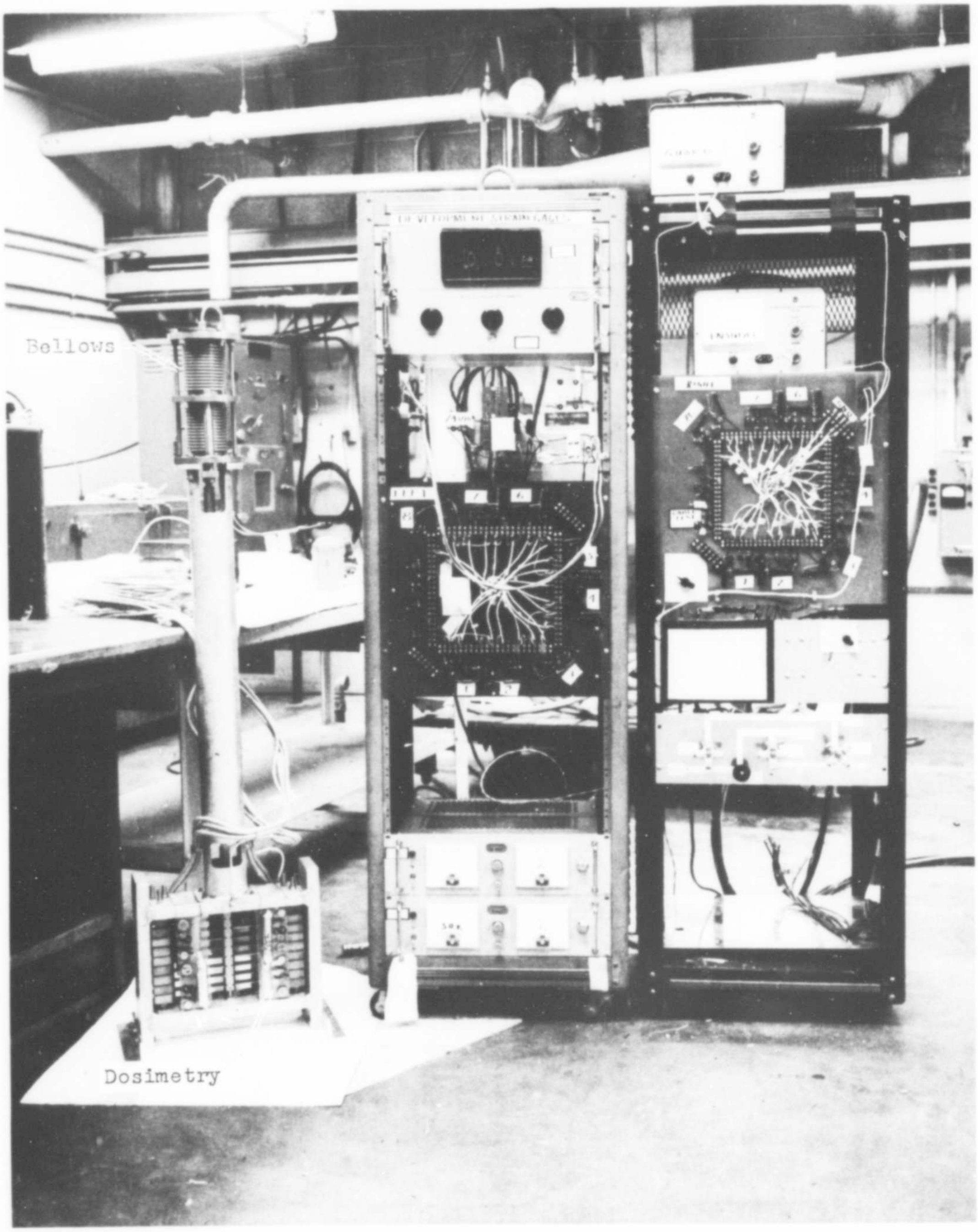

Figure 3-4 Developmental Strain Gages: East Fixture and Instrumentation

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31-7970

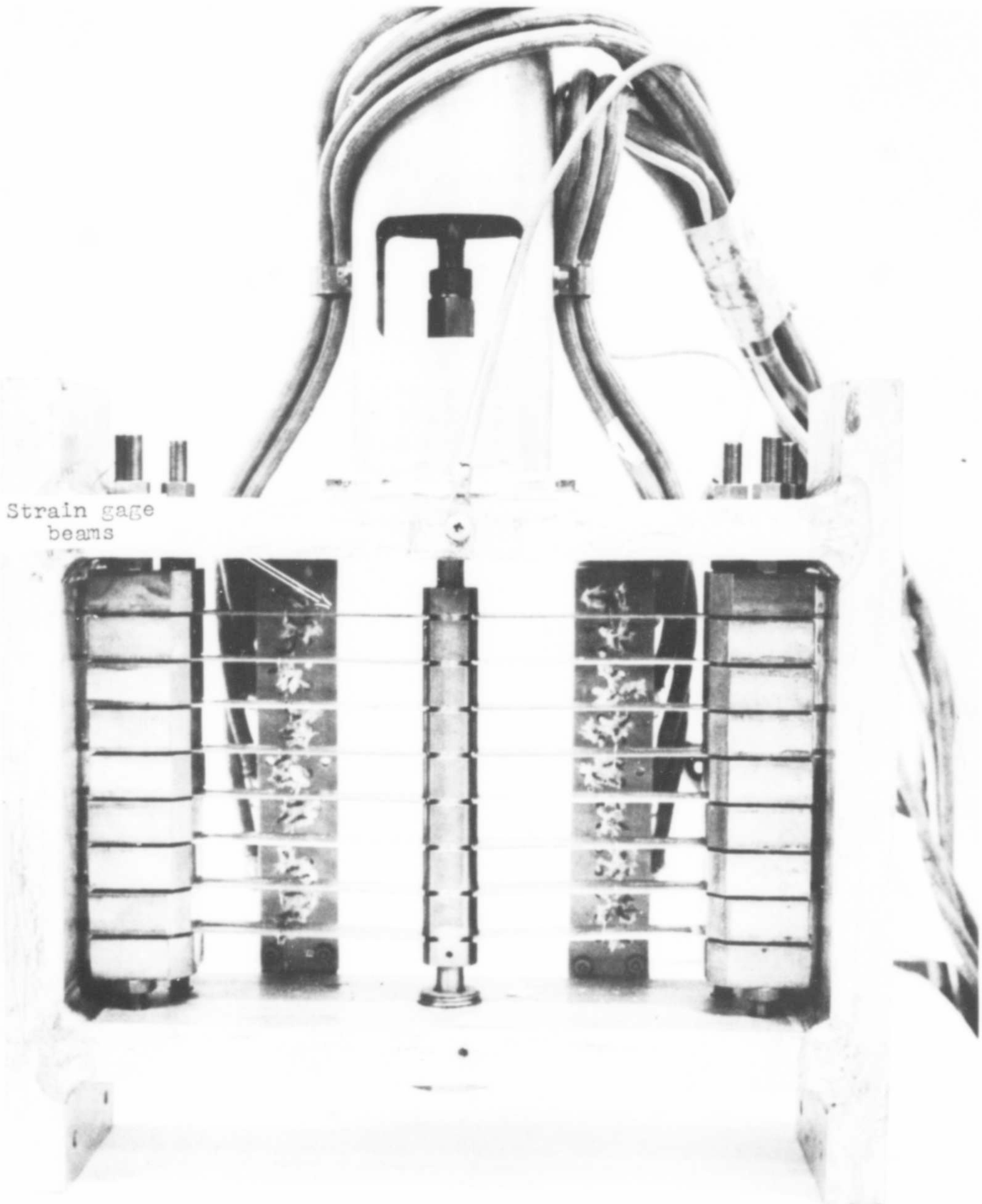

Figure 3-5. Developmental Strain Gages: East Dewar Position

The power-level portion of the abscissa in Figures 3-6 through 3-19 represents a logarithmic scale. The abscissa values for preirradiation are meaningless except for indicating sequence.

No irradiation response data are presented for the 2-LL (left lower), 3-LU, 4-LL, 2-RU, 3-RU and 4-RU strain gages because they were inoperative prior to the test.

Table 3-1 shows the insulation resistance values before, during and after irradiation.

3.3 Discussion

East Irradiation Position

The strain gages in the east reactor position had been previously irradiated for 150 Mw-hr in GTR-12A test. One gage lead opened (external to the gage) during the postirradiation warmup. This lead was repaired before the GTR-13 preirradiation lab-data runs were performed.

The circuits of gages 2-RU and 3-RU were found to be open during the preirradiation ambient data run. Electrical continuity checks determined that both gage filaments were open internally.

Seven more gages failed during the preirradiation lab LN_2 data run. Continuity checks determined that these failures were also internal.

All but two of the remaining gages failed during the preirradiation LN_2 data run in the reactor area (three days subsequent to the lab LN_2 data run).

The two remaining gages failed before reactor startup, so no irradiation data were obtained.

West Irradiation Position

Out of the twenty strain gages seven failed before reactor startup, two failed during irradiation, and one failed after postirradiation warmup to ambient temperature.

The insulation resistances were sensitive particularly to dose rate; the effect of accumulated dose being quite small in comparison. Six resistances dropped to values of less than one megohm. The final resistance values of gages 2-LU and 3-LU were 7.4 ohms and 215 ohms, respectively. However, these failures may very well have been of a mechanical nature instead of an effect of radiation.

Since the strain gage fixture was not provided with the capability of mechanically positioning the strain gages to a null (zero) condition, the exact determination of a zero shift is not possible. However, the output voltage data indicates no significant zero shifts.

Two gages experienced decreases in sensitivity during irradiation. However, postirradiation inspection revealed that both gages had partially pulled loose from the beams due to weld failure.

Fourteen days after irradiation a laboratory test was performed to determine the effects of ambient to LN_2 to ambient temperature cycling upon the irradiated gages. This was a static test, the beams remaining in a "no flexed" position from the time that the gages were immersed in LN_2 until they had warmed up to ambient temperature. The following is the chronological sequence of events which occurred during the test:

Time	Event
1122	Dewar containing gages filled with LN_2
1125	Gage fixture lifted out of LN_2
1220	Gage 4-LU failed
1230	Gage 1-RU failed
1250	Gage 5-LU failed
1300	All ice melted from beams
1310	Gage 5-RL failed
1320	Gage 1-LU failed
1325	Gage 3-LL failed
1340	Gage 2-RL failed
1445	Test terminated. Gage 5-LL still functioning.

Subsequent to the postanalysis test, the potting compound (50% Epon 828 and 50% Versamid 115) was dissolved from the gage to permit a visual inspection of the gage leads and completion network. The positive lead of most of the gages was found to have been eroded, apparently by electrolytic action as shown in the 100:1 micro-photographs in Figure 3-20. It is interesting to note that the sixteen strain gages which failed in the east fixture were not potted, and microscopic examination showed no indication of errosion of the external leads.

In conclusion, the significant aspect of this test was the failure of thirty five of the thirty-six gages in a manner that indicates a cause other than irradiation.

The lowering of the insulation resistance appears to be the only gage parameter affected by irradiation.

