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EXAMINATION RESULTS OF THE THREE MILE ISLAND RADIATION DETECTOR HP-R-212

Geoffrey M. Mueller

Published January 1984

Sandia National Laboratories
Albuquerque, New Mexico

Prepared for EG&G Idaho, Inc.
and the U.S. Department of Energy
Three Mile Island Operations Office
Under DOE Contract No. DE-AC07-76ID01570

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EXAMINATION RESULTS OF THE THREE MILE ISLAND RADIATION DETECTOR HP-R-212

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ABSTRACT

Area radiation detector HP-R-212 was removed from the Three Mile Island containment building on November 13, 1981. The detector apparently started to fail during November 1979 and by the first part of December 1979 the detector readings had degraded from 1 R/hr to 20 mR/hr. This report discusses the cause of failure, detector radiation measurement characteristics, and our estimates of the total gamma radiation dose received by the detector electronics.

Prepared for the
U. S. Department of Energy
Three Mile Island Operations Office
under DOE ALO B&R No. AG-35-30-10

ACKNOWLEDGEMENTS

This examination was administered by the Technical Integration Office at Three Mile Island. Jim Mock and Florante Soberano of that office were helpful in coordinating the removal and shipment of the detector.

At Sandia National Laboratories A. E. Asselmier performed the transistor gamma dose testing, and J. D. Anderson and C. B. Berglund of Health Physics assisted in the radiological work.

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I. INTRODUCTION AND SUMMARY FINDINGS

This report summarizes the results of our examination of Three Mile Island unit 2 (TMI-2) radiation detector HP-R-212. This report discusses the cause of failure and gives an estimate of the total gamma radiation dose received by the detector electronics. What is not covered here, but will be covered in a later report, is this detector's response to very high radiation levels where its output becomes multivalued.[1] This examination is a part of the on-going TMI-2 Instrumentation and Electrical Equipment Examination Program.

A. Background

On November 13, 1981 the third area radiation detector (HP-R-212) was removed from the Three Mile Island Unit-2 containment building for examination and laboratory testing. This area radiation detector was located in the Equipment Hatch area at the 305-foot level. The detector is a gamma radiation monitor manufactured by Victoreen (Model 857-2) and employs a Geiger-Mueller (GM) tube to detect events. It is of the same design as radiation detectors HP-R-211 and HP-R-213, which were analyzed earlier.[1,2] HP-R-212 was not powered up during the accident; however, it was powered up 92 days after the accident and worked for 5 months. Electrical measurements were made on the instrument from the TMI-2 control room by Metropolitan Edison Company (Met Ed.) and Technology for Energy, Inc. (TEC).[3] The detector was delivered to Sandia National Laboratories on January 26, 1982 for electrical examination.

B. Findings and Recommendations

1. The stripchart recording of HP-R-212 indicates that the detector was functional when it was turned on and worked for five months. At that time the output of the detector dropped from the nearly 1 R/hr reading to 20 mR/hr (Figure 1). Examination of the detector showed the failure to be a GM tube that had apparently used up the quench gas and was in continuous discharge. This design of detector is not capable of driving 366 meters (1200 feet) of cable at a frequency of 40 KHz. Therefore, when the GM tube went into continuous discharge, the output did not go to a reading of 10 R/hr as it should have, but read 20 mR/hr. If this detector is expected to work into "long" cable lengths and give the proper output readings at the ratemeter for this type of failure, I recommend that the output drive circuit in the detector and the input circuit for the ratemeter log pump circuit be redesigned.

2. A new GM tube from our test detector was placed in the HP-R-212 detector circuit. The detector then functioned normally when exposed to gamma radiation up to 20 R/hr.

3. We estimate the total gamma radiation dose accumulated by this detector to be approximately 4.5×10^5 rads.

II. DESCRIPTION

HP-R-212 (SN 340) is one of six containment building area radiation monitors. It was mounted near the Equipment Hatch at the 305-foot elevation. The detector was connected to its ratemeter readout electronics module in the TMI-2 control room through about 366 meters (1,200 feet) of instrumentation cable. The wiring diagram for HP-R-212 is shown in Figure 2.

III. MECHANICAL EXAMINATION

The detector outside case showed the same pitting and corrosion around the connector as was seen in HP-R-211 and HP-R-213 (Figure 3 through Figure 6); however, this could be expected when the environment it was exposed to is considered. The O-Ring seal did a fair job of sealing the canister (Figure 7).Swipes taken on the inside of the canister indicate that ony a small amount of radioative materials had leaked in to contaminate the printed wiring assembly. A microscopic examination of the printed wiring assembly showed it to be free of foreign material except for some solder flux around most of the solder joints (Figure 8 and Figure 9), apparently residual from the manufacturing operation.

IV. ELECTRICAL EXAMINATION

Several electrical parameters were measured in an attempt to determine the failure mode of the detector. For comparison, data were also taken on a test detector (Victoreen SN 673), which is the same model as HP-R-212. Table 1 lists the unpowered resistance measurements taken at Sandia and TMI. The probable differences in the readings are those due to differences in the ohmmeters used. These readings are all normal readings.

TABLE 1. UNPOWERED 212 MEASUREMENTS

OHMETER POLARITY/ LINE TO LINE MEAS.		RESISTANCE (OHMS)		
+	-	212 at TMI	212 at SANDIA	TEST DETECTOR
+10V	GND	7.70K	6.55K	6.40K
GND	+10V	15.2K	12.85K	11.67K
+10V	SIG	8.70K	8.54K	7.95K
SIG	+10V	7.10K	6.19K	5.59K
GND	SIG	9.94K	9.23K	8.44K
SIG	GND	7.40K	7.06K	6.98K
+600V	GND	OPEN	OPEN	OPEN
GND	+600V	OPEN	OPEN	OPEN
CS1	CS2	38.0	28.3	24.2
CS2	CS1	40.0	28.3	24.2

For the powered measurements, a standard Victoreen Model No. 856-20 ratemeter was used to supply power and process the detector signal output. Table 2 shows the DC voltages and meter reading obtained when HP-R-212 was initially powered. Again, the TMI and test detector data are included for comparison.

TABLE 2. POWERED 212 MEASUREMENTS (DC)

QUANTITY MEASURED		MEASUREMENT		
		212 at TMI	212 at SANDIA	TEST DETECTOR
+10V	(V)	10.1	10.03	10.06
SIG.	(V)	4.3	4.11	0.07/10.0
+600V	(V)	469.0	528.8	599.1
+22V	(V)	19.1	20.6	21.1
CS I	(ma)	1.80	2.44	2.55
MTR	(mR/H)	45	110	0.15
REC	(mv)	---	5.94	0.35

The voltages measured for the signal and the +600-volt supply were not as they should have been in a properly operating detector. The signal voltage should have had a square wave-shape, with an amplitude of 0 volts to 10 volts. The switching rate of this voltage should have been very slow (1 Hz). The signal line was observed to be a 40 kHz triangle waveshape. These measurements were made with 366 meters (1,200 feet) of RG58 coaxial cable between the detector and the ratemeter (simulating the TMI-2 cable length). The +600-volt supply was measured low, indicating that the GM tube was in continuous discharge, drawing a higher current than normal, and pulling the +600-volt supply down.

These measurements were all made through the detector connector without opening the detector. The detector was eventually opened, and node voltages were measured. These DC node voltages are shown on a schematic of the detector in Figure 10. Since the detector's output was switching, some of the voltages are the average of the signal at the measured nodes. These voltages are circled. The GM tube was found to be in continuous discharge. The faulty GM tube was removed and replaced with a good GM tube. The DC node voltages were then recorded with the new GM tube and are shown in Figure 11. The detector was then exposed to ^{60}Co at the Sandia Vertical Range Facility. The detector output reading versus input ^{60}Co source level is shown in Figure 12. The detector operates properly over its normal 0.1 mR/hr to 10 R/hr range. The error in radiation measurement is caused by not calibrating this detector (GM tube) with the ratemeter. The anti-jam circuit was activated at an input level of 32 R/hr.

The detector was exposed to radiation levels as high as 600 R/hr. With a short piece of coaxial cable in the signal line between the detector and the ratemeter the system functioned normally. When the 366 meters (1,200 feet) of cable was placed in the signal line, the system functioned normally up to 10 R/hr. At higher levels (up to 600 R/hr) the output dropped off to read 3 to 4 R/hr. A short was placed across the GM tube representing a failed GM tube in continuous discharge. The output then dropped to 40 mR/hr. It did not matter whether the detector was exposed to radiation or not, the output read 40 mR/hr. This phenomenon was found to be caused by the inability of the output circuit of the detector to drive the 366 meters (1,200 feet) of RG58 coaxial cable with a 40 kHz (anti-jam generated) squarewave. The signal was a degenerated triangle wave shape no longer going from 0 to 10 volts. This would then give a lower than 10 R/hr reading on the meter. This phenomenom will be discussed in more detail in another report. Appendix A shows the sequence of events performed in troubleshooting the detector.[4,5]

V. GM TUBE ANALYSIS

The GM tube used in the Victoreen Model 857-2 Detector is an Amperex GM tube, Model 18509. Appendix B contains a pamphlet on "General Operating Recommendations Geiger-Mueller Tubes," and a data sheet for the Amperex type 18509 GM tube.

The GM tube is used in the Detector as recommended, and is operated within the specified limitations. When the GM tube is ionized a pulse appears at the base of Q1 (Figure 11), which in turn causes the Flip-Flop (Q4 and Q5) to change state. Each time the tube is ionized the Flip-Flop changes state. This produces an output frequency at the output (Q6 and Q7) that is one-half that of the GM tube ionization frequency.

The upper range of this GM tube is specified at 300 R/hr, while the detector it is used in operates up to 10 R/hr. When the exposure rate exceeds 10 R/hr the anti-jam circuit (Q2 and Q3) cuts in and causes the Flip-Flop circuit to oscillate at 40 KHz.

When a GM tube fails due to ageing, it has used up the quench gas in the tube. The tube then goes into a condition called continuous discharge. Once the GM tube is ionized, it stays on and doesn't turn off. When this occurs in the detector, it activates the anti-jam circuitry, causing the Flip-Flop circuit to oscillate at 40 kHz.

With a long enough exposure to radiation, a GM tube will come to the end of its life and go into continuous discharge. However, in this application (HP-R-212) the detector output circuit could not drive 366 meters (1200 feet) of RG-58, 50-ohm coaxial cable, at a frequency of 40 KHz. The resultant waveshape was a degraded signal that produced a 45 mR/hr reading at TMI-2.

The GM tube that was in HP-R-212 was in continuous discharge when received. It was noted, however, that when power was first applied to the detector, the GM tube would function normally for about fifteen seconds before going into continuous discharge. This is a normal condition for a GM tube that has used up its quench gas.

The GM tube was powered on for appoximately 3,700 hours at an average radiation level of 900 mR/hr. The graph of the typical count rate as a function of dose rate in Appendix B indicates that for 900 mR/hr the count rate is approximately 1.7×10^3 counts/second. For the total time of 3,700 hours of exposure, this yields a total number of counts on the GM tube to be 2.26×10^{10}. The average total counts for a GM tube to fail is 5×10^{10} counts. This shows that the GM tube was approaching the average total counts for a GM tube when it failed.

We obtained some new GM tubes from Amperex, and set up a GM tube ageing experiment. Two GM tubes were continuously exposed to a radiation level of 100 R/hr. One GM tube was powered up normally and one GM tube was unpowered for a comparison. A biased GM tube in a radiation field loses some of its quench gas due to chemical reactions inside the tube as ionizations occur. In an unpowered GM tube these chemical reactions do not occur as readily. As a GM tube approaches the end of its life, the detector output would start reading a higher level output than is true, since there isn't enough quench gas left to "quench" the ionization of the gas in the tube.[6,7,8,9]

At the termination of the experiment the GM tube had been exposed to 100 R/hr for 2,040 hours. This was a total dose of 2.04×10^5 R and the total counts/second calculates to be 22.5×10^{10} counts. The powered tube had not shown any signs of decaying at the termination of the experiment. This was a total number of counts that was 4.5 times higher than the expected total life counts. The unpowered tube, as expected, showed no signs of degradation either.

With this GM tube working so much longer than the average, it leads me to believe that the GM tube that failed in HP-R-212 was a weak or aged tube.

VI. TOTAL GAMMA DOSE

All of the transistors were functional when the electronic circuit was examined. The transistors were removed from the circuit and analyzed. The transistor current gain (HFE or BETA) degradation of these transistors, as compared to new nonradiated transistor samples, is shown in Table 3, along with the manufacturer of each transistor removed from the printed circuit board.

