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EXAMINATION RESULTS OF THE THREE MILE ISLAND RADIATION DETECTOR HP-R-213

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ABSTRACT

Area radiation detector HP-R-213 was removed from the Three Mile Island containment building on May 28, 1981. The detector apparently failed at the time of the hydrogen burn, and afterwards indicated radiation levels of less than 0.1mR/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.

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. Asselmeier performed the transistor gamma dose testing, and J. D. Anderson and C. B. Berglund of Health Physics assisted me 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-213. In this report I discuss the cause of failure and estimate 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 detectors' 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 May 28, 1981 the second area radiation detector (HP-R-213) was removed from the Three Mile Island Unit 2 containment building for examination and laboratory testing. This area radiation detector was located in the Incore Instrument Service area at the 347 foot level. The detector is a gamma radiation monitor manufactured by Victoreen (Model 857-2) and employs a GM tube to detect events. It is of the same design as radiation detector HP-R-211 which was analyzed earlier.[1] HP-R-213 was operational during the accident up until the hydrogen burn occurred at which time its output went to zero. In situ electrical measurements were made on the instrument from TMI-2 control room by General Public Utilities (GPU) and Technology for Energy, Inc. (TEC).[2] The detector was delivered to Sandia National Laboratories on June 30, 1981 for electrical examination.

B. Findings and Recomendations

1. The stripchart recording of HP-R-213 indicates that the detector failed at or near the time of the hydrogen burn (Figure 1). The examination of the failed detector showed the cause of failure to be a cracked GM tube. Due to the presence of numerous chips and scratches around the glass-to-metal seal, the glass was apparently in a weakened state prior to the hydrogen burn. It is likely that the tube failed as a result of the mechanical shock imparted to the entire detector assembly by the hydrogen burn. It is less likely that the tube failed because of the change in atmospheric pressure. The glass thickness and printed circuit board mounting method should allow a good quality tube to withstand substantially higher shocks; i.e., no inherent weakness in the present design can be identified. It is recommended that tighter quality controls be instituted to prevent this type of failure in the future.

2. The GM tube from the test detector was placed in the HP-R-213 detector circuit. The detector then functioned normally when exposed to gamma radiation up to 20 R/hr.

3. I estimate the total gamma radiation dose accumulated by this detector to be approximately 9.9 x 10^5 rads.

II. DESCRIPTION

HP-R-213 (SN326) is one of six containment building area radiation monitors. It was mounted on the D ring wall at the 347 foot elevation near the incore tube exit ports. The detector was connected to its ratemeter readout electronic module in the TMI-2 control room through about 104 meters (341 feet) of instrumentation cable. The wiring diagram for HP-R-213 is shown in Figure 2.

III. MECHANICAL EXAMINATION

The detector outside case shows the same pitting and corrosion around the connector as was seen in HP-R-211 (Figure 3 through Figure 6); however, this is normal when the environment it was exposed to is considered. The O-ring seal did a good job, even though it had some damage where it was apparently pinched at some time (Figure 7). Swipes taken on the inside of the canister indicate that no radioactive materials leaked in to contaminate the printed wiring assembly. A microscopic examination of the printed wiring assembly showed it to have solder flux around most of the solder joints (Figure 8 and Figure 9).

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 SN673), which is the same model as HP-R-213. Table 1 lists the unpowered resistance measurements taken at Sandia and TMI. Probably the only differences in readings are those due to differences in ohmmeters. These readings are all normal.

TABLE 1. UNPOWERED 213 MEASUREMENTS

OHMMETER POLARITY/ LINE TO LINE MEAS.		RESISTANCE (OHMS)		
+	-	213 at TMI	213 at SANDIA	TEST DETECTOR
+10V	GND	7.40K	7.10K	6.40K
GND	+10V	11.80K	12.73K	11.67K
+10V	SIG	8.32K	8.55K	7.95K
SIG	+10V	6.70K	6.55K	5.59K
GND	SIG	8.78K	9.11K	8.44K
SIG	GND	7.25K	8.15K	6.98K
+600V	GND	OPEN	OPEN	OPEN
GND	+600V	OPEN	OPEN	OPEN
CS1	CS2	41.0	29.2	24.2
CS2	CS1	41.0	29.2	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 voltage and meter readings obtained when HP-R-213 was initially powered. Again, the TMI and test detector data are included for comparison. The voltages measured are all proper except that the SIG output of HP-R-213 did not switch from its high state to its low state. This indicated to me that the GM tube was not discharging, or was in continuous discharge. It was possible to change the states by turning power off and on. These measurements were all made through the detector connector without opening the detector. The detector was eventually opened, and node voltages were measured.

TABLE 2. POWERED 213 MEASUREMENTS (DC)

QUANTITY MEASURED		MEASUREMENT		
		213 at TMI	213 at SANDIA	TEST DETECTOR
+10V	(V)	11.1	10.11	10.06
SIG.	(V)	---/10.95	0.10/9.99	0.07/10.0
+600V	(V)	599.0	599.2	599.1
+22V	(V)	19.4	21.5	21.1
CS I	(ma)	1.95	2.96	2.55
MTR	(mR/hr)	<.1	<.1	0.15
REC	(mv)	---	-0.33	0.35

These DC node voltages are shown on a schematic of the detector in Figure 10. The dual voltages shown are the two states of the flip-flop. These DC voltages are all normal; however, AC measurements made with an oscilloscope showed that the GM tube was not switching.

The faulty GM tube was replaced, and the detector was observed to function normally. Using the new GM tube, the detector was exposed to ^{60}Co at the Sandia Vertical Range Facility. The detector output reading versus input ^{60}Co source level is shown in Figure 11. 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 with the ratemeter. The anti-jam circuit was activated at an input level of 17.5 R/hr. The detector was exposed to radiation levels as high as 600 R/hr with and without 150 meters (492 feet) of RG58 coaxial cable in the SIG output line. Appendix A shows the sequence of events performed in troubleshooting the detector.[3]

V. GM TUBE ANALYSIS

The GM tube was initially examined under a microscope and was found to have chipped glass around the seal between the glass and the chrome-iron cathode cylinder. Several scratches were on the glass seals also; however, no "breaks" were obvious. The tube was then x-rayed to determined if the anode was out of position. The x-ray shown in Figure 12 shows the anode to be properly positioned. A leak test was made to determine the integrity of the tube's seal. In this test one end of the tube was exposed to helium at a pressure of one atmosphere while a vacuum was drawn on the other end of the tube. The presence of helium was then looked for. A small leak was detected in this way. When the tube was later removed from its protective housing the anode end simply fell off. It appears that one of the glass scores had weakened the glass to the point that the hydrogen burn shock caused the crack to propagate to the point of releasing the neon and helium gas and bromine or chlorine quench gas.

VI. TOTAL GAMMA DOSE

All of the transistors were functional when the electronics was examined. The transistors were removed from the circuit and analyzed. The transistor current gain (HFE, 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	12.0
185	Q2	MOTOROLA 2N3906 PNP	50.5
250	Q3	FAIRCHILD 2N3565 NPN	73.5
80	Q4	FAIRCHILD 2N3903 NPN	13.0
80	Q5	FAIRCHILD 2N3903 NPN	13.0
185	Q6	MOTOROLA 2N3906 PNP	34.5
140	Q7	FAIRCHILD 2N3904 NPN	16.5

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 plotted 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]

HP-R-213 was operating during the accident and I assume that the majority of the radiation exposure was during that first 10 hours before the GM tube failed.

TABLE 4. TRANSISTOR TOTAL DOSE

TRANSISTOR TYPE	HFE RANGE (RADS) MIN	AVE	MAX
2N3565...Q3 FSC (HFE=73.5)			
FSC (10 ea)	0.90E5	3.80E5	14.40E5
NAT (10 ea)	2.20E5	4.80E5	11.30E5
AVE	1.55E5	4.30E5	12.85E5
x1.6 (Annealing Factor)	2.48E5	6.88E5	20.56E5
÷3.0 (Biasing Factor)	0.83E5	2.29E5	6.85E5
2N3904...Q7 FSC (HFE=16.5)			
FSC (10 ea)	3.60E5	6.50E5	22.00E5
NAT (10 ea)	12.30E5	16.80E5	19.00E5
AVE	7.95E5	11.65E5	20.50E5
x1.6 (Annealing Factor)	12.72E5	18.64E5	32.80E5
÷3.0 (Biasing Factor)	4.24E5	6.21E5	10.93E5
2N3906...Q2 (HFE=50.5), Q6 (HFE=34.5) (HFE AVE=42.5), ALL MOT			
FSC (5 ea)	1.25E5	1.42E5	2.80E5
NAT (10 ea)	4.80E5	23.00E5	44.00E5
TI (10 ea)	2.15E5	2.80E5	3.80E5
AVE	2.73E5	9.07E5	16.87E5
x1.6 (Annealing Factor)	4.37E5	14.52E5	26.99E5
x1.7 (Biasing Factor)	7.43E5	24.68E5	45.88E5
2N3903...Q1 (HFE=12.0), Q4 (HFE=13.0), Q5 (HFE=13.0) (HFE AVE=12.7), ALL FSC			
FSC (2 ea)	2.70E5	10.50E5	25.50E5
GE (10 ea)	8.00E5	11.00E5	16.80E5
NAT (10 ea)	7.20E5	14.00E5	17.00E5
AVE	5.97E5	11.83E5	19.77E5
x1.6 (Annealing Factor)	9.55E5	18.93E5	31.63E5
÷3.0 (Biasing Factor)	3.18E5	6.31E5	10.54E5
OVERALL AVERAGE TOTAL DOSE	3.92E5	9.87E5	18.55E5

These figures are a good approximation assuming that the detector did receive the majority of its total dose in the first hours of the accident. I don't know whether HP-R-213 was left powered up after the GM tube failed; however, I feel most of the damage was done while the detector was powered up. The average total gamma dose seen by these transistors is approximately 9.9×10^5 rads. This is my main indicator of the total dose that the detector received (a period of 792 days from March 28, 1979 to May 28, 1981) while it was in the containment building.

