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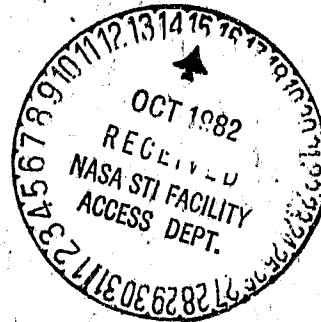
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Total-Dose Radiation Effects Data for Semiconductor Devices

William E. Price
Keith E. Martin
Donald K. Nichols
Michael K. Gauthier
S. Frederick Brown

September 1, 1982

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NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

FOREWORD

Copies of Volumes I and II of this publication can be obtained through a written request to the Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109, c/o W. E. Price, M/S 83-103, requesting JPL Publication 81-66, <u>Total-Dose Radiation Effects Data for Semiconductor Devices</u>, Volumes I and II.

All data were generated by the JPL Radiation Effects and Testing Group, Section 514.

ABSTRACT

Volume III of this three-volume set provides a detailed analysis of the data in Volumes I and II, most of which was generated for the Galileo Orbiter Program in support of NASA space programs. Volume I includes total ionizing dose radiation test data on diodes, bipolar transistors, field effect transistors, and miscellaneous discrete solid-state devices. Volume II includes similar data on integrated circuits and a few large-scale integrated circuits. The data of Volumes I and II are combined in graphic format in Volume III to provide a comparison of radiation sensitivities of devices of a given type and different manufacturer, a comparison of multiple tests for a single date code, a comparison of multiple tests for a single lot, and a comparison of radiation sensitivities vs time (date codes).

All data were generated using a steady-state 2.5-MeV electron source (Dynamitron) or a Cobalt-60 gamma ray source. The data that compose Volume III represent 26 different device types, 224 tests, and a total of 1040 devices.

A comparison of the effects of steady-state electrons and Cobalt-60 gamma rays is also presented.

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SECTION I

INTRODUCTION

Volumes I and II of this publication contain an extensive total-dose data base for semiconductor devices. However, they do not present certain useful types of data analysis regarding the variability in the total-dose-induced radiation sensitivity.

This variability can arise from different processes used by different manufacturers, process changes in the course of time for a given manufacturer (intentional or otherwise), and even differences between devices grouped in a single data code or from a single wafer lot. These variations are examined in terms of the data obtained for part types tested two or more times. Part-by-part variations in this data for a single test run are found only in the test data on file at the Jet Propulsion Laboratory.

SECTION II

DOCUMENT USES AND LIMITATIONS

This volume combines and analyzes certain of the test data contained in Volumes I and II of this publication. As such, it offers a useful comparison of the variability in radiation responses of different devices that might be considered in the development (circuit design) of a radiation-hardened system.

The data presented here cannot be used as a substitute for a comprehensive testing program of the devices actually used in a given system. It will be clear, on inspecting the data herein, that there are large lot-to-lot or wafer-to-wafer variations in the response of samples of a given device type. The differences in response of functionally identical devices fabricated by different manufacturers are even greater. There was no attempt to remove maverick (outlier) devices from the data plots. Thus, some of the data plots may appear anomalous when compared with other plots for the same device type.

There is also some preselection of devices that were tested for the spacecraft programs carried out by the Jet Propulsion Laboratory (JPL). In testing, mainly for the Voyager Project, a wide variety of part types and manufacturers were surveyed. Some manufacturers were eliminated because the manufacturing facilities lacked qualification by JPL, and some parts were rejected because the radiation degradation was too severe. The result is that the parts tested (Volumes I and II report the results of these tests) do not represent the full array of part types and manufacturers that are available and used by other electronic systems builders.

SECTION III

RADIATION SOURCES AND DOSIMETRY

The data were generated using either a 2.5-MeV Dynamitron electron accelerator or a Cobalt-60 gamma ray source. The dose units are in Grays (Gy) where 1 Gray equals 100 rads [for example, 2500 rads(Si) = 25 Gy(Si)].

A. ELECTRON ACCELERATOR (DYNAMITRON)

The Dynamitron electron accelerators at JPL and the Boeing Radiation Effects Laboratory (BREL) provide a 2.5-MeV electron beam using a range of beam currents of 10^8 to 10^{10} electrons/cm^2/sec. All test devices were irradiated at each fluence level for exposure times between 5 and 45 minutes.

The parts test geometry for the two Dynamitron test facilitites is essentially the same. The electron beam is brought out of the beam tube into air through a 0.05-mm titanium window, copper and aluminum scattering foils, and 0.9 m of air. Each of these materials scatters the electrons slightly so that the scattered beam has a variation in uniformity of less than 20 percent over the array of parts being tested. The parts test array is confined within a 25-cm-diameter circle perpendicular to the direction of the beam. At the center of the circle is the aperture of a vacuum Faraday cup, which is used to measure the flux and fluence of the electron beam. The beam is approximately centered on the Faraday cup with a quadrupole magnet prior to the installation of the test samples. The output from the Faraday cup is a current that is fed into a current integrator, which is calibrated daily against a standard current source. The integrator is set to shut off the electron beam automatically when the desired fluence level is received at the Faraday cup.