TABLE 3. TRANSISTOR BETA'S

HFE OF SIMILAR TYPE DEVICES PRE-RAD		MANUFACTURER AND TYPE	HFE POST-RAD
80	Q1	FAIRCHILD 2N3903 NPN	12.1
185	Q2	MOTOROLA 2N3906 PNP	82.0
250	Q3	FAIRCHILD 2N3565 NPN	46.1
80	Q4	FAIRCHILD 2N3903 NPN	30.5
80	Q5	FAIRCHILD 2N3903 NPN	12.8
185	Q6	MOTOROLA 2N3906 PNP	103.1
140	Q7	FAIRCHILD 2N3904 NPN	37.9

The transistor curves shown in Appendix B are the curves generated for the same transistor types used in HP-R-211.[1] The HFE values recorded in Table 3 are drawn on the curves shown in Appendix B. The total dose for each of the transistor types is summarized in Table 4. The annealing and biasing factors are also accounted for in Table 4.[1]

TABLE 4. TRANSISTOR TOTAL DOSE

TRANSISTOR TYPE	HFE RANGE (RADS) MIN	AVE	MAX
2N3565...Q3 FSC (HFE=46.1)			
FSC (10 ea)	1.70E5	14.00E5	60.00E5
NAT (10 ea)	5.80E5	11.00E5	25.00E5
AVE	3.75E5	12.50E5	42.50E5
x 1.6 (Annealing Factor)	6.00E5	20.00E5	68.00E5
÷ 3.0 (Biasing Factor)	2.00E5	6.67E5	22.67E5
2N3904...Q7 FSC (HFE=37.9)			
FSC (10 ea)	0.70E5	1.30E5	2.40E5
NAT (10 ea)	2.90E5	3.80E5	4.40E5
AVE	1.20E5	2.55E5	3.40E5
x 1.6 (Annealing Factor)	1.92E5	4.08E5	5.44E5
÷ 3.0 (Biasing Factor)	0.64E5	1.36E5	1.81E5
2N3906... Q2 MOT(HFE= 82.0), Q6 MOT (HFE=103.1), (HFE AVE=92.5)			
FSC (5 ea)	0.34E5	0.44E5	1.05E5
NAT (10 ea)	1.20E5	6.20E5	13.00E5
TI (10 ea)	0.46E5	0.95E5	1.80E5
AVE	0.67E5	2.53E5	5.28E5
x 1.6 (Annealing Factor)	1.07E5	4.05E5	8.45E5
x 1.7 (Biasing Factor)	1.81E5	6.88E5	14.37E5
2N3903...Q1 (HFE=12.1), Q4 (HFE=30.5), Q5 (HFE=12.8) (AVE HFE=18.5), ALL FSC			
FSC (2 ea)	1.50E5	4.70E5	11.50E5
NAT (10 ea)	3.70E5	7.50E5	9.80E5
GE (10 ea)	3.70E5	5.60E5	7.40E5
AVE	2.97E5	5.93E5	9.57E5
x 1.6 (Annealing Factor)	4.75E5	9.49E5	15.31E5
÷ 3.0 (Biasing Factor)	1.58E5	3.16E5	5.10E5
OVERALL AVERAGE TOTAL DOSE	1.51E5	4.52E5	10.99E5

From Table 4 the total dose was calculated to be approximately 4.5×10^5 Rads. This is the main indicator of the total dose that the detector received (a period of 961 days from March 28, 1979 to November 13, 1981) while it was in the containment building.

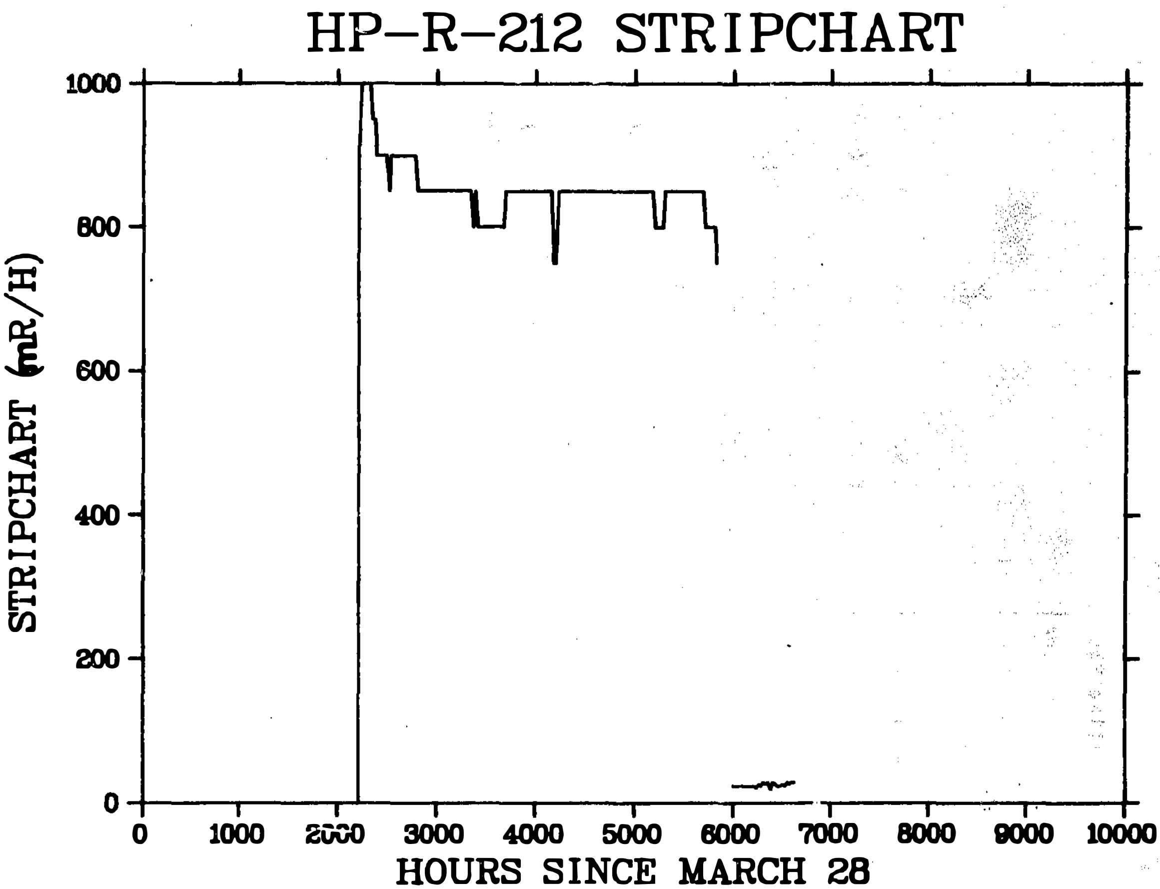


FIGURE 1. HP-R-212 STRIPCHART. This record shows that the detector was turned on June 28, 1979, 2208 hours after the March 28, 1979 incident. The output level started at 1 R/hr and decayed to about 700 mR/hr, 154 days later. At this time the GM tube failed and the reading dropped to 20 mR/hr.

