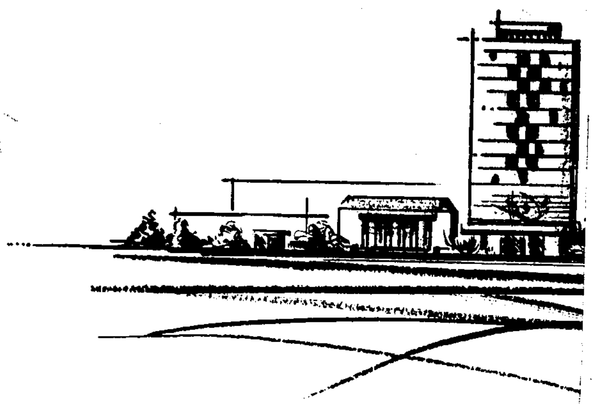
66-548

RESEARCH REPORT

[redacted]

N67 17995
(ACCESSION NUMBER)
(THRU)
125
(PAGES)
(CODE)
09
(CATEGORY)
CR-81607
(NASA CR OR TMX OR AD NUMBER)
FACILITY FORM 602



GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

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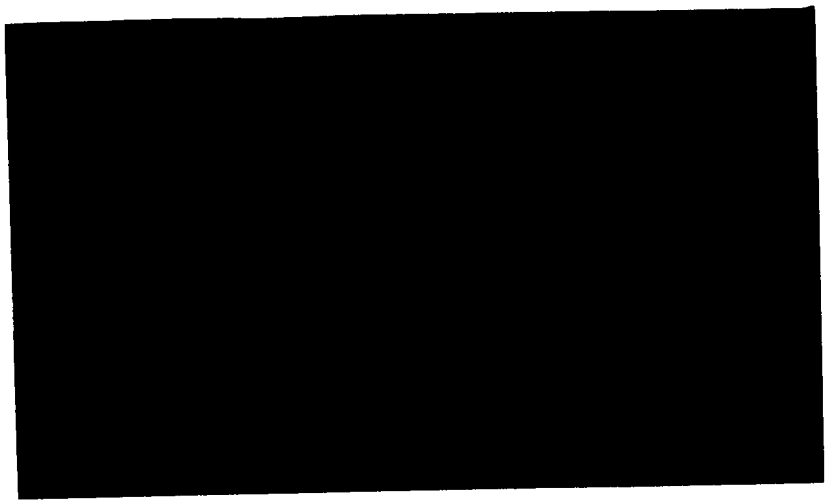

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FINAL REPORT

on

A STUDY OF THE RELIABILITY OF ELECTRONIC COMPONENTS IN A NUCLEAR RADIATION ENVIRONMENT

VOLUME II: THE REVISED TEST PROCEDURE

for

JPL TEST NO. 617, PHASE II

to

JET PROPULSION LABORATORY

~~Contract Number~~ 950458

by

C. L. Hanks and D. J. Hamman

BATTELLE MEMORIAL INSTITUTE
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"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, pursuant to a subcontract issued under Prime Contract NAS7-100 between the California Institute of Technology and the United States of America represented by the National Aeronautics and Space Administration."

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A STUDY OF THE RELIABILITY OF ELECTRONIC COMPONENTS IN A NUCLEAR RADIATION ENVIRONMENT

VOLUME II. THE REVISED TEST PROCEDURE

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INTRODUCTION

This is the final report on the revisions of the test procedures for JPL Test No. 617, Phase II, on the project entitled " Study of the Reliability of Electronic Components in a Nuclear-Radiation Environment", Contract No. 950458 (File 2998).

The purpose of this report is to provide a single document covering these test procedures, including all modifications and revisions that have occurred since the program was initiated. The objectives in preparing this document are: (1) to define the current test program, (2) to utilize the experience and documentation that presently exist, and (3) to use the test procedure in the preparation of the final report covering the results of the test program.

PURPOSE OF PROGRAM

The purpose of the program for which this document describes the complete test procedure is to determine qualitatively and experimentally the behavior of selected electronic parts in a specified radiation environment. The electronic parts, radiation environments, other environmental constituents, electrical loading, and measurement procedures are described elsewhere in this test procedure.

SCOPE OF PROGRAM

The program consists of testing and analysis directed toward expanding the limited knowledge of the reliability of the specified electronic parts in an environment compatible with a spacecraft utilizing nuclearelectric propulsion or auxiliary power. Particular emphasis is placed upon the determination of the interaction of various specified test environments and the establishment of failure rates on a catastrophic basis for each part type.

DESCRIPTION OF TEST SPECIMENS

The test specimens include 100 parts of each of the types listed in Table 1, with the exceptions as noted. The parts were selected on the basis of the recommendations made during Phase I (literature survey) of this program and represented parts with structural variances that had a low probability of imminent obsolescence.

TEST DESIGN

The following is a general discussion of the test design, including how the design will satisfy the purpose of the test program and the comparisons and correlations that will be made.

In order to simulate a nuclear-electric spacecraft environment and assess the interaction of various environmental constituents, the original test design consisted of 5 groups of 20 units of each part type listed in Table 1, with the exception of the CBS-7871 photomultipliers, the Clairex CL-605 cadmium sulfide cells, the fiber optic discs, the International Rectifier 1N2063, and the Cinch and Bendix connectors. The 5 groups of the original test design and their environmental conditions are identified as Test Groups I through V in the block diagram of the basic test design shown in Figure 1.

Test Groups VI and VII, which are also shown in the basic test design of Figure 1, were added to the original test design as a supplemental effort. These additional groups provide comparison between the effects of operating and nonoperating (static) conditions under identical environmental conditions as originally specified for Test Groups I and III. However, all part types are not included in Test Groups VI and VII, and several of those in Test Group VI are excluded from Test Group VII, as indicated by notations in Table 2.

The Cinch and Bendix connectors and the International Rectifier 1N2063 are the only part types being subjected to several of the conditions shown in the basic test design, Figure 1, that are not divided into groups of 20 units. The 1N2063 power rectifiers were limited to 24 specimens because of their physical size and the necessity to test them under nonoperating conditions due to the current required to provide operation during the test. The 24 specimens were divided into 5 groups, four units in Test Group I and five units each in Test Groups II through V. The connectors were additional part types added to the program as part of the supplemental effort that provided for Test Groups VI and VII. Therefore, they were not included in all the test groups and were limited to 30 mated pairs with ten units each in Test Groups I, III, and IV.

The testing of the photomultipliers, cadmium sulfide cells, and fiber optic discs has been completed as a separate effort in this program, i.e., they are not subjected to the conditions and requirements of the basic test design of Figure 1. Instead, they were irradiated in a cobalt-60 gamma source. The gamma exposure rate was approximately 1×10^6 ergs g^{-1}(C) hr^{-1}, with a planned duration of exposure of 1000 hours at an ambient temperature of 15 to 20 C and normal atmospheric pressure. Two separate tests were performed, the first of which consisted of exposing the 20 photomultipliers, with fiber optic discs mounted on the face of 9 of them, to the above specified environmental conditions for 200 hours. The test was discontinued at that time due to the large quantity of

TABLE 1. DESCRIPTION OF COMPONENT PARTS INCLUDED IN THE PROGRAM

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Manufacturer's Rating
Capacitors			
Aerovox[a]	P323ZN2 (metalized paper)	001	1.0 $\mu f \pm 10\%$; D. F. = 1% max at 25 C; 200 Vdc at 125 C and below; IR = 2000 megohms at 25 C, 50 megohms at 50 C, and 20 megohms at 100 C
Sprague	118P10592S2 (metalized paper/Mylar)	002	1.0 $\mu f \pm 10\%$; D. F. = 1% max at 25 C; 200 Vdc at 125 C and below; IR = 2000 megohms at 25 C, 500 megohms at 50 C, and 40 megohms at 100 C
Good-All[b] (TRW Electronics)	683G10592W2 (Mylar)	003	1.0 $\mu f \pm 10\%$; D. F. = 1% max at 25 C; 200 Vdc up to 85 C; 100 Vdc from 85 C to 125 C; IR = 40,000 megohms at 25 C, 20,000 megohms at 50 C, and 1000 megohms at 100 C
General Electric[a]	5K106AA6 (tantalum foil)	004	2.0 $\mu f \pm 20\%$; D. F. = 10% at 25 C; 25% at 125 C; 100 Vdc at 125 C and below; 150 Vdc at 85 C; I_L = 2 μA at 25 C, and 15 μA at 125 C
Fansteel	HP56C50D1 (solid tantalum)	005	56 $\mu f \pm 10\%$; ESR = 7.7 ohms at 25 C; 75 Vdc at 50 C, 50 Vdc at 125 C; I_L = 7 μA at 25 C, and 28 μA at 125 C
Diodes			
Fairchild[b]	FD1184 (silicon, switching)	006	I_o = 75 mA at 25 C; 50 Vdc; 250 mw at 25 C, 0 mw at 175 C, 208 mw at 50 μ C; and 125 mw at 100 C; V_F = 1.0 Vdc max at 30 mA and 25 C; I_R = 0.1 μA max at 50 Vdc and 25 C; I_R = 100 μA max at 50 Vdc and 150 C
Fairchild	FD643 (silicon, switching)	007	I_o = 300 mA at 25 C; 60 Vdc; 500 mw at 25 C, 0 mw at 175 C, 416 mw at 50 C, 250 mw at 100 C; V_F = 1.2 Vdc max at 400 mA and 25 C (5 μsec pulse, 1% duty cycle); I_R = 0.1 μA max at 60 Vdc and 25 C; I_R = 100 μA max at 60 Vdc and 150 C
Texas Instruments	1N916 (silicon, switching)	008	I_o = 75 mA at 25 C; I_o = 10 mA at 150 C; 75 Vdc; 250 mw at 25 C, 175 mw at 50 C, 75 mw at 100 C; V_F = 1.0 Vdc max at 10 mA and 25 C; I_R = 0.025 μA at 20 Vdc and 25 C; I_R = 50 μA at 20 Vdc and 150 C
Silicon Controlled Switches			
General Electric[b]	3N58	009	I_o = 100 mA at 100 (25)[g] C; V_B = 40 Vdc; V_R = 40 Vdc; 300 (200)[g] mw at 25 C, 240 (160)[g] mw at 50 C, 120 (80)[g] mw at 100 C; V_F = 1.5 Vdc max at 50 mA and 25 C; I_B = 20 μA at 40 vac and 150 C with R_{GC} = 10 K; I_R = 20 μA at 40 vac and 150 C with R_{GC} = 10 K; I_H = 1.5 mA max; I_{GFC} = 1 μA max; V_{GFC} = 0.65 v max
Power Rectifiers			
International Rectifier[c]	1N2063 (silicon)	010	I_o = 400 amp at 135 C stud temp; 500 Vdc; V_F = 1.1 v at 400 amp (one-cycle average), 140 C junction temp; I_R = 55 mA at 500 V (one cycle average), 170 C

TABLE 1. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Manufacturer's Rating
Zener Diodes			
Hoffman[b]	1N822 (double anode)	011	V_Z = 5.9 to 6.5 Vdc at 7.5 mA and 25 C; I_Z = 7.5 mA at 150 C; Z_Z = 15 ohms max at 7.5 mAdc and 25 C; 400 mw at 25 C
Pacific Semi-conductor	1N756A	012	I_o = 230 mAdc; V_Z = 7.79 to 8.61 Vdc at 20 mA and 25 C; 500 mw at 25 C, 75 mw at 175 C; I_R = 0.1 μA max at 1.0 Vdc and 25 C; I_R = 20 μA max at 1.0 Vdc and 150 C; Z_Z = 8.0 ohms max at 20 mAdc
Resistors			
Texas Instruments[a]	CG (carbon film)	013	100 K-ohms ± 1%; 1/4 watt; 350 v max
Corning[b]	C-07 (metal oxide film)	014	100 K-ohms ± 2%; 1/4 watt to 70 C; approx. 1/6 watt at 100 C; 250 v max
Allen-Bradley[a]	CB (carbon composition)	015	100 K-ohms ± 5%; 1/4 watt to 70 C; approx. 1/6 watt at 100 C; 250 v max
New England Instruments[b]	78PSH-128-16 (conductive plastic)	016	20 K-ohms ± 10%; 1 watt at 25 C; 0.75 watt at 50 C; 0.25 watt at 100 C; dielectric strength 1000 vrms at standard atmosphere
Transistors			
Fairchild	2N911 (silicon, NPN)	017	0.5 watt at 25 C; 0.43 watt at 50 C; 0.16 watt at 100 C; V_{CBO} = 100 V at 25 C; V_{CEO} = 60 v at 25 C; h_{FE} = 35 min, 70 typ. at I_C = 10 mA, V_{CE} = 10 v; $V_{BE(sat)}$ = 0.8 Vdc max, 0.6 Vdc min at I_C = 10 mA, I_B = 1.0 mA; $V_{CE(sat)}$ = 0.4 Vdc max at I_C = 10 mA, I_B = 1.0 mA; h_{fe} = 2.5 min at I_C = 50 mA, V_{CE} = 10 v, f = 20 mc; I_{CBO} = 0.025 μA at V_{CB} = 75 V; I_{CBO} = 15 μA at 150 C and V_{CB} = 75 v; I_{EBO} = 0.025 μA at V_{EB} = 5.0 v; BV_{EBO} = 7 min at I_E = 100 μA; BV_{CBO} = 100 min at I_C = 100 μA
Fairchild[b]	2N914 (silicon, NPN)	018	0.36 watt at 25 C; 0.31 watt at 50 C; 0.20 watt at 100 C; V_{CBO} = 40 v; V_{CEO} = 15 v; h_{FE} = 30 min, 55 typ. at I_C = 10 mA, V_{CE} = 1.0 v; h_{FE} = 10 min, 17 typ. at I_C = 500 mA, V_{CE} = 5.0 v; $V_{BE(sat)}$ = 0.8 Vdc max, 0.7 Vdc min, at I_C = 10 mA, I_B = 1.0 mA; $V_{CE(sat)}$ = 0.7 Vdc max at I_C = 200 mA, I_B = 20 mA; h_{fe} = 3.7 typ. at I_C = 20 mA, V_{CE} = 10 v, f = 100 mc; I_{CBO} = 0.025 μA at V_{CB} = 20 Vdc; I_{CBO} = 15 μA at 150 C and V_{CB} = 20 Vdc; I_{EBO} = 0.1 μA at V_{EB} = 4.0 Vdc; BV_{EBO} = 5.0 Vdc min at I_E = 10 μA; BV_{CBO} = 40 Vdc min at I_C = 1.0 μA
Fairchild[b]	2N915 (silicon, NPN)	019	0.36 watt at 25 C; 0.31 watt at 50 C; 0.20 watt at 100 C; V_{CBO} = 70 v at 25 C; V_{CEO} = 50 v at 25 C; h_{FE} = 40 min, 160 max at I_C = 10 mA, V_{CE} = 5.0 v; $V_{BE(sat)}$ = 0.9 Vdc max, I_C = 10 mA, I_B = 1.0 mA; $V_{CE(sat)}$ = 1.0 Vdc max at I_C = 10 mA, I_B = 1.0 mA; h_{fe} = 2.5 min at I_C = 10 mA, V_{CE} = 15 v, f = 100 mc; I_{CBO} = 0.010 μA max at V_{CB} = 60 Vdc; I_{CBO} = 30 μA max at 150 C and V_{CB} = 60 Vdc; BV_{CBO} = 70 Vdc min at I_C = 100 μA; BV_{EBO} = 5.0 Vdc min at I_E = 100 μA

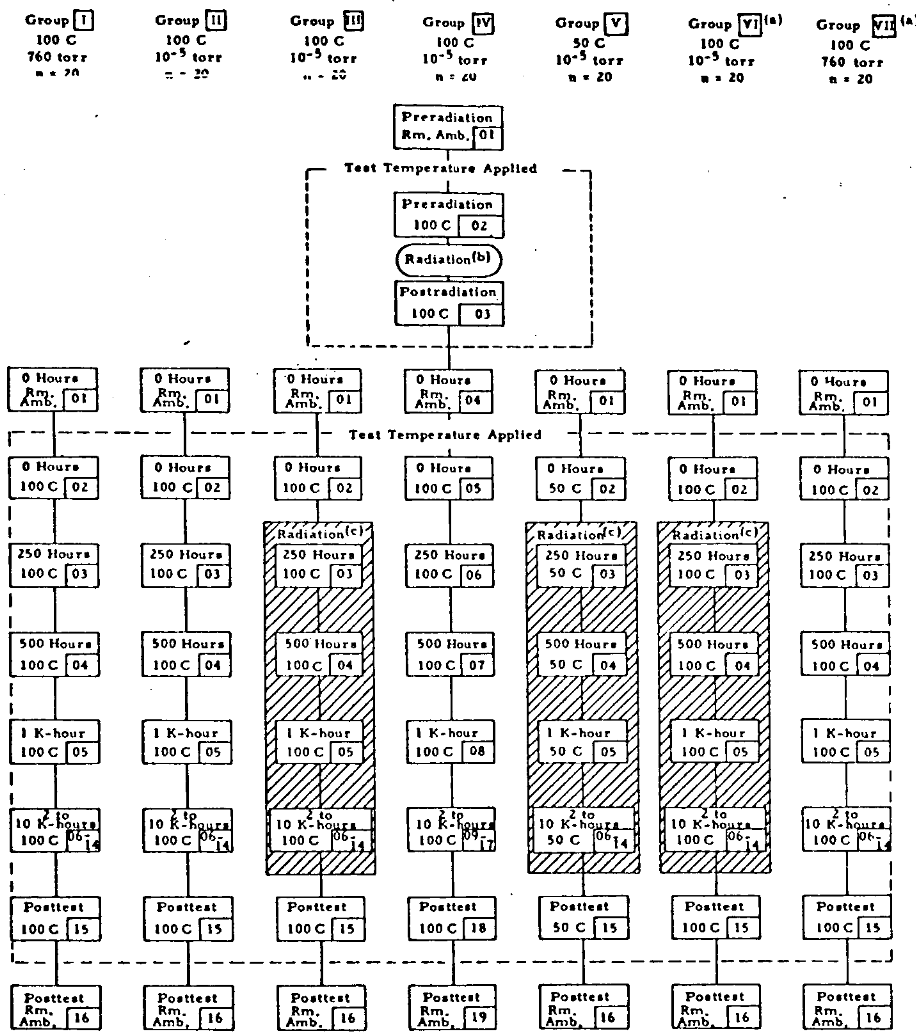
TABLE 1. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Manufacturer's Rating
Transistors (continued)			
Fairchild[b]	2N1132 (silicon, PNP)	020	0.6 watt at 25 C; 0.5 watt at 50 C; 0.3 watt at 100 C; V_{CBO} = 50 v at 25 C; V_{CEO} = 35 v at 25 C; h_{FE} = 30 min, 90 max at I_C = 150 mA, V_{CE} = 10 v; h_{FE} = 25 min at I_C = 5.0 mA, V_{CE} = 10 v; $V_{BE(sat)}$ = 1.3 v max at I_C = 150 mA, I_B = 15 mA; $V_{CE(sat)}$ = 1.5 v max at I_C = 150 mA, I_B = 15 mA; h_{fe} = 3.0 min, 4.5 typ. at I_C = 50 mA, V_{CE} = 10 v, f = 20 mc; I_{CBO} = 1.0 μA max at 25 C and V_{CB} = 30 Vdc; I_{CBO} = 100 μA at 150 C and V_{CB} = 30 Vdc
Fairchild	2N2297 (silicon, NPN)	021	0.8 watt at 25 C; 0.69 watt at 50 C; 0.45 watt at 100 C; V_{CBO} = 80 V; V_{CEO} = 35 v; h_{FE} = 40 min, 120 max at I_C = 150 mA, V_{CE} = 10 v; h_{FE} = 15 min at I_C = 1.0 amp, V_{CE} = 10 v; $V_{BE(sat)}$ = 2.0 Vdc max at I_C = 1.0 amp, I_B = 100 mA; $V_{CE(sat)}$ = 0.2 Vdc max at I_C = 150 mA, I_B = 15 mA; I_{CBO} = 0.010 μA max at V_{CB} = 60 Vdc; I_{CBO} = 10 μA max at 150 C and V_{CB} = 60 Vdc; I_{EBO} = 0.010 μA max at V_{EB} = 5.0 Vdc; BV_{CBO} = 80 Vdc min at I_C = 100 μA; BV_{EBO} = 7 Vdc min at I_E = 100 μA
Texas Instruments	2N930 (silicon, NPN)	022	0.3 watt at 25 C; 0.25 watt at 50 C; 0.15 watt at 100 C; V_{CEO} = 45 v; V_{EBO} = 5 v; I_C = 30 mA; I_{CES} = 0.01 μA max at V_{CE} = 45 Vdc, I_{CES} = 10 μA max at 170 C and V_{CE} = 45 Vdc; I_{EBO} = 0.01 μA max at V_{EB} = 5 Vdc; BV_{CEO} = 45 v min at I_C = 10 mA; h_{FE} = 100 min, 300 max at I_C = 10 μA, V_{CE} = 5 v; h_{FE} = 150 min at I_C = 500 μA, V_{CE} = 5 v; h_{FE} = 600 max at I_C = 10 mA, V_{CE} V_{CE} = 5 v; $V_{CE(sat)}$ = 1 Vdc max at I_C = 10 mA, I_B = 0.5 mA; h_{fe} = 150 min at I_C = 1 mA, V_{CE} = 5 v, f = 1 k_c
Texas Instruments[b]	2N1050 (silicon, NPN)	023	1.0 watt at 25 C; 0.85 watt at 50 C; 0.55 watt at 100 C; V_{CBO} = 120 v; V_{EBO} = 6 v; I_{EBO} = 250 μA max at V_{EB} = 6 Vdc; I_{CBO} = 15 μA max at V_{CB} = 30 Vdc; I_{CBO} = 350 μA max at 150 C and V_{CB} = 30 Vdc; h_{FE} = 30 min, 90 max, at I_C = 500 mA, V_{CE} = 10 v; $V_{CE(sat)}$ = 7.5 max at I_C = 500 mA, I_B = 100 mA
Texas Instruments	2N2412 (silicon, PNP)	024	0.3 watt at 25 C; 0.26 watt at 50 C; 0.17 watt at 100 C; V_{CBO} = 25 v at 25 C; V_{CEO} = 20 v at 25 C; V_{EBO} = 5 v at 25 C; I_{CES} = 10 nA max at V_{CE} = 25 Vdc; I_{CES} = 10 μA max at 150 C and V_{CE} = 25 Vdc; I_{EBO} = 10 nA max at V_{EB} = 5 Vdc; h_{FE} = 20 min at I_C = 50 μA, V_{CE} = 0.5 v; h_{FE} = 40 min 120 max at I_C = 10 mA, V_{CE} = 0.5 v; h_{FE} = 20 min at I_C = 50 mA, V_{CE} = 1 v; $V_{CE(sat)}$ = 0.20 Vdc max at I_C = 10 mA, I_B = 1 mA; h_{fe} = 1.4 min, 2.0 typ., at I_C = 10 mA, V_{CE} = 10 v, f = 100 mc; BV_{CEO} = 20 Vdc min at I_C = 10 mA
Philco[b]	2N861 (silicon, PNP)	025	0.15 watt at 25 C; 0.12 watt at 50 C; 0.05 watt at 100 C; V_{CB} = 25 v; V_{CEO} = 25 v; V_{EB} = 20 v; I_{CBO} = 0.1 μA max at V_{CB} = 10 Vdc; I_{CBO} = 15 μA max at 125 C and V_{CB} = 10 Vdc; I_{EBO} = 1 μA max at V_{EB} = 20 Vdc; h_{FE} = 25 min, 75 max at I_C = 5 mA, V_{CE} = 0.5 Vdc; $V_{CE(sat)}$ = 0.15 Vdc at I_C = 5 mA, I_B = 0.5 mA; BV_{CBO} = 25 Vdc min at I_{CBO} = 1 μA; BV_{CEO} = 25 Vdc min at I_{CEO} = 25 μA

TABLE 1. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Manufacturer's Rating
Relays			
Sigma	32RJD90GD-GSP (hermitic seal)	026	DPDT; dual coil; 2-amp contact rating; 100 mw sensitivity; 90 ohms each coil; 1 x 10^4 operations, no load
Switches			
Minneapolis-Honeywell	1HM1 (gas filled, hermetic seal)	027	SPDT; 5-amp resistive load, 3 amp inductive; 28 Vdc; 7-oz max operating force; temp to 121 C;
Transformers			
Triad	SP-13 (TF5RX13ZZ) (interstage)	028	Primary 20 K-ohm CT, Secondary 800-ohm CT, 40 mw; max primary d-c unbalance 0.5 ma; IR test voltage 500 Vrms
Photomultipliers			
CBS(d)	7817	029	2000 Vdc, anode to cathode; 250 Vdc, last dynode and anode; 5 mA average anode current; 1-watt average anode dissipation; current amplification, 170,000 at 1250 v, 2,000,000 at 1750 v
Cadmium Sulfide Cells			
Clairex(d)	CL-605 (cadmium sulfide)	030	166 K-ohms at 2 foot-candles; 300 v; 75 mw
Fiber Optic Discs			
Mosaic Fabrications, Inc.(e)		031	
Connectors			
Cinch(f)	DEM-9P-NM-10 DEM-9S-NM-10	032 032	5-amp contact rating; 1700 Vdc peak, flashover; 310 F max temp
Bendix(f)	PT06A-8-4P PT00A-8-4S	033 033	5-amp contact rating

(a) Total sample size of 120 specimens.
(b) Total sample size of 140 specimens.
(c) Total sample size of 24 specimens.
(d) Total sample size of 20 specimens.
(e) Total sample size of 10 specimens.
(f) Total sample size of 30 of each mating connector pair.
(g) Rating reduced by manufacturer.



(a) Nonoperating (static) test groups.
(b) 100 hours at 3×10^7 n cm^2 sec^{-1} and 1×10^7 ergs g^{-1}(C) hr^{-1}.
(c) 10,000 hours at 3×10^5 n cm^2 sec^{-1} and 1×10^5 ergs g^{-1}(C) hr^{-1}.

xx Measurement Interval
Group Measurement Number

FIGURE 1. BASIC TEST DESIGN

failures. The cadmium sulfide cells were irradiated separately and completed the 1000 hours at the required conditions. Measurement intervals were every 100 hours throughout the 200- and 1000-hour exposures.

The purpose of the major program effort requires the description of the behavior of selected electronic parts in a specified radiation environment over a 10,000-hour period. The particular environment of special interest is a temperature of 100 C, under vacuum, at radiation exposure rates of 1×10^9 fast n cm^{-2} hr^{-1} and 1×10^5 ergs g^{-1}(C) hr^{-1} of gamma radiation for 10,000 hours. The measurement schedule shown in Figure 1 for the parameters specified in Table 2 will provide the data necessary to describe the device behavior as a function of radiation exposure under vacuum at 100 C. This is the environment designated as Group III in Figure 1.

In addition, the test plan allows for: the separation of vacuum effects (Groups I and II); the separation of radiation effects (Groups I and III); some indication of temperature effects (Groups III and V); and the comparison between the effects of long-term, low-level, radiation exposure and the long-term effects of short-term, high-level radiation exposure (Groups III and IV, respectively). The total radiation in both cases will be the same.

The environmental conditions for Group III in Figure 1 were specified by the Jet Propulsion Laboratory as typical of what might be expected on the electronic equipment in a space vehicle using a nuclear auxiliary power system. The environmental conditions of the other groups were chosen, as already described, to separate the effects of the various environmental constituents.

The life-test conditions (voltages and currents) as described in the section entitled Life-Test Procedures and Table 19 were chosen on the basis of the device ratings specified by the manufacturers and the environmental conditions being considered plus, in many cases, a derating factor typical of normal application procedures. Some life-test conditions were based on engineering experience when sufficient information was not available for quantitative evaluation of all factors. It should be noted that Groups VI and VII were included in the program at the request of the Jet Propulsion Laboratory in order to compare the effect of radiation on energized devices against nonenergized devices.

The data gathered during measurement of the devices will be treated or analyzed in the following ways:

(1) Initial distributions of parameter values. These will include minimum, median, and maximum values, along with the standard deviation and other statistical information.

(2) Distributions plus other statistical information about parameter value changes at each measurement period.

This statistical information will be provided on Computed Statistics Sheets and will be prepared for the Jet Propulsion Laboratory by another contractor. Battelle will furnish to the Jet Propulsion Laboratory the raw data from the measurements that are necessary for the preparation of the Computed Statistics Sheets.

TABLE 2. PARAMETER MEASUREMENTS AND CONDITIONS

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Parameters to be Measured (During Irradiation Except as Indicated by * Which are Pre- and Postirradiation Only)	Measurement Conditions
Capacitors				
Aerovox[a]	P323ZN2	001	Capacitance and dissipation factor Leakage current, lead to lead	400 cps 200 v
Sprague[b]	118P10592S2	002	Capacitance and dissipation factor Leakage current, lead to lead	400 cps 200 v
Good-All	683G10592W2	003	Capacitance and dissipation factor Leakage current, lead to lead	400 cps 100 v
General Electric[a]	5K106AA6	004	Capacitance and dissipation factor Leakage current, lead to lead	120 cps a-c volts = 15, d-c volts = 50 100 v
Fansteel[b]	HP56C50D1	005	Capacitance and dissipation factor Leakage current, lead to lead	120 cps a-c volts = 15, d-c volts = 50 50 v
Diodes				
Fairchild	FD1184	006	I_R V_F C_j*	V_R = 50 v I_F = 5 ma, 30 ma*, and 0.1 ma* 100 kc (50-mv signal ac, 0 vdc)*
Fairchild[b]	FD643	007	I_R V_F C_j*	V_R = 60 v I_F = 100 ma, 400 ma*, and 0.1 ma* 100 kc (50-mv signal ac, 0 vdc)*
Texas Instruments[b]	1N916	008	I_R V_F C_j*	V_R = 20 v I_F = 1 ma, 10 ma*, and 0.1 ma* 100 kc (50-mv signal ac, 0 vdc)*
Silicon Controlled Switches				
General Electric	3N58	009	V_G for turn-on	40 v on anode 800-ohm load
			V_{BO} V_F Holding current, I_H	10 K-ohms, gate to cathode I_F = 50 ma 10 K-ohms, gate to cathode
Power Rectifiers				
International Rectifier[b]	1N2063	010	I_R	200 vdc
Zener Diodes				
Hoffman	1N822	011	V_Z	I_Z = 7.5 ma (regulated to 0.1%) also measure at -55 C*
			Z_Z	I_Z = 7.5 ma and 1.0 ma + 10% I_Z ac

TABLE 2. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Parameters to be Measured (During Irradiation Except as Indicated by * Which are Pre- and Postirradiation Only)	Measurement Conditions
Zener Diodes (Continued)				
Pacific Semiconductor[b]	PS4653 (1N756A)	012	V_Z	I_Z = 20 ma; also measure at -55 C*
			Z_Z	I_Z = 20 ma and 1.0 ma + 10% I_Z ac
Resistors				
Texas Instruments[a]	CG	013	Resistance	
			Insulation resistance*	
Corning	C-07	014	Resistance	
			Insulation resistance*	
Allen-Bradley[a]	CB	015	Resistance	
			Insulation resistance*	
Potentiometers				
New England Instruments	78PSH-128-16	016	Total (end to end) resistance	
			Insulation resistance	200 v, element to case
			Independent linearity*	Per NAS 710*
			Noise*	
Transistors				
Fairchild[b]	2N911	017	h_{FE}	I_C = 10 ma, V_{CE} = 10 v (pulsed) I_C = 100 ma, V_{CE} = 10 v (pulsed)[e]
			I_{CBO}	V_{CB} = 75 v
			$V_{CE(SAT)}$	I_C = 10 ma, I_B = 1 ma
			BV_{CBO}*	I_{CB} = 100 μa*
			LV_{CEO}*	I_{CE} = 30 ma* (pulsed)
Fairchild	2N914	018	h_{FE}	I_C = 100 ma, V_{CE} = 5 v (pulsed) I_C = 10 ma, V_{CE} = 1 v (pulsed)
			I_{CBO}	V_{CB} = 20 v
			$V_{CE(SAT)}$	I_C = 200 ma, I_B = 20 ma
			BV_{CBO}*	I_{CB} = 10 μa*
			LV_{CEO}*	I_{CE} = 30 ma (pulsed)*
			I_{EBO}*	V_{EB} = 4 v*
			h_{fe}*	I_C = 10 ma, V_{CE} = 10 v (f = 100 mc)*

TABLE 2. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Parameters to be Measured (During Irradiation Except as Indicated by * Which are Pre- and Postirradiation Only)	Measurement Conditions
Transistors (Continued)				
Fairchild	2N915	019	h_{FE}	I_C = 10 ma, V_{CE} = 5 v (pulsed)
				I_C = 10 ma, V_{CE} = 1 v (pulsed)
				I_C = 100 ma, V_{CE} = 10 v (pulsed)
			I_{CBO}	V_{CB} = 15 v
			$V_{CE(SAT)}$	I_C = 10 ma, I_B = 1 ma
			BV_{CBO}*	I_C = 100 μa*
			LV_{CEO}*	I_C = 10 ma* (pulsed)
Fairchild	2N1132	020	h_{FE}	I_C = 150 ma, V_{CE} = 10 v (pulsed)
				I_C = 10 ma, V_{CE} = 10 v (pulsed)
			I_{CBO}	V_{CB} = 3 v
			$V_{CE(SAT)}$	I_C = 150 ma, I_B = 15 ma
			BV_{CBO}*	I_C = 100 μa*
Fairchild(b)	2N2297	021	h_{FE}	I_C = 150 ma, V_{CE} = 10 v (pulsed)
				I_C = 10 ma, V_{CE} = 10 v (pulsed)
			I_{CBO}	V_{CB} = 60 v
			$V_{CE(SAT)}$	I_C = 150 ma, I_B = 15 ma
			BV_{CBO}*	I_C = 100 μa*
			LV_{CEO}*	I_C = 10 ma (pulsed)*
			I_{EBO}*	V_{EB} = 5.0 v*
			h_{fe}*	I_C = 1 ma, V_{CE} = 5 v, f = 1 kc*
Texas Instruments(b)	2N930	022	h_{FE}	I_C = 100 ma, V_{CE} = 10 v (pulsed)(f)
			I_{EBO}	V_{EB} = 5 v
			$V_{CE(SAT)}$	I_C = 10 ma, I_B = 0.5 ma
			I_{CES}*	V_{CE} = 45 v*
			BV_{CEO}*	I_C = 10 ma (pulsed)*
			h_{fe}	I_C = 1 ma, V_{CE} = 5 v (f = 1 kc)*
Texas Instruments	2N1050	023	h_{FE}	I_C = 500 ma, V_{CE} = 10 v (pulsed)
				I_C = 10 ma, V_{CE} = 10 v (pulsed)
				I_C = 100 ma, V_{CE} = 10 v (pulsed)
			I_{CBO}	V_{CB} = 30 v
			$V_{CE(SAT)}$	I_C = 500 ma, I_B = 100 ma
			BV_{CBO}*	I_E = 250 μa*
			I_{EBO}*	V_{EB} = 6 v*
Texas Instruments(b)	2N2412	024	h_{FE}	I_C = 10 ma, V_{CE} = 10 v (pulsed)
			I_{EBO}	V_{EB} = -5 v
			$V_{CE(SAT)}$	I_C = 10 ma, I_B = 1 ma
			I_{CES}*	V_{CE} = -25 v*
			BV_{CEO}*	I_C = 10 ma (pulsed)*
			h_{fe}*	I_C = 10 ma, V_{CE} = 10 v, f = 100 mc*

TABLE 2. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Parameters to be Measured (During Irradiation Except as Indicated by * Which are Pre- and Postirradiation Only)	Measurement Conditions
Transistors (Continued)				
Philco	2N861	025	hFE	I_C = 10 ma, V_{CE} = 10 v (pulsed) I_C = 10 ma, V_{CE} = 1 v (pulsed) I_C = 100 ma, V_{CE} = 10 v (pulsed)[e]
			I_{CBO}	V_{CB} = 10 v
			$V_{CE(SAT)}$	I_C = 5 ma, I_B = 0.5 ma
			BV_{CBO}*	I_C = 10 μa*
Relays				
Sigma[b]	32RJD90GD-GSP	026	Voltage to close	
			Insulation resistance	200 v
Switches				
Minneapolis-Honeywell[b]	1HM1	027	Open-position resistance	200 v
			Activation pressure*	
			Contact resistance*	
Transformers				
Triad[b]	SP-13 (TF5RX13ZZ)	028	Insulation resistance	200 v
			Excitation current	At 35 v rms, 400 cps, secondary open
Photomultipliers				
CBS[c]	7817	029	Anode current	Measure with and without illumination (calibrated light source) at 1500 volts anode to cathode with dynode voltage divider 150 K-ohms per dynode; use Hewlett-Packard micro-microammeter
Cadmium Sulfide Cells				
Clairex[c]	CL-605	030	Cell voltage	Measure with and without illumination (approximately 400 ft-c) (calibrated source), accuracy 1% or better
			Cell resistance	Same as for cell voltage
Fiber Optic Discs				
Mosaic Fabrication[c]		031	Light transmission	Measure light transmission using spectrophotometer from 2800 to 5500 A; measure first disc at first measurement period, second disc at second interval, etc., for the 10 discs; intervals should be equally distributed through test period; attempt will be made to anneal radiation effects in optics

TABLE 2. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Test Item Code Number	Parameters to be Measured (During Irradiation Except as Indicated by * Which are Pre- and Postirradiation Only)	Measurement Conditions
Connectors				
Cinch[d]	DEM-9P-NM-10	032	Insulation leakage	200 vdc, with plug and socket joined
	DEM-9S-NM-10	032	Pin to pin	
			Pin to case	
Bendix[d]	PT 06A-8-4P	033	Insulation leakage	200 vdc, with plug and socket joined
	PT 00A-8-4S	033	Pin to pin	
			Pin to case	

(a) Excluded from Test Group VII.
(b) Excluded from Test Groups VI and VII.
(c) Separate 1000-hour test with gamma exposure of 1×10^6 ergs $g^{-1}(C)\ hr^{-1}$; 20 photomultipliers and cadmium sulfide cells, 10 fiber optic discs.
(d) Excluded from Test Groups II, V, VI, and VII; sample size of 10 mate pairs.
(e) h_{FE} measurement at this condition was discontinued after 4000 hours.
(f) I_C = 10 mA and V_{CE} = 5.0 volts after 4000 hours.

Assuming that copies of the Computed Statistics Sheets are supplied to Battelle, Battelle will prepare graphical illustrations showing the time and radiation variation of parameters for the different test groups. These graphical illustrations will be prepared, if practical, for each parameter measured, of each device type, in each test group.

The graph of a parameter's behavior in one test group will be compared with those of the same parameter in the other test groups in order to aid in the separation of the various environmental and life-test effects.

Estimates of failure rates (catastrophic) will be made when appropriate within the scope of the contract.

Anomalous or erratic behavior will be discussed when required by parametric measurements.