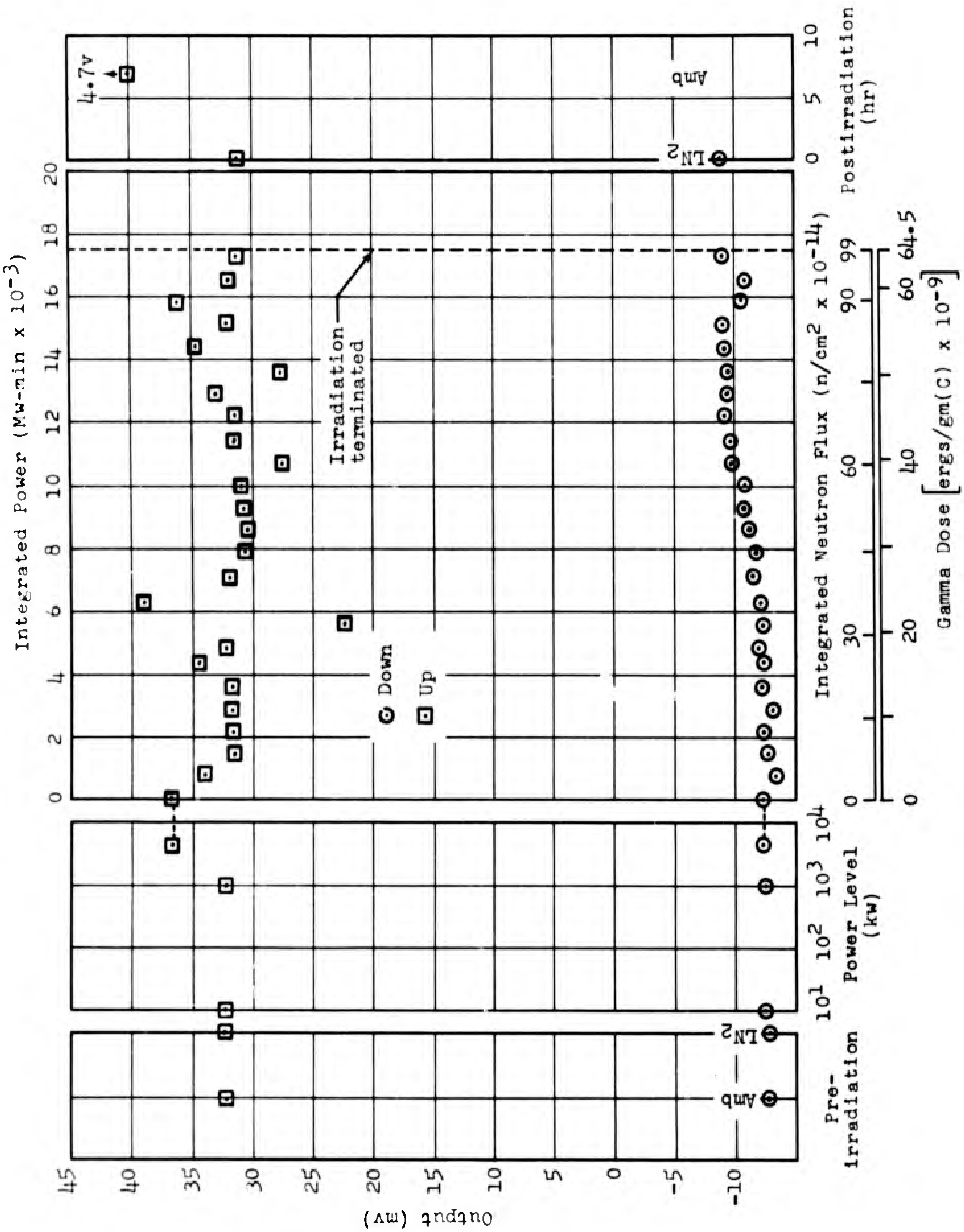

Figure 3-6 Output Signal vs Irradiation: Gage 1, Upper Side of Left Beam

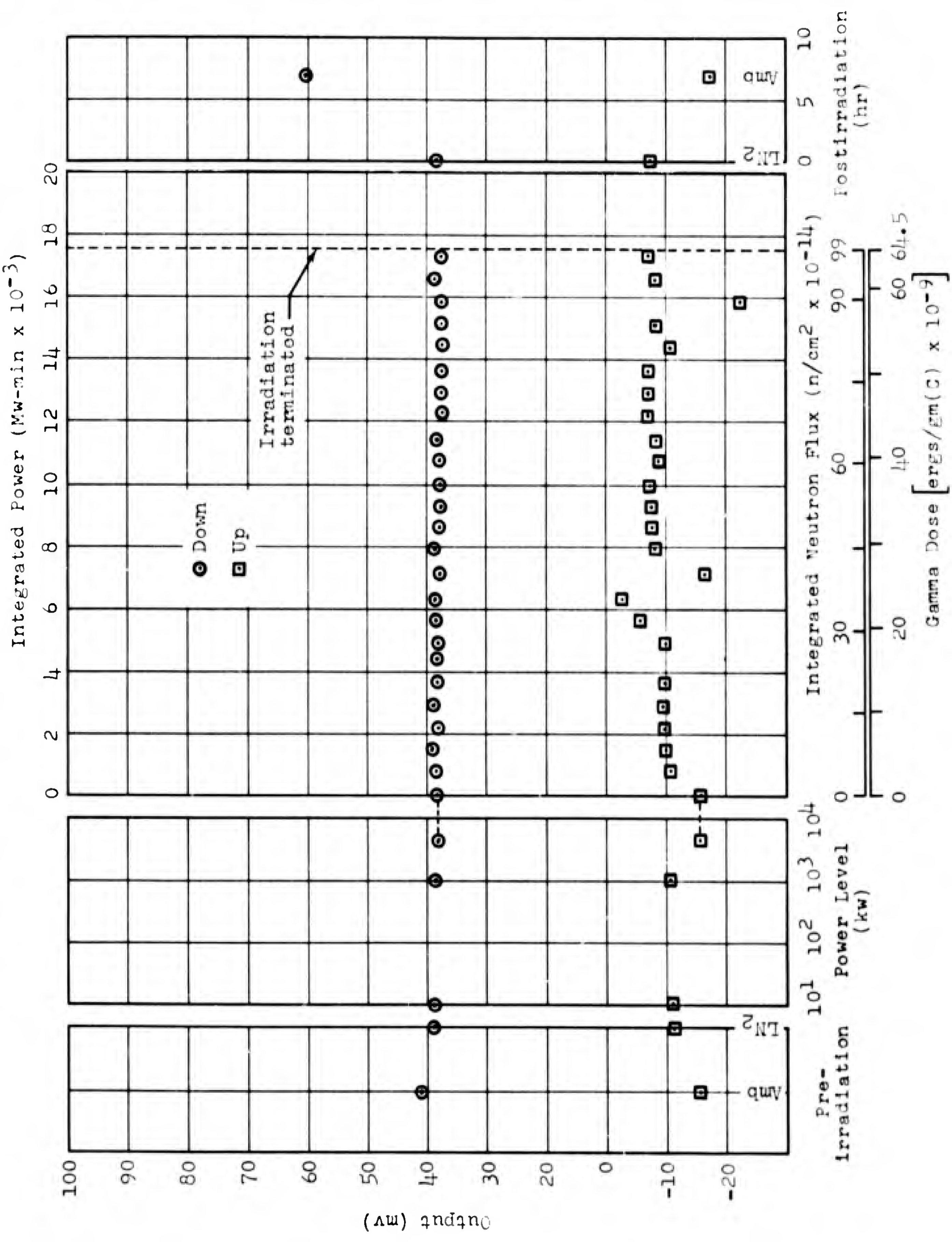

Figure 3-7 Output Signal vs Irradiation: Gage 1, Lower Side of Left Beam

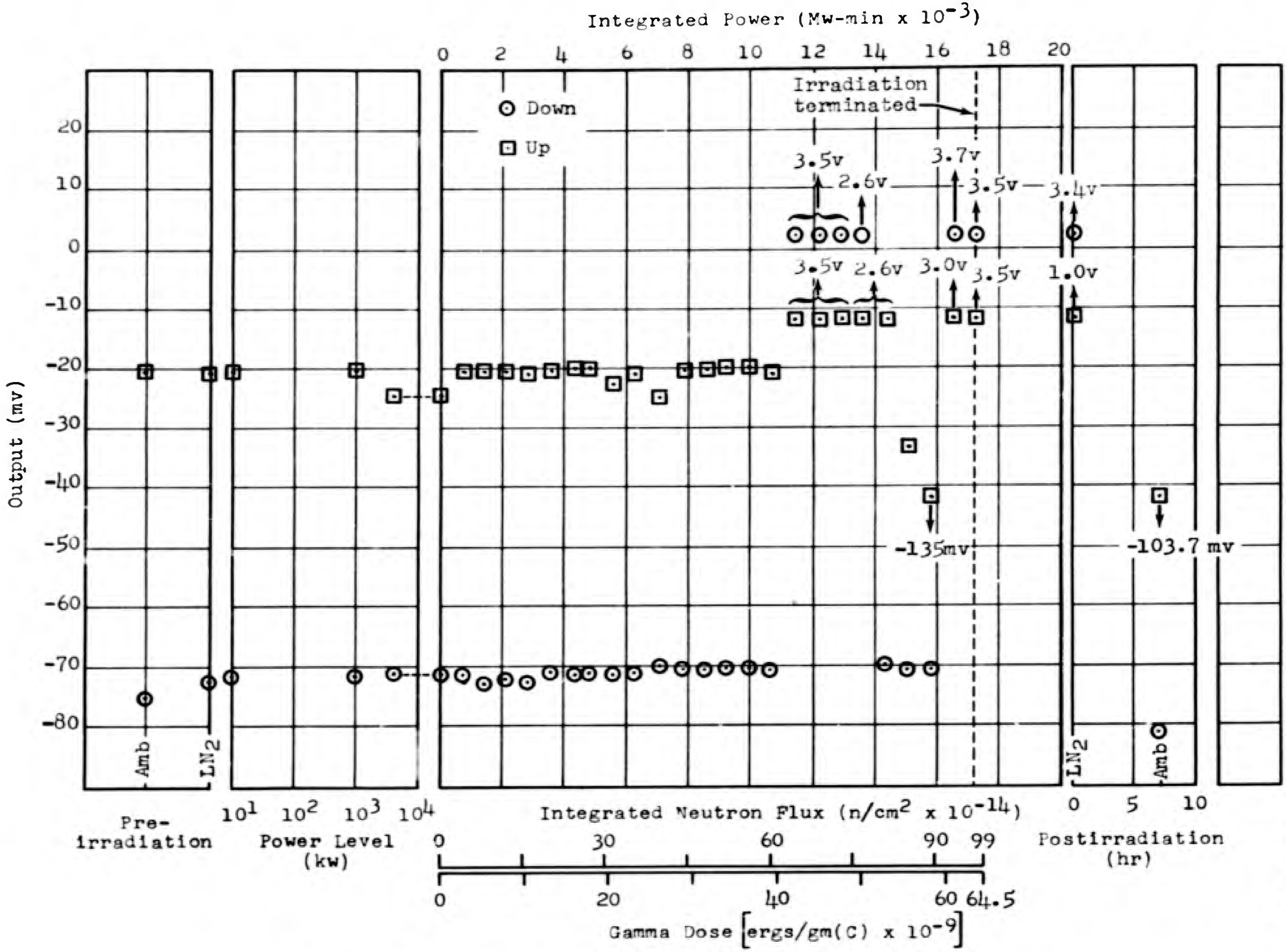

Figure 3-8 Output Signal vs Irradiation: Gage 2, Upper Side of Left Beam

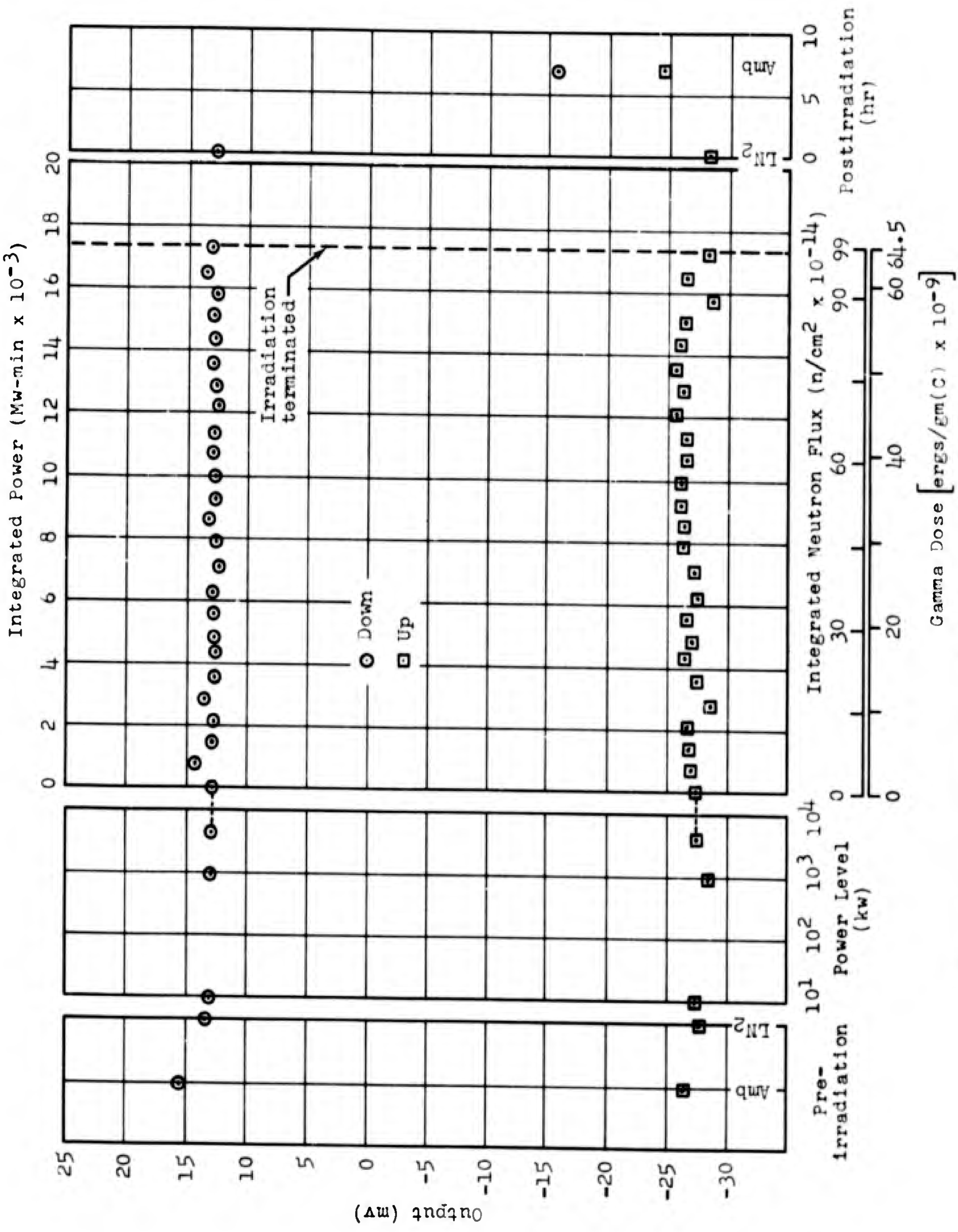

Figure 3-9 Output Signal vs Irradiation: Gage 3, Lower Side of Left Beam

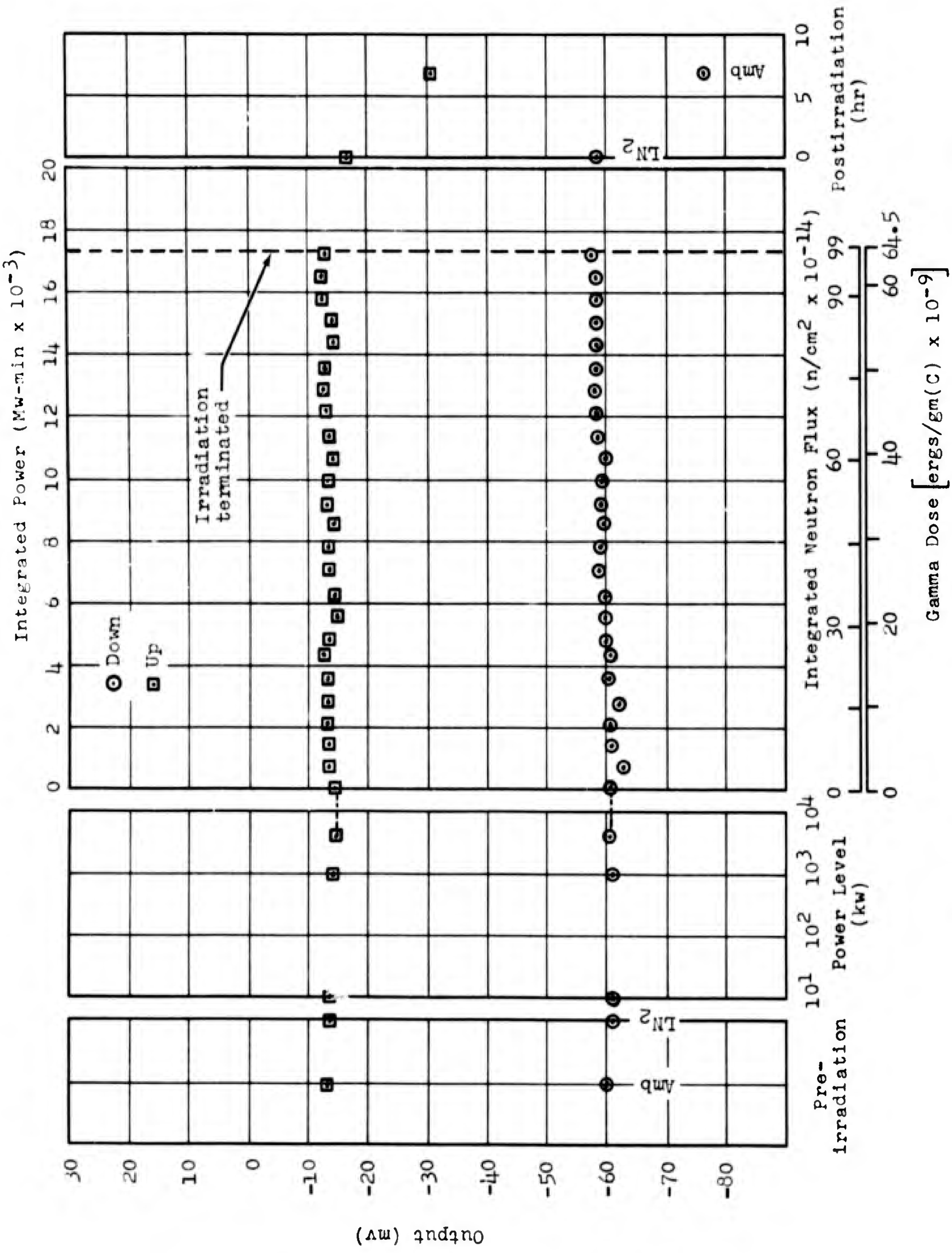

Figure 3-10 Output Signal vs Irradiation: Gage 4, Lower Side of Left Beam

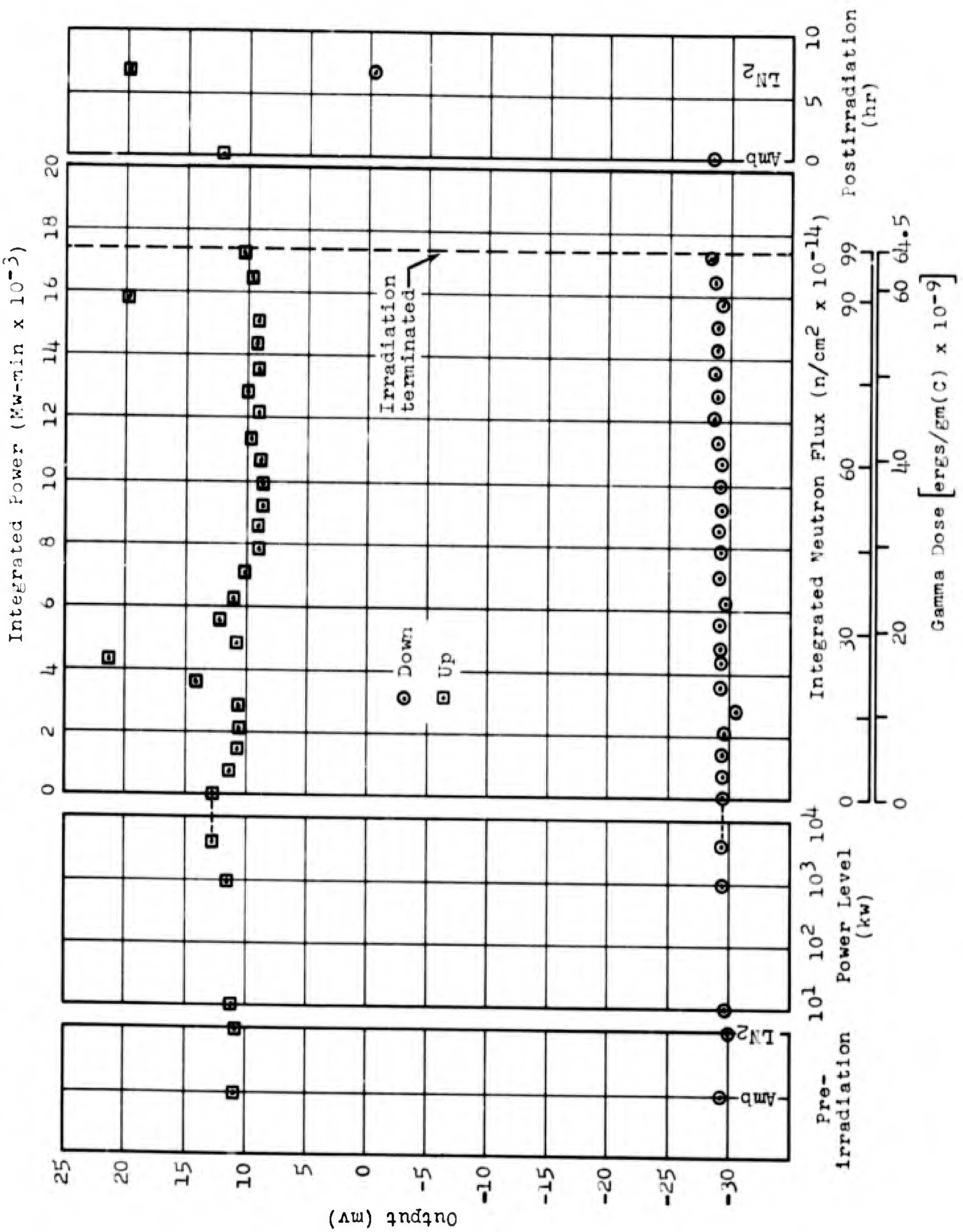

Figure 3-11 Output Signal vs Irradiation: Gage 5, Upper Side of Left Beam

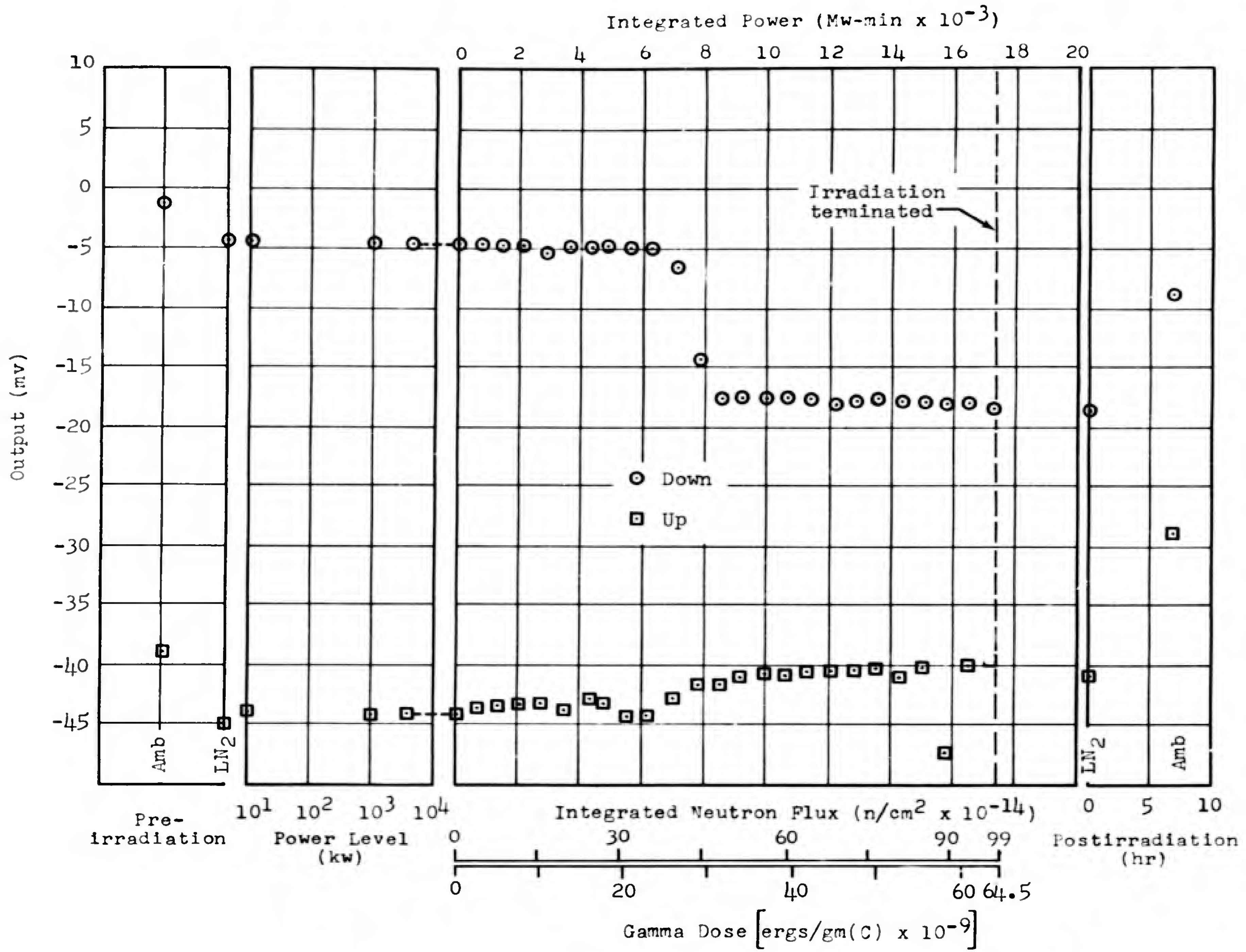

Figure 3-12 Output Signal vs Irradiation: Gage 5, Lower Side of Left Beam

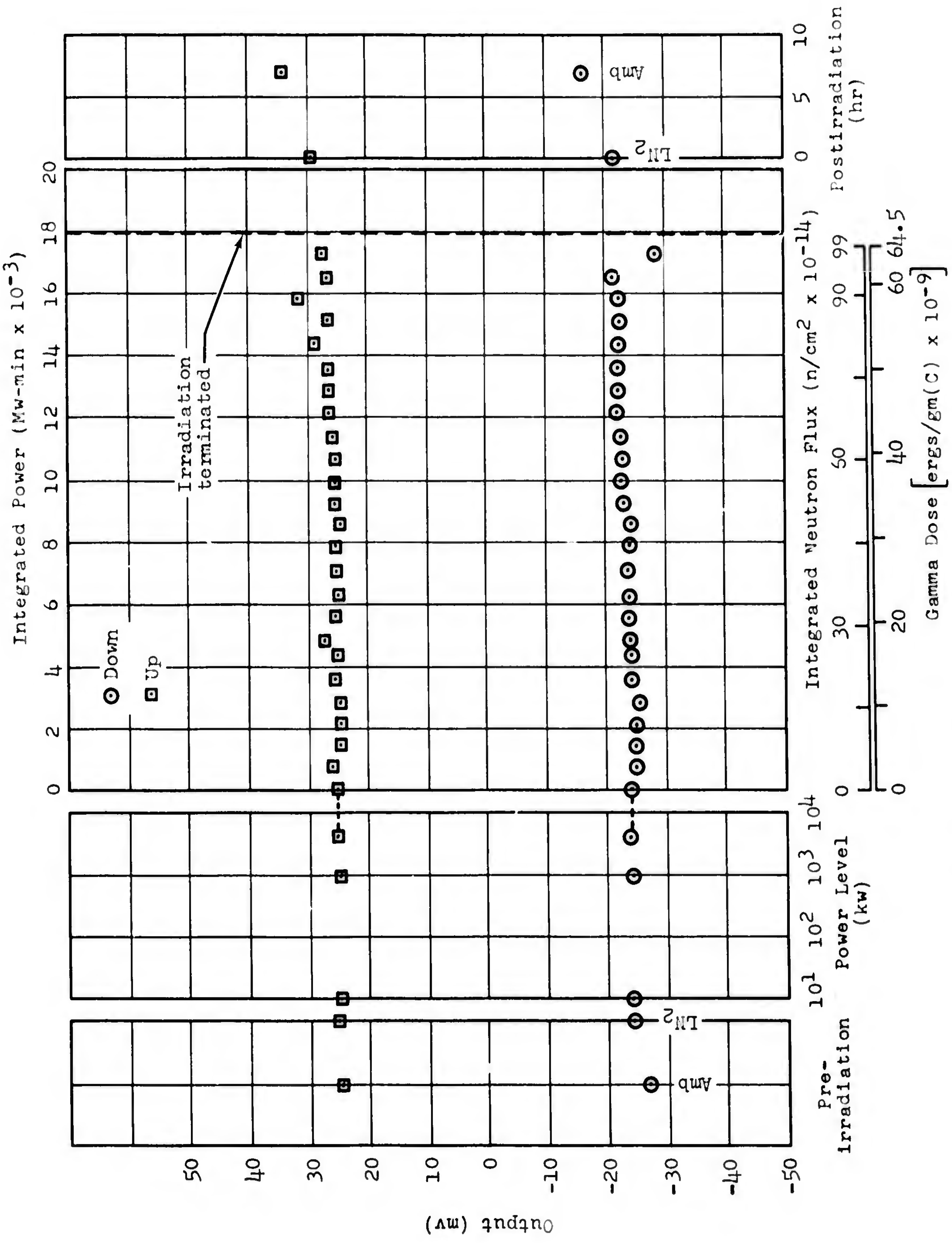

Figure 3-13 Output Signal vs Irradiation: Gage 1, Upper Side of Right Beam