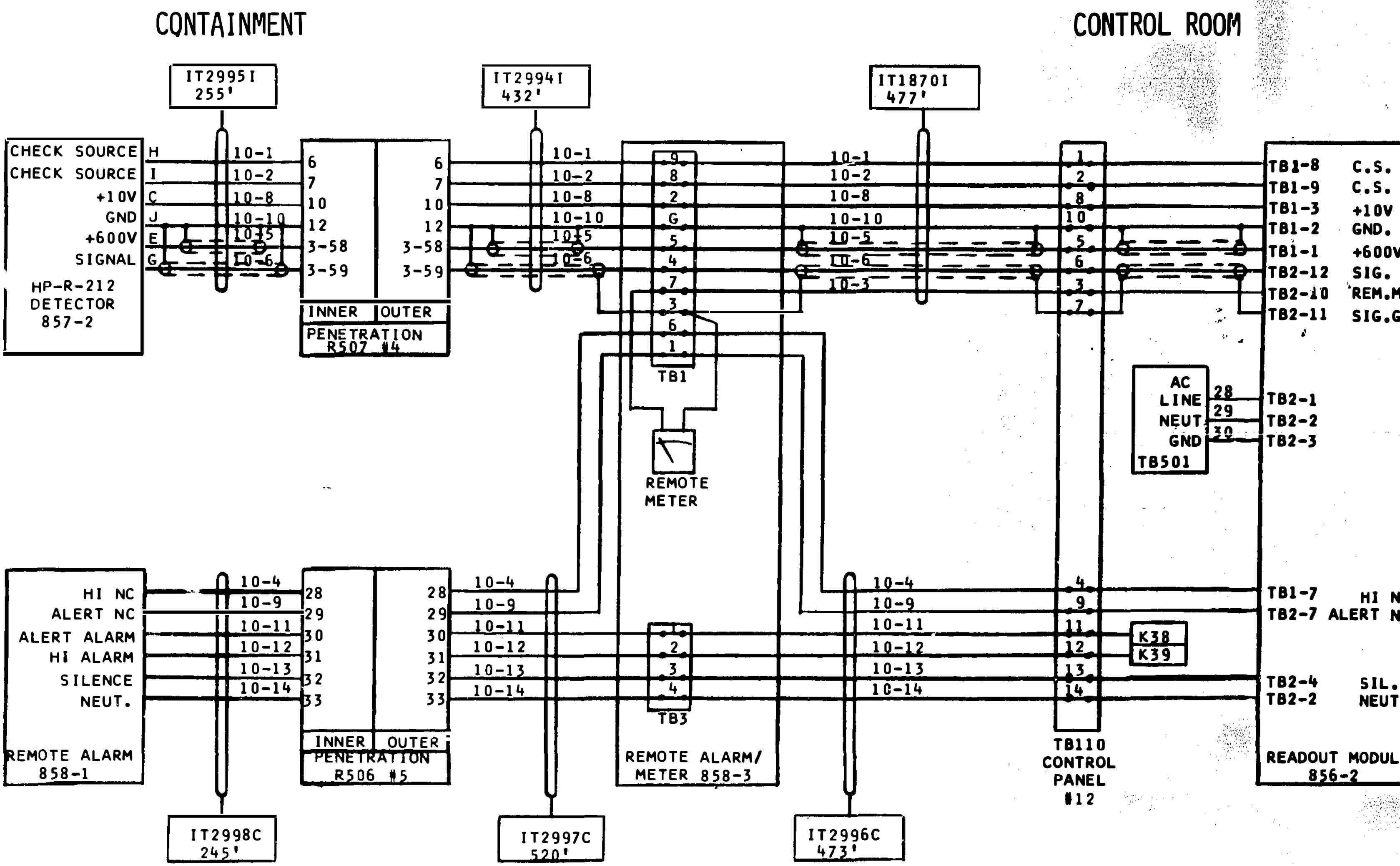


FIGURE 2. HP-R-212 WIRING DIAGRAM

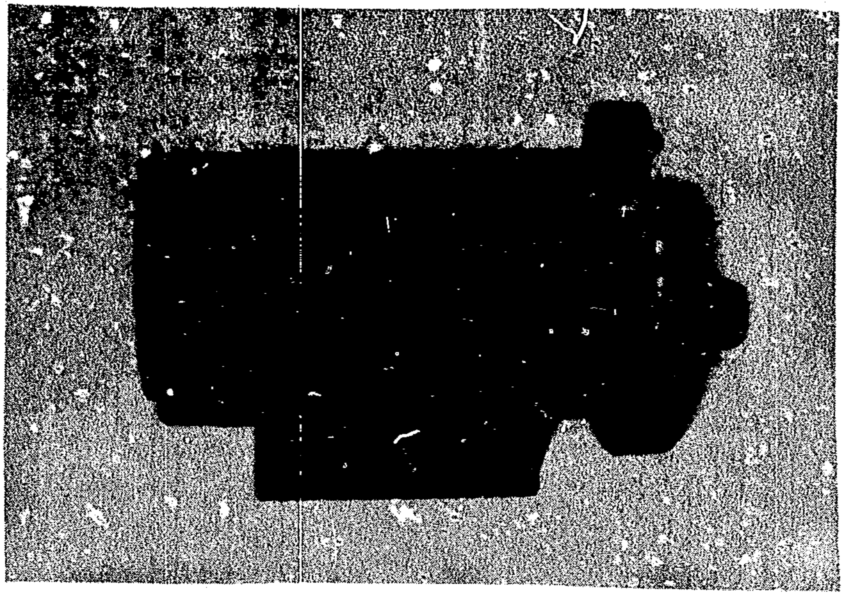


FIGURE 3. HP-R-212 DETECTOR, SIDE VIEW

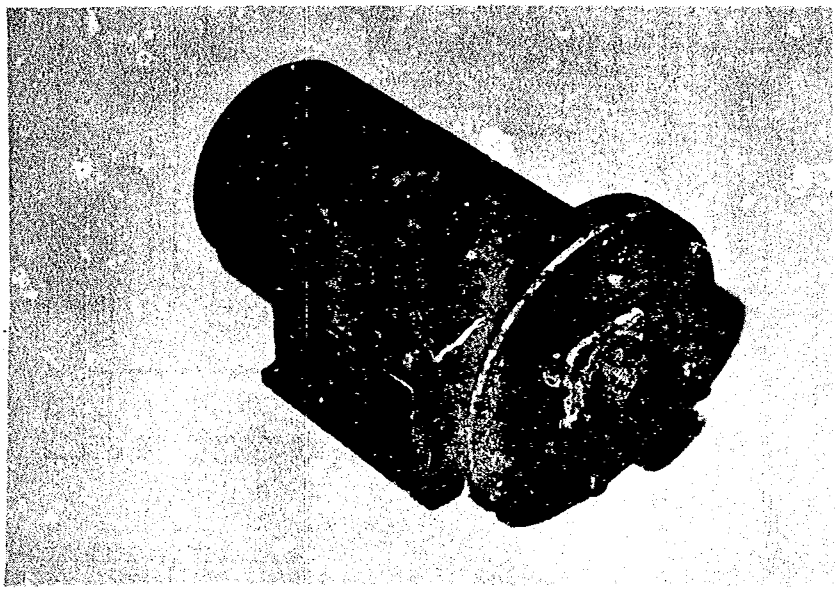


FIGURE 4. HP-R-212 DETECTOR, DIAGONAL VIEW

FIGURE 5. HP-R-212 DETECTOR, CONNECTOR VIEW

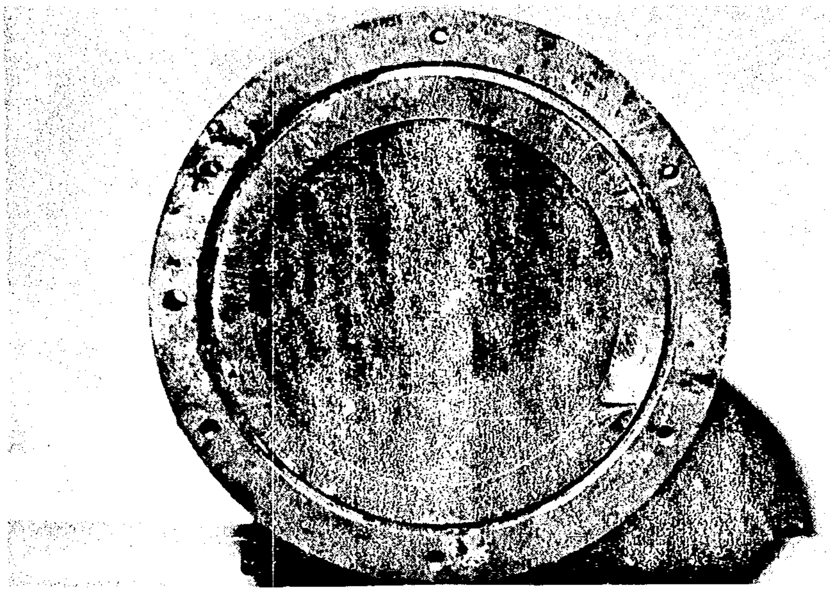


FIGURE 6. HP-R-212 DETECTOR, CANISTER OPENED

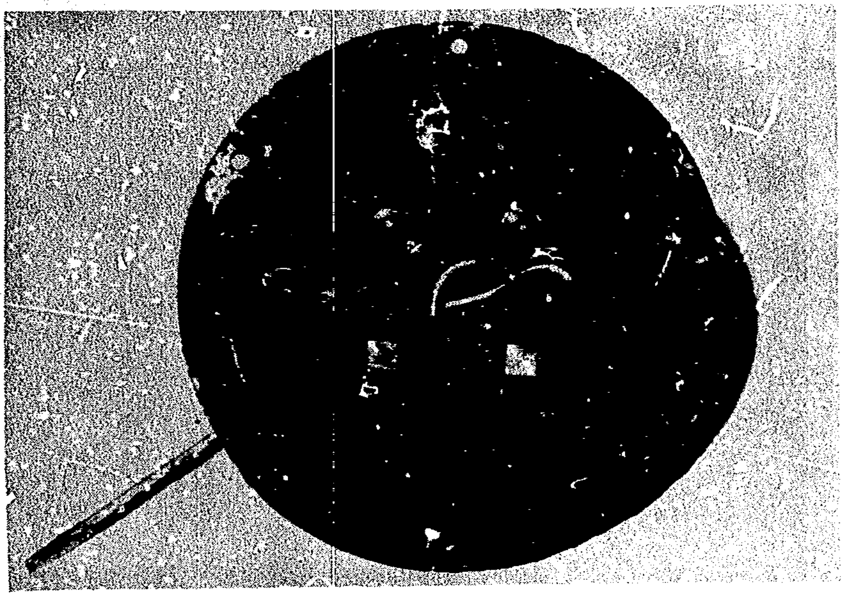


FIGURE 7. HP-R-212 DETECTOR, INSIDE BULKHEAD WITH "O" RING

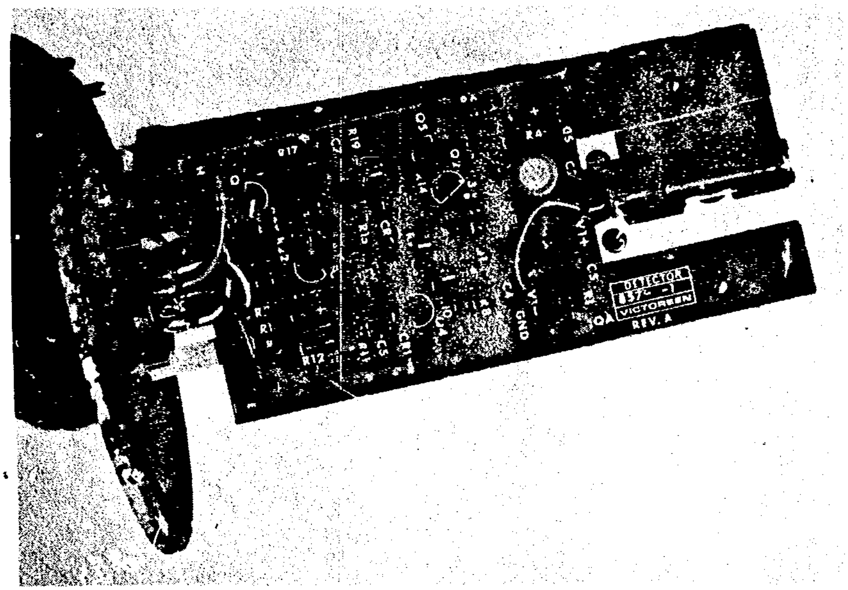


FIGURE 8. HP-212 DETECTOR, P.C. BOARD COMPONENT SIDE

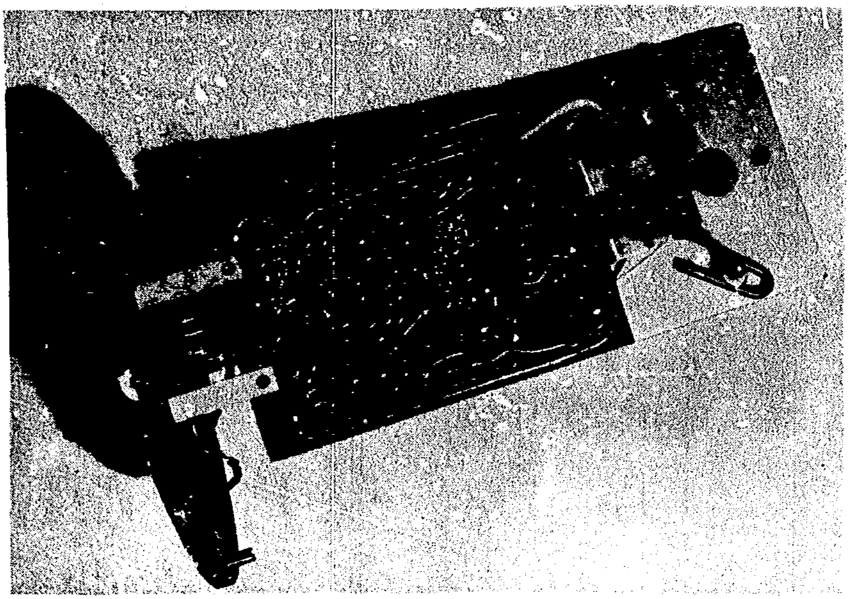


FIGURE 9. HP-212 DETECTOR, P.C. BOARD FOIL SIDE

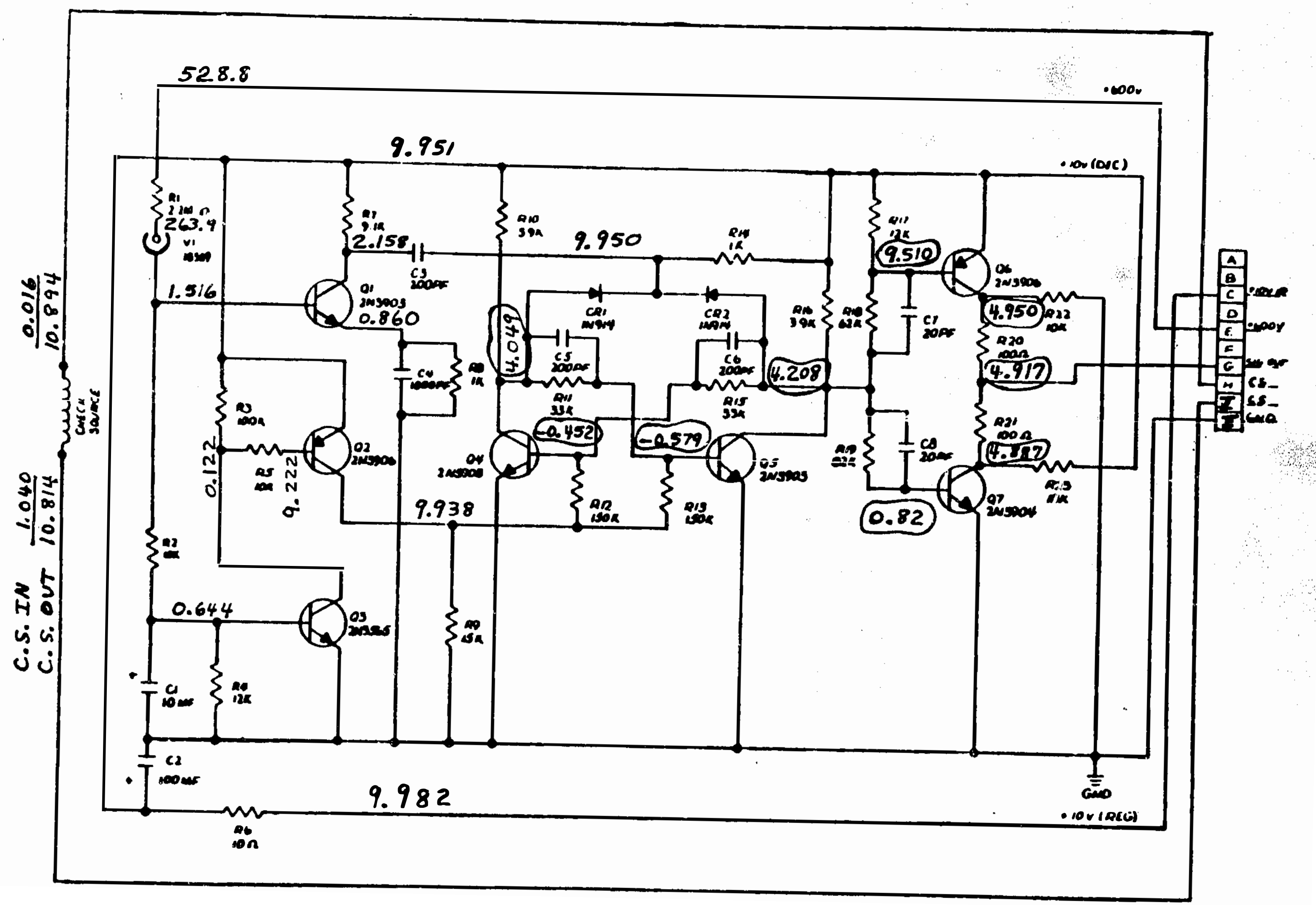


FIGURE 10. CIRCUITRY OF GAMMA DETECTOR 857-2, HP-R-212, PRE-REPAIR

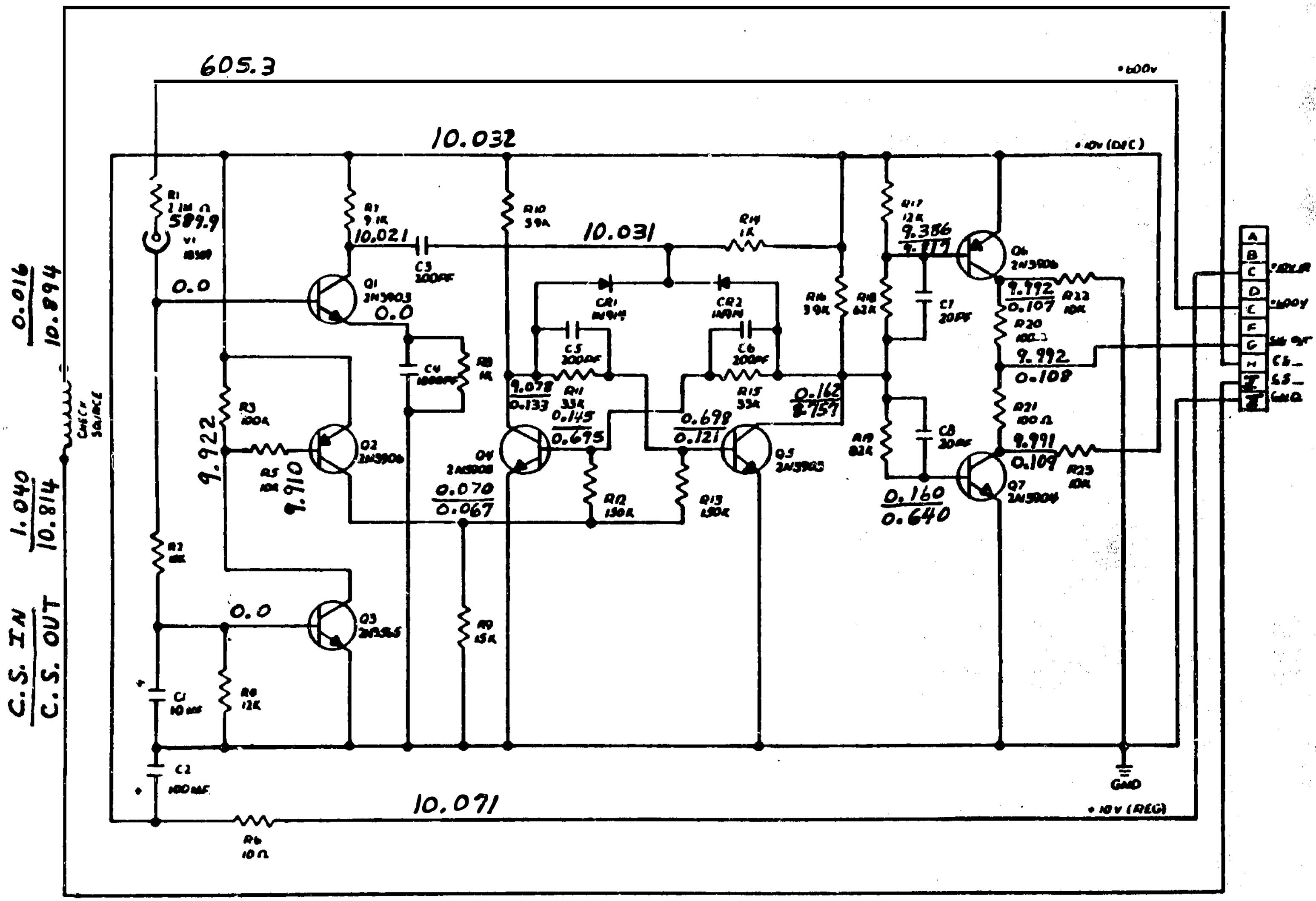


FIGURE 11. CIRCUITRY OF GAMMA DETECTOR
857-2, HP-R-212, POST-REPAIR

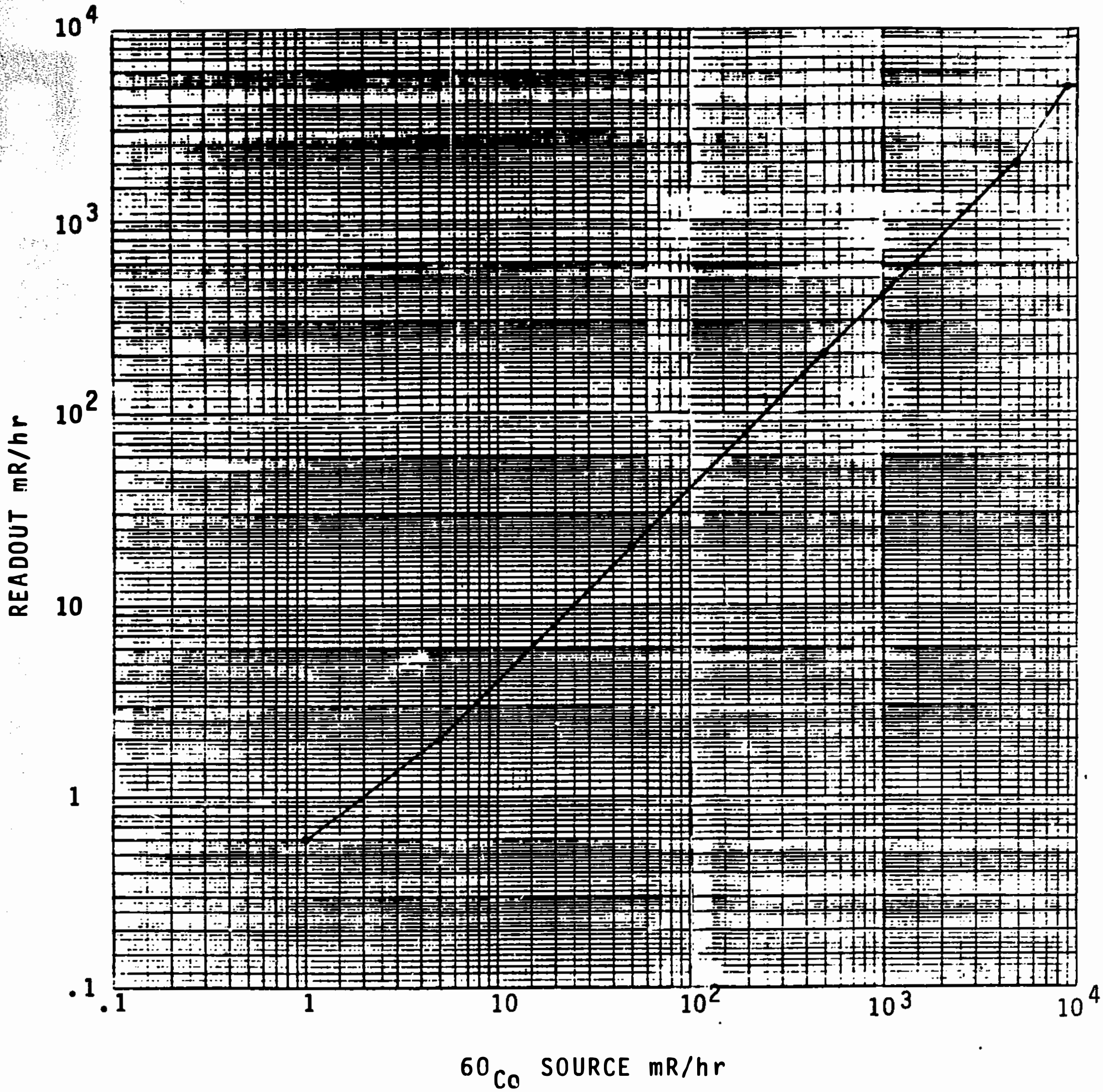


FIGURE 12. REPAIRED HP-R-212 DETECTOR RESPONSE WITH A REPLACED GM TUBE

APPENDIX B

SECTION 1

GENERAL OPERATIONAL RECOMMENDATIONS
GEIGER-MUELLER TUBES

SECTION 2
GEIGER-MUELLER TUBE
TYPE 18509

GENERAL OPERATIONAL RECOMMENDATIONS
GEIGER-MULLER TUBES

Where appropriate, the terminology used conforms to the following publications:– IEC50-531, IEC100, IEC151-25.

1. GENERAL

1.1 Geiger-Müller radiation counter tubes (G.M. tubes) are intended to detect alpha particles, beta particles, gamma or X-radiation.

1.2 A G.M. tube is a gas-filled device which reacts to individual ionizing events, thus enabling them to be counted.

1.3 A G.M. tube consists basically of an electrode at a positive potential (anode) surrounded by a metal cylinder at a negative potential (cathode). The cathode forms part of the envelope or is enclosed in a glass envelope. Ionizing events are initiated by quanta or particles entering the tube either through the window or through the cathode and colliding with the gas molecules.

1.4 The gas filling consists of a mixture of one or more rare gases and a quenching agent.

1.5 Quenching is the process of terminating a pulse ionizing current in a G.M. tube. Optimum quenching in our tubes is obtained by the quenching gases used in conjunction with the recommended anode resistor.

2. The capacitance of a G.M. tube is that between anode and cathode, ignoring the capacitive effects of external connections.

3. OPERATING CHARACTERISTICS

3.1. Starting voltage

This is the lowest voltage applied to a G.M. tube at which pulses of 1 V amplitude appear across the tube. See fig. 1.

3.2 Plateau

This is the section of the counting rate versus voltage characteristic (with constant irradiation), over which the counting rate is substantially independent of the applied voltage. Unless otherwise stated, the plateau is measured at a counting rate of approximately 100 count/s.

3.3 Plateau threshold voltage

This is the lowest voltage applied which corresponds to the start of the plateau for the stated sensitivity of the measuring circuit. See fig. 1.

3.4 Plateau length

This is the range of applied voltage over which the plateau extends. See fig. 1.

3.5 Plateau slope