MEASUREMENTS AND MEASUREMENT PROCEDURES

The type of parameter measurements and the procedures used in their performance are presented in this section. These include a description of the methods, conditions, procedure, and equipment used for each parameter measured during the entire test program.

Parameters

The parameters to be measured and the conditions at which they are measured are listed in Table 2 for all test parts included in this program.

Special Preliminary and Final Measurements

Certain component-part parameters are measured only before and after irradiation and are not monitored during irradiation. These are specialized measurements made with special circuits that are not part of the regular data-processing system. All of these measurements are made with short leads rather than the usual 60 to 110 foot test leads.

Transistor LV_{CEO}

Considerable confusion seems to exist in the industry as to the definition of this parameter, and in particular as to how LV_{CEO} differs from BV_{CEO}. According to the GE Transistor Manual, BV_{CEO} is the breakdown voltage for a specified collector current with the base not connected. Figure 2 shows a breakdown characteristic curve. The GE definition of BV_{CEO} would correspond to Point A if I_C is the specified collector current. Fairchild Semiconductor Publication APP-4 gives a somewhat different definition. Here, BV_{CEO} is defined as the peak value of the curve, equivilent to Point C in Figure 2. LV_{CEO}, as defined by Fairchild, is the minimum voltage shown at Point B.

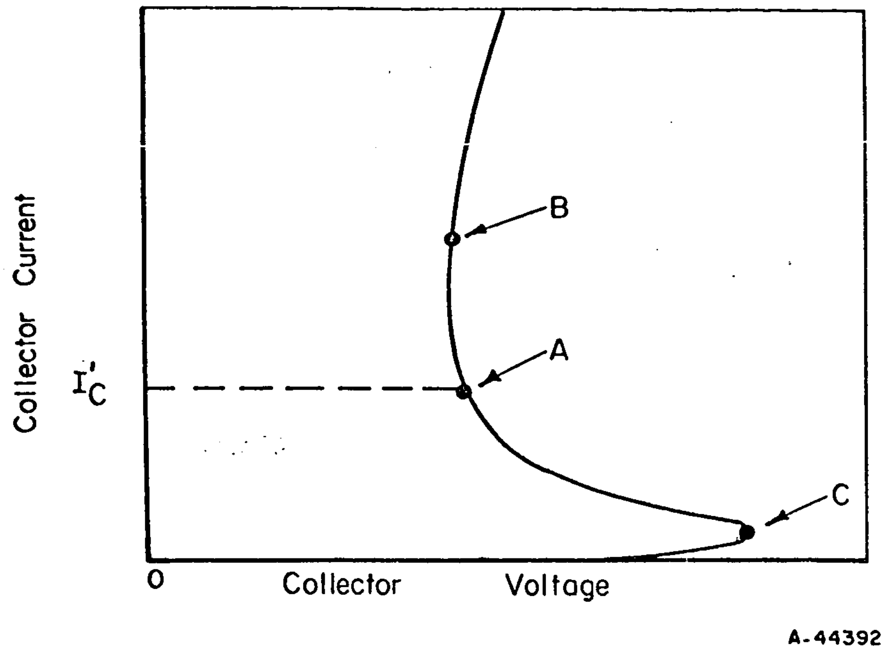


FIGURE 2. TRANSISTOR BREAKDOWN VOLTAGES

When a current is specified as a condition of measurement of either LV_{CEO} or BV_{CEO}, the Fairchild definitions cannot apply except by chance and the measurement for both LV_{CEO} and BV_{CEO} essentially conforms to the GE definition for BV_{CEO}. However, there is a broad minimum around Fairchild's LV_{CEO} point, and for reasonable values of collector current, the BV_{CEO} voltages measured will not be greatly different from Fairchild's LV_{CEO}. When a collector current is specified, as is done in Test Procedure 617, there is no difference between LV_{CEO} and BV_{CEO}. Thus, the measurements which have been made may be interpreted as being either LV_{CEO} or BV_{CEO} measured at the specified current.

The test procedure for making this measurement is to connect the collector and emitter terminals (base is open) to a pulse generator whose output current is limited to the desired current for measurement (see Figure 3). A carefully calibrated oscilloscope is used to monitor the collector-to-emitter voltage under pulse excitation. The pulse amplitude control is rotated slowly until breakdown is indicated by an increase followed by a sudden drop in the voltage. This new voltage amplitude is the desired breakdown voltage. The estimated accuracy of this measurement is ±4 per cent.

Transistor BV_{CBO}

Transistor breakdown voltage, BV_{CBO}, is the voltage existing from collector to base at a specified current, with no connection at the emitter. The circuit used is shown in its basic form in Figure 4. The voltage applied is slowly and carefully increased

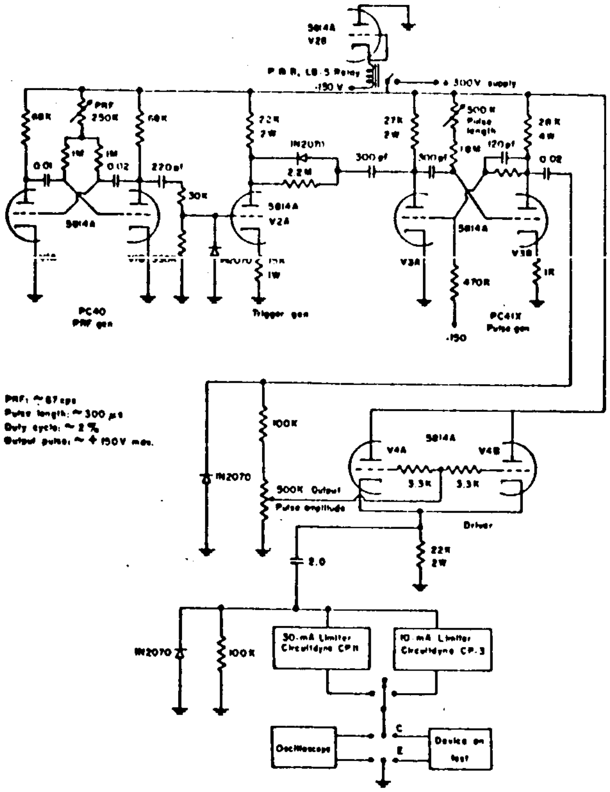


FIGURE 3. CIRCUIT FOR MEASURING LV_{CEO} AND BV_{CEO}

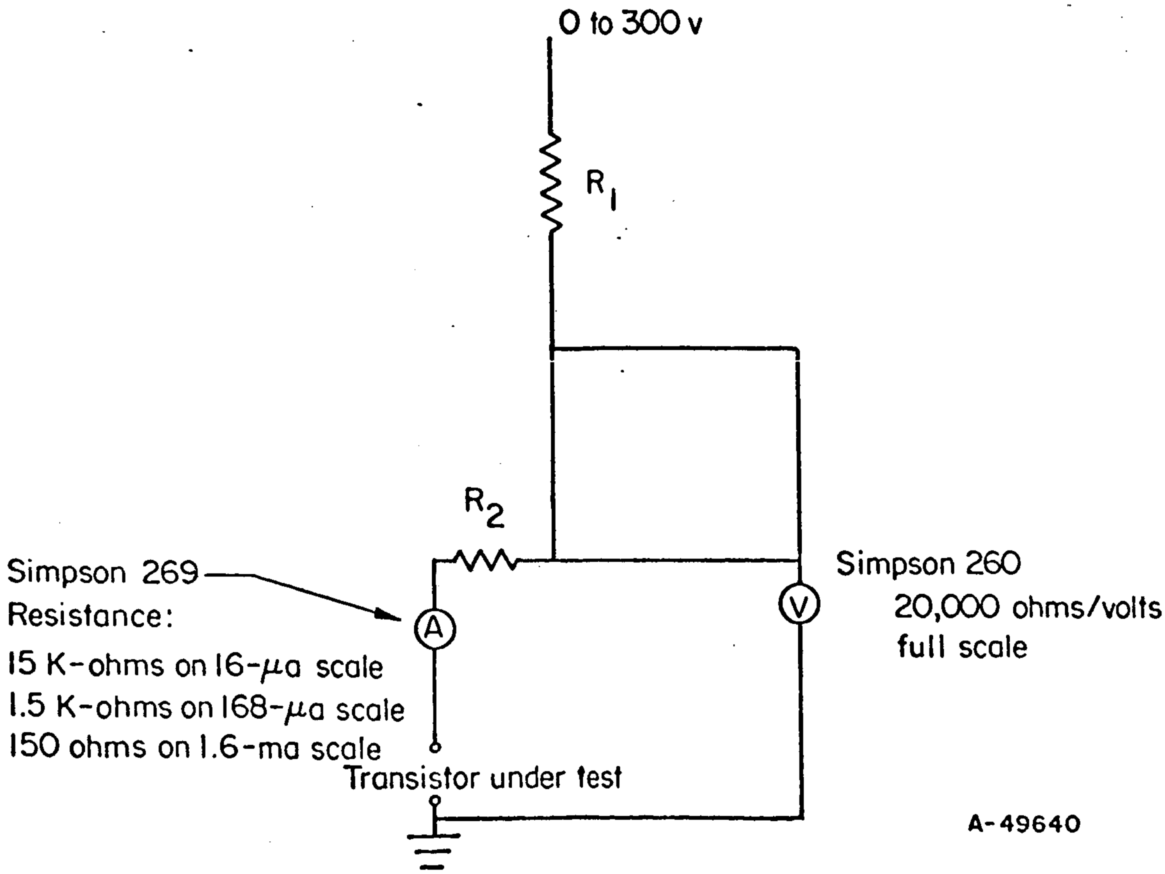


FIGURE 4. SIMPLIFIED BV_{CBO} MEASUREMENT CIRCUIT

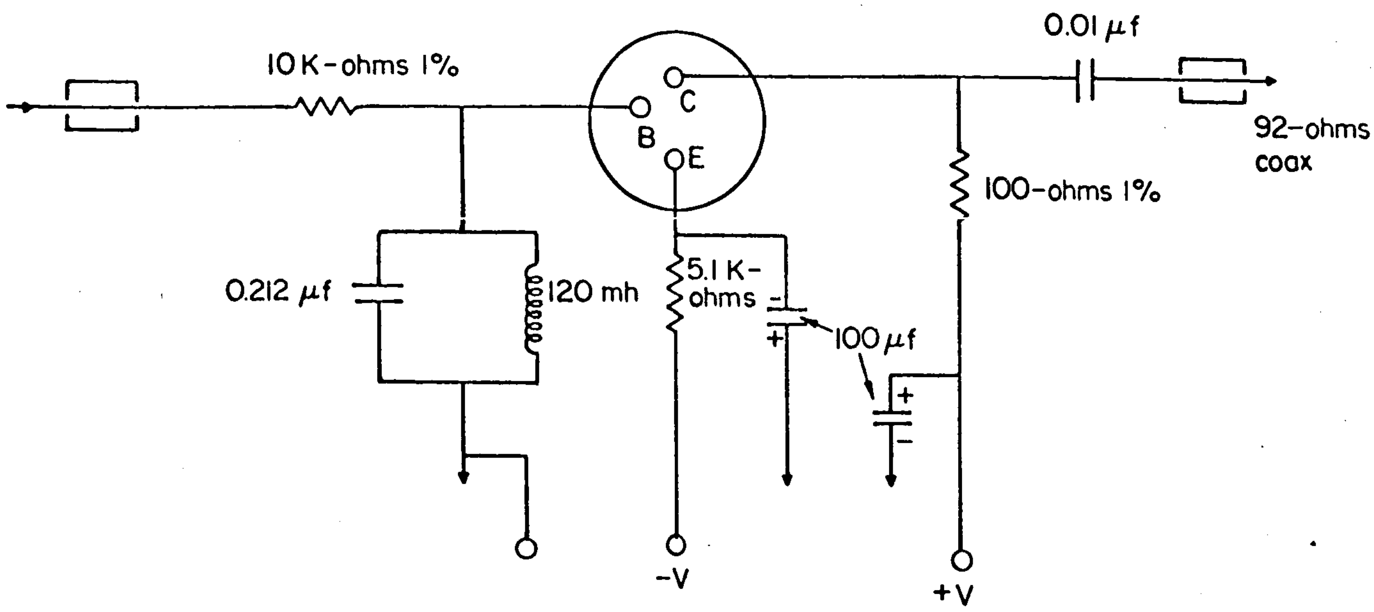


FIGURE 5. CIRCUIT OF TEST UNIT FOR MEASURING h_{fe} AT 1 KC

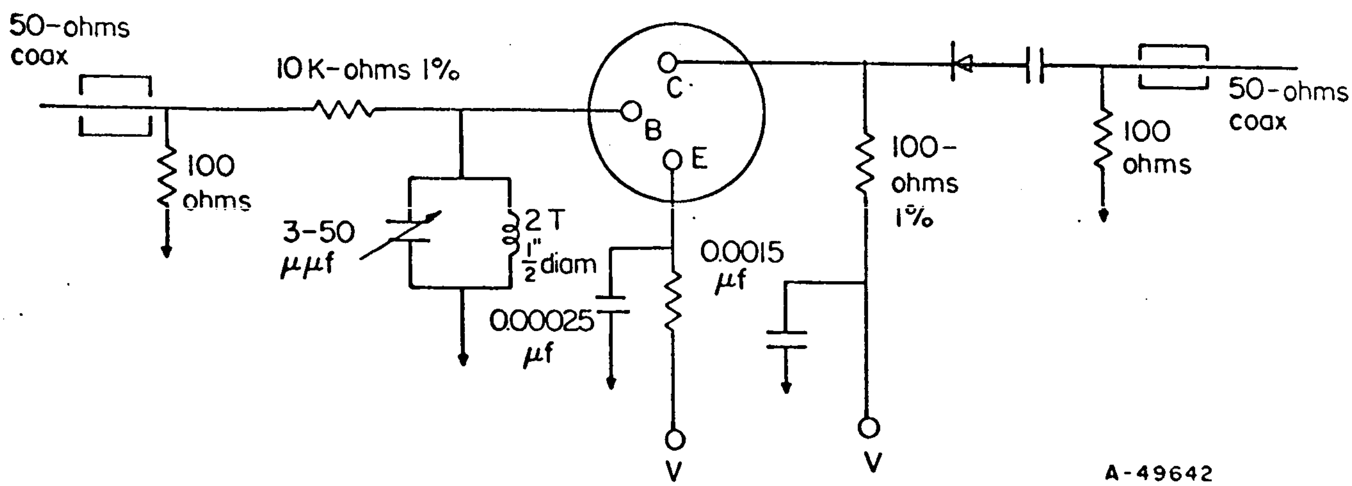


FIGURE 6. CIRCUIT OF TEST UNIT FOR MEASURING h_{fe} AT 100 MC

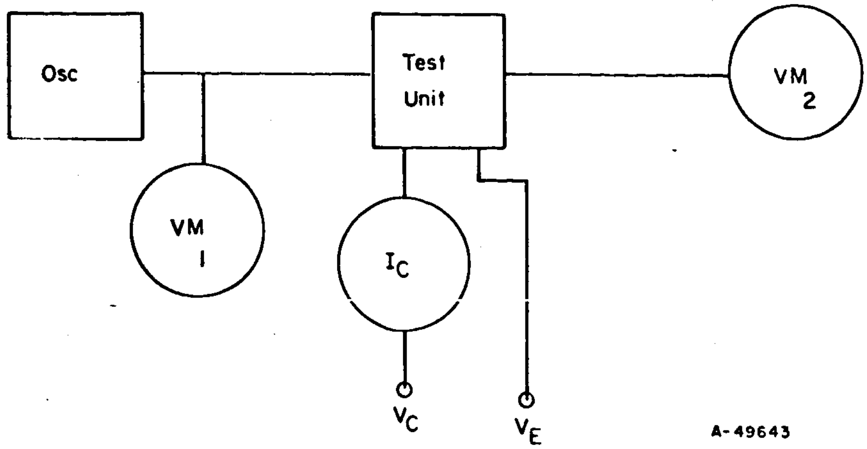


FIGURE 7. CIRCUIT SHOWING ASSOCIATED EQUIPMENT USED IN MEASURING h_{fe}

Associated Equipment Used in Measuring h_{fe} at 1 Kc

Osc. - Hewlett-Packard 200 CD
I 53209
EE Div. No. 847-38

VM 1 - Ballantine Model 300
I-23355
Inst. Lab. No. 705-526

VM 2 - Ballantine Model 300
I-11123
Inst. Lab. No. 5-528

I_C Meter - Weston 280
Inst. Lab. No. C1163

V_E Supply - Transistor Power Supply
I-53148 0-50 vdc

V_C Supply - Transistor Power Supply
I-53149 0-100 vdc

Input Voltage - 0.1 vrms, 1000 cycles

Associated Equipment Used in Measuring h_{fe} at 100 Mc

Osc. - Hewlett Packard 608 D
I47268
EE Div. No. 847-145

VM 1 - Built into 608 D

I_C Meter - Weston 280
Inst. Lab. No. C-1163

VM 2 - Standing Wave Indicator
Hewlett Packard 415 B
I 51334
EE No. 847-161

V_E Supply - Transistor Power Supply
I 53148 0-50 vdc

V_C Supply - Transistor Power Supply
I 53149 0-100 vdc

Cable - RG 58/AU

Input Voltage - 0.35 vrms, 1×10^8 cycles
60% Modulation

until the ammeter, A, indicates the desired current. Voltage drop, V, is then measured. BV_{CBO} is given by this measurement less the drop across R_2, a carefully calibrated series resistor. The estimated accuracy of this measurement is within ±7 per cent.

One sample of each transistor type has been mounted on a card. It is recommended that these samples be maintained as control samples to aid in setting up the measurements at the end of the irradiation test.

Transistor A-C Gain

Transistor a-c current gain, h_{fe}, is measured at either 1,000 cps or at 100 mc. The high-frequency measurement is rather challenging because the gain being measured is really a complex quantity, whose magnitude is to be determined.

The common base configuration of the test transistors is used for d-c biasing, while the transistor operates in the common emitter configuration for a-c signals (see Figures 5-7). The collector-current sensing resistor is 100 ohms, which approximates a short circuit. In the case of the 100-mc measurements this load resistor is paralleled by a diode and 100 ohms in series to provide proper termination for the coaxial line. The inaccuracies introduced by these loads are effectively cancelled by the calibration process as follows:

> The transistor is removed and a jumper inserted in the test socket between base and collector. This is equivalent to a current gain of one for calibration purposes. Then, when the transistor is replaced in the socket, the resulting change in output is the change in current gain.

In each case when a measurement is made or the circuit is calibrated, the high-Q tuned circuit in the base circuit is adjusted for maximum output to assure an effective a-c open circuit. The estimated accuracy of these measurements is ±5 per cent.

Potentiometer Linearity

To determine potentiometer linearity, a plot of ratio versus angular shaft rotation is obtained. This is achieved by driving the potentiometer at exactly 1 rpm while recording the potentiometer output versus time on a Honeywell recorder operating at 10 inches/minute (see Figure 8). Thus, 10 inches on the time base corresponds to 360 degrees of shaft rotation. The estimated accuracy of this measurement is ±0.125 millivolt.

Potentiometer Noise

The circuit of Figure 9 is used to measure potentiometer noise. As can be seen, the potentiometer shaft is motor driven at 5 rpm, and a-c noise is recorded at a sensitivity of 25 mv full scale, which proves to be quite adequate. The input current to the potentiometer is 1 ma, dc. The estimated accuracy of this measurement is ± 0.125 millivolt.

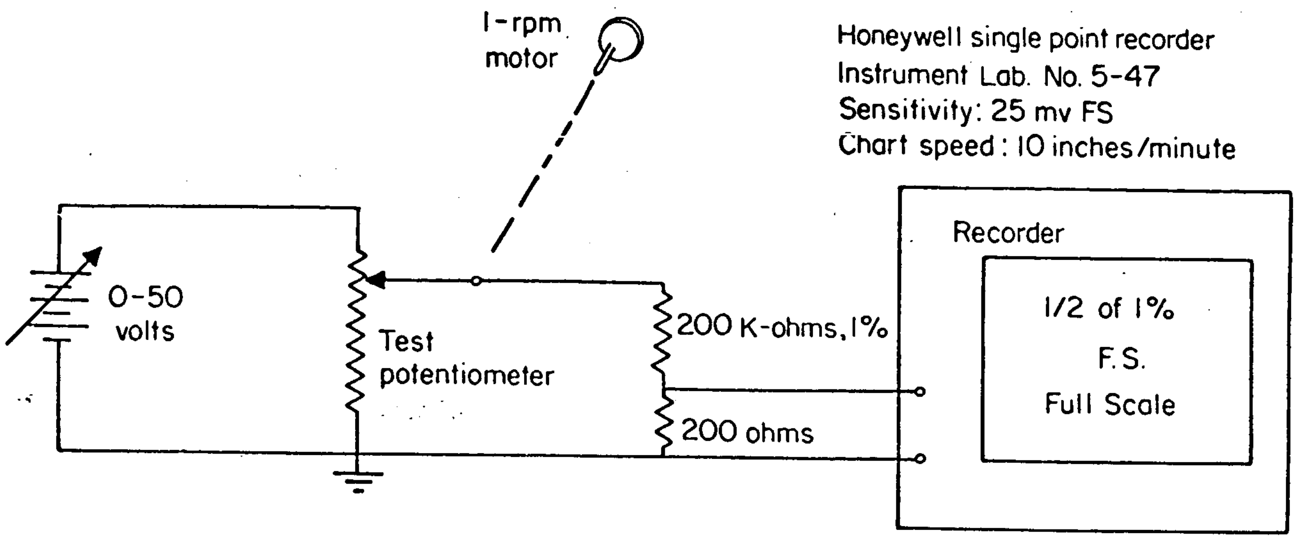


FIGURE 8. POTENTIOMETER LINEARITY TEST CIRCUIT

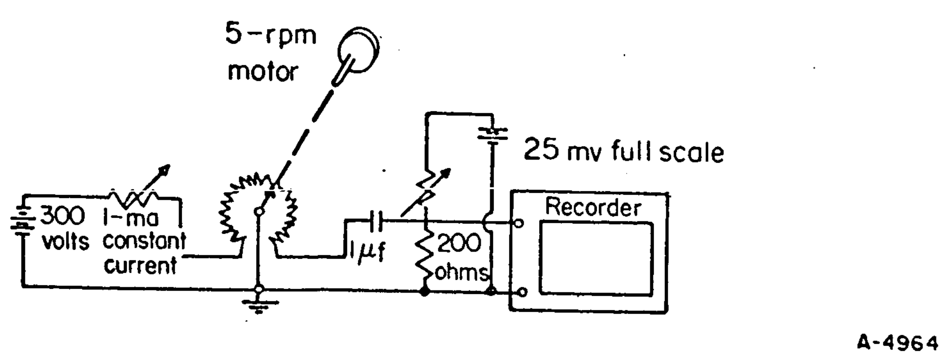


FIGURE 9. POTENTIOMETER NOISE-TEST CIRCUIT

Diode Junction Capacitance

Diode junction capacitance was measured with a Boonton Model 74-CS8 capacitance bridge, with the diode mounted in a General Radio Type 274 plug, modified by the addition of diode clips at the input end of the plug. The estimated accuracy of this measurement is that of the instrument: ± (0.25 per cent + $\frac{1000}{Rp}$ pf + 0.000 pf), Rp being the parallel resistance in ohms.

Resistor Insulation Resistance

The insulation resistance of resistors was measured with an Electronic Instruments Ltd. "twenty million megohmmeter" Model 29A, using a special clip on the resistor body, with the other lead attached to the two resistor leads in parallel. The clip arrangement is to be saved for use on postirradiation measurements. The estimated accuracy of this measurement is 80 per cent at 2×10^{13} ohms, 40 per cent at 1×10^{13} ohms, 20 per cent at 5×10^{12} ohms, and 12 per cent at 3×10^{12} ohms, with 500 vdc applied to specimen.

Switch Contact Resistance

The contact or "on" resistance on the switch was measured by a Leeds and Northrup Kelvin Bridge Ohmmeter No. 4285. During this measurement, the switch was held "on" by a special jig. The estimated accuracy of this measurement is that of the instrument, which is ±0.25 per cent for the range of measurements that were observed.

Switch Activation Pressure

The mechanical pressure required to activate the switch was measured by mounting the specimen in a special jig and slowly applying pressure, using a Chatillon Scale Model PPL-1 until activation was noted (see Figure 10). Readings were taken just after activation; however, this reading was within 0.01 pound of the last reading before activation. The estimated accuracy of this measurement is ±0.01 pound.

Reference Voltage at -55 C

The circuit of Figure 11 is used to measure the reference voltage of the Zener diodes at -55 C. The conditions for measurement are first established by adjusting the voltage source for the required drop across the 1-K-ohm precision resistor with a test specimen placed in the circuit. This adjustment sets the circuit operation to the specified constant current condition. The reference voltage of the diodes is then measured by attaching the leads from the diode to be measured to the circuit and depressing the push-button switch. The reference voltage is read on the digital voltmeter. The estimated accuracy for this measurement is the accuracy of the digital voltmeter, which is ±1 low-order digit.

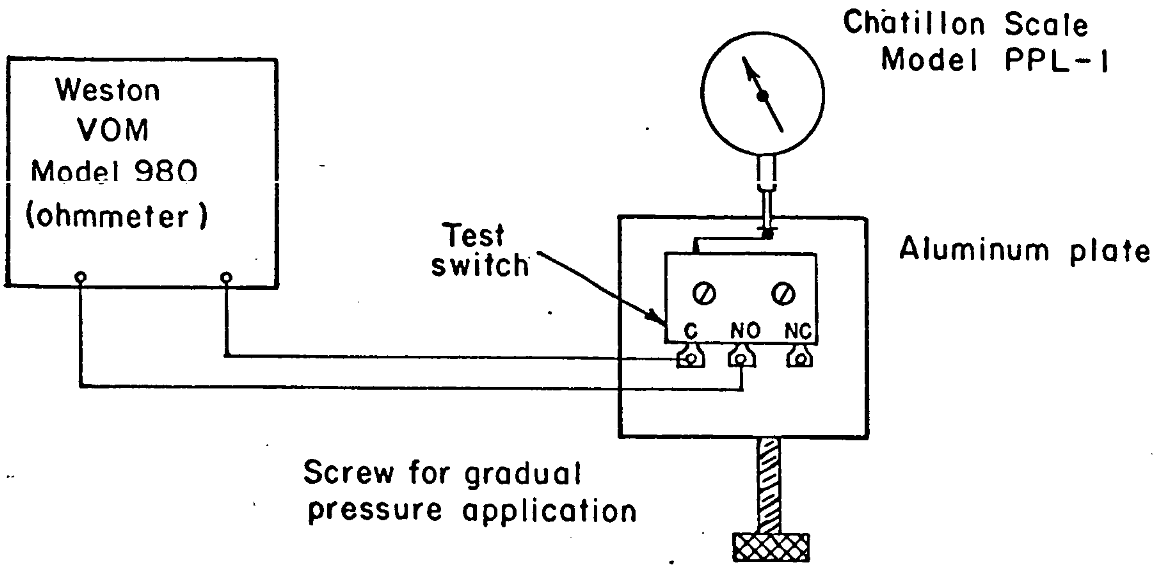


FIGURE 10. JIG AND CIRCUIT FOR MEASURING SWITCH ACTIVATION PRESSURE

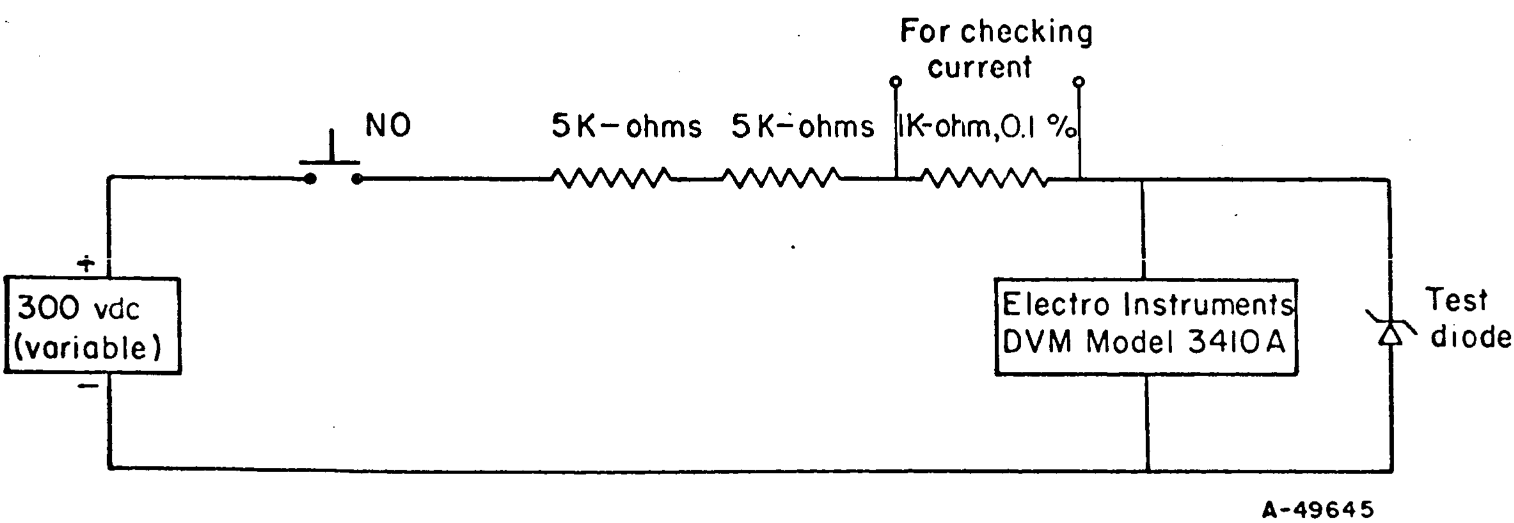


FIGURE 11. CIRCUIT FOR MEASURING V_Z AT -55 C

Measurements Performed With The Automatic Data Recording System

An automatic data-recording system is used to facilate data recording and processing of measurements performed at scheduled intervals during the actual life-test period. The system has several features of special value for this type of application:

(1) Each measurement is punched on a separate data card to retain complete flexibility of processing. The individual cards may be processed in any manner that promises to yield the most significant results.

(2) The system assures proper identification of all data, and accurate entry.

(3) All measurements must be verified by the operator before entry, to assure accuracy.

(4) Test specimens may be put on load immediately prior to measurement to assure that thermal equilibrium is achieved before making critical parameter measurements.

(5) Measurements are made on an Electro Instruments Model 3410-A a-c/d-c digital voltmeter, which features four digits of readout with an accuracy of ±1 digit on d-c and ±2 digits or ±0.1 per cent on a-c.

For measurement of the majority of the parameters, individual parameter-measurement circuits are used in conjunction with the digital voltmeter in the data system. For measurement of some parameters, such as capacitance, measurements are made on separate equipment, after which the data are hand entered onto the punch cards through a manual entry section of the data system. In all cases the data system selects the specimen and enters its identifying number on the punch card.

Normal operating procedures for using the automatic data-recording system when the measured parameter is recorded automatically from the digital voltmeter include:

(1) Connect the circuit box for the desired parameter to the system by plugging it in the space provided.

(2) Connect the system to the electronic parts to be measured through the multiple wire cables and connectors provided.

(3) Adjust the circuit box and system controls to the required measuring conditions.

(4) Switch the system control for automatic operation.

(5) When the measurement control cycle stops at the read or measurement position, check the reading on the digital voltmeter; if the reading is normal push the digital voltmeter lock switch and then the punch command switch.

(6) If the reading is abnormal or questionable for any reason, recycle the system without advancing to another specimen and observe the parameter value or reading obtained.

(7) If the reading is the same or normal, push the digital voltmeter lock switch and then the punch command switch.

This procedure is continued until a particular parameter measurement has been performed on every unit of that part type, whereupon the above is repeated on a similar part with the same circuit box or a new circuit box is connected and a similar procedure is followed for another parameter.

When the measurement is made on separate equipment, rather than with the digital voltmeter, and requires manual entry of the data, the following procedure is followed:

(1) Set up the necessary instrumentation through the data system to obtain automatic selection and identification of the individual specimen as well as other identifying information.

(2) Connect the system to the electronic parts to be measured through the multiple wire cables and connectors.

(3) Measure the parameter, i.e., capacitance and dissipation factor, for capacitors, and gate voltage to fire, breakover voltage, or holding current for silicon controlled switches.

(4) Enter the value or values in the manual data entry panel of the data system and verify this reading on the associated digital readout.

(5) Push the punch command switch and advance to the next specimen.

For a more detailed, step-by-step procedure for each parameter measurement see Appendix A, Circuit Operation Procedure and Check List.

The various measurement circuits used in conjunction with the automatic data-recording system are described below in a simplified fashion. Details are omitted on complexities such as (1) relays, switches, signal lights, etc., which provide communications with the automatic data-recording system, and (2) switching arrangements to provide required bias conditions. The circuit descriptions emphasize the basic method of measurement rather than the complete detailed circuit diagrams, which tend to be confusing.

Leakage Current

The same circuit arrangement is used to measure all of the following leakage parameters:

(1) Capacitor leakage current

(2) Diode reverse current, I_R

(3) Potentiometer element-to-case leakage current

(4) Transistor leakage currents, I_{CBO}, I_{EBO}, and I_{CES}

(5) Connector pin-to-pin and pin-to-case leakage current

(6) Relay-insulation leakage current

(7) Transformer-insulation leakage current

(8) Switch open-position leakage current.

A switching arrangement is used to connect the measurement circuit to the correct terminals and to provide the correct voltage polarity. Provision has been made for shorting the base to the emitter for I_{CES} measurements. The supply voltage is set to the specified value by the operator. For each specimen, the following sequence operates automatically:

(1) Charge the specimen through a 1-K-ohm resistor for a fixed time interval.

(2) Connect measurement shunt.

(3) Delay a fixed interval for stabilization, then lock the digital voltmeter.

(4) Operator verifies reading, and recycles the charge and delay process if needed.

(5) Discharge specimen.

(6) Punch data, and proceed to next specimen.

The measurement shunts used are 1 megohm, 100 K-ohm, 10 K-ohm, and 1 K-ohm, all ±0.1 per cent (see Figure 12). The shunt is selected so that its IR drop will be less than 1 volt, which keeps the applied voltage within 1 volt of the specified voltage. With the digital voltmeter to be used, the circuit sensitivity will range down to about 0.005 μa. Additional sensitivity would not be justified because of the stray leakage paths between the instrumentation and the specimen. Voltmeter loading of the measurement shunts is negligible. In order to eliminate the effects of a-c pickup in the leads running to the specimens, a 1-μf capacitor is used across the two highest valued shunts. These capacitors were removed after 4000 hours as possible contributors to the catastrophic failure of semiconductor components. The data system is arranged to automatically provide correct decimal location as shunts are changed, thereby reducing the chances for operator error.

The estimated accuracy of this measurement is +5, -1 per cent with a minimum reading of 2 to 4 nanoamperes. It should be noted that, if and when a test specimen degrades as to its leakage current parameter and the current increases into the high milliampere range, a loss of accuracy occurs due to the amount of voltage drop across the 1 K-ohm ± 0.1 per cent current sensing resistor.

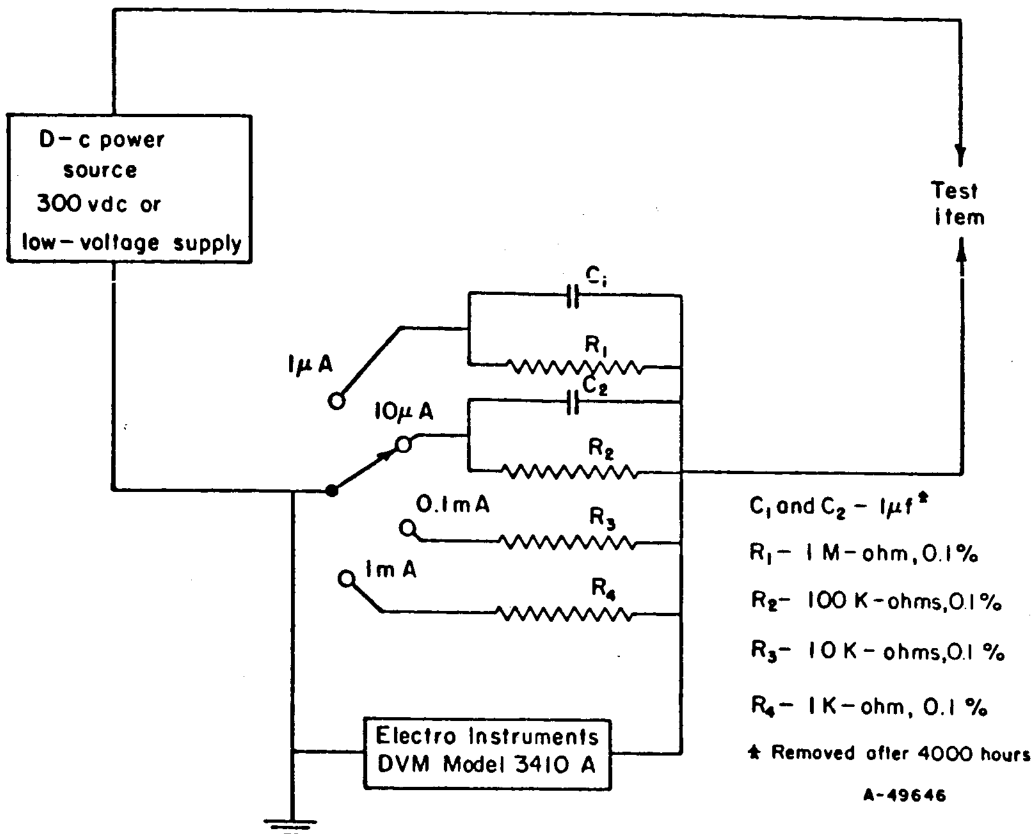


FIGURE 12. BASIC CIRCUIT FOR MEASURING LEAKAGE CURRENT

Capacitance and Dissipation Factor

The capacitance and dissipation factor of the capacitors are measured on a General Radio Type 1611-B capacitance test bridge with an external 400-cps oscillator and filter for the nonelectrolytic capacitors. The internal filter for 120 cps and a 120-cps signal are used to measure the electrolytic types. Data are hand entered, using the card identification feature of the automatic data system as well as the specimen selector, although sequencing of measurement operations is manual. The estimated accuracy of the capacitance measurement is ±2 per cent, while that of the dissipation factor is approximately ±(2 per cent of dial reading +0.05 per cent x f/60 dissipation factor) +0.12 D. F.

Diode Voltage Drop

The same circuit arrangement is used for measurement of both diode forward drop, V_F, and Zener voltage, V_Z (see Figure 13). A switching arrangement is used to assure proper bias-current polarity. The more critical measurement, Zener voltage, is performed with separate current-carrying leads and voltage-pickup leads to minimize the effects of lead resistance (see Figure 13).