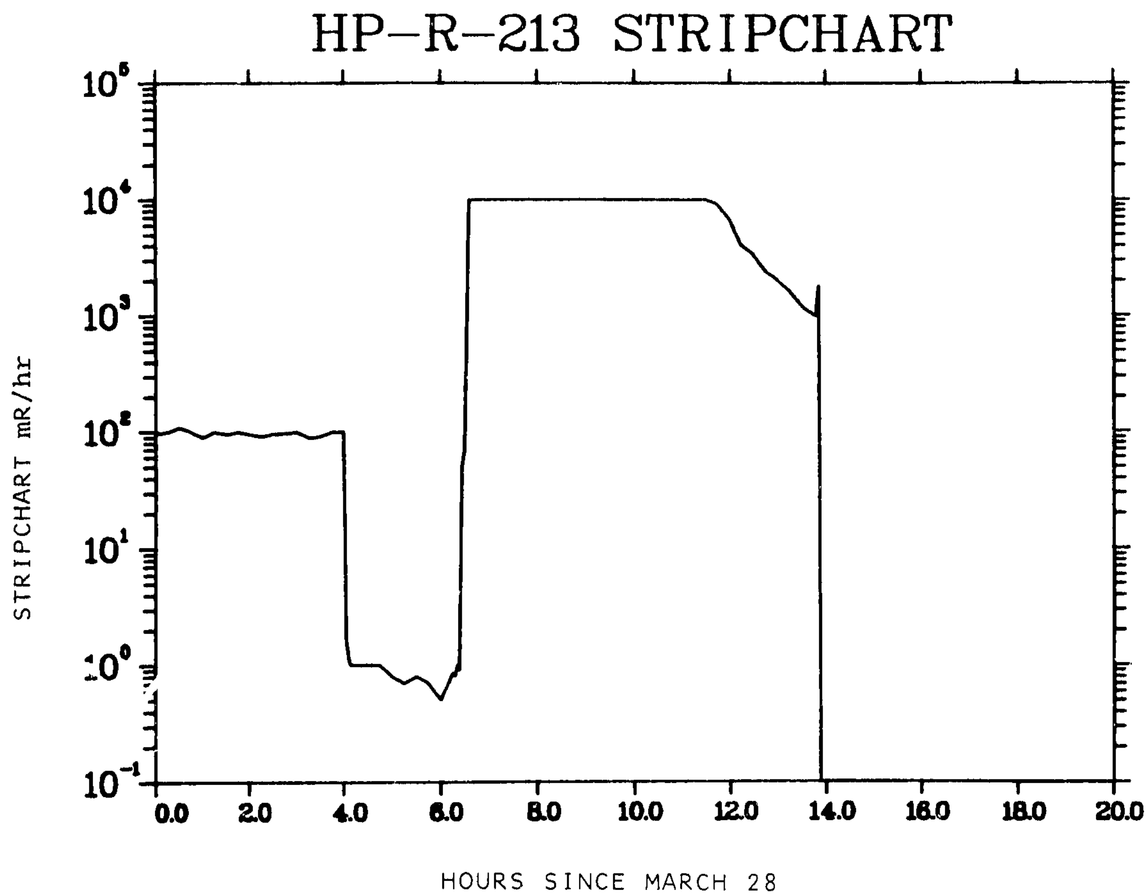


FIGURE 1. HP-R-213 STRIPCHART. This record shows the radiation levels measured by HP-R-213 during the first 20 hours of March 28, 1979. Reactor trip occurs at 4:00 AM, and the first evidence of fuel failure or shine can be seen at approximately 6:24 AM. Detector HP-R-213 was the first containment area monitor to indicate abnormal radiation levels. The anti-jam circuit operates properly until about 11:45 AM at which time an apparent drop in radiation level occurs. I suspect this to be caused by radiation damage to the detector resulting in "multivalued" behavior[1]. The detector output drops sharply to minimum scale at the time of the hydrogen burn where it remained until it was taken out of service.