This is the change in counting rate over the plateau length, expressed in % per volt. See fig. 1.

3.6 Recommended supply voltage

This is the supply voltage at which the G.M. tube should preferably be used. This voltage is normally chosen to be in the middle of the plateau. See fig. 1.

OPERATING CHARACTERISTICS (continued)

3.7 Background

This is the counting rate in the absence of the radiation which the G.M. tube is intended to measure.

3.8 Dead time

This is the time interval, after the initiation of a discharge resulting in a normal pulse, during which the G.M. tube is insensitive to further ionizing events. See fig.4.

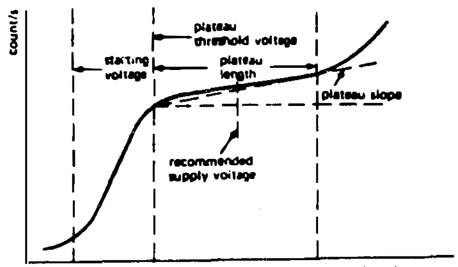


Fig.1

4 MEASURING CIRCUITS

4.1 Measuring circuit A

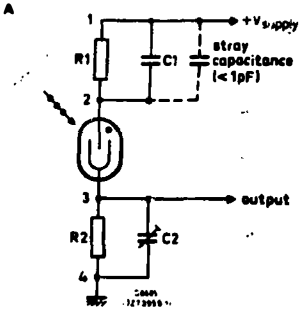


Fig.2

Notes:

1. The input resistance and capacitance of the measuring equipment are represented by R2 and C2 respectively.
2. R1 is specified by the manufacturer and should be mounted as near as possible to the anode connector.
3. When applying a rectangular pulse at 1 with the tube inserted but short-circuited, C2 should be adjusted to give an undistorted pulse at 3. Under these conditions R1 x (C1 + stray capacitance) = R2 x C2.
4. The measuring equipment consists of an emitter follower with a pulse shaper, a limiting amplifier and a scaler. Unless otherwise stated, the tube is measured with the circuit given in the data, with a ^{60}Co source and at the recommended supply voltage (mid-plateau).

4.2 Measuring circuit B

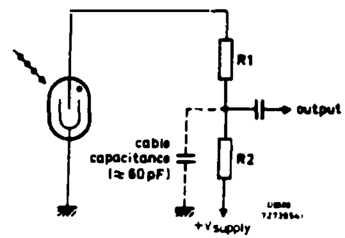


Fig.3

Note: The value of the anode resistor R_1 should not be less than that specified under LIMITING VALUES in the data.

5. NOTES

5.1 Resolution time (of a counting system)

This is the minimum time interval between two distinct ionizing events which enables both to be counted.

5.2 Recovery time

This is the minimum time interval between the initiation of a normal size pulse and the initiation of the next pulse of normal size. See fig.4.

5.3 Pulse amplitude

The pulse amplitude of a G.M. tube may be approximated by the equation:

$$P = b \times (V_{supply} - V_{starting})$$

where P = pulse amplitude

V_{supply} = anode supply voltage

$V_{starting}$ = starting voltage

$$b = \frac{R_2}{R_1 + R_2} \quad \text{(See measuring circuit)}$$

The tap on the load resistor minimizes the influence of a capacitive load.

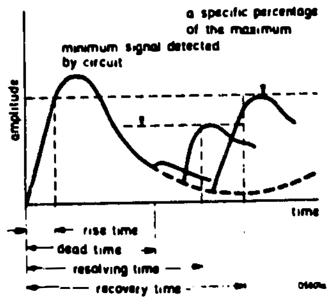


Fig.4

5.4 Anode resistor

Normally the tube should be operated with an anode resistor of the value indicated in the measuring circuit, or higher. Decreasing the value of the anode resistor not only decreases the dead time but also the plateau length. A decrease in resistance below the limiting value may affect tube life and lead to its early destruction.

The anode resistor should be connected direct to the anode connector of the tube to ensure that parasitic capacitances of leads will not increase too greatly the capacitive load on the tube. An increase in capacitive load has the tendency to increase the pulse amplitude, the pulse duration, the dead time, and the plateau slope. In addition the plateau length will be shortended appreciably. Shunt capacitances of more than 20 pF may destroy the tube.

