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ORNL Fission Counter FC-3 Quality Assurance Report, Vol. 1: Fission Counter Development

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[redacted]

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INSTRUMENTATION AND CONTROLS DIVISION

ORNL FISSION COUNTER FC-3 QUALITY ASSURANCE REPORT, VOL. 1: FISSION COUNTER DEVELOPMENT

W. T. Clay
J. T. De Lorenzo V. K. Paré G. C. Guerrant

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Reports in this series are as follows:

ORNL/TM-5725	ORNL Fission Counter FC-3 Quality Assurance Report, Vol. 1: Fission Counter Development
ORNL/TM-5726	ORNL Fission Counter FC-3 Quality Assurance Report, Vol. 2: Fission Counter Specifications and Assembly/Testing Procedures

ABSTRACT

The ORNL fission counter FC-3 was developed as the first step towards an advanced neutron detection system for use in LMFBRs. This counter has a neutron sensitivity of 0.77 count sec^{-1} $[nv(th)]^{-1}$ when operated at 400°C (750°F) in a 10^6 R/hr gamma background. The pulse electronics for signal processing were designed such that the overall performance of the entire detection system is near optimum. This document describes the development of the FC-3 at ORNL and qualification tests at ANL and gives preliminary results from irradiation tests in the EBR-II. This information is given in compliance with the requirements of the ORNL quality assurance program.

PREFACE

The *ORNL Fission Counter FC-3 Quality Assurance Report* consists of two volumes:

Vol. 1: Fission Counter Development, ORNL/TM-5725

Vol. 2: Fission Counter Specifications and Assembly/Testing Procedures, ORNL/TM-5726.

Volume 1 is a general description of the entire development program. Volume 2 contains specific information such as specifications, assembly procedures, and testing procedures that were developed as part of this program and would be essential for fabrication of another counter.

In these two documents, mention of a product brand neither endorses the product nor implies a preference over other products for the same purpose.

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INTRODUCTION

The authors prepared this and a companion document (Vol. 2, ref. 1) to record the development of a fission counter (FC-3) for reactor in-core service so that its faithful reproduction in any subsequent fabrication will be ensured and that its expected performance will be duplicated. The principal objective of this work was to develop a neutron sensor that would operate as a low-level flux monitor (LLFM) during reactor startup and as a subcriticality monitor at extremely high temperatures and in high gamma backgrounds experienced in-core in a liquid-metal fast breeder reactor (LMFBR). This document and its companion Volume 2 were prepared in response to the quality assurance program at Oak Ridge National Laboratory (ORNL). The principal objective of this program is that it shall provide a means for the establishment, control, and verification of the required quality of design, development, procurement, fabrication, construction, inspection, installation, operation, and maintenance of all experimental or conventional operational and test facilities and systems.

2. DESIGN GOALS

The overall goal of the ORNL neutron sensor development program is to develop advanced neutron detection systems for use by the nuclear power industry. The initial goal is to develop a fission counter with a neutron sensitivity of 1.0 count sec^{-1} $[nv(th)]^{-1}$ for in-core service at 400°C (750°F) and 10^6 R/hr. The ultimate goal is to develop a fission counter for service at 590°C (1100°F) and 10^6 R/hr in the second core of the Fast Flux Test Reactor (FFTF) and in future LMFBRs. Commercial fission counters currently available for use as LLFMs in the FFTF have been qualified for operation at only 150°C (300°F), and, hence, they require cooled thimbles. If ORNL successfully develops a counter for operation at 590°C, cooled thimbles would not be needed; this would result in a substantial savings in plant cost and improved efficiency of plant operation.

To be qualified for reactor service, the fission counter must withstand an integrated dose corresponding to a 1-year lifetime, which is a fast-neutron dose of 3×10^{17} nvt.

For such demanding temperature and gamma rejection performances, the factors that affect detector optimization must be thoroughly analyzed and understood. Also, the pulse electronics for signal processing must be designed such that the overall performance of the entire detection system is near optimum.

3. DESCRIPTION OF FISSION COUNTER FC-3

Fission counter FC-3 (ORNL drawing Q-5419) is contained in an all-welded, stainless steel can. The high voltage applied to the counter is split evenly (+ and −) between two mineral-insulated (MI) cables to greatly reduce the probability of high-voltage breakdown pulse noise.

Three concentric cylindrical electrodes electroplated with $^{235}U_3O_8$ are rigidly held by twelve (six each of two types) alumina step insulators (Fig. 1). This arrangement makes assembly easier and provides a guard ring throughout the counter-cable assembly.

Since the counter is self-compensating for axial and radial thermal expansion, no springs are required for its construction.

The entire can is enclosed by a zirconium shield, which does not exceed the permitted maximum 7.6 cm (3 in.) OD. The shield reduces the gamma response of the counter by attenuating the low-energy gamma background.

Pickup of electromagnetic interference, which is common near reactors, is minimized by a low-noise, current-pulse floating differential preamplifier. The instrumentation from the output of the preamplifier consists of three linear pulse amplifiers with variable gain, a discriminator with a variable threshold, a scaler-timer, a count-rate meter, and two power supplies. All of these instruments were calibrated and evaluated for long-term laboratory operation. The pulse-shaping time-constants, which are part of the three-amplifier network, are optimimum to achieve the best gamma rejection performance.

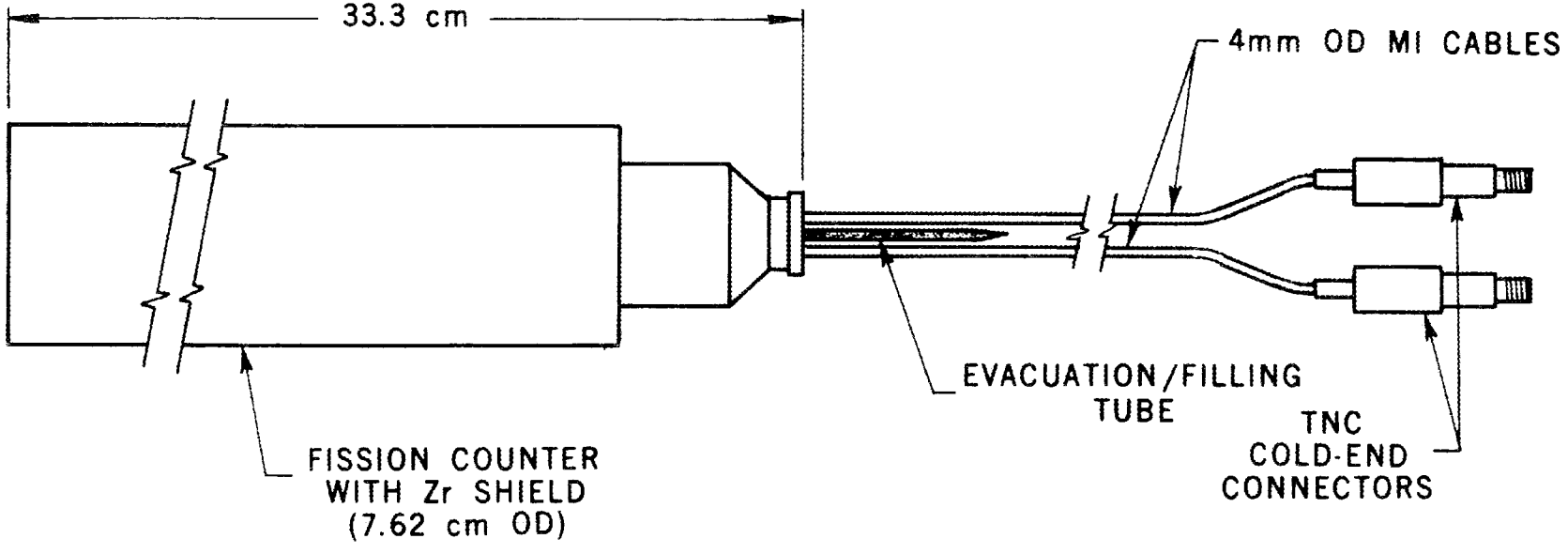

Fig. 1. ORNL fission counter FC-3.

3.1 Fission Counter Specifications

The general specifications for the FC-3 fission counter assembly are as follows:

Operating temperature:	400°C
Gas pressure:	1900 torr (2.5 atm)
Gas filling:	90% Ar - 10% N_2
Sensitive area:	1063 cm^2
Electrode spacing:	0.15 cm (0.060 in.)
Sensitive volume:	84.1 cm^3
Operating voltage:	Split voltage, ΔV = 400 V (+200 and -200 V)
Collection time:	∿50 nsec
Pulse rise time:	∿50 nsec
Pulse fall time:	∿170 nsec
Electrode coating:	2 mg/cm^2
Coating material:	U_3O_8
^{235}U enrichment:	>99.9%
Total ^{235}U:	1.90 g
Shielding:	Zr, 0.584 cm (0.230 in.)
Diameter:	6.35 cm (2.5 in.); 7.62 cm (3 in.) with shield
Counter length:	26.4 cm (10.4 in.); 33.3 cm (13.1 in.) with shield
Electrode material:	type 304L stainless steel
Insulator material:	Al_2O_3 (99.5% pure)
Cable length:	9.75 m (32 ft)
Cable diameter:	4 mm (0.158 in.)
Cable insulator:	MgO
Sensitive length:	17.8 cm (7.0 in.)
Neutron sensitivity:	0.92 count sec^{-1} $[nv(th)]^{-1}$ at 0 R/hr
	0.77 count sec^{-1} $[nv(th)]^{-1}$ at 1×10^6 R/hr
	0.21 count sec^{-1} $[nv(th)]^{-1}$ at 6×10^6 R/hr

Gamma sensitivity (^{60}Co):	3.38×10^{-11} A-hr R^{-1} (with Zr shield)
Alpha current:	6.4×10^{-10} A .

3.2 Configuration and Dimensions

The internal construction, external appearance, and pertinent physical dimensions of the fission counter assembly with cables and gamma shield are illustrated in Figs. 1-4.

3.3 Identification

The following identification is etched on the outside can of the fission counter:

ORNL I & C

FC-3

3.4 Weight of Materials

The weights of the materials used to fabricate the fission counter assembly are as follows:

Fission Counter:	
Stainless steel (304L)	1.77 kg
Al_2O_3 (99.5%)	16.4 g
FN-42 (42% Ni - 58% Fe)	0.420 g
U_3O_8 ($\geqslant$ 99.9% ^{235}U)	2.126 g
Nickel	36 g
Argon - Nitrogen	1900 torr (2.5 atm)
Cable:	
Copper	65.0 g/m of cable length
Stainless steel (304L)	57.5 g/m of cable length
MgO (63% packing density)	5.59 g/m of cable length
Shield:	
Zirconium	2.90 kg

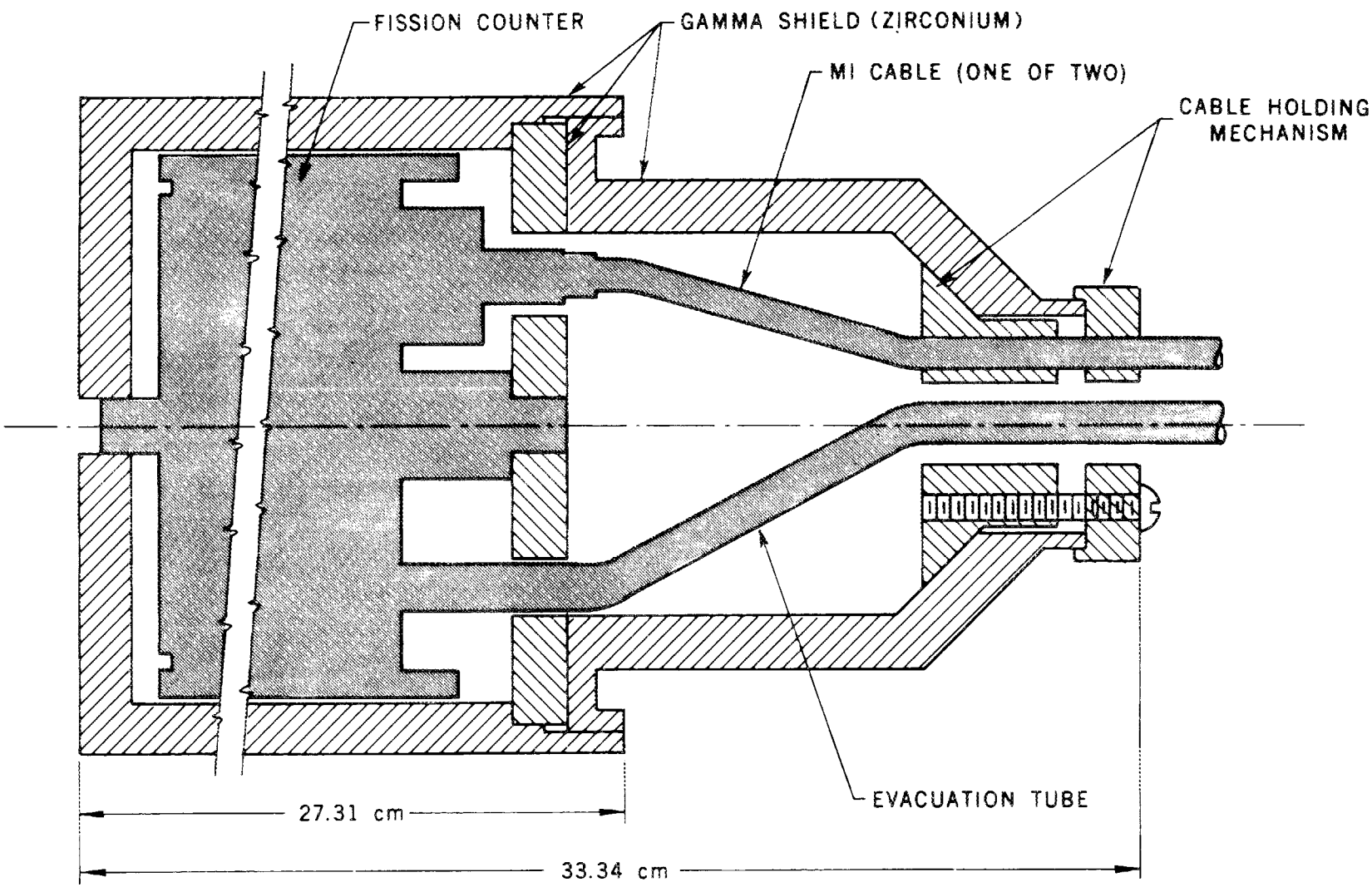

Fig. 2. Dimensions, ORNL fission counter FC-3.