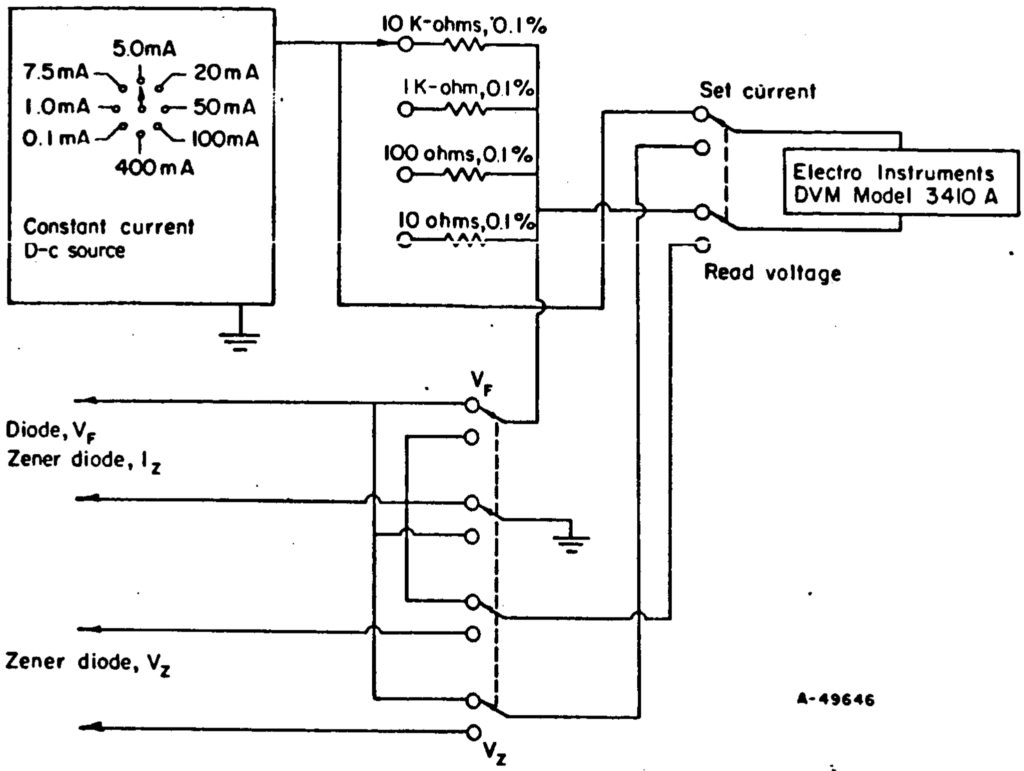


FIGURE 13. BASIC CIRCUIT FOR MEASURING FORWARD VOLTAGE DROP, V_F, AND ZENER VOLTAGE, V_Z

The current bias is provided by a 500-volt constant-current source, and is set by monitoring with ±0.1 per cent precision resistors and the digital voltmeter. The automatic-measurement sequence allows for an adjustable warm-up time interval under measurement bias conditions prior to recording the measurement. Actual voltage readings are made with the digital voltmeter.

The estimated accuracy of the forward-voltage-drop measurement is ±(1 per cent ±1 digit). The estimated accuracy of the Zener voltage measurement, due to the separate current-carrying leads, is that of the digital voltmeter, ±1 digit.

Zener-Diode Dynamic Resistance

The dynamic resistance, Z_Z, of Zener diodes is the a-c resistance of the diode when in Zener breakdown. A block diagram of the measurement circuit for this parameter is shown in Figure 14. The undesired a-c flow through the constant d-c source is negligible because of the very high impedance of this source compared with the low impedance of the Zener diode. Separate voltage-pickup leads are employed so that lead resistance going to the specimen will not enter into the reading. The estimated accuracy of this measurement is ±5 per cent.

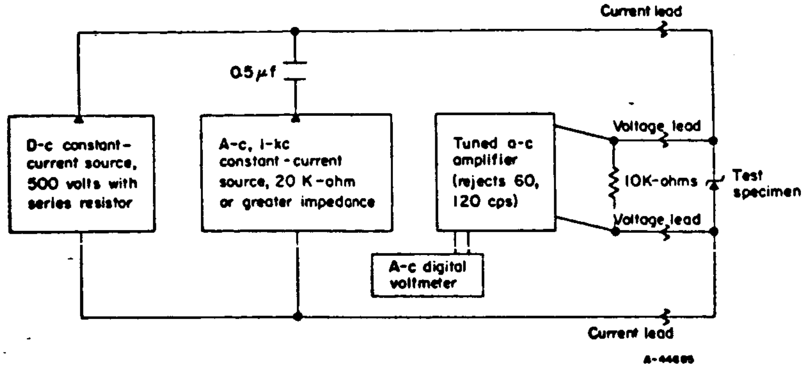


FIGURE 14. CIRCUIT FOR ZENER DIODE DYNAMIC RESISTANCE

Silicon Controlled Switch, 3N58

Measurement of the special parameters, V_G for turn-on, V_{BO}, and I_H of the silicon controlled switch, call for operations that can be most efficiently performed manually. These measurements are performed using the specimen-selection and data-card identification functions of the automatic data system, but with manual sequencing. The voltmeters and ammeters are specially calibrated analog meters rather than the data-system digital voltmeter.

To measure V_G for turn-on, the circuit of Figure 15 is used. The anode voltage is first applied by closing Switch S_1, which charges the 10-μf capacitor, providing a slow build-up of anode voltage. If the 40-volt bias were applied directly, premature firing might result. The gate voltage is gradually increased until firing is indicated by a sudden change in voltmeter reading. Gate voltage for turn-on is that voltage on the meter just prior to the jump.

The estimated accuracy of this measurement is ±2 per cent with a calibrated meter.

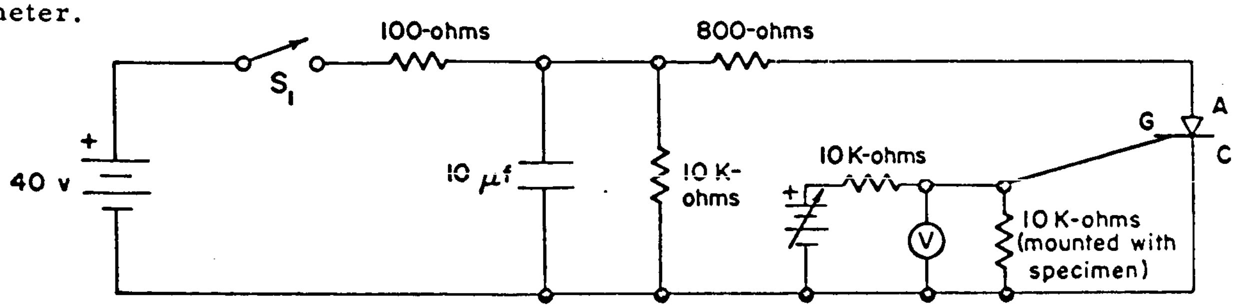


FIGURE 15. CIRCUIT FOR V_G TURN-ON

For measurement of breakover voltage, V_{BO}, the circuit of Figure 16, is employed.

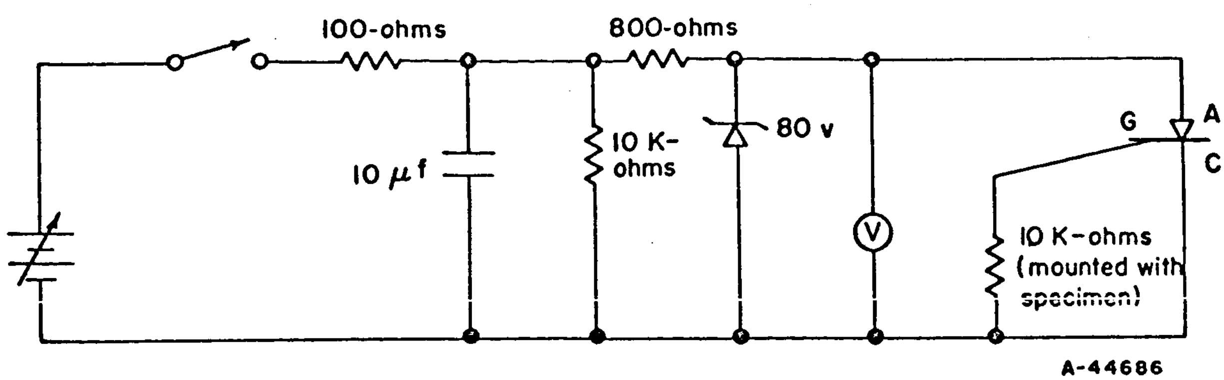


FIGURE 16. CIRCUIT FOR V_{BO}

The anode voltage is increased until firing is noted by a sudden drop in the voltmeter reading. Breakover voltage is that voltage on the meter just before the drop occurs. To prevent damage to the test specimen, no tests will be run at voltages greater than 80 volts. This voltage protection is assured by an 80-volt Zener diode. The estimated accuracy of this measurement is ±2 per cent with the calibrated meter.

The holding current, I_H, is measured by the circuit of Figure 17.

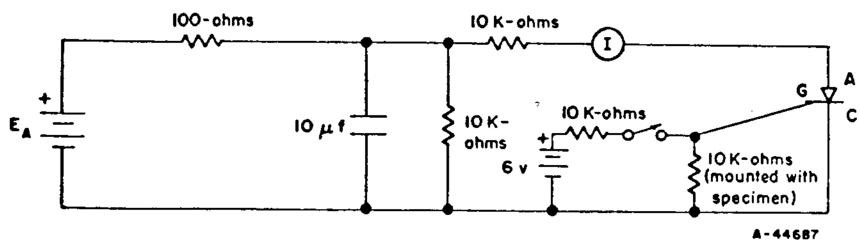


FIGURE 17. CIRCUIT FOR I_H

With voltage E_A at 40 volts, the switch is momentarily closed to fire the test specimen. Then E_A is decreased slowly until the anode current suddenly drops to zero. The holding current is the current just before this drop occurs. The estimated accuracy of this measurement is ±3 per cent.

Resistance

The resistance of the resistors and potentiometers is measured by applying a 0.1-ma test current from a constant-current source consisting of a regulated 300-volt supply with a 3-megohm series resistor. Current is monitored across a 5 K-ohm ± 0.1 per cent precision resistor. The resistance reading is obtained by reading the voltage across the specimen resistor using the digital voltmeter (see Figure 18). The estimated accuracy of this measurement is ±(0.5 per cent ±1 digit).

Relay, Voltage to Close

The voltage required to close the relay will be measured by manually increasing the coil voltage until contact closure is noted. The voltage will be measured just after

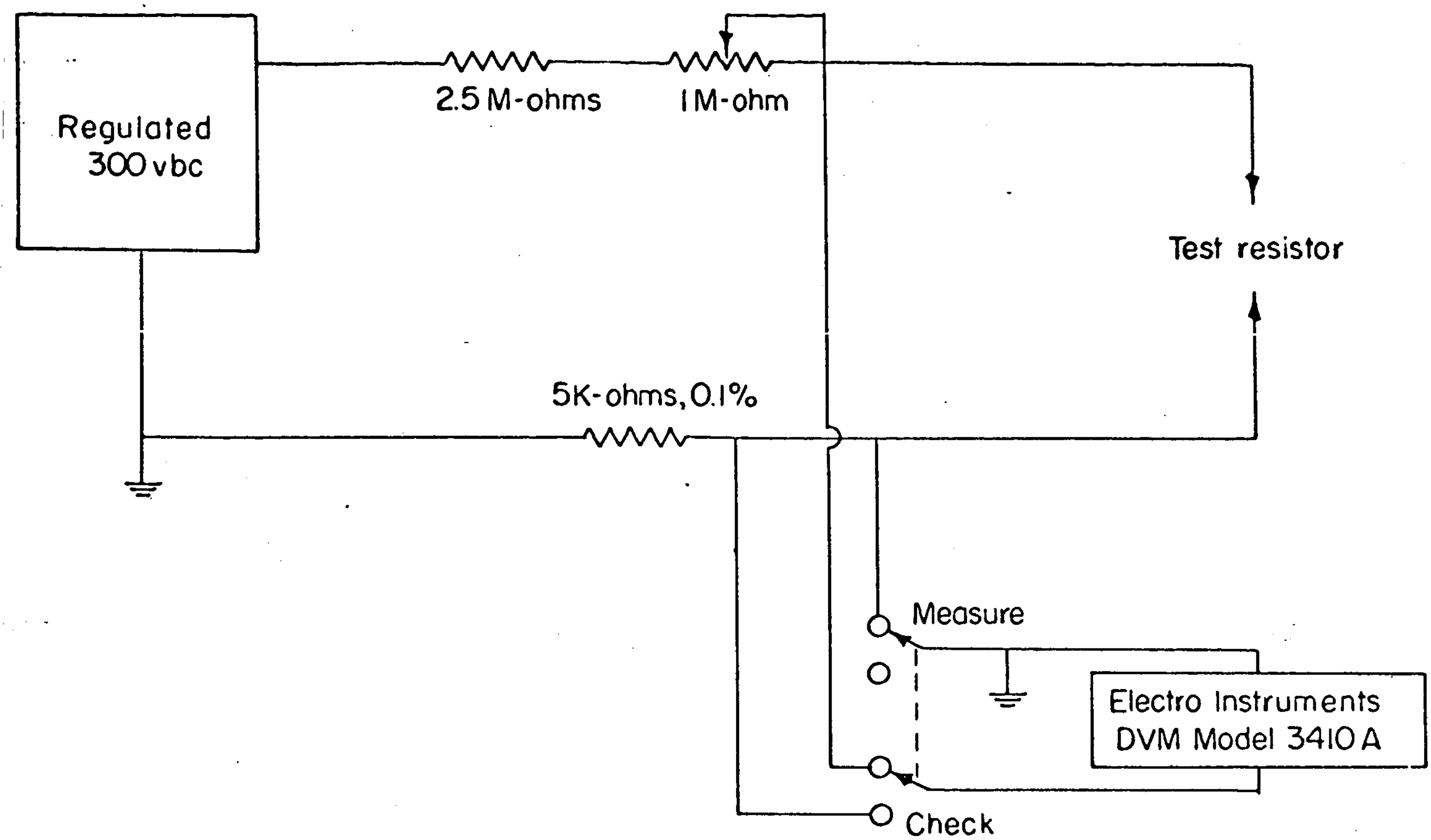


FIGURE 18. BASIC CIRCUIT FOR MEASURING RESISTANCE OF RESISTORS AND POTENTIOMETERS

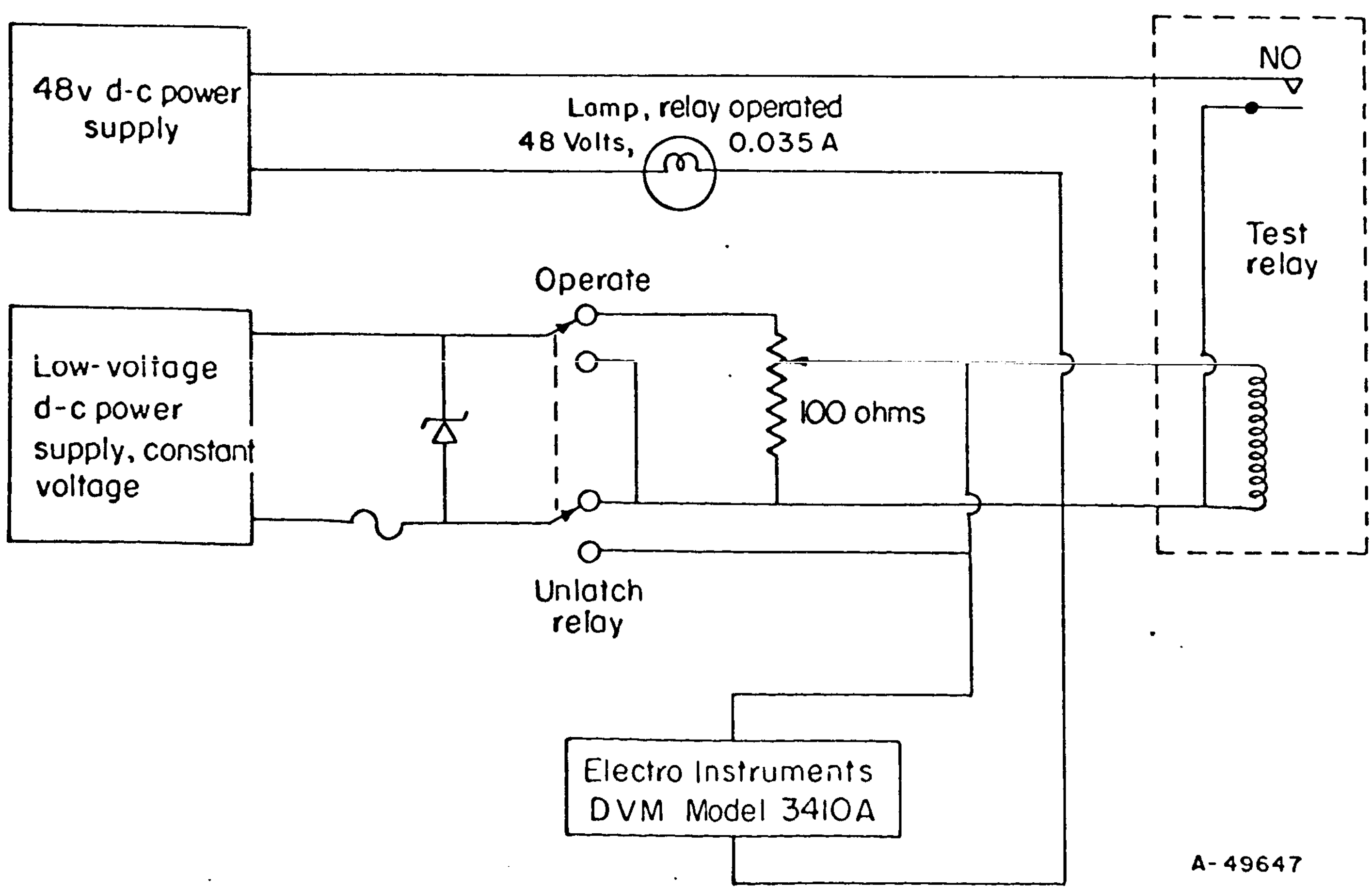


FIGURE 19. BASIC CIRCUIT FOR MEASURING VOLTAGE TO CLOSE RELAY

closure is obtained, using the digital voltmeter. Then the relay will be unlatched prior to proceeding to the next specimen. A Zener diode is used to prevent the accidental application of excessive voltage to the relay coil (see Figure 19). The estimated accuracy of this measurement is ±(2 per cent ±1 digit).

Transformer Excitation Current

Transformer excitation current is measured with the secondary open by application of a 35-volt rms signal at 400 cps to the primary and measuring the resultant current by use of a 1 K-ohm ± 0.1 per cent shunt and the a-c digital voltmeter (see Figure 20). The estimated accuracy of this measurement is ±(2 per cent ±2 digits).

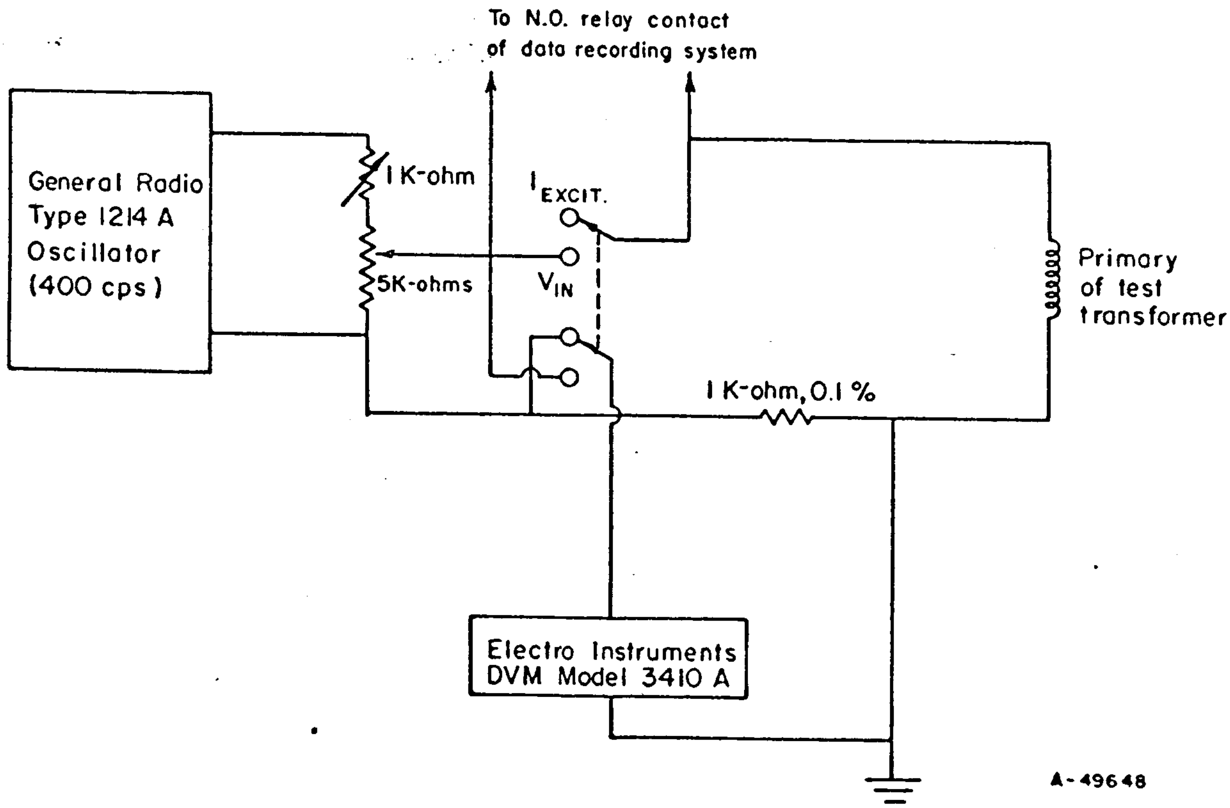


FIGURE 20. BASIC CIRCUIT FOR MEASURING EXCITATION CURRENT OF TRANSFORMERS

Transistor Saturation Voltage

Transistor saturation voltage, $V_{CE(SAT)}$, is the collector-to-emitter voltage when specified base and collector currents are flowing. Constant-current sources are used to supply the specified bias currents. The base current is driven at 10 volts, and the collector current is driven at 300 volts with appropriate series resistors. A Zener diode limits the voltage applied to the transistor to 12 volts. The collector-current relay is interlocked in such a manner that it cannot be activated unless the base-current relay has been activated.

Saturation voltage is measured by the digital voltmeter, using separate voltage pickup leads going to the specimen. Since these voltage leads carry negligible current, their IR drop is not significant. Current is supplied through separate leads (see Figure 21). The estimated accuracy of this measurement is that of the digital voltmeter which is ±1 digit.

Transistor h_{FE}

During the initial stages of this program, i.e., Group Measurements 01, 02, and 03 of Test Group 4 in Figure 1, a Battelle constructed unit was used to measure transistor d-c current gain, h_{FE} (see Figure 22). The operator adjusts I_B until the specified I_C is obtained. The specified collector current for a particular test, flowing through resistor R_C, develops a collector output voltage, E_C, as indicated. The base current required to produce this specified collector current, flowing through R_B, produces the base output voltage, E_B. The collector and base output voltages (E_C and E_B) are amplified by separate amplifiers with gains of 100 and are applied to diode peak detectors as shown. A pulse transformer that acts as a voltage sensor and also provides isolation so that the collector output may be referenced to ground is connected across the collector resistor R_C and the input to the amplifier. The transformer is provided with a potentiometer R, which is adjusted to yield an effective turns ratio of 1:1.

It should be mentioned that h_{FE} is actually the ratio of the collector current to base current. However, since the ratio meter used for these measurements will not read ratios greater than 0.9999, the reciprocal of h_{FE} ($1/h_{FE}$) must be read with this instrumentation. The results from this equipment are inverted during data processing.

Since the denominator input of the digital ratio meter has a relatively low impedance (100 K-ohms), it is fed from the 10 K-ohm end of the 90 K-ohm and 10 K-ohm voltage divider, thus reducing loading effects. The base voltage output, or numerator, is supplied from a variable voltage divider, where the resistor R_X is selected to produce the proper gain ratio between the collector and base circuits, thus compensating for the inequality of the resistors R_C and R_B.

In actuality, the h_{FE} measuring instrument is much more complex than this simple description indicates. All of the measurements made are pulse measurements, using a pulsed signal in the base circuit with a repetition rate of approximately 67 and a pulse length of 30 μsec (2 per cent duty cycle). The amplifiers are, therefore, a-c coupled pulse amplifiers designed to operate with pulsed signals only.

Since a wide range of transistor types are being tested under a wide range of bias conditions, a large number of values of resistors R_B and R_C are required to establish the necessary test conditions for each transistor type and to assure that the signal level to the amplifiers will yield linear operation. Each combination of the Resistors R_C and R_B requires a different value for the Resistor R_X to establish proper gain ratio, as previously mentioned. The R_X resistors are selected automatically for all combinations of R_C and R_B by a somewhat involved switching arrangement, making use of a specially constructed 17-position, 17-pole rotary selector switch. This switch selects values of R_X so that the ratio of the numerator to denominator output voltage is either $1/h_{FE}$ or $10/h_{FE}$, as desired.

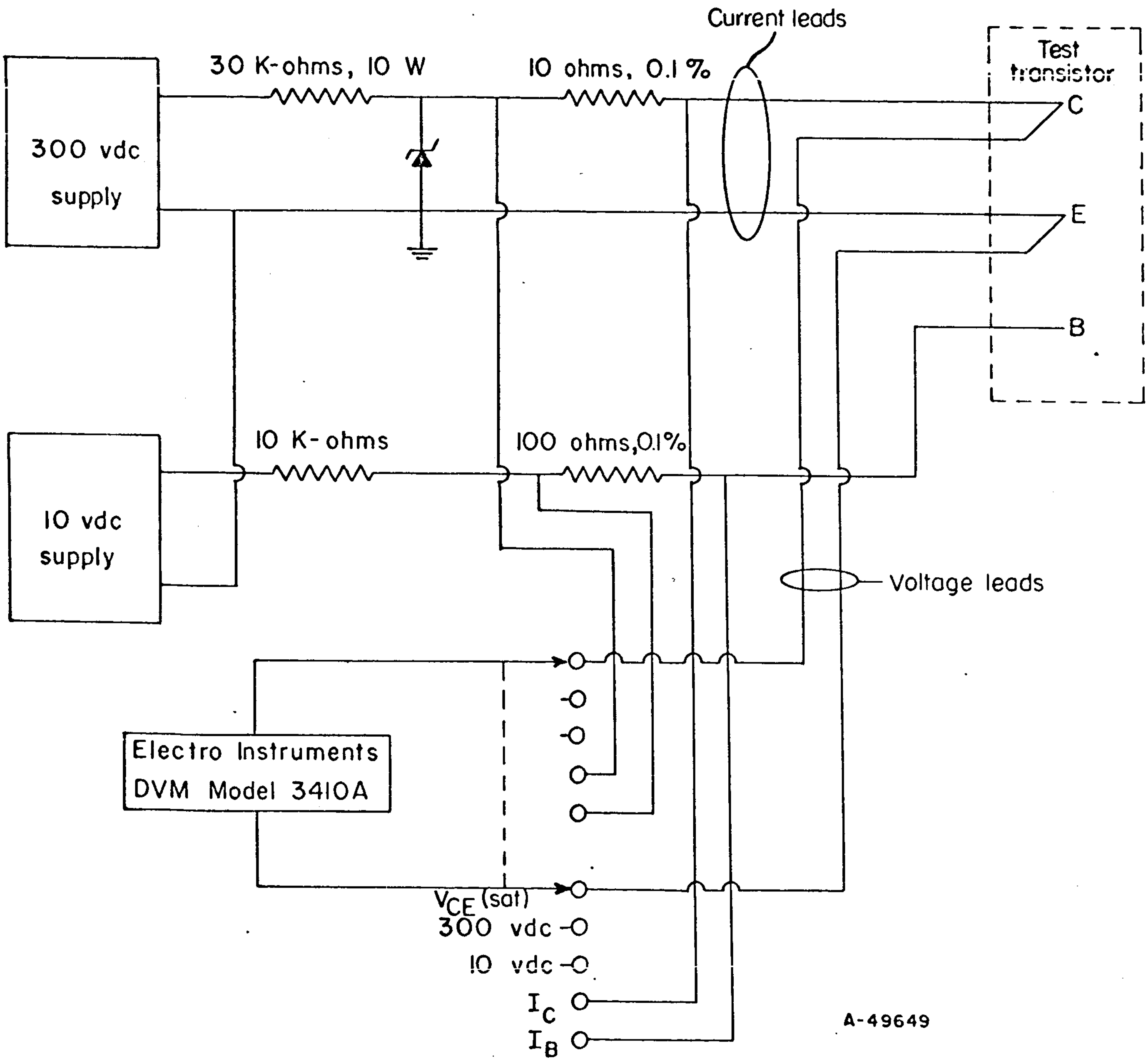


FIGURE 21. BASIC CIRCUIT FOR MEASURING TRANSISTOR SATURATION VOLTAGE, $V_{CE\ (sat)}$

Note: Current-limiting resistors are those used for the 2N911 and will vary between transistor types.

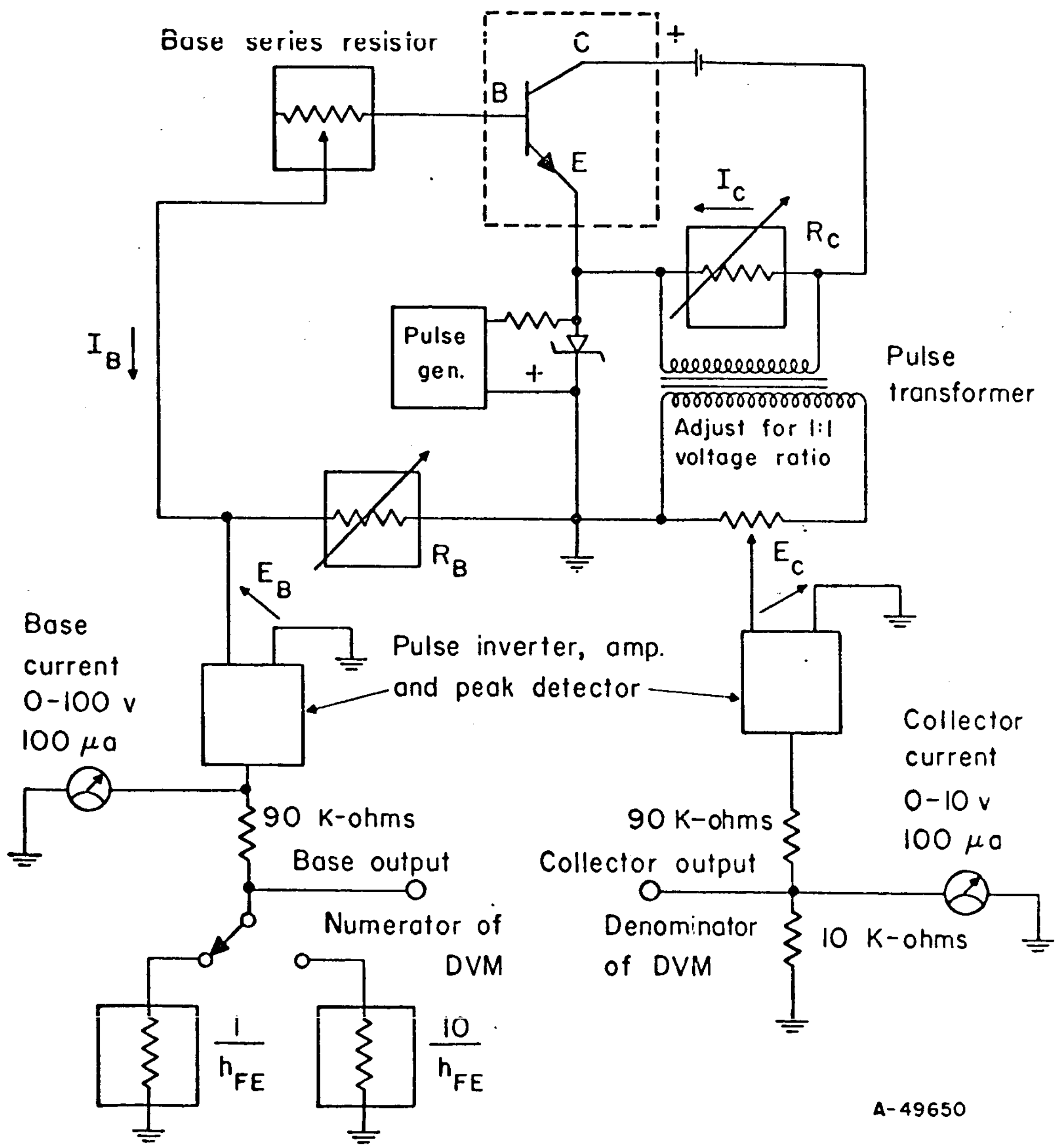


FIGURE 22. CIRCUIT FOR MEASURING PULSED D-C GAIN, h_{FE}

The best estimation of the accuracy of this instrumentation is ±10 per cent, but due to difficulties during its operation for the measurement periods mentioned above, the error factor may even be greater than this for some of the data that were obtained. Therefore, this instrumentation was replaced with a Fairchild Semiconductor (Instrumentation), digital readout h_{FE} tester, Model 50, prior to the initial measurements or measurement Group 01 for Test Groups 01, 02, 03, 05, 06, and 07, and Measurement Group 04 for Test Group 04.

The Fairchild Model 50 h_{FE} tester has been incorporated into the automatic data-recording system for the purpose of selecting individual specimens and to provide the necessary identifying information. A relay buffer unit provides for direct punching of the digital h_{FE} output into the data punch cards. The estimated accuracy of the h_{FE} measurements using the Fairchild Model 50 h_{FE} tester is that of the instrument, ±2 per cent.

Photomultiplier Anode Current

The photomultiplier anode current was measured manually with the circuit shown in Figure 23 with a source voltage of 1500-volts dc. The instrument used for measuring the current was a Keithley electrometer, Model 210, and a Keithley decade current shunt. The estimated accuracy of this measurement is ±5 per cent based upon the electrometer accuracy and the precision of the shunt.

Fiber-Optic-Disc Light Transmission

The light transmission of the fiber optic discs was measured from 2800 to 5500 A, using a Beckman Model DU spectrophotometer. One of the ten specimens was used as a control sample or standard disc to provide a calibration check of the spectrophotometer. The accuracy of the light-transmission measurements is estimated to be within 0.1 per cent, the accuracy of the spectrophotometer.

Cadmium Sulfide Cell Voltage

The cadmium sulfide cell voltage was measured manually, using the circuit shown in Figure 24a with both bright and dim illumination. A Keithley electrometer, Model 210, was used in measuring the voltage drop across the cells. The estimated accuracy of this measurement is that of the electrometer, ±3 per cent.

Cadmium Sulfide Cell Resistance

The resistance of the cadmium sulfide cells was calculated from measurements of the current in the circuit shown in Figure 24b. A Keithley electrometer, Model 210, with a Keithley decade current shunt unit was used for measuring the current. Using the current value thus obtained, the total resistance of the circuit was calculated. The sum of the decade shunt resistance and the 1 K-ohm dropping resistor was then subtracted from the total resistance for the resistance value of the cadmium sulfide cell. This procedure was followed for measurements with dim and bright illumination. The estimated accuracy of this measurement is approximately ±8 per cent.

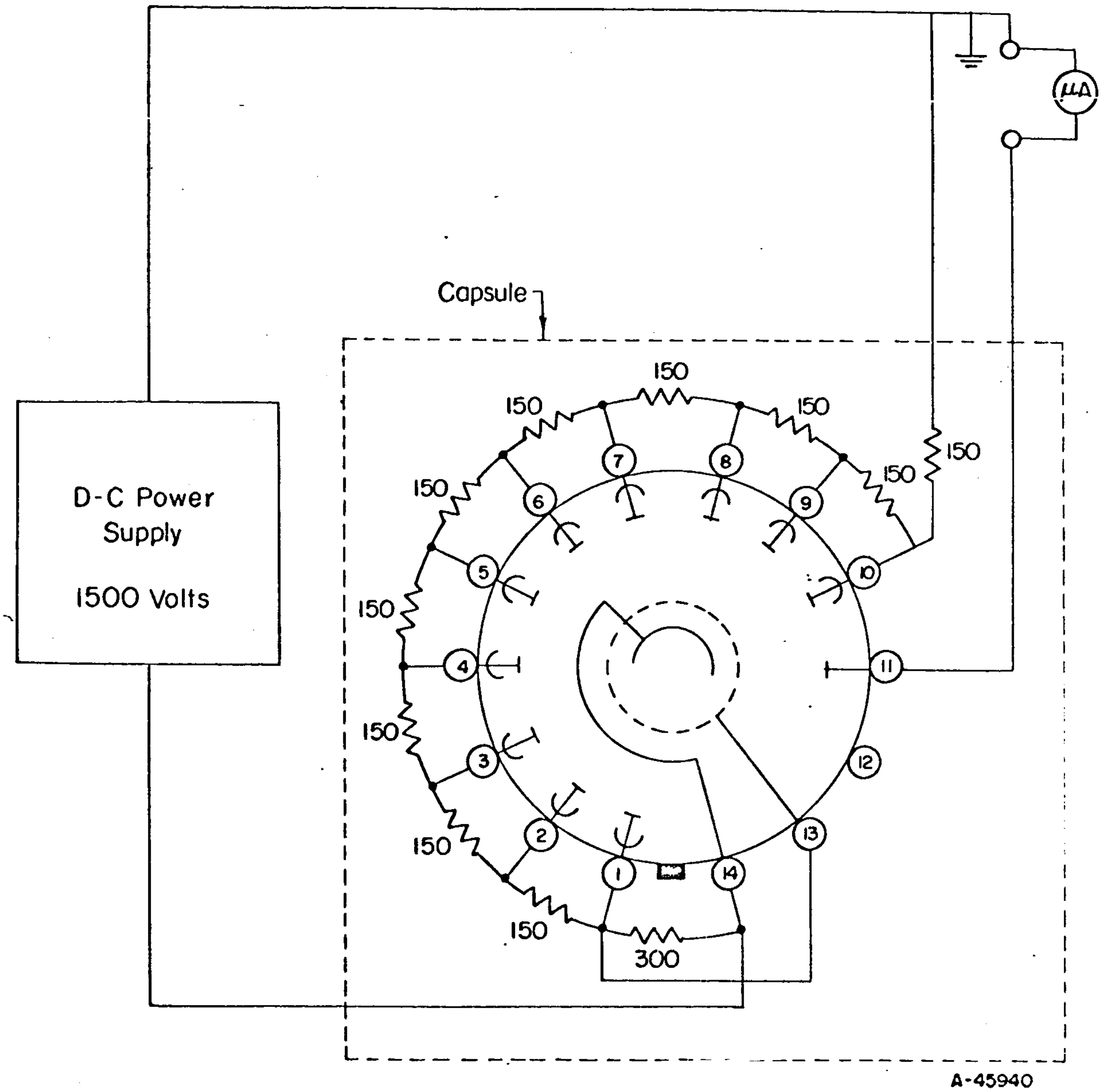


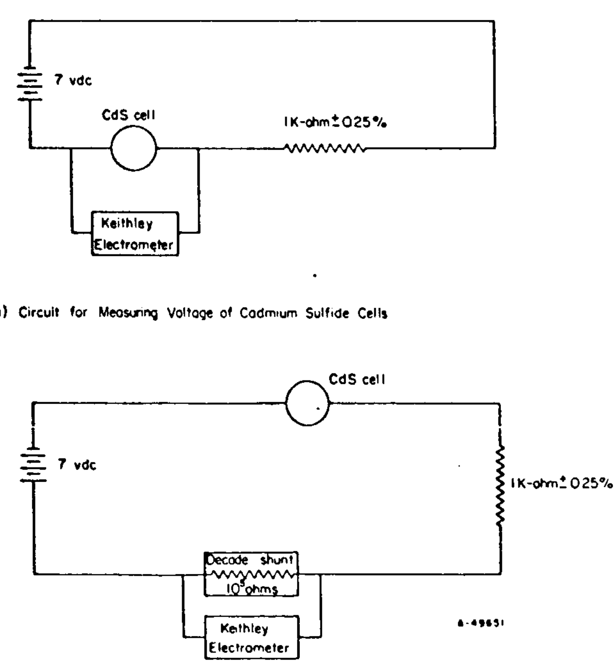
FIGURE 23. DIAGRAM OF CIRCUIT USED FOR MEASURING THE LIGHT AND DARK CURRENTS OF THE PHOTOMULTIPLIER TUBES

All resistor values are in K-ohms.