5.5 Maximum counting rate

The maximum counting rate is approximately $1/\tau$ (τ = dead time). For continuous stable operation it is recommended that the counting rate is adjusted to a value in the linear part of the counting rate/dose rate curve.

5.6 Dead time losses

After every pulse, the tube is temporarily insensitive during a period known as the dead time (τ). Consequently, the pulses that occur during this period are not counted. At a counting rate of N count/s the tube will be dead during $100 \times N \times \tau$% of the time, so that approximately $100 \times N \times \tau$% of the countr will be lost.

If, in an experiment, the inaccuracy must be < 1%, N should be less than $1/100\tau$ count/s.
Example: If τ = 20 µs, an inaccuracy of 1% is reached at a counting rate of approximately 500 count/s.

5.7 Background

See definition under 3.7. The most important sources of background are:

1. Gamma radiation from the environment and from cosmic radiation.
2. Mesons from cosmic radiation.
3. Beta particles from contamination and impurities of the materials from which the detector itself is made.
4. Spontaneous discharge or pulses in the detector and the counting circuit that do not originate from radiation.

From published experimental data the gamma contribution accounts for approximately 70% of the background and a further 25% (approximately) is due to cosmic mesons. For the majority of G.M. tube applications, the background may be reduced to an acceptable level by shielding the tube with lead or steel. Thus most of the gamma contribution is eliminated.

5.8 Counting rate/dose rate curves

These are measured with, or corrected for, a ^{60}Co source perpendicular to the tube axis, at the recommended supply voltage, unless otherwise stated. The curves shown are typical. Deviation of up to approximately ± 10% may occur.

5.9 Current/dose rate curves

These are measured with, or corrected for, a ^{60}Co source perpendicular to the tube axis, unless otherwise stated. The curves shown are typical. Deviation of up to approximately ± 20% may occur.

5.10 Dead time curves

These represent the dead time (see 3.8 and fig.4) as a function of the supply voltage, measured with pulsed X-radiation in the recommended circuit, unless otherwise stated. The curves shown are typical. The maximum value is stated under OPERATING CHARACTERISTICS. Note that a higher anode resistor results in a higher dead time.

5.11 Energy response curves

These represent the energy sensitivity (in count/R) as a function of the radiation energy (in keV), measured in the recommended circuit and in the linear part of the counting rate/dose rate curve. The curves shown are typical. Deviation depends on energy and construction.

NOTES (continued)

5.12 Polar response curves

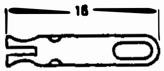
These represent the relative sensitivity as a function of the angle of irradiation (as defined in the drawing), measured in the recommended circuit. The curves shown are typical.
Deviation depends on energy and construction.

6. LIMITING VALUES

The limiting values of G.M. tubes are given in the Absolute Maximum Rating System in accordance with IEC Publication 134.
Absolute maximum ratings are limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions.
These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environmental variations and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and of all other electronic devices in the equipment.
The equipment manufacturer should design so that, initially and throughout life, no absolute maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply voltage variation, equipment control adjustment, load variation, signal variation, environmental conditions, and variations in characteristics of the device under consideration and of all other electronic devices in the equipment.

7. MOUNTING

G.M. tubes must not be clamped tightly in the vicinity of glass-metal seals. Great care must be taken in handling and fixing thin walled glass and thin metal tubes. Mica windows are extremely fragile and must never be touched.
Low capacitance between anode and cathode is essential, i.e. the shortest possible connections between anode terminal and load resistor must be made.
Soldering to the anode pin or to the cathode wall will destroy the tube. Most types are provided with a cathode lead or strap. This lead should be used for connection to the cathode. Tubes with an anode pin are supplied with an anode connector (see drawing). Only this connector should be used for connection to the anode.



D8587   7Z79123

Fig.6

8. STORAGE AND HANDLING

The tube should not be stored at ambient temperatures outside the limits given under the heading LIMITING VALUES on the data sheets.
To prevent leakage between the anode and the cathode, the tube should be dry and clean.
Condensation of water vapour may cause a short-circuit between anode and cathode.

9. OUTSIDE PRESSURE

In tubes provided with a mica window, the gas pressure outside the tube should neither be lower than 35 kPa (≈ 26 cm Hg) nor higher than the atmospheric pressure (unless otherwise stated) and changes in pressure should be gradual.
Care should be taken not to expose tubes with very thin envelopes to pressures substantially higher than atmospheric.

10. ENERGY DEPENDENCE

The sensitivity of G.M. tubes to gamma radiation is influenced considerably by the energy of the radiation.
At energies above about 300 to 400 keV, the action of the tube is due to emission of electrons from the cathode and the higher the atomic number of the cathode material the greater will be the electron emission. Radiation with an energy of less than 300 to 400 keV is absorbed by the gas filling, the absorption increasing as the energy decreases. This gives rise to the characteristic peak in sensitivity which occurs at about 60 keV, below which the sensitivity decreases rapidly due to cut-off by the thickness or density of the cathode wall. By using an external filter a near linear sensitivity can be obtained.

11. LIFE

11.1 Storage life

If stored in a cool dry place, free from continuous or severe vibration, there is hardly any deterioration in the tube's characteristics. A storage life of years is not unusual.

11.2 Operational life

The operational life of a G.M. tube is expressed in counts (discharges). Theoretically the quenching gas, ionized during a discharge, should be re-combined between discharges. However, minute quantities will be chemically bound, no longer taking part in the quenching process. This will lead to a gradual shortening of the plateau length, and, for a given working voltage, to an increased counting rate. This will cumulate in a continuous state of discharge of the tube, rendering it useless.
Apart from the accumulated number of counts registered, the ambient temperature during operation is of prime importance to the life of the tube. At temperatures above 50 °C, changes in the gas mixture may occur, possibly reducing the total number of counts attainable. Short periods of operation (not exceeding 1 h) up to approximately 70 °C should not prove harmful, but life will progressively decrease with increasing temperature.
Thus, depending on application and circumstances, the quenching gas could be exhausted in as little as a few hours or theoretically last for many years.
For these reasons G.M. tubes cannot be guaranteed unconditionally for a specified period of time.

NEVER

1. Exceed the LIMITING VALUES
2. Solder to the tube
3. Bend the anode pin
4. Touch the mica window

GEIGER-MÜLLER TUBE

Halogen quenched γ and high energy β (> 0.5 MeV) radiation counter tube

QUICK REFERENCE DATA

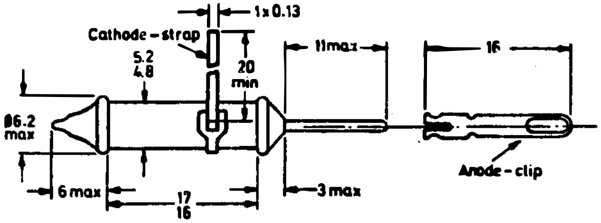
Dose rate range	10^{-3} to 3×10^{2}	R/h
Plateau threshold voltage	500	V
Plateau length	150	V
Recommended supply voltage	575	V
Chrome-iron cathode	80 to 100	mg/cm²

This data must be read in conjunction with 'General operational recommendations — Geiger-Müller tubes'

MECHANICAL DATA

Dimensions in mm

Fig.1



D7073

Use only anode connector supplied with tube.

CATHODE

Thickness	80 to 100	mg/cm²
Sensitive length	16	mm
Material	chrome-iron	

FILLING

neon, helium, halogen

CAPACITANCE

Anode to cathode	1.2	pF

OPERATING CHARACTERISTICS (Ambient temperature ≈ 25 °C)

Measured in circuit of Fig.2

Starting voltage	max.	380	V
Plateau threshold voltage	max.	500	V
Plateau length		150	V
Recommended supply voltage		575	V
Plateau slope	max.	0.15	%/V
Background (shielded with 50 mm Pb with an inner liner of 3 mm Al), at recommended supply voltage	max.	2	count/min
Dead time, at recommended supply voltage	max.	15	μs

LIMITING VALUES (Absolute max. rating system)

Anode resistor	min.	2.2	MΩ
Anode voltage	max.	550	V
Ambient temperature continuous operating	max.	+70	°C
	min.	−40	°C
storage	max.	+75	°C

LIFE EXPECTANCY

Life expectancy at ≈ 25 °C 5×10^{10} count

MEASURING CIRCUIT

R_1 = 2.2 MΩ
R_2 = 47 kΩ
C_1 = 1 pF

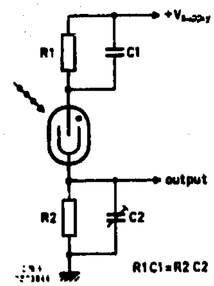
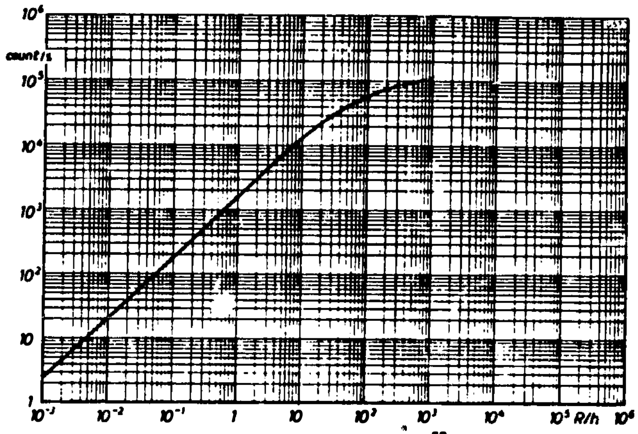
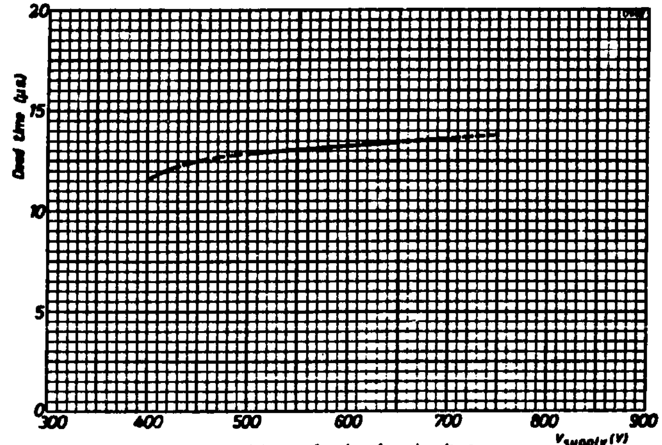


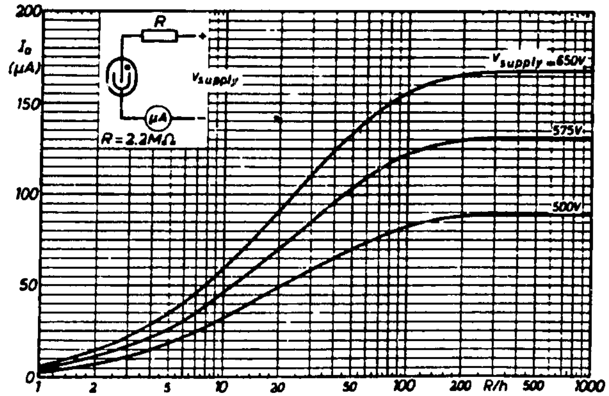
Fig.2



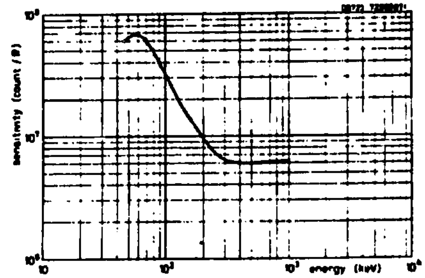
Typical count rate as a function of dose rate (^{60}Co)



Typical dead time as a function of supply voltage



Typical current as a function of dose rate (^{60}Co)



Typical energy response curve (side response)