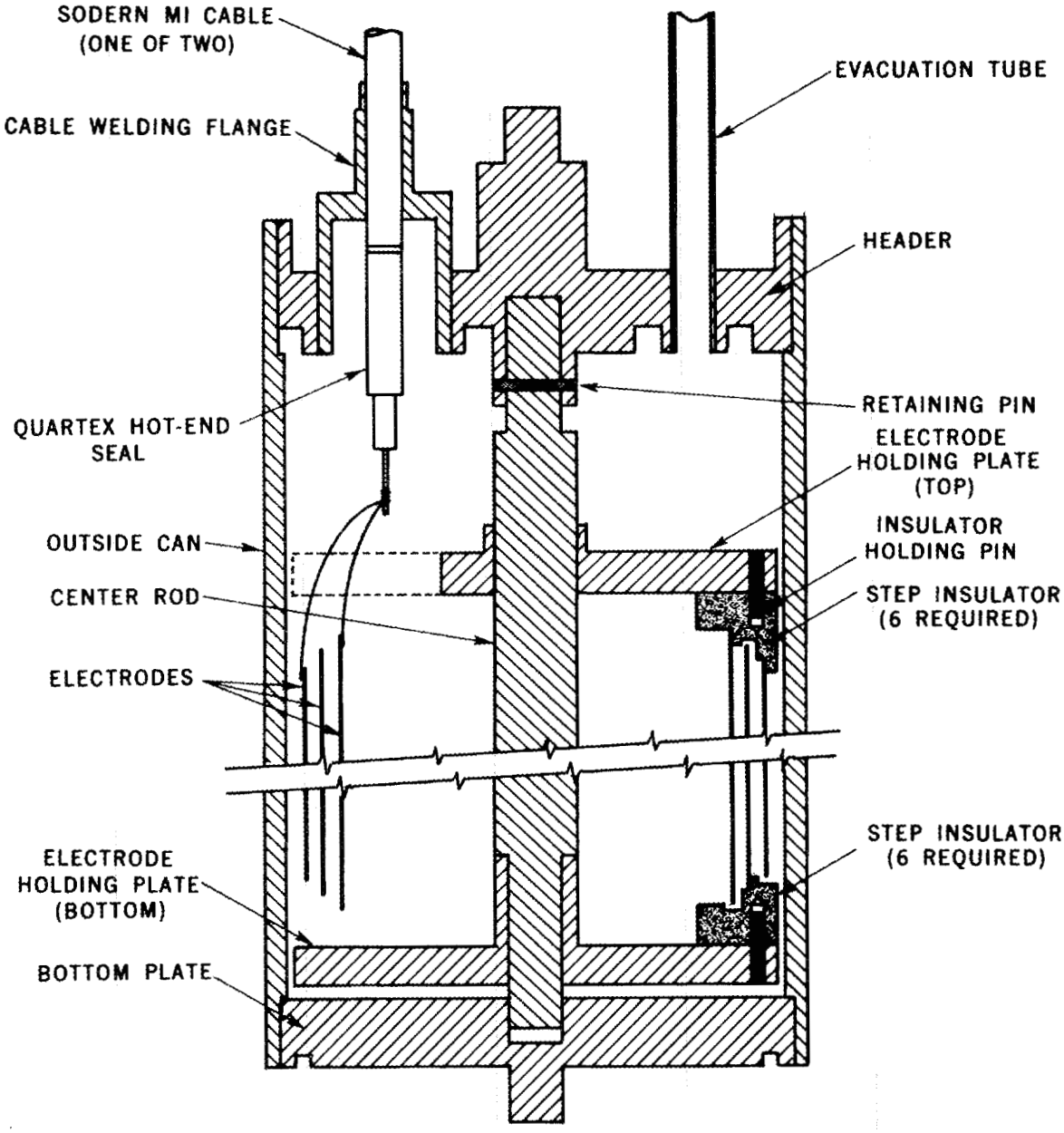

Fig. 3. ORNL fission counter FC-3 with cables and gamma shield.

PHOTO 0632-73

Fig. 4. ORNL fission counter FC-3 with cables; gamma shield not installed.

4. PERSONNEL CERTIFICATION

The FC-3 fission counter was fabricated and tested by a technician with the following minimum qualifications:

1. High school graduate and 3 years of experience in fabricating and testing radiation detectors.
2. Knowledge of the characteristics of and ability to use all electronic equipment specified for testing the counter.
3. Knowledge of the characteristics of and ability to use the following equipment for fabrication: helium leak detector, spot welder, and semiautomatic TIG welding machine.

The Project Engineer supervised the technician as he fabricated and tested the fission counter. The engineer also reviewed all test data.

Most of the welds in the fission counter assembly were made by the technician in accordance with the welding procedure described in Vol. 2, Sect. 11 (ref. 1). All other welds were made in accordance with ORNL-WPS-307 Welding Procedures. The welder was certified to make welds according to this procedure. Specific information concerning each weld is given in the assembly procedures described in Vol. 2, Sects. 3 and 5 (ref. 1).

5. MI CABLE ASSEMBLY AND TESTING

The assembly and testing of the two MI cables were the most critical and time consuming steps, since this work had to be executed in a careful way at both the counter end (hot end) and the instrument end (cold end) of both cables. [Complete assembly procedures are given in Vol. 2, Sect. 3 (ref. 1).] Voltage was applied to the cable assembly at all times during the testing period. When a specific test was not in progress, a standby voltage was applied to the cables. [Details are given in Vol. 2, Sect. 4, Fig. 8 (ref. 1).]

Before they were installed in the fission counter, the two cables were pretested at temperature and with 200 V applied according to the

schedule in Fig. 5. Voltage breakdown noise data, taken nearly every day at two pulse height selector (PHS) settings, gave, respectively, ∿1 count/10 sec and ∿100 counts/10 sec due to electronic noise. No statistically significant increases in the noise count rates were observed during the tests. The dots on the graph indicate the day and temperature at which the insulation resistance measurements were made. The insulation resistance remained above 10^9 Ω at 450°C (850°F) and above 10^8 Ω at 566°C (1050°F).

Instrumentation block diagrams are given in Figs. 1-8 in Vol. 2 (ref. 1) to show the electrical connections for the cable tests.

6. FISSION COUNTER ASSEMBLY AND PRELIMINARY TESTING

FC-3 was fabricated in strict accordance with the drawings (Q-5419) and assembly procedures contained in Vol. 2, Sect. 5 (ref. 1). The procedures cover processing of components, assembly, and preliminary testing. The counter was vacuum pumped at temperature for ∿146 hr, of which ∿30 hr was at 480°C (900°F). It was essential that this temperature be above the counter testing temperature. Due to the potential nitriding problem, the counter was tested at 450°C max at ORNL and at 400°C max at the EBR-II. For this reason, 480°C was chosen as the vacuum pumping temperature instead of 590°C.

7. FISSION COUNTER TESTING AT ORNL

Since it was essential that FC-3 undergo extensive testing at ORNL prior to final testing at the EBR-II, the characteristics of the fission counter were determined and documented at ORNL for future reference. During the ORNL tests, all malfunctions noted were repaired.

Voltage was applied to the counter at all times during the test period. When a specific test was not in progress, a standby voltage was applied to the counter. [Details are given in Vol. 2, Fig. 8 (ref. 1).]

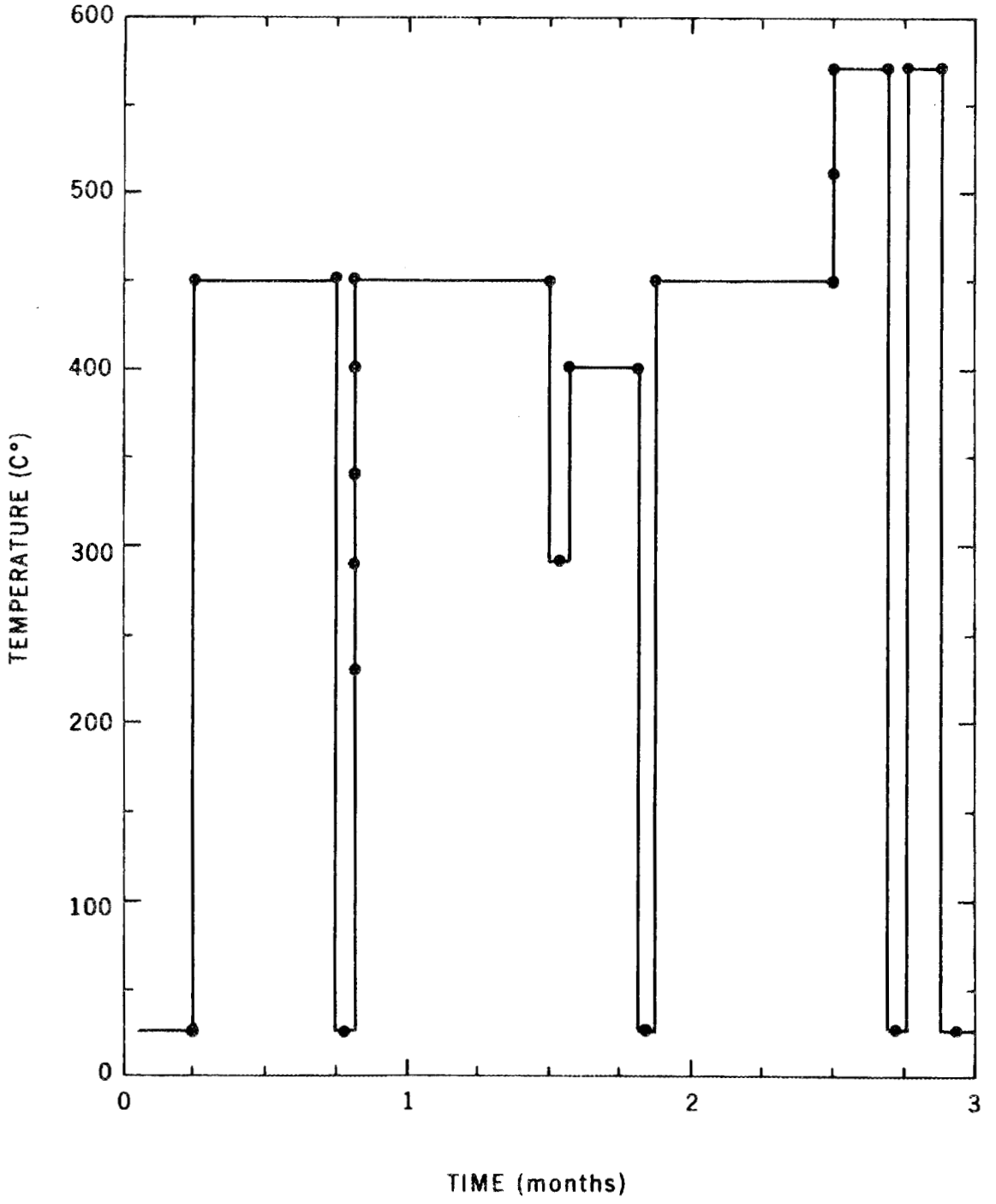

Fig. 5. Cable temperature testing schedule.

7.1 Integral Pulse Height Distribution Test

Historically, integral pulse height distribution (PHD) curves have been used to compare the merits of a fission counter and its associated electronics for conditions anticipated during application.

PHD curves were taken before and after all other tests at ORNL. There were no measurable differences, which would indicate counter degradation during testing, between the two curves. Details concerning the PHD tests are given in Vol. 2 (ref. 1): electronic block diagram, Sect. 4; electronic calibration, Sect. 12; and PHD curve intercomparison, Sect. 13.

Integral pulse height distributions for neutrons, electronic noise, and for a gamma dose rate of 1×10^6 R/hr are given in Fig. 6. In Figs. 7 and 8, neutron and noise characteristics obtained before and after the 720-hr furnace test at 450°C are plotted. No measurable degradation of its performance was observed during these tests.

7.2 Counting Loss Test

Counting loss was evaluated by using the ORNL TSF-SNAP reactor as a variable source of neutrons. Observed count rates were taken at 1-sec intervals while the reactor was on a stable positive period of $\sim$9 sec. As shown in Fig. 9, the counts lost in the reactor power range, where an appreciable loss occurred, was estimated by determining the "true" count rate; that is, the counting data from the first two decades of reactor power increase (where the counting loss was negligible) were extrapolated. The true count rate minus the observed count rate equaled the counting loss. The counts lost were 8% at a true count rate of 1×10^6 counts/sec and 22% at 2×10^6 counts/sec. The electronics for this test are illustrated in Figs. 2 and 3 of Vol. 2 (ref. 1).

Although this test was not essential to the development of the FC-3 fission counter, it was informative that the counting loss of the neutron detection system was not excessive at 1×10^6 counts/sec.