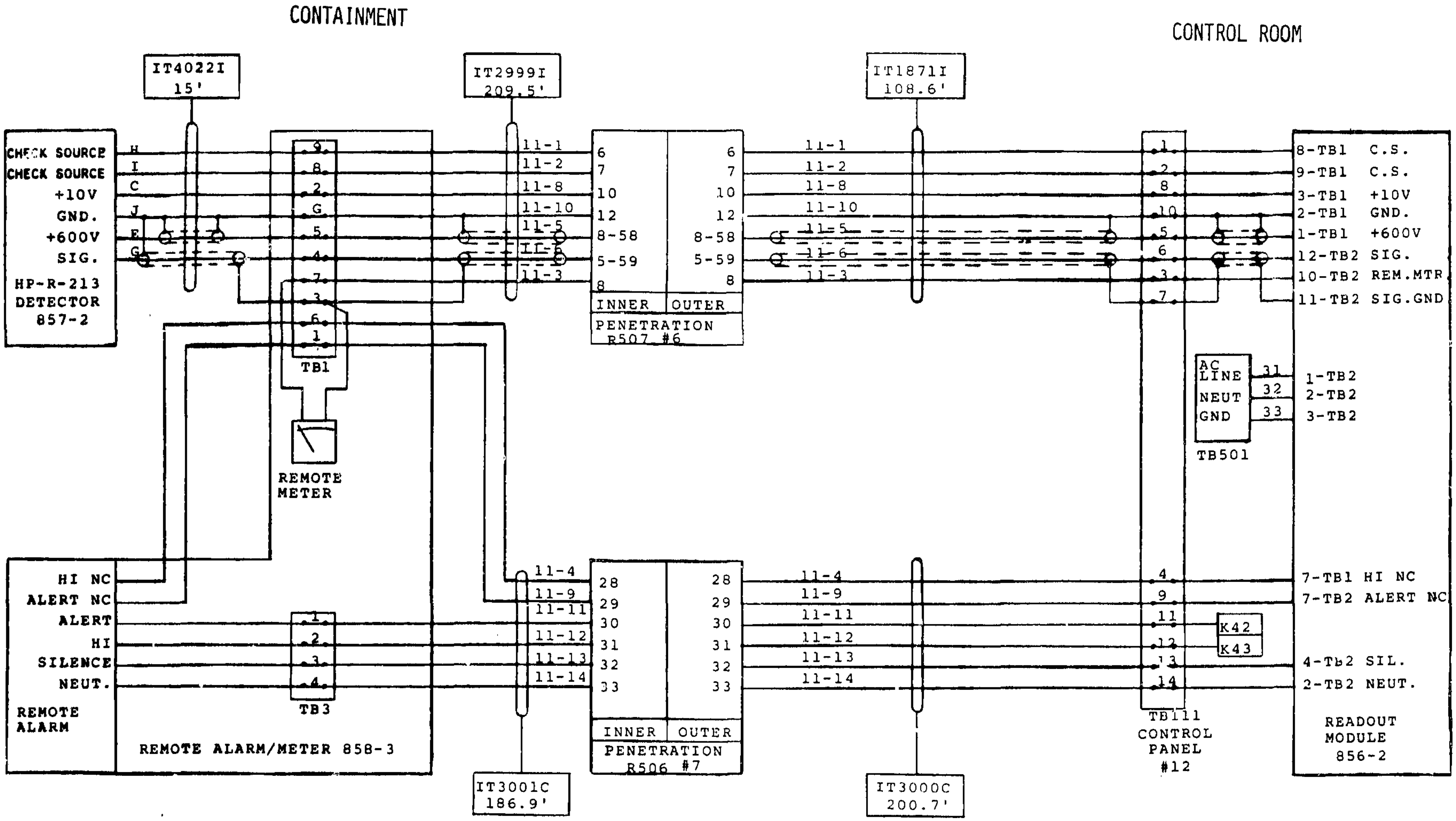


FIGURE 2. HP-R-213 WIRING DIAGRAM

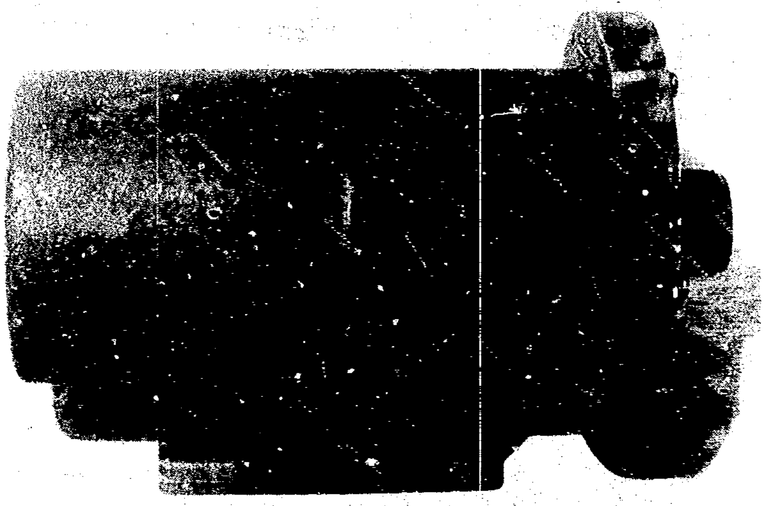


FIGURE 3. HP-R-213 DETECTOR, SIDE VIEW

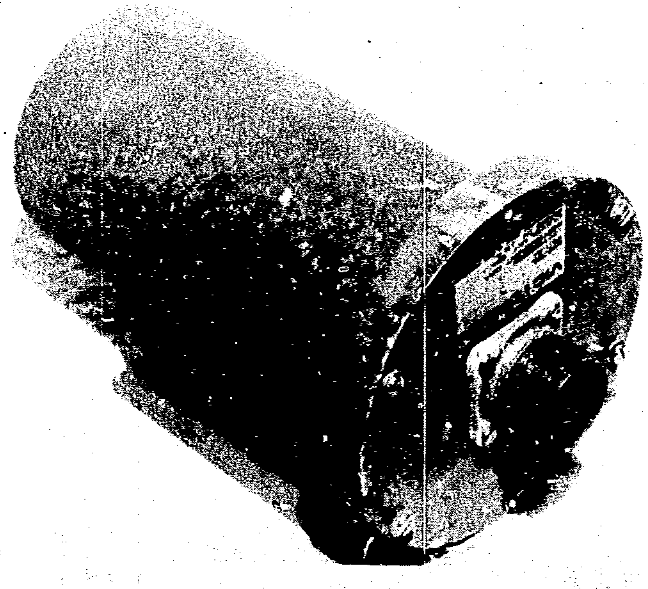


FIGURE 4. HP-R-213 DETECTOR, DIAGONAL VIEW

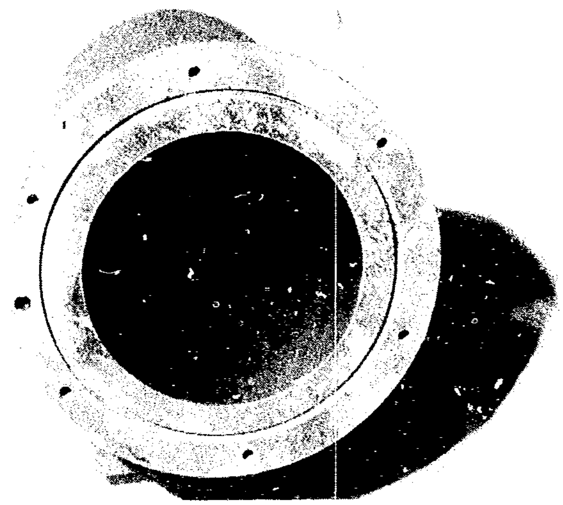


FIGURE 5. HP-R-213 DETECTOR CANISTER, OPENED

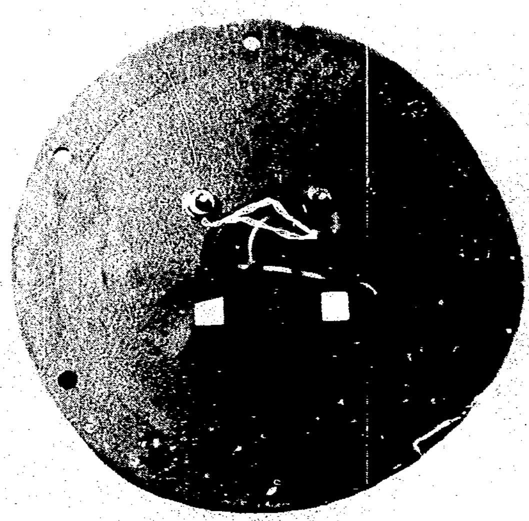


FIGURE 6. HP-R-213 DETECTOR, INSIDE BULKHEAD

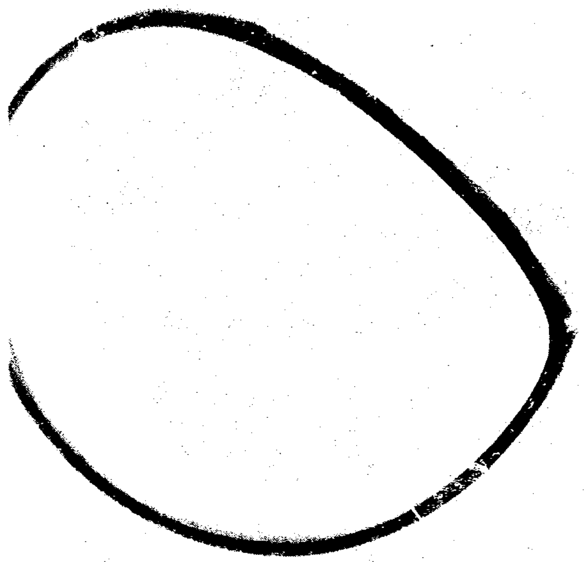


FIGURE 7. HP-R-213 DETECTOR "O" RING SEAL

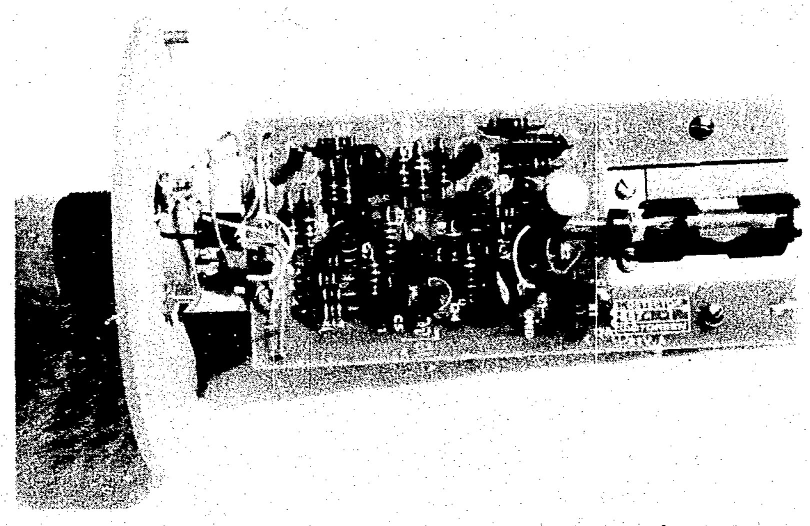


FIGURE 8. HP-R-213 DETECTOR P.C. BOARD COMPONENT SIDE

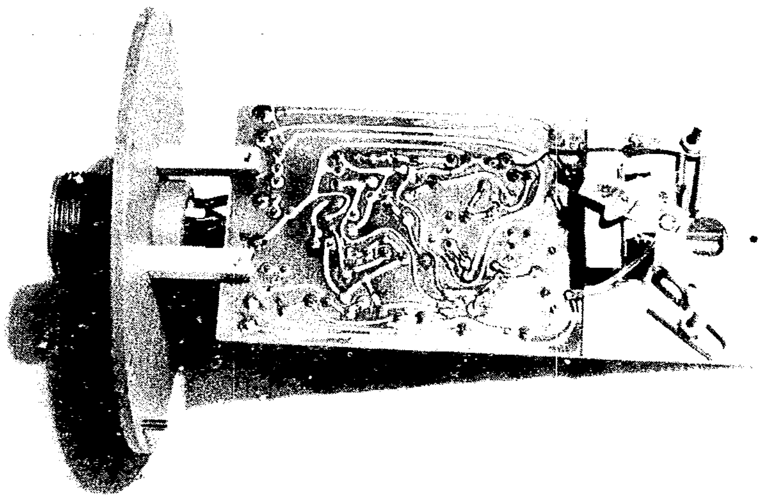


FIGURE 9. HP-R-213 DETECTOR P.C. BOARD FOIL SIDE

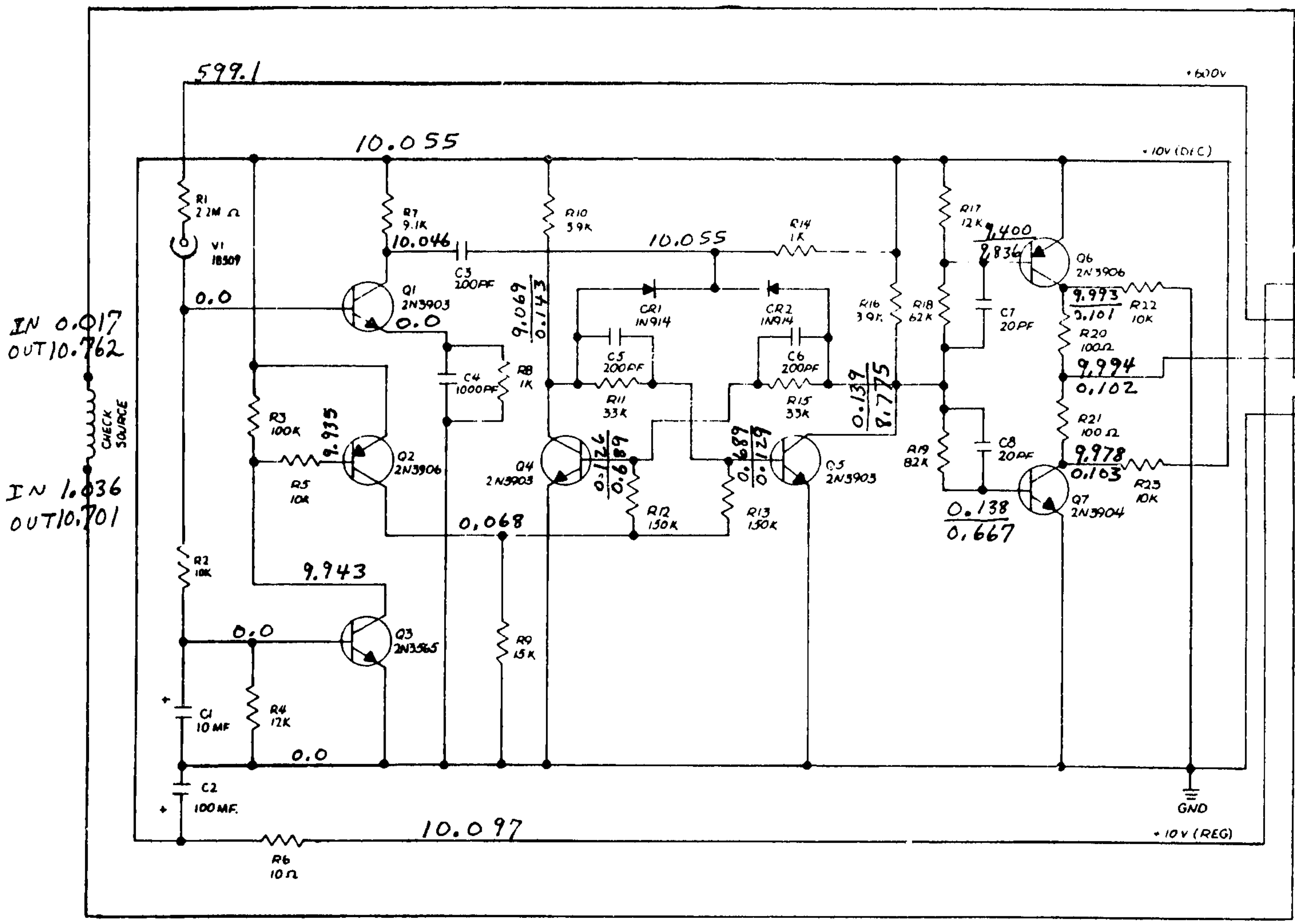


FIGURE 10. CIRCUITRY OF GAMMA DETECTOR 857-2