TABLE 3. TEST ENVIRONMENTS

Test Group	Temperature, C	Pressure	Radiation
1	100	760 torr	None
2	100	10^{-5} torr	None
3	100	10^{-5} torr	3×10^5 n cm^{-2} sec^{-1} 1×10^5 ergs g^{-1}(C) hr^{-1}
4[(a)]	100	10^{-5} torr	3×10^7 n cm^{-2} sec^{-1} 1×10^7 ergs g^{-1}(C) hr^{-1}
5	50	10^{-5} torr	3×10^5 n cm^{-2} sec^{-1} 1×10^5 ergs g^{-1}(C) hr^{-1}
6[(b)]	100	10^{-5} torr	3×10^5 n cm^{-2} sec^{-1} 1×10^5 ergs g^{-1}(C) hr^{-1}
7[(b)]	100	760 torr	None

(a) Group 4 was irradiated at the indicated levels for 100 hours, and then no radiation for the 10,000 hours of life test.
(b) Groups 6 and 7 are non-operating or static-load conditions with environmental conditions identical to Groups 3 and 1, respectively.



(a) Circuit for Measuring Voltage of Cadmium Sulfide Cells

(b) Circuit for Measuring Current to Calculated Resistance of Cadmium Sulfide Cells

FIGURE 24. CIRCUITS USED IN MEASURING ELECTRICAL CHARACTERISTICS OF CADMIUM SULFIDE CELLS

DESCRIPTION OF ENVIRONMENTS

Descriptions of the environments, including the combination of conditions and the tolerances on these conditions, are presented in this section of the report. In addition, the controls and records that are maintained and methods of measurement and their accuracy are described.

General

For the purpose of simulating a nuclear-electric spacecraft environment and for assessment of the interaction of various environmental constituents, with the exception of the CBS-7817 photomultipliers, the Clairex CL-605 CdS cells, and the fiber optics, the various electronic part types were divided into three to seven test groups (as indicated in Figure 1 and Table 1). These groups are being subjected to the environmental conditions shown in Table 3.

The photomultiplier, CdS cells, and fiber optics were not subjected to the conditions of Table 3. Instead, they were irradiated in a cobalt-60 gamma source. The gamma exposure rate was 1.04×10^6 ergs g^{-1}(C) hr^{-1}, with the CdS cells being exposed for 1000 hours. The photomultiplier and fiber optics were also to be exposed for 1000 hours, but the test was discontinued after 200 hours due to the large percentage of failures observed. The ambient temperature for these tests was approximately 15 to 20 C, and the test specimens were at normal atmospheric pressure.

Vacuum System

The high-vacuum facilities are designed for continuous operation in a radiation environment at 10^{-5} mm Hg. Basic equipment for each system consists of a 6-inch diffusion pump (maximum unbaffled pumping speed is 1500 liters/sec at pressures less than 1×10^{-3} torr) and a 14-liters/sec forepump. Use of a 6-inch chevron-plate baffle, located immediately above the diffusion pump, maintains back streaming of pumping-fluid vapors at a minimum. A 6-inch pneumatic valve is mounted between the baffle and test section, thus providing protection to both the pumps and specimens in case of mechanical and/or electrical failure. All piping is nominal 6-inch-ID aluminum except for the specimen chamber, or test section, which has a 12-inch ID.

The evacuated chamber, which contains the test specimens, is 40 inches long and is approximately centered at the 28-inch-diameter fission plate on the horizontal thermal column of the Battelle Research Reactor. System pressure is monitored by Nottingham-type ionization gages placed both at the test section proper and approximately 14 feet above the test section. The 3/4-inch-thick aluminum top plate is drilled to accept 37-pin hermetically sealed receptacles used to gain electrical access to the components. Two of the systems have 26 of these receptacles each (962 electrical leads), and one system has 36 receptacles (1312 electrical leads). The "brackets" on which specimens are to be mounted are suspended from the 3/4-inch-thick aluminum plate containing the receptacles. A resistance-type electrical heater wrapped in a helical fashion surrounding the component brackets is used to maintain the prescribed environmental temperature. Copper-constantan thermocouples are placed in strategic locations to provide temperature data and temperature control.

With one of the systems at room temperature and void of test specimens, pressure-versus-time data were obtained. A 24-hour pump-down period resulted in a vacuum of 6.7×10^{-6} torr in the volume where the test specimens are now located and 1.6×10^{-6} torr at a location 14 feet above the test section.

The purpose of the two points for measuring the vacuum obtained is to provide a reference between the vacuum in the test section and the pipe section 14 feet above the test section. By establishing this reference prior to the radiation-induced failure of the test-section ionization gages, the approximate degree of vacuum at the test section may be estimated at later intervals during the test by comparing the pipe-section readings to values obtained before the gages failed. The estimated accuracy of the vacuum measurements is + a factor of 2, - a factor of 10. Vacuum measurements are performed and recorded twice daily.

No tolerance has been established for the vacuum environment. The over-all design goal was 1×10^{-5} or better; however, it was doubtful from the beginning that this degree of vacuum could be obtained with the outgassing expected from the electronic test parts and the wiring within the chambers. Therefore, the vacuum-environment tolerance was left at whatever could be obtained.

Temperature

The chamber for the 100 C, atmospheric-pressure test group, i.e., Test Group 1, is a Blue M, Model POM-1406CX, environmental chamber with an over-temperature control. No cycling of the temperature above and below the control point occurs with this chamber according to the manufacturer.

Temperature control for the 100 C vacuum chambers, including the radiation capsules, is provided by Foxboro Type 4041-40 units. The over-all tolerance or temperature range for these 100 C chambers is 100 C + 0, - 7 C.

The temperature of the 50 C vacuum environment chamber is actually maintained at 60 C by the heat from the power dissipated by the test specimens, and no additional heating is being provided at this time. The over-all tolerance for this environmental condition is, therefore, - 10 C, + 3, for the 60 C temperature.

The temperature is monitored by copper constantan thermocouples in each of the five chambers being used in the 10,000-hour life test. The temperatures are checked periodically, every 100 hours or less, but no record is kept of these measurements. The estimated accuracy of these temperature measurements is ±1 per cent.

Nuclear Dosimetry

This section summarizes the nuclear environmental measurements in mock-ups of the irradiation facilities. The mock-up dosimetry consisted of measurements of fast-neutron and resonance-neutron energy spectra and neutron flux and gamma exposure-rate distributions. Two sets of nuclear environmental conditions were monitored in accordance with the desired test environments specified in JPL Test Procedure 617.

Nuclear measurements were performed in one mock-up to determine the position of a test facility that would result in a total fast-neutron flux of 3×10^7 n cm^{-2} sec^{-1} and a gamma exposure rate of 1×10^7 ergs g^{-1}(C) hr^{-1}. This location will be referred to as the "high flux" position. In addition, two mock-ups were positioned to give a total fast-neutron flux of 3×10^5 n cm^{-2} sec^{-1} and a gamma exposure rate of 1×10^5 ergs g^{-1}(C) hr^{-1}. The location of either of these mock-ups is referred to as the "low-flux" position. The mock-ups were surrounded with 0.020-inch-thick cadmium sleeves in order to reduce the thermal-neutron flux so that induced radioactivity will be minimized.

The measured volume-averaged fast fluxes and gamma exposure rates for the high- and low-flux positions are summarized below. The uncertainties are estimated as ±20 per cent for the high-flux and ±15 per cent for the low-flux neutron exposure values. The uncertainties are estimated as ±5 per cent for the gamma values.

	High-Flux Location	Low-Flux Location	
	Mock-Up No. 1	Mock-Up No. 2	Mock-Up No. 3
Fast flux (n cm^{-2} sec^{-1})	2.80×10^7	2.82×10^5	3.34×10^5
Gamma exposure [ergs g^{-1}(C) hr^{-1}]	(a)	1.04×10^5	1.06×10^5

(a) See text.

Fast-Neutron Flux and Energy Spectrum

The fast-neutron energy range extends from 0.1 Mev to 18 Mev. The threshold-detector method was used to determine the total fast-neutron flux and integral fast-neutron energy spectrum. In this technique various threshold detectors are irradiated in the same flux, and the total neutron flux above each threshold is determined from the induced activities. The radioactivants that were used and their effective threshold energies and cross sections are listed in Table 4.

TABLE 4. FAST-NEUTRON THRESHOLD DETECTORS

Reaction	Energy Threshold	Cross Section, barns
Pu^{239} (n, f)	4 Kev	2.0
In^{115} (n, n) In^{115m}	1.4 Mev	0.299
Ni^{58} (n, p) Co^{58}	2.5 Mev	0.226
S^{32} (n, p) P^{32}	2.9 Mev	0.278
Al^{27}(n, α) Na^{24}	6.9 Mev	0.040

The fast-neutron energy spectrum was measured along the axis of mock-up No. 1 at a point 20 inches from the bottom of the test region. The spectrum is shown in Figure 25.

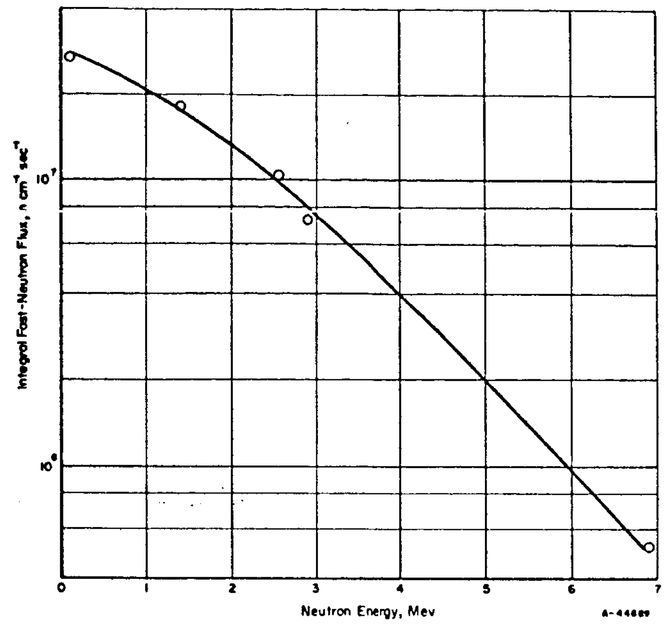


FIGURE 25. FAST-NEUTRON SPECTRUM

The effective energy threshold of the Pu^{239} (n, f) reaction is considerably below the 0.1-Mev lower energy limit for fast neutrons, and consequently it will measure the total fast-neutron flux plus a portion of the resonance-neutron flux. The resonance-neutron flux contribution to the total flux measured by the plutonium reaction was found to be approximately 25 per cent of the total. The plutonium flux was corrected for this resonance flux and the datum point plotted at 0.1 Mev in Figure 25.

The fast-neutron flux distribution in mock-up No. 1 (see Figure 26) was measured with indium foils. The indium threshold flux was corrected to total fast-neutron flux by use of the neutron spectrum shown in Figure 25. Values are listed in Table 5.

TABLE 5. FAST-NEUTRON FLUX DISTRIBUTIONS IN MOCK-UP NO. 1 (HIGH FLUX)

Distance From Bottom of Test Region, inches	Total Fast-Neutron Flux, 10^7 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
5	2.06	1.05	1.19	0.91	1.28
10	3.69	--	1.53	--	1.95
15	4.47	2.06	1.92	1.94	2.50
20	4.78	--	2.08	--	2.70
25	5.36	2.21	2.12	2.15	2.61
30	4.58	--	1.67	--	2.12
35	2.08	1.21	1.17	1.10	1.33

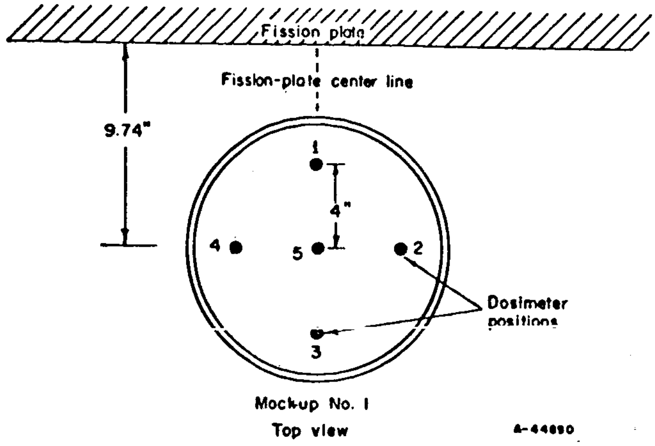


FIGURE 26. POSITIONS OF FAST- AND THERMAL-NEUTRON FLUX MONITORS (HIGH FLUX)

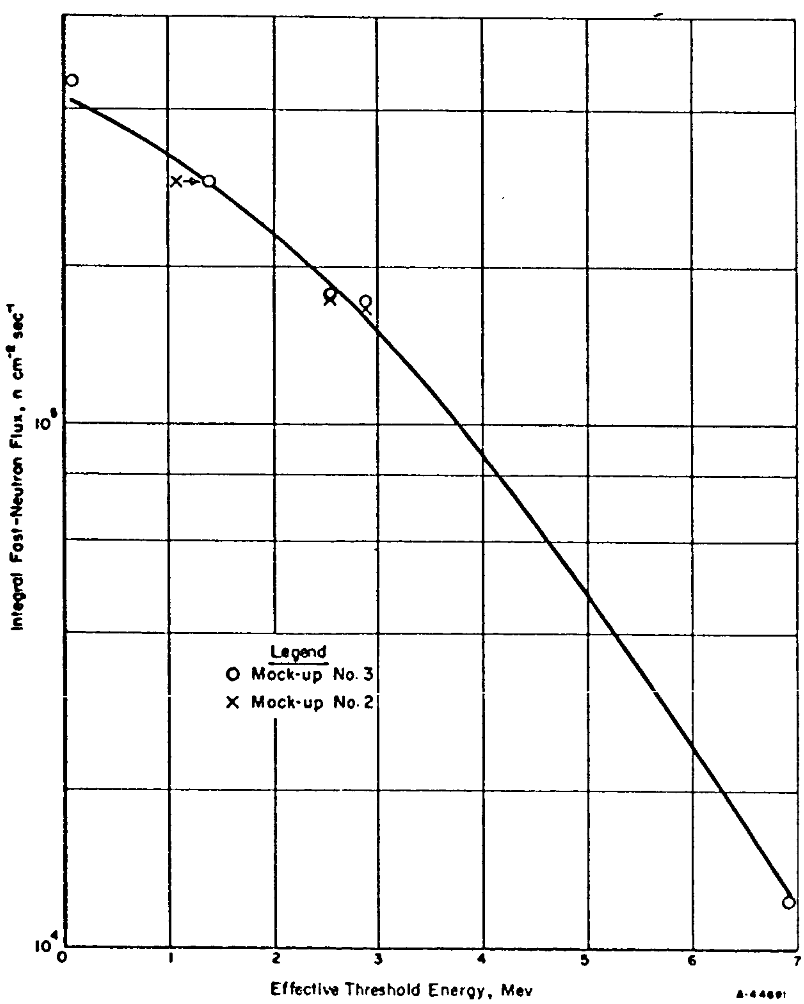


FIGURE 27. FAST-NEUTRON SPECTRUM

The fast-neutron energy spectrum was measured along the axis of mock-up No. 3 at a point 20 inches from the bottom of the test region. Since the fast-neutron energy spectrum in mock-up No. 2 should be the same as in No. 3, the spectrum was only checked with three threshold detectors. The fast-neutron energy spectrum measured in mock-up No. 3 is shown in Figure 27. The spectrum measurements in mock-up No. 2 have been normalized to No. 3 in order to demonstrate the agreement in the two spectrums.

Indium foils were used to determine the fast-neutron distributions in both low-flux mock-ups (see Figure 28). These values are listed in Tables 6 and 7.

TABLE 6. FAST-NEUTRON FLUX DISTRIBUTIONS IN MOCK-UP NO. 2 (LOW FLUX)

Distance From Bottom of Test Region, inches	Total Fast-Neutron Flux, 10^5 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
10	3.37	1.61	1.90	1.69	3.05
20	5.50	3.14	2.32	2.73	4.10
30	3.71	2.34	2.12	1.78	2.89

TABLE 7. FAST-NEUTRON FLUX DISTRIBUTIONS IN MOCK-UP NO. 3 (LOW FLUX)

Distance From Bottom of Test Region, inches	Total Fast-Neutron Flux, 10^5 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
10	4.45	2.32	2.28	2.51	3.78
20	5.68	3.55	2.76	2.82	4.23
30	4.50	2.12	2.77	2.50	3.87

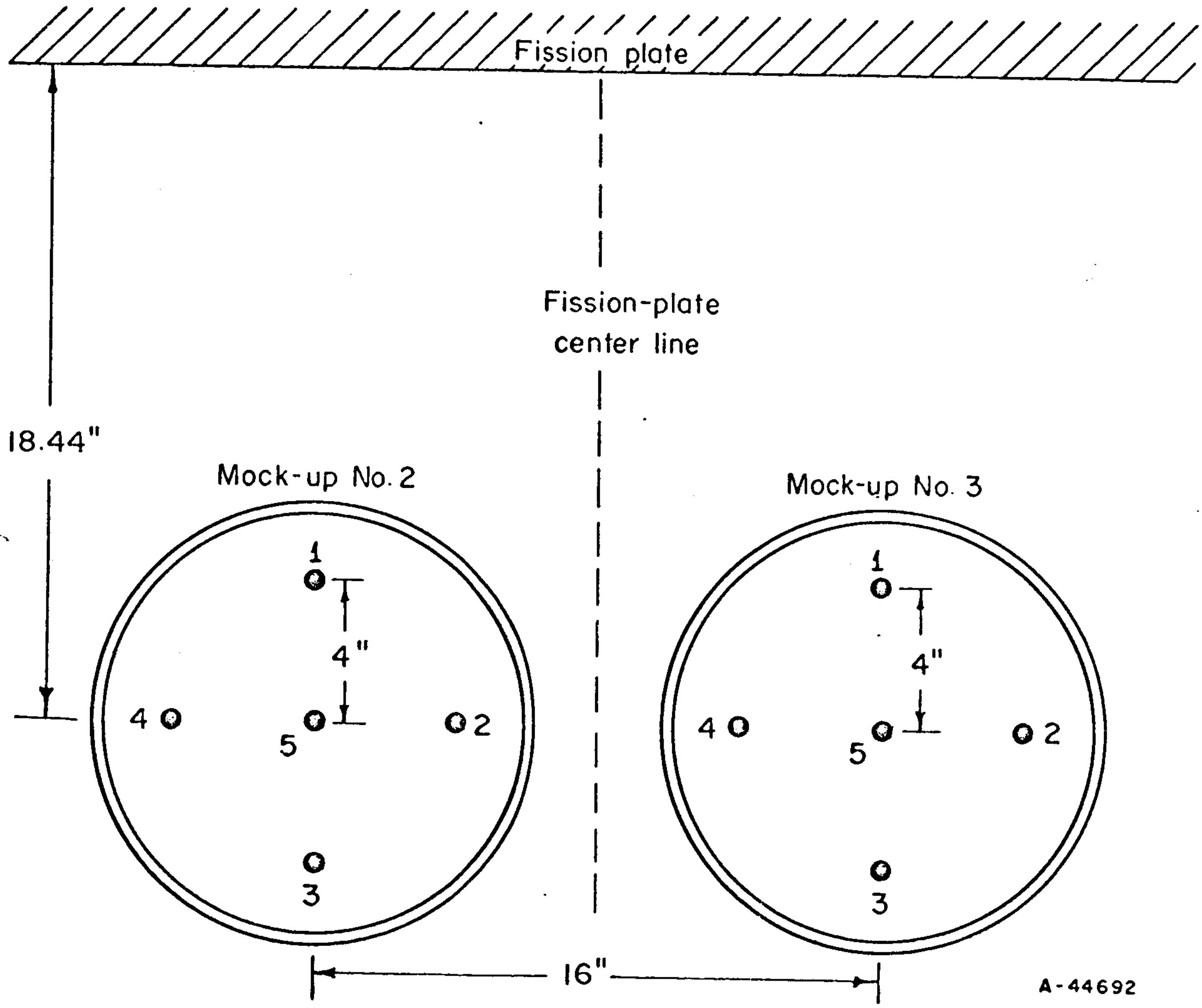


FIGURE 28. POSITIONS OF THERMAL-NEUTRON FLUX MONITORS (LOW FLUX)

Gamma Exposure-Rate Measurements

The gamma exposure rate in the mock-ups was measured with 10-cc graphite-walled ionization chambers. The chambers are filled with carbon dioxide at atmospheric pressure, and a small flow of gas is maintained while measurements are being made. The chamber output is constant with applied voltage from 250 volts to above 1000 volts. A 500-v battery, which was enclosed in a case to restrict leakage currents, was used as a power supply. Current output was measured with a Keithley Model 414 micro-microammeter.

Each chamber was calibrated against a copper-modified ferrous sulfate chemical dosimeter at the Battelle Gamma Facility. The ion chamber and the chemical dosimeter, which are approximately the same size and shape, were irradiated at the geometrical center of a cobalt-60 source using a centering device to insure reproducibility of their position. Two or more chemical-dosimeter measurements were made for each source intensity. The current output was found to be linear over the calibration range.

In order to obtain the required gamma exposure rates in the test facilities, several spent fuel elements were positioned behind the capsule mock-ups. The location of these elements with respect to the mock-ups in the low-flux position is shown in Figure 29. The elements were located approximately 20 inches from the center of the mock-ups. This will permit an adjustment of the position of the elements as they decay during the 10,000-hour test irradiation time. The gamma exposure rate will be periodically checked during the test irradiation in external monitor tubes which are shown in front of each capsule mock-up. Gamma exposure-rate values in the low-flux mock-ups are listed in Tables 8 and 9.

TABLE 8. GAMMA EXPOSURE RATES IN MOCK-UP NO. 2

Distance From Bottom of Test Region, inches	Gamma Exposure Rates, 10^5 ergs g^{-1}(C) hr^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
6.25	0.60	0.64	0.78	0.54	0.66
8.25	0.65	0.74	0.93	0.61	0.75
10.25	0.72	0.83	1.10	0.70	0.84
12.25	0.77	0.92	1.27	0.76	0.93
14.25	0.81	1.01	1.43	0.81	1.02
16.25	0.85	1.09	1.57	0.86	1.08
18.25	0.88	1.13	1.66	0.89	1.12
20.25	0.89	1.16	1.70	0.90	1.15
22.25	0.89	1.16	1.70	0.91	1.15
24.25	0.88	1.13	1.64	0.90	1.13
26.25	0.85	1.08	1.53	0.86	1.08
28.25	0.81	1.07	1.40	0.82	1.02
30.25	0.76	0.91	1.22	0.76	0.93
32.25	0.69	0.80	1.04	0.68	0.84

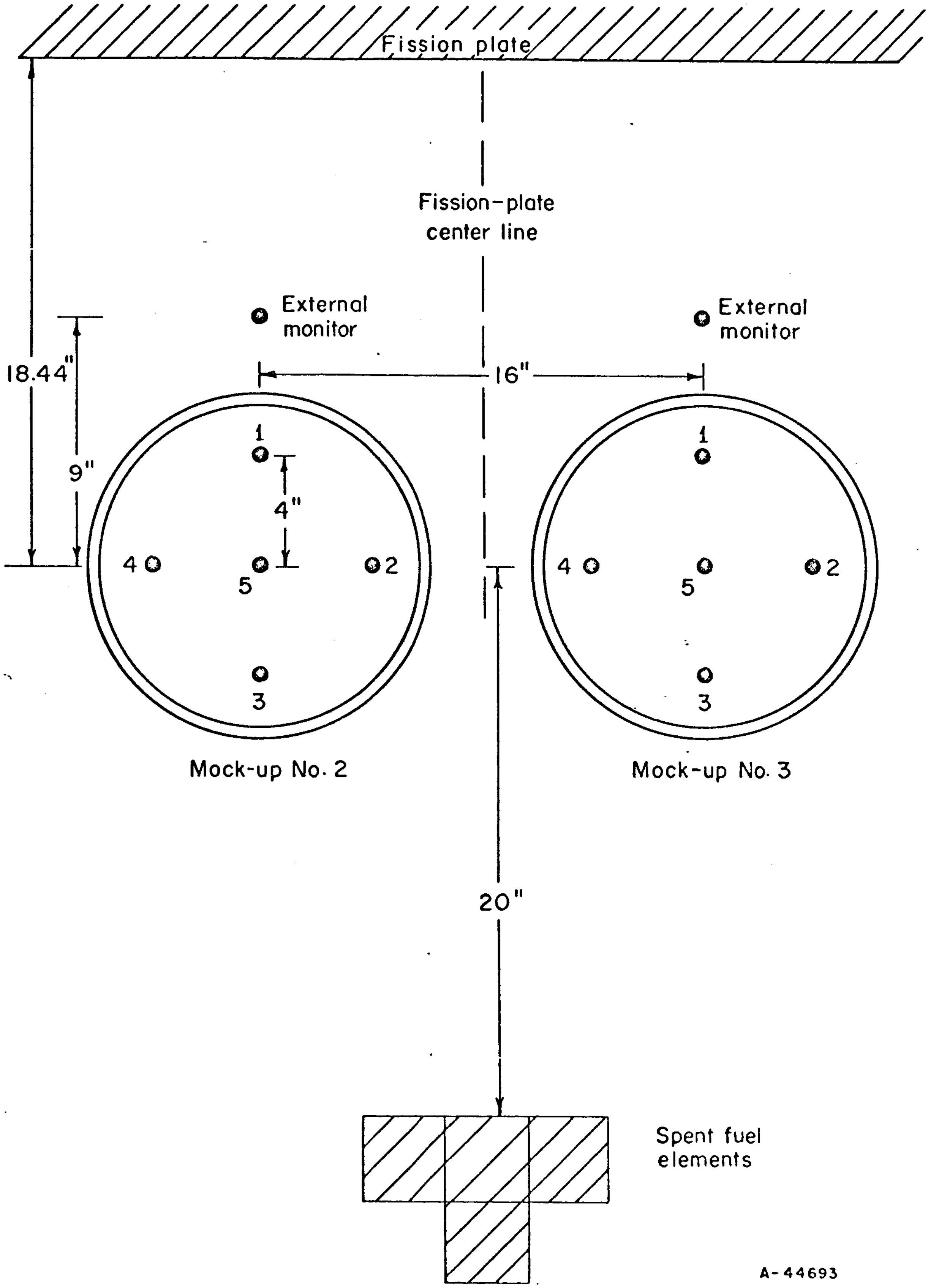


FIGURE 29. GAMMA CHAMBER POSITIONS (LOW FLUX)

TABLE 9. GAMMA EXPOSURE RATES IN MOCK-UP NO. 3

Distance From Bottom of Test Region, inches	Gamma Exposure Rates, 10^5 ergs g^{-1}(C) hr^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
6.25	0.61	0.56	0.78	0.61	0.70
8.25	0.67	0.63	0.92	0.72	0.78
10.25	0.73	0.72	1.09	0.82	0.86
12.25	0.78	0.78	1.26	0.91	0.95
14.25	0.83	0.84	1.44	1.01	1.03
16.25	0.88	0.90	1.57	1.08	1.09
18.25	0.90	0.93	1.67	1.13	1.14
20.25	0.91	0.95	1.72	1.15	1.16
22.25	0.92	0.95	1.71	1.16	1.16
24.25	0.90	0.93	1.65	1.13	1.14
26.25	0.87	0.90	1.55	1.07	1.10
28.25	0.83	0.84	1.41	1.01	1.04
30.25	0.78	0.78	1.24	0.90	0.95
32.25	0.71	0.70	1.06	0.80	0.85

The gamma exposure rate was also measured in the external tubes at a point 20.25 inches from the bottom of the test region. The value obtained for mock-up No. 2 was 0.65 x 10^5 ergs g^{-1}(C) hr^{-1}, and that obtained for No. 3 was 0.77 x 10^5 ergs g^{-1}(C) hr^{-1}.

Preliminary gamma exposure-rate measurements in the high-flux position resulted in values approximately a factor of two below the desired values. In order to increase the gamma exposure rate by a factor of two, it will be necessary to use one or possibly two spent fuel elements whose decay time after removal from the core of the Battelle Research Reactor is less than that of the present elements. These required measurements will not be performed until about a week before the scheduled test irradiation.

Resonance-Neutron Flux Measurements

The cadmium difference method, which utilizes the resonance activation integral of resonance-type foils, was used to achieve spectral knowledge in the resonance energy region. Resonance neutrons are defined here to be neutrons with energies between 0.4 ev and 0.1 Mev. This method assumes that the neutron energy spectrum in the resonance energy interval can be written as

$$\phi(E)dE = \frac{\phi_o}{E}\, dE, \quad (1)$$

where $\phi(E)dE$ is the neutron flux between energies E and E + dE, and ϕ_o is a spectral function parameter that is given by

$$\phi_o = \frac{2.27\ \phi_{th}}{(CR - 1)(1 + \alpha)}, \tag{2}$$

where

ϕ_{th} = thermal-neutron flux

CR = cadmium ratio

α = ratio of resonance activation to 1/v activation in the foil.

The factor 2.27 includes the effect of cadmium cover thickness. The spectral function parameter, ϕ_o, was calculated for a number of reactions using the measured cadmium ratio, and from this the differential flux corresponding to that reaction was determined. It should be noted that this method is valid only if the neutron flux has a 1/E distribution. In this case ϕ_o will be the same for each resonance detector.

The resonance-neutron energy spectrum in the high-flux position was measured along the axis of the mock-up at a position 20 inches from the bottom of the test region. A set of three resonance detectors was irradiated at this position. The resonance detectors, their resonance energies, and their ϕ_o values are listed in Table 10. The measured spectrum is shown in Figure 30. It is seen that ϕ_o is nearly constant, and the assumption that the neutron flux has a 1/E distribution is justified.

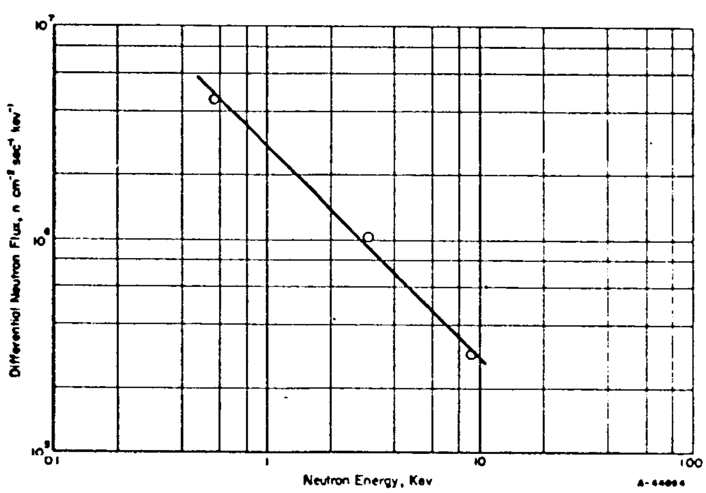


FIGURE 30. RESONANCE-NEUTRON FLUX SPECTRUM

TABLE 10. RESONANCE-NEUTRON DETECTORS

Reaction	Resonance Energy, ev	ϕ_o, 10^6 n cm^{-2} sec^{-1}
Cu^{63} (n, γ) Cu^{64}	570	2.55
V^{51} (n, γ) V^{52}	3000	3.08
Al^{27} (n, γ) Al^{28}	9100	2.60

Bare and cadmium-covered gold foils were used to measure the thermal-neutron flux distribution in the mock-up*, and values for the spectral function parameter were calculated from Equation (2). Values of ϕ_o are listed in Table 11.

Total resonance flux in selected energy intervals can be found from integration of Equation (1) using the ϕ_o values from Table 11. Insufficient activation of the V^{51} and Al^{27} resonance detectors precluded their use in the low-flux position. Copper was used in the low-flux position, and it was assumed that a 1/E distribution was valid. This assumption appears justified, since the nuclear environment of the low-flux position with respect to the high-flux position has only been modified by approximately 1 foot of water. Values of ϕ_o are listed in Tables 12 and 13.

TABLE 11. ϕ_o DISTRIBUTIONS IN MOCK-UP NO. 1 (HIGH FLUX)

Distance From Bottom of Test Region, inches	ϕ_o, 10^6 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
4	2.22	2.03	2.07	2.12	2.12
12	3.04	2.50	2.46	2.57	2.58
20	3.14	2.67	2.56	2.77	2.75
28	3.02	2.50	2.49	2.49	2.62

TABLE 12. ϕ_o DISTRIBUTIONS IN MOCK-UP NO. 2 (LOW FLUX)

Distance From Bottom of Test Region, inches	ϕ_o, 10^3 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
5	7.27	6.78	6.58	6.38	7.23
15	11.50	9.12	8.74	9.04	9.40
25	11.41	8.93	8.56	9.38	9.83
35	6.87	6.40	6.22	6.39	6.47

TABLE 13. ϕ_o DISTRIBUTIONS IN MOCK-UP NO. 3 (LOW FLUX)

Distance From Bottom of Test Region, inches	ϕ_o, 10^3 n cm^{-2} sec^{-1}				
	Position 1	Position 2	Position 3	Position 4	Position 5
5	7.88	6.88	7.18	7.03	7.38
15	10.96	8.69	8.68	9.05	9.48
25	11.84	8.62	8.92	9.00	9.47
35	7.10	6.30	5.98	6.10	6.42

* These thermal-neutron flux values were measured without the cadmium sleeve around the mock-up.

Thermal-Neutron Flux

The thermal-neutron flux and flux distributions were measured in the mock-ups by activation of gold foils, both bare and cadmium covered. The difference in the two activities is attributed to thermal neutrons. The upper energy limit for thermal neutrons is chosen as 0.4 ev, which represents the effective cutoff energy for 0.020-inch-thick cadmium covers.

The results of the thermal-neutron flux measurements in the high-flux position are listed in Table 14, and the positions of the foils in a given horizontal plane in mock-up No. 1 are shown in Figure 26.

TABLE 14. THERMAL-NEUTRON FLUX DISTRIBUTIONS IN THE MOCK-UP (HIGH FLUX)

Distance From Bottom of Test Section, inches	Thermal-Neutron Flux, 10^6 n cm^{-2} sec^{-1}		
	Position 1	Position 2	Position 3
4	2.90	4.74	5.90
12	5.62	6.69	6.56
20	7.84	7.69	6.98
28	9.98	9.64	9.14

Thermal flux values for the low-flux position are listed in Tables 15 and 16, and the positions of the foils in the mock-ups are shown in Figure 28.

TABLE 15. THERMAL-NEUTRON FLUX DISTRIBUTIONS IN MOCK-UP NO. 2 (LOW FLUX)

Distance From Bottom of Test Section, inches	Thermal-Neutron Flux, 10^4 n cm^{-2} sec^{-1}		
	Position 1	Position 2	Position 3
5	2.28	2.06	2.14
15	3.58	4.04	3.85
25	6.17	5.43	5.71
35	11.66	8.34	8.95

TABLE 16. THERMAL-NEUTRON FLUX DISTRIBUTIONS IN MOCK-UP NO. 3 (LOW FLUX)

Distance From Bottom of Test Section, inches	Thermal-Neutron Flux, 10^4 n cm^{-2} sec^{-1}		
	Position 1	Position 2	Position 3
5	1.05	0.80	1.01
15	1.49	1.55	1.39
25	3.28	2.79	2.70
35	8.79	6.29	6.62

Time/radiation records are kept on the basis of the cycled operation of the Battelle Research Reactor during the test program and will be verified by dosimetry measurements at the end of the program. Examples of the information contained in or obtained from these records are shown in Tables 17 and 18.

Table 17 identifies the two capsules by number. The exposure values listed are averages over the volumes of the capsules occupied by the test components. Neutron exposures listed are for fast neutrons only (i.e., $E \geq 0.1$ Mev) and must be considered as preliminary indications of the actual doses received. These values are based on neutron flux distributions measured in the mock-ups of the irradiation capsules and do not include perturbations due to the test components or assembly, or any time-dependent distribution changes. Postirradiation analysis of in-pile neutron dosimeters will provide more accurate determinations of actual doses received by individual components or groups of components.

TABLE 17. APPROXIMATE NEUTRON AND GAMMA EXPOSURES

	Integrated Exposures			
	Neutrons ($n\ cm^{-2}$)		Gamma [$ergs\ g^{-1}$(C)]	
Irradiation Period	Capsule 1[a]	Capsule 2[b]	Capsule 1	Capsule 2
BRR Cycle 166	8.5×10^{10}	1.0×10^{11}	1.06×10^{7}	1.05×10^{7}
BRR Cycle 167	2.9×10^{11}	3.4×10^{11}	2.93×10^{7}	2.91×10^{7}
BRR Cycle 168	2.2×10^{11}	2.6×10^{11}	2.31×10^{7}	2.30×10^{7}
0 - 250 hours	2.4×10^{11}	2.8×10^{11}	2.64×10^{7}	2.62×10^{7}
250 - 500 hours	2.6×10^{11}	3.0×10^{11}	2.60×10^{7}	2.57×10^{7}
Total in-pile[c]	6.0×10^{11}	7.0×10^{11}	6.30×10^{7}	6.26×10^{7}

(a) Test Group 5.
(b) Test Group 3.
(c) Estimated integrated exposures from experiment startup through BRR Cycle 168.

Table 18 provides a history of the experiment and reactor operating times, and an account of the exposure times accumulated during successive operating periods. Note that the total times of neutron and gamma exposures will not always be equal because of the independence of their sources. Short-term reactor scrams or unscheduled shutdowns result in interruptions of neutron exposures but not gamma exposures. This is not true during long reactor shutdowns because the gamma source is removed also. The exposure times will be equalized periodically by subjecting the capsules to neutron irradiation only.