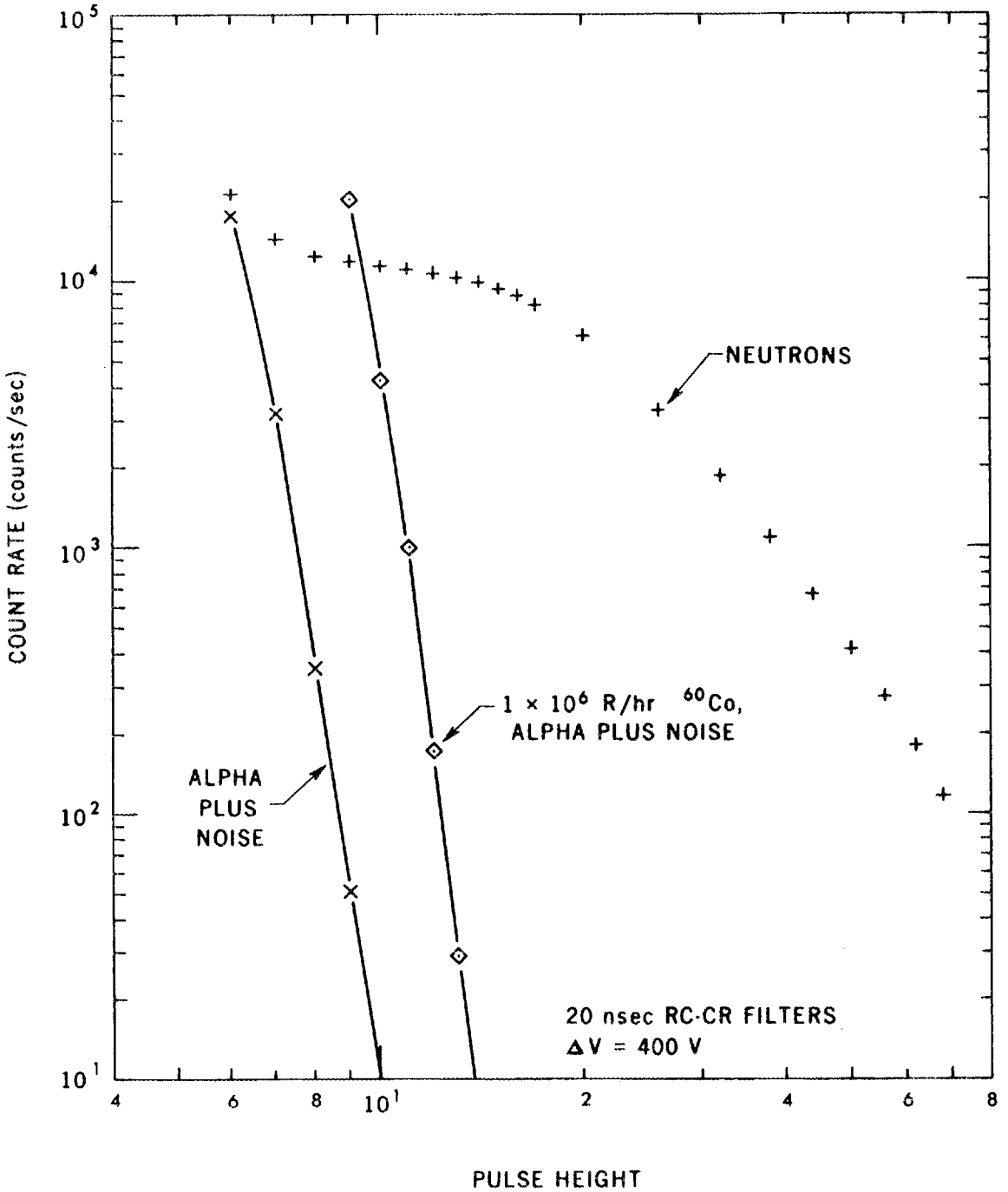

Fig. 6. Integral pulse height distribution, with neutrons and alpha and gamma radiation.

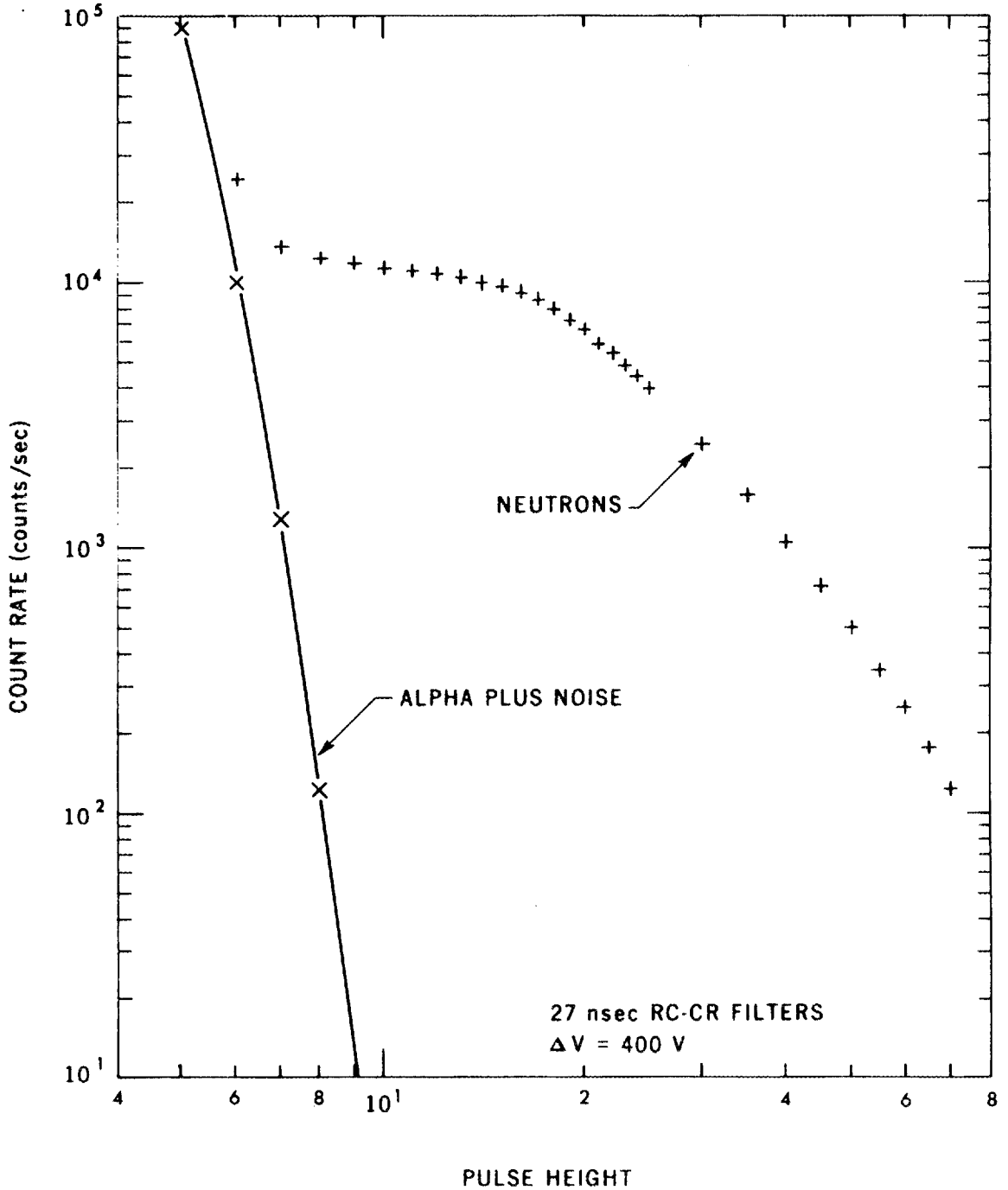

Fig. 7. Integral pulse height distribution before furnace test.

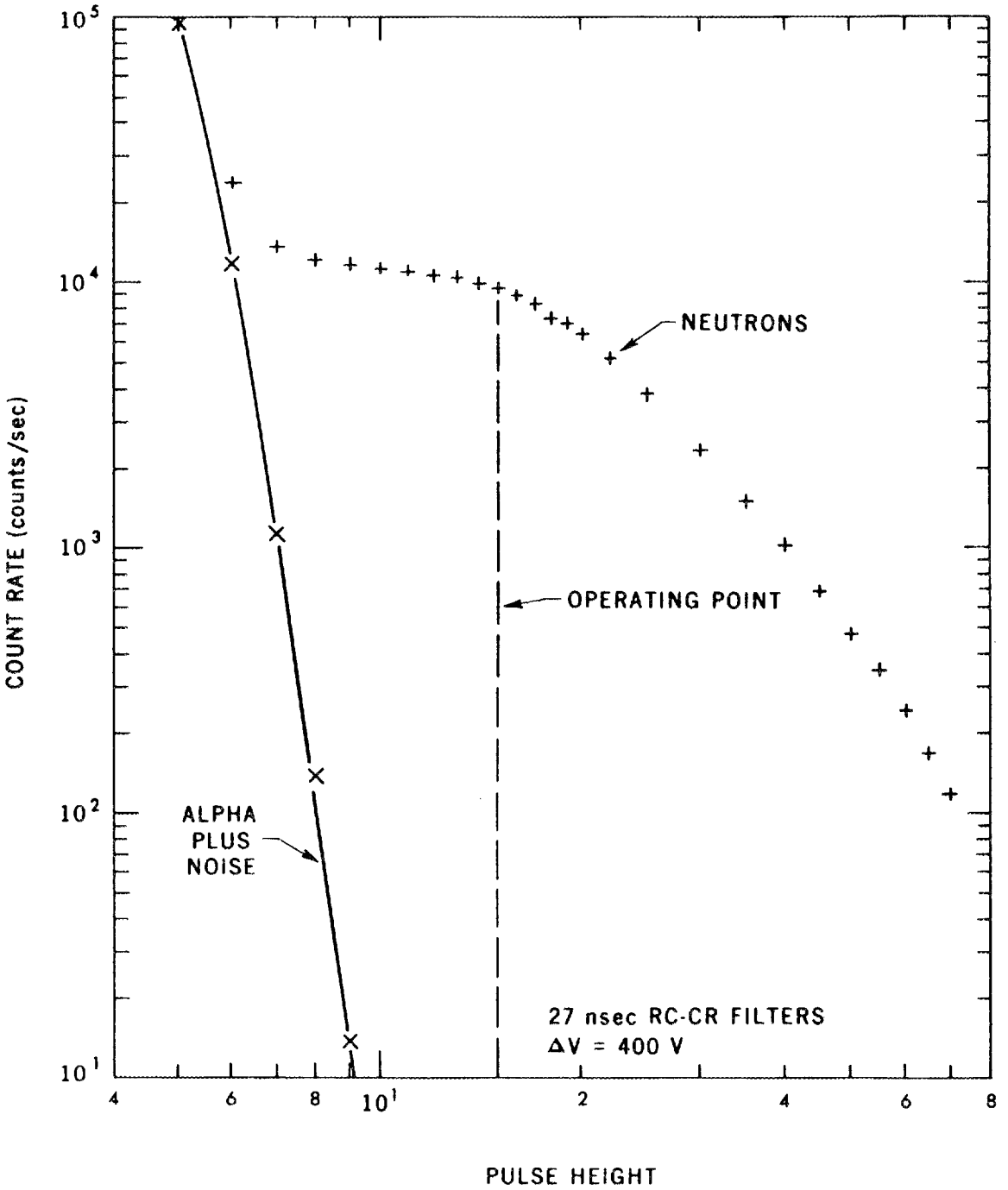

Fig. 8. Integral pulse height distribution after furnace test.

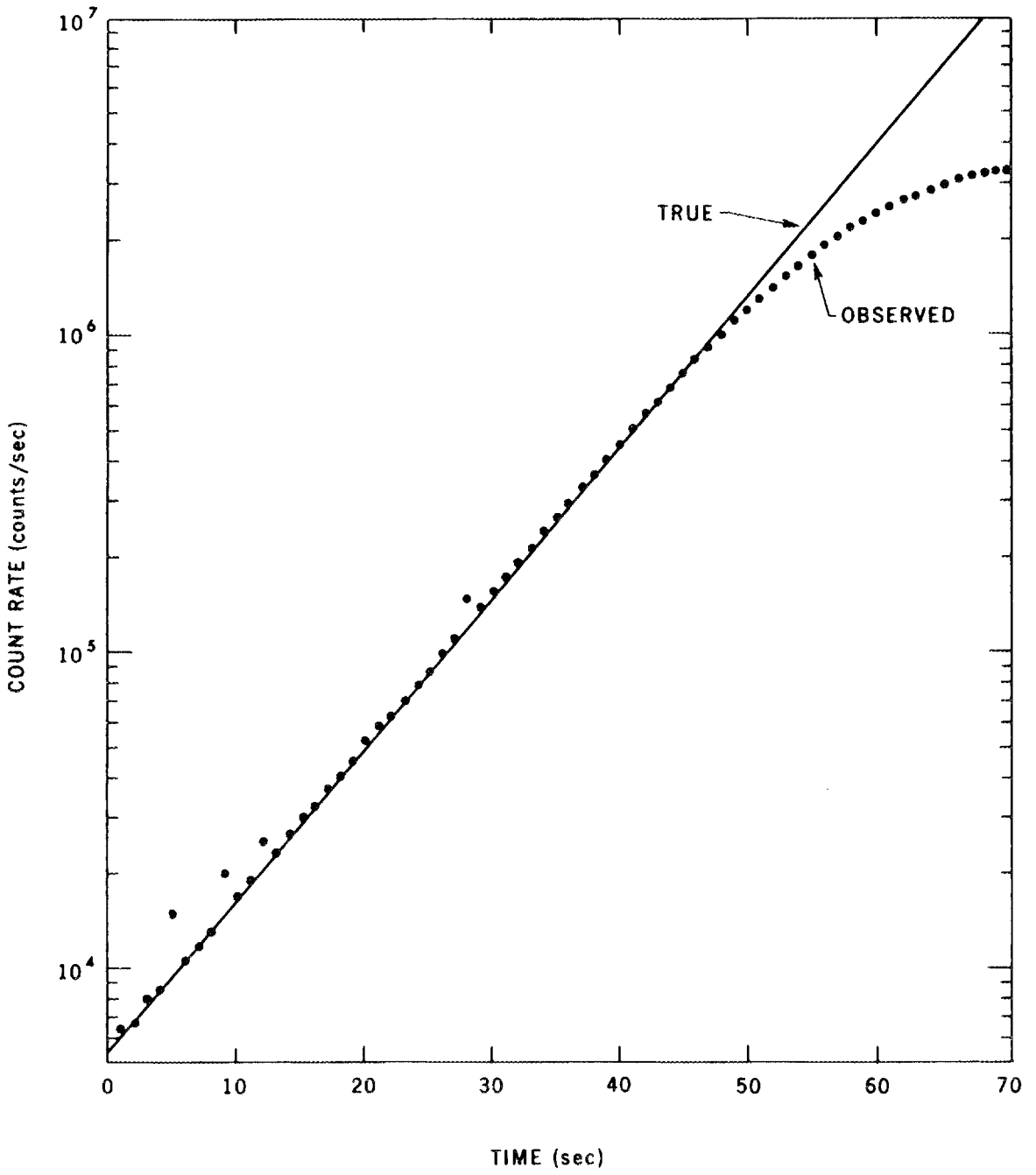

Fig. 9. Counting loss test results.