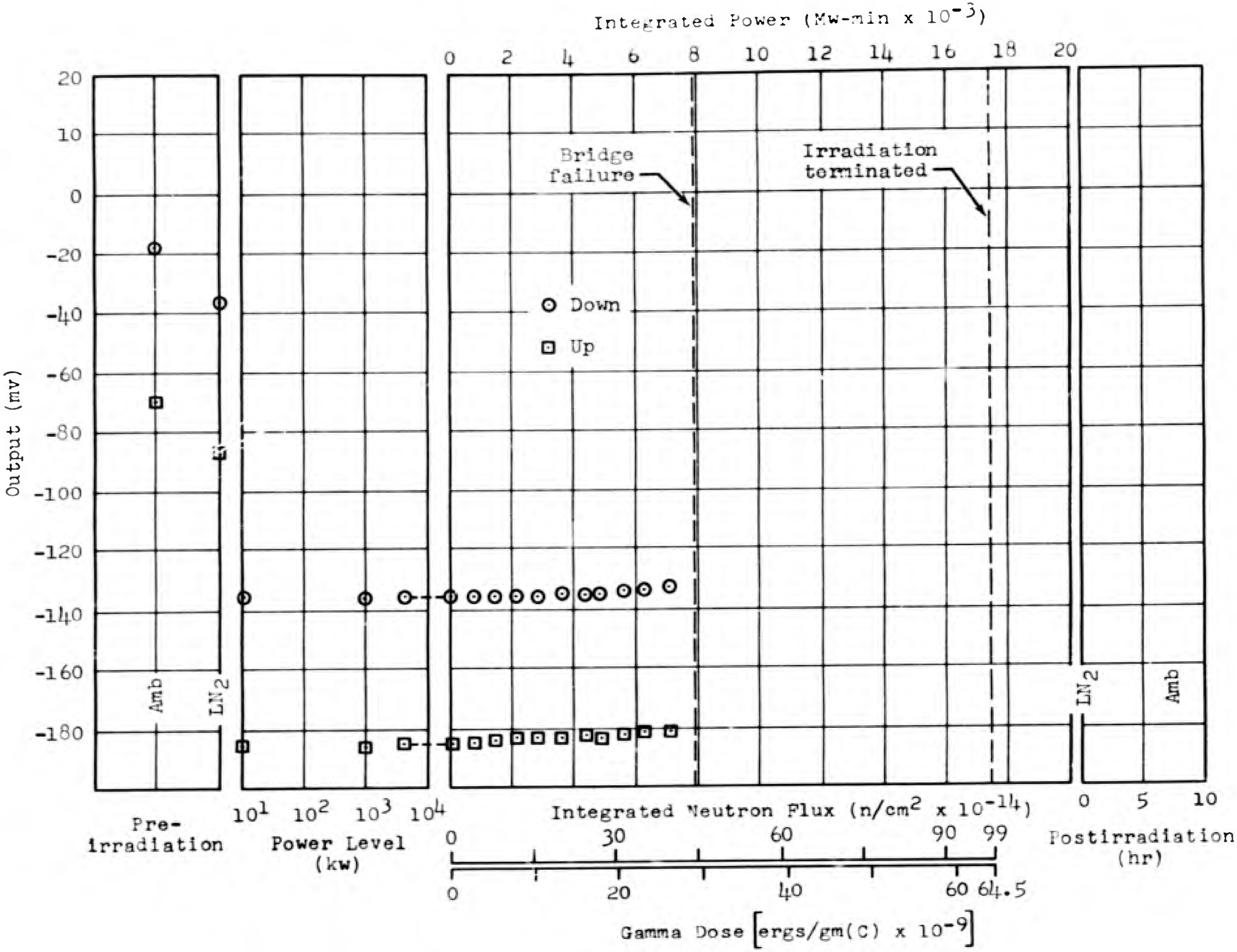

Figure-14 Output Signal vs Irradiation: Gage 1, Lower Side of Right Beam

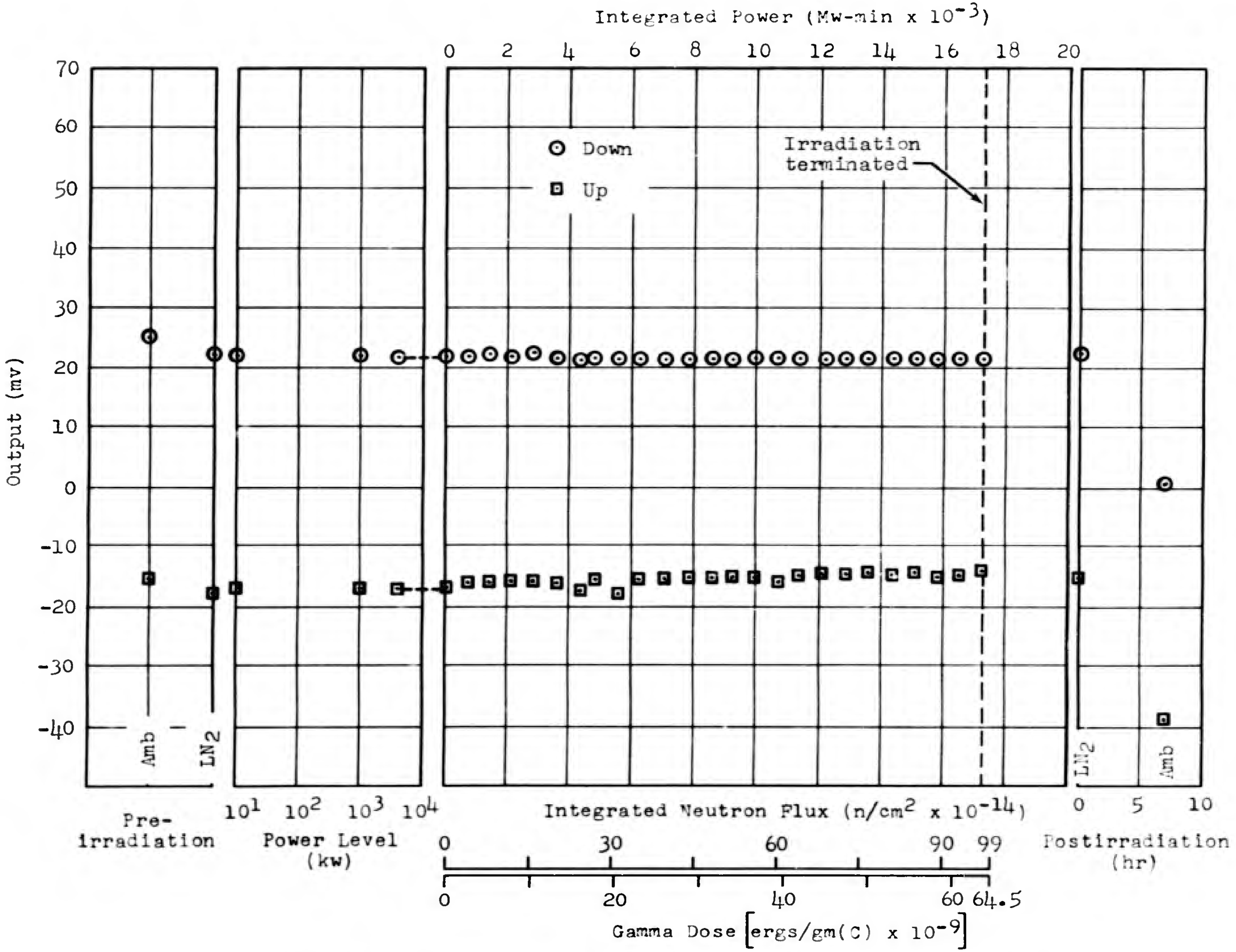

Figure 3-15 Output Signal vs Irradiation: Gage 2, Lower Side of Right Beam

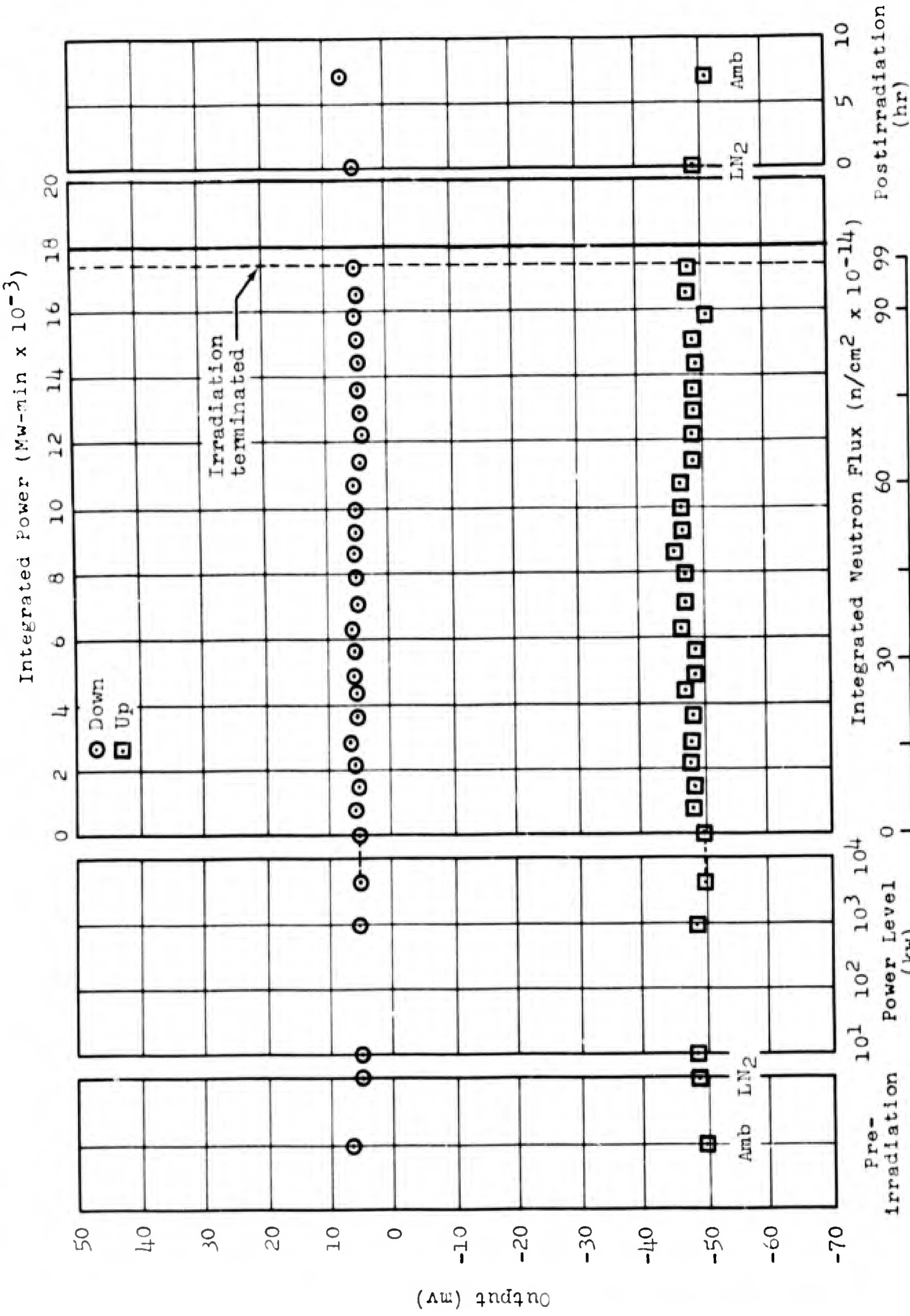

Figure 3-16 Output Signal vs Irradiation: Gage 3, Lower Side of Right Beam

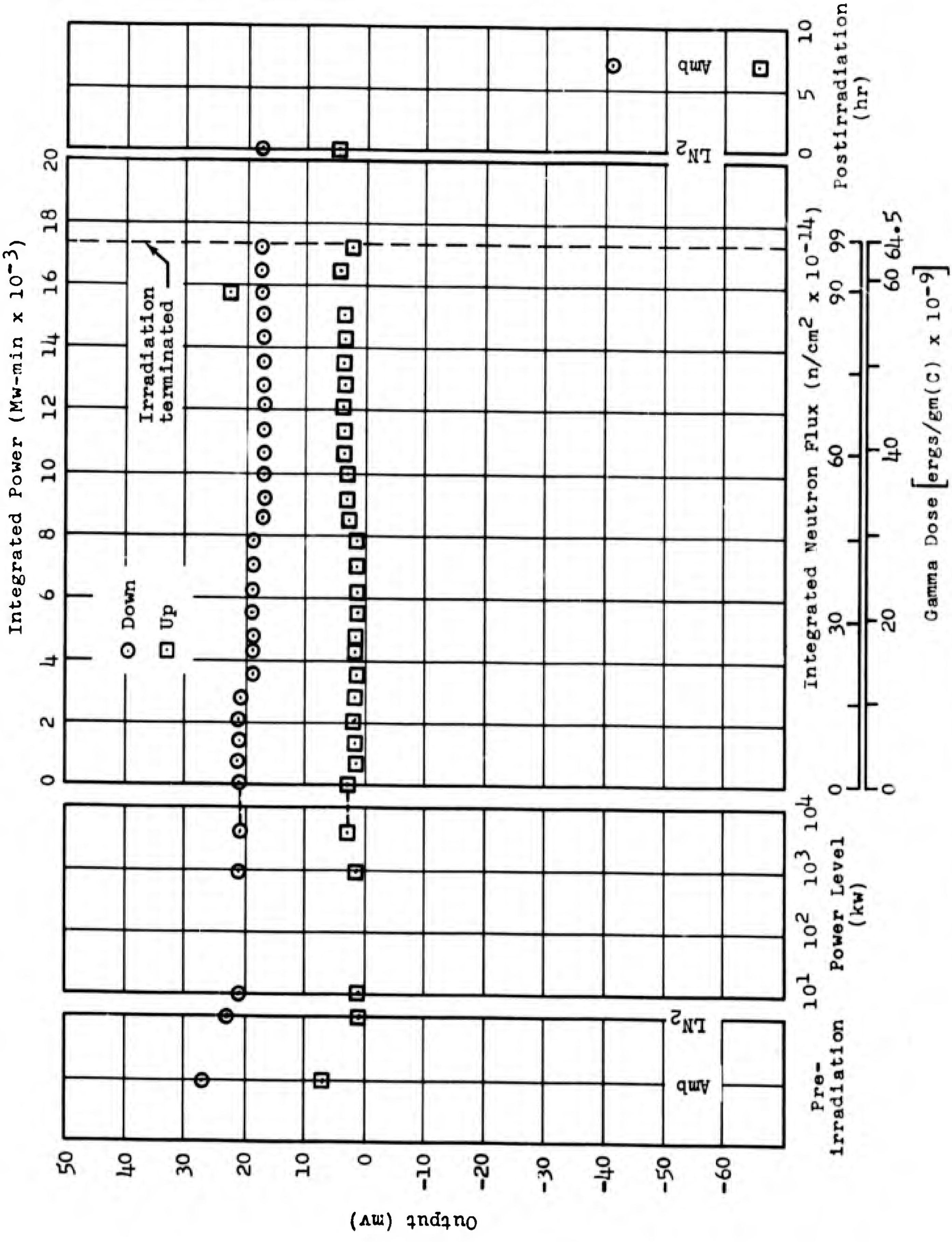

Figure 3-17 Output Signal vs Irradiation: Gage 4, Lower Side of Right Beam

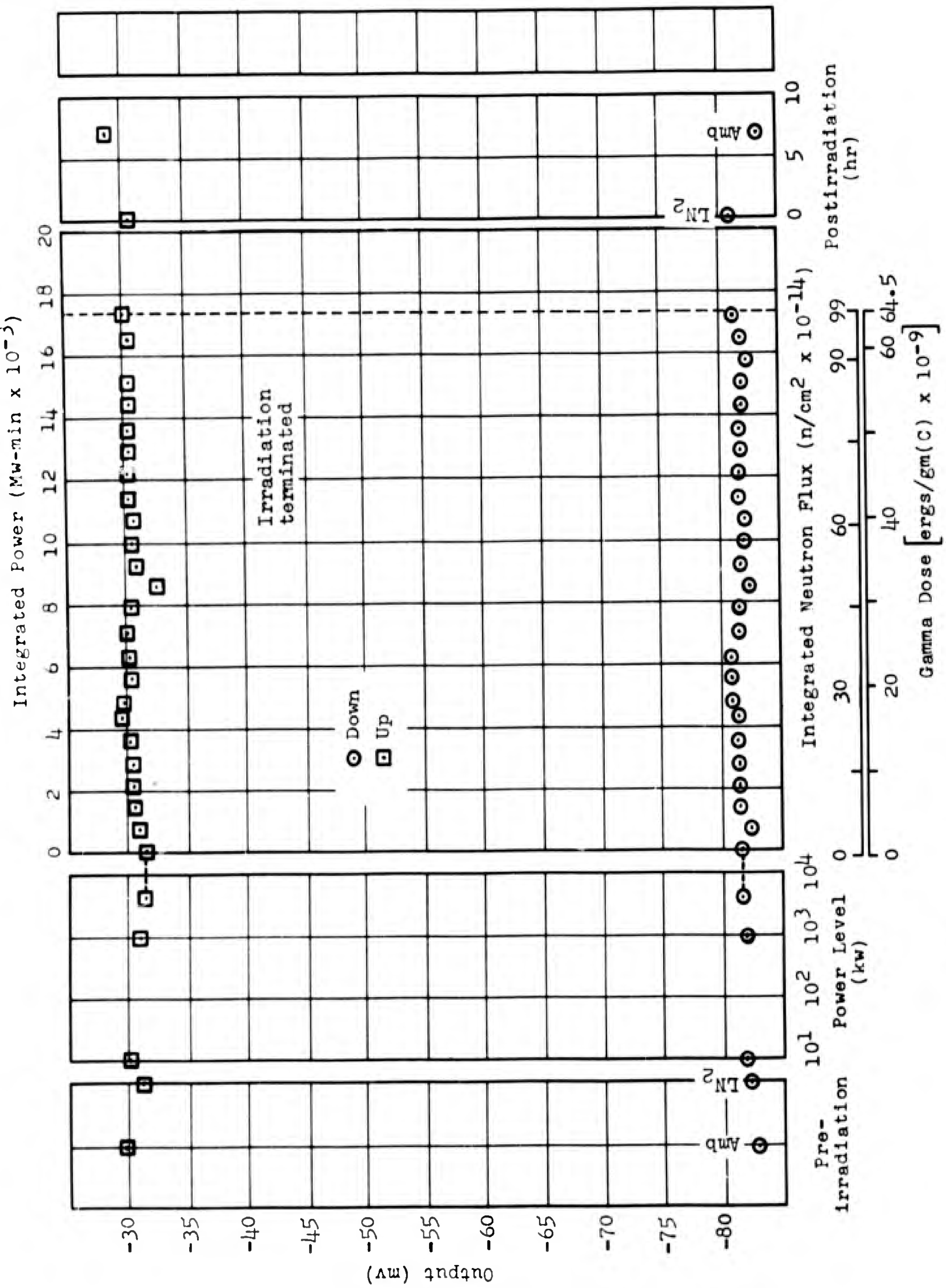

Figure 3-18 Output Signal vs Irradiation: Gage 5, Upper Side of Right Beam

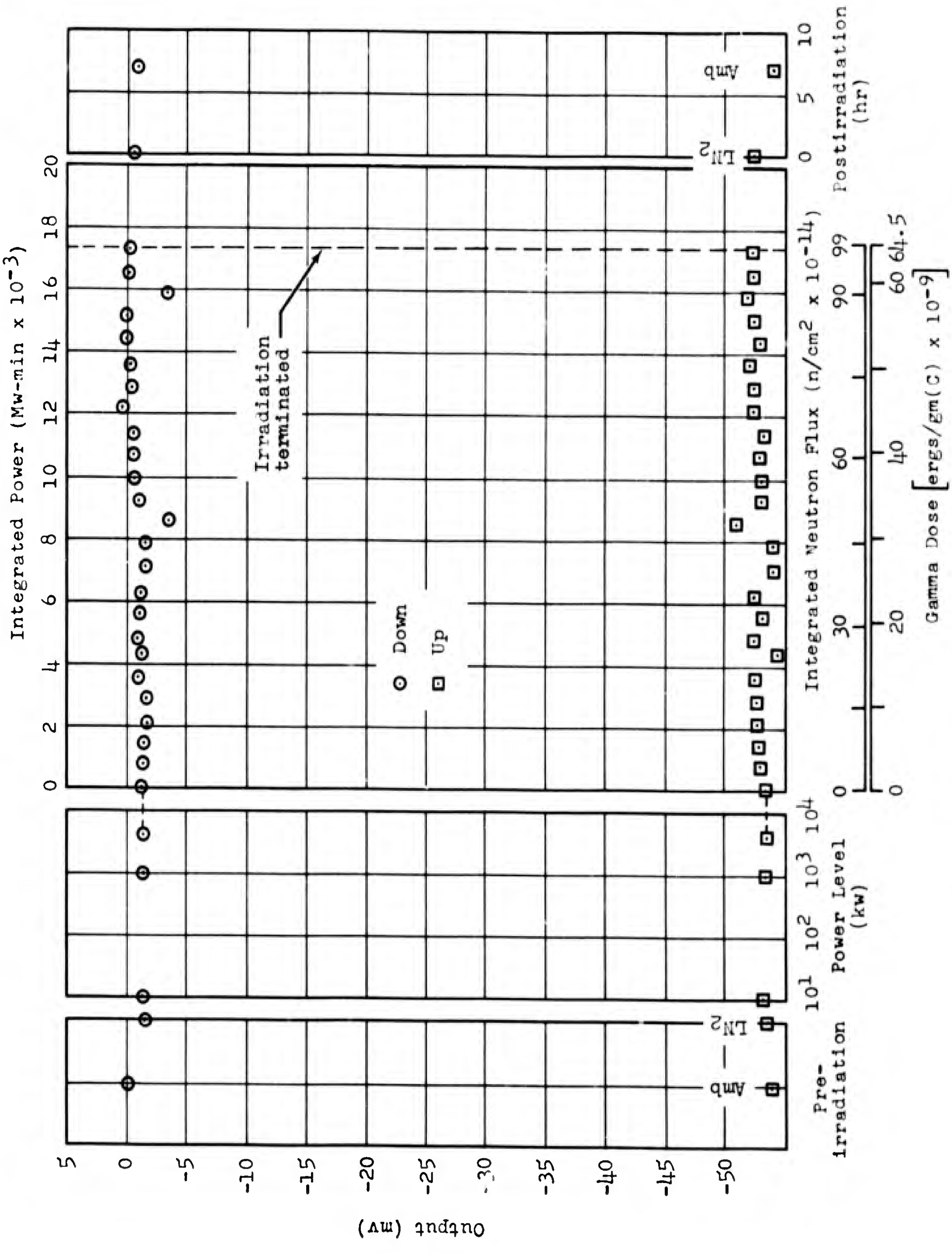

Figure 3-19 Output Signal vs Irradiation: Gage 5, Lower Side of Right Beam

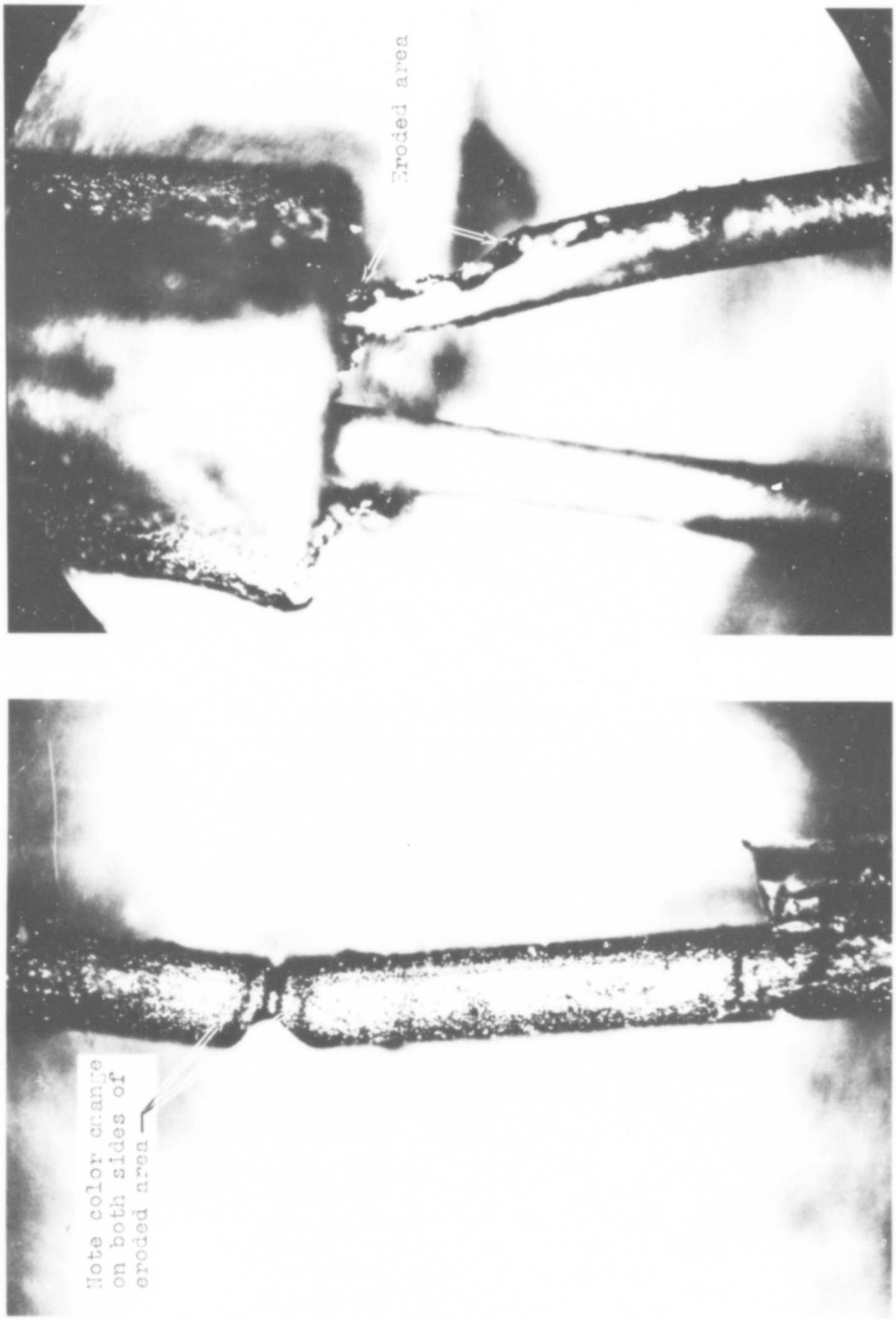

Figure 3-20 Eroded Strain Gage Leads

Table 3-1

Development Strain Gages:
Insulation Resistance
(megohms except where designated ohms)