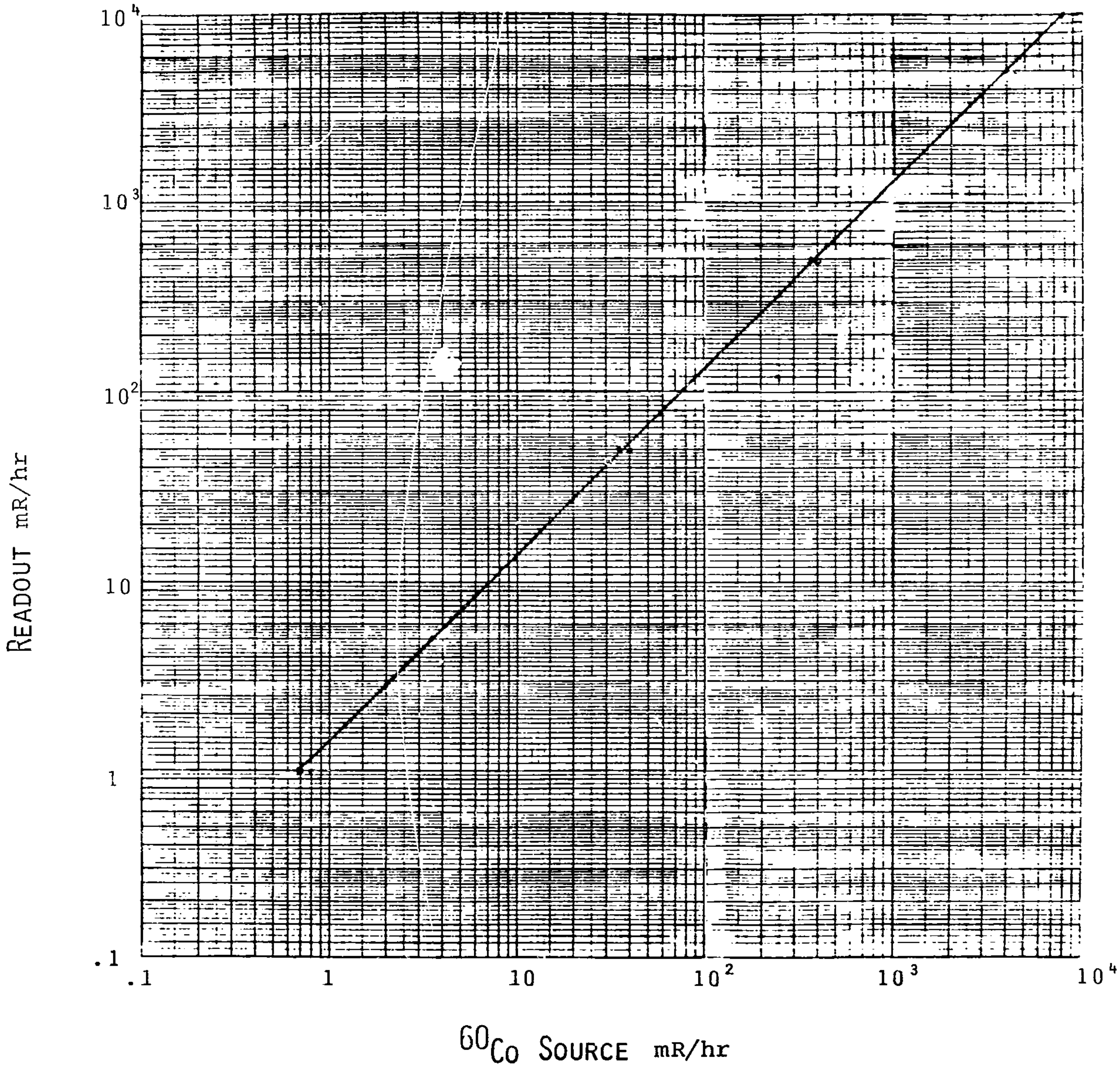


FIGURE 11. REPAIRED HP-R-213 DETECTOR RESPONSE
WITH A REPLACED GM TUBE

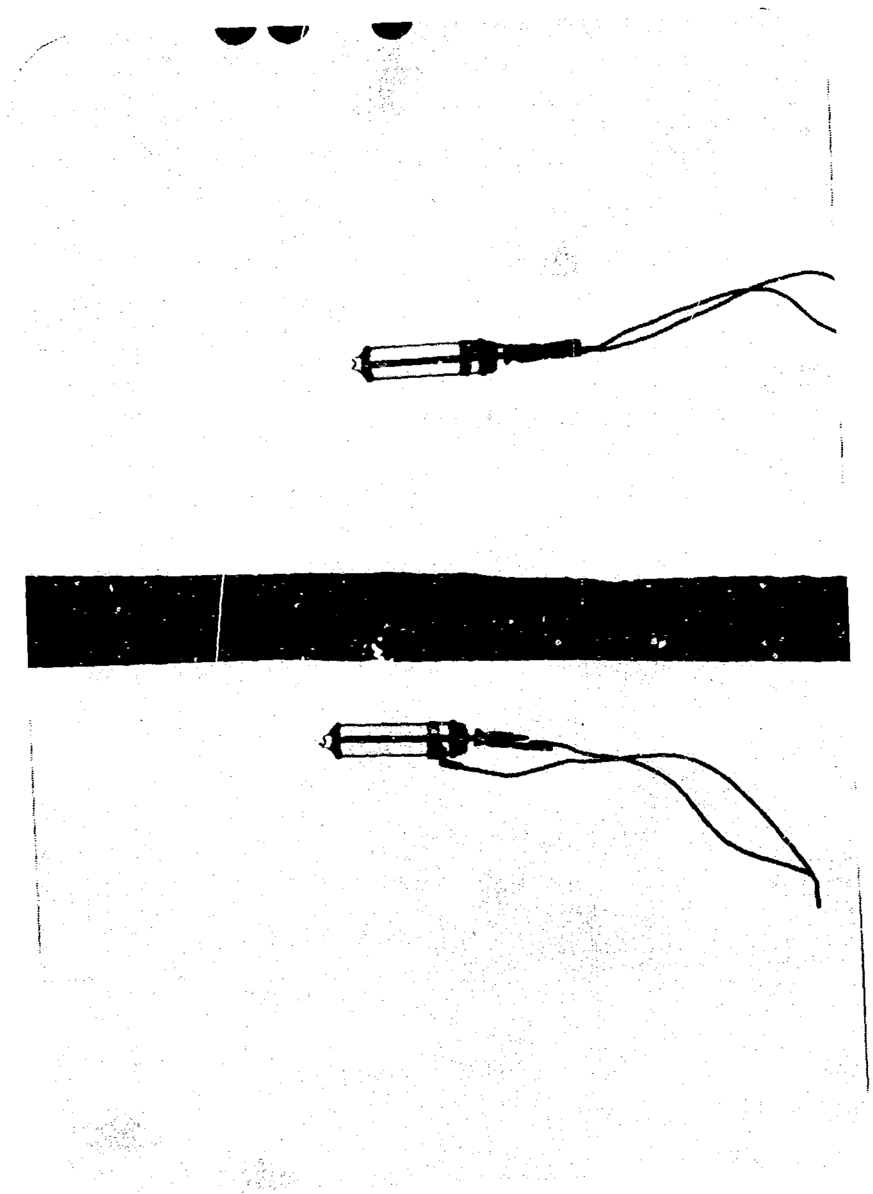


FIGURE 12. X-RAY OF GM TUBE.
TOP VIEW IS ROTATED 90° FROM BOTTOM VIEW

APPENDIX A

Examination Sequence

1. Gamma and gamma/beta survey

2. Swipes on outside of detector

3. Unpowered resistance measurements

4. Powered DC measurements

   a) Found output to be non-functional

   b) Output either high (10V) or low (0V) at turn on

5. Checked Detector at ^{60}Co source up to 600 R/hr with no response

6. Removed P.C. Board from Canister

   a) Took swipes
      1) inside canister
      2) on P. C. board

   b) Visual inspection of P. C. board
      1) 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 not conducting