7.3 Count Rate and DC Current Tests

7.3.1 Count Rate vs Voltage

The neutron count rate versus counter voltage is shown in Fig. 10 for both room temperature and 400°C. The reason for the difference in the two curves is that the neutron moderator assembly used when the counter was in the furnace was less efficient than the laboratory assembly. A block diagram of the electronics for this test are shown in Figs. 2 and 3 of Vol. 2 (ref. 1).

7.3.2 Leakage Current Test

The dc leakage current vs temperature for the FC-3 fission counter was measured (Fig. 11) in the absence of neutron and gamma radiations. The nonlinearity of the curve at lower temperatures is attributable to alpha current. The electronic block diagram for this test is shown in Fig. 5 of Vol. 2 (ref. 1).

7.4 Temperature Test

FC-3 was tested at 450°C for 30 days. Also, the counter temperature was cycled five times from room temperature to 450°C. Periodically, the counter insulation resistance, breakdown pulse noise, and neutron counting performance were determined while it was at temperature. No measurable degradation was detected during the test.

Complete details for this test are given in Vol. 2, Sect. 14 (ref. 1).

8. GAMMA SHIELD DESCRIPTION

To improve its performance, the fission counter was equipped with a 0.584-cm-thick zirconium gamma shield, designed as an integral part of the assembly. All commercially available materials having a $Z \geqslant 26$ were considered for this purpose, based on their gamma attenuation, neutron absorption, and system compatibility.

After all out-of-reactor tests of the fission counter were completed, the zirconium shield was installed over the counter and tack welded in

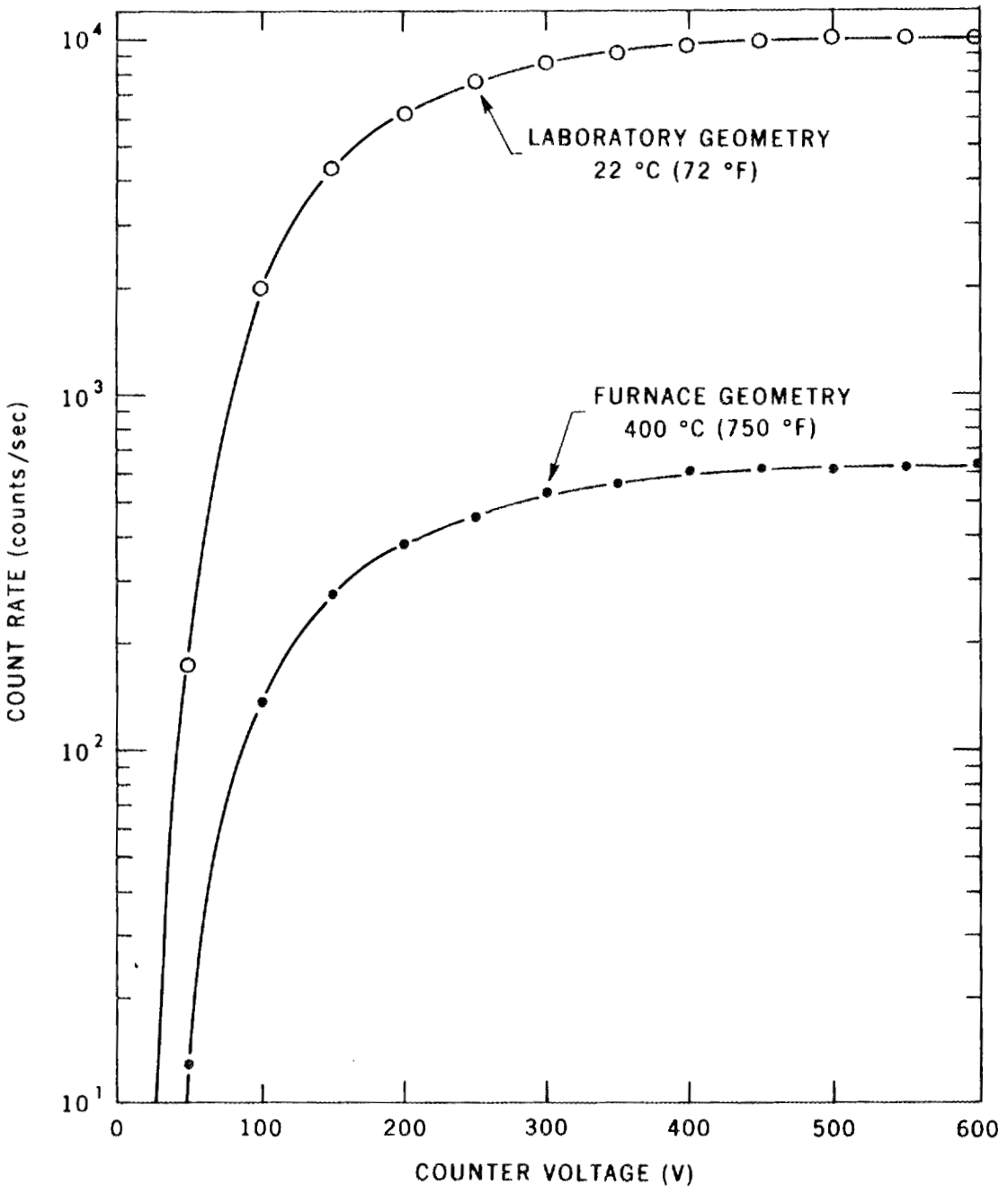

Fig. 10. Voltage effects on counting rate.

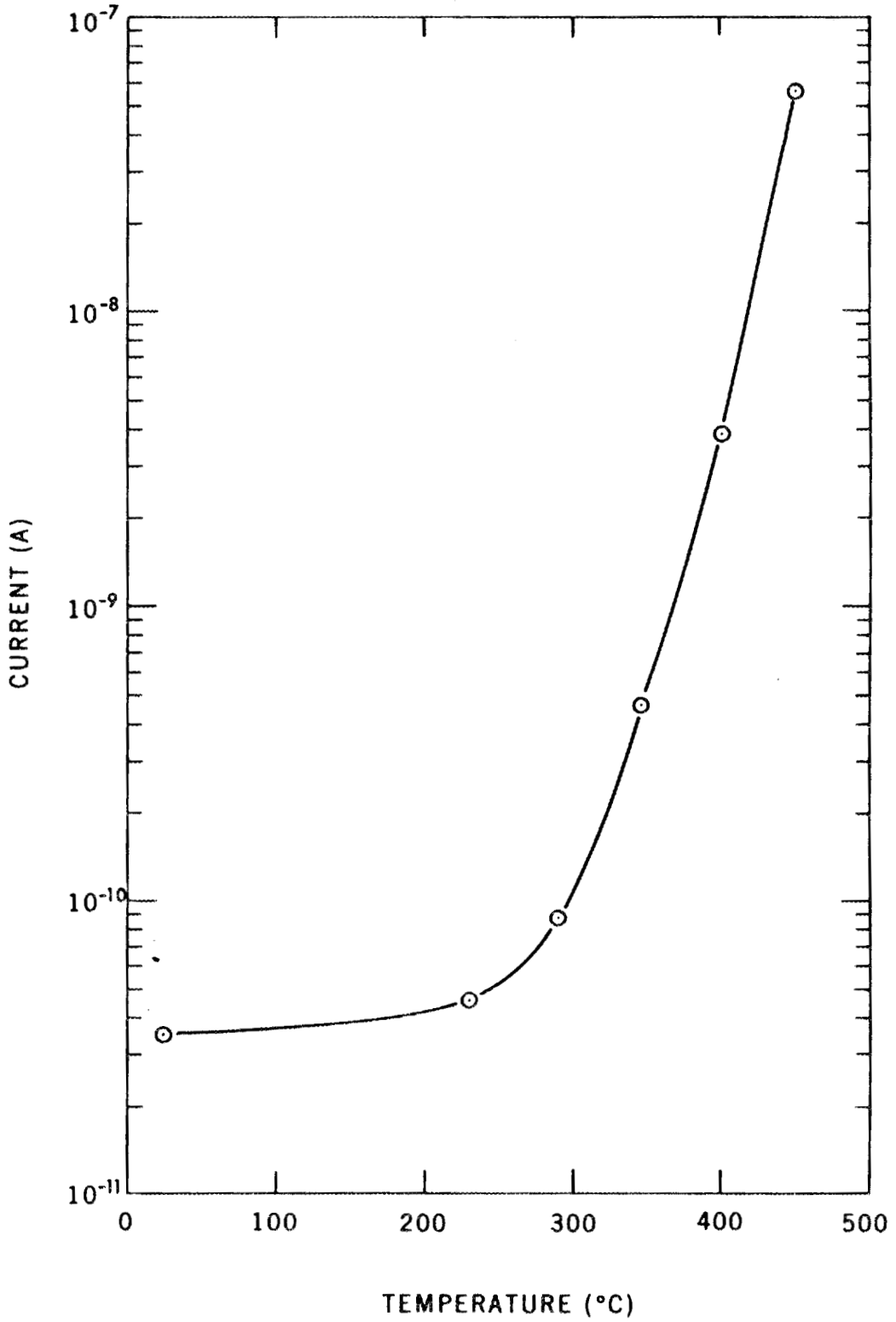

Fig. 11. Temperature effects on leakage current.

two places (180° apart). (Caution. *Welding of zirconium must be done in an inert atmosphere.*)

9. ANL PRELIMINARY TESTING

Prior to final qualification of the fission counter for insertion in the EBR-II reactor, in which the environment is typical of liquid-metal fast breeder reactors, the counter was required to pass preliminary tests at ANL.[2] The purpose of these tests was to reveal design flaws in the counter that could cause an early shutdown during the EBR-II irradiation.

In these preliminary tests the following data were recorded at room temperature, to establish a reference, and at various temperatures to 400°C: electrode capacitance; insulation resistance; dc alpha-plus-leakage saturation characteristics (with and without a gamma background); noise-plus-alpha, mean-square voltage characteristics; neutron counting saturation characteristics; collection times; and noise-plus-alpha and neutron integral bias curves. In addition, neutron integral bias curves were plotted with the counter in a gamma background at room temperature. For all tests, the fission counter and its two high-temperature cables were enclosed in the assembly as shown in Fig. 12.

The description of all test set-ups, test instruments, and test results are given in Sect. 12, Appendix.

10. EBR-II TESTS

The final qualification for the developmental high temperature counter FC-3 was in the J-2 thimble of the EBR-II reactor with the counter at 399°C. The principal purpose of this reactor test was to evaluate the effects of radiation damage caused mainly by fast neutrons. In a typical low level flux monitor application of the counter, virtually all the neutron dose is sustained while the counter is in the retracted position with the reactor at full power. It is anticipated that under these conditions, the neutron flux will be $\sim 1 \times 10^{10}$ nv with a gamma dose rate of $\sim 10^{6}$ R/hr.

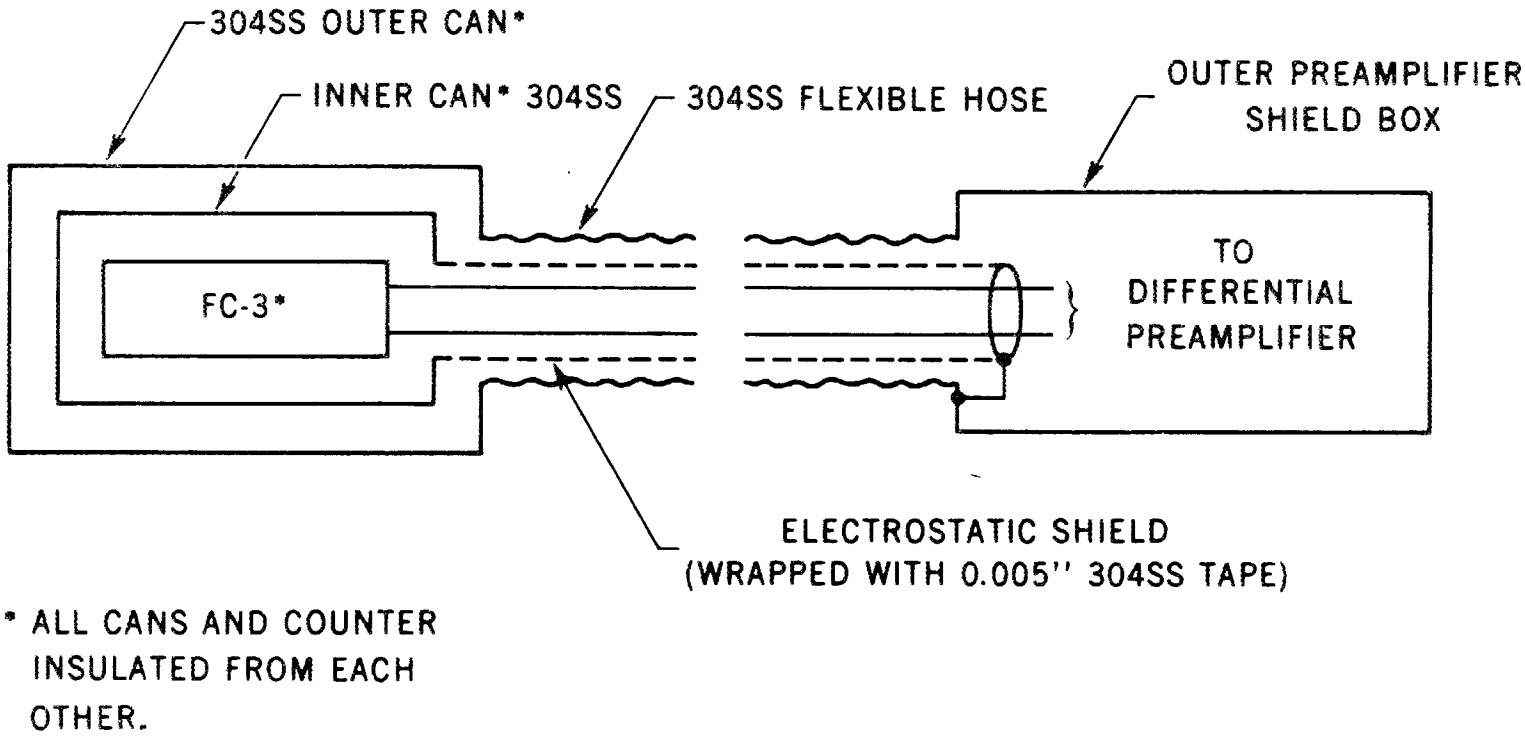

Fig. 12. Fission counter-MI cable test assembly.