Strain Gage	Pre LN_2	10 kw	100 kw	1 Mw	3 Mw	4,400 Mw-min	8,600 Mw-min	12,900 Mw-min	17,400 Mw-min	Post LN_2	Post Amt
1-LU	47,000	4,170	5,000	1,000	41.7	333	333	313	278	3,300	1.22
1-LL	500,000	7,150	5,000	1,000	715	312	294	294	250	2,780	6.25
2-LU	455,000	7,150	5,000	1,000	625	385	357	7.9Ω	7.6Ω	9.6Ω	7.4Ω
2-LL	17.5	*	*	*	1.67	250	455	500	500	925	25
3-LU	31.2	*	*	*	1.92	215Ω	215Ω	215Ω	215Ω	216Ω	215Ω
3-LL	1,200	3,300	5,000	833	833	385	333	333	278	1,665	7.14
4-LU	50,000	3,570	5,000	833	715	333	294	278	250	192	0.100
4-LL	50,000	0.050	1,665	*	715	480Ω	357	278	263	0.980	357
5-LU	178.5	31.3	11.1	3.33	1.67	2.17	2.08	0.794	1.25	1.72	0.005
5-LL	172.5	29.4	10.2	2.50	1.79	0.962	1.25	0.55	0.33	0.735	0.004
1-RU	178.5	31.3	10.2	2.50	2.27	1.0	1.22	0.55	0.33	0.746	0.004
1-RL	178.5	31.3	10,400	3.33	2.0	1.04	1.25	0.55	0.33	0.757	0.004
2-RU	500,000	151.5	556	29.4	27.8	19.2	18.5	17.8	22.7	12.8	156
2-RL	500,000	156	556	31.3	27.8	20	18.5	26.3	16.7	45.5	666
3-RU	500,000	147	500	25	32.7	16.1	15.6	21.7	16.7	7.7	1.04
3-RL	500,000	135	500	27.8	26.3	20.7	16.1	22.7	16.1	6.1	82
4-RU	250,000	9,400	5,000	1,000	1,000	500	500	285	313	2,500	0.014
4-RL	100,000	8,440	5,000	1,000	83.3	455	29	385	294	2,940	0.042
5-RU	71,500	10,400	5,000	1,250	1,250	625	834	715	500	2,630	2.38
5-RL	125,000	9,440	5,000	1,000	1,000	455	455	333	313	3,570	0.520

*Less than 50K

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IV. THERMOCOUPLES
(Test 23/L302)

4.1 Test Method

Two thermocouples were irradiated at a test temperature of approximately 2500°F. One thermocouple was comprised of tungsten with 5% rhenium vs tungsten with 26% rhenium (W-5Re/W-26Re); the other thermocouple was tungsten vs tungsten with 26% rhenium (W/W-26Re).

The thermocouples were mounted inside heater elements in specially designed heater boxes (Fig. 4-1) that were placed in the north irradiation position. The heater boxes were supplied by AGC. The resistance-type heater elements were controlled by power supplies in the control room (Fig. 4-2). Power to the heaters was programmed so that the maximum rate of temperature change was 85°F/min or less.

The structural portions of the heater boxes were cooled by flowing gaseous nitrogen through the thermocouple mounting bosses and gaseous helium through the interior of the boxes.

Data were recorded at each power level and every eight hours throughout the irradiation. Data were also recorded during a manual reactor shutdown after approximately 75 Mw-hr.

4.2 Data Presentation

The ratio of thermocouple output (Mv) to heater input power (watts) was plotted as a function of integrated reactor power (Fig. 4-3). The ratio (in place of the thermocouple output) was plotted because the heater input power varied

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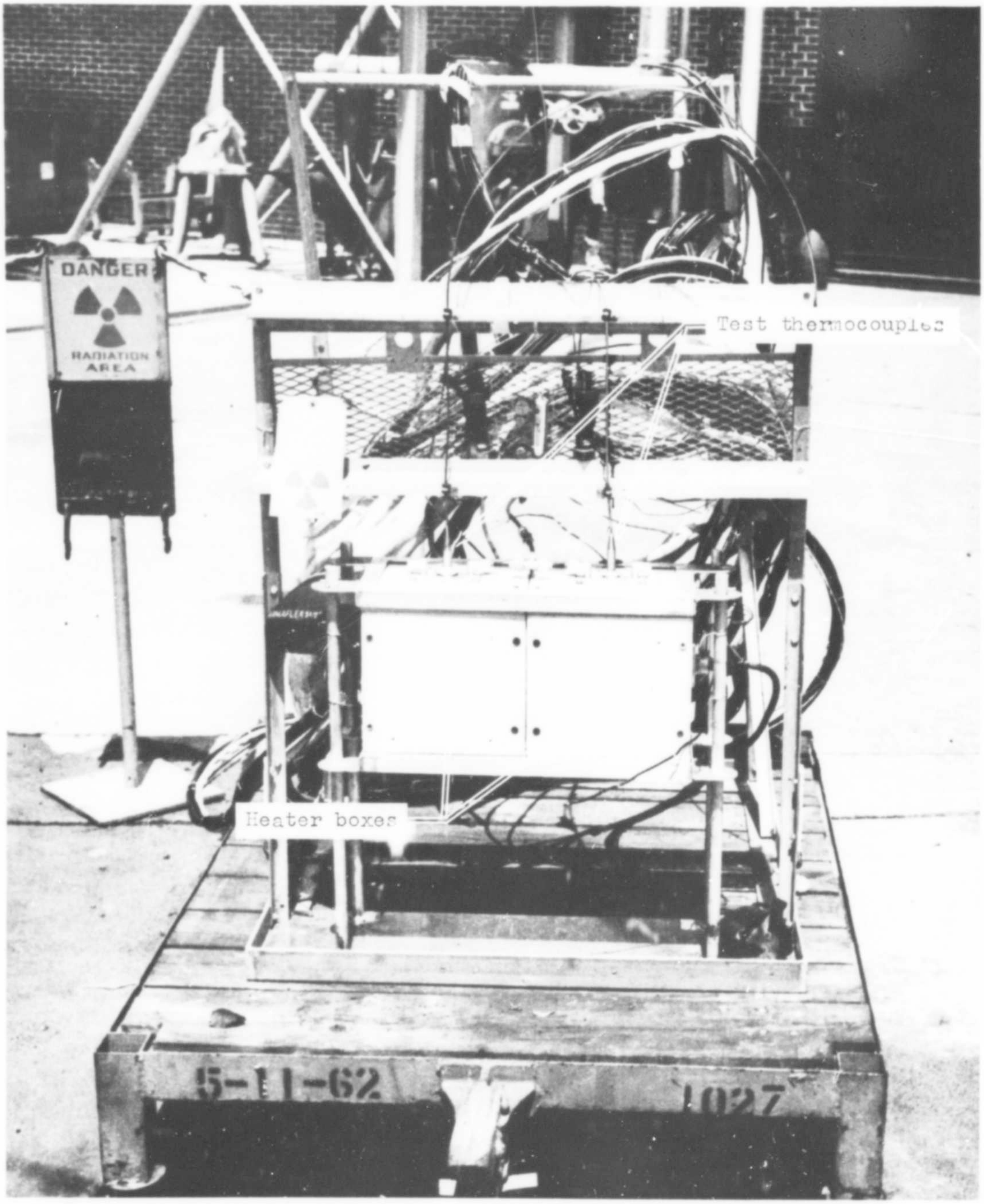

Figure 4-1 Thermocouple Heater Boxes

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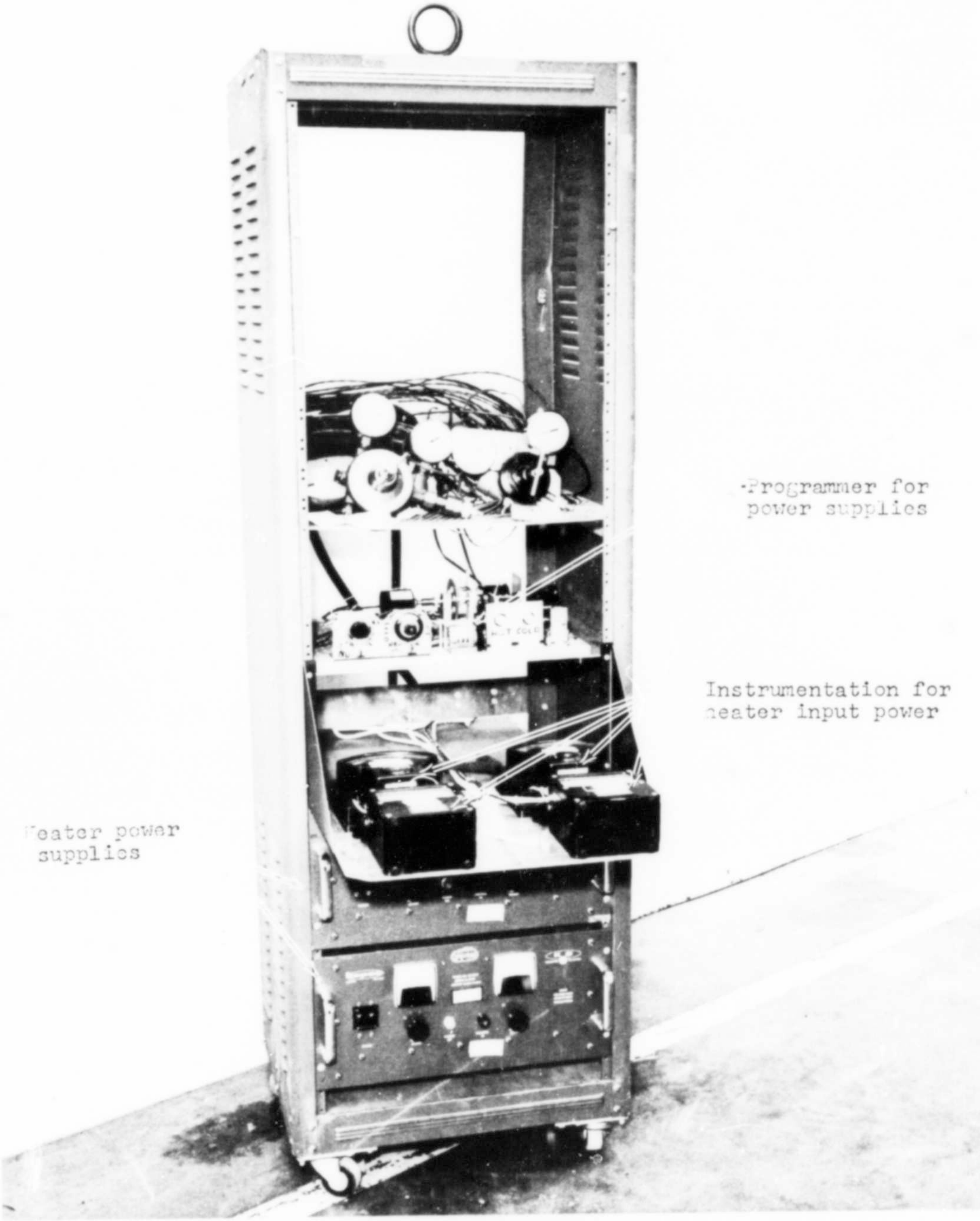

Figure 4-2 Thermocouple Heater Control and Supply

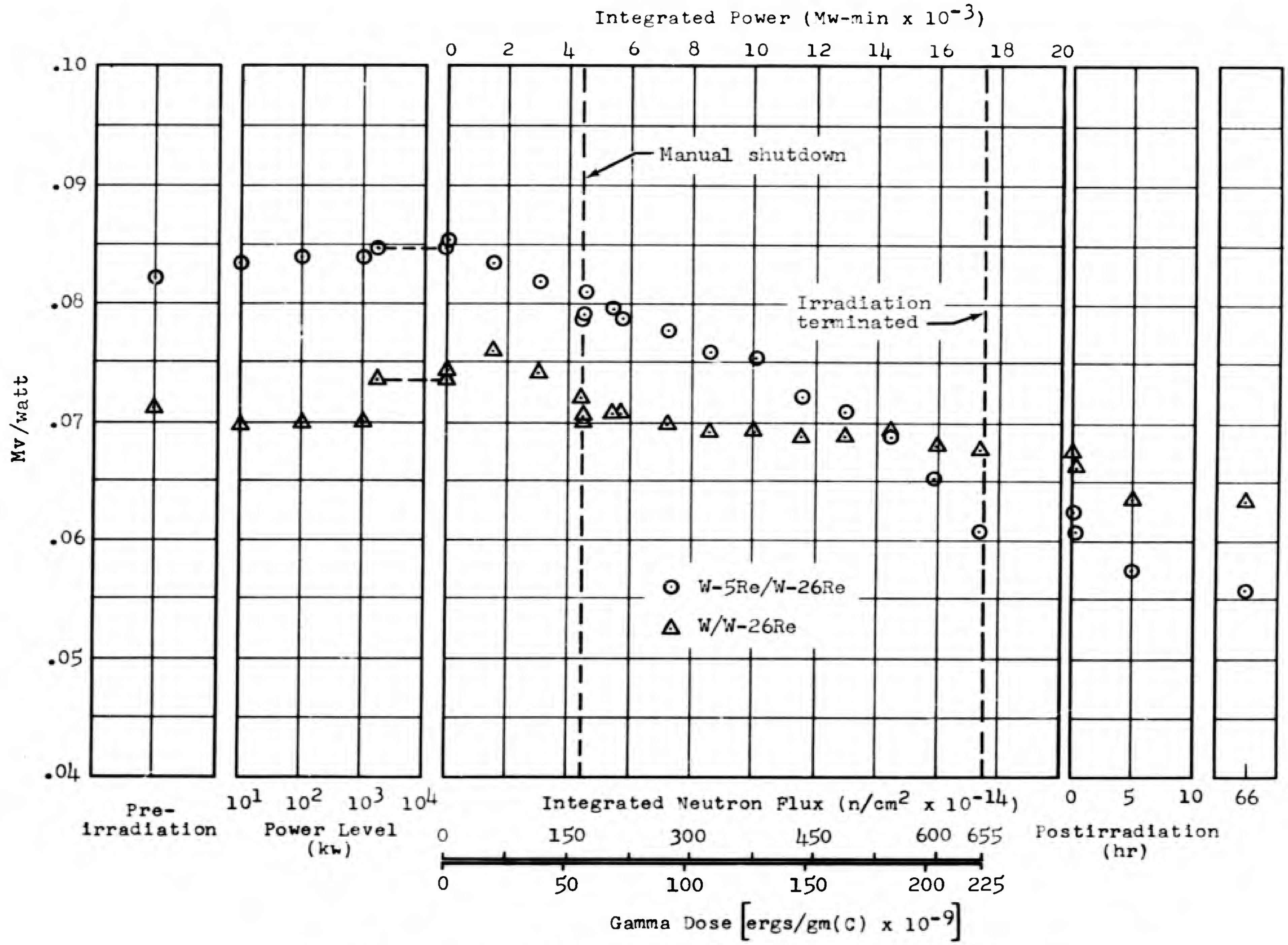

Figure 4-3 Ratio of Thermocouple Output to Heater Power Input vs Radiation Exposure

slightly between data cycles.

4.3 Discussion

The integrated neutron fluxes to which the thermocouples were exposed was 6.5 x 10^{16} n/cm^2 (E 2.9 Mev) and 1.6 x 10^{15} n/cm^2 (E 0.48 ev). The gamma dose was 2.2 x 10^{11} ergs/gm(C). A description of dosimetry location will be found in Appendix B.

After approximately 25 hours of irradiation the reactor was shut down and 3 cycles of data were taken on each thermocouple. The deviation at this point was small compared to the deviation at the end of the test.

A comparison of the postirradiation data and the preirradiation data indicate that the ratio of thermocouple output to heater input power decreased for each thermocouple. The W/W-26Re thermocouple decreased 10.9 percent and the W-5Re/W-26Re thermocouple decreased 31.3 percent. If it is assumed that the heaters functioned consistently throughout the test, then it can be said that the decrease in ratio is due to a decrease in thermocouple output. This decrease in thermocouple output is attributed to radiation effects (see Fig. 4-3).

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V. CONTROL DRUM PLATE SECTION
(Test 15/W002)

5.1 Test Method

The control drum plate section was mounted in its experimental test assembly (Figs. 5-1 and 5-2). The assembly consisted of a spring-clamp arrangement mounted in an aluminum framework. Three copper constantan thermocouples were mounted on the plate section and the assembly. Eight tensile test specimens of the same material composition as the plate section were clamped in aluminum holders attached to the assembly framework. A polyethylene shield (neutron attenuator and thermalizer) of 1/2-in. thickness was attached to the reactor side of the assembly. The assembly was placed in a NASA dewar and subsequently mated to the east dolly of the GTR shuttle system (Appendix A).

The plate section was stressed at ambient temperature, by the compression of the loading spring. The instrument used to measure spring deflection, from the no-load condition, is depicted in Figure 5-3. The spring was compressed until a constant load of 500 lb was transmitted to the plate section. The amount of spring deflection required for a load of 500 lb was 0.411 in. as determined from a plot of load vs deflection in inches for the spring used.

The dewar was then filled with LN_2 to a level which covered the plate section. The LN_2 level was controlled at this level for several hours after which the spring deflection was again measured and recorded.