   b) Replaced GM tube with new tube

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

9. Inspected GM Tube

   a) Microscope inspection

   b) X-Ray inspection

   c) Leak check

10. Removed the transistors for analysis

    a) Measured the HFE of the transistors

    b) Made total dose estimate

APPENDIX B

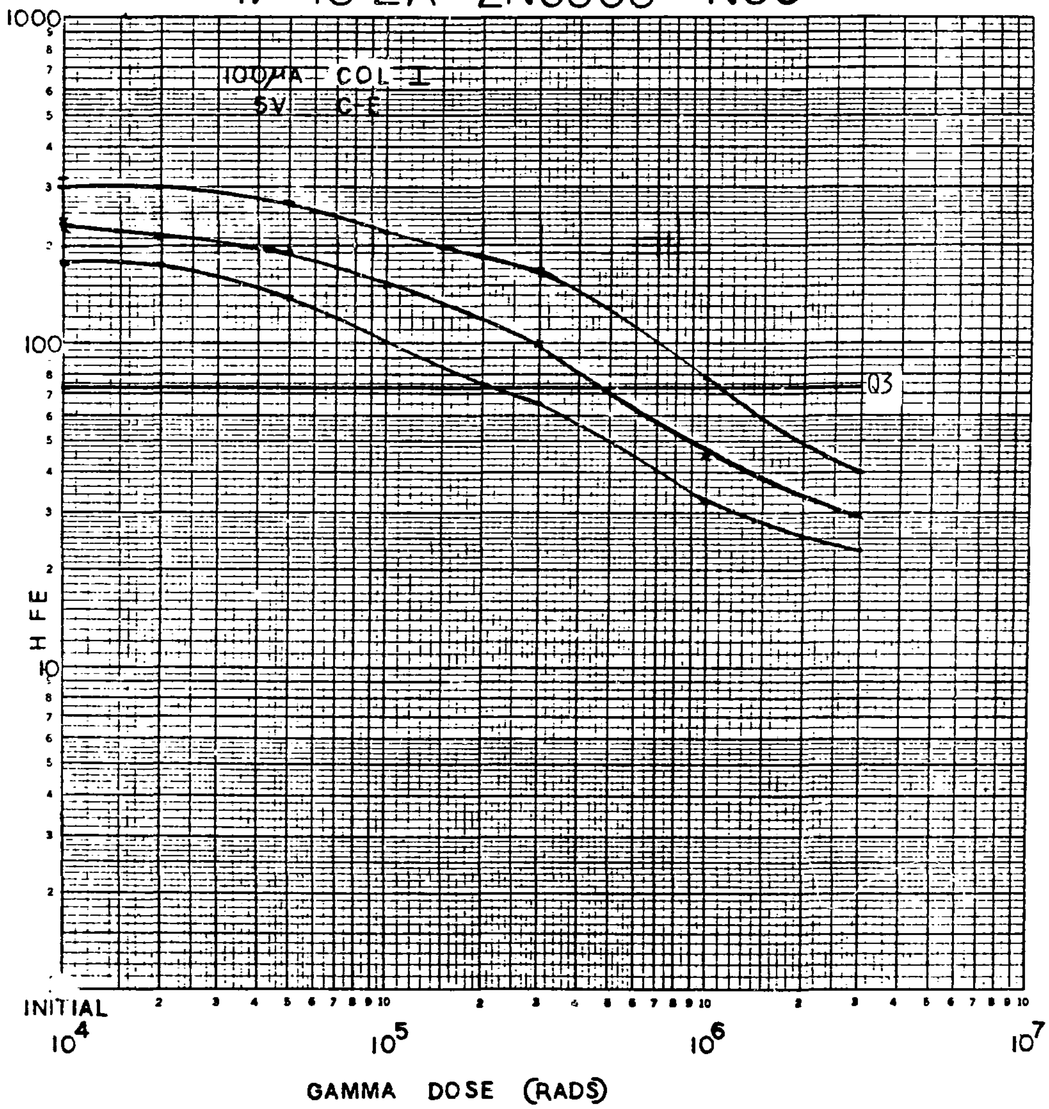
Transistor Characteristics

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-213. The number of devices of each type as well as the manufacturer is listed on each graph.

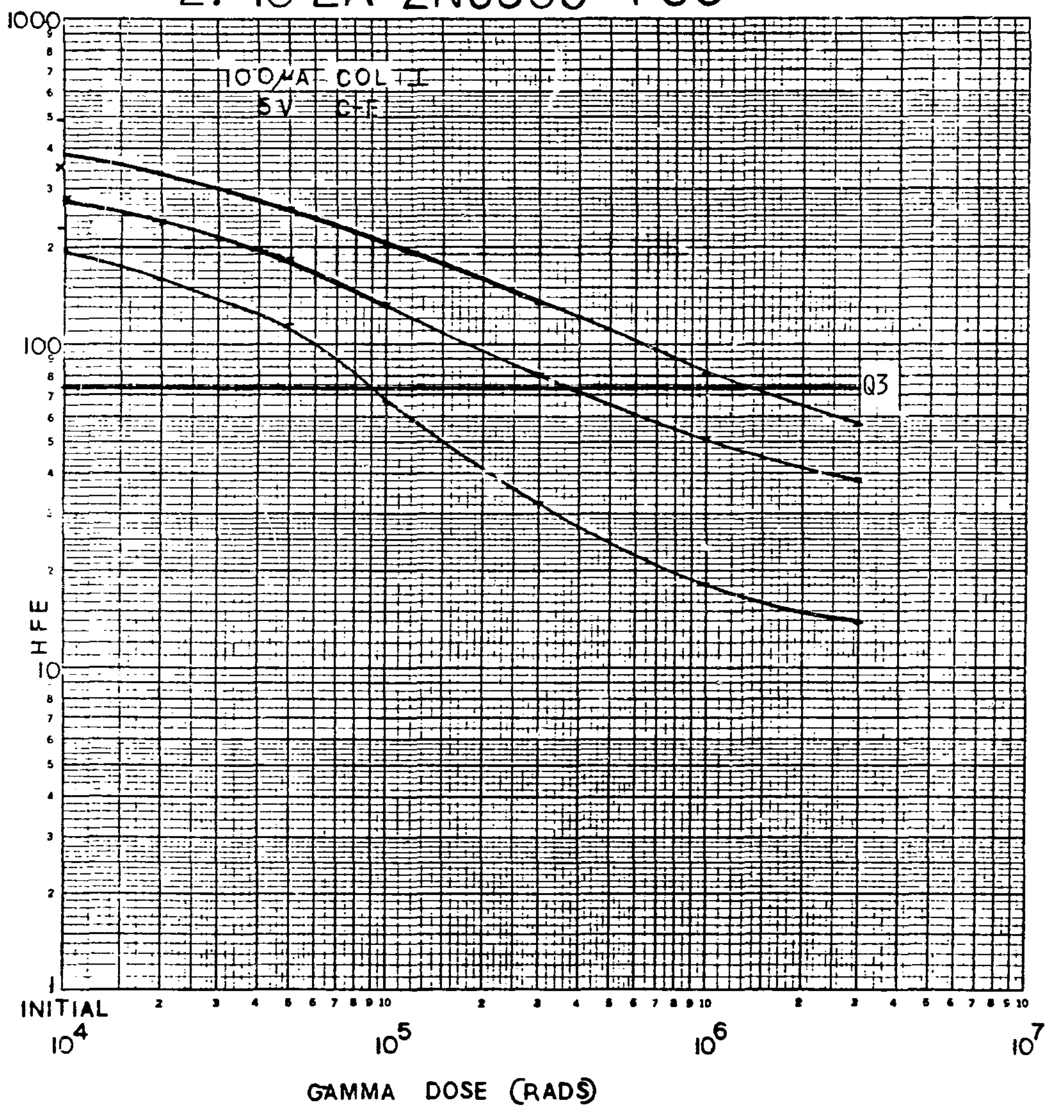
Contents

1. Graph, 10 each 2N3565 NSC
2. Graph, 10 each 2N3565 FSC
3. Graph, 10 each 2N3903 NSC
4. Graph, 2 each 2N3903 FSC
5. Graph, 10 each 2N3903 GE
6. Graph, 10 each 2N3904 NSC
7. Graph, 10 each 2N3904 FSC
8. Graph, 10 each 2N3906 NSC
9. Graph, 5 each 2N3906 FSC
10. Graph, 10 each 2N3906 TI