If the detector is to be qualified for use in a reactor, it must be capable of withstanding an integrated dose corresponding to a 1-year lifetime. Typically this is a fast neutron dose of 3×10^{17} nvt. The test environment in the J-2 thimble is calculated[3] to be $\sim 6.4 \times 10^{10}$ nv of fast neutrons and $\sim 3.5 \times 10^{5}$ R/hr of gamma dose rate, and it required $\sim$1400 hr of operation to achieve the 1-year dose.

The in-reactor testing started near the first of May 1975, and has proceeded until the present time. The total accumulated neutron fluence represents over 4 years of operation in a typical liquid-metal fast breeder reactor environment. Figure 13 represents the integral bias curves obtained before and after this period of operation in the EBR II. Figures 14 and 15 show the dc current and count rate saturation characteristics, respectively, before and after this period of time. Operation of the counter has not been adversely affected by the irradiation and any differences in the curves can be attributed to different reactor power levels.

The description of the data collection system for the EBR-II tests is given in Sect. 12, Appendix.

11. REFERENCES

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2. A. L. Taboas and W. L. Buck, *Preliminary Testing at ANL of the ORNL FC-3 and the TCE (British) DC-14B, S/N 7304-69 Fission Counter-Chambers*, ANL-CT-75-45824-0004 (September 5, 1975).

3. A. L. Taboas, Trip Report to R. S. Zeno, ANL Intra-Lab Memo CT/IC1121, Jan. 5, 1975.

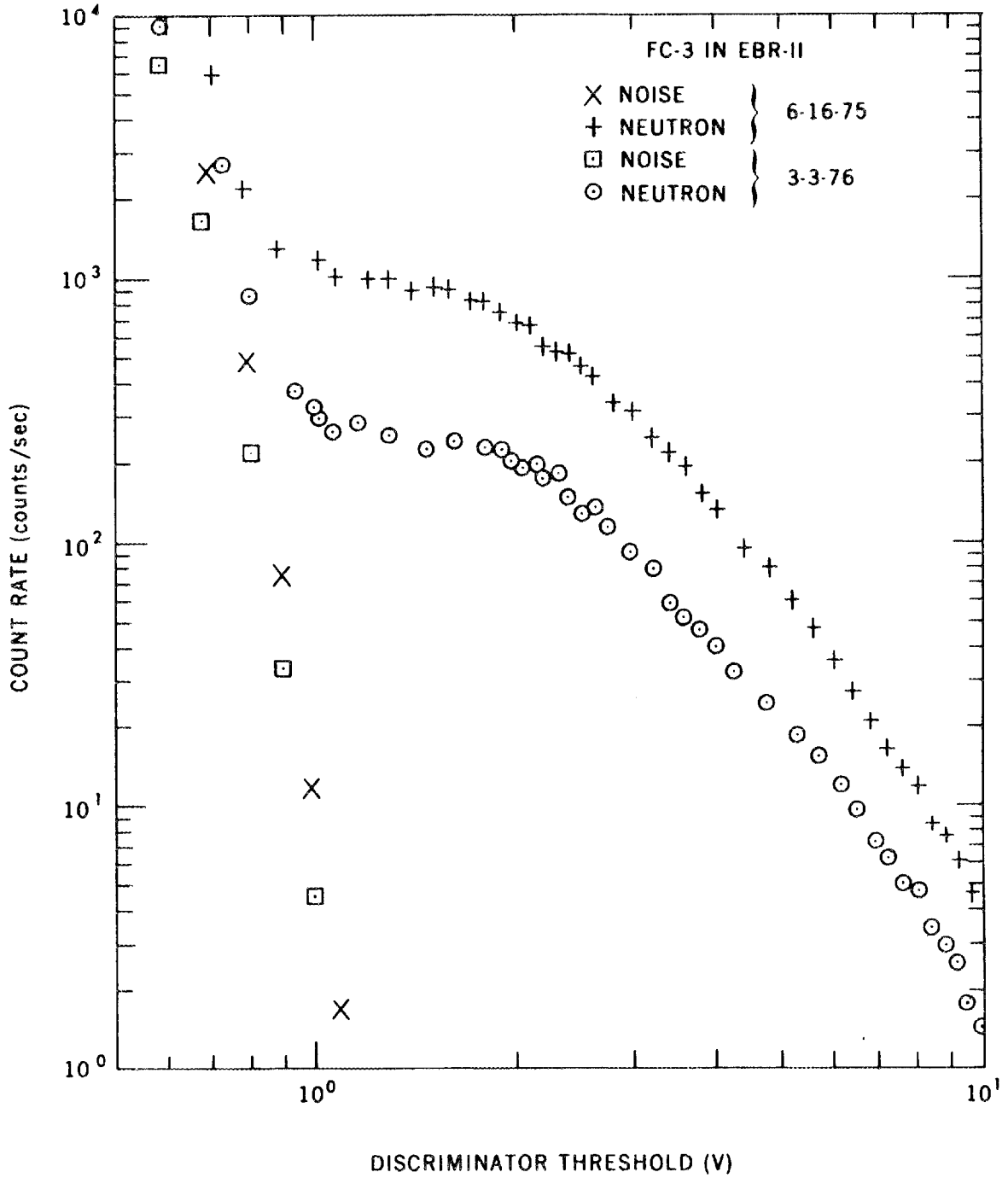

Fig. 13. Neutron integral bias in EBR-II.

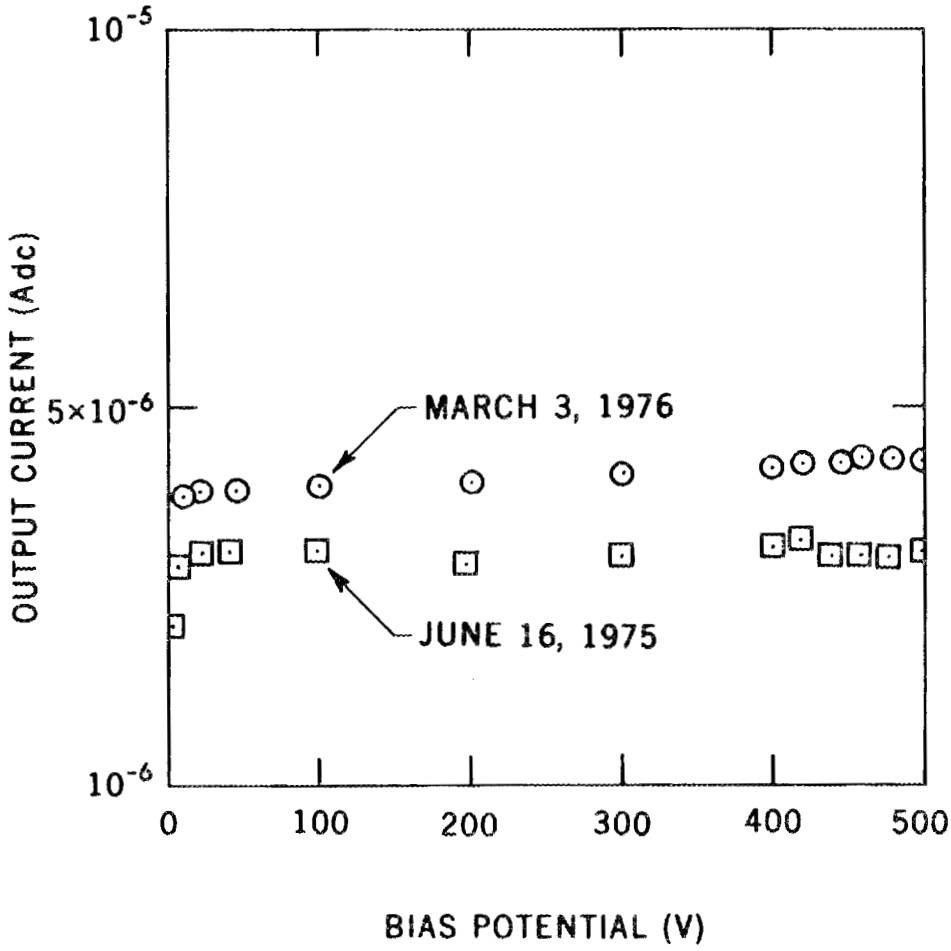

Fig. 14. DC saturation characteristic in EBR-II.

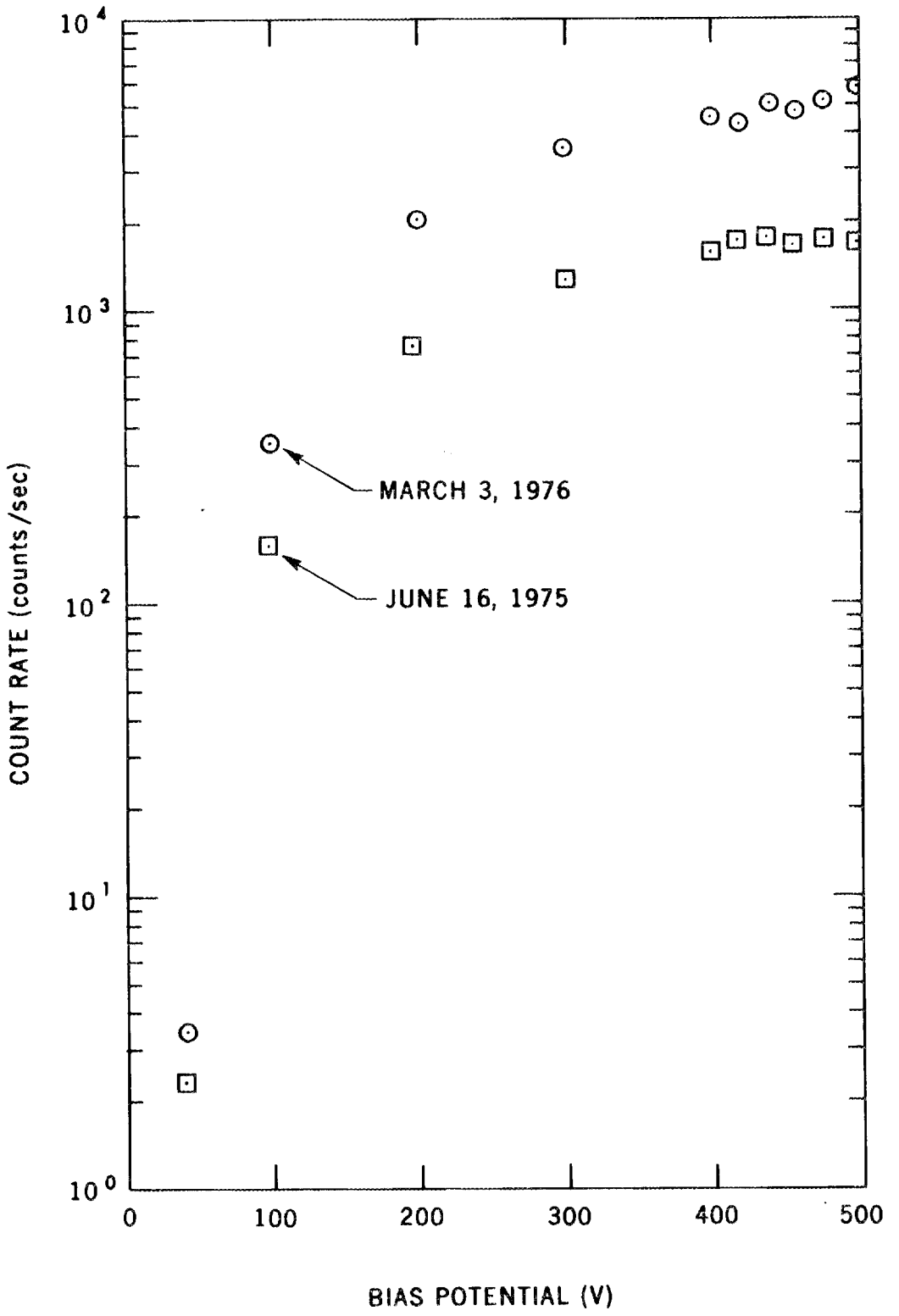

Fig. 15. Count-rate saturation characteristic in EBR-II.

12. APPENDIX

12.1 Test Set-Up

Block diagrams of the test configuration are shown in Figs. 16-18. A list and description of the test instruments and accessories is given in Table 1. The Tektronix 7902 oscilloscope with a 7A12 plug-in was used for the measurement of electron collection times. A Tektronix 7A13 differential comparator was used with a Tektronix 7904 oscilloscope to measure the amplitude of the test pulse from the pulse generator (Hewlett-Packard 8002A) in Fig. 18. The significant modifications to the current-sensitive preamplifier (Gulf Electronic System, model ELJ 296-000) consisted (1) of reducing the values of the resistors in the high voltage filter and of the signal decoupling resistor to minimize voltage drops from the direct component of the counter current at high gamma dose rates, and (2) of increasing the value of the summing resistor for the test pulse to prevent an increase of electronic noise by the test pulse system.