Also given are the dates and times at which the 250-hour and 500-hour irradiation points were reached. These are determined from neutron exposure times; the gamma exposure times are slightly different but can be found from the data in Table 18.

TABLE 18. HISTORY OF EXPERIMENT OPERATION

BRR Cycle	Date (1964)	Time	Remarks[a]	Duration of Exposures During Intervals, hours	
				Neutrons	Gamma
166	9-24	0930	JPL Startup	--	--
	9-28	0934	JPL Shutdown	96.07	96.07
167	9-30	1153	JPL Startup	0.00	0.00
	10-5	1647	BRR Shutdown	124.90	124.90
	10-5	1740	BRR Startup	0.00	0.88
	10-12	0930	JPL Shutdown	159.83	159.83
168	10-14	1025	JPL Startup	0.00	0.00
	10-16	1119	BRR Shutdown	48.90	48.90
	10-16	1150	BRR Startup	0.00	0.52
	10-23	0900	JPL Shutdown	165.17	165.17

Note: 250 hours of accumulated irradiation time occurred at 2242 on October 6, 1964.
500 hours of accumulated irradiation time occurred at 1008 on October 19, 1964.
Total accumulated irradiation time from experiment startup through BRR Cycle 168 was 594.9 hours.

(a) JPL Startup: Neutrons and gamma started simultaneously.
JPL Shutdown: Neutrons and gamma shut down simultaneously.
BRR Shutdown: Neutrons only shut down.
BRR Startup: Neutrons only started.

Facilities for Photosensitive Devices

CBS 7817 Photomultiplier Tubes

Irradiation of the photomultiplier tubes was done in the chamber shown schematically in Figure 31. The 20 photomultiplier tubes were mounted in 10 pairs equally spaced around the polished stainless steel spherical reflector as shown. This geometry allows for equal irradiation of the photomultiplier tubes by placing 10 cobalt-60 source rods equally spaced among the tubes on a diameter of 12 inches and placement of 5 additional, equally spaced, source rods on a 14-inch diameter to obtain the desired 1×10^6 ergs g^{-1}(C) hr^{-1} dose rate at the dynode section of the photomultiplier tubes. A mock-up chamber was used with the cobalt-60 source rods to determine the optimum geometry for proper gamma flux density.

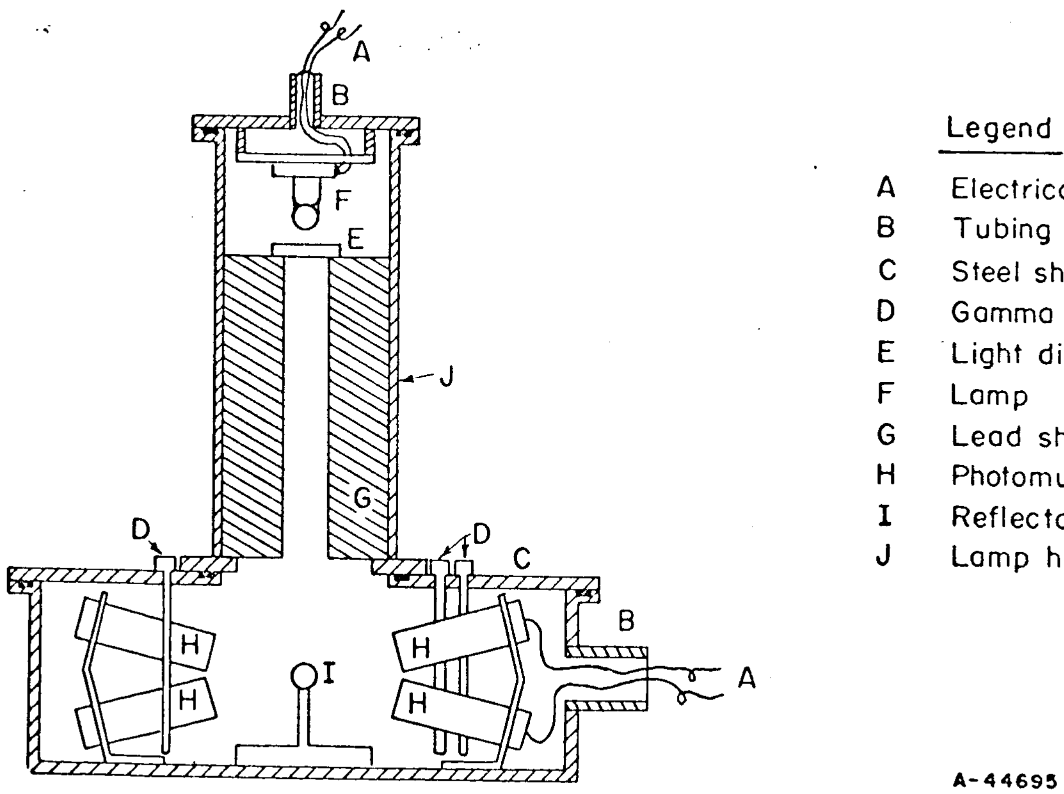


FIGURE 31. SCHEMATIC CROSS SECTION OF GAMMA IRRADIATION TEST CHAMBER

The light source to obtain the 10^{-8} lumen was a small tungsten-filament lamp, operated somewhat below its rated voltage to insure a constant output for the test. A ground-glass diffusing plate was placed between the lamp and the reflecting sphere to assure constant light intensity over the upper spherical reflector surface, and hence constant intensity on all photomultiplier faces. The inside of the chamber was coated with a flat-black, nonreflective coating to reduce multiple reflections into the photomultiplier tubes. In order to minimize darkening of the lamp envelope and ground-glass diffuser by gamma radiation, the lamp and diffuser were mounted 20 inches above the reflecting sphere and shielded from direct radiation from the source rods by at least 3 inches of lead, as indicated in Figure 31.

Operation of the lamp at below rated voltage moved the peak intensity of the source farther into the infrared than is normal for a tungsten-filament lamp. However, since enough lamp intensity in the visible region was still available for the proper illumination and since the photomultiplier tubes respond only to the visible region between 0.2 and 0.7 micron, this should not have any adverse effect on the test results.

Fiber-Optic Discs

The fiber-optic discs were placed in the test chamber concurrently with the photomultiplier tubes. One disc was placed over the central receiving area of each of 9 of the photomultipliers at the beginning of the 1000-hour test. One disc was to be removed at each 100-hour period (starting with the 200-hour interval) and inspected for spectral transmittance. Although the discs were not mounted in positions of maximum radiation flux, they receive a gamma radiation intensity of approximately 0.93×10^6 ergs g^{-1}(C) hr^{-1}.

The radiation exposure of the photomultiplier tubes and fiber-optic discs was terminated after 200 hours because of the large quantity of failures that occurred. The photomultiplier tubes were insensitive to the 10^{-8} lumen light source, and the light-transmitting properties of the fiber optics had degraded approximately 80 to 90 per cent.

Clairex CL-605 CdS Cells

The test chamber described above and shown schematically in Figure 31 was also used to test the CdS cells under gamma irradiation and with an illumination sufficient to reduce cell resistance to approximately 5000 ohms (~400 foot-candles). Seven volts was applied to each cell through 1000-ohm dropping resistors.

For this 1000-hour test, the photomultiplier tubes and mounts and the spherical reflector were removed. The 5 cobalt-60 source rods formerly on a 14-inch diameter were evenly spaced among the other 10 rods on the 12 inch diameter, thereby increasing the gamma dose rate near the center of the chamber. The CdS cells were mounted in two horizontal straight rows of 10 each directly above the spherical reflector mounting block shown in Figure 31. The thickness of the lead shielding was reduced to allow a 4-1/2-inch-diameter light beam to pass down in direct incidence upon the cells. The light source was a Type Q500T3/CL-120V Quartz line. Sufficient voltage was applied to obtain 400-foot-candles of illumination. A special test was made on a Krylon black coated steel specimen. This specimen was given a gamma irradiation equal to that to be used on the final apparatus to determine the feasibility of using this coating inside the chamber to reduce internal light reflection. No change in the coating could be noted, and this coating was used for the final assembly.

The estimated accuracy of the gamma dosimetry which followed the same procedures and methods outlined above for the other radiation exposures. The estimated accuracy of the dosimetry for the gamma radiation is ±5 per cent.

LIFE-TEST PROCEDURES

This section provides details of the life-test procedures in the specific environments such as the handling, mounting, wiring, and connections of the test specimens. The life-test stress conditions for each part type is defined, and a simple schematic of each loading circuit is presented. Details of the mounting positions and photographs of the facility are shown in Appendix B.

Visual Inspection and Identification

The various part types were visually inspected for obvious defects in workmanship and assigned a number from 000 through 099, 119, or 139 depending upon the total sample size required (see Table 1). Following the assignment of specimen numbers for identification purposes, the preliminary or specialized measurements that required special circuits and minimum lead length were performed prior to the mounting of the parts for the life-test environments. These measurements included LV_{CEO} and a-c current gain, h_{FE}, of the transistors; potentiometer linearity and noise; diode junction capacitance; resistor insulation resistance; switch contact resistance; and switch activation pressure.

Mounting and Wiring Specimens

The method of mounting specimens for exposure to the four vacuum environments includes a tripod structure of aluminum plates and support rods. The plates, on which the specimens are mounted, are 10 inches in diameter, with a 2- or 3-inch hole in the center to facilitate the wiring of the chamber interior. Lead-mounted specimens are supported by their leads which are soldered to ceramic standoff insulators. Parts with supports are mounted by these supports, except that the 2N1050 transistor is supported by its leads rather than by the stud provided.

When completed, the plates with the components attached were assembled into vertical stacks supported by three 1/2-inch rods. These rods are equally spaced on a 4-1/2-inch center, and thus form a tripod support for the entire component-part mounting assembly.

The component parts to be subjected to a 100 C ambient at normal atmospheric pressure are mounted in open lattice-type trays to permit free air circulation within the environmental chamber. These trays are constructed of aluminum and Teflon strips interlocked much like the dividers of an egg crate. The test specimens are suspended in the open areas between the interlocking strips.

Wiring within the capsules to be subjected to radiation and the vacuum chamber that is not to be irradiated is point-to-point between the hermetically sealed electrical feed-through receptacles and the component parts. The wire that was used is double Silotex (Type DX) manufactured by Anaconda Wire and Cable Company. It is a solid-copper magnet wire which is glass insulated with a silicone bond. This wire was selected on the basis of radiation resistance and low outgassing properties.

The wiring between the various environmental chambers and the loading circuits located in the instrumentation room consists of vinyl-insulated lead wire placed in aluminum pipe and steel wireways. All wire is terminated on barrier strip panels in the instrumentation room, with the wire to the radiation capsules also having similar terminations near the shielding pool of the reactor. The latter is to provide a point for disconnecting the leads to the radiation capsules to facilitate their removal from the radiation environment. The maximum wire lengths to the specimens in the radiation capsules and the nonirradiated environments are 110 feet and 60 feet, respectively.

Overcoming Lead-Length Effects

Since the test specimens are electrically loaded and measured while under irradiation, it is necessary to make measurements and supply power from a remote location with as much as 110 feet of wire connecting the specimens to the electrical circuits. This arrangement causes some difficulties, of which three significant areas will be discussed in detail.

Resistance of Lead Wires

The maximum total circuit resistance leading to each specimen is approximately 1 ohm. This resistance is ordinarily not significant except where the low saturation voltage of transistors is to be measured, and where very precise measurements of Zener diode voltage are required. For these measurements, four connecting wires are used. Two of these wires supply current to the specimen, while the other two are used for measuring voltage. Since practically no current flows in the voltage leads, the resistive IR drop is negligible.

Silicon-Controlled-Switch Instability

The 3N58 silicon-controlled switch is turned "on" by very small signals applied to the gate. Since this gate offers a high impedance, stray pickup on only a few inches of open wire is often sufficient to fire the switch. Obviously, unwanted turn-on at the end of 100 feet of wire would be a severe problem. Experiments under conditions simulating the actual test conditions indicated that the problem can be eliminated by using a 10 K-ohm shunting resistor from control gate to cathode in order to reduce the effective input impedance. Therefore, each 3N58 controlled switch was mounted with a 10 K-ohm resistor from gate to cathode physically located adjacent to the test specimen inside the irradiation test chamber. To assure that the resistors themselves would not be unduly radiation sensitive, Texas Instruments Type CG 1/4 carbon-film resistors were used. The experimental data will reflect any major changes that occur in these resistors, as well as changes in the 3N58 controlled switch.

Transistor Oscillation

When transistors are operated at the end of a transmission line such as is necessary in conducting this program, oscillation presents a difficult problem. Strong high-frequency oscillation was found to occur in all test-transistor types except the 2N1050 which has a comparatively limited high-frequency gain and therefore is not as prone to such oscillations as are the other types. Several different modes of oscillation were obtained by making slight changes in the experimental conditions. After trying several approaches to eliminate oscillation, it was determined that rather strong measures would be needed to assure freedom from oscillation during the test operation and parameter measurements. For all transistor types except the 2N1050, three small (0.001 μf) capacitors were used, connected as shown in Figure 32.

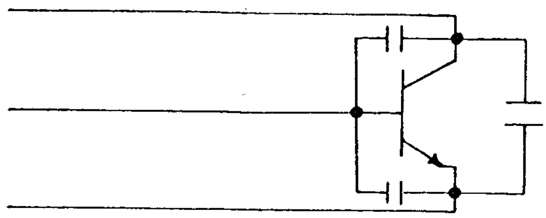


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FIGURE 32. OSCILLATION SUPPRESSION

These capacitors were mounted physically adjacent to the test transistors and therefore are exposed to the radiation environment. The capacitors selected for this application are the Corning Glass Type CYFM15C capacitors that have been previously tested and have undergone an initial burn-in to assure reliability. No significant degradation of these capacitors is expected. For the 2N1050 transistors (which do not seem to oscillate) a 100-ohm resistor was inserted in the base lead to assure complete freedom from oscillation. Texas Instruments Type CG 1/4 carbon-film resistors were selected for this application.

Loading Circuits

The loading circuits are used to apply electrical operating power to the specimens under test and are mounted on tempered fiber-board panels. These circuits were designed for maximum operating stability and overload prevention while retaining circuit simplicity. Connection between the loading circuits and the lead wires to the electronic parts on test is provided by 100-pin North Electric connectors. The system is so designed that by use of a double cable arrangement from the automatic data-recording system it is only necessary to interrupt the load to a specific specimen during actual measurement, as illustrated in Figure 33. The specific circuits are discussed below under each component-part classification with the loading conditions for individual part types listed in Table 19.

TABLE 19. COMPONENT PART OPERATING CONDITIONS

Item	Rating	Conditions
Capacitors		
Aerovox (P323ZN)	200 Vdc	(100%) 200 Vdc, applied
Sprague (118P)	200 Vdc	(100%) 200 Vdc, applied
Good-All (683G)	200 Vdc	(50%) 100 Vdc, applied
GE (29F1614) (5K106AA6)	100 Vdc	(100% 100 Vdc, applied
Fansteel (HP)	50 Vdc	(100%) 50 Vdc, applied
Diodes		
Fairchild (FD1184)	75 mA, 50 V	Half-wave, 26.5 Vrms, applied, I_o = 56.8 mA
Fairchild (FD643)	300 mA, 60 V	Half-wave, 31.8 Vrms, applied, I_o = 226 mA
TI (IN916)	75 mA, 75 V	Half-wave, 39.8 Vrms, applied, I_o = 57 mA
GE (3N58)	100 mA, 40 V	Half-wave, 21.0 Vrms, applied, 2.0 Vdc applied to gate, I_o = 30 mA at 100 C, 60 mA at 50 C
Int. Rect. (1N2063)	225 A, 500 V	Nonoperating, static only
Hoffman (1N822), Zener	7.5 mA, 6.2 V	7.5 mAdc, 12.4 Vdc, applied
PSI (PS4653), Zener	20 mA, 8.2 V	20 mAdc, 16.4 Vdc, applied
Resistors		
TI (CG)		1/16 watt, 79.2 Vdc, applied
Corning (C-07)		1/16 watt, 79.2 Vdc, applied
A-B (CB)		1/16 watt, 79.2 Vdc, applied
New Eng. Inst. Co. (78P)		1/10 watt, 44.7 Vdc, applied
Transistors		
Fairchild (2N911)	0.16 watt at 100 C	See Table 20
Fairchild (2N914)	0.20 watt at 100 C	Ditto
Fairchild (2N915)	0.20 watt at 100 C	"
Fairchild (2N1132)	0.30 watt at 100 C	"
Fairchild (2N2297)	0.45 watt at 100 C	"
TI (2N930)	0.15 watt at 100 C	"
TI (2N1050)	0.55 watt at 100 C	"
TI (2N2412)	0.172 watt at 100 C	"
Philco (2N861)	0.05 watt at 100 C	"
Relay		
Sigma (32RJD90GD)		Operate 10,000 times, one operation/sec for 100 sec every 100 hours. 6 Vdc applied

TABLE 19. (Continued)

Item	Rating	Conditions
Switch		
Minneapolis-Honeywell (1HM1)		Nonoperating
Transformer		
Triad	40 mw	Dissipate 20 mw in a 1,200-ohm load on secondary at 400 cps, 24.5 Vrms
Connectors		
Cinch		Nonoperating
Bendix		Nonoperating

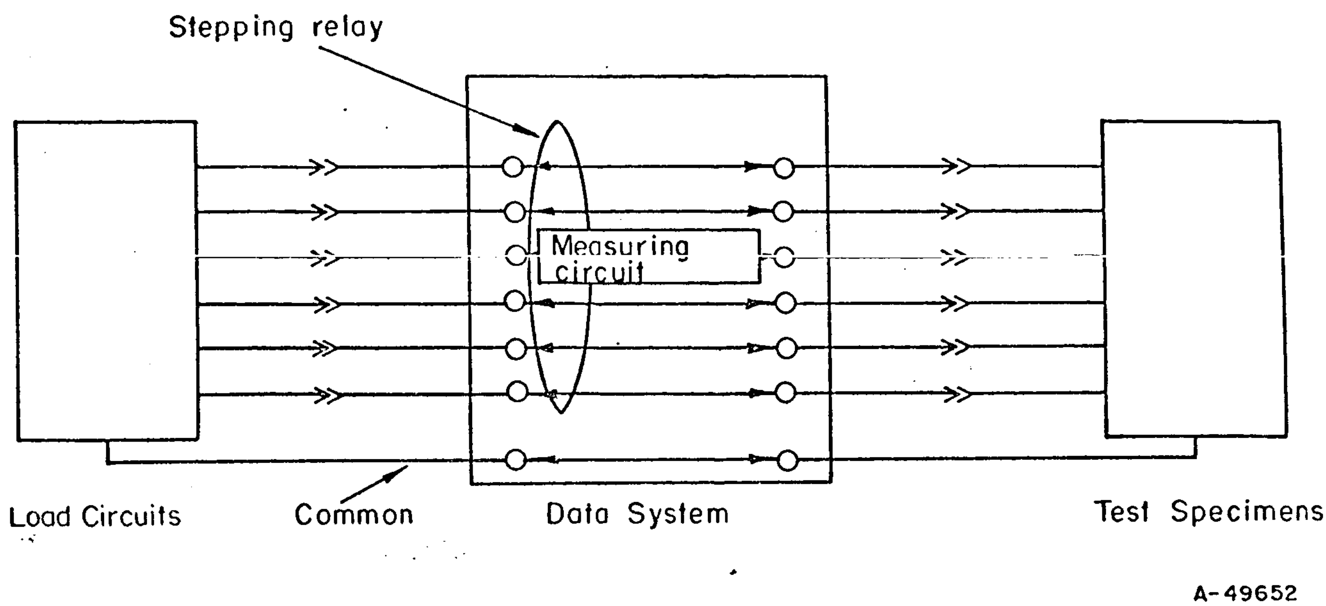


FIGURE 33. SWITCHING CIRCUIT FOR INTERRUPTING LOAD TO SPECIMEN BEING MEASURED WHILE LOAD CONTINUES TO BE APPLIED TO OTHER SPECIMENS

Transistor

The circuit of Figure 34 is used for loading transistors. In this circuit, Resistors R_C and R_B and potentiometer $R_{B(POT)}$ are separate for each test specimen, while power supplies V_{BB} and V_{CC} are common for all specimens of a given type. The potentiometer is used to set I_B and thereby to adjust $I_C = h_{FE}I_B$ to the required value. This adjustment is periodically repeated during the test to compensate for changes in h_{FE}. Resistor R_C is selected so that, under the specified operating conditions, the voltage drop, I_CR_C, is equal to the operating transistor voltage, V_{CE}. Therefore, the supply, V_{CC}, is set at $2V_{CE}$. With this arrangement, the specified power dissipation in the transistor, I_CV_{CE}, is at the maximum possible power available from the circuit, thus protecting against overstressing the transistor due to drifts in transistor characteristic or accidental misadjustment of the control, $R_{B(POT)}$. This arrangement also leads to minimum sensitivity of dissipated power to small drift-induced changes in collector current, I_C, as is indicated in the following derivation:

$$P_{dissipated} = V_{CE}I_C$$

$$= (V_{CC} - I_CR_C)\, I_C$$

$$= V_{CC}I_C - R_CI_C^2$$

$$\frac{\partial P}{\partial I_C} = V_{CC} - 2R_CI_C \; .$$

But we have selected

$$V_{CE} = I_C R_C \quad \text{and}$$

$$V_{CC} = 2V_{CE} = 2I_C R_C \,.$$

Therefore, $\dfrac{\partial P}{\partial I_C} = 0$ at the operating point.

Examination of the equations also shows that the operating point is the maximum of the P versus I_C curve, so that the circuit arrangement will not permit the transistor to be overstressed.

The values for the resistors and power voltages for the various transistor types are listed in Table 20. The power supplies each consist of an autotransformer followed by a full-wave bridge rectifier (silicon diodes) and a choke-input filter.

TABLE 20. TRANSISTOR LOADING CIRCUITS

Transistor Type	Operating Power, watts	Operating Conditions		Circuit Parameters					Circuit Minimum β
		V_{CE}, volts	I_C, mA	R_C, ohms (± 1%)	V_{CC}, volts	V_{BB}, volts	$R_{B(POT)}$ K-ohms	R_B, K-ohms	
2N911	0.08	10	8	1,250	+20	+1.5	100	2	22
2N914	0.1	10	10	1,000	+20	+5	250	5	12
2N915	0.1	10	10	1,000	+20	+5	250	5	12
2N1132	0.15	10	15	667	-20	-3	100	2	13
2N2297	0.225	25	9	2,778	+50	+1.5	250	5	28
2N930	0.075	10	7.5	1,330	+20	+5	1000	5	9
2N1050	0.275	25	11	2,273	+50	+1.5	250	2	31
2N2412	0.135	4	21.6	185	-8	-3	100	2	19
2N861	0.025	5	5	1,000	-10	-3	250	5	11

Zener Diode

The circuit of Figure 35 is used for loading Zener diodes.

There is a separate ±1 per cent resistor, R, for each diode specimen, while the power supply, V_B, is common. Values are selected so that $I_Z R = V_Z$ and $V_B = 2V_Z$.

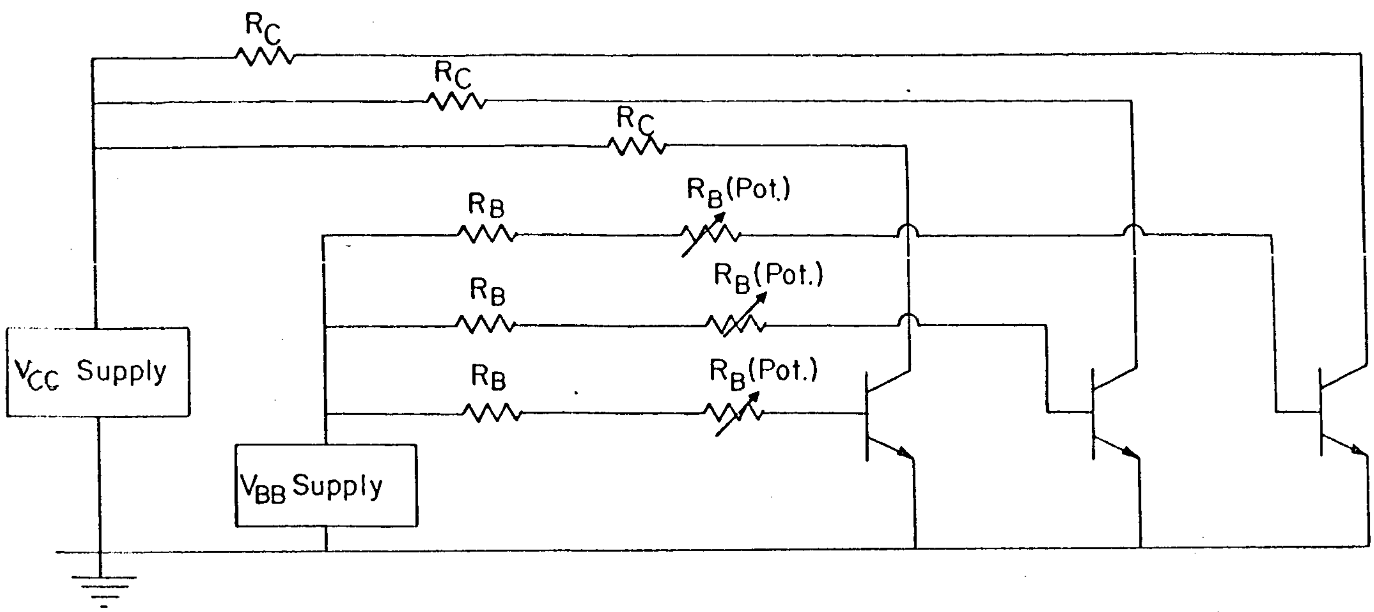


FIGURE 34. TRANSISTOR LOADING CIRCUIT, ALL UNITS OF A SINGLE TYPE CONNECTED AS SHOWN WITH COMMON POWER SUPPLIES

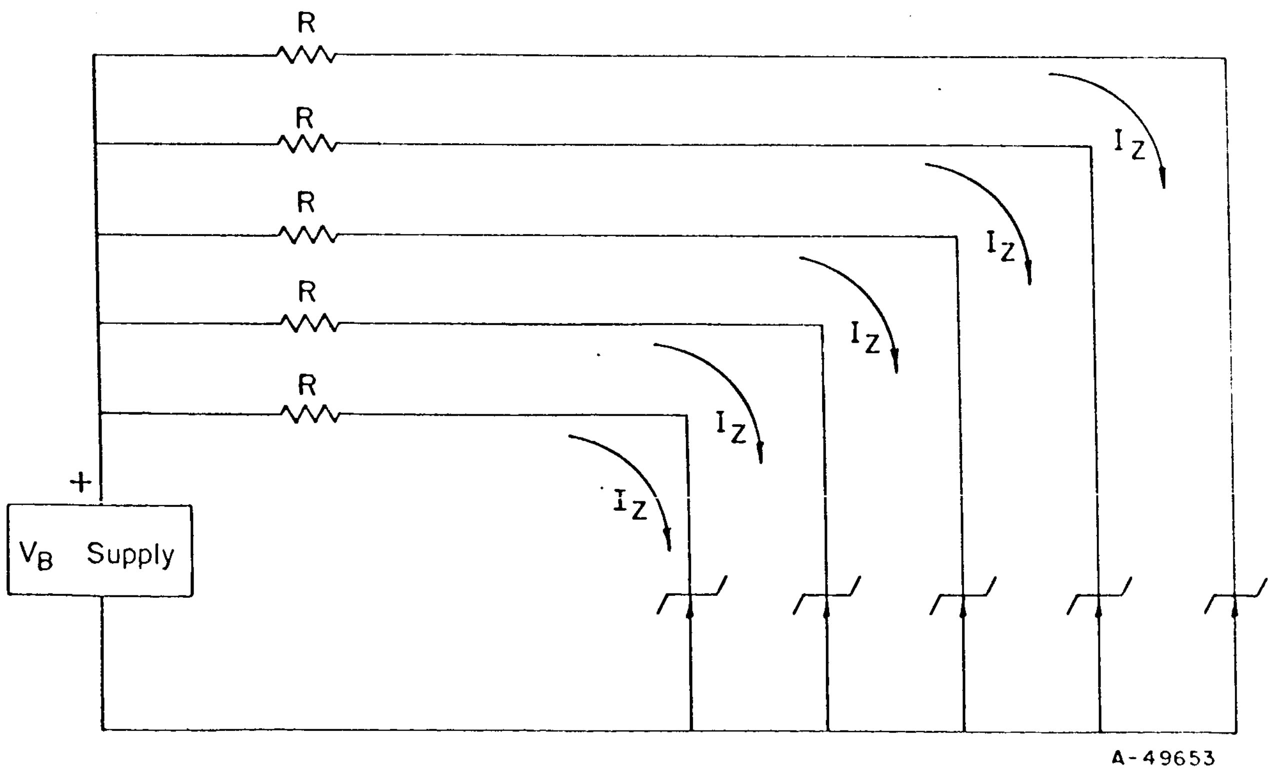


FIGURE 35. ZENER DIODE LOADING CIRCUIT, ALL UNITS OF A SINGLE TYPE CONNECTED AS SHOWN WITH A COMMON POWER SUPPLY

This circuit tends to maintain constant power dissipation in the diode under varying Zener voltage, V_Z, as can be seen from the following derivation:

$$P = I_Z V_Z$$

$$= \left(\frac{V_B - V_Z}{R}\right) V_Z$$

$$= \frac{1}{R} \left(V_B V_Z - V_Z^2\right)$$

$$\frac{\partial P}{\partial V_Z} = \frac{1}{R} \left(V_B - 2V_Z\right) .$$

But we have selected $V_B = 2V_Z$. Therefore, $\frac{\partial P}{\partial V_Z} = 0$ at the operating point. Specific values of voltages and resistors are listed in Table 21.

TABLE 21. ZENER DIODE LOADING

Type	V_Z, volts	Operating I_Z, mA	Circuit Parameters V_B, volts	R, ohms
1N822	6.2	7.5	12.4	827
PS4653	8.2	20	16.4	410

Rectifying Diode

Diodes are operated as rectifiers with specified average current when operated as a half-wave rectifier and specified peak applied reverse voltage. These specified conditions uniquely determine the 60 cycle ac source voltage and the series resistor to be used. The circuit parameters are tabulated in Table 22.

TABLE 22. RECTIFYING DIODE LOADING

Diode Type	V_{supply}, V rms	R, ohms	I_o, mA	V_{out}, Vdc
FD1184	26.5	212	56.8	12.0
FD643	31.8	63.7	226	14.4
1N916	39.8	318	57	18.1

One-half of the test diodes are connected in each polarity so as to balance the load on the autotransformers used to operate the diodes, as illustrated in Figure 36.

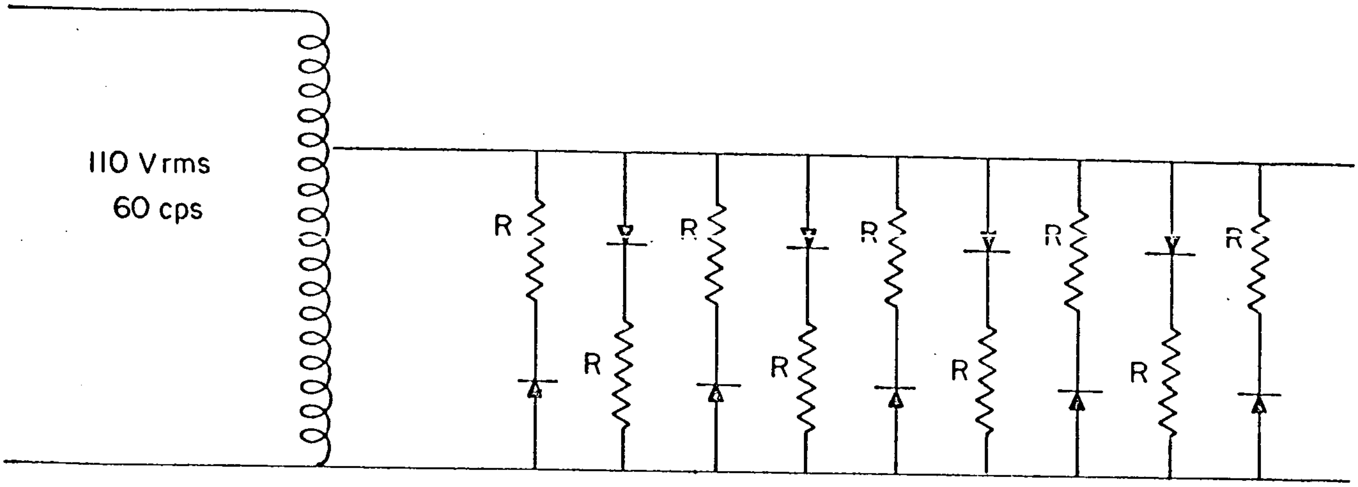


FIGURE 36. RECTIFYING DIODE LOADING CIRCUIT, ALL UNITS OF A SINGLE TYPE CONNECTED AS SHOWN WITH A COMMON POWER SUPPLY

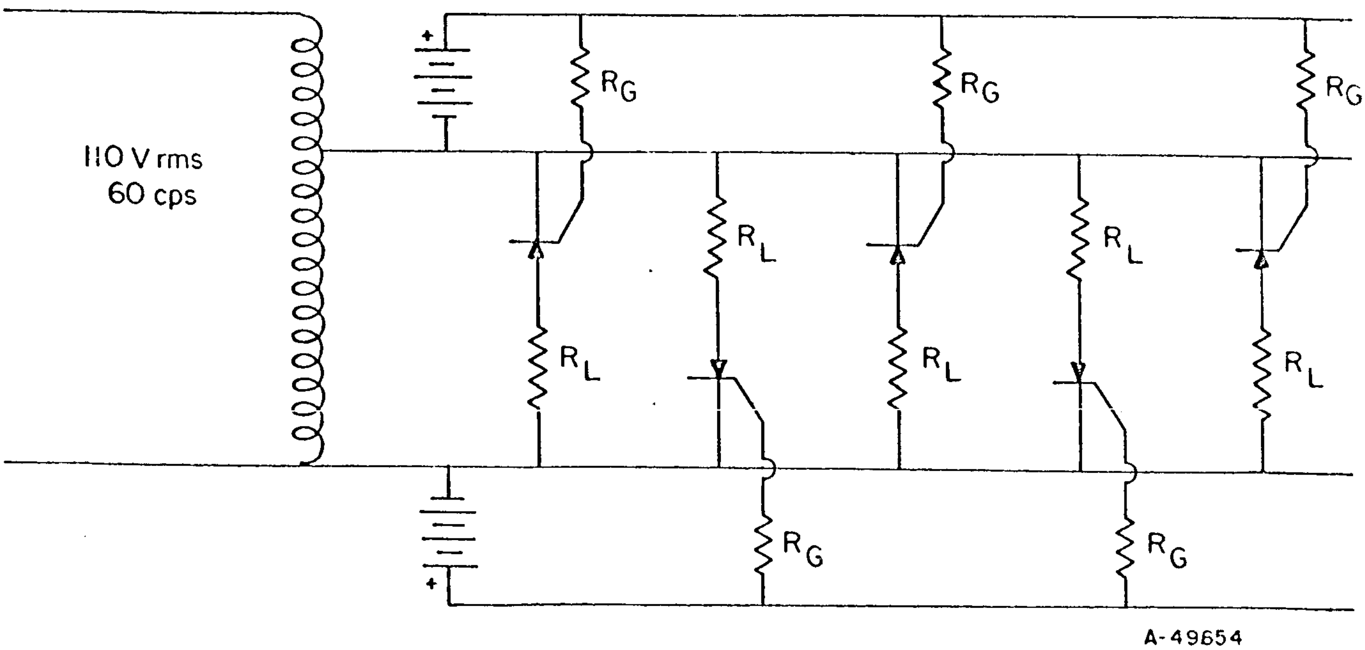


FIGURE 37. SILICON CONTROLLED SWITCH, 3N58, LOADING CIRCUIT, ALL UNITS CONNECTED AS SHOWN WITH COMMON POWER SUPPLIES

Silicon-Controlled Switch

The 3N58 controlled switch is operated as a rectifier in the same manner as the rectifying diodes, but with the addition of gate bias to permit conduction in the forward direction as illustrated in Figure 37. During the high-flux radiation exposure the units in Test Group 4 were operated with a supply voltage of 30 volts rms, and 180-ohm series or load resistors. However, prior to the start of the 10,000-hour life test, the loading circuits for the 3N58 silicon controlled switches were modified at the request of the Sponsor. This modification consisted of a reduction in the operating level of the devices from an applied voltage of 30 volts rms and a half-wave rectified output current of 75 milliamperes for all test environments to 30 and 60 milliamperes at 100 C and 50 C, respectively, with 21 volts rms applied. This required an increase in the resistance of the load resistors for the 100 C test temperature from the original 180 ohms to 315 ohms and a decrease in those for the 50 C test temperature to 158 ohms.

Capacitor

Capacitors are to be operated at a specified voltage. Each capacitor is connected with a 180-ohm series resistor and a fuse (with burn-out indicator lamp) to the required power-supply potential as shown in Figure 38. Series resistors are used to prevent transient charging currents from blowing fuses on good capacitors, and to aid in limiting power dissipation during capacitor burn-out. It is important to limit this power in order to attempt to prevent capacitor explosion, which could cause severe problems in the high-vacuum test chambers.

Resistor and Potentiometer

Loading of the 100-K-ohm resistors is achieved by direct connection to a 79.2-volt d-c power source to supply 1/16 watt per resistor as specified. The potentiometers, Type 78P, are loaded by a 44.7-volt-d-c power supply connected end-to-end to supply 1/10 watt per specimen. The resistor and potentiometer loading circuits are illustrated in Figure 39, with the potentiometer circuit represented by dashed lines.

Relay

The relays will be operated by the circuit shown in Figure 40 at the specified voltage by hand switching the power supply according to the specified intervals. The coils will not be activated except during these operating sequences. There is to be no connection to the relay contacts during operation.

Transformer

The transformers are supplied with a 400-cps signal at 24.5 volts on the primary, with individual 1,200-ohm load resistors on the secondaries, as illustrated in Figure 41.