APPENDIX A

Examination Sequence

1. Gamma and gamma/beta survey

2. Swipes on outside of detector

3. Unpowered resistance measurements

4. Powered DC measurements
   Found output to be running continuously at 40 KHz

5. Checked detector at ^{60}Co source up to 600 R/hr with no response (40 KHz output always)

6. Removed Printed Circuit Board from Canister

   a) Took swipes

      1) inside canister

      2) on P.C. Board

   b) Visual inspection of P.C. Board
      Flux on foil side of P.C. Board

   c) Decontaminated P.C. Board

   d) Took swipe of P.C. Board again

7. Performed troubleshooting of detector circuit

   a) Found GM tube in continuous discharge

   b) Replaced GM tube with new tube

8. Checked detector at ^{60}Co source up to 600 R/hr

9. Removed the transistors for analysis

   a) Measured the HFE of the transistors

   b) Made total dose estimate

10. Made GM tube analysis

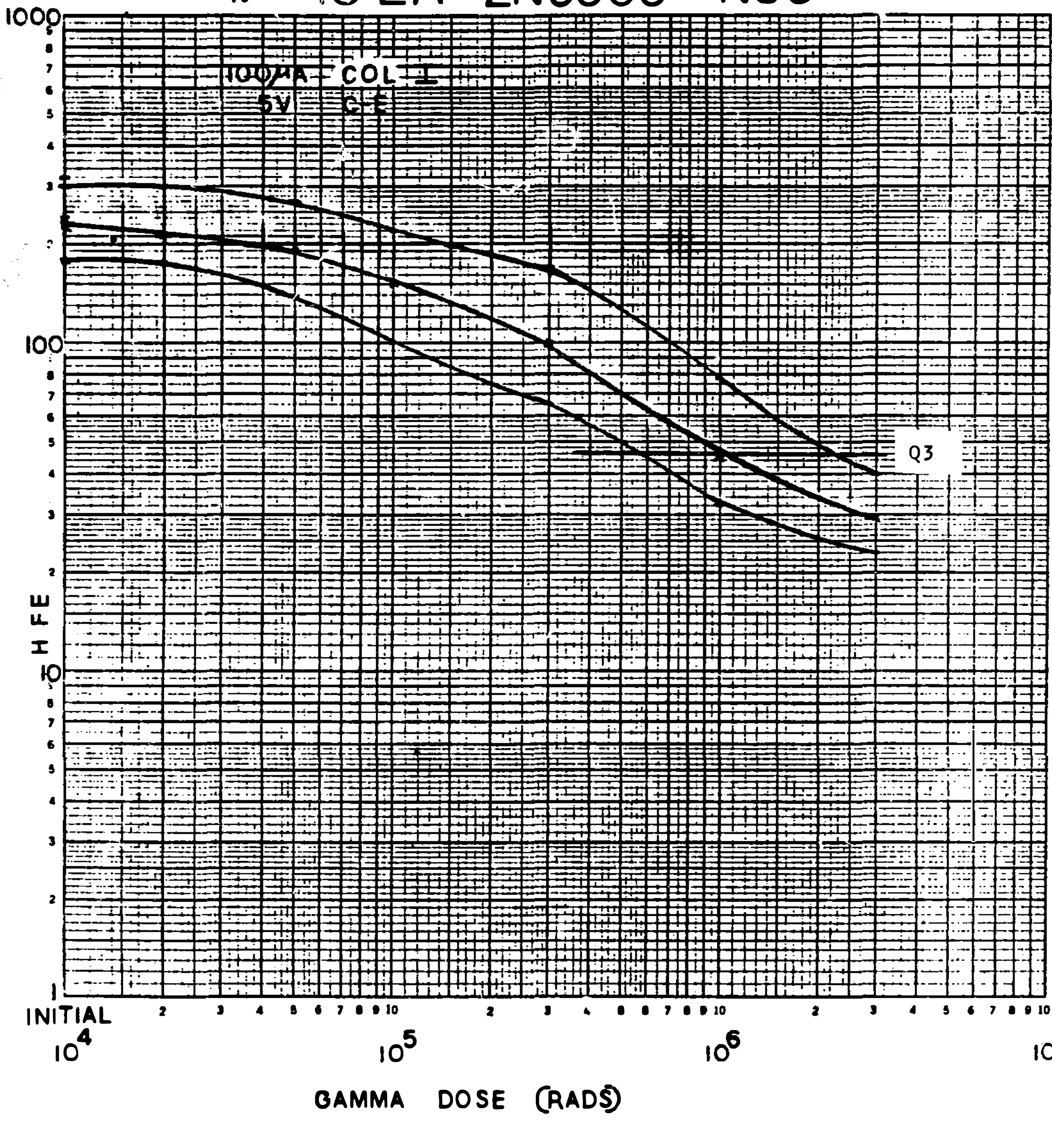
APPENDIX C

Transistor Characteristics

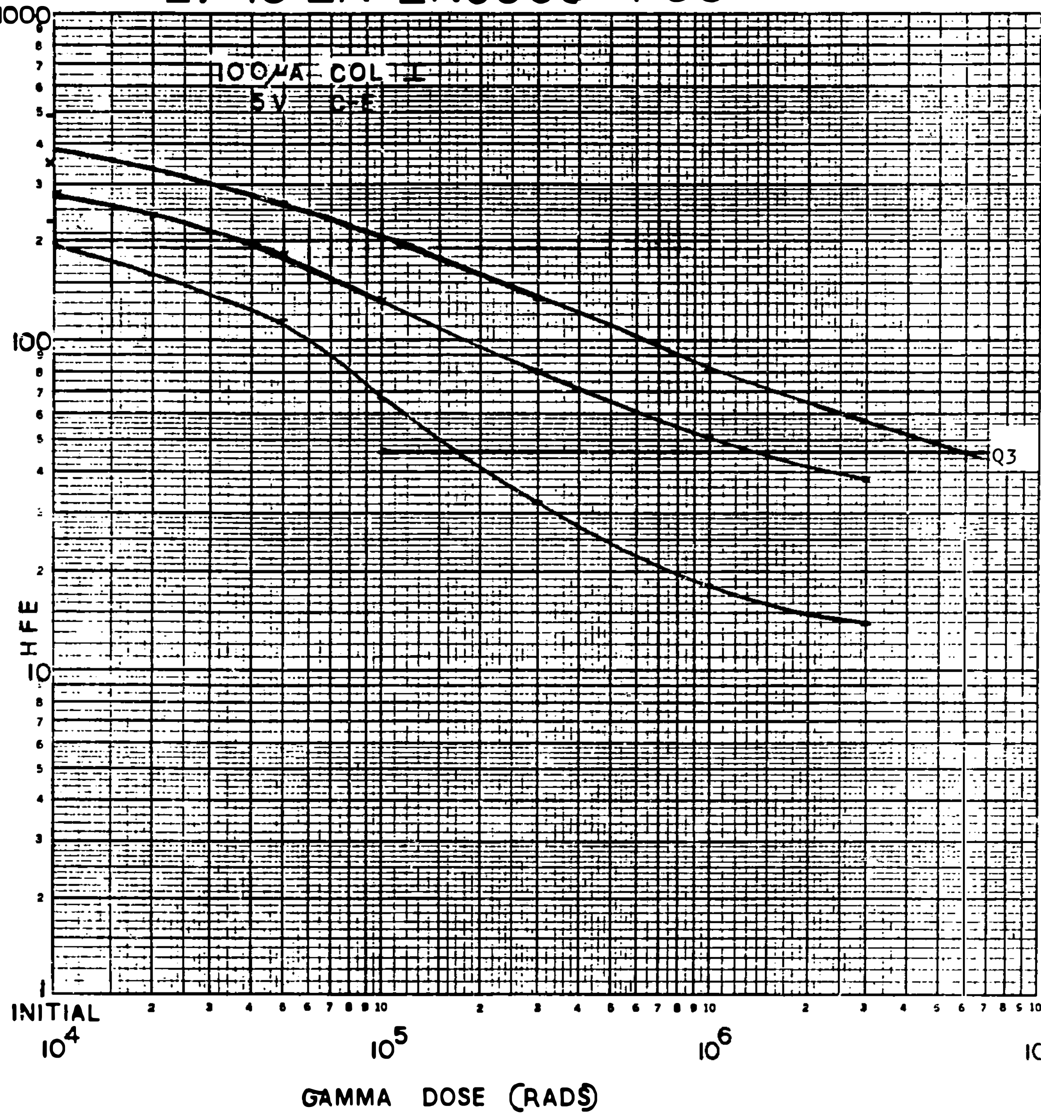
Transistor current gain, HFE, degradation is plotted in the curves given here versus cumulative gamma radiation dose. Eighty-seven devices from four manufacturers were passively exposed to a ^{60}Co source in progressive steps, and the characteristics were measured after each step. Transistor HFE's are plotted for collector currents of 100 microamperes. The three curves shown for each device type represent HFE characteristics from the minimum device, the maximum device and the average of all the devices of that manufacturer. Also shown are the intersections of these curves with the HFE values measured for the devices removed from HP-R-212. The number of devices of each type as well as the manufacturer is listed on each graph.