Additionally, to accommodate the split-voltage operation of the counter, the dc measurement was obtained by connecting a picoammeter between the return lead of the negative high voltage supply and the ground. The negative high voltage supply was modified to provide an isolated return connector. (Although the leakage resistance of the "floating" supply limited the useful range of the picoammeter, good measurements of currents $>10^{-10}$ A were obtained.)

The linear amplifier coarse gain was set at ×64 and the fine gain at ×2.90. As shown in Fig. 18, a 51-Ω termination was used at the input to the amplifier. The amplifier was used in the inverting mode with 20-nsec-integration and 20-nsec-differentiation time constants. The single-channel analyzer was used in the dual integral mode with a 91-Ω termination on its input.

12.2 Test Results

A summary of the measured data at room temperature is given in Table 2. No mean-square voltage sensitivity is reported because of the lack of a calibrated high neutron flux. A summary of the elevated temperature effects on alpha dc current and insulation resistance is given in Table 3.

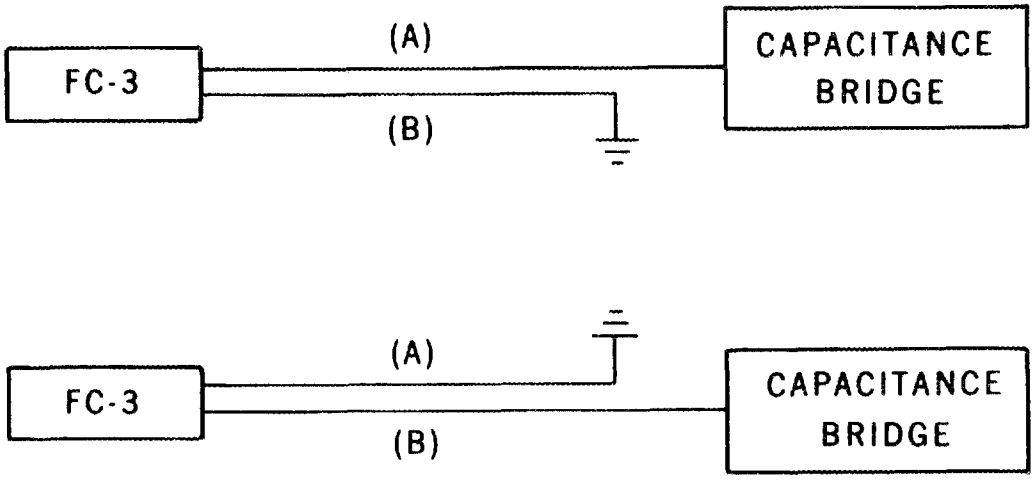

Fig. 16. Fission counter-MI cable capacitance measurements.

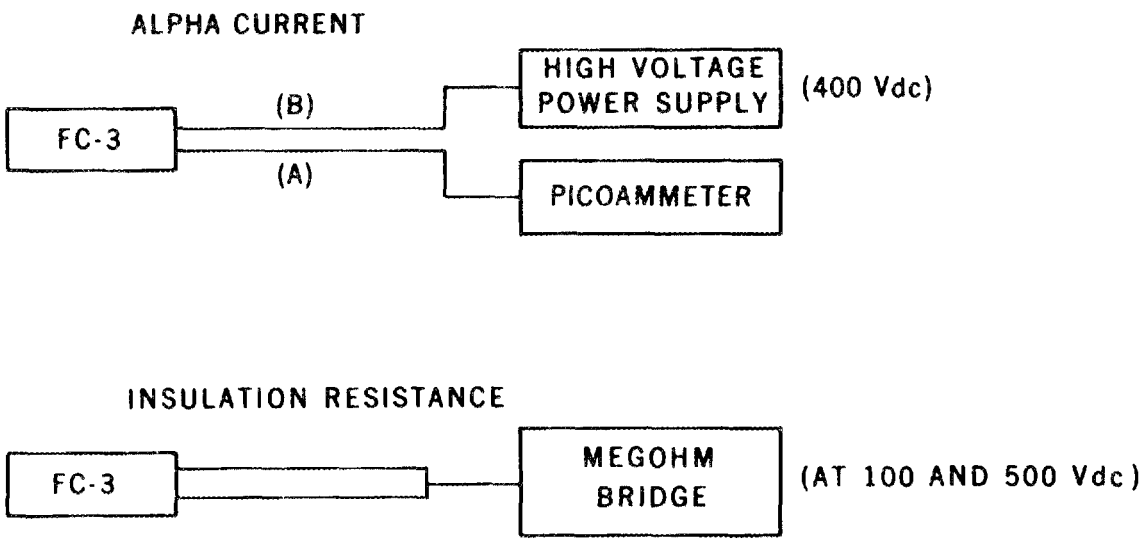

Fig. 17. Alpha current and insulation resistance measurements.

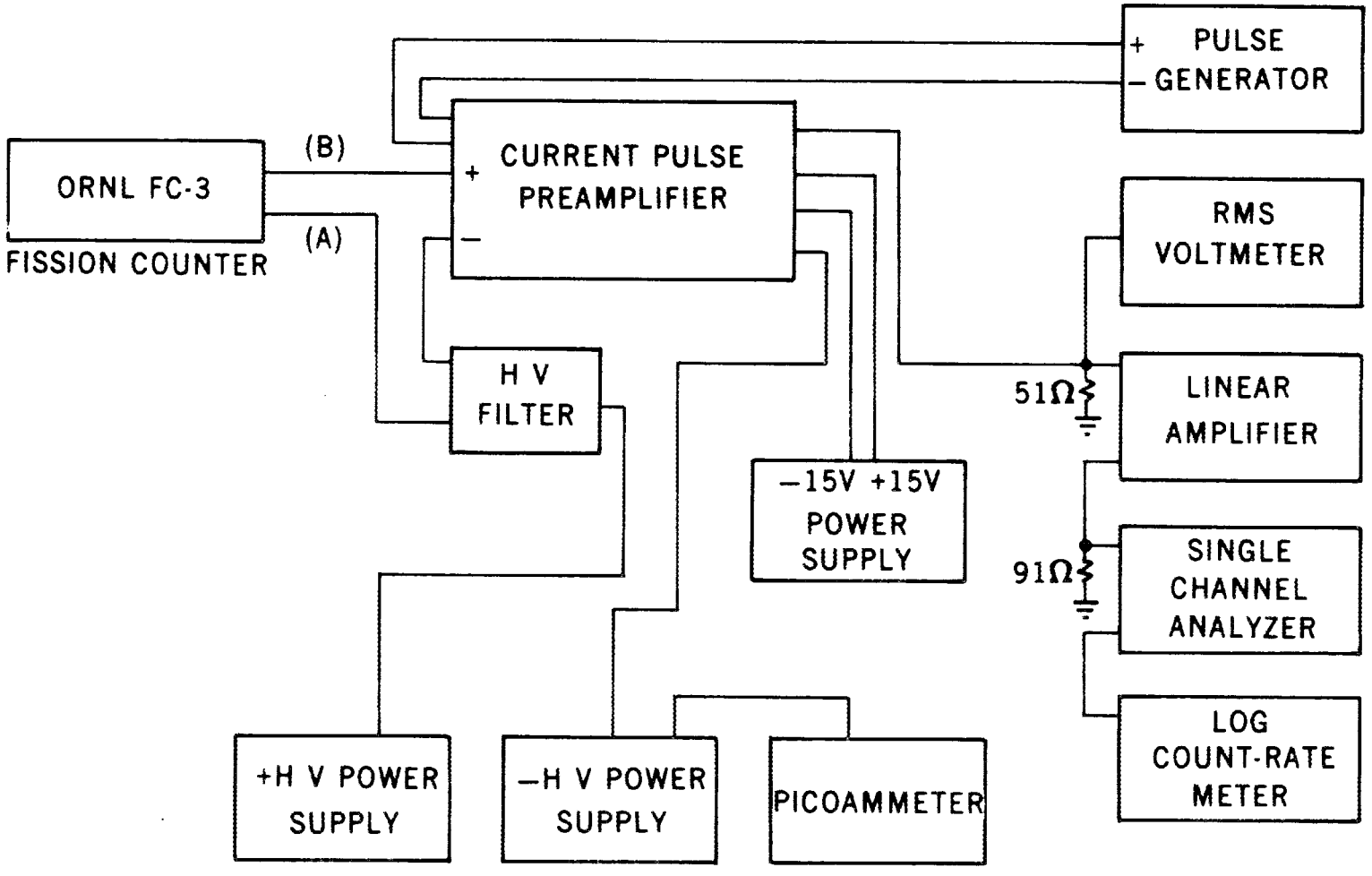

Fig. 18. Diagram of instrumentation for measurement of fission counter operation.

Table 1. List of test instruments

Instrument	Manufacturer	Model No.
Auto-ranging picoammeter	EG&G	ME-920A
High voltage power supply (+)	John Fluke	4150A
High voltage power supply (-)	John Fluke	4150A
NIM power supply	Hewlett-Packard	5580B
Dual-output dc power supply	Power/Mate Corp.	PT-15A
Current-pulse preamplifier	Gulf Electronic	ELJ 296-000[a]
Amplifier	Hewlett-Packard	5582A
Single-channel analyzer	Hewlett-Packard	5583A
Log count-rate meter	Gulf Electronic	LCR-2
Auto-ranging true rms voltmeter	Hewlett-Packard	3403C[a]
Pulse generator	Hewlett-Packard	8002A
Multimeter-counter	Hewlett-Packard	5306A
Automatic capacitance bridge	Hewlett-Packard	4270A
Megohm bridge	General Radio	1644A
Picoammeter	Keithley	410
Oscilloscope	Tektronix	547
Differential amplifier[b]	Tektronix	1A5
Oscilloscope	Tektronix	7940
Dual time base[b]	Tektronix	7B92
Dual trace amplifier[b]	Tektronix	7A12
Differential comparator[b]	Tektronix	7A13

[a]Modified by ANL.

[b]Component of oscilloscope.

Table 2. Summary of FC-3 data measured at room temperature

Variable	Measured Value
Alpha current, A	6.5×10^{-10}
Neutron current sensitivity, A/nv[a]	1.6×10^{-13}
Counting sensitivity, counts sec^{-1} nv^{-1}[a,b]	0.83
Gamma current sensitivity, AR^{-1} hr^{-1}[c]	
at $\sim 1.7 \times 10^5$ R/hr	3.15×10^{-11}
at $\sim 1.7 \times 10^6$ R/hr	3.38×10^{-11}
Detector cable capacitance at 1 kHz, pF	
Signal	1880
Excitation	2030
Insulation resistance, Ω	
at 100 V	1.9×10^{11}
at 500 V	1.6×10^{11}
Collection time, nsec	∿200

[a]Using the neutron source barrel facility described by G. E. Yingling, A. L. Taboas, and F. G. Zayas, *Neutron Source Barrel Facility*, ANL CT-74-45824-0010 (December 1974).

[b]At a discriminator dial setting where the count rate due to a gamma radiation dose of 1.7×10^6 R/hr is ∿1 count/sec.

[c]Irradiated by ^{60}Co.

Table 3. Effect of increased furnace temperature on FC-3 alpha current and insulation resistance

Temperature [°C(°F)]	Alpha Current at 400 V dc (A)	Insulation Resistance at 100 V (Ω)	Insulation Resistance at 500 V (Ω)
21 (70)[a]	6.5×10^{-10}	1.9×10^{11}	1.6×10^{11}
149 (300)	6.8×10^{-10}	2.1×10^{11}	1.7×10^{11}
232 (450)	6.2×10^{-10}	1.9×10^{11}	1.5×10^{11}
316 (600)	1.5×10^{-10}	6.0×10^{11}	5.8×10^{10}
399 (750)	2.5×10^{-10}	4.5×10^{11}	4.4×10^{9}

[a]Room temperature.

Figure 19 shows the effect of temperature on the electrode capacitances at a test frequency of 1 kHz.

Figure 20 shows the dc saturation characteristics of the counter (at room temperature) for three levels of gamma background: 0, 1.7×10^5 and 1.7×10^6 R/hr.

Figure 21 shows the saturation characteristics of the mean-square voltage at the output of the preamplifier for five values of counter temperature. The neutron source was outside the furnace for this measurement.

Figure 22 shows the neutron counting characteristics of the counter for two arrangements. The data at 25°C were obtained with the counter in the ANL lab geometry with a 14-Ci Pu-Be source (see footnote *a*, Table 1). The data for Fig. 22 were obtained with the counter in a furnace with the neutron source positioned externally, and the data also apply to five temperature values as indicated.

Figure 23 shows the noise and integral bias curves for the counter in the ANL lab geometry at 25°C and for a repeated test with the counter in the furnace and the neutron source external to the furnace for two temperatures, 25 and 399°C. The counting rate data were obtained from front panel readings of a five-decade, log count rate meter. (Greater accuracy can be obtained with a scaler-timer instrument.)

Integral bias curves at room temperature with a neutron source and two levels of gamma background (1.7×10^5 and 1.7×10^6 R/hr) are given in Figs. 24, and 25, respectively.

12.3 Data Collection for EBR-II Tests

Data for all EBR-II tests were recorded with three systems: (1) the Data Acquisition System (DAS), (2) the Automatic Data Retrieval System (ADRS), and (3) manually.

Data recorded by the DAS included counter excitation voltages (positive and negative for the split voltage operation), preamplifier ac output voltages, counter dc currents, discriminator voltages, count rates, and certain signals from the plant instruments monitoring the operation of the reactor. All data points were recorded every 10 min, giving a continuous observation at these key data points.