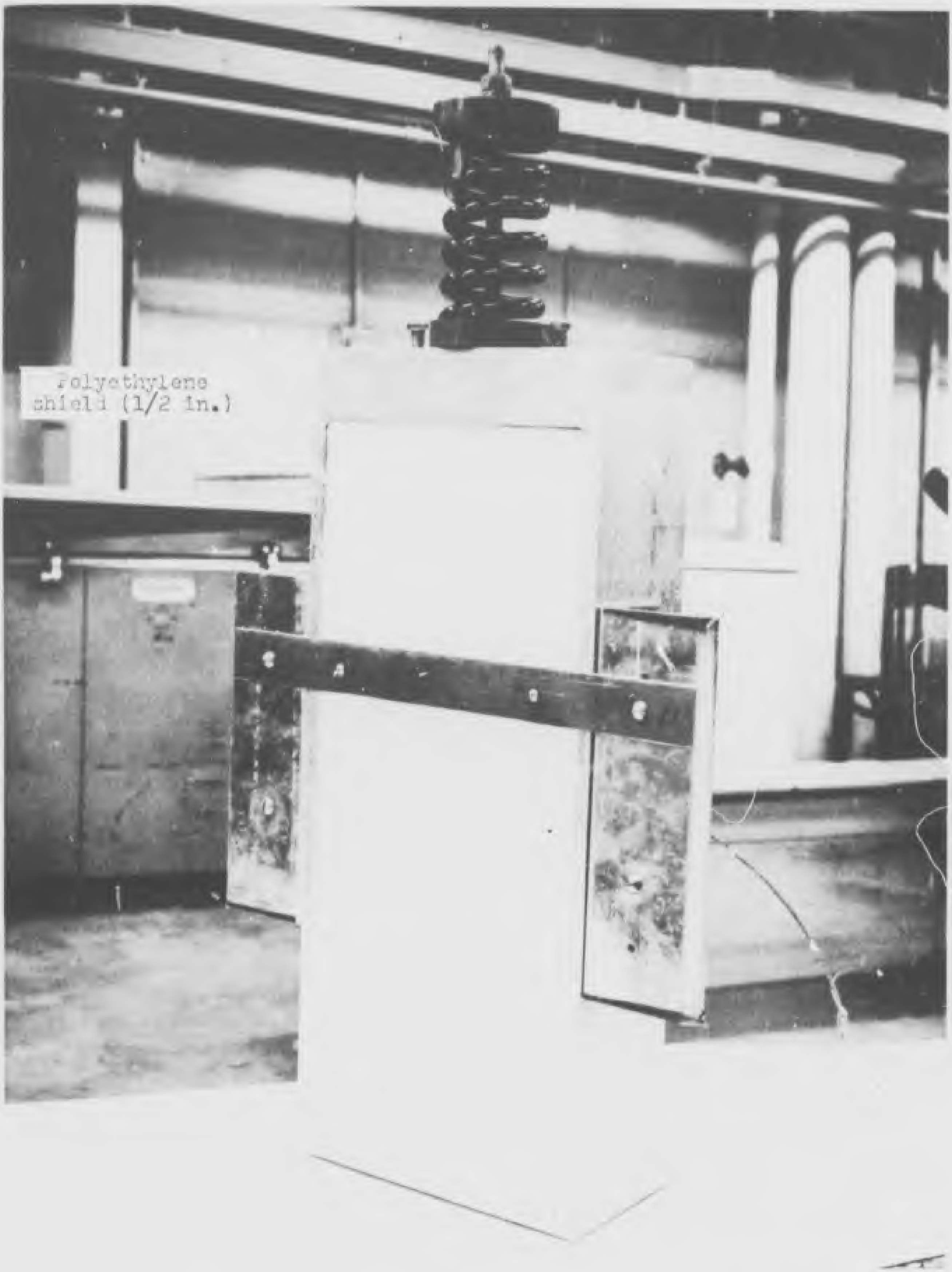

Figure 5-1 Control Drum Plate Section Experimental Assembly: Front View

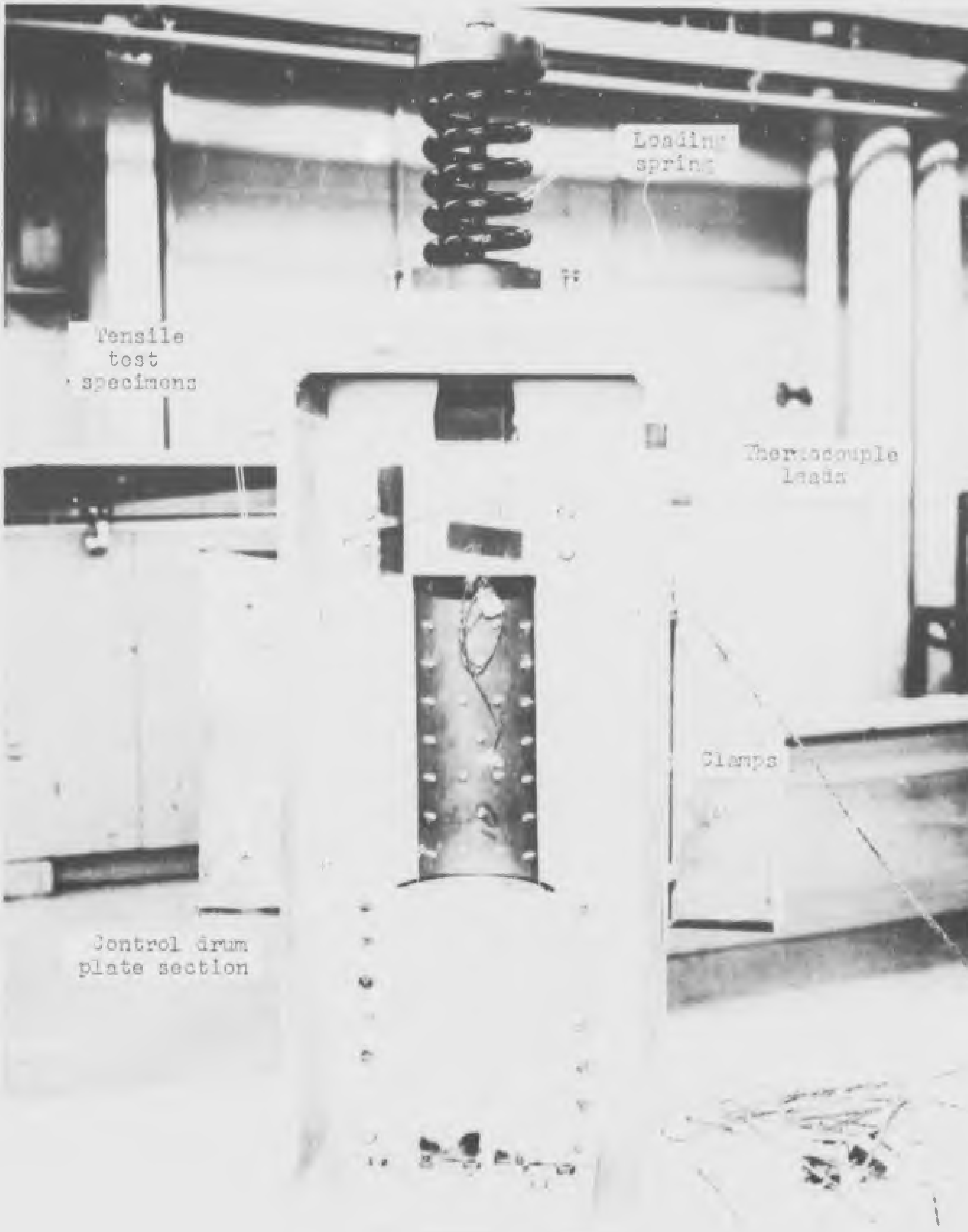

Figure 5-2 Control Drum Plate Section Experimental Assembly: Rear View

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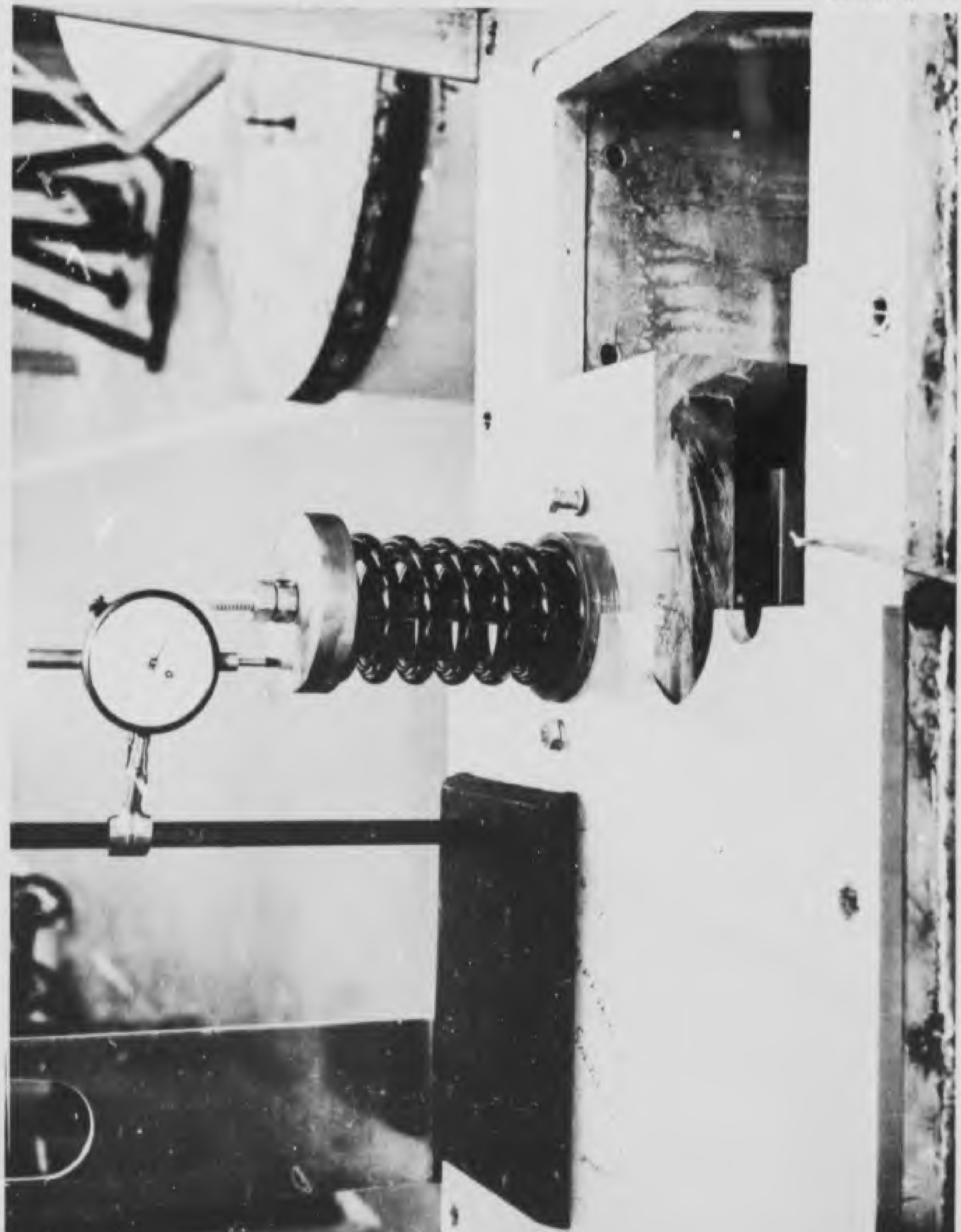

Figure 5-3 Dial Gage Used to Measure Spring Deflection

The experimental assembly was then lowered into position and the irradiation begun.

Approximately three days after the irradiation and with the experimental assembly at ambient temperature, the spring deflection was again measured and recorded. The load on the plate section was released at this time by returning the spring to the no-load condition.

The control drum plate section and the static tensile test specimens were returned to WANL for postirradiation testing. Hardness, dimensions, weight, dye penetrant check, and metallography tests are to be made on the plate section and tensile test performed on the tensile specimens.

5.2 Data Presentation

A plot of load vs deflection in inches for the spring used is given in Figure 5-4. The plot was furnished by WANL.

The load spring deflections in inches from the no-load condition as measured and recorded before and after the irradiation are given below.

Temperature	Preirradiation	Postirradiation
Ambient	0.411	0.409
Liquid Nitrogen	0.401	-

5.3 Discussion

The control drum plate section remained submerged in LN_2 continuously except for a brief period on 9 June 1964 when the liquid feed system malfunctioned and the temperature in the dewar approached $0^{o}F$.

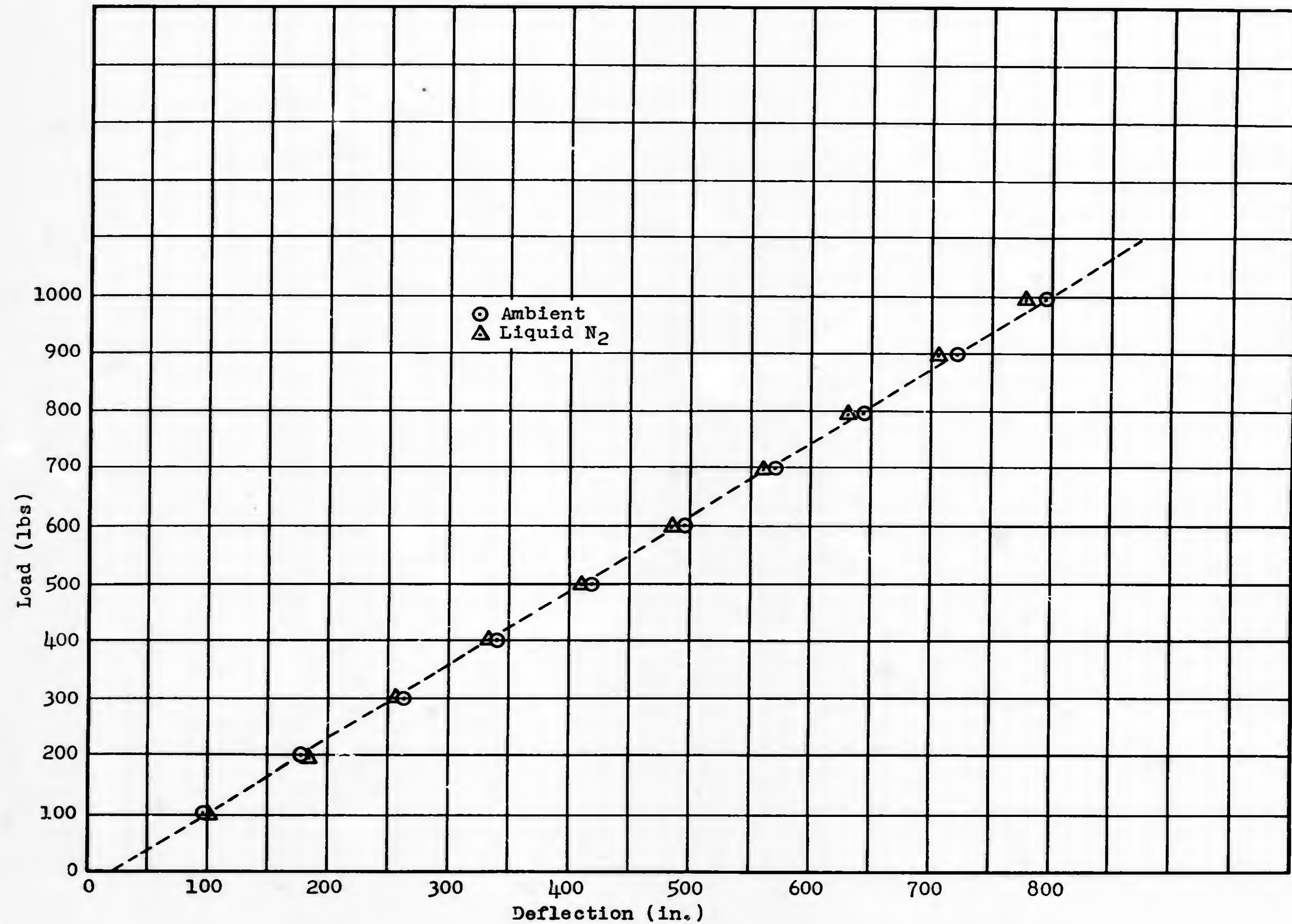

Figure 5-4 Load vs Spring Deflection for Control Drum Plate Section Test

VI. PIEZOELECTRIC CERAMIC DISCS
(Test 23/W003)

6.1 Test Method

Thirty-four piezoelectric discs such as utilized in piezoelectric accelerometers were irradiated. The discs were of various ceramic compositions, thicknesses, and diameters. They were installed in a wire mesh basket in rows with a perforated spacer separating each row (Figures 6-1 and 6-2).

The basket was suspended in a 21-ft-long watertight container. This container replaced a reactor fuel element in the core of the reactor. The discs were irradiated in this position to obtain as high dose rate radiation environment as possible.

The container was pressure tested to 40 psig prior to installation. A relief valve adjusted to 10 psig maintained approximately that amount of gaseous nitrogen pressure on the container throughout the test. The flow rate of gaseous nitrogen was the maximum allowable consistent with design of the test system.

Four copper constantan thermocouples monitored the temperature of two inside walls of the container, the test discs, and the gas inside the container. The outputs of these thermocouples were continuously recorded by a Brown multipoint recorder. These temperatures were the only data recorded during irradiation; however, data were recorded

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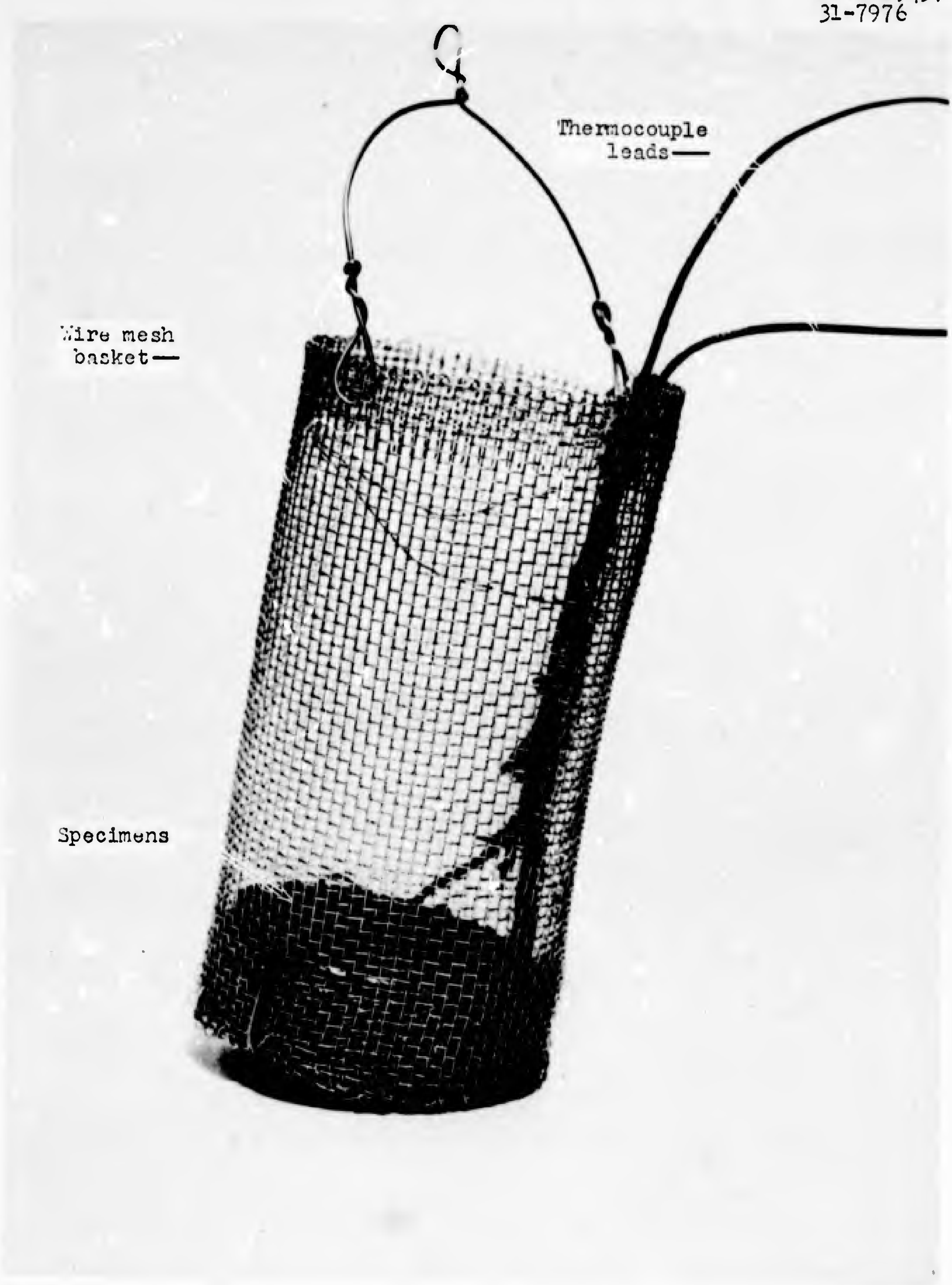

Figure 6-1 Mounting Basket Containing Piezoelectric Ceramic Discs:
Side View

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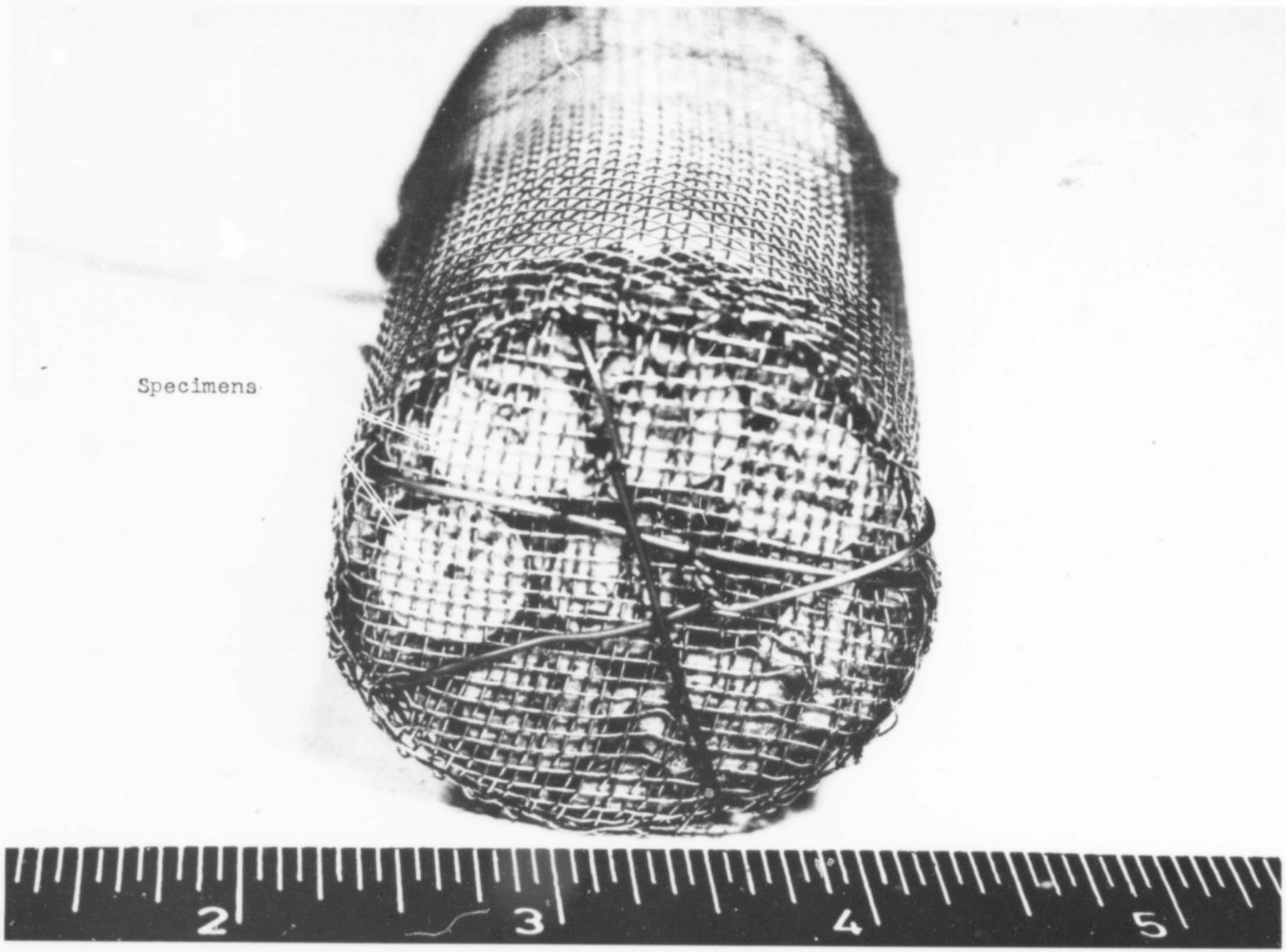


Figure 6-2 Mounting Basket Containing Piezoelectric Ceramic Discs: End View

for each disc prior to and after irradiation. The instrumentation used is shown in Figure 6-3, and the wiring diagram for testing the discs is shown in Figure 6-4.

6.2 Data Presentation

The preirradiation data is presented in Table 6-1. No postirradiation data will be reported because of the circumstances described in the following section.