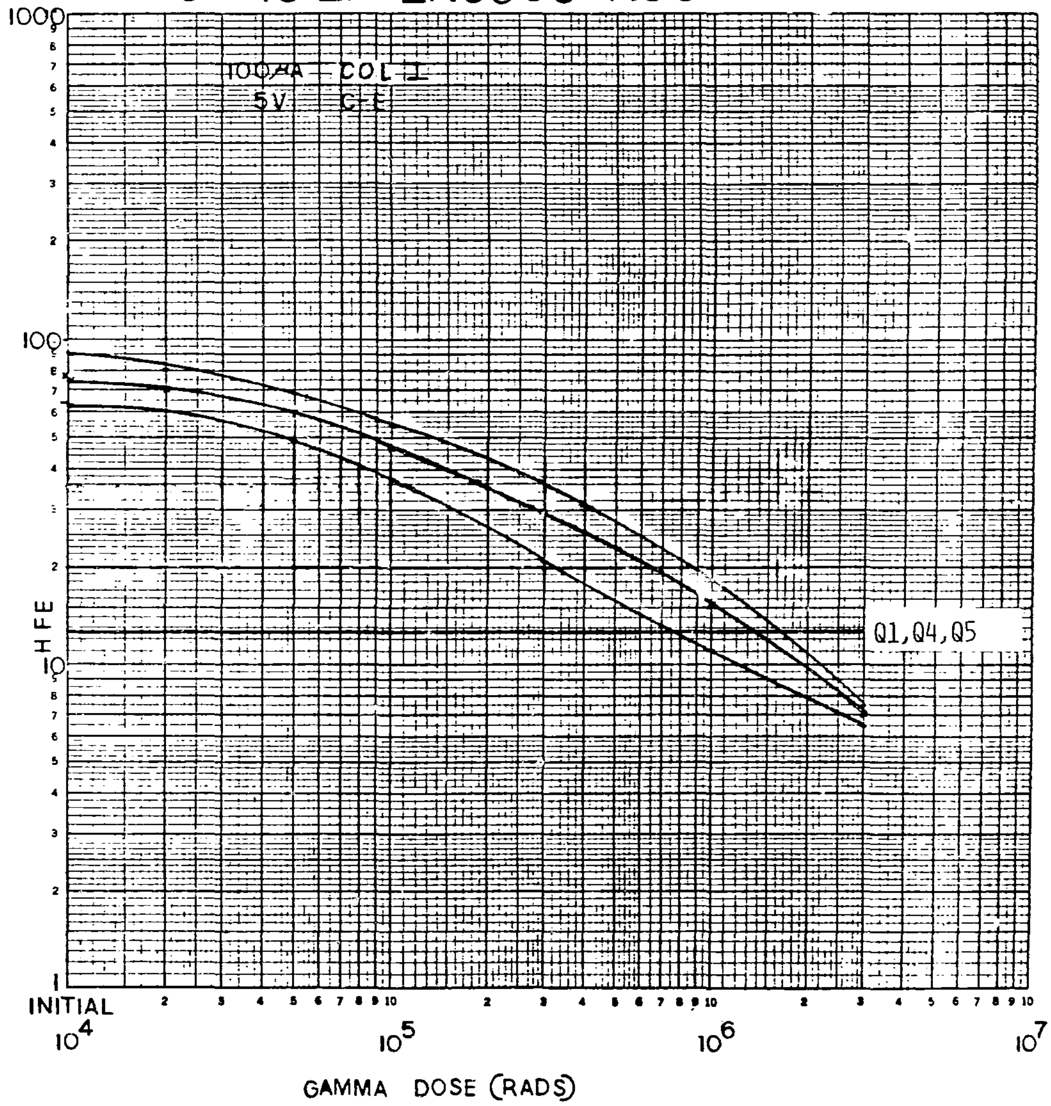
I. 10 EA 2N3565 NSC



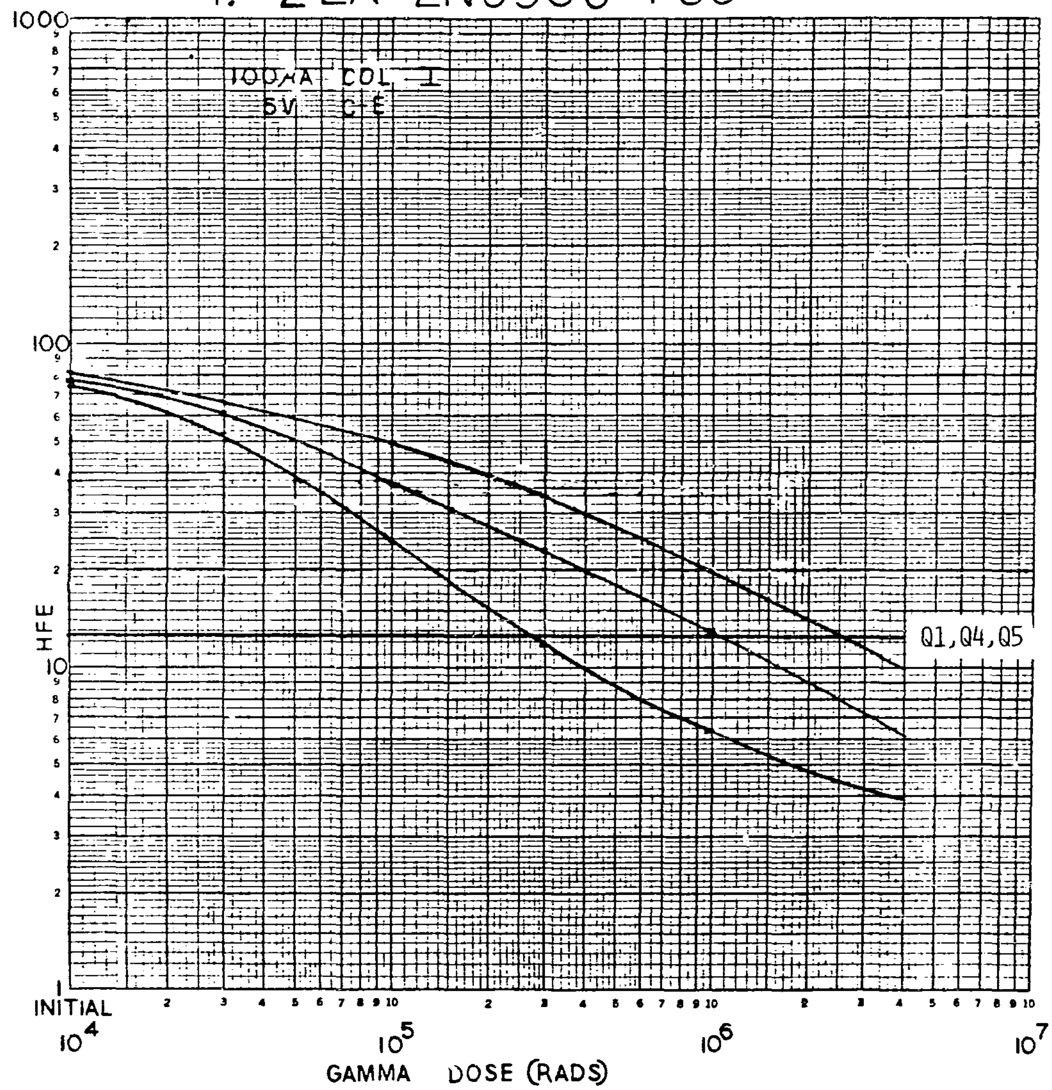
2. 10 EA 2N3565 FSC



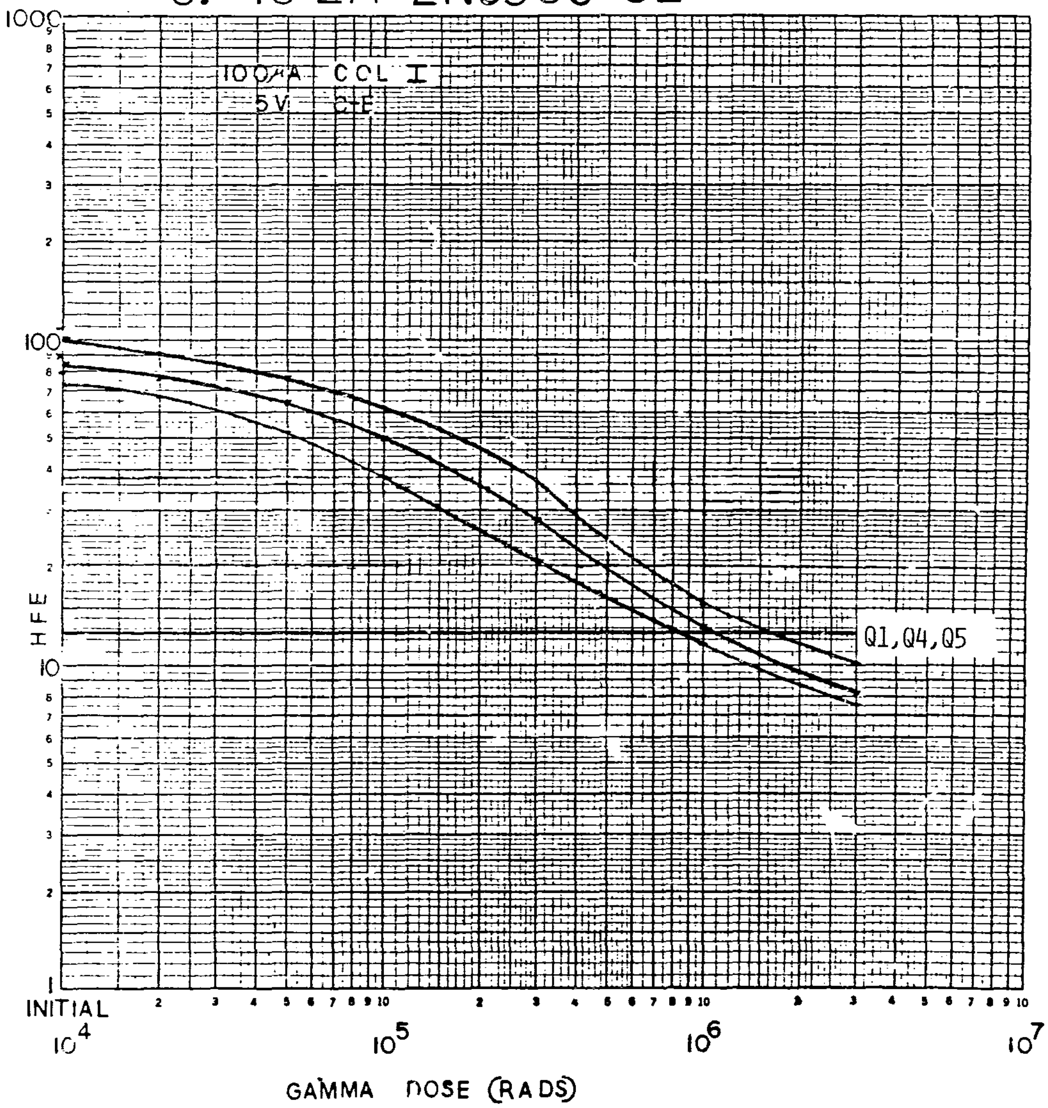
3. 10 EA 2N3903 NSC

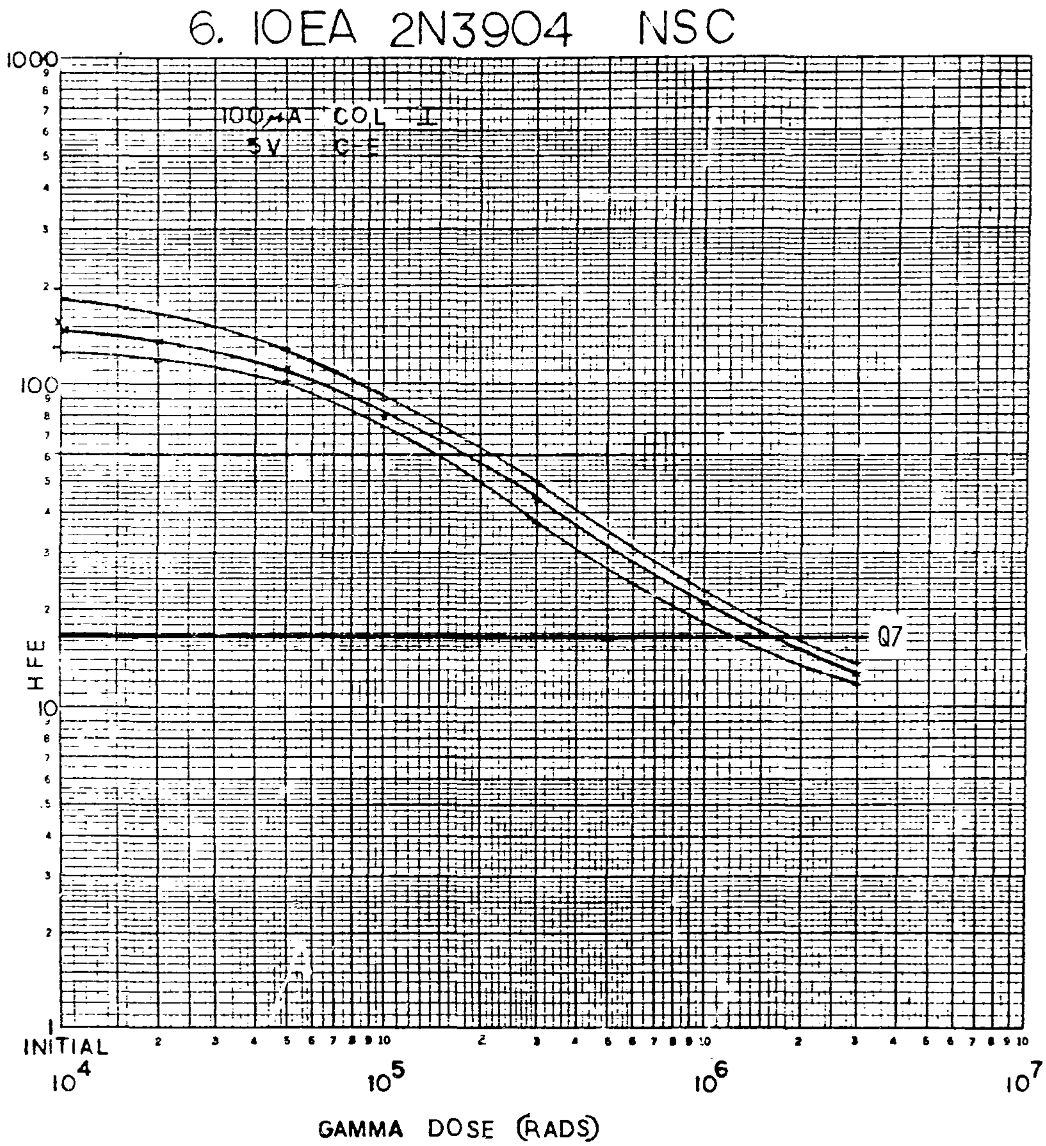


4. 2EA 2N3903 FSC

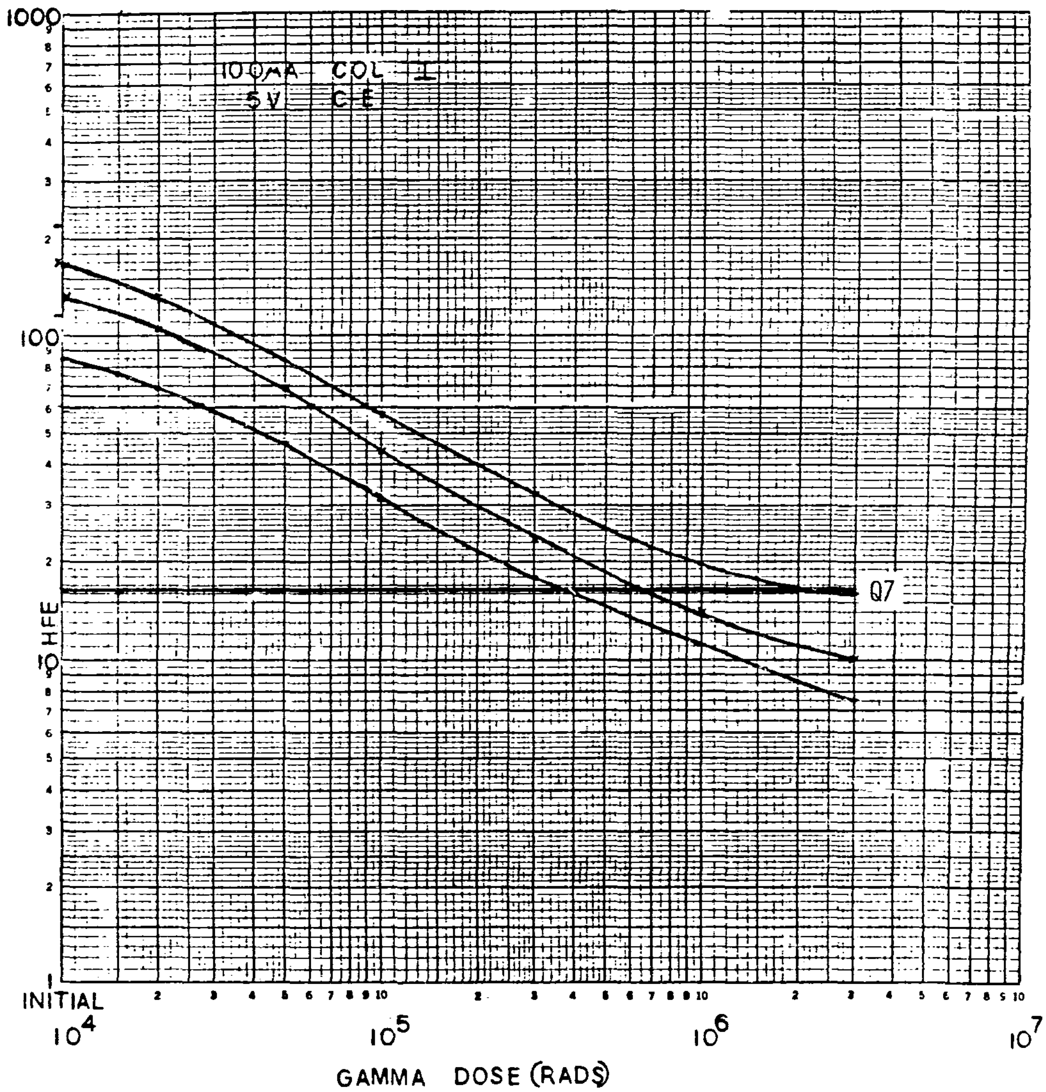


5. 10 EA 2N3903 GE