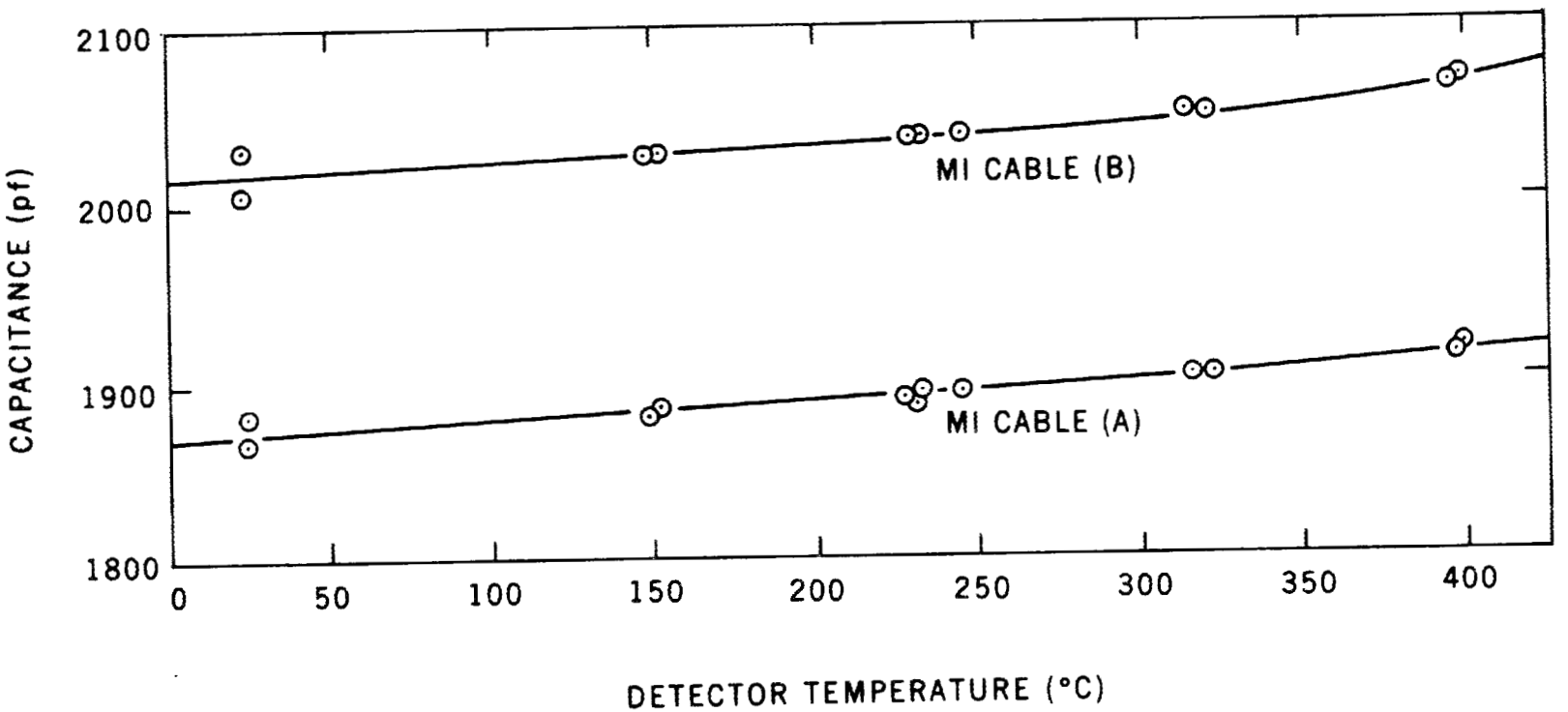

Fig. 19. Fission counter-MI cable capacitance as a function of temperature.

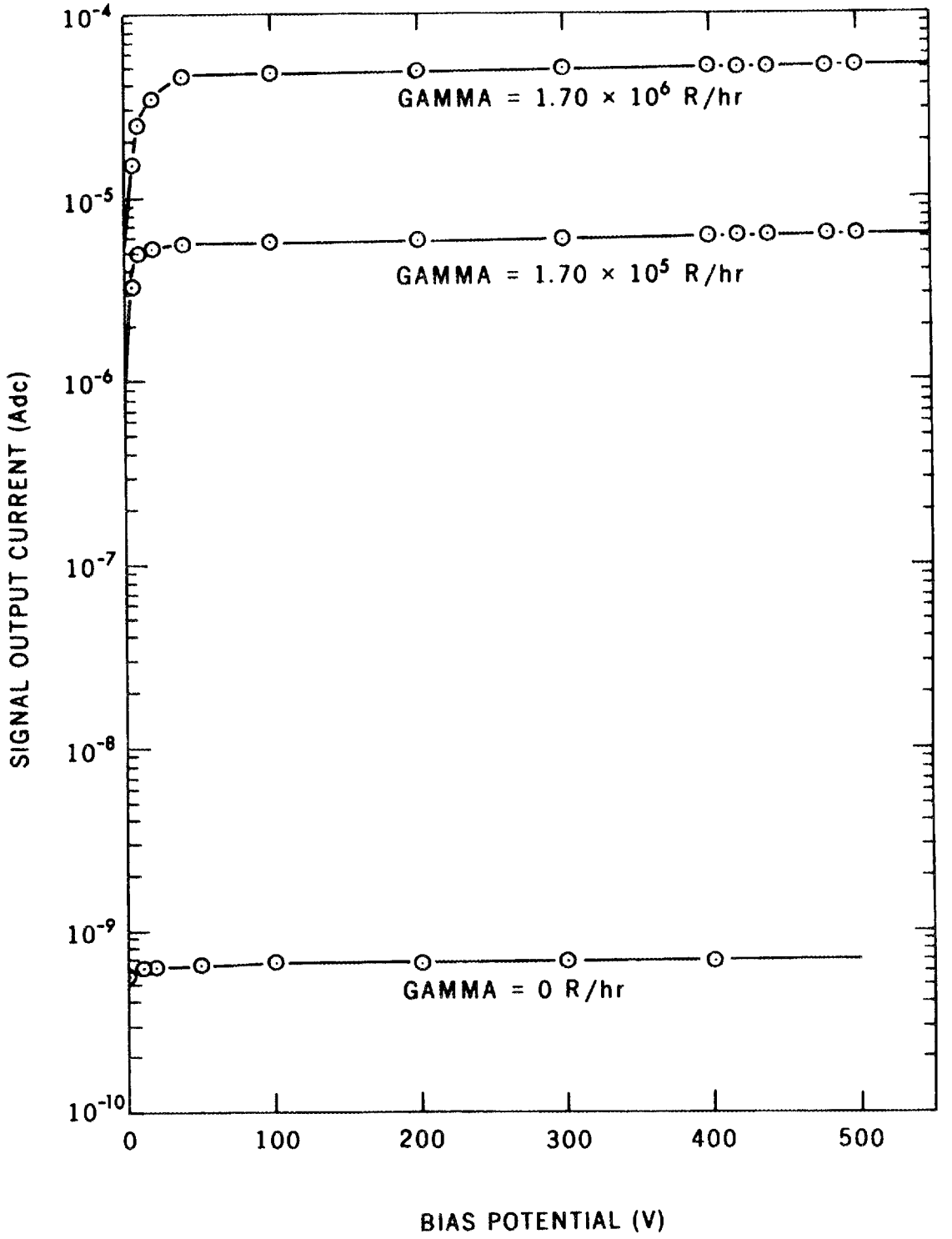

Fig. 20. Fission counter dc saturation characteristic as a function of gamma background.

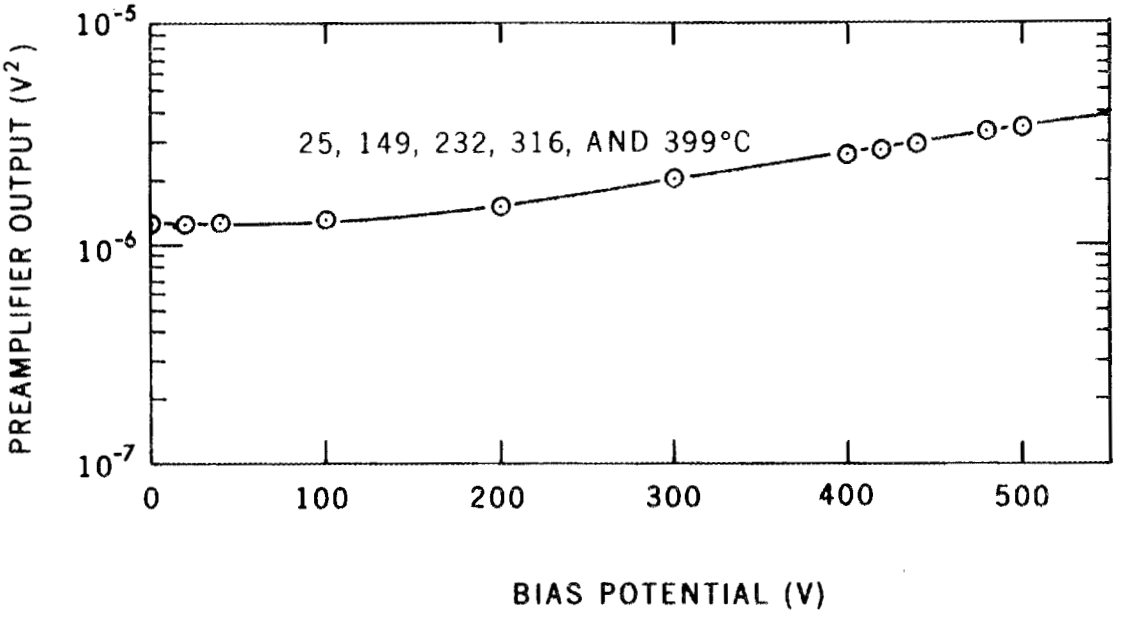

Fig. 21. Mean-square saturation characteristic at the preamplifier output.

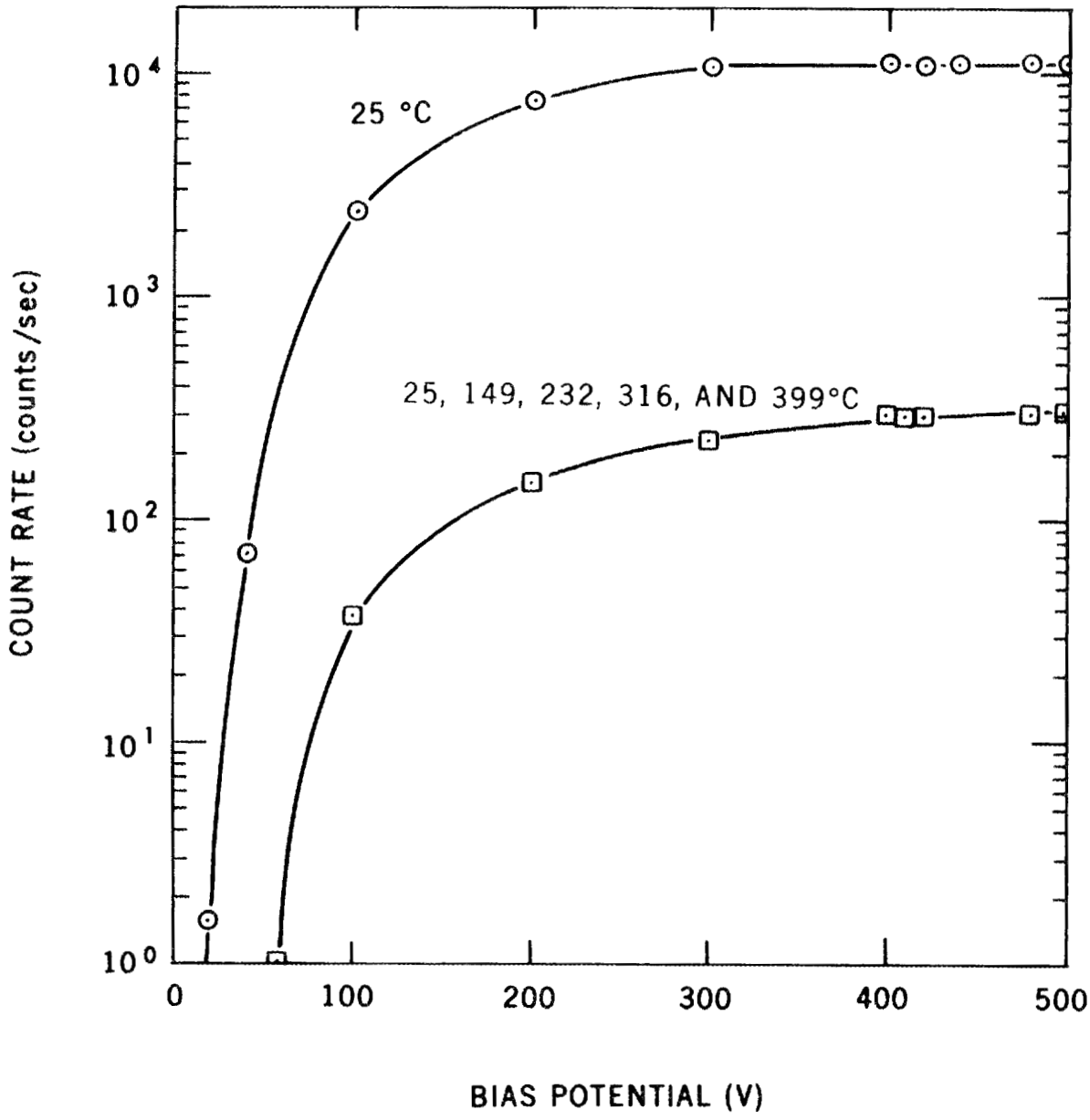

Fig. 22. Fission counter count-rate saturation characteristic.