6.3 Discussion

With maximum allowable gaseous nitrogen flow, the temperature of the discs increased 10°F per minute to 275°F at the 1-Mw power level. The temperature increased 30°F per minute to 635°F at the 3-Mw power level. The discs were removed from the reactor core approximately one hour after reactor shutdown and were removed from the basket approximately three hours after shutdown. The discs and basket indicated 500R per hour which necessitated personnel to work rapidly and for a short period of time. Because of this handling several discs were broken. The discs that were not broken were greatly discolored. This discoloration made identification extremely difficult. The discoloration may be caused by either the high temperature alone or the combined effect of a high irradiation dose and high temperature. The electrical characteristics of the 16 unbroken discs were tested at approximately 4, 17, 85, 160, 350, and 600 hours after termination of the test. The results of the postirradiation data show that the discs are electrically incapacitated. Therefore there is no postirradiation data presented.

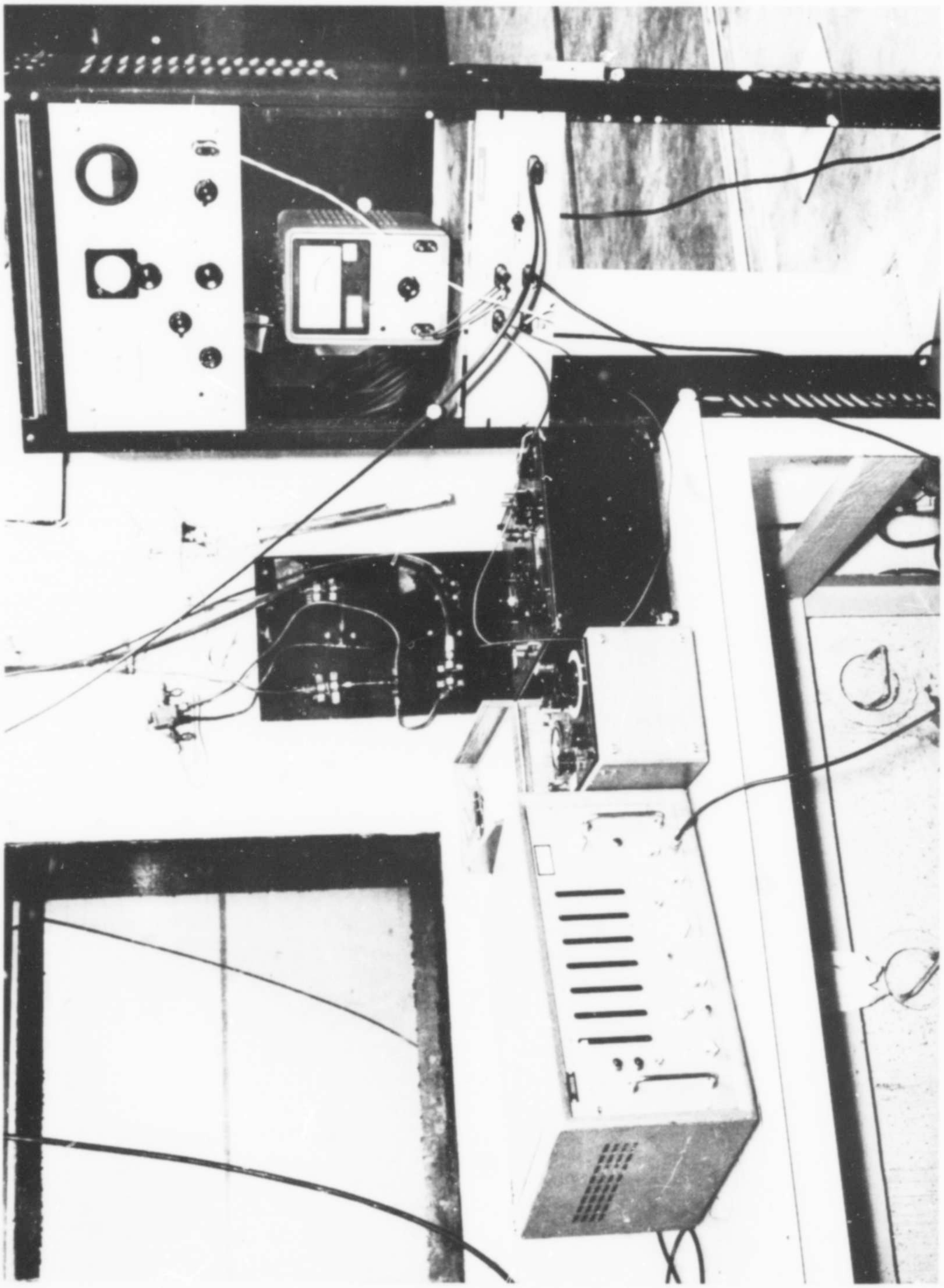


Figure 6-3 Instrumentation for Piezoelectric Ceramic Discs

Table 6-1

Piezoelectric Ceramic Discs Preirradiation Data

Disc Identification	Resonant Frequency (kc)	Anti-Resonant Frequency (kc)	Disc Voltage (mv)		Capacitance (pfd)	Insulation Resistance (megohms)	Dissipation Factor (%)
			Resonant	Anti-Resonant			
Gulton A-1	207.74	211.55	5.7	840	675	72	2.45
A-2	206.82	210.44	6.0	850	712	30	3.08
A-4	205.92	209.42	6.55	870	672	65	2.40
B-4	175.55	199.67	2.35	1300	1770	72	8.40
B-5	178.20	200.34	2.50	1250	1740	80	12.5
B-6	176.39	201.49	2.50	1350	1700	150	12.3
C-1	155.47	180.74	2.07	910	2870	70	6.4
C-2	155.56	178.54	2.17	885	2680	95	6.45
C-4	156.09	179.19	2.18	840	3030	32.5	6.8
D-1	171.20	200.46	2.04	880	3050	80	4.8
D-2	172.03	200.47	2.10	860	2960	120	4.6
D-3	170.86	198.72	2.10	860	2970	85	4.8
E-2	249.26	259.56	2.05	602	2350	57	6.15
E-4	249.35	260.85	2.05	690	2350	60	5.5
E-5	249.97	261.63	2.0	760	2270	68	3.9
F-1	265.50	269.05	3.08	562	1600	1.35	27
F-2	257.72	261.03	2.78	450	1630	1.58	21.2
F-4	260.18	263.70	2.95	560	1680	1.2	26.8
G-1	170.85	193.84	2.05	2150	1760	43	1.3
G-2	171.53	195.39	2.06	2180	1740	80	1.05
G-3	171.39	195.33	2.05	2150	1820	80	1.1
H-1	170.34	186.24	3.7	560	2350	15	10.6
H-5	171.66	186.50	3.2	500	2050	80	3.8
H-6	167.93	182.77	3.3	580	2160	17	11.0
I-1	168.18	189.14	2.45	1900	2150	9.7	3.0
I-3	167.71	188.66	1.90	1900	2190	11.0	2.1
I-5	167.02	188.22	1.8	1850	2190	9.8	2.6
Columbia -3	170.77	188.47	3.65	1290	960	100	2.0
-4	170.75	188.42	3.6	1270	962	130	1.8
-5	172.00	189.24	3.9	1110	940	130	2.0
Clevite -1	154.04	177.51	3.8	1480	900	100	1.7
-2	159.83	168.95	8.1	690	820	160	2.5
-1*	207.31	211.75	3.25	14.5	12300	32	1.8
-2*	210.77	214.73	3.2	9.3	12600	2.7	1.8

*Large crystals

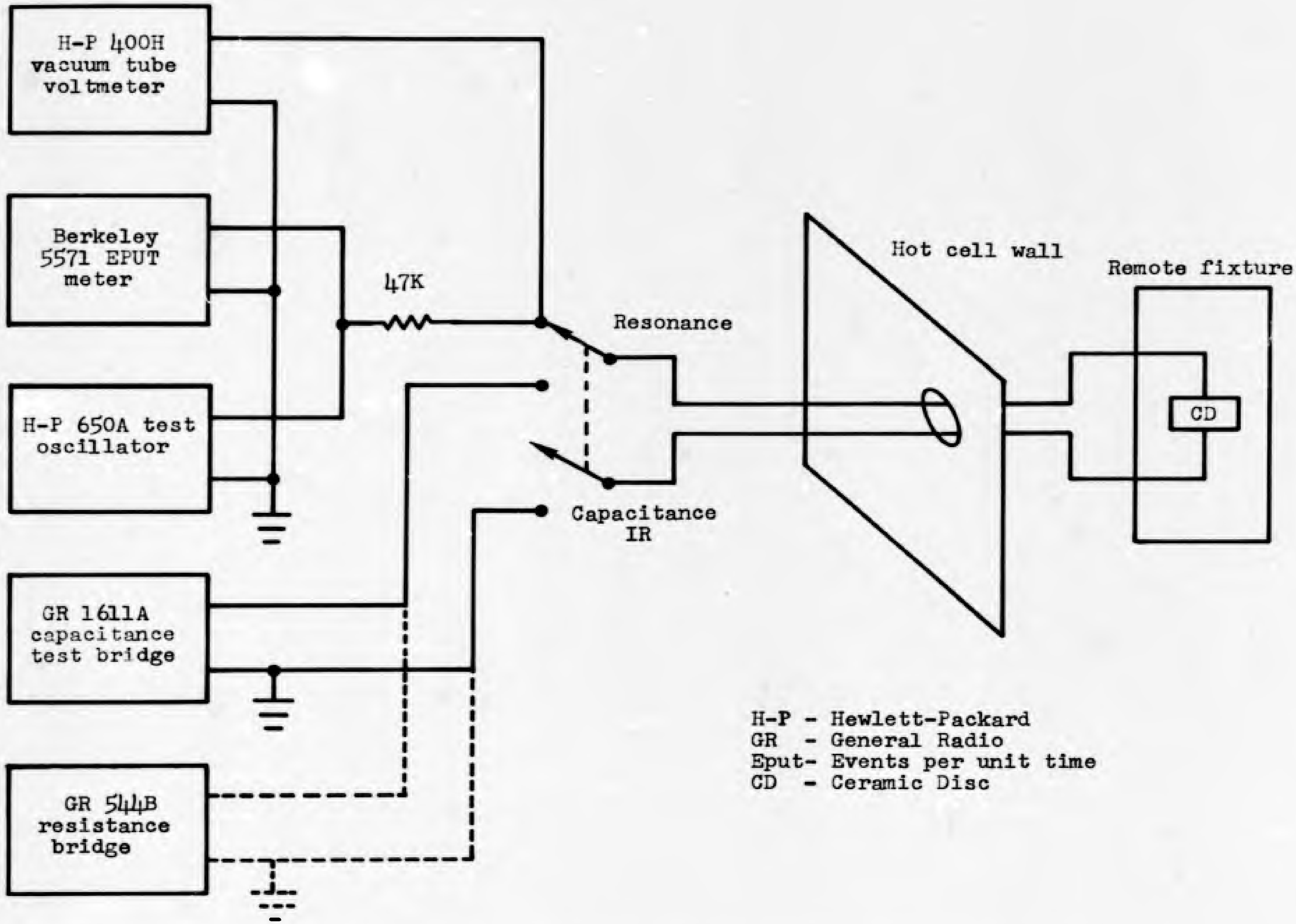


Figure 6-4 Wiring Diagram for Testing Ceramic Discs in Hot Cell

APPENDIX A

GTR RADIATION EFFECTS TESTING SYSTEM

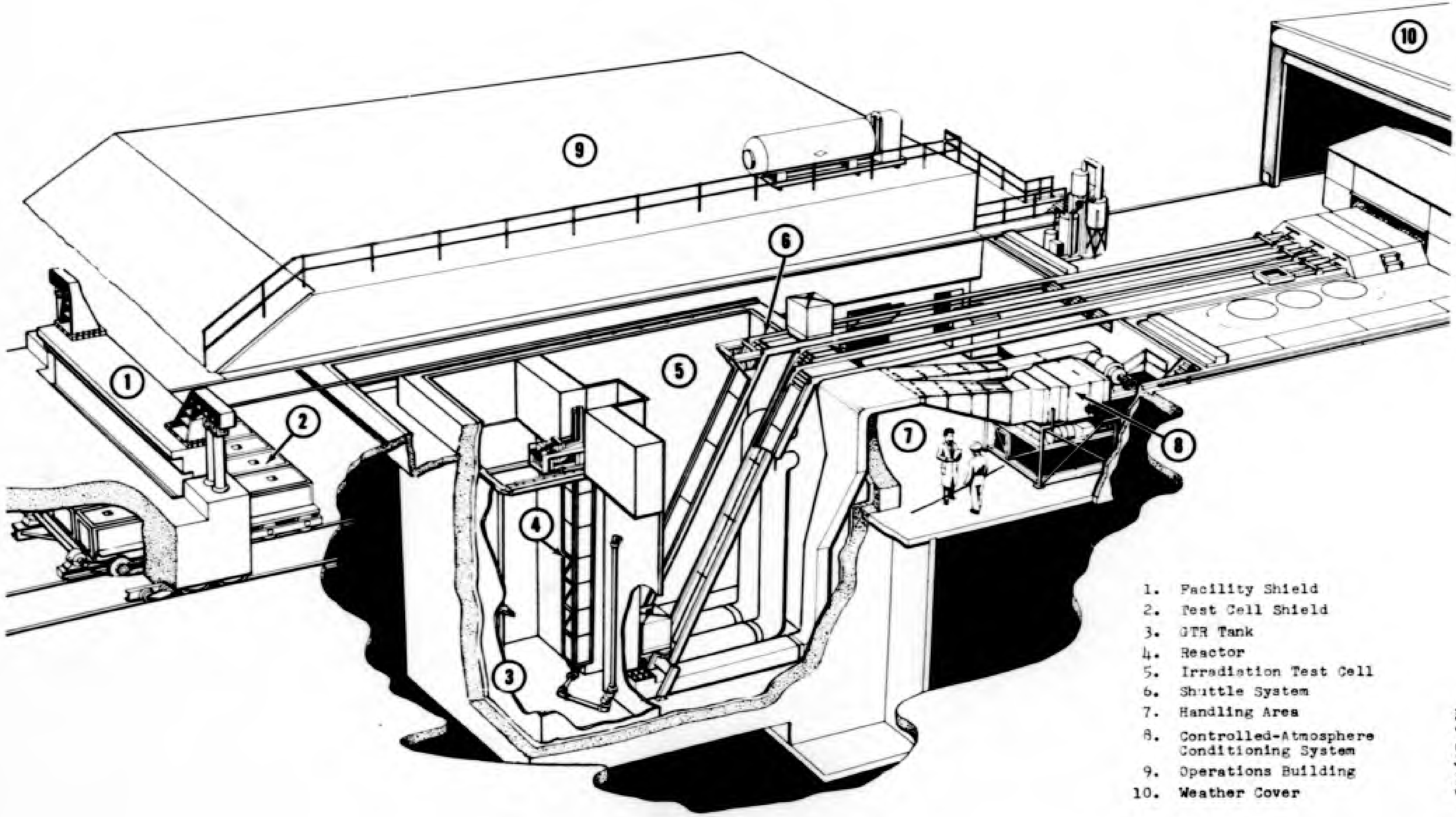
APPENDIX A

GTR RADIATION EFFECTS TESTING SYSTEM

The GTR Radiation Effects Testing System is located in the Reactor Operations Area at the north end of the NARF complex. Figure A-1 is a plan view and Figure A-2 is a cutaway view of the system. A closeup of the irradiation test cell and the reactor tank is pictured in Figure A-3. During operation, the reactor is moved into the closet-like structure built into the north wall of the GTR tank. Items to be irradiated can be located on the north, east, or west sides of the closet, as indicated in the figures.

The reactor closet is constructed of 1-in. aluminum plate and is partially covered by 1/4-in.-thick boral to attenuate thermal neutrons. The boral extends 36 in. east and west from the closet along the tank wall and 36 in. up and down from the horizontal centerline of the reactor core. The centerline is 57 in. above the test-cell floor.

The Ground Test Reactor (GTR) is a heterogeneous, highly enriched, thermal reactor that utilizes water as neutron moderator and reflector, as radiation shielding, and as coolant. Maximum power generation is 3 Mw. The GTR, in an aluminum enclosure to facilitate cooling-water flow, is suspended by an open framework that is carried on a horizontal positioning mechanism at the top of the reactor tank. This mechanism permits the reactor to be positioned at distances ranging from



1. Facility Shield
2. Test Cell Shield
3. GTR Tank
4. Reactor
5. Irradiation Test Cell
6. Shuttle System
7. Handling Area
8. Controlled-Atmosphere Conditioning System
9. Operations Building
10. Weather Cover

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Figure A-2 Cutaway View of GTR Radiation Effects System

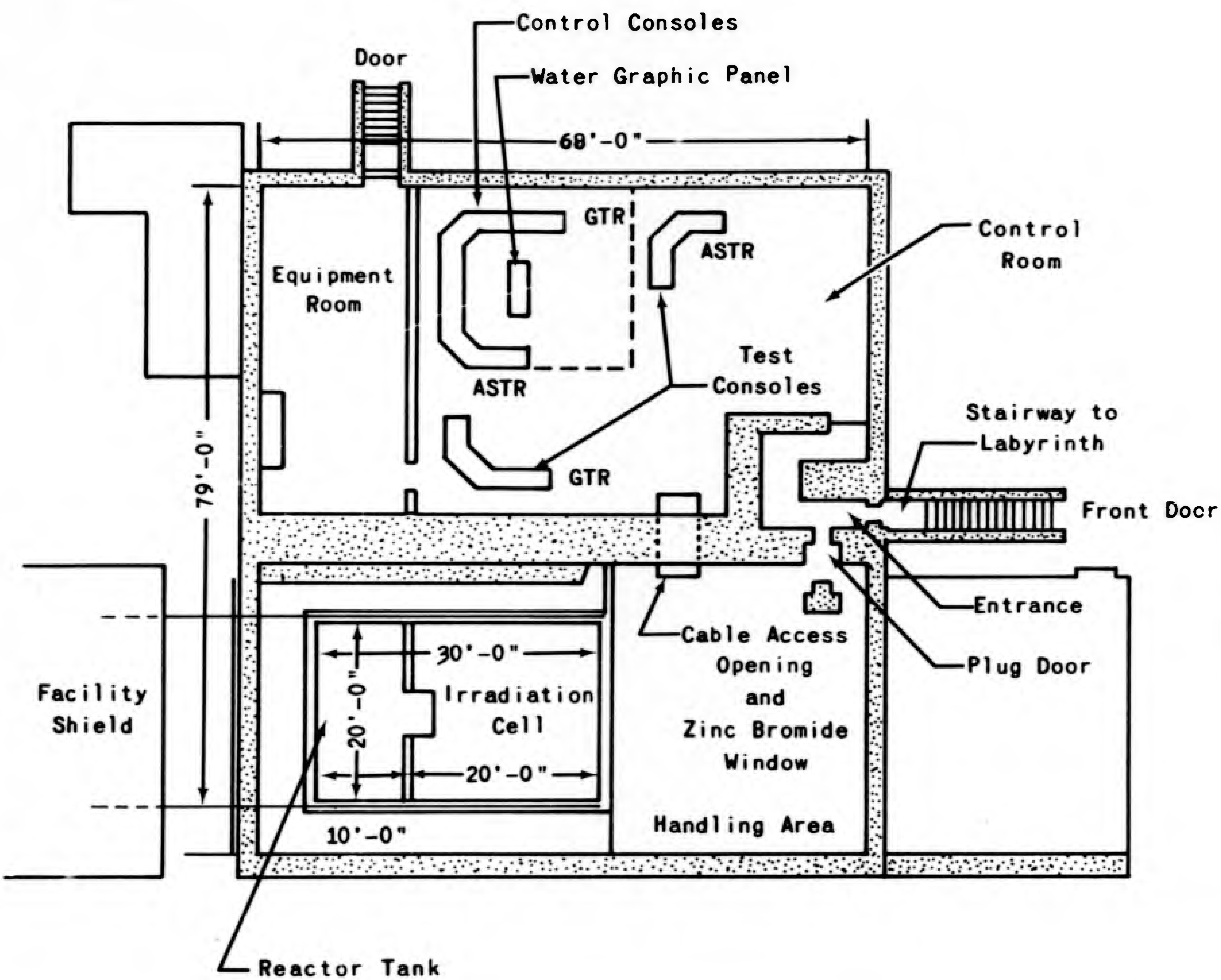

Figure A-1 Plan View of GTR Radiation Effects Testing System and Adjacent Reactor Control Room

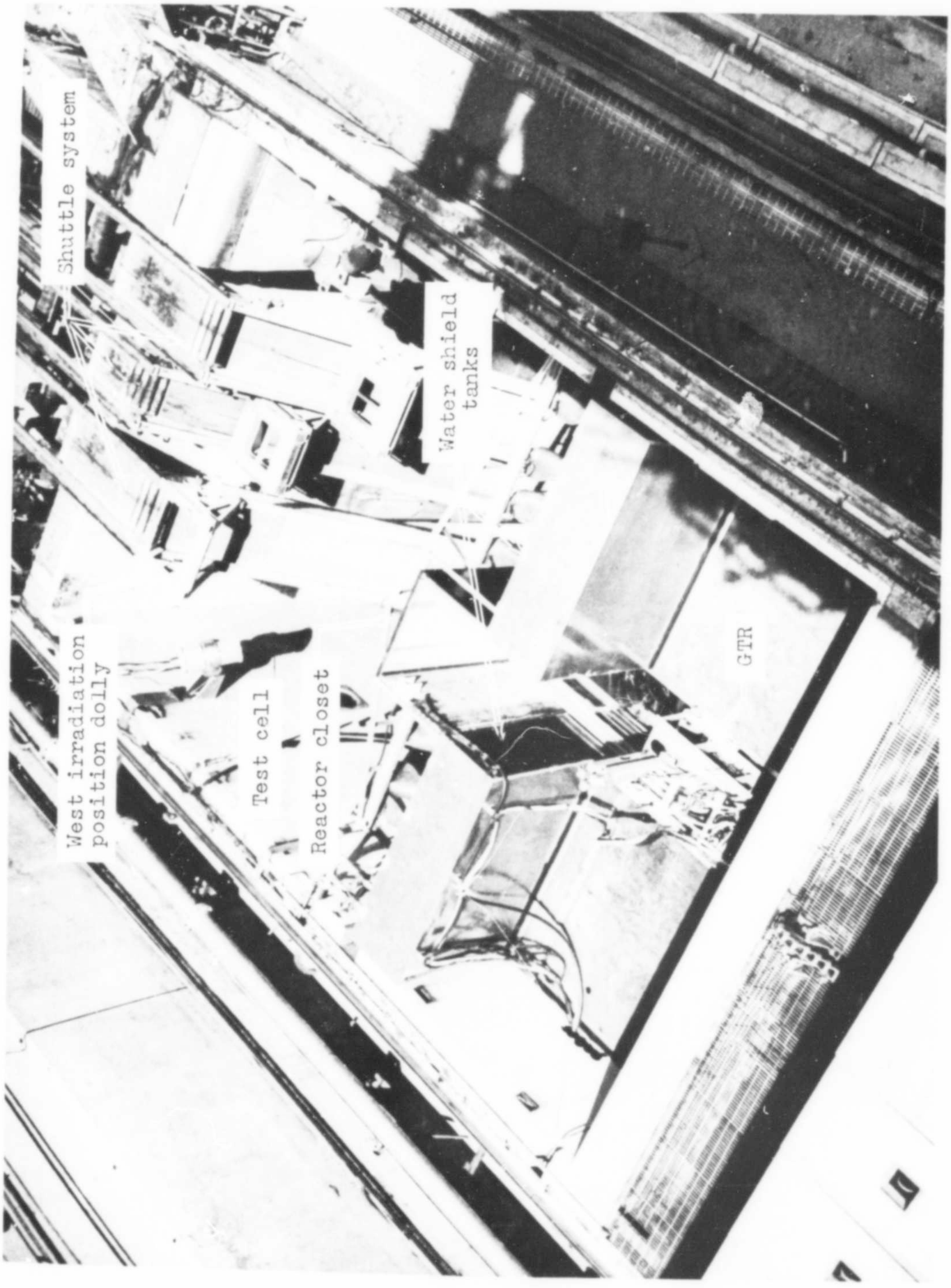

Figure A-3 Irradiation Test Cell and Reactor Tank

2 to 87 in. from the north face of the closet.