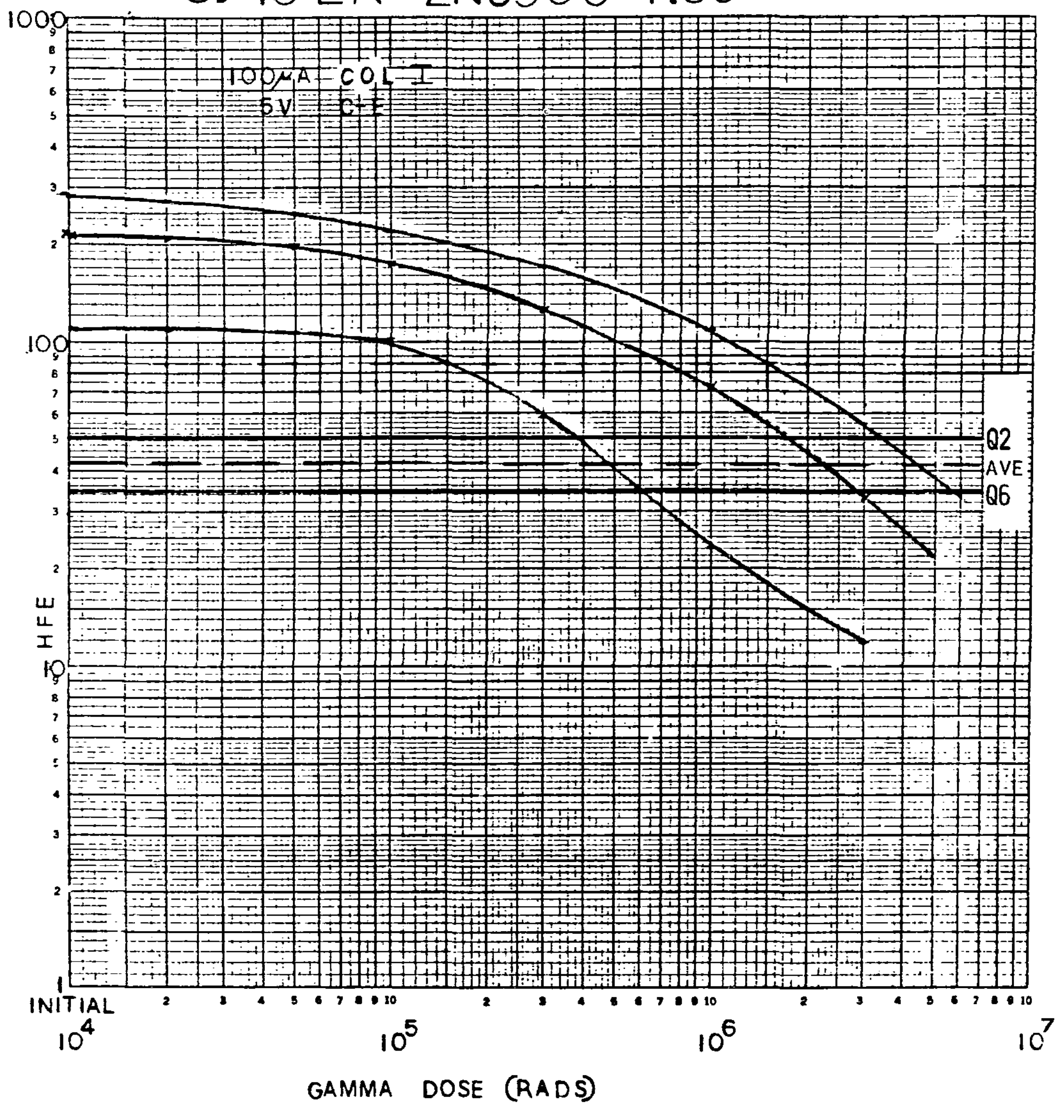



6. 10EA 2N3904 NSC
100μA COL I
5V C-E
HFE
Q7
INITIAL
GAMMA DOSE (RADS)

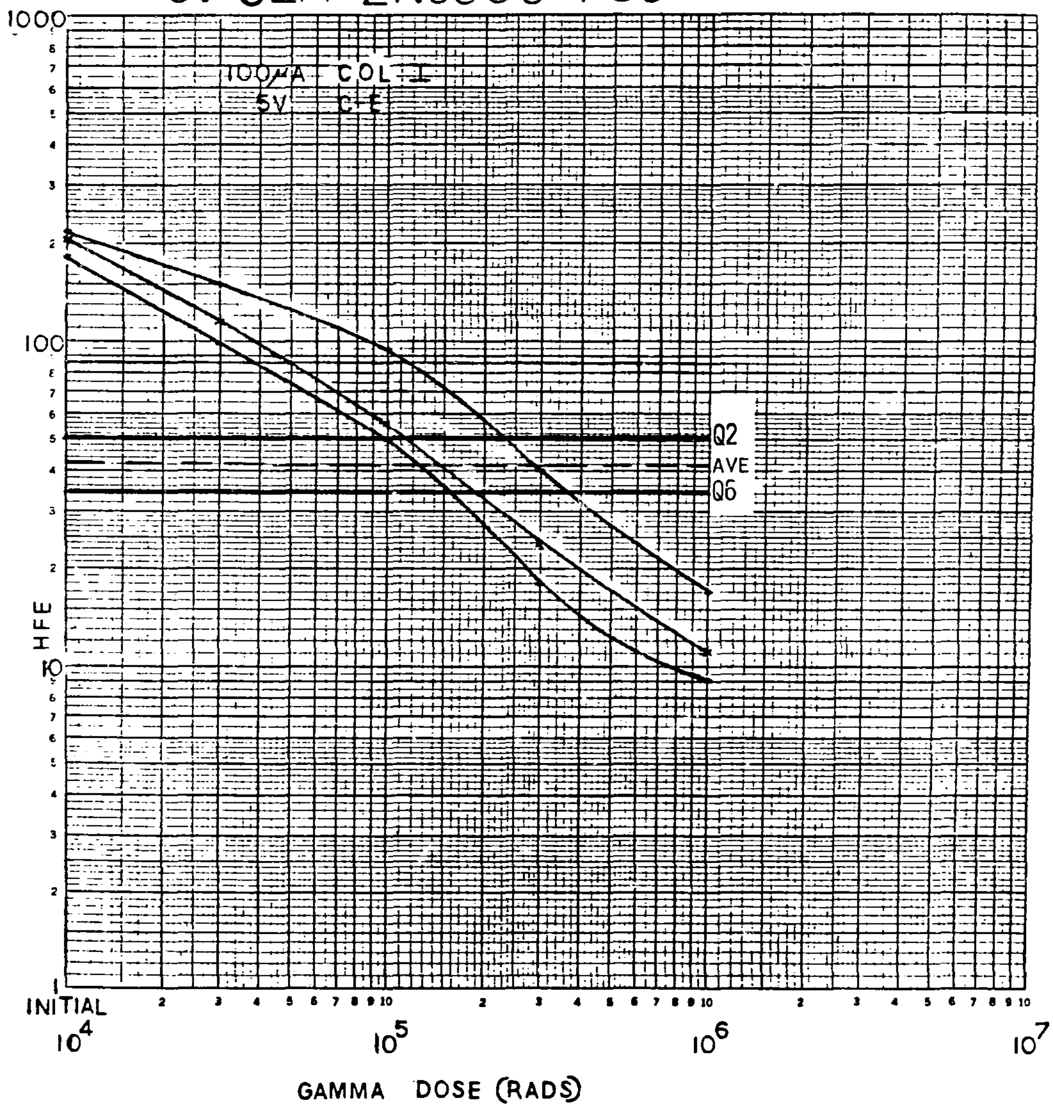
7. 10 EA 2N3904 FSC



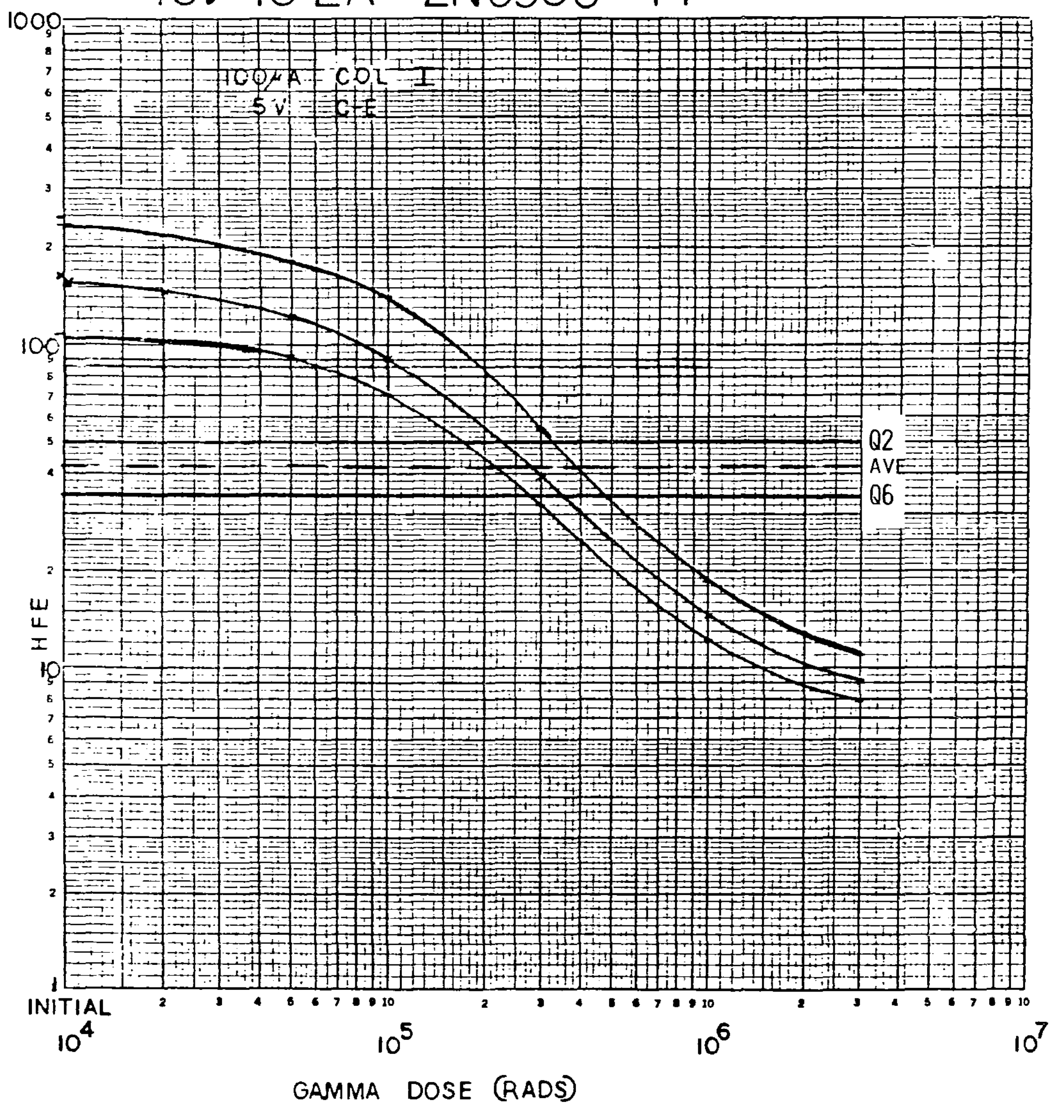
8. 10 EA 2N3906 NSC



9. 5EA 2N3906 FSC



10. 10 EA 2N3906 TI



REFERENCES

1. Examination Results of the Three Mile Island Radiation Detector HP-R-211, M. B. Murphy, G. M. Mueller, F. V. Thome, SAND 81-0725, September 1981.

2. Field Measurements and Interpretation of TMI-2, Instrumentation: HP-R-213, J. E. Jones, J. T. Smith, M. V. Mathis, GEND-IF-017, Volume IX, January 1982.

3. Sandia Laboratory Notebook, ENG-F-837, Geoffrey M. Mueller, 1981.