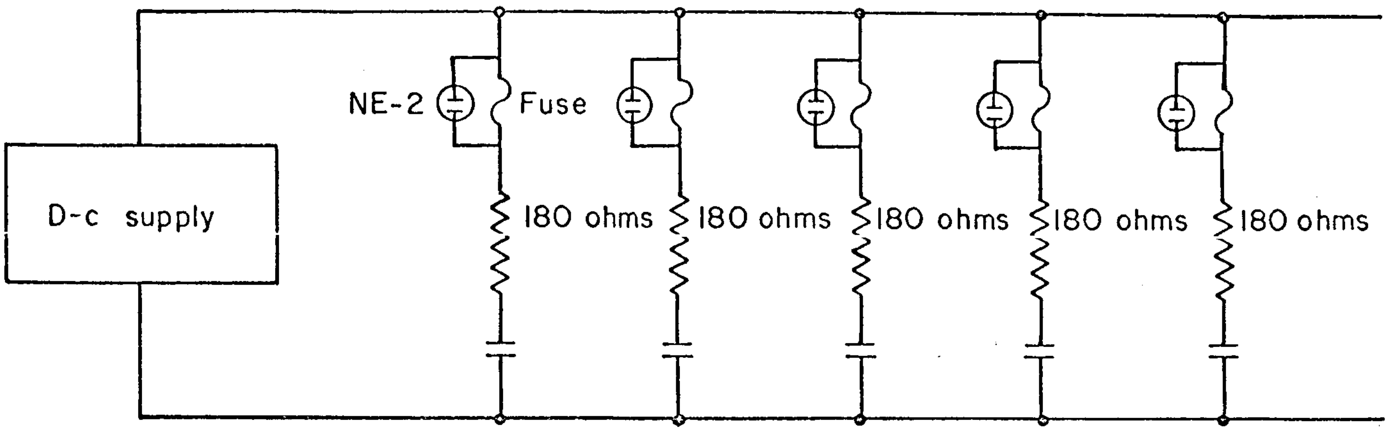


FIGURE 38. CAPACITOR LOADING CIRCUIT, ALL UNITS OF A SINGLE TYPE CONNECTED AS SHOWN WITH A COMMON POWER SUPPLY

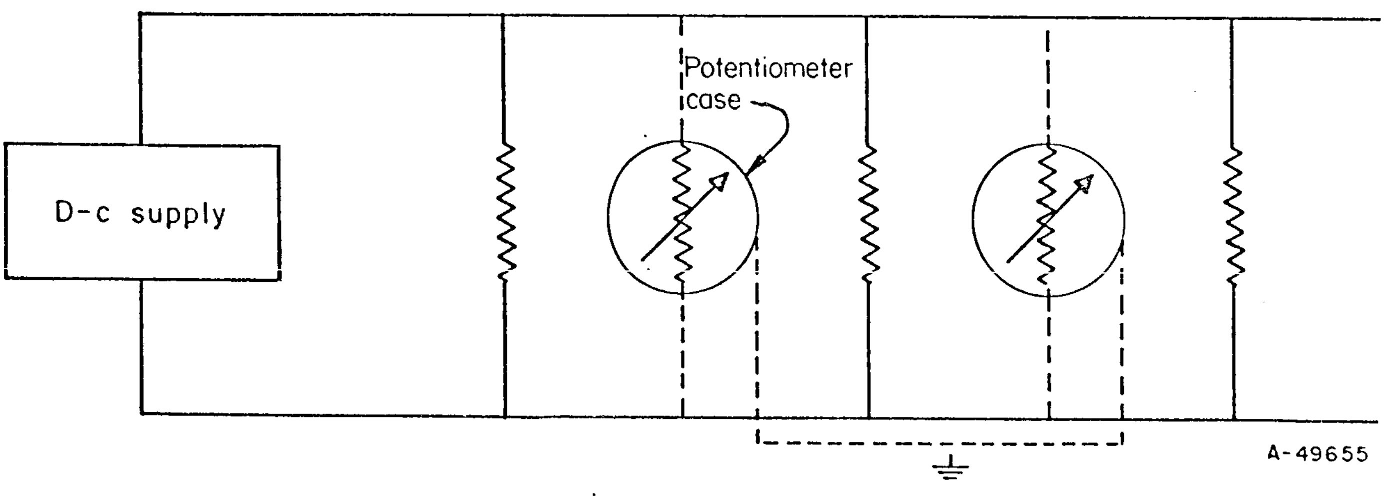


FIGURE 39. RESISTOR OR POTENTIOMETER LOADING CIRCUIT, ALL UNITS OF A SINGLE TYPE CONNECTED AS SHOWN WITH A COMMON POWER SUPPLY

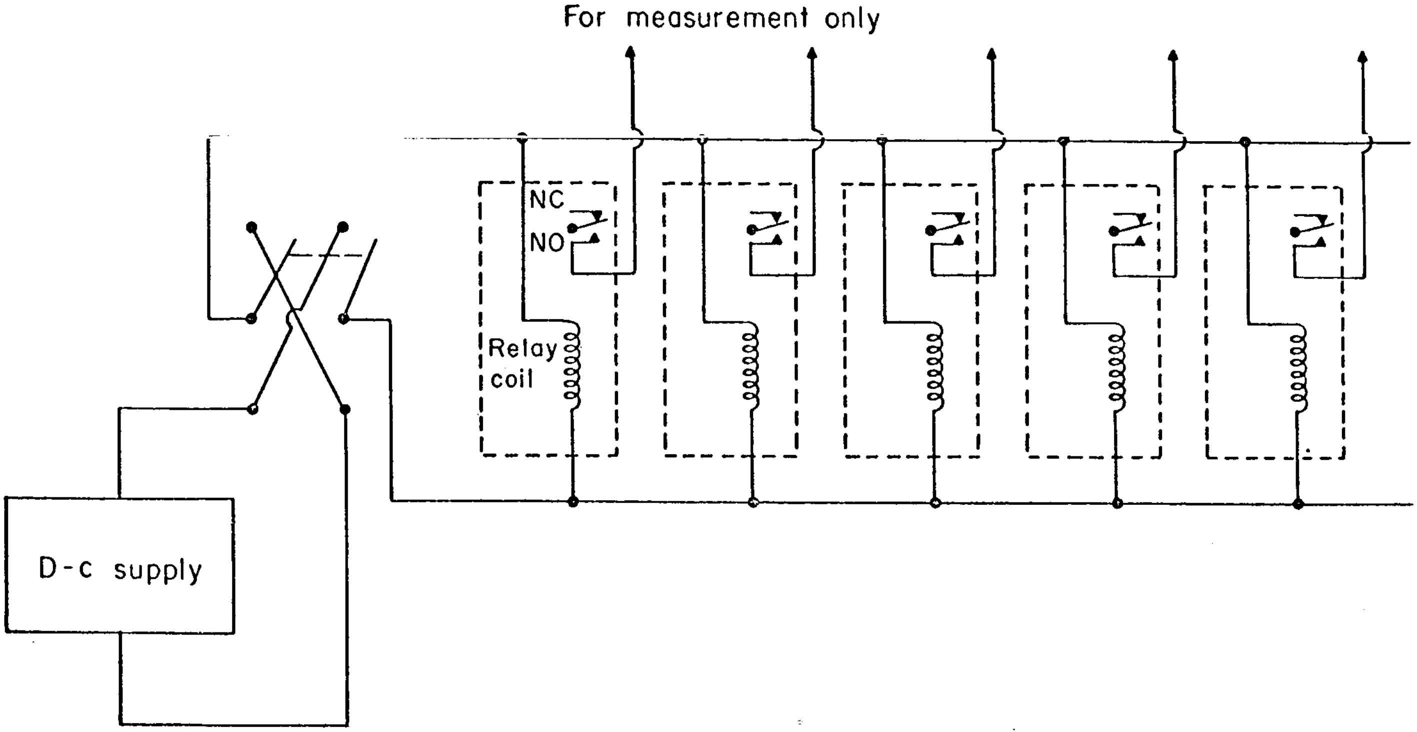


FIGURE 40. RELAY OPERATING CIRCUIT, ALL UNITS CONNECTED AS SHOWN WITH A COMMON POWER SUPPLY AND REVERSING SWITCH

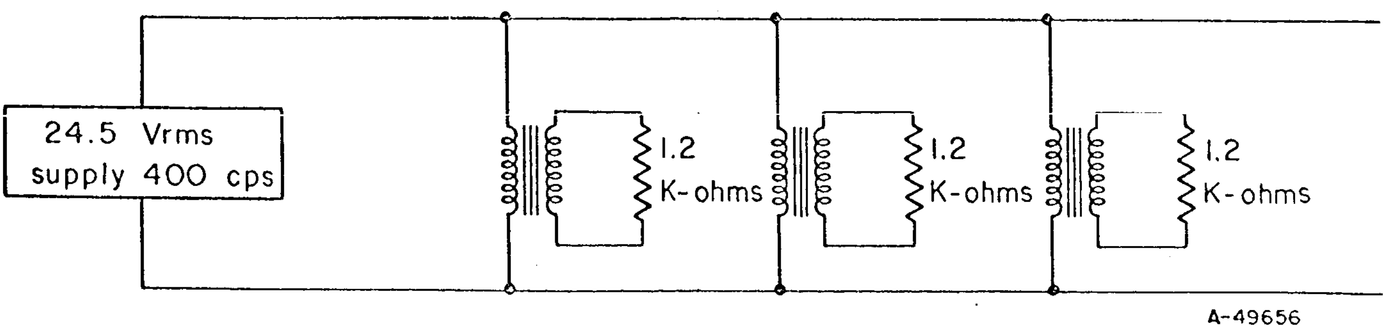


FIGURE 41. TRANSFORMER LOADING CIRCUIT, ALL UNITS CONNECTED AS SHOWN WITH A COMMON OSCILLATOR POWER SUPPLY

Photomultiplier Tube

The photomultiplier tubes were operated at 1500 volts, as shown in Figure 42, with a light intensity of 10^{-8} lumens. Each dynode has a 150 K-ohm resistor between it and the adjacent dynode with a 300 K-ohm resistor between the first dynode and the anode. The method used in mounting the photomultiplier tubes is described in the preceding section on environments. Switching was limited to the controls on the power supply and a system of banana jacks for measuring the anode current.

Cadmium Sulfide Cell

The cadmium sulfide cells were operated with a supply voltage of 7 volts dc. Individual 1 K-ohm dropping resistors were provided for each cell (see Figure 43). A constant light source of approximately 400 foot-candles was directed on to the CdS cells during the test and was obtained from a Type Q500T3/CL-120 V Quartzline lamp manufactured by General Electric. Therefore, the cells were illuminated and in a low-resistance state during the 1000-hour test.

DATA-RECORDING PROCEDURES

Two methods of data recording are used in this program: automatic recording on 80-column punch cards and manual recording on data sheets or in laboratory record books. The latter method has been limited to the gamma-exposure tests of the photomultiplier tubes, fiber optics, and cadmium sulfide cells; and the preliminary measurements where special instrumentation and limited lead length made automatic data recording impractical. This procedure will also be followed for similar measurements at the termination of the program.

The automatic data-recording system, briefly described in the section of this report entitled Measurements and Measurement Procedures, is used for all measurements other than those mentioned above. This data system automatically records the parameter measurement and the required identifying information on punch cards in accordance with the following format:

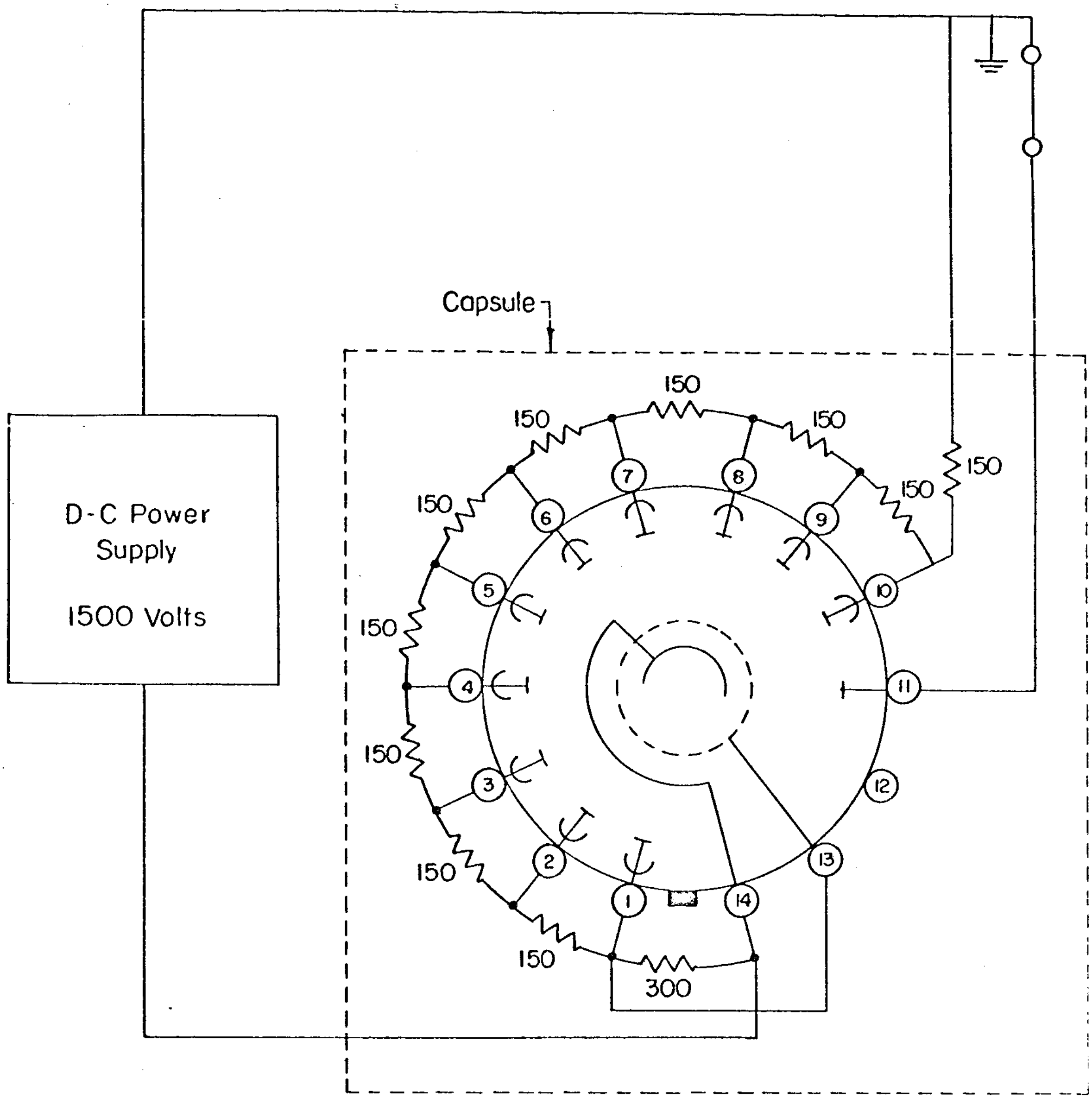


FIGURE 42. PHOTOMULTIPLIER TUBE LOADING CIRCUIT, ALL UNITS CONNECTED AS SHOWN

All resistor values are in k-ohms.

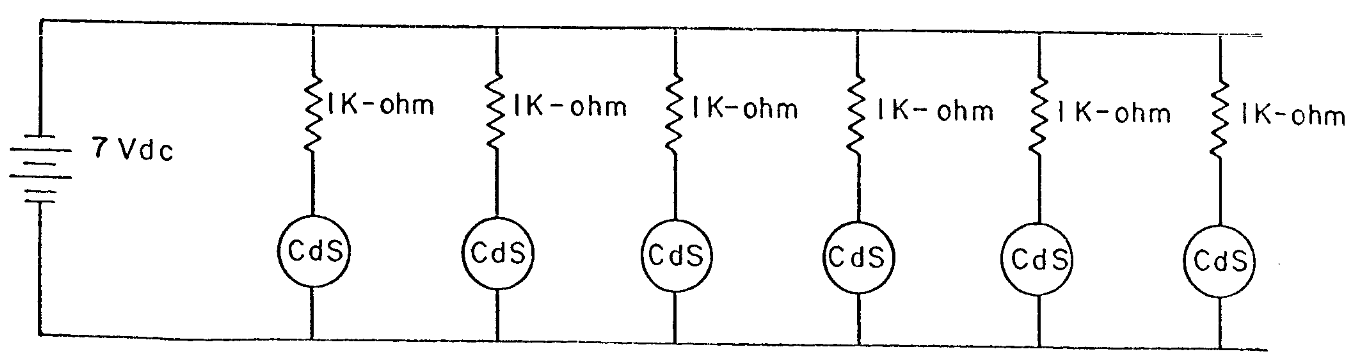


FIGURE 43. CADMIUM SULFIDE CELL LOADING CIRCUIT, ALL UNITS CONNECTED AS SHOWN

CARD FORMAT CODE DETAILS

Card Columns	Description of Information Recorded
1	Must be left blank
2, 3, 4, 5	"6415"
6, 7	Month
8, 9	Day
10, 11	Year
12—14	Measurement Period Hours x 1/10 i.e., 250 hrs = 025, 1000 hrs = 100, etc.
15	Last zero which will be supplied by program board
16	Operator Identification 1 Erlenbach 2 Richardson, etc.
17, 18	Measurement Code 01 Leakage, I_R, I_{CBO} 02 I_{EBO} 03 I_{CES} 04 Capacitance 05 Dissipation Factor 06 V_F or V_Z, first listed bias 07 V_F or V_Z, second listed bias 08 V_F or V_Z, third listed bias 09 Z_Z first listed bias 10 Z_Z second listed bias 11 V_G turn on 12 V_{BO} 13 I_H 14 Resistance 15 h_{FE} first listed bias 16 h_{FE} second listed bias 17 $V_{CE(SAT)}$ 18 Relay voltage to close 19 Transformer excitation current 20 --- coding for special pre- and post-measurements (already taken) 22 h_{FE} third listed bias
19, 20, 21, 22	Component Type

Component	Code
Aerovox P323ZN	3231
Sprague 118 P	1181
Goodall 683G	6831
GE 29F1614	6142
Fansteel HP	0056
Fairchild FP1184	1184
Fairchild FD643	0643
TI 1N916	0916
GE 3N58	3058
IR 1N2063	2063
Hoffman 1N822	0822
PSI PS4653	4653

TI GG 100 K	1001
Corning C-07	1002
AB CB Resistor	1003
N. Eng. Inst. 78P	7820
2N911	2911
2N914	2914
2N915	2915
2N1132	1132
2N2297	2297
2N930	2930
2N1050	1050
2N2412	2412
2N861	2861
Relay	2000
Switch	3000
Transformer	4000
Bendix (PT00A8)	5008
Cinch (DEM-9)	5009

23 Specimen number from information entry

0 = Numbers 0, --- 99

1 = Numbers 100 ---

24, 25 Specimen number from scanner automatically entered

Note: Add the decimal entries to get floating decimal result

26 - 29 DVM reading (entered automatically)

30 DVM decimal

Note: This entry is automatically supplied as follows:

.XXXX = 0

X.XXX = 1

XX.XX = 2

XXX.X = 3

XXXX. = 4

31, 32 Decimal from data entry Example: 1.000 = .1000 51 code

DECIMAL ENTRIES

Circuit	Entry	Resulting Units of Measurement
Leakage	43	Amps
$V_{CE(SAT)}$	50	Volts
Relay	49	Volts
Transformer	47	Amps
V_F, V_Z	50	Volts
Resistance	54	Ohms
Z_Z I_{ac} = .1mA	52	Ohms
I_{ac} = 1 mA	51	Ohms
h_{FE}	49	$1/h_{FE}$ (BMI constructed unit)
h_{FE}	50	h_{FE} (Fairchild Model 50)

Example 1 A = 1×10^{-6} amp = .10000 45, where the decimal code is derived by the following addition

43 = from col 28, 29

1 from circuit

1 from DVM

45

33	Decimal from circuit (automatic)
	STD and $V_{CE(SAT)}$, 0 punch always
	Leakage 1 = $x10^{-6}$ amp
	2 = 10^{-5} amp
	3 = 10^{-4} amp
	4 = 10^{-3} amp
	h_{FE} 1 = $1/h_{FE}$; 2 = $10/h_{FE}$
	Relay 1 punch always
34 – 37	Manual data entry 1
	Used in recording:
	1 - Capacitance (capacitors)
	2 - Gate voltage to fire (3N58)
	3 - Breakover voltage (3N58)
	4 - Holding current (3N58)
38 & 39	Decimal for manual data entry 1
40 – 43	Manual data entry 2
	Used in recording:
	1 - Dissipation factor (capacitors)
44 & 45	Decimal for manual entry 2
46	Flag

CARD FORMAT SUMMARY

Columns	
1	Blank
2 – 5	Project Number
6 – 11	Date
12 – 15	Elapsed time (zero is added in column 15 by program boards)
16	Operator code
17 – 18	Measurement code
19 – 22	Component type
23	Specimen number from data entry
24 – 25	Specimen number from scanner
26 – 29	DVM reading
30	DVM decimal
31 – 32	Decimal from data entry
33	DVM decimal from measurement circuit
34 – 37	Data one
38 – 39	Data one decimal
40 – 43	Data two
44 – 45	Data two decimal
46	Flag

The above card format is then converted to the following format by computer as a supplemental effort to this program. The purpose of this conversion is to provide data cards to the Jet Propulsion Laboratory in accordance with their Specification No. ZPP-2090-Gen for processing to obtain Computed Statistics Sheets as required by JPL Specification No. APP-2040-GenA:

PUNCH CARD FORMAT

Test Code - Columns 1 and 2. The Test Code as designated by JPL will always be 08. This two digit number is used to differentiate various test programs.

Component Code - Columns 3, 4, and 5. The three-digit code listed in Table 23 is used to identify the manufacturer and the manufacturer's part number.

Type of Test Code - Column 6. As designated by JPL, all data cards will contain a 2 for the test code.

Group Code - Columns 7 and 8. The group code identifies the groups within the test design as shown at the top of Figure 1 of this test procedure and the following table:

Coding for Identifying Groups Within the Test Design

Group Code	Specimen Numbers	Test Conditions
01	20 - 39	100 C, 760 torr, operational
02	40 - 59	100 C, 10^{-5} torr, operational
03	00 - 19	100 C, 10^{-5} torr, operational(a)
04	60 - 79	100 C, 10^{-5} torr, operational(b)
05	80 - 99	50 C, 10^{-5} torr, operational(a)
06	100 - 110	100 C, 10^{-5} torr, static(a)
07	120 - 139	100 C, 760 torr, static

Temperature Code - Columns 9 and 10. The temperature code identifies the temperatures at which various measurements are performed. These codes are as follows:

01 - Room ambient
02 - 50 C
03 - 100 C

Group Measurement Code - Columns 11 and 12. The Group Measurement Codes are given in the boxes at the lower right hand corners of the measurement interval blocks of the basic test design shown in Figure 1 of this procedure. Codes 05 through 17 for Test Group 4 and Codes 02 through 14 for the six other test groups correspond to the various measurement times. The other group measurement codes are for the preliminary and final measurements and/or tests.

Number of Parameters - Column 13. The number of parameters recorded in the punch card is entered in Column 13. For this program it will be either 1, 2, 3, 4, or 5 (although the card format permits up to 10 parameters to be recorded in a single card). See Table 24 for further information concerning which parameters are recorded in the various data fields.

(a) 10,000 hours at 3×10^5 n cm^2 sec^{-1} and 1×10^5 ergs g^{-1}(C) hr^{-1}.
(b) 100 hours at 3×10^7 n cm^2 sec^{-1} and 1×10^7 ergs g^{-1}(C) hr^{-1}.

TABLE 23. COMPONENT CODE

Part Type and Manufacturer	Manufacturer's Type Number	Component Code Number
Capacitors		
Aerovox	P323ZN2	001
Sprague	118P10592S2	002
Good-All	683G10592W2	003
General Electric	5K106AA6	004
Fansteel	HP56C50D1	005
Diodes		
Fairchild	FD1184	006
Fairchild	FD643	007
Texas Instruments	1N916	008
Silicon Controlled Switches		
General Electric	3N58	009
Power Rectifiers		
International Rectifier(a)	1N2063	010
Zener Diodes		
Hoffman	1N822	011
Pacific Semiconductor	1N756A	012
Resistors		
Texas Instruments	CG	013
Corning	C-07	014
Allen-Bradley	CB	015
Potentiometers		
New England Instruments	78PSH-128-16	016
Transistors		
Fairchild	2N911	017
Fairchild	2N914	018
Fairchild	2N915	019
Fairchild	2N1132	020
Fairchild	2N2297	021
Texas Instruments	2N930	022
Texas Instruments	2N1050	023
Texas Instruments	2N2412	024
Philco	2N861	025
Relays		
Sigma	32RJD90GD-GSP	026

TABLE 23. (Continued)

Part Type and Manufacturer	Manufacturer's Type Number	Component Code Number
Switches		
Minneapolis-Honeywell	1HM1	027
Transformers		
Triad	SP-13 (TF5RX13ZZ)	028
Photomultipliers		
CB5[a]	7817	029
Cadmium Sulfide Cells	CL-605	030
Clairex[a]		
Fiber-Optic Discs		
		031
Connectors		
Cinch[a]	DEM-9P-NM-10 DEM-9S-NM-10	032
Bendix[a]	PT 06A-8-4P PT 00A-8-4S	033

(a) Data Cards not prepared on these parts.

TABLE 24. PARAMETER DATA FIELD ASSIGNMENTS

Component Type and Code Number	Field No. 1	Field No. 2	Field No. 3	Field No. 4	Field No. 5
Capacitors					
001	Capacitance	Dissipation factor	Leakage current[a]	--	--
002	Capacitance	Dissipation factor	Leakage current[a]	--	--
003	Capacitance	Dissipation factor	Leakage current[a]	--	--
004	Capacitance	Dissipation factor	Leakage current[a]	--	--
005	Capacitance	Dissipation factor	Leakage current[a]	--	--
Diodes					
006	V_F	I_R	--	--	--
007	V_F	I_R	--	--	--
008	V_F	I_R	--	--	--
Silicon Controlled Switch					
009	V_F	V_G	V_{BO}	I_H	--
Zener Diodes					
011	V_Z	Z_{Z1}	Z_{Z2}	--	--
012	V_Z	Z_{Z1}	Z_{Z2}	--	--
Resistors					
013	Resistance	--	--	--	--
014	Resistance	--	--	--	--
015	Resistance	--	--	--	--
Potentiometers					
016	Resistance	Leakage current[a]	--	--	--
Transistors					
017	I_{CBO}	$V_{CE(sat)}$	h_{FE1}	h_{FE2}	--
018	I_{CBO}	$V_{CE(sat)}$	h_{FE1}	h_{FE2}	--

TABLE 24. (Continued)

Component Type and Code Number	Field No. 1	Field No. 2	Field No. 3	Field No. 4	Field No. 5
Transistors (Continued)					
019	I_{CBO}	$V_{CE(sat)}$	h_{FE_1}	h_{FE_2}	h_{FE_3}
020	I_{CBO}	$V_{CE(sat)}$	h_{FE_1}	h_{FE_2}	--
021	I_{CBO}	$V_{CE(sat)}$	h_{FE_1}	h_{FE_2}	--
022	I_{EBO}	$V_{CE(sat)}$	h_{FE_1}	--	--
023	I_{CBO}	$V_{CE(sat)}$	h_{FE_1}	h_{FE_2}	h_{FE_3}
024	I_{EBO}	$V_{CE(sat)}$	h_{FE_1}	--	--
025	I_{CBO}	$V_{CE(sat)}$	h_{FE_1}	h_{FE_2}	h_{FE_3}
Relays					
026	V_{close}	Leakage current[(a)]	--	--	--
Switches					
027	Leakage current[(a)]	--	--	--	--
Transformer					
028	Excitation current	Leakage current[(a)]	--	--	--

(a) Leakage current is a measure of insulation resistance to facilitate automatic data recording.

Number of Last Field – Column 14. The number of the last data field containing data will be entered in Column 14. For this program it will be either 1, 2, 3, 4, or 5.

Number of Cards – Column 15. The number of cards used to record a complete set of data on any single specimen will be entered in Column 16. For this program it will always be a 1, since all data on a single specimen at a specific measurement interval are combined on one card.

Number of This Card – Column 16. The number of a particular card in the set of cards to record a complete set of data on any single specimen will be entered in Column 16. For this program it will always be a 1.

Data Form Code – Column 17. The form in which the data are recorded will be entered in Column 17. A 1 indicates decimal form and 2 indicates range form. The two forms are the following:

Decimal	XX.XX
Range	R.XXXX

For this program a 2 will always be punched in Column 17 indicating the range form.

Serial Number – Columns 18, 19, and 20. The serial number or specimen number identifies the particular specimen within a component type and will have a range from 000 to 139 for this program.

Data Fields – Columns 21 through 70. Columns 21 through 70 contain ten data fields of five columns each.

Failure – Column 71. Column 71 will normally be punched 0. In the case of catastrophic failure, a 1 will be punched in Column 71.

Parameter Data Field Assignments. The data field assignments for the various parameter measurements are shown in Table 24 for each component code number used in this program.

Range Data Form. The range data form is in R.XXXX format for this program with the following range factors:

RANGE FORM	EQUIVALENT TO
PLUS XXXX	.XXXX TIMES 10 MINUS 6
MINUS XXXX	.XXXX TIMES 10 MINUS 5
9XXXX	.XXXX TIMES 10 MINUS 4
8XXXX	.XXXX TIMES 10 MINUS 3
7XXXX	.XXXX TIMES 10 MINUS 2
6XXXX	.XXXX TIMES 10 MINUS 1
5XXXX	.XXXX TIMES 10 PLUS 0
4XXXX	.XXXX TIMES 10 PLUS 1
3XXXX	.XXXX TIMES 10 PLUS 2
2XXXX	.XXXX TIMES 10 PLUS 3
1XXXX	.XXXX TIMES 10 PLUS 4
0XXXX	.XXXX TIMES 10 PLUS 5

Parameter Units. The units in which the various parameters are recorded are:

Parameter	Units
Voltage	volts
Current	amperes
Resistance (for resistors and potentiometers)	thousands of ohms (K-ohms)
Dynamic impedance (Zener diodes)	ohms
Capacitance	microfarads
Dissipation factor	per cent
h_{FE}	--

DATA VERIFICATION

All data, whether recorded manually or automatically, is verified immediately at the site of the measuring activity. The automatic data-recording system, where the measurements are punched on 80-column data cards, provides data verification for both automatically and manually entered data. The reading on the digital voltmeter is verified prior to the punching of the data card when the system is in the automatic mode of operation. If the reading is questionable, the measurement sequence is repeated by recycling the data system without advancing to another specimen. Similarly, manually entered data are verified on a keyboard visual verification unit prior to punching the data on to the data card.

In addition to the data verification at the time of measurement, the information contained on the data cards is further verified when collated for processing by the computer into the JPL Specification ZPP-2090-Gen card format. The information contained in the latter is also checked in the form of data or card tabulations before the cards are shipped to the Jet Propulsion Laboratory.

Preliminary and final measurements that are made without the use of the data-recording system (i.e., measurements are recorded in laboratory record books or on data forms designed for that purpose) are verified in that the circuitry is checked before the measurements are made and the readings are checked for consistency.

FAILURE VERIFICATION

Failure verification will be limited to final electrical measurements that will be performed when the program is terminated. These electrical measurements will consist of whatever is necessary to verify that a particular part has actually failed. This verification will apply to catastrophic failure only.

Electrical measurements used in verifying failures will be identical with those used during the test but with the specimens removed from the environmental chamber. Thus, the effect of lead length and possible electrical interference will be eliminated during the measurements to verify catastrophic failures.

CLH:DJH/slp:so

APPENDIX A

CIRCUIT OPERATION PROCEDURES FOR PARAMETER MEASUREMENTS EMPLOYING THE AUTOMATIC DATA-RECORDING SYSTEM

CIRCUIT OPERATION PROCEDURES FOR PARAMETER MEASUREMENTS EMPLOYING THE AUTOMATIC DATA-RECORDING SYSTEM

Appendix A gives the complete step-by-step procedures for performing parameter measurements with the various circuits and instrumentation used with the automatic data-recording system. These procedures include tabular information as to the measurement conditions, i.e., amount and type of electrical signal applied during measurement.

The instrumentation that is used to provide input voltages and/or signals to the circuit boxes used in the automatic data-recording system include:

(1) 500 VDC Power Supply, Hewlett Packard Model 712 A
(2) 300 VDC Power Supply
(3) Low Voltage Power Supply, Power Design Inc., Model 4005
(4) 400 CPS Generator, General Radio Model 1214A.

CIRCUIT OPERATION CHECK LIST

RESISTANCE, Resistors and Potentiometers

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "Standard" program board
2. Number of steps in cycle = 7
3. Set Timer Number 1 at 3 sec.
4. Set 300-volt power supply to 300, all others off
5. DVM on DC
6. Set up ID and decimal entries
   - Decimal = 54
   - Measurement code = 14
   - Component-type Identification (Columns 19 through 22)

TI GG	(100K)	1001
Corning C-07	(100K)	1002
A-B CB	(100K)	1003
N. Eng. Inst. 78P	(20K)	7820

C. Setting on Circuit

1. On first test specimen prior to measurement, when "latch, then punch" light is on, set switch to Check
2. Adjust for a DVM reading of .5000, DVM "on"
3. Return SW to read and DVM to STANDBY

D. Operating Sequence

1. When "latch then punch" light appears
   a. Press latch DVM when reading is satisfactory. If you wish to try again, operate DVM manually
   b. When DVM reading is latched where you want it, press "punch"
2. Periodically repeat group "C" above

TABLE A-1. DATA-SYSTEM CONNECTIONS FOR MEASUREMENT OF COMPONENT-PART PARAMETERS

Component Part to be Tested	Data-System Scanner Connector Levels			Scanner Bypass	
	28	29	30	31	32
Capacitors	+ Lead			- Lead (common)	
Diodes, FD1184, FD643, and 1N916	Anode			Cathode (common)	
3N58, cont. switch	Anode	Gate		Cathode (common)	
Zener diodes, 1N822 PS4653	Anode, current	Anode, voltage		Cathode, current (common)	Cathode, voltage (common)
1N2063, rect.	Anode			Cathode (common)	
Resistors	Lead	Common			
Potentiometers	Element	Element		Case, gnd. (common)	
Transistors	Base	Collector, current	Collector, voltage	Emitter, current (common)	Emitter, voltage (common)
Relays	Contact	Coil		Contact and coil (common)	
Transformers	Primary 1	Primary 2	Secondary 1	Secondary 2 (common)	
Switches	NO contact			Common contact	
Connectors	Lead	Common lead		Case, gnd. (common)	

RELAY, VOLTS TO CLOSE

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "h_{FE}-Relay" program board
2. Number os steps in cycle = 10
3. Set Transistor Power Supply at 6 volts constant voltage. All others off.
4. DVM on DC
5. Set up ID and decimal entries
   Decimal = 49
   Component type = 2000 (Columns 19 through 22)
   Measurement code = 18

C. Settings on Circuit

1. Switch at "normal"
2. "Adjust V" potentiometer full off (counterclockwise)

D. Operating Sequence

1. When "adjust to close ---" light appears
   a. Adjust V upward until "relay closed" lamp just lights (Increase voltage of transistor P. S. if needed)
   b. Press "unlock DVM"
2. "Turn back V---", lamp should light. If not, manually lock DVM with button provided. Manually operate DVM if needed to get a satisfactory reading.
3. Turn "adjust V" back
4. Throw "unlatch relay" switch up and then return. "Relay closed" lamp should go out.
5. Press "punch" button

TRANSFORMER EXCITATION CURRENT

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "Standard" program board
2. Number of steps = 7
3. Set Timer Number 1 at 3 seconds
4. Set GR oscillator to 400 cps, full on. All other supplies off.
5. DVM on AC
6. Set up ID and Decimal Entries
   Decimal = 47
   Component type = 4000 (Columns 19 through 22)
   Measurement code = 19
   + Others

C. Settings on Circuit

1. Set switch on "V in", DVM to ON. Adjust for reading of 35.00 (after osc. warms up)
2. Return switch to "I excit" and RETURN DVM TO STANDBY

D. Operating Procedure

1. When "latch then punch" light appears
   a. Press latch DVM when reading is satisfactory. If you wish to repeat the measurement, operate DVM manually
   b. When DVM reading is latched where you want it, press "punch"
2. Periodically repeat group "C" above

LEAKAGE CURRENT

A. Connections

1. See Table A-1.

B. Settings on Data System

1. Use "Leakage" program board
2. Number of steps in cycle = 15
3. Set (charging) timer Number 2 as follows
   45 seconds for capacitors
   5 seconds for other specimens
4. Set (final charge) Timer Number 1 as follows
   5 seconds for capacitors
   5 seconds for other specimens
5. Use 300-volt power supply (higher voltage) or transistor power supply (lower voltage)
6. DVM on DC
7. Set up ID and decimal entries

   See Table 2 for ID Information
   Decimal = 43
   + Others

C. Settings on Circuit

1. Switch for measurement to be performed
2. Recycle switch at "operate"
3. a. Switch to "set voltage", DVM to ON
   b. Select "hi volts" (300 volt supply) or "lo volts" (transistor supply)
   c. Adjust power supply to correct measurement voltage as shown in Table A-2. (In some cases, it will be necessary to use a 45-volt battery in series with the transistor power supply)
   d. Return switch to "measure", return DVM TO STANDBY
4. Set range switch so that decimal is always full left but avoid left hand zeros whenever possible. (Range switch position will be recorded on data card automatically.)

D. Operating Sequence

1. When punch light appears, evaluate readings
   a. Was range switch set connected? If not, change it and recycle the circuit with recycle switch. (Hold switch at recycle through Step 15)
   b. If reading is satisfactory, press "punch" button

Note: It may be necessary to use the "manual DVM latch" button prior to above steps.

TABLE A-2. BIAS CONDITIONS FOR LEAKAGE-CURRENT MEASUREMENTS

Component Part	Part ID Code (Columns 19 through 22)	Bias Conditions
Capacitors		
Aerovox (P323ZN)	3231	200 Vdc
Sprague (118P)	1181	200 Vdc
Good-All (683G)	6831	100 Vdc
GE (29F1614 Tant.	6142	100 Vdc
Fansteel (HP) Tant.	0056	50 Vdc
Diodes		
FD1184	1184	V_R = 50 Vdc
FD643	0643	V_R = 60 Vdc
1N 916	0916	V_R = 20 Vdc
1N 2063	2063	V_R = 200 Vdc
Transistors		
2N911 (NPN)	2911	I_{CBO} at V_{CB} = 75 Vdc
2N914 (NPN)	2914	I_{CBO} at V_{CB} = 20 Vdc
		*I_{EBO} at V_{EB} = 4 Vdc
2N915 (NPN)	2915	I_{CBO} at V_{CB} = 15 Vdc
2N1132 (PNP	1132	I_{CBO} at V_{CB} = 30 Vdc
2N2297 (NPN)	2298	I_{CBO} at V_{CB} = 60 Vdc
		*I_{EBO} at V_{EB} = 5.0 Vdc
2N930 (NPN)	2930	I_{EBO} at V_{EB} = 5.0 Vdc
		*I_{CES} at V_{CE} = 45 Vdc
2N1050 (NPN)	1050	I_{CBO} at V_{CB} = 30 Vdc
		*I_{EBO} at V_{EB} = 6 Vdc
2N2412 (PNP)	2412	I_{EBO} at V_{EB} = -5 Vdc
		*I_{CES} at V_{CE} = -25 Vdc
2N861 (PNP)	2861	I_{CBO} at V_{CB} = 10 Vdc
Potentiometers		
78P (20K)	7820	IR, element to case, at 200 Vdc
Connectors		
Bendix (PT00A-8)	5008	IR, pin to pin and pin to case, at 200 Vdc
Cinch (DEM-9)	5009	

TABLE A-2. (Continued)

Component Part	Part ID Code (Columns 19 through 22)	Bias Conditions
Relays		
Sigma (32RJD90GD)	2000	IR, NO contact to coil, at 200 Vdc
Transformers		
Triad (SP-13)	4000	IR, primary to secondary, at 200 Vdc
Switches		
Minn. Honey. (1HM1)	3000	IR, NO contact to common, at 200 Vdc

*Initial or preirradiation and postirradiation at room ambient only.