Adjacent to the north wall of the irradiation cell is the handling area. Equipment permanently installed in the handling area includes a Davis explosion meter and environmental conditioning equipment for the GTR Radiation Effects Testing System.

An integral part of the GTR testing facility is the shuttle system, which is used to move test assemblies into irradiation position. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the reactor closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be operated from either the control room or the dolly motor-drive shed on the north ramp. Full-coverage televiewing of the entire shuttle system is provided by means of a closed-circuit television in the control room.

The control room (Fig. A-1) is a below-grade, reinforced concrete structure adjacent to the GTR system. The control room provides a shielded area for reactor instrumentation, control consoles, and test systems as well as special test equipment needed to conduct radiation experiments.

APPENDIX B

DOSIMETRY TECHNIQUES AND DATA

APPENDIX B

DOSIMETRY TECHNIQUES AND DATA

B.1 Nuclear Measurements

Nuclear measurements were obtained from dosimetry packets attached to, or near, the test components and on the outside faces of the test dewars. Each packet consisted of a 3-1/2- by 3-in. aluminum plate with the following detectors attached:

- one sulfoxy pellet for measuring fast-neutron ($E > 2.9$ Mev) integrated flux;
- two phosphorous pellets (one bare, on cadmium-covered) for measuring thermal-neutron ($E < 0.48$ ev) integrated flux; and
- one nitrous-oxide dosimeter for measuring gamma dose (this dosimeter was not included on packets placed inside the LN_2 dewars).

In Section B.3 are presented figures which show the dosimetry packet locations. The figures are viewed from the reactor unless noted otherwise. The dosimetry readouts for the packets are given in tables. Where more than one packet was used with a test item, the integrated neutron fluxes and gamma doses in this report are averages of the values shown for the packets.

B.1.1 Neutron

The sulfoxy pellets used for fast-neutron measurements were molded from Epon X-18 epoxy resin. These pellets were developed for use in high-flux irradiations and are usable at temperatures ranging from -423° to +450°F. The resin contains a curing agent, sulfonyl dianitine, having 12.9% sulfur by weight. Since the curing agent is bound to the resin in a chemical reaction, a uniform dispersion of sulfur is assured.

Standard foil techniques were used in specifying the neutron field (Ref. 3). All foils were counted and the data reduced by an IBM 7090 digital-computer program.

The neutron integrated flux values appearing in this report were obtained from readouts of the dosimeter packets located within the dewars.

B.1.2 Gamma

The gamma doses appearing in this report for test items in LN_2 dewars were obtained by exposing nitrous-oxide (N_2O) dosimeters (Ref. 4) outside the dewars at both the front and back faces and interpolating between the measurements. (Gamma dosimeters in packets exposed in a liquid-nitrogen environment are not usable.) For the test items that were not inside LN_2 dewars, the N_2O dosimeters were located at, or near, the individual components.

The N_2O dosimeters used at NARF consist of a quartz shell forming a volume of about 24 cc that is filled with a measured quantity of N_2O gas, then flame-sealed. Upon exposure to gamma radiation, the following reaction is produced in the gas:

$$6\ N_2O \longrightarrow 5\ N_2 + O_2 + 2\ NO_2.$$

Readout is accomplished by measuring the moles of $N_2 + O_2$ produced per mole of original N_2O and relating this ratio to the gamma dose by means of a calibration curve.

Energy dependence of the N_2O system is air-equivalent (within 10%) between 150 kev and 5 Mev. The dosimeters are usable (with available calibration curves) in the dose and temperature ranges of from 10^8 to 3.8×10^{11} ergs/gm(C) and -90° to 120°C, with a reproducibility of 7% to 9% in the GTR field. This temperature range may be extended by applying temperature correction factors (Ref. 3) to the dosimeter readouts if the temperature of the dosimeters is known.

B.2 Analytical GTR Neutron Spectrum

The neutron spectrum (Ref. 5) of the GTR in a water moderator has been measured to be Maxwellian at thermal energies ($E <$ 0.48 ev), approximately E^{-1} from about 0.5 ev to 0.1 Mev, and essentially a fission spectrum for higher energies. In Figure B-1, this spectral shape has been mathematically altered to account for the attenuation of the thermal flux by the boral surrounding the reactor in the dry-pool configuration. The resulting spectrum has been shown to represent the actual spectrum fairly accurately. (Note: This spectrum does not apply to the east position where the boral shield was removed for this test.)

Flux measurements have been made in the thermal-, epithermal-, and fast-neutron energy ranges by use of a variety of thermal, resonance, and threshold detectors. Fast-neutron flux measurements ($E > 2.9$ Mev) made on the dry side with the boral in place agree well with those made on the wet (tank) side. The measured thermal flux is in general agreement with that obtained by integration of the analytical curve shown in Figure B-1.

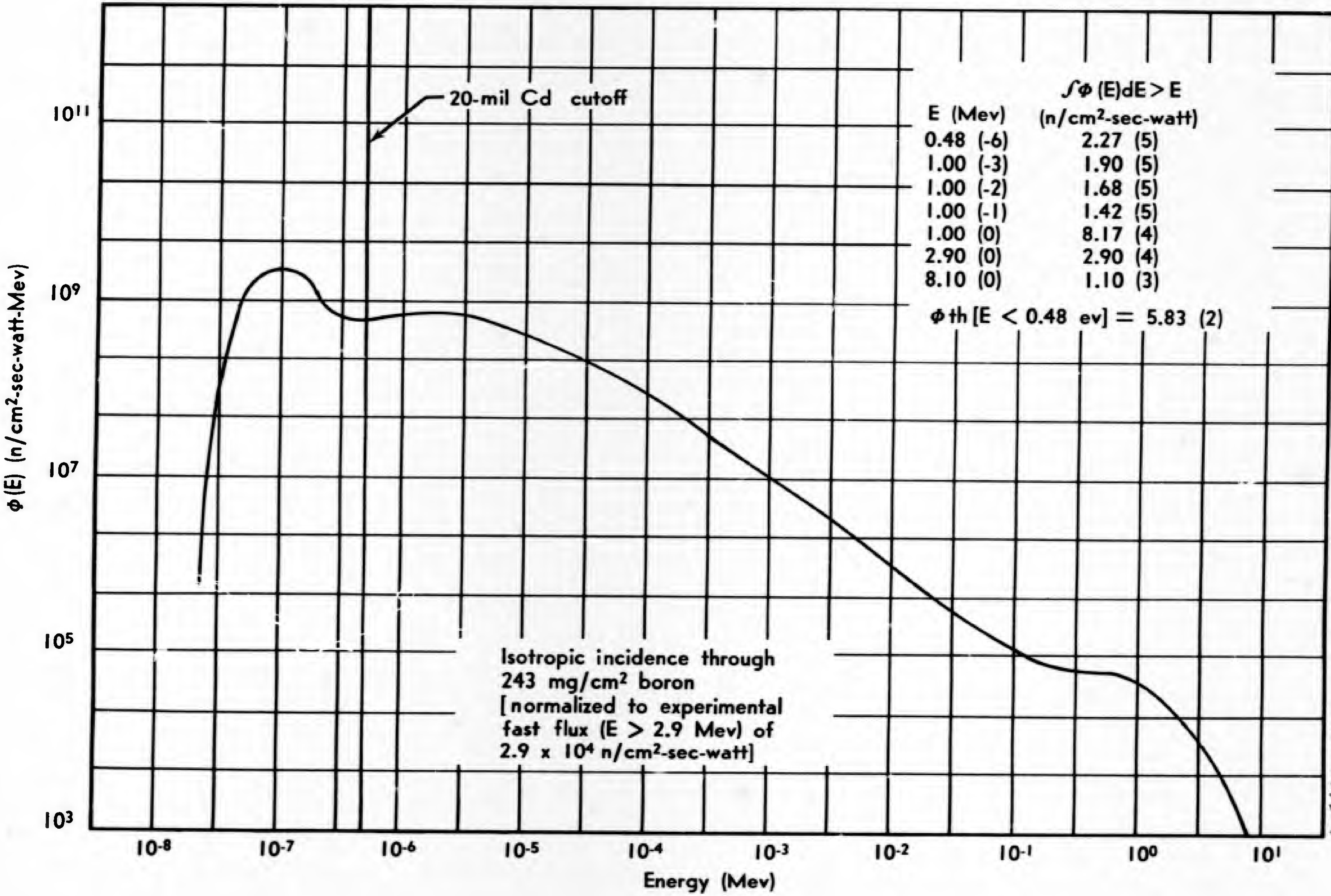

Figure B-1 Analytical GTR Neutron Spectrum

B.3 Dosimetry Data

B.3.1 Developmental Strain Gages (West)

Eight dosimetry packets were inside the west cryogen dewar containing the strain gages. Eighteen additional packets were mounted on the front and back faces (9 each) of the dewar. The locations of the packets inside the dewar are shown in Figure B-2. The neutron fluxes measured with the inside packets are listed in Table B-1. The locations of the packets on the outside of the dewar are depicted in Figure B-3. Packet numbers with the suffix "B" were located on the back face of the dewar directly behind their counterpart on the front of the dewar. Neutron fluxes and gamma doses measured with the packets on the outside of the dewar are given in Table B-2.

Table B-1

Dosimetry Readouts (Inside Dewar) for West Developmental Strain Gages

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)
1	1.2(16)	3.7(14)
2	1.2(16)	2.9(14)
3	1.3(16)	7.8(14)
4	1.2(16)	6.5(14)
5	8.3(15)	4.4(14)
6	6.5(15)	4.8(14)
7	8.8(15)	4.4(14)
8	6.6(15)	5.8(14)

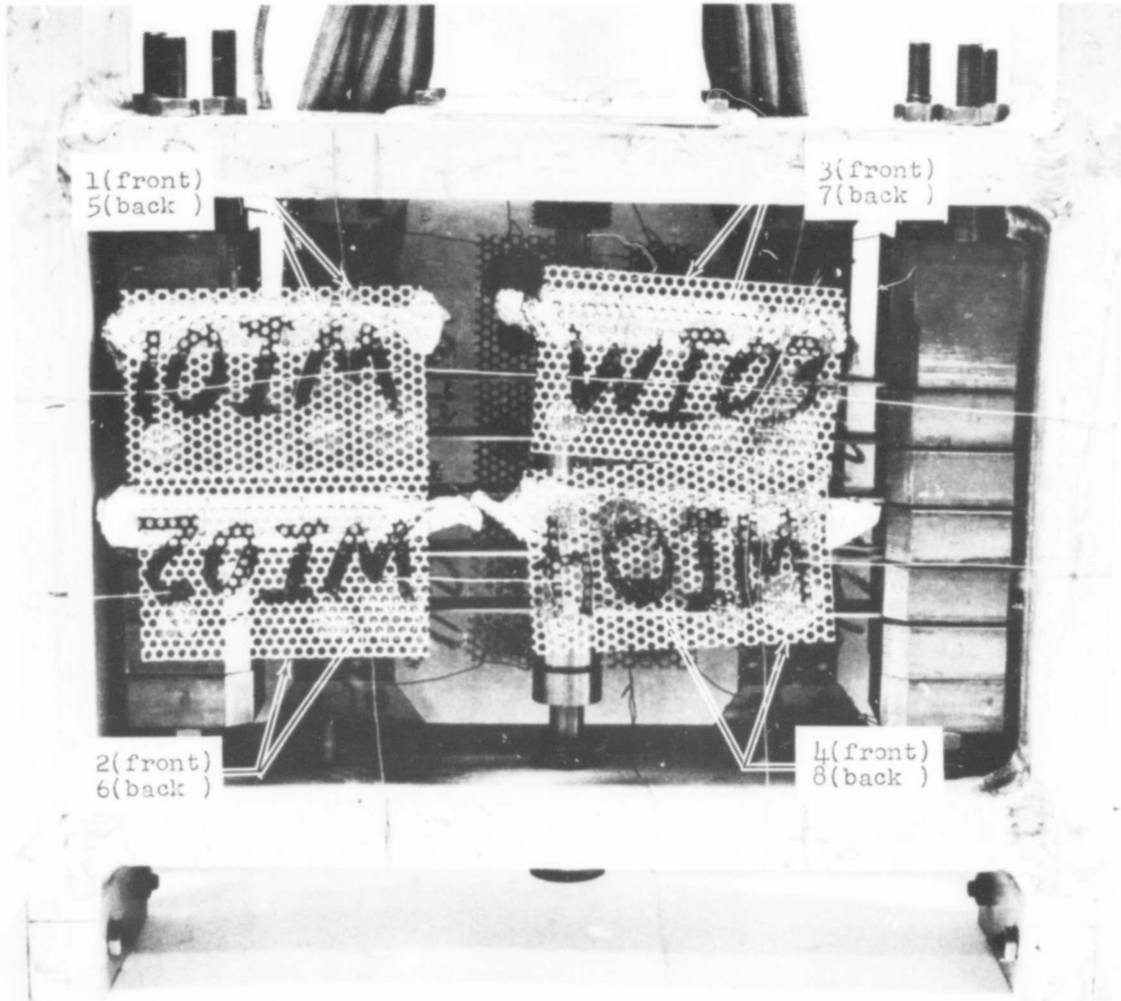

Figure B-2 Dosimetry Packets Attached to West Developmental Strain Gages

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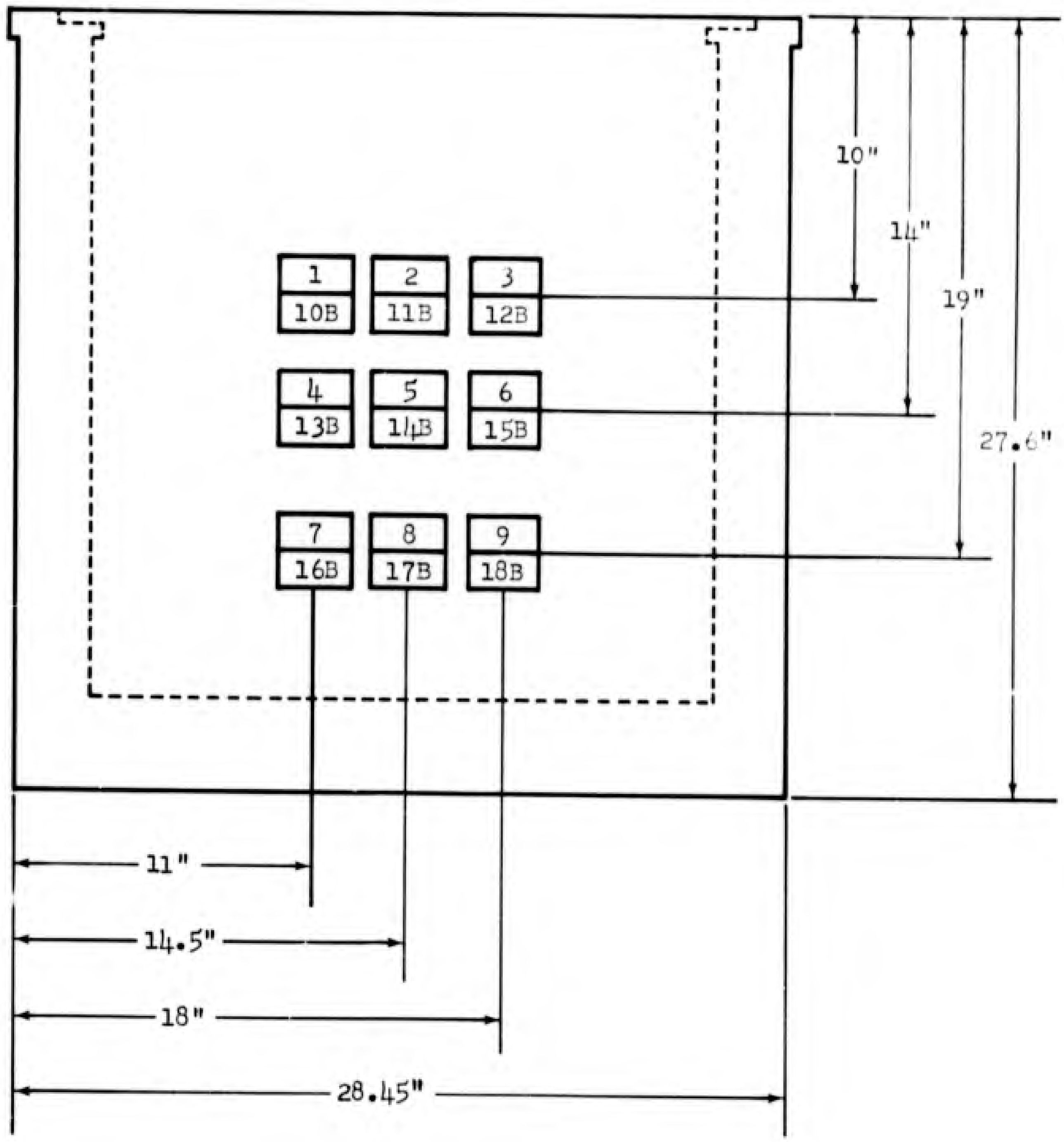

Figure B-3 Dosimetry Packet Loactions on Outside of West LN_2 Dewar for GTR Test 13

Table B-2

Dosimetry Readouts (Outside Dewar) for West Developmental Strain Gages

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)	N_2O [ergs/gm(C)]
1	4.3(16)	4.7(14)	2.8(11)
2	4.6(16)	5.1(14)	3.1(11)
3	4.0(16)	7.9(14)	3.1(11)
4	4.0(16)	2.8(14)	2.8(11)
5	4.2(16)	3.7(14)	3.1(11)
6	3.5(16)	5.3(14)	2.8(11)
7	2.9(16)	3.1(14)	2.8(11)
8	2.9(16)	3.4(14)	2.2(11)
9	2.5(16)	5.3(14)	1.8(11)
10	2.3(15)	1.3(15)	1.3(10)
11	2.5(15)	1.3(15)	1.3(10)
12	2.4(15)	1.4(15)	1.3(10)
13	1.9(15)	1.1(15)	1.1(10)
14	2.2(15)	1.4(15)	1.4(10)
15	2.1(15)	1.4(15)	1.4(10)
16	1.6(15)	-	1.2(10)
17	2.0(15)	3.1(15)	1.8(10)
18	1.7(15)	2.0(15)	1.2(10)

B.3.2 Developmental Strain Gages (East) and Control Drum Plate Section

Eight dosimetry packets were mounted on the strain gage fixture located in the east cryogen dewar. Eighteen additional packets were located on the front and back faces (9 each) of the dewar. The locations of the packets mounted on the fixture are shown in Figure B-4. The neutron fluxes measured with the inside packets are listed in Table B-3.

Table B-3

Dosimetry Readouts (Inside Dewar) for East Developmental Strain Gages

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)
8	1.1(16)	2.9(15)
9	1.0(16)	5.7(15)
10	9.6(15)	3.3(15)
11	8.3(15)	5.8(15)
12	4.9(15)	1.7(15)
13	5.7(15)	1.1(15)
14	4.3(15)	1.7(15)
15	4.8(15)	1.1(15)

Nine dosimetry packets were mounted on the control drum plate section assembly. The locations of these packets are shown in Figure B-5. The neutron fluxes measured with those packets are listed in Table B-4.