Contents

I. 10 EA 2N3565 NSC



2. 10 EA 2N3565 FSC



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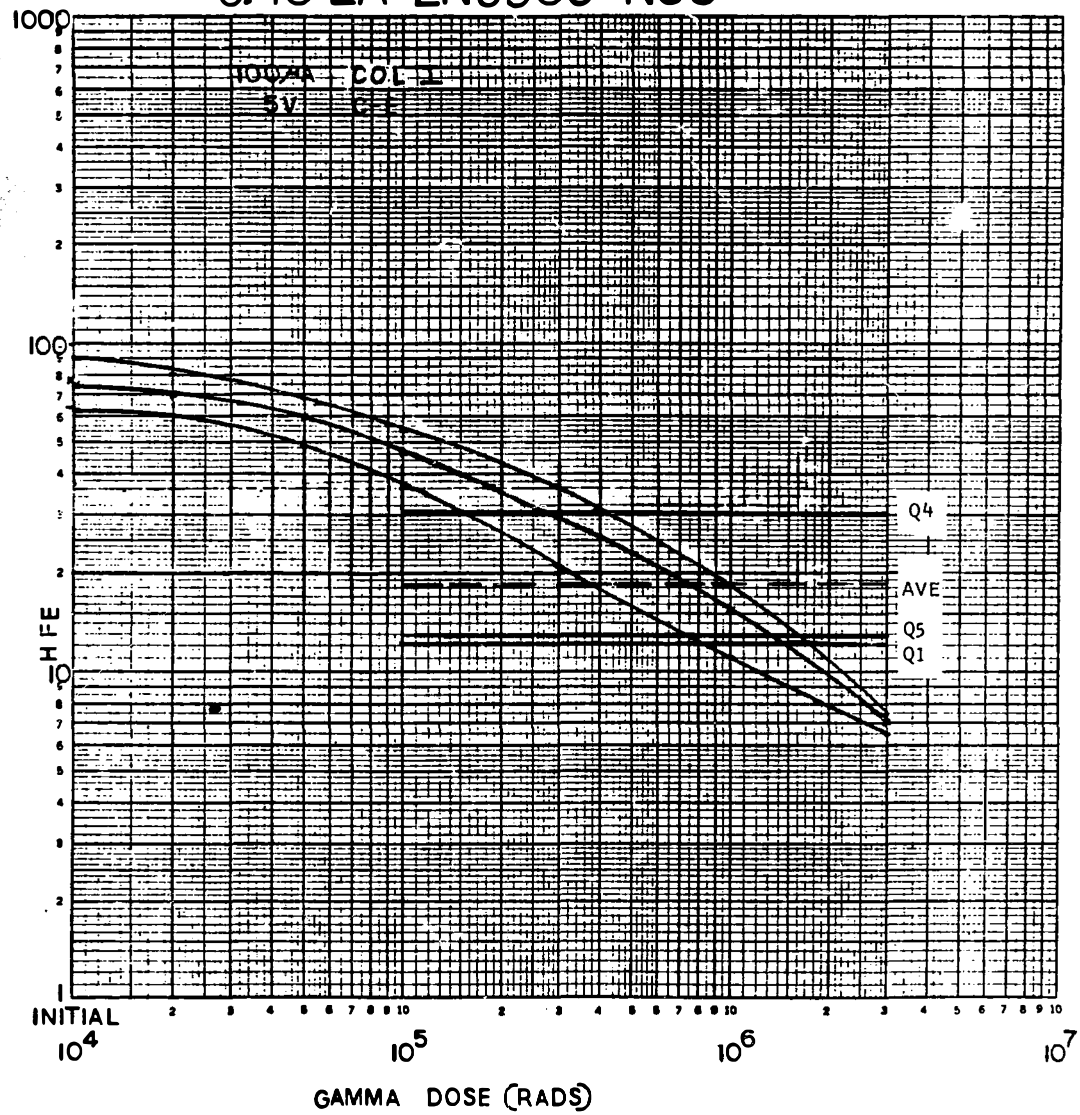
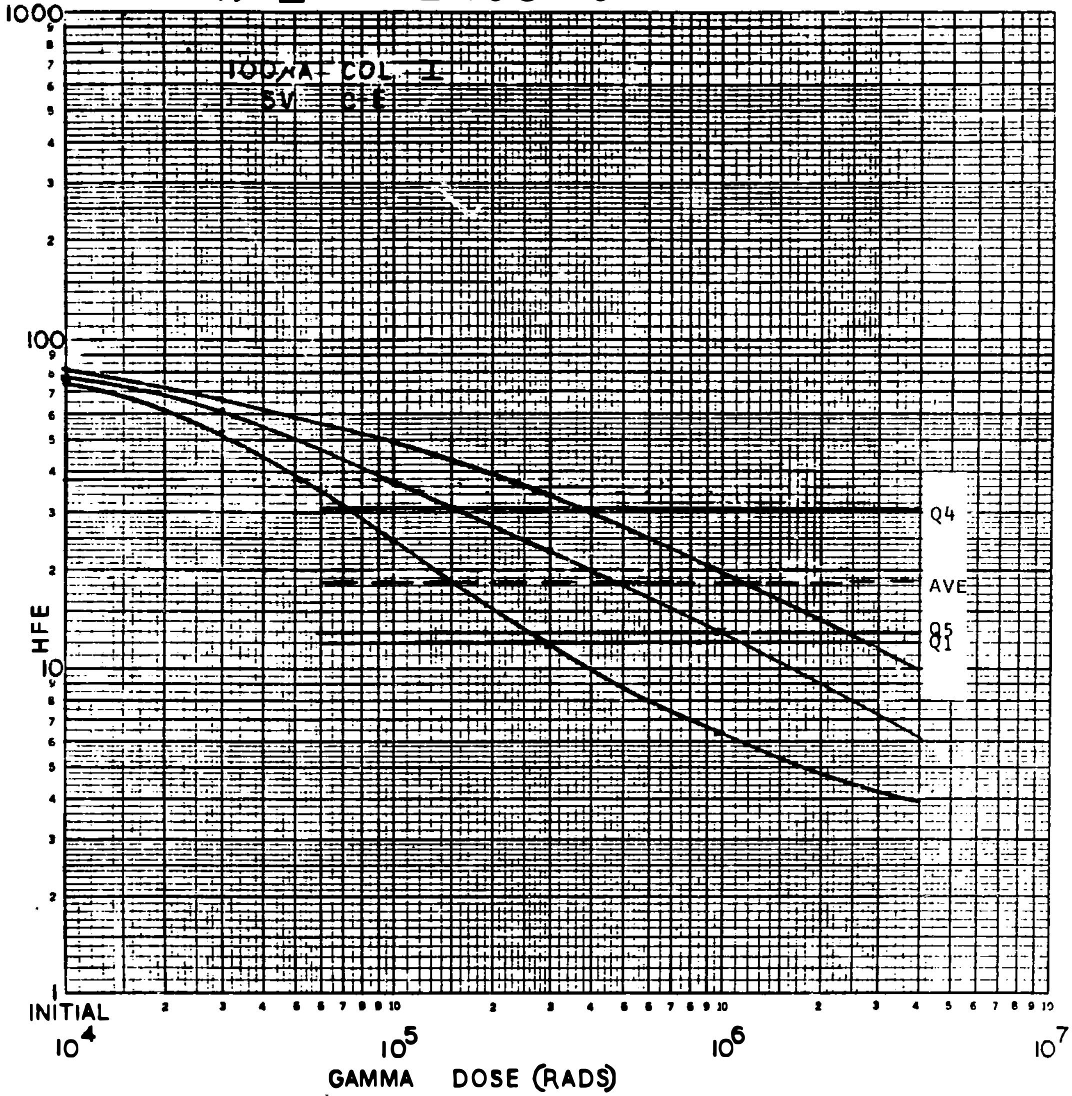
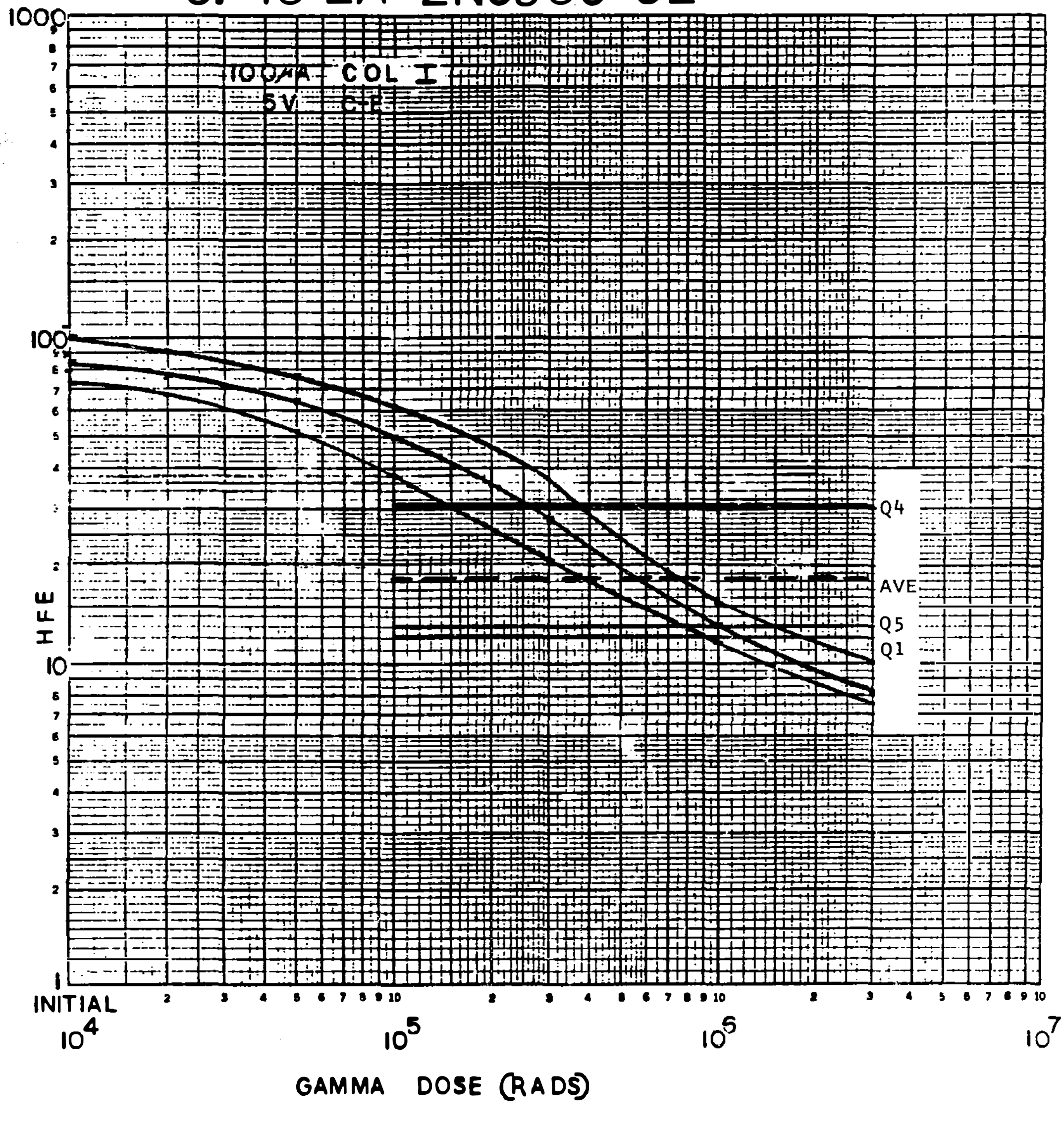