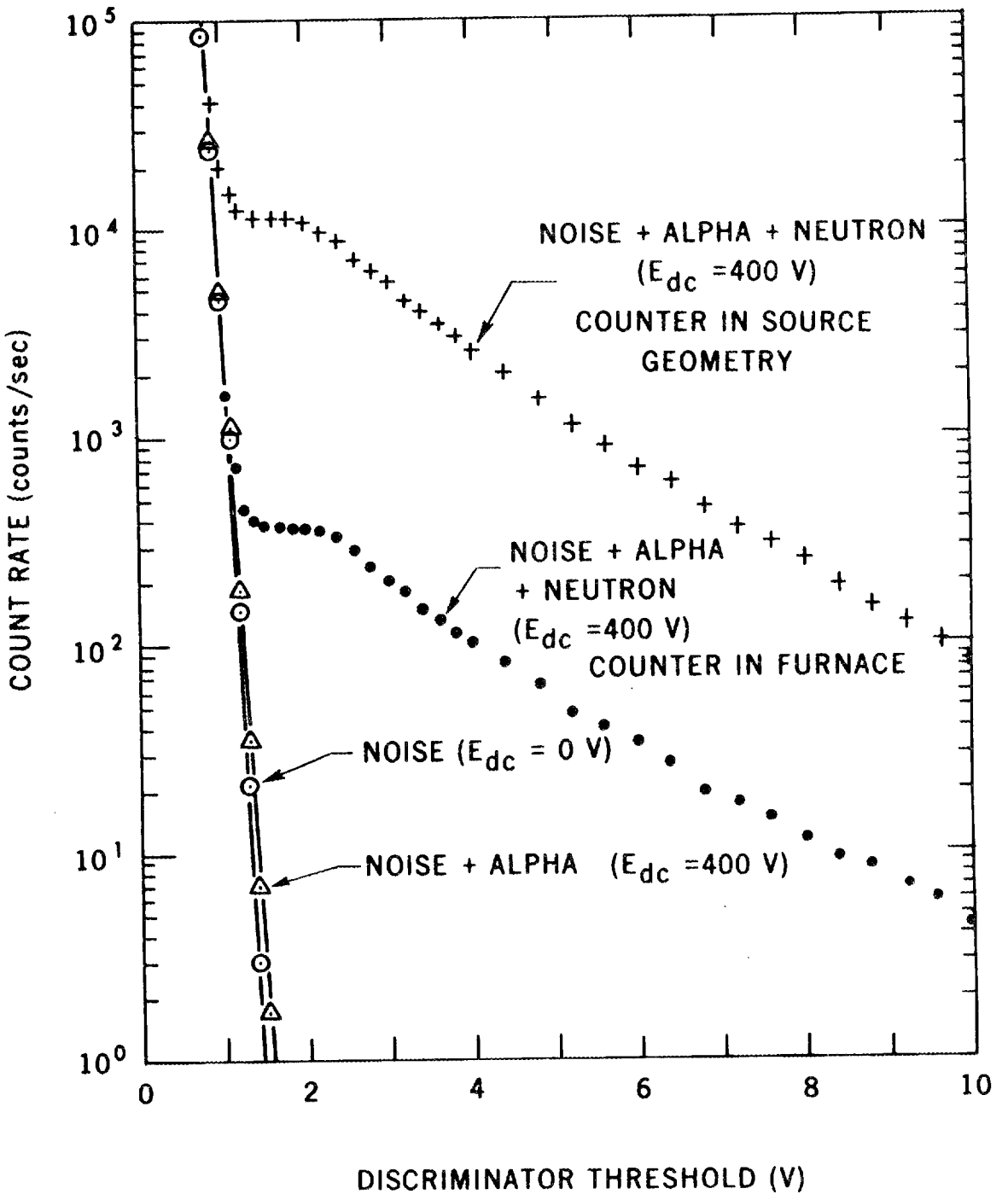

Fig. 23. Neutron integral bias with no gamma background.

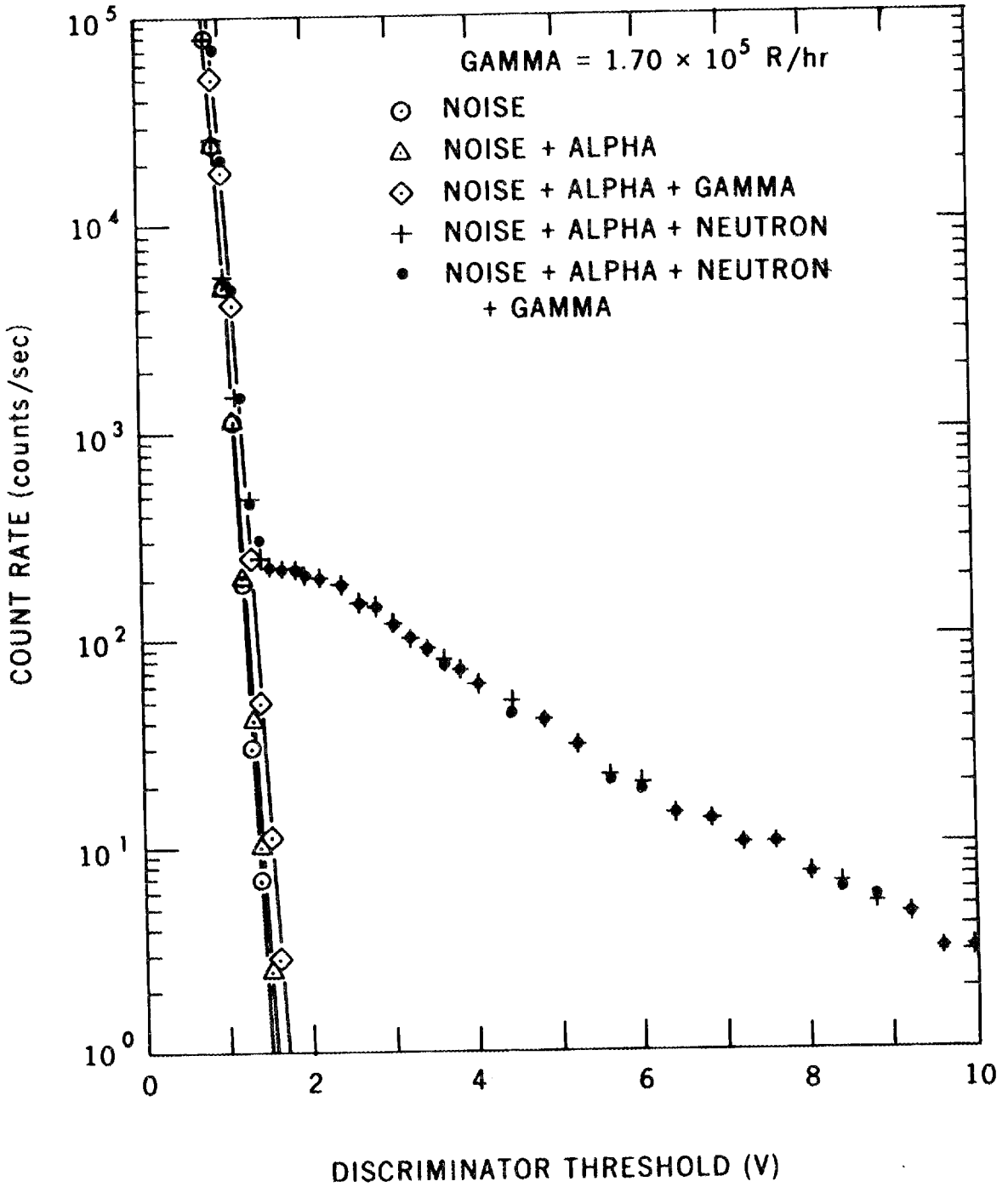

Fig. 24. Neutron integral bias with 1.7×10^5 R/hr gamma background.

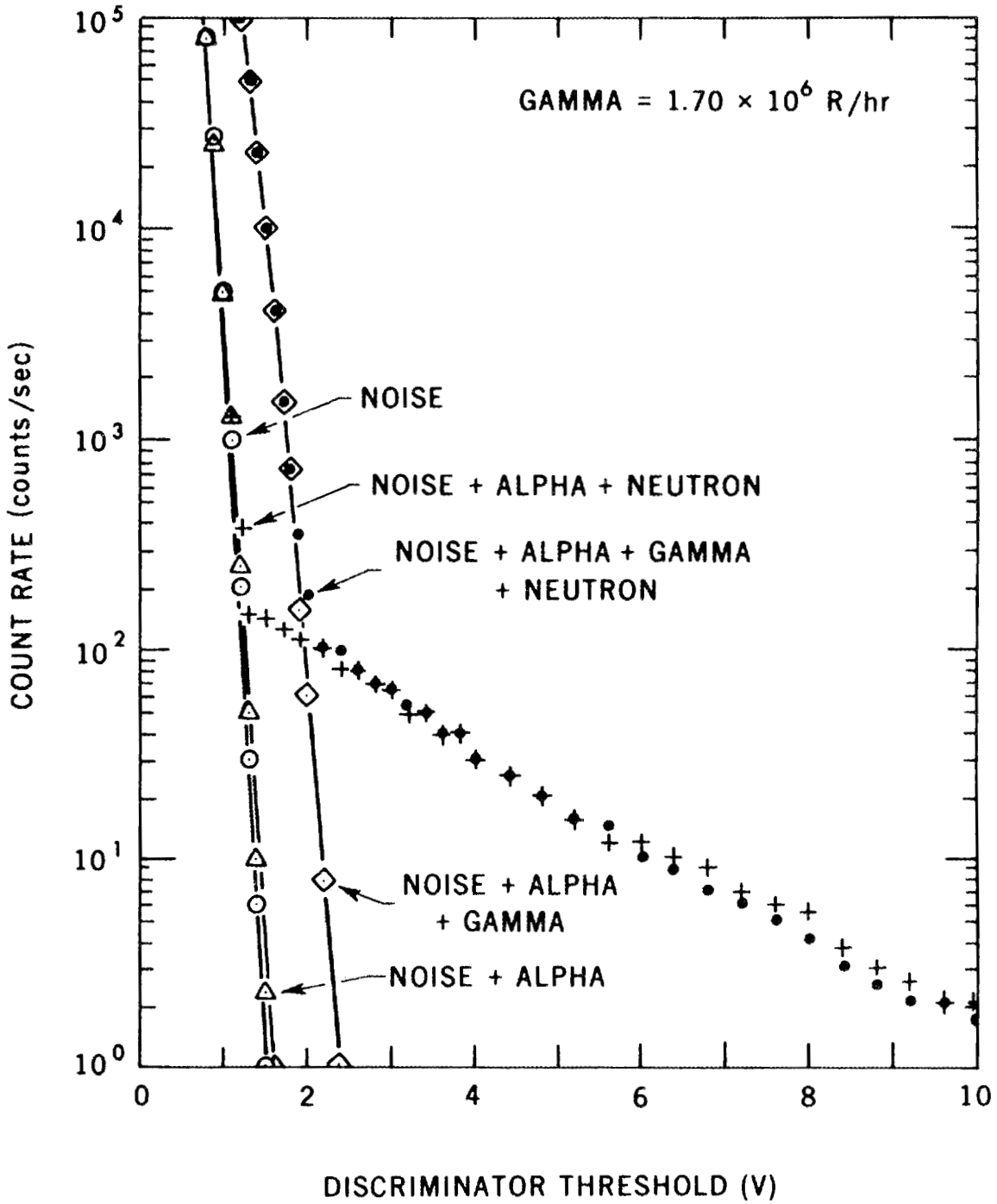

Fig. 25. Neutron integral bias with 1.7×10^6 R/hr gamma background.

Data recorded by the ADRS were taken at less frequent intervals (once a day during full power operation or on special occasions as described below) and included counter excitation voltages, four key temperature readings, ac output voltage of the preamplifier, counter dc currents, discriminator voltage, and count rates. The ADRS automatically varied the discriminator voltage to yield the neutron integral bias curve and automatically adjusted the counter excitation voltage to yield noise integral bias curves plus dc current and count rate saturation curves.

Manual data were taken once a day during full-power runs (or at special occasions described below) to include count rate, dc current, and ac voltage. These were recorded as a function of the counter excitation voltage from which both dc and count rate saturation characteristics could be obtained.

The manual data sheets were sent to the experimenter at least once a week. The ADRS data were sent to the experimenter at least daily. The DAS data was sent at the end of each reactor cycle.

The schedule for the acquisition of all data is summarized as follows:

Scheduled Shutdown--Full Power. One hour before a scheduled shutdown, data shall be recorded by the ADRS. This data record shall be a part of the shutdown checksheet.

50-500-kW--Midrun and End of Run Shutdowns. After a power level of 50-500 kW is reached and has been steady for at least 10 min, data shall be recorded by the ADRS. This data record shall be a part of the shutdown checksheet.

Shutdown After All Rods are Down. Within one hour after all rods are down, data shall be recorded by the ADRS. The DAS shall be programmed, using zero power as a signal, to start data acquisition.

Extended Shutdown. Data shall be recorded by the ADRS once every 8 hr for the first 3 days after all rods are down. The DAS shall be programmed to continue data acquisition for the 3 days. Thereafter, data shall be recorded manually once each day during the rest of the shutdown.

Unscheduled Shutdown. As soon as possible after the shutdown, data shall be recorded by the ADRS. The DAS shall be programmed, using zero power as a signal, to start data acquisition 1 hr after zero power is reached. Data shall be recorded manually once daily during the remainder of the shutdown period.

Prestartup. Approximately 2 hr prior to the approach to critical, data shall be recorded by the ADRS. The DAS sample interval shall be 1 min except when data are recorded by the ADRS. This data record shall be a part of the startup checksheet.

50-500-kW Power Level--Initial and Midrun Startups. After a power level of 50-500 kW is reached and has been steady for at least 10 min, data shall be recorded by the ADRS. This data record shall be a part of the approach to power checksheet.

Full-Power--Startup. Within 1 hr after full power is reached, data shall be recorded by the ADRS. This data record shall be a part of the approach to power checksheet.

Full-Power Operation. Once each day during full-power operation, data shall be recorded both by the ADRS and manually.

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