DIODES V_Z AND V_F

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "Standard" program board
2. Number of steps in cycle = 7
3. Set timer Number 1 at 3 seconds
4. For bias through 20 mA, set 500-volt power supply to 500, all others are off.
5. Turn on transistor power supply, set constant current for 50, 100, or 400 mA. Other power supplies are off.
6. Set up ID and decimal entires

   Decimal = 50

   See Table A-3 for Part ID Code (Columns 19 through 22)

C. Settings on Circuit

1. Set V_F - V_Z switch
2. Set bias switch to proper position (see Table A-3)
3. Adjust bias
   a. Switch to "set I", DVM on
   b. Adjust corresponding potentiometer as follows:

I position	Correct DVM Reading
0. 1 mA	1. 000
1. 0 mA	1. 000
7. 5 mA	7. 500
5. 0 mA	5. 000
20 mA	2. 000
50 mA*	5. 000
100 mA*	1. 000
400 mA*	4. 000

* Adjust using constant current setting on transistor power supply

4. Return switch to "read", DVM TO STANDBY

D. Operating Sequence

1. When "latch then punch" light appears
   a. Press latch DVM when reading is satisfactory. If you wish to repeat the measurement, operate DVM manually
   b. When DVM reading is latched where you want it, press "punch"
2. Periodically repeat group "C" above

TABLE A-3. BIAS CONDITIONS FOR REFERENCE VOLTAGE (V_Z) AND FORWARD VOLTAGE DROP (V_F) MEASUREMENTS OF DIODE SPECIMENS

Component Part	Part ID Code (Columns 19 through 22)	Bias Conditions
FD 1184	1184	V_F at I_F = 5 mA, 30 mA*, and 0.1 mA*
FD 643	0643	V_F at I_F = 100 mA, 400 mA*, and 0.1 mA*
IN 916	0916	V_F at I_F = 1 mA, 10 mA*, and 0.1 mA*
3N58	3058	V_F at I_F = 50 mA
IN822	0822	V_Z at I_Z = 7.5 mA (regulated to 0.1%)
PS 4653	4653	V_Z at I_Z = 20 mA

*Preirradiation and postirradiation at room ambient only.

ZENER IMPEDANCE, Z_Z

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "Standard" program board
2. Number of steps in cycle = 7
3. Set Timer Number 1 at 3 seconds
4. Set 500-volt power supply to 500
5. Set 300-volt power supply to 250
6. Set G. R. generator to 1 KC, amplitude half on
7. DVM normally on AC
8. Set up ID and decimal entries
   Decimal = 52 (I_{ac} = 0.1 mA)
   51 (I_{ac} = 1 mA)
   See Table 4 for Part ID Code (Columns 19 through 22)
   + Others

C. Settings on Circuit

1. Calibrate amplifier
   a. Set switch to "calibrate input"
   b. DVM on AC and on
   c. Turn on calibration source
   d. Set "calibrate input" to .1000 volt
   e. Set switch to "read"
   f. Adjust "calibrate" for 10.00 volts
   g. Turn off calibration source
   h. RETURN DVM TO STANDBY
2. Set I_{dc} bias
   a. DVM on DC, ON
   b. Switch on "I_{dc}"
   c. Adjust potentiometer corresponding to desired I_{dc} bias (see Table A-14). DVM reads directly in mA
   d. RETURN DVM TO STANDBY
3. Set I_{ac} bias
   a. DVM on AC and on
   b. Switch on "I_{ac}"
   c. Adjust potentiometer corresponding to desired I_{ac} bias (see Table 4). DVM reads directly in mA
   d. DVM TO STANDBY
4. Switch on "read"
5. DVM on AC, STANDBY

D. Operating Sequence

1. When "latch then punch" light appears
   a. Press "latch DVM" when reading is satisfactory. If you wish to repeat the measurement, operate DVM manually
   b. When DVM reading is latched where you want it, press "punch"
2. Periodically repeat group "C" above

TABLE A-4. BIAS CONDITIONS FOR ZENER IMPEDANCE (Z_Z) MEASUREMENTS OF REFERENCE DIODES

Component Part	Part ID Code	Bias Conditions
1N 822	0822	I_Z at 7.5 mAdc - 1.0 mAac
		I_Z at 1.0 mAdc - 0.1 mAac
PS 4653	4653	I_Z at 20 mAdc - 1.0 mAac
		I_Z at 1.0 mAdc - 0.1 mAac

TRANSISTOR $V_{CE(SAT)}$

A. Connections

1. See Table A-1

B. Settings on Data System

1. $V_{CE(SAT)}$ program board
2. Number of steps in cycle = 9
3. Set Timer Number 1 to 3 seconds
4. Set 300-volt power supply to 300 v
5. Set transistor power supply at 10 volt (2N911, 2N915, 2N930, 2N2412, 2N861) constant current at required value for I_C (2N1132, 2N914, 2N2297, 2N1050, see Table A-5)
6. Double check to be sure that I_B supply is actually operating
7. DVM on DC
8. Set up ID and decimal entries
   Decimal = 50
   Measurement code = 17
   See Table 5 for Part ID Code (Columns 19 through 22)
   + Others

C. Settings on Circuit

1. Set switch for proper transistor type
2. Set switch at "300.0" DVM ON, adjust 300-volt power supply for a DVM reading of 300.0 (Selector must be on 2N911)
3 a. For 2N911, 2N915, 2N930, 2N2412, 2N861 ONLY, set switch at "10.00", DVM on and adjust transistor power supply in the voltage mode for a reading of 10.00. (Selector must be on 2N911)
   b. For 2N1132, 2N914, 2N2297, 2N1050 set switch to I_C, and adjust the transistor power supply in the constant current mode until DVM reads 1/100 x I_C required. See Table 5.
4. Check I_C and I_B (DVM reads 1/100 x I_C in mA and 1/10 x I_B in mA) I_C should be within 2 per cent and I_B within 5 per cent. Adjust power supplies if needed. See Table A-5.
5. Return switch to "read", DVM TO STANDBY

D. Operating Sequence

1. When "latch, then punch" light appears
   a. Press "latch DVM" when balance occurs
   b. Manually re-run DVM if required
   c. When DVM reading is satisfactory, press "punch"

TABLE A-5. BIAS CONDITIONS FOR COLLECTOR-EMITTER SATURATION VOLTAGE ($V_{CE(SAT)}$) MEASUREMENTS OF TRANSISTORS

Component Part	Part ID Code	Bias Conditions
2N911 (NPN)	2911	I_C = 10 mA, I_B = 1 mA
2N914 (NPN)	2914	I_C = 200 mA, I_B = 20 mA
2N915 (NPN)	2915	I_C= 10 mA, I_B = 1 mA
2N1132 (PNP)	1132	I_C = 150 mA, I_B = 15 mA
2N2297 (NPN)	2297	I_C = 150 mA, I_B = 15 mA
2N930 (NPN)	2930	I_C = 10 mA, I_B = 0.5 mA
2N1050 (NPN)	1050	I_C = 500 mA, I_B = 100 mA
2N2412 (PNP)	2412	I_C = 10 mA, I_B = 1 mA
2N861 (PNP)	2861	I_C = 5 mA, I_B = 0.5 mA

TRANSISTOR h_{FE} (Battelle Constructed Instrumentation)

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "h_{FE} Relay" program board
2. Number of steps in cycle = 10
3. Set 300-volt power supply to 300 (pulse generator dc Base drive)
4. Set 500-volt power supply to 300 (amplifier)
5. Turn on pulse generator, adjust as appropriate
6. DVM on RATIO
7. Set up ID and decimal entries
   Decimal = 49
   - Others
8. Set Transistor Supply (see Table A-6)

C. Settings on Circuit

1. Select NPN or PNP (see Table A-6)
2. Set Collector Current Switch (see Table A-6)

D. Operating Sequence

1. When "adjust I_B, then unlock DVM" light appears, adjust base controls until I_C meter reads on the red line (50 μ A)
2. Adjust base sampling resistor switch until I_B meter reads between 40 μA and 70 μA. (Preferably near high end).
3. Check I_C meter. If necessary re-adjust base controls.
4. Press "unlock DVM"
5. Use "manual DVM lock" switch if necessary
6. When reading appears correct ($1/h_{FE}$ on $10/h_{FE}$)* and is locked, turn base adjust to minimum I_B. (All potentiometers must be fully counterclockwise)
   (Note: If this is not done, program will "hang up" on next specimen)
7. Press "punch" to continue program.

*Avoid two left zero digits by switching to "X10". Otherwise use (X1). Decimal will be entered automatically. DVM may be manually rerun if reading is not satisfactory.

TABLE A-6. BIAS CONDITIONS FOR D-C GAIN (h_{FE}) MEASUREMENT OF TRANSISTORS

Transistor Type	Polarity	Part ID Code	Measurement Condition Code[a]	I_C, mA	Transistor Power-Supply Setting, volts[b]
2N911	NPN	2911	1	10	10.5
			2[c]	100	10.5
2N914	NPN	2914	1	100	5.5
			2	10	1.5
2N915	NPN	2915	1	10	5.5
			2	10	1.5
			3	100	10.5
2N1132	PNP	1132	1	150	10.5
			2	10	10.5
2N2297	NPN	2297	1	150	10.5
			2	10	10.5
2N930	NPN	2930	1[d]	100	10.5
2N1050	NPN	1050	1	500	10.5
			2	10	10.5
			3	100	10.5
2N2412	PNP	2412	1	10	10.5
2N861	PNP	2861	1	10	10.5
			2	10	1.5
			3[c]	100	10.5

(a) Used to identify conditions at which h_{FE} measurements are performed.

(b) Power supply is set to a value 0.5 volt greater than the V_{CE} value desired to compensate for voltage drop in Battelle-constructed equipment. These values, less 0.5 volt, are used for V_{CE} setting on Fairchild Model 50.

(c) Discontinued after 4000 hours.

(d) I_C = 10 mA and V_{CE} = 5.0 volts after 4000 hours.

TRANSISTOR h_{FE} (Fairchild Model 50)

A. Connections

1. See Table A-1

B. Settings on Data System

1. Use "Fairchild Model 50 h_{FE}" program board
2. Number of steps in cycle = 6
3. Set up ID and decimal entries
   Decimal = 50
   -Others

C. Settings on Circuit

1. Select NPN or PNP (see Table A-6)
2. Set Collector Current Switch (see Table A-6)
3. Set Collector-Emitter Voltage (see Table A-6)

D. Operating Sequence

1. Clear short indicator if necessary
2. Press "real" button
3. While "real" button is depressed and satisfactory reading is obtained on instrument, press "punch" button
4. If reading is questionable release "read" button and repeat Steps 2 and 3 to verify or correct reading.

3N58 CONTROLLED SWITCH

I - V_{GF}, Gate Voltage to Fire

A. Connections (see Diagram (a), Figure A-1)

B. Settings on Data System

1. "Manual" program board
2. Manual board in punch
3. Set Up ID and decimal entries
   a. ID Code 3058 in Columns 19 through 22
   b. Decimal = 50 in Columns 38 and 39

C. Operation of Circuit

Start E_g at zero, increase slowly. Firing voltage is indicated by a jump in the voltmeter reading. Gate voltage to fire is that voltage on the meter just before the jump.

Expected range: 0. 4 v to 0. 65 v.

D. Operating Sequence

1. Punch V_{GF} value obtained in C on manual keyboard (Data entry one)
2. Depress punch buttons
3. Advance specimen selector to next specimen

3N58 CONTROLLED SWITCH

I - V_{BO}, Breakdown Voltage

A. Connections (see Diagram (b), Figure A-1)

B. Settings on Data System

1. "Manual" program board
2. Manual board in punch
3. Set up ID and decimal entries
   a. ID Code 3058 in Columns 19 through 22
   b. Decimal = 52 in Columns 38 and 39

C. Operation of Circuit

Start E_A below 40v, increase slowly. Firing voltage is indicated by a sudden drop in the voltmeter reading. Breakover voltage is that voltage on the meter just before the drop.

Expected range: 40 to 80 volts

Do not test above 80 volts. This would result in excessive current.

D. Operating Sequence

1. Punch V_{BO} value obtained in C on manual keyboard (Data entry one)
2. Depress punch buttons
3. Advance specimen selector to the next specimen.

3N58 CONTROLLED SWITCH

I - I_H, Holding Current

A. Connections (see Diagram (c), Figure A-1 and A-2)

B. Settings on Data System

1. "Manual" program board
2. Manual board in punch
3. Set up ID and decimal entries
   a. ID Code 3058 in Columns 19 through 22
   b. Decimal = 48 for X.X, 47 for 0.XX, and 46 for 0.0X mA in Columns 38 and 39

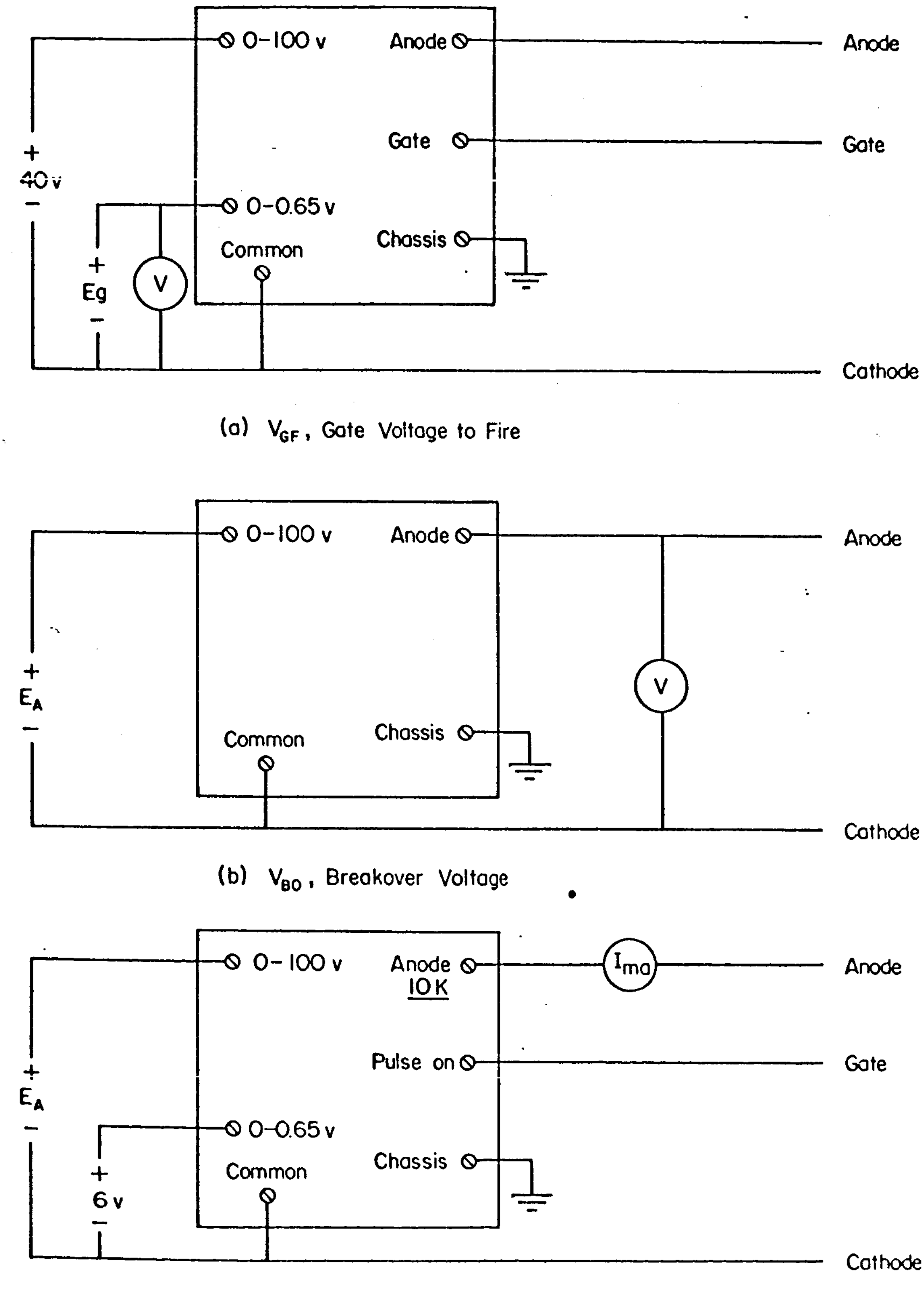
C. Operation of Circuit

Start E_A at about 40 v. Turn device on by depressing switch NO momentarily. Decrease E_A slowly until the current suddenly drops to zero. I_H is the current just before the drop.

Expected range: 0.05 to 2 ma.

D. Operating Sequence

1. Punch I_H value obtained in C on manual keyboard (data entry one)
2. Depress punch buttons
3. Advance specimen selector to next specimen.



(c) I_H, Holding Current

FIGURE A-1. CIRCUITS FOR MEASURING CONTROLLED SWITCHES

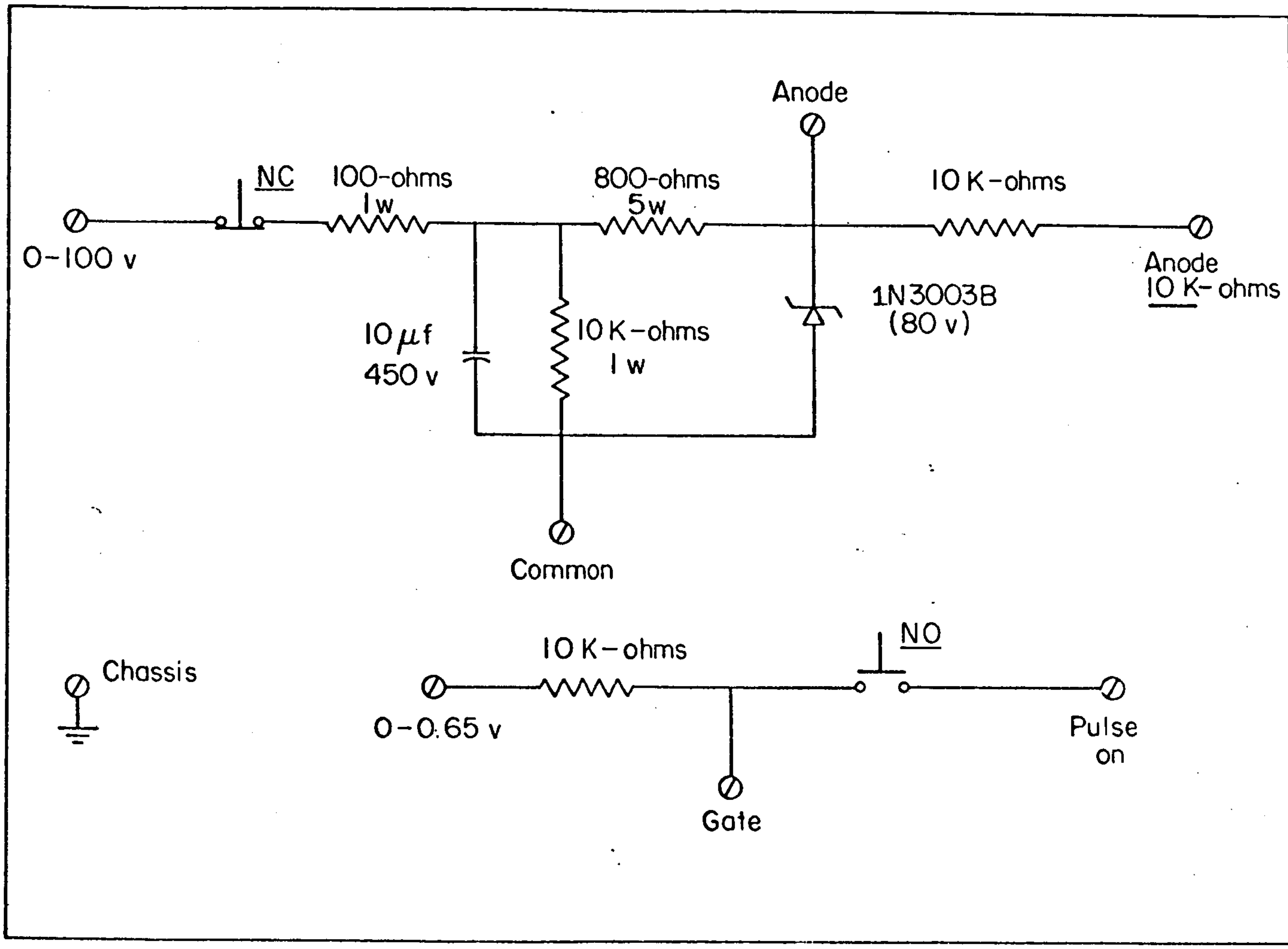


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FIGURE A-2. CONTROLLED SWITCH MEASURING-BOX CIRCUITRY

CAPACITANCE AND DISSIPATION FACTOR

A. Connections

1. Connect the high and low terminals of the bridge to the Cap. - and Cap. - terminals of the CRS and CAP Measurement circuit, respectively

B. Settings on Data System

1. "Manual" program board
2. Manual board in punch
3. Set up ID and decimal entries
   a. See Table A-7 for ID number for capacitor under test
   b. Decimal entries

      1.0 and 2.0 μf capacitors, 51 in Columns 38 and 39
      56 μf capacitors, 52 in Columns 38 and 39
      Per cent dissipation factor, 52 in Columns 44 and 45

C. Settings on Circuit

1. Apply d-c bias to tantalum capacitors as indicated in Table A-7 No d-c bias required on other types.
2. Adjust oscillator according to frequency indicated in Table A-7 for capacitor type to be measured.

Use external oscillator (from power-supply panel of data system), and external plug-in filter.

D. Operating Sequence

1. Bring bridge to balance
2. Punch readings in manual keyboard of Data System
3. Depress punch buttons
4. Advance specimen selector to next part to be measured

TABLE A-7. CONDITIONS FOR CAPACITANCE AND DISSIPATION-FACTOR MEASUREMENTS OF CAPACITOR SPECIMENS

	Part ID Code	Measurement Conditions
Aerovox (P323ZN), 1.0 μf	3231	400 cps
Sprague (118P, 1.0 μf	1181	400 cps
Good-All (683G), 1.0 μf	6831	400 cps
GE (29F1614)(5K106AA6), 2.0 μf	6142	120 cps, a-c volts = 15, d-c volts = 50
Fansteel (HP), 56 μf	0056	120 cps, a-c volts = 15, d-c volts = 50

Data System Automatic Sequences

STANDARD PROGRAM

Applications: Resistance, Transformer Excitation Current, Diode V_F and V_Z, Zener Impedance

Sequence:

1. Apply Bias
2. Delay (Timer Number 1)
3. Unlatch DVM
4. Operator manually latch DVM
5. Operator manually commands punch
6. Remove bias
7. Punch
8. Select next specimen

H_{FE} - RELAY PROGRAM

Applications: Transistor H_{FE}, Relay volts to close

Sequence:

1. Confirm that I_B drive is set low (this is overridden with relay circuit)
2. Close V_{BB}, R_B (base) circuit for transistors; close coil circuit for relay
3. Close V_{CC}, R_C (collector) circuit for transistors; nonfunctional for relay
4. Operator manually adjusts bias
5. Operator manually unlocks DVM
6. DVM locks automatically
7. Operator manually commands punch
8. Open V_{CC}, R_C (collector) circuit on transistors
9. Open V_{BB}, R_B (base) circuit or coil circuit
10. Punch
11. Select next specimen

LEAKAGE PROGRAM

Application: All leakage- and reverse-current measurements

Sequence:

1. Charge specimen (Timer Number 2)
2. Connect measurement shunt

3. Delay (Timer Number 1)
4. Release DVM, automatic hold at balance
5. Operator manually commands to punch
6. Discharge specimen
7. Punch
8. Select next specimen

$V_{CE(SAT)}$ PROGRAM

Application: Transistor $V_{CE(SAT)}$

Sequence:

1. Apply base current
2. Apply collector current
3. Delay (Timer Number 1)
4. Release DVM
5. Operator manually locks DVM
6. Operator manually commands to punch
7. Remove collector current
8. Remove base current
9. Punch
10. Select next specimen

APPENDIX B

<u>PHOTOGRAPHS OF TEST FACILITY AND LOCATION OF TEST SPECIMENS RELATIVE TO THE FISSION PLATE OF THE REACTOR'S THERMAL COLUMN</u>

PHOTOGRAPHS OF TEST FACILITY AND LOCATION OF TEST SPECIMENS RELATIVE TO THE FISSION PLATE OF THE REACTOR'S THERMAL COLUMN

The construction and design of the loading panels required to provide the specified operating conditions for the various test components included in the program are shown in Figure B-1. The automatic data-recording system is shown to the left of the loading panels mounted in two relay racks.

Figure B-2 is a photograph of the vacuum system and associated piping for the 100 C, high-flux capsule, which is submerged in the shielding pool shown in the foreground.

The two control environment test chambers are shown in Figure B-3. The test components mounted in the vacuum chamber are enclosed by an aluminum cylinder having a metal-sheathed heating element wound in a helical manner about its outer surface. The aluminum cylinder and the heating element provide the 100 C test temperature for the components contained in the chamber, which will also be subjected to a vacuum of 1.0×10^{-5} torr or less.

The component parts in the environmental oven are mounted in open lattice-type trays to permit free air circulation within the chamber. These trays are constructed of aluminum and Teflon strips interlocked much like the dividers of an egg crate. The test specimens, which are to be subjected to an ambient temperature of 100 C and normal atmospheric pressure, are suspended in the open areas between the interlocking strips.

The component parts being subjected to radiation and/or vacuum environments are mounted on aluminum plates 10 inches in diameter. These plates are assembled onto tripod structures, using three 1/2-inch aluminum rods for support which are attached to the top plates of the radiation capsules and the base plate of the vacuum chamber to be used for the 10^{-5} torr control test. Figure B-4 is a photograph of the mounting assembly for the 10,000-hour, low-flux, 100 C radiation capsule (Test Group 3) and illustrates the design and construction of these assemblies.

Figures B-5 through B-21 illustrate the approximate location of the various test specimens as mounted on the aluminum plates and relative to the main radiation source, the fission plate of the reactor's thermal column. Spent fuel elements from the Battelle Research Reactor will be located as necessary to increase the gamma exposure rate to the desired values.

The locations of the primary groups or operational test specimens that are included in all three radiation capsules are shown in Figures B-5 through B-15.

The locations of the supplemental groups or nonoperating test specimens that are also included in the radiation-capsule assembly for Test Group 3 (10,000-hours of low flux, 100 C ambient) are shown in Figures B-16 through B-20. Many of the nonoperating conditions are also included in the 100 C control test at atmospheric pressure (Test Group 1).

The Bendix and Cinch connectors, whose locations relative to the fission plate are shown in Figure B-21, are limited to the 100 C ambient high- and low-flux radiation capsules (Test Groups 3 and 4) and the 100 C control test at atmospheric pressure (Test Group 1).

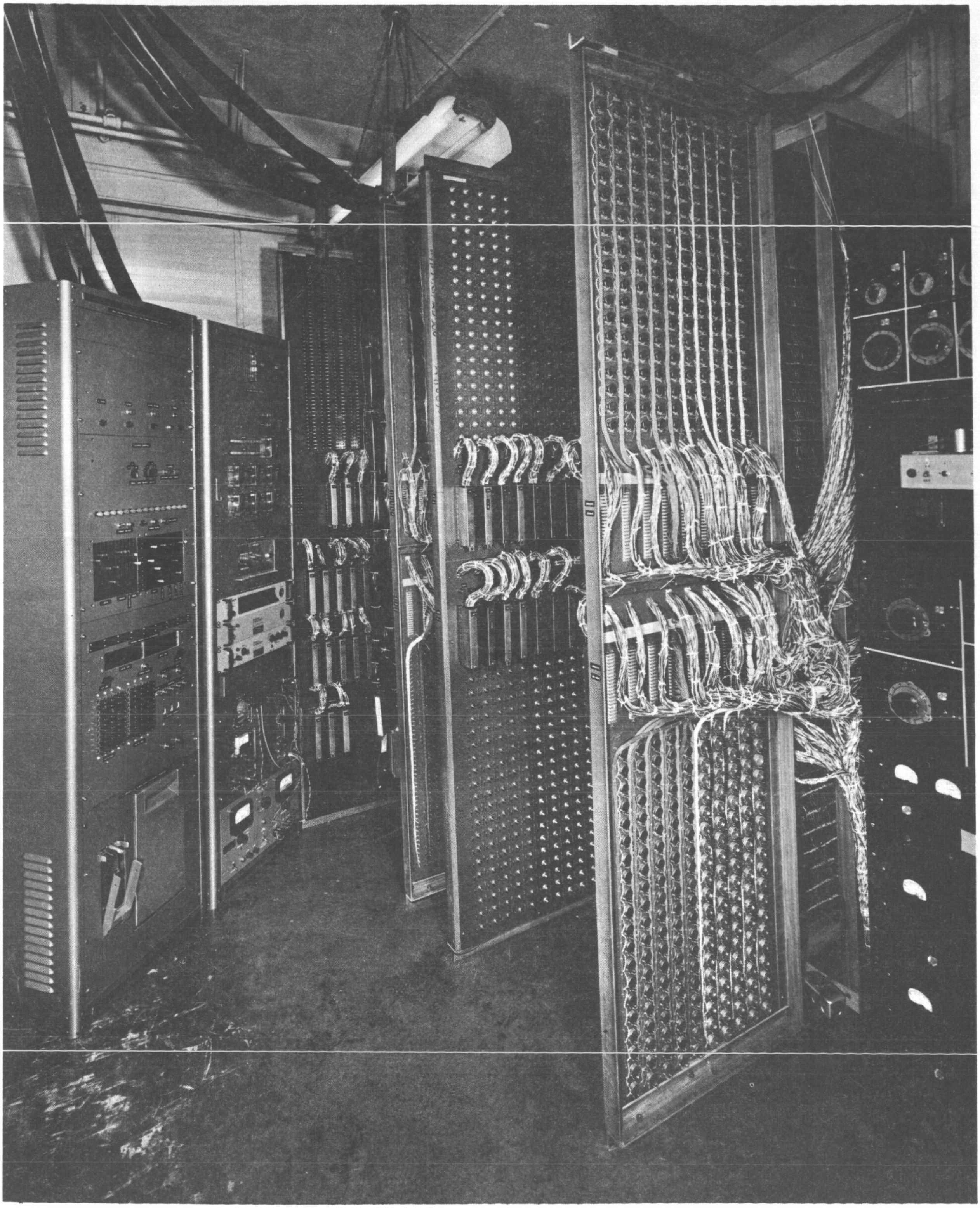

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FIGURE B-1. THE LOADING PANELS AND AUTOMATIC DATA-RECORDING SYSTEM FOR THE OPERATION AND MEASUREMENT OF THE VARIOUS TEST COMPONENTS

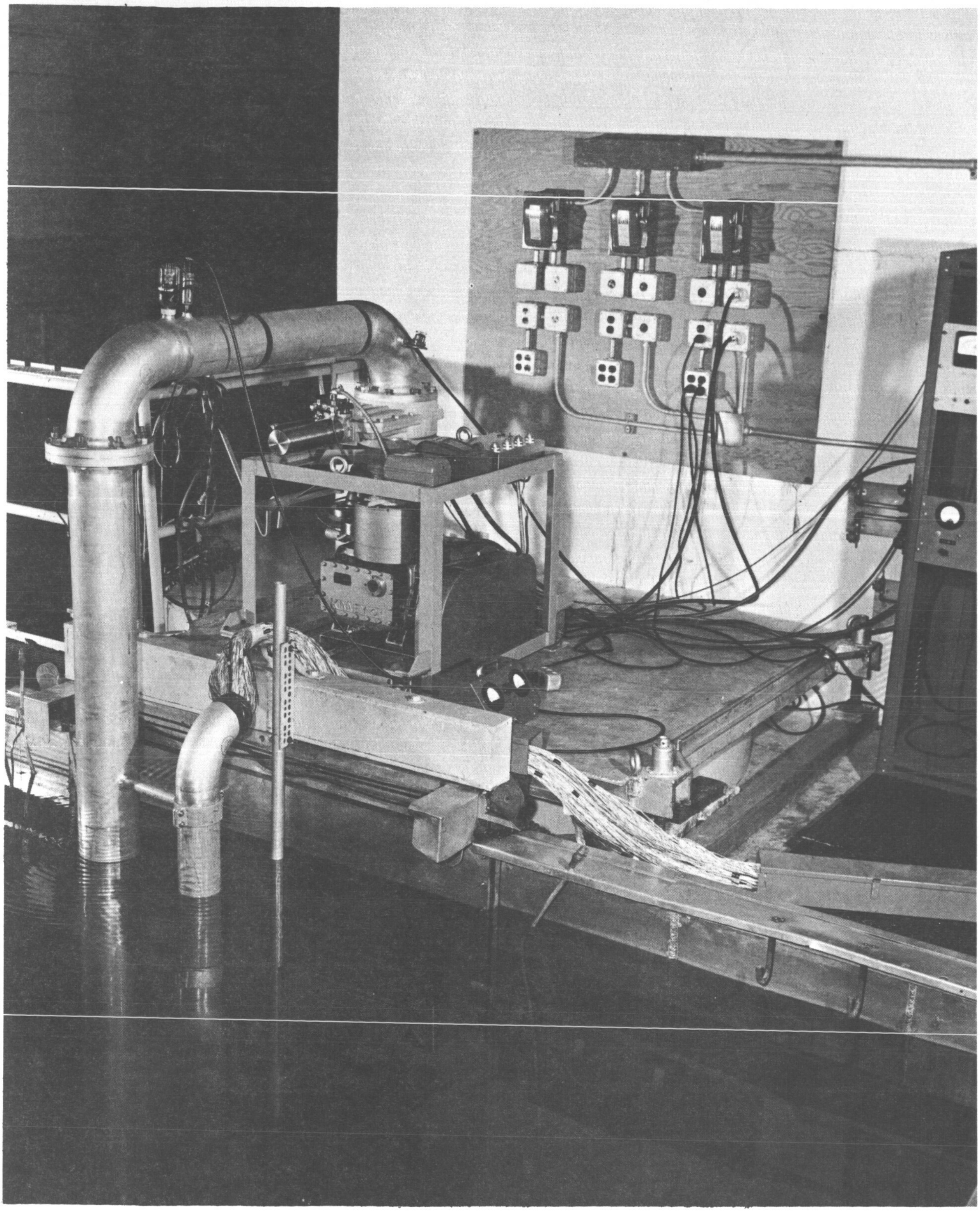

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FIGURE B-2. THE VACUUM SYSTEM AND ASSOCIATED PIPING FOR THE 100 C, HIGH-FLUX CAPSULE

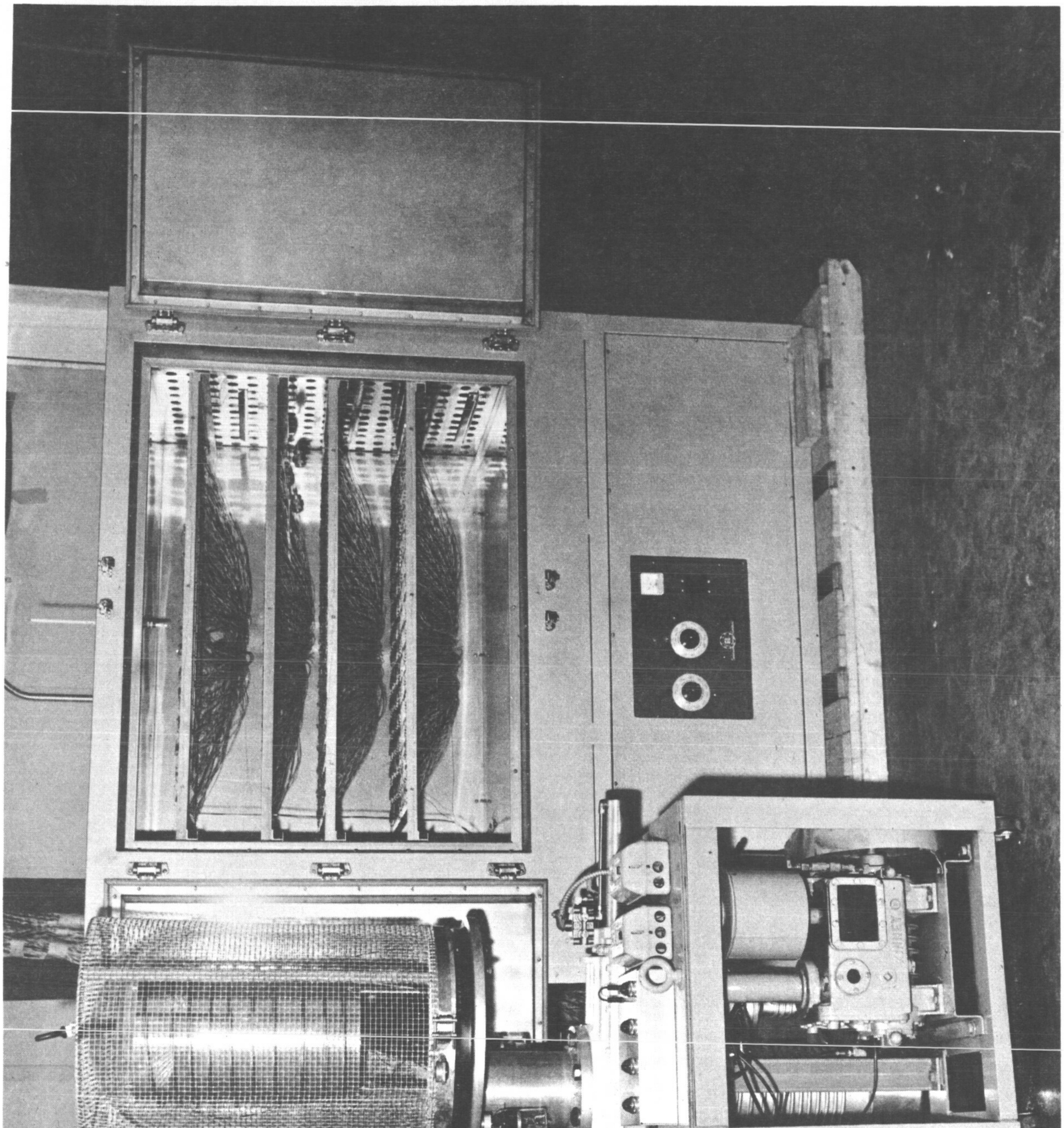

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FIGURE B-3. THE TWO CONTROL ENVIRONMENT TEST CHAMBERS TO BE USED IN THE RADIATION STUDY