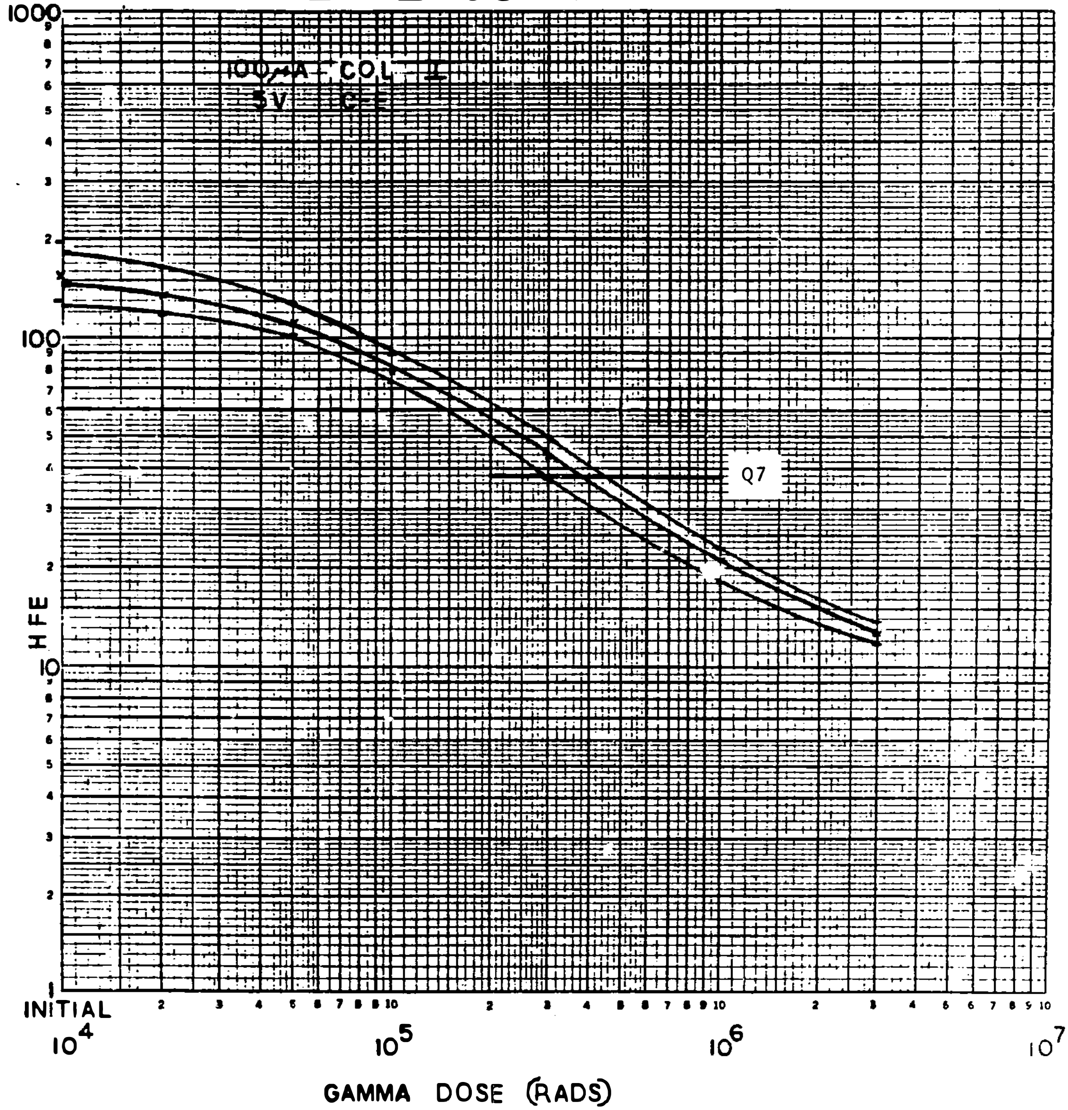
4. 2 EA 2N3903 FSC



5. 10 EA 2N3903 GE



6. 10EA 2N3904 NSC



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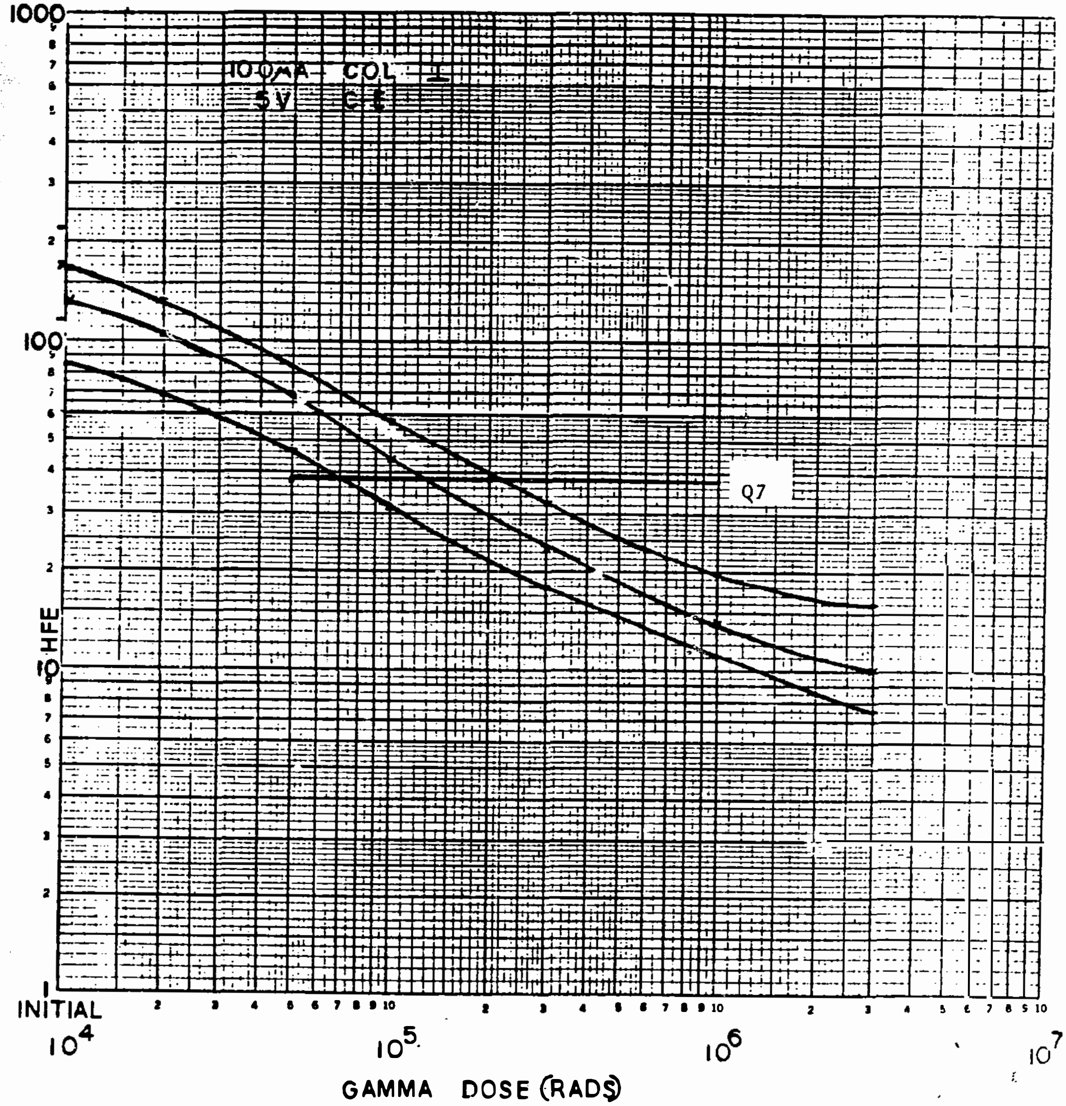
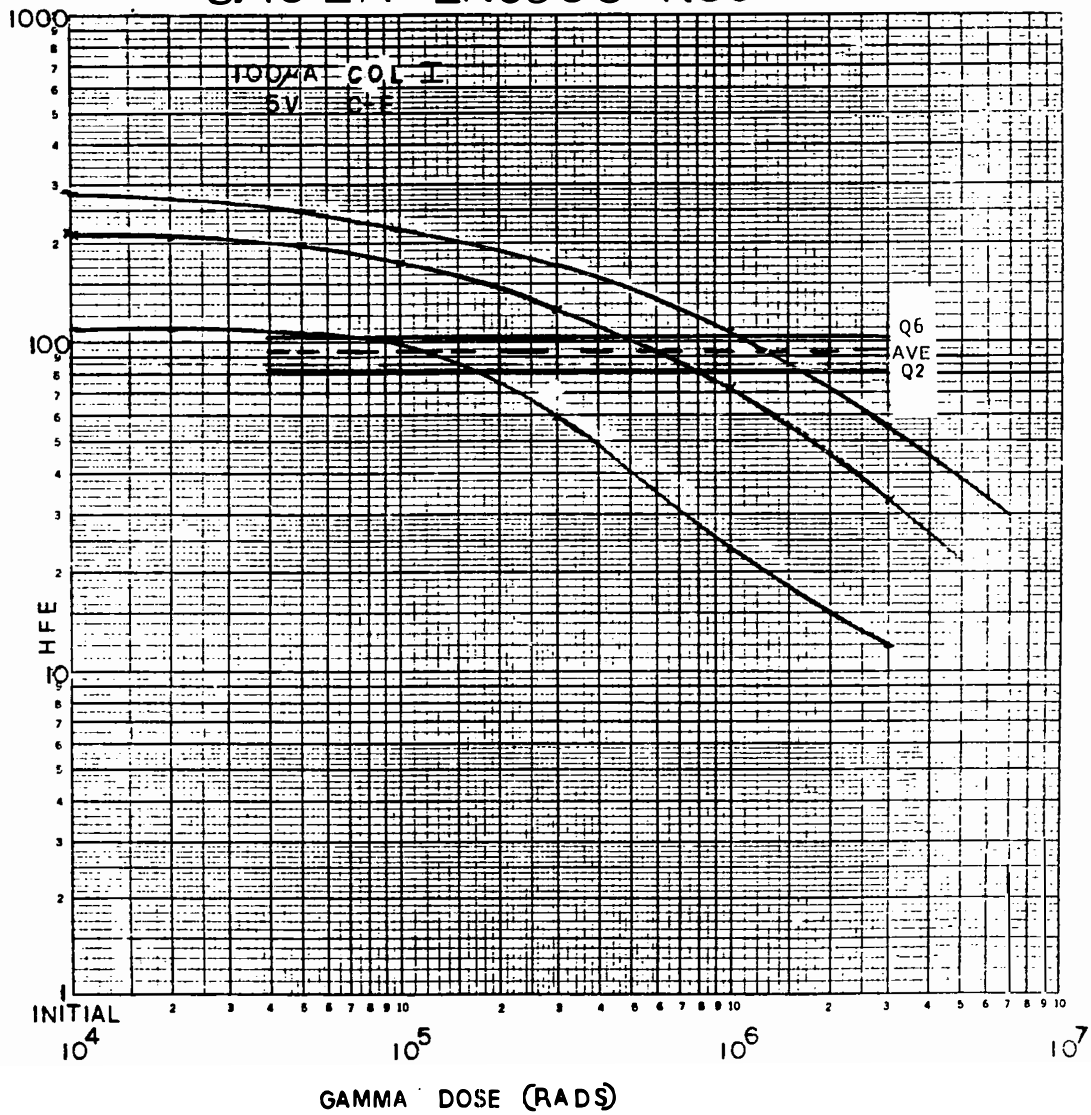
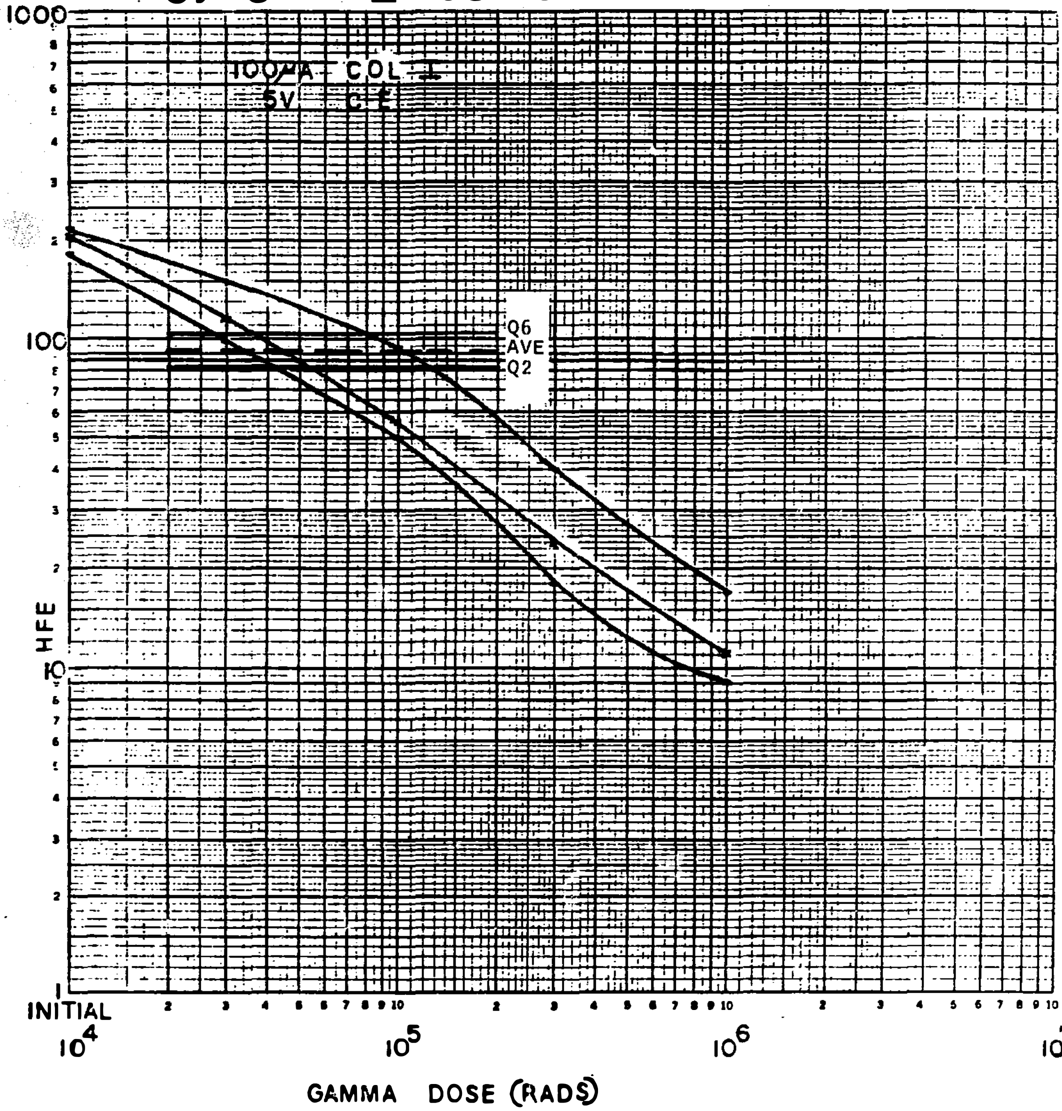


8.10 EA 2N3906 NSC



9. 5EA 2N3906 FSC



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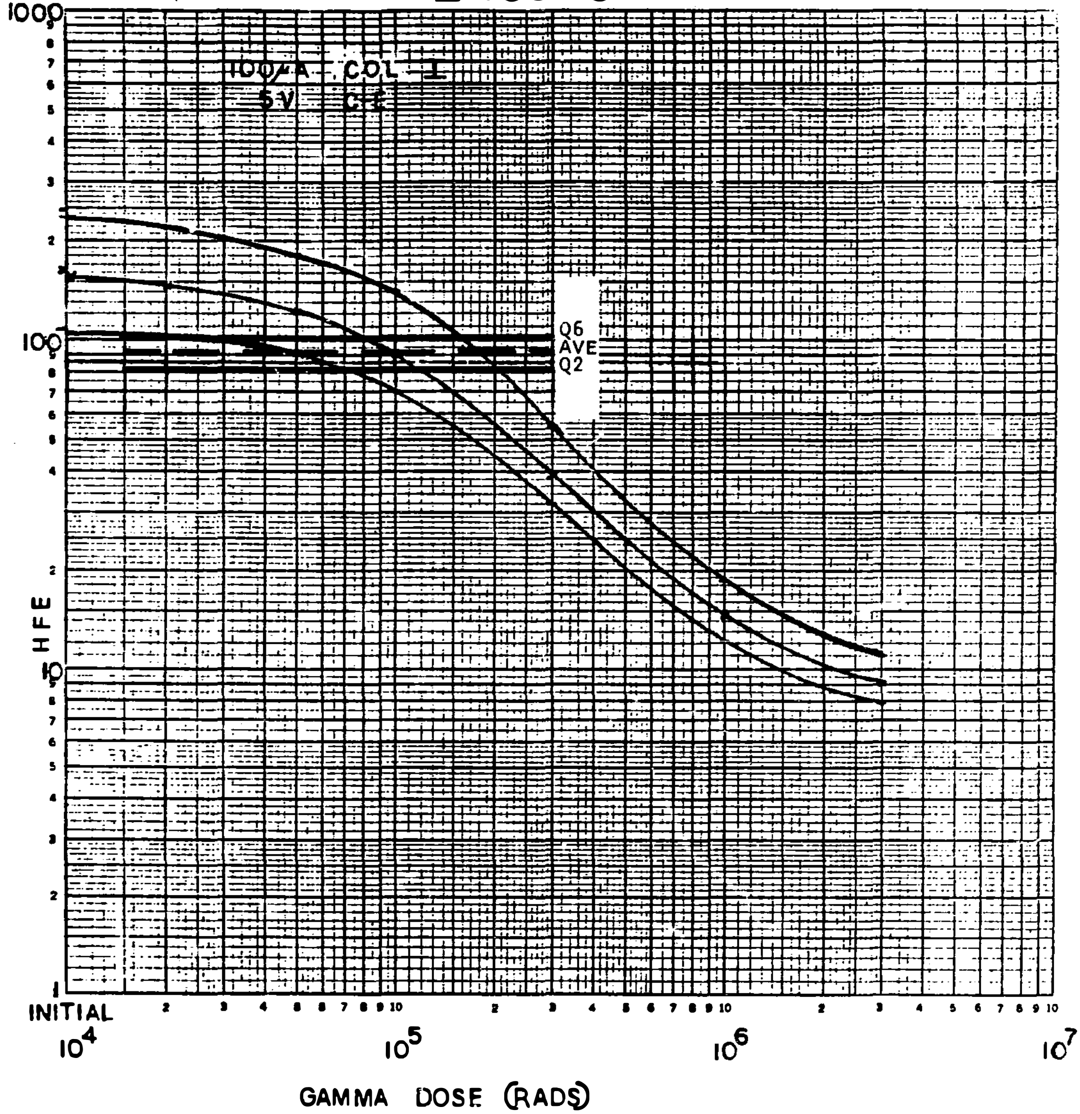

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