NPC 21,476
31-7970

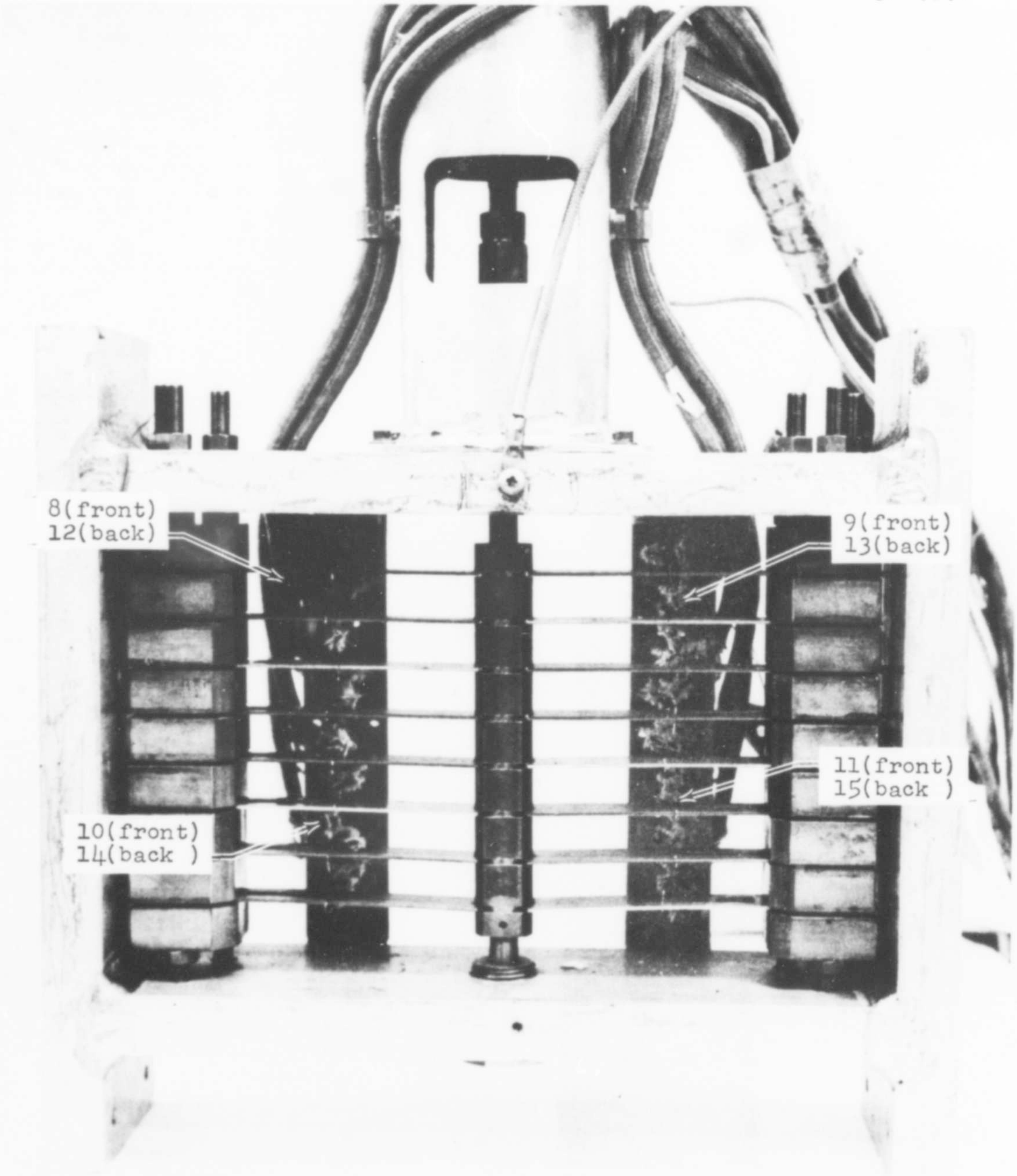

Figure B-4 Dosimeter Packet Locations on East Developmental Strain Gages

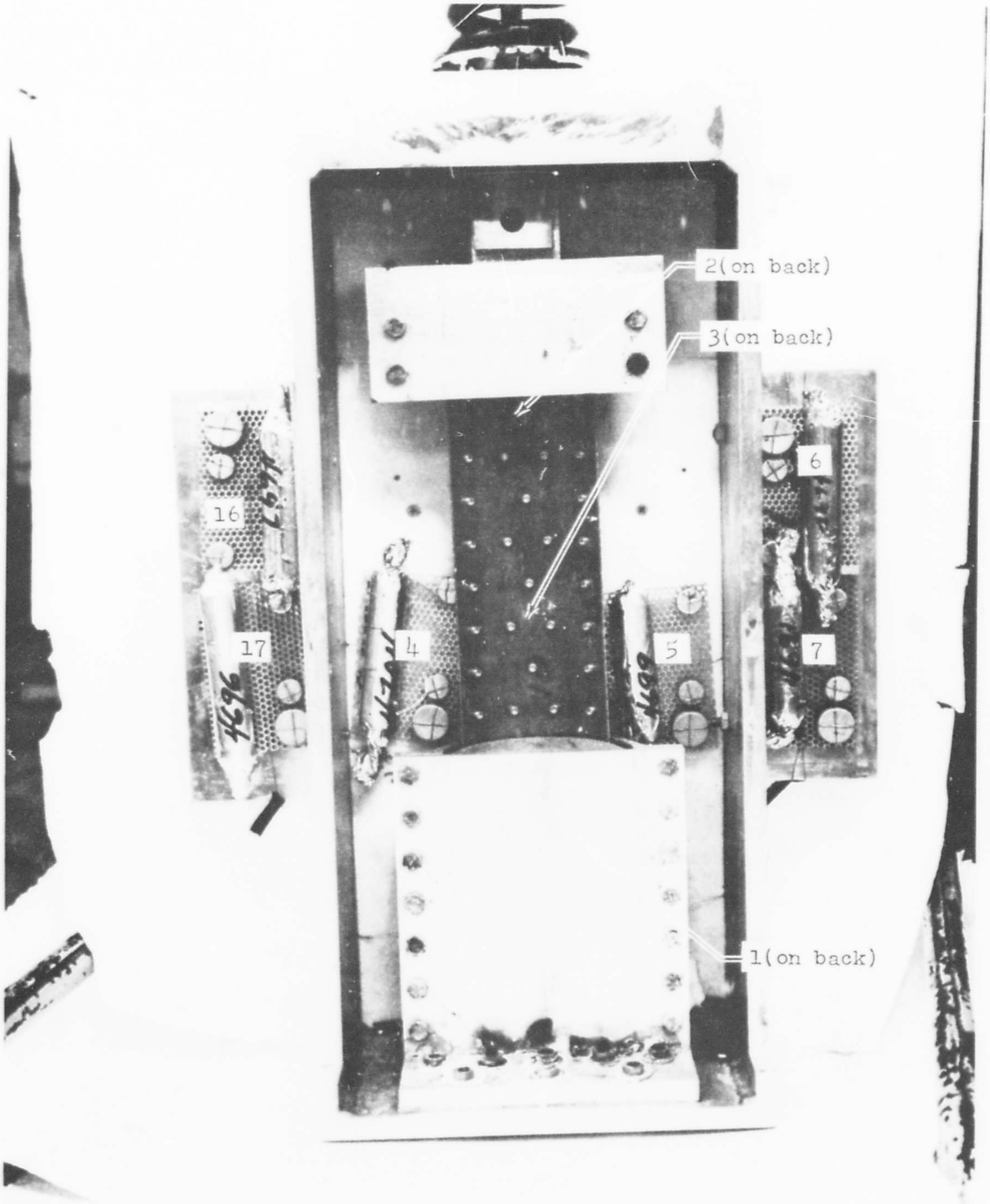

Figure B-5 Dosimetry Packets Attached to Control Drum Plate Section

Table B-4

Dosimetry Readouts (Inside Dewar) for
Control Drum Plate Section

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)
1	1.6(16)	4.1(16)
2	2.0(16)	5.8(16)
3	2.1(16)	4.1(16)
4	2.1(16)	6.5(16)
5	1.9(16)	5.8(16)
6	1.2(16)	2.2(16)
7	1.6(16)	3.3(16)
16	1.6(16)	-
17	1.5(16)	2.3(16)

The locations of the packets on the outside of the dewar are depicted in Figure B-6. Neutron fluxes and gamma doses measured with the packets on the outside of the dewar are given in Table B-5.

B.3.3 Thermocouples

Twelve dosimetry packets were mounted on the front and back faces (6 each) of the heater boxes. The locations of these packets is shown in Figure B-7. Neutron fluxes and gamma doses measured with these packets are given in Table B-6.

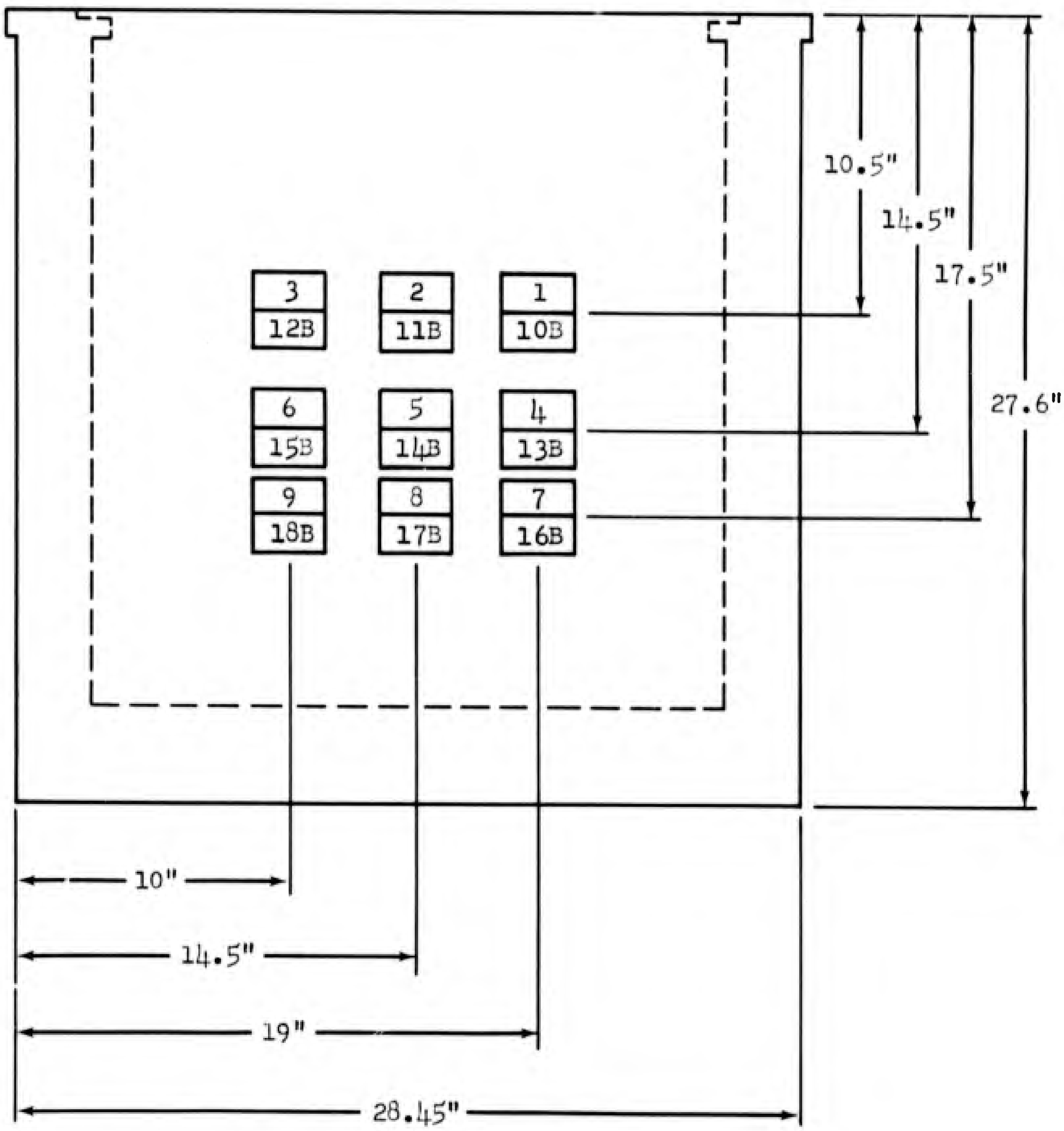

Figure B-6 Dosimetry Packet Location on Outside of East LN_2 Dewar for GTR Test 13

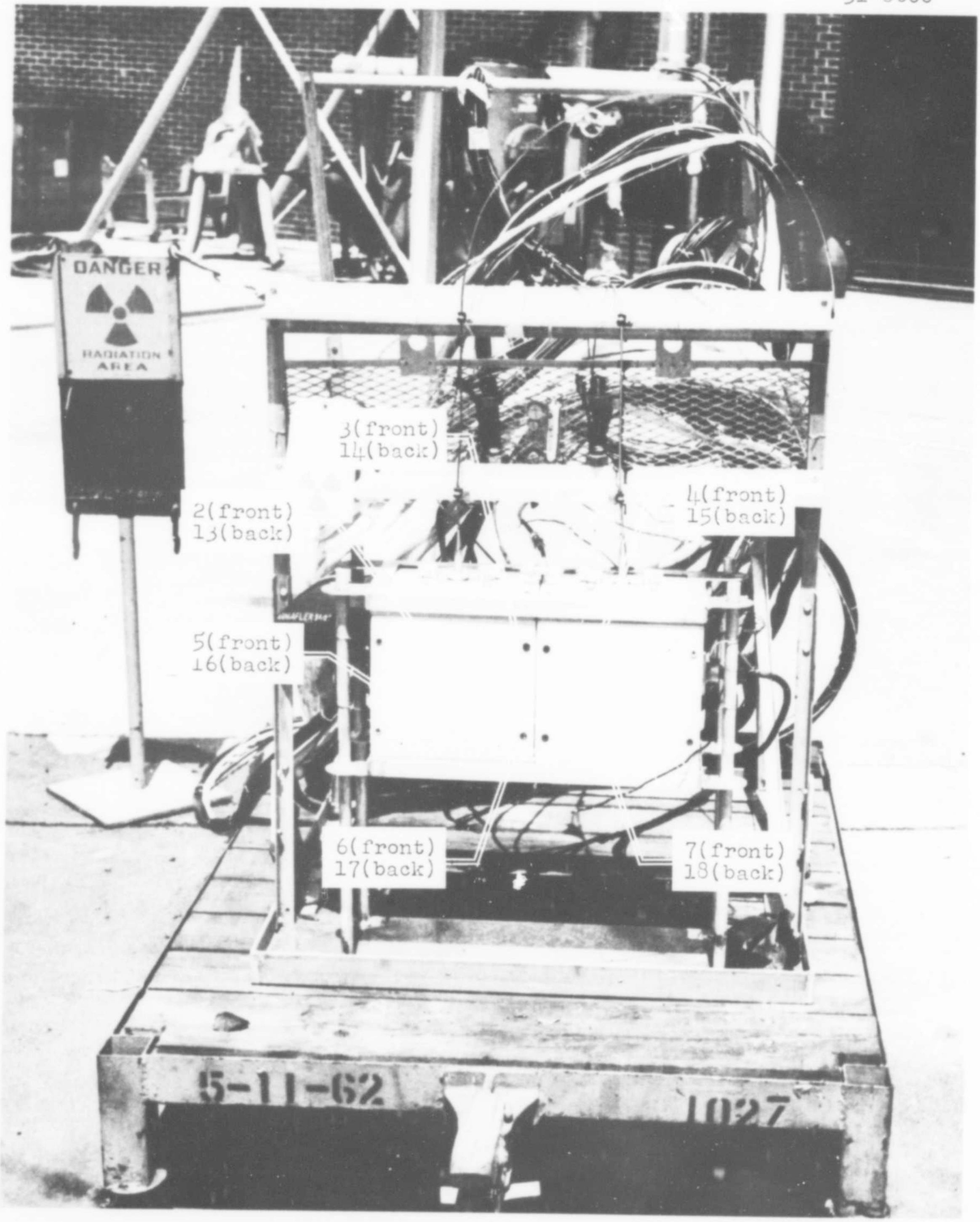

Figure B-7 Dosimetry Location on Thermocouple Heater Boxes

Table B-5

Dosimetry Readouts (Outside Dewar) for East Developmental Strain Gages and Control Drum Plate Section

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)	N_2O [ergs/gm(C)]
1	4.4(16)	3.6(17)	3.1(11)
2	6.2(16)	-	>3.8(11)
3	5.8(16)	2.9(17)	>3.8(11)
4	4.4(16)	-	3.1(11)
5	6.0(16)	3.6(17)	>3.8(11)
6	5.6(16)	2.6(17)	3.7(11)
7	3.9(16)	3.0(17)	2.4(11)
8	4.9(16)	3.0(17)	3.1(11)
9	4.8(16)	2.2(17)	>3.8(11)
10	1.9(15)	2.8(15)	1.2(10)
11	2.3(15)	3.2(15)	1.2(10)
12	2.4(15)	4.6(15)	1.3(10)
13	2.0(15)	2.0(15)	1.2(10)
14	2.3(15)	2.4(15)	1.3(10)
15	2.5(15)	2.5(15)	1.6(10)
16	1.7(15)	1.8(15)	1.1(10)
17	2.1(15)	2.9(15)	-
18	1.7(15)	1.8(15)	1.1(10)

Table B-6

Dosimetry Readouts for Thermocouples

Dosimetry Packet No.	Sulfoxy (n/cm^2, E > 2.9 Mev)	Phosphorous (n/cm^2, E < 0.48 ev)	N_2O [ergs/gm(C)]
2	1.1(17)	-	>3.8(11)
3	1.4(17)	5.4(14)	3.6(11)
4	1.2(17)	2.0(15)	>3.8(11)
5	1.2(17)	-	3.7(11)
6	1.5(17)	8.2(14)	3.6(11)
7	1.3(17)	2.0(15)	>3.8(11)
13	4.1(16)	1.4(15)	1.4(11)
14	3.8(16)	1.8(15)	1.8(11)
15	3.6(16)	2.0(15)	1.5(11)
16	4.3(16)	1.6(15)	1.8(11)
17	4.7(16)	2.0(15)	-
18	5.1(16)	-	1.6(11)

B.3.4 Piezoelectric Ceramic Discs

The piezoelectric ceramic discs were irradiated in the same configuration as were the pulse preamplifiers that were irradiated in GTR Test 7 (GD/FW Report FZK-170-3). A separate mapping run in the dummy fuel element was made in order to obtain additional dosimetry data for the pulse preamplifiers. Since these mapping data were used to determine flux and dose information for the piezoelectric ceramic discs, the experiment is described below.

To perform the mapping experiment, five dosimeter packets were positioned within a fuel element capsule. Each packet contained:

- one sulfur pellet
- one N_2O dosimeter
- two gold foils (one bare and one cadmium-covered).

The capsule was inserted into the reactor core (NW corner) and irradiated for 1 hr at a power level of 1.13 Mw.

The results of the mapping experiment are depicted graphically in Figure B-8. A scaled representation of the capsule is superimposed on the graph to locate the dosimeter packets. The abscissa values correspond to the locations of the dosimeter packets in the capsule. Integrated neutron fluxes and gamma doses were obtained by extrapolation to 17,700 Mw-min, the irradiation period for the piezoelectric ceramic discs in GTR Test 13.

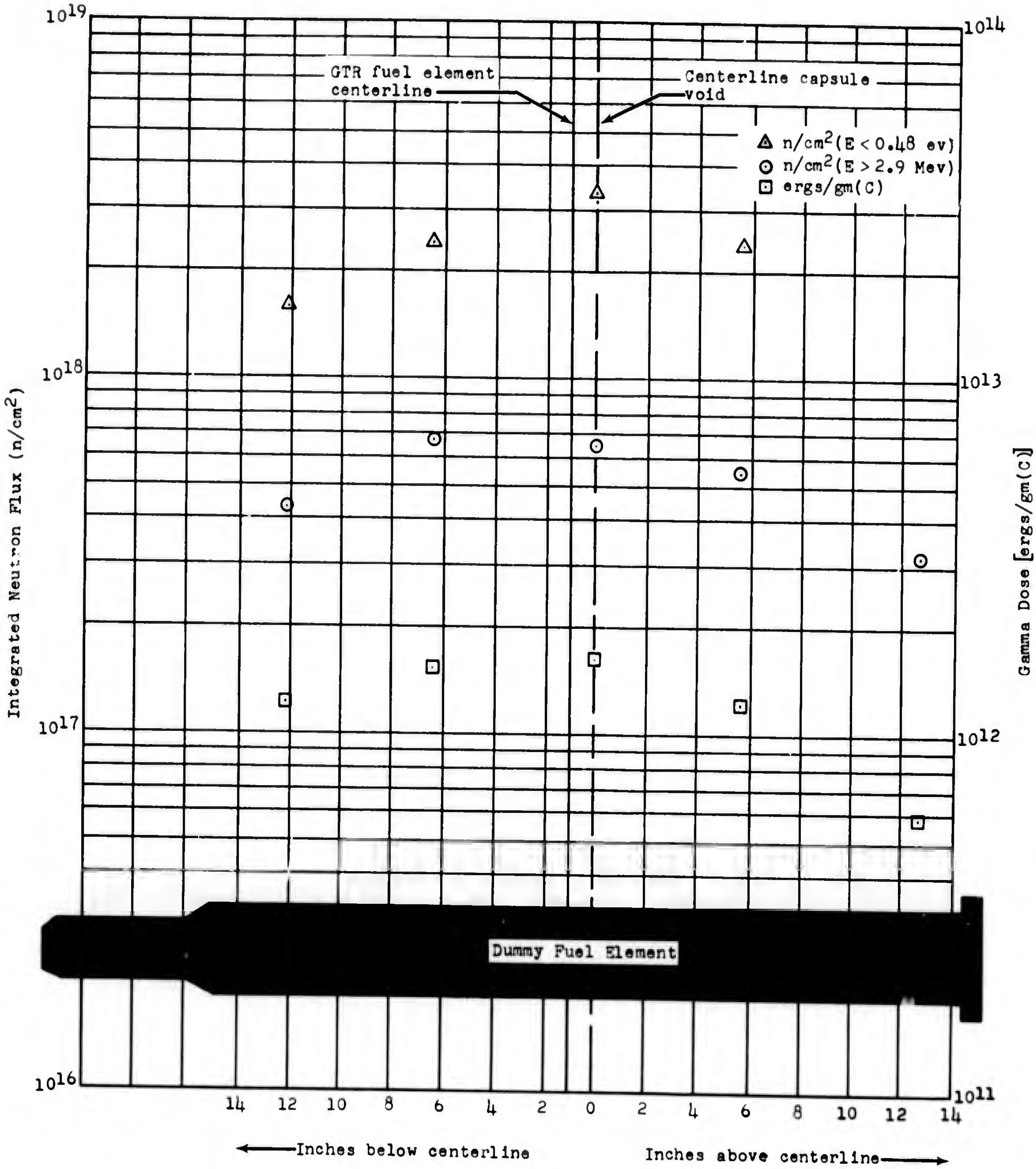

Figure B-8 Mapping Data for Coaxial Cables

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1. Final Test Specifications for Ground Test Reactor (GTR) Irradiation Test Number 13. Aerojet-General Corporation Report No. RN-S-0102.

2. NARF Facilities Handbook. General Dynamics/Fort Worth Report FZK-185 (March 1964).

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5. Dungan, W. E., Specification of the Neutron Flux in the Radiation Effects Testing Facility. Convair - Fort Worth Report MR-N-270 (NARF-60-23T, July 1960).