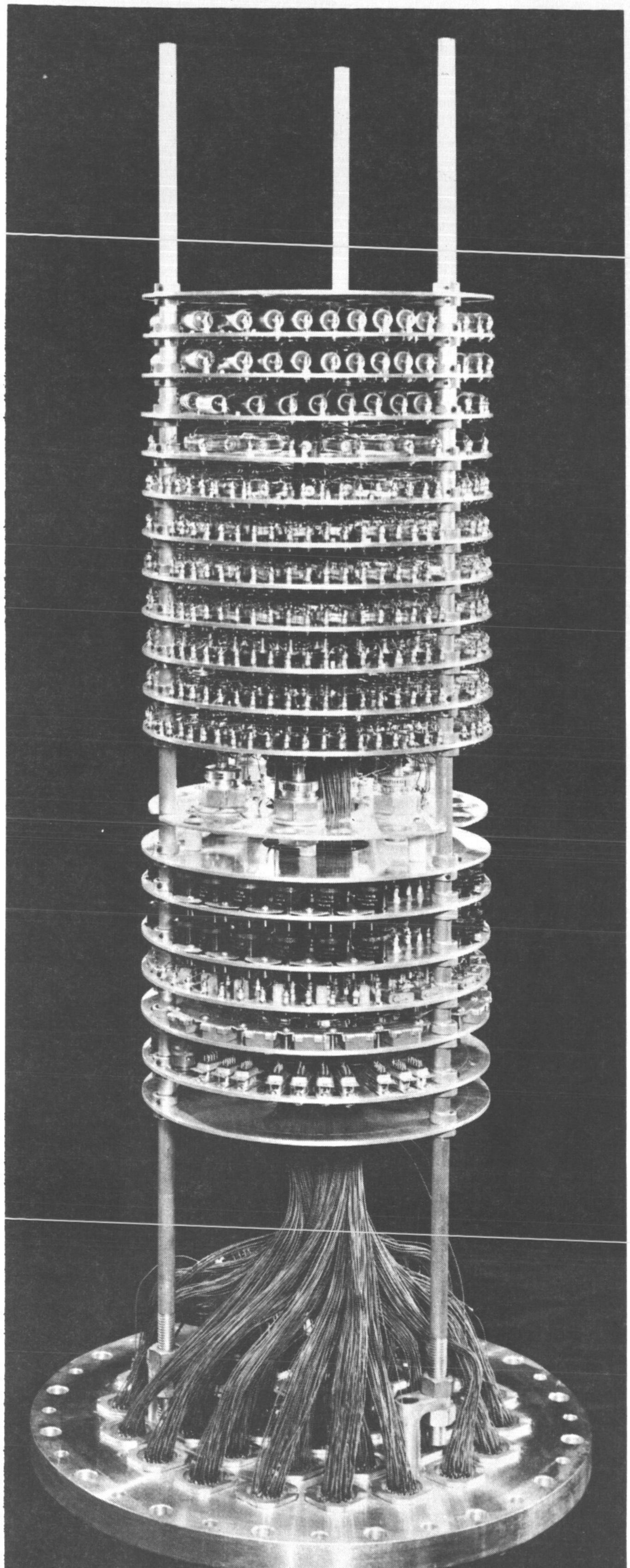

FIGURE B-4. MOUNTING ASSEMBLY FOR THE TEST GROUP 3 RADIATION CAPSULE

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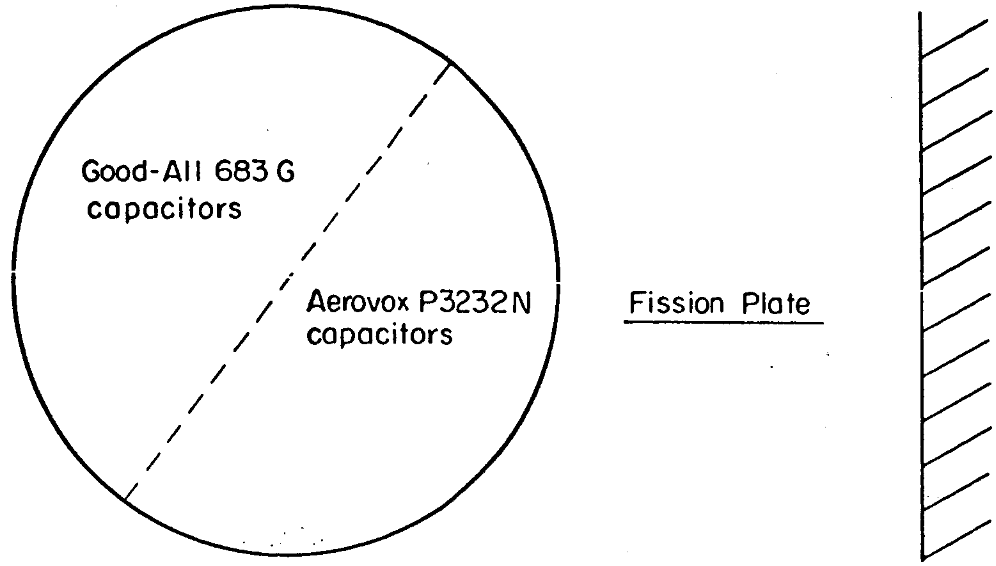

FIGURE B-5. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF AEROVOX AND GOOD-ALL CAPACITORS TO THE FISSION PLATE OF THE THERMAL COLUMN

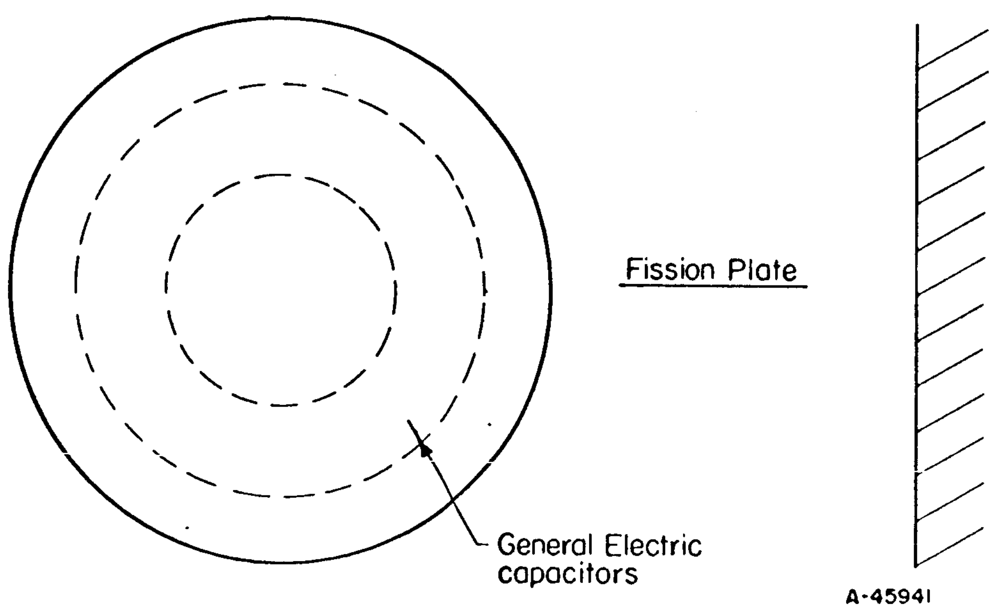

FIGURE B-6. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF GENERAL ELECTRIC CAPACITORS TO THE FISSION PLATE OF THE THERMAL COLUMN

The capacitors are evenly spaced in a radial manner.

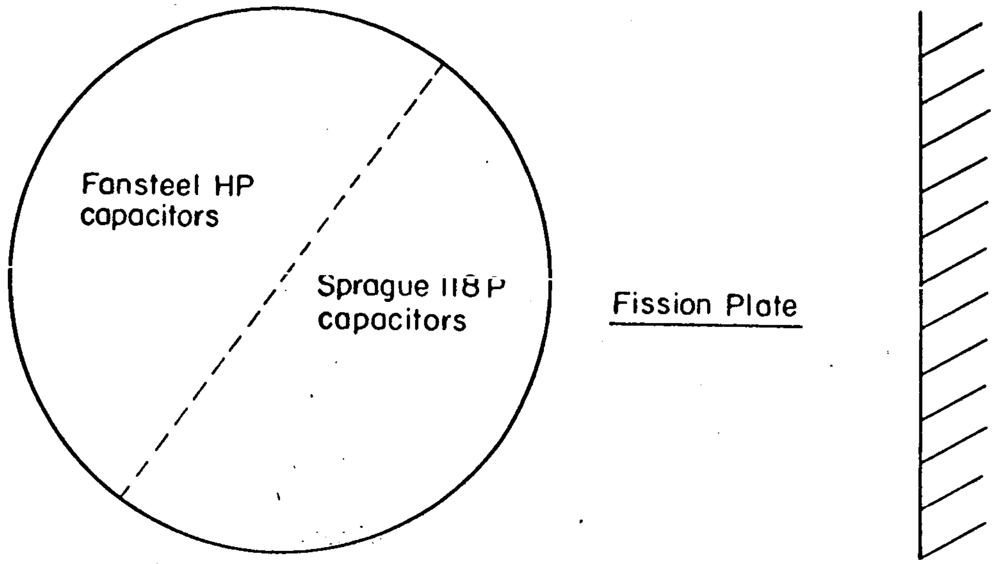

FIGURE B-7. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF FANSTEEL AND SPRAGUE CAPACITORS TO THE FISSION PLATE OF THE THERMAL COLUMN

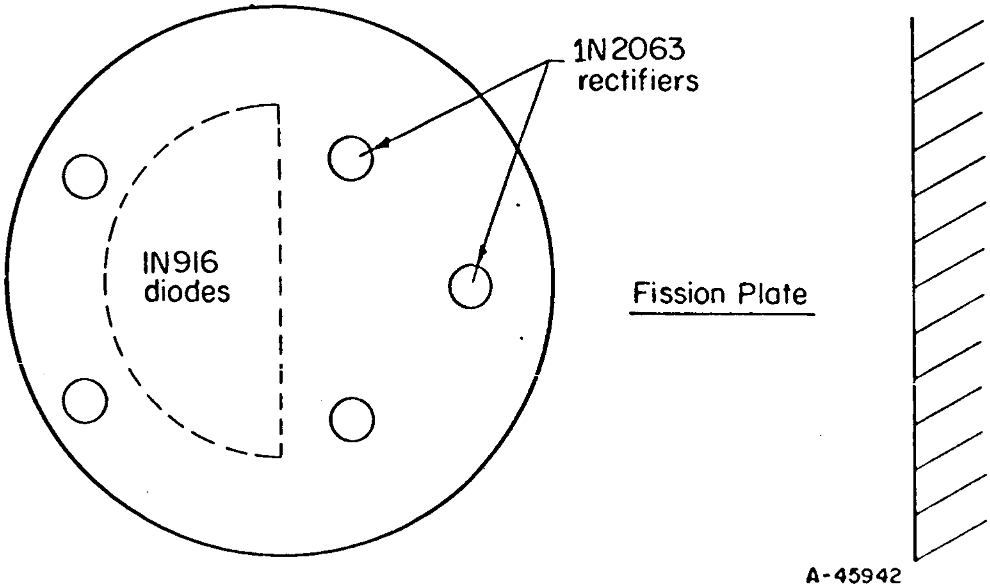

FIGURE B-8. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF 1N916 DIODES AND 1N2063 RECTIFIERS TO THE FISSION PLATE OF THE THERMAL COLUMN

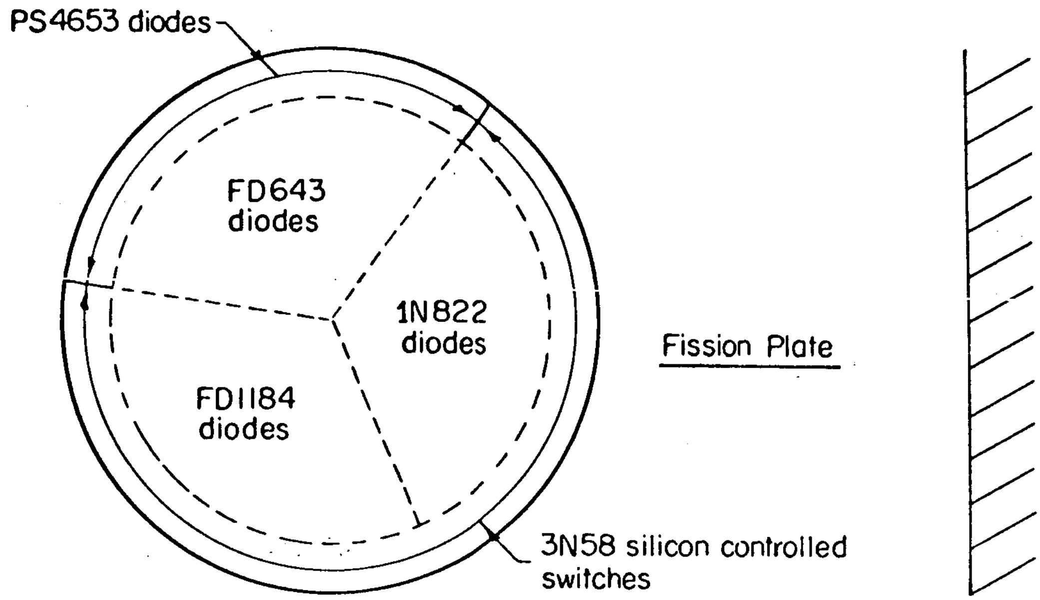

FIGURE B-9. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF FD643, FD1184, PS4653, AND 1N822 DIODES, AND 3N58 SILICON CONTROLLED SWITCHES TO THE FISSION PLATE OF THE THERMAL COLUMNS

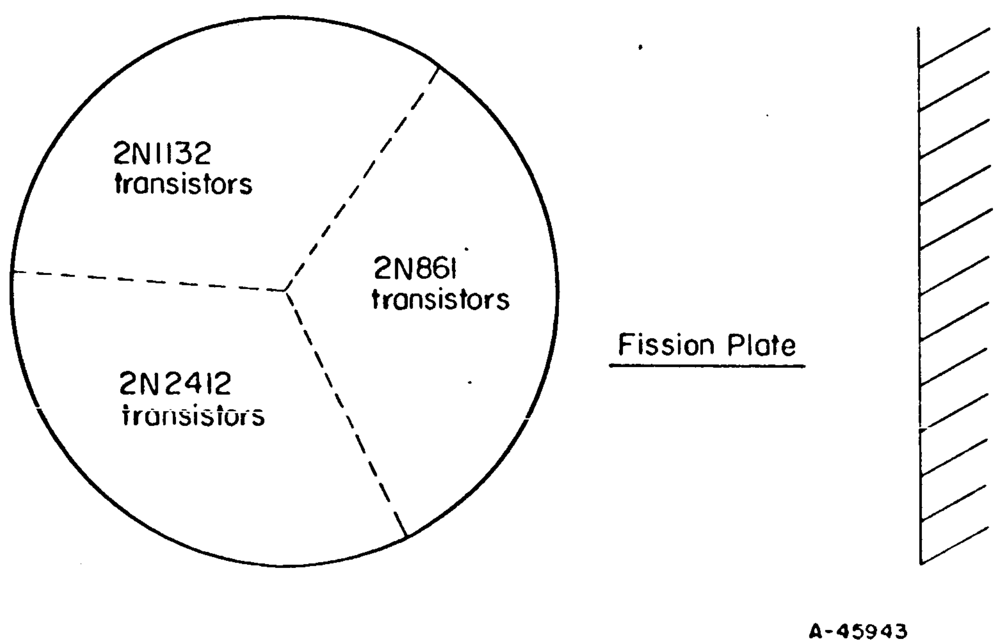

FIGURE B-10. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF 2N1132, 2N861, AND 2N2412 TRANSISTORS TO THE FISSION PLATE OF THE THERMAL COLUMN

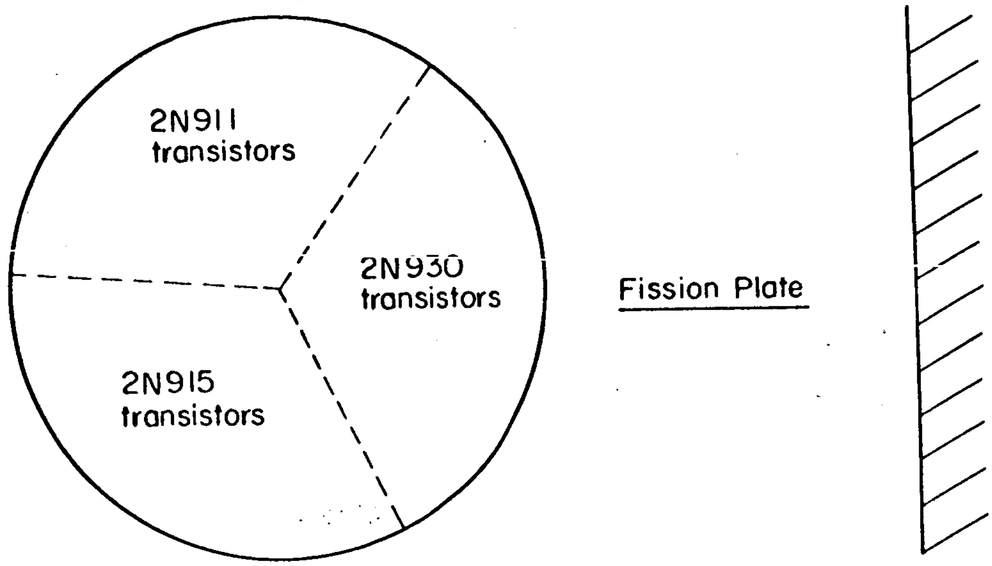

FIGURE B-11. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF 2N911, 2N930, AND 2N915 TRANSISTORS TO THE FISSION PLATE OF THE THERMAL COLUMN

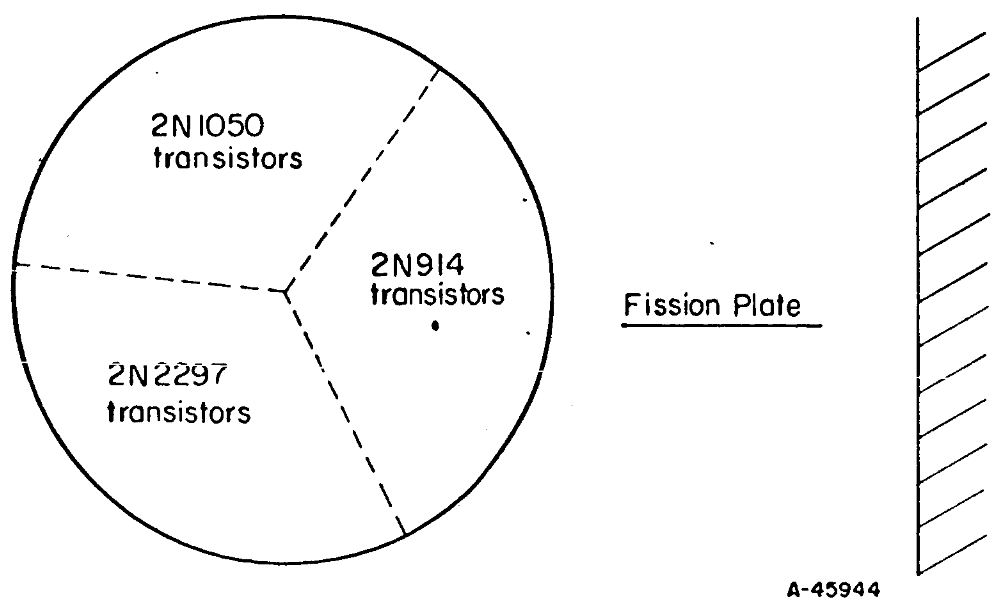

FIGURE B-12. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF 2N1050, 2N914, AND 2N2297 TRANSISTORS TO THE FISSION PLATE OF THE THERMAL COLUMN

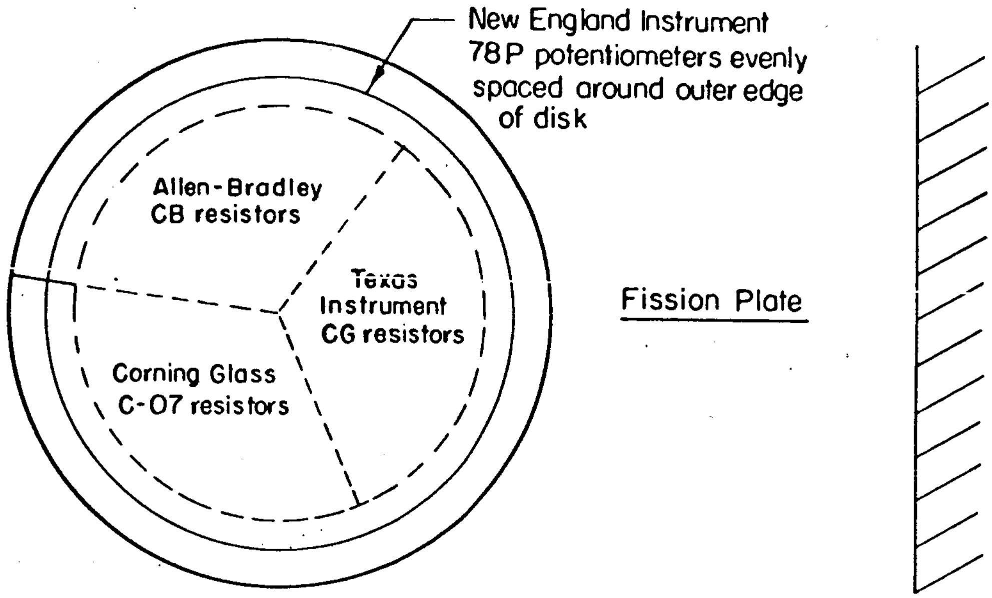

FIGURE B-13. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF CB, CG, AND C-07 RESISTORS, AND 78P POTENTIOMETERS TO THE FISSION PLATE OF THE THERMAL COLUMN

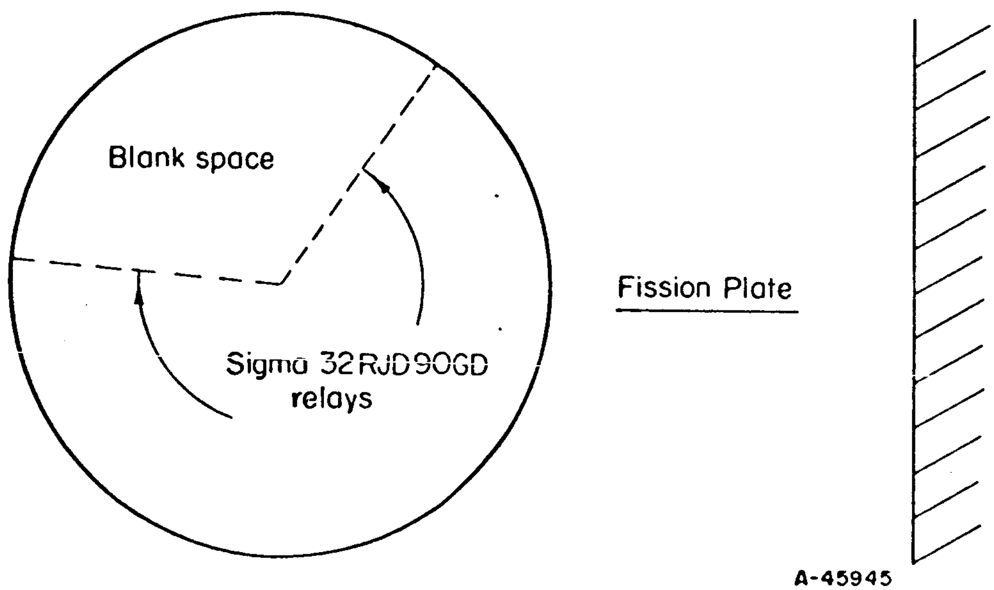

FIGURE B-14. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF SIGMA RELAYS TO THE FISSION PLATE OF THE THERMAL COLUMN

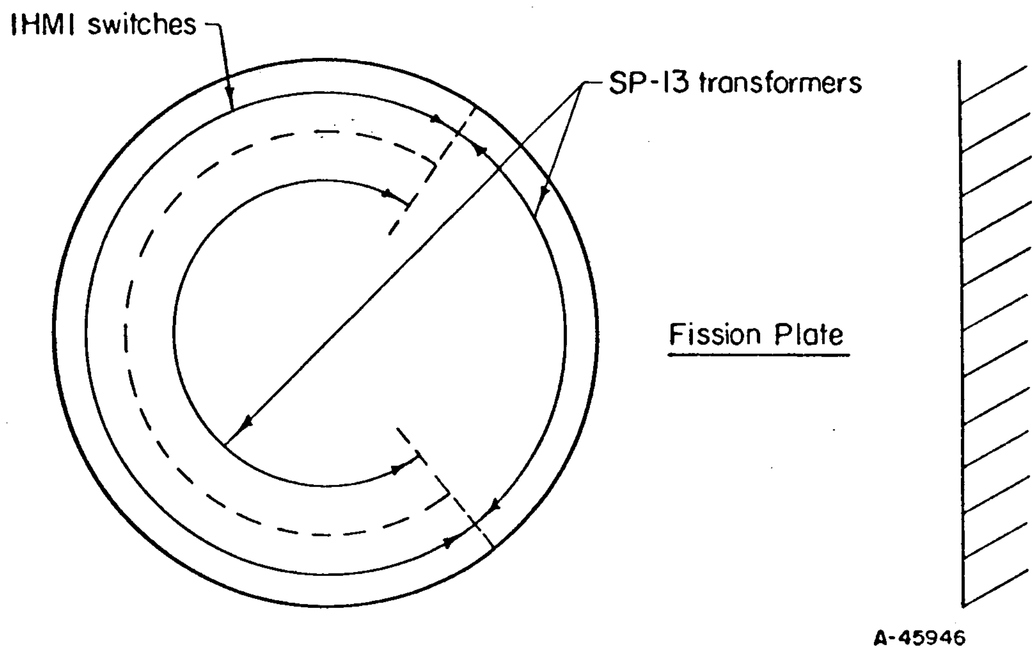

FIGURE B-15. RELATIVE POSITIONS OF THE PRIMARY GROUPS OF SWITCHES AND TRANSFORMERS TO THE FISSION PLATE OF THE THERMAL COLUMN

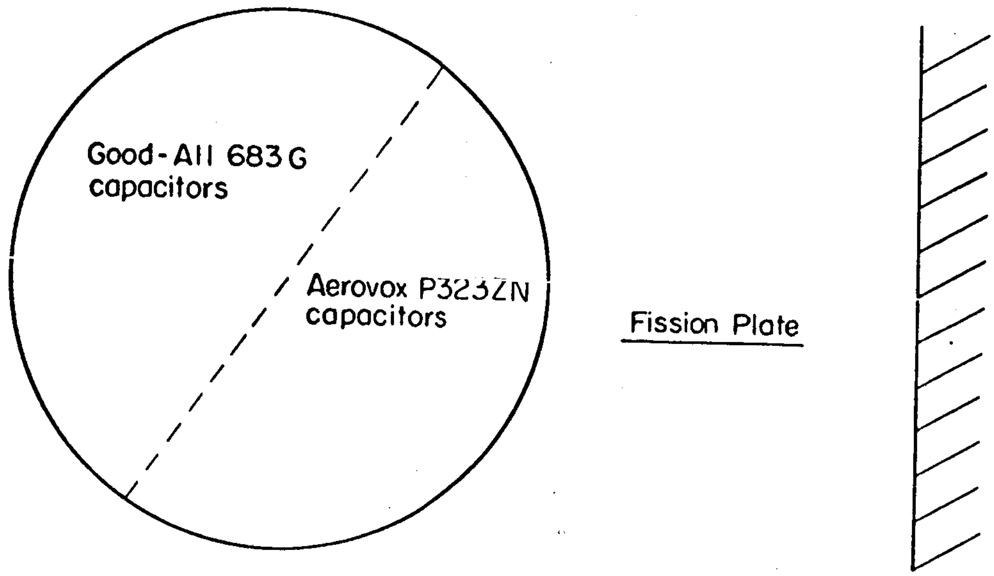

FIGURE B-16. RELATIVE POSITIONS OF THE SUPPLEMENTAL (NONOPERATIONAL) GROUP OF GOOD-ALL AND AEROVOX CAPACITORS TO THE FISSION PLATE OF THE THERMAL COLUMN

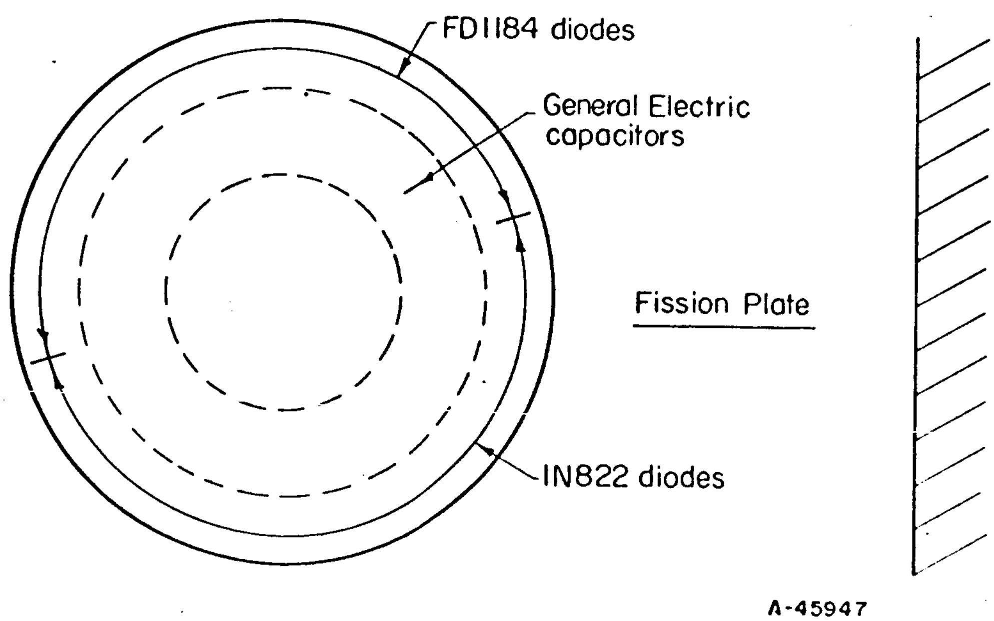

FIGURE B-17. RELATIVE POSITIONS OF THE SUPPLEMENTAL (NONOPERATIONAL) GROUP OF GENERAL ELECTRIC CAPACITORS, AND FD1184 AND 1N833 DIODES TO THE FISSION PLATE OF THE THERMAL COLUMN

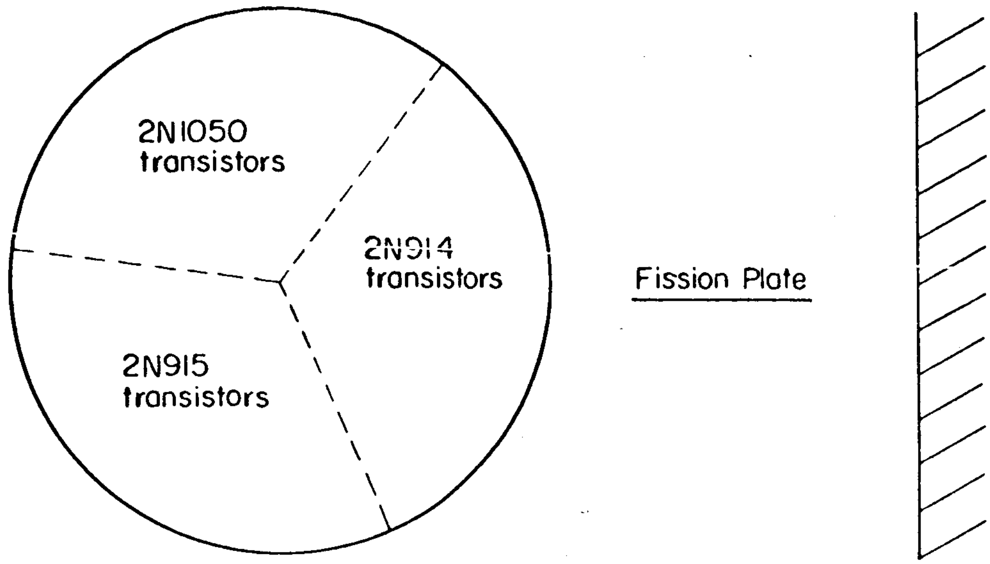

FIGURE B-18. RELATIVE POSITIONS OF THE SUPPLEMENTAL (NONOPERATIONAL) GROUP OF 2N1050, 2N914, AND 2N915 TRANSISTORS TO THE FISSION PLATE OF THE THERMAL COLUMN

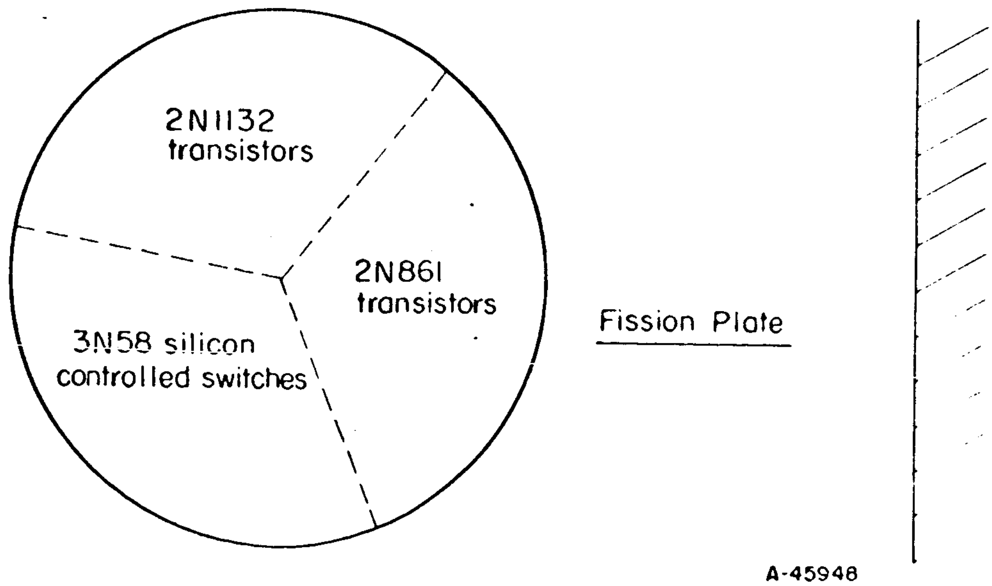

FIGURE B-19. RELATIVE POSITIONS OF THE SUPPLEMENTAL (NONOPERATIONAL) GROUP OF 2N1132 AND 2N861 TRANSISTORS, AND 3N58 SILICON CONTROLLED SWITCHES TO THE FISSION PLATE OF THE THERMAL COLUMN

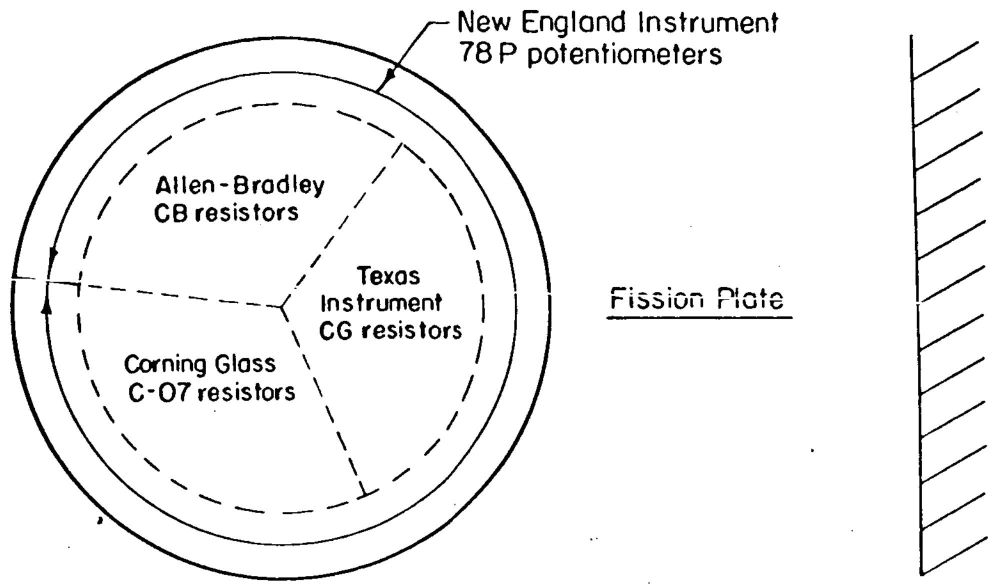

FIGURE B-20. RELATIVE POSITIONS OF THE SUPPLEMENTAL (NONOPERATIONAL) GROUP OF CB, CG, AND C-07 RESISTORS, AND THE FISSION PLATE OF THE THERMAL COLUMN

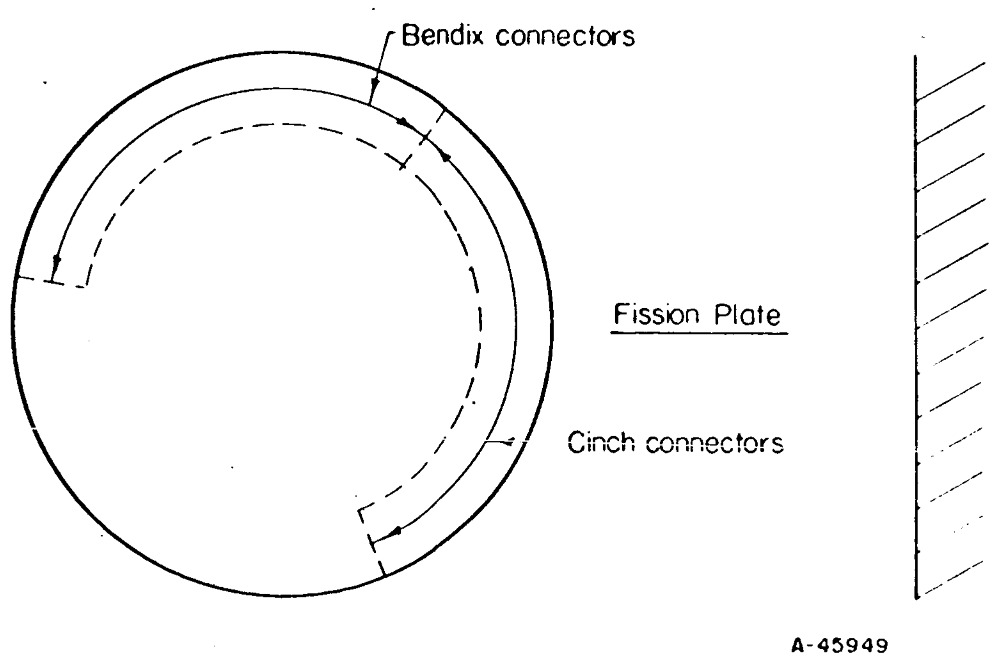

FIGURE B-21. RELATIVE POSITIONS OF THE SUPPLEMENTAL GROUP OF BENDIX AND CINCH CONNECTORS TO THE FISSION PLATE OF THE THERMAL COLUMN