B. COBALT-60 SOURCES

The Cobalt-60 gamma ray sources at JPL and BREL were both used. The gamma rays consisted primarily of 1.17- and 1.33-MeV photons with lower-energy photons and secondary electrons arising from scattering and absorption. The gamma field was uniform within ±10 percent in the area where parts were exposed. A thermoluminescent dosimeter (TLD), containing lithium fluoride/ Teflon microrods, was used for uniformity checks. Calibration of the source was performed with Landsverk ion chambers of ±2-percent accuracy, traceable to the National Bureau of Standards. Bimonthly dose rate computations were performed to account for the radioactive decay of the Cobalt-60 source. Exposure times with the Cobalt-60 sources were typically 5 to 10 minutes for each radiation level. Longer times (up to 4 hours) were required for high-dose applications since the maximum uniform dose rate available was 150 Gy/min [15,000 rad(Si)/min] at JPL.

SECTION IV

TEST SETUP AND PROCEDURES

A. GENERAL REMARKS

The test setup and procedures used here were developed in accord with the specifications of MIL-STD-883B (August 1977), method 1019.1. All tests were done at $25^{\circ}C \pm 3^{\circ}C$, using low-noise power sources and instrumentation subject to periodic calibration. Some tests were performed in situ (without removing the test devices from the radiation area), whereas others required remote testing. In the latter event, a mobile bias fixture was used to maintain bias except during the brief measurement period.

A detailed test plan was written for each test; the plan included part description, irradiation bias conditions, radiation levels, electrical parameters to be measured, and measurement conditions. The data were processed by hand and by computer, and the calculation of normal standard deviations was made after deletion of clearly erroneous data.

B. IN-SITU TESTING

A matrix board switching system was built to be used as a master control and switching panel. It was located outside the irradiation area for all in situ tests. The board interfaced the devices under test (DUT) to the power supplies and measurement equipment via a special 15-meter (50-foot), double-shielded cable (see Figure 4-1). A built-in potentiometer for each DUT could be used to control bias voltages and currents. The matrix board was designed with very high insulation resistance so that very low current measurements (10-50 pA) could be made.
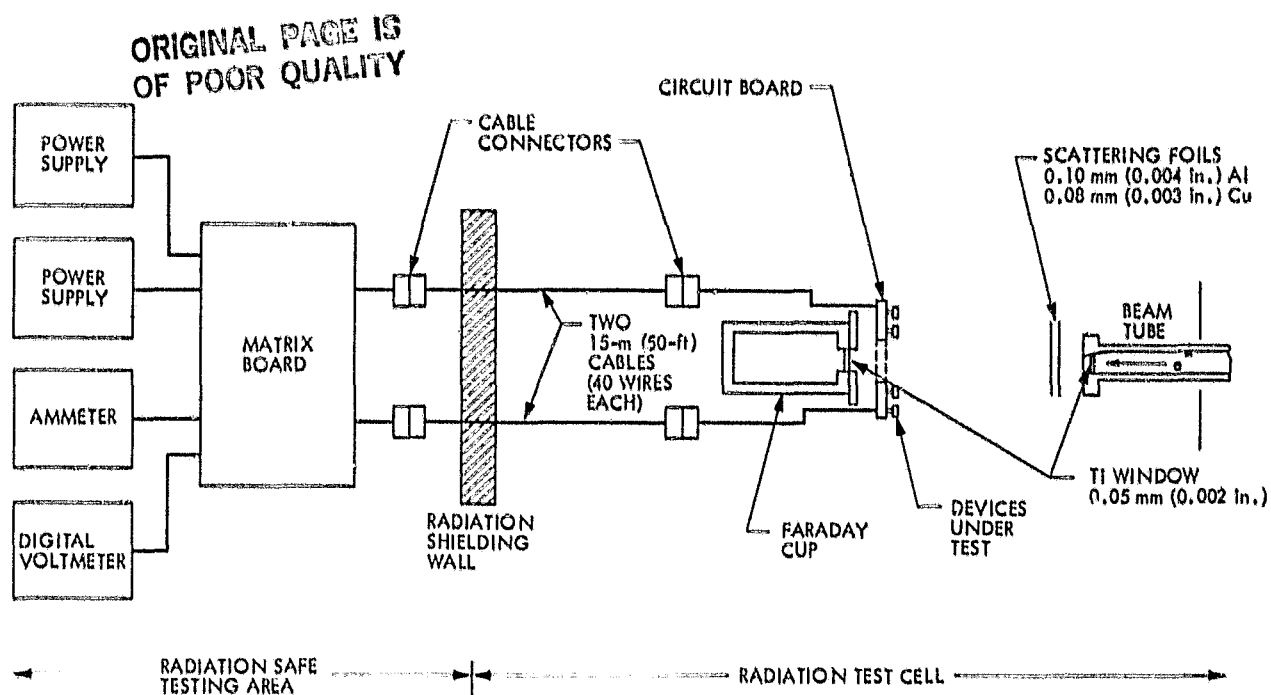
Figure 4-1. Block Diagram of the Test Setup for In Situ Testing
With the Electron Accelerator (Dynamitron)

C. NON-IN SITU TESTING

For the remote (non-in situ) tests, the DUTs were removed from the site
for approximately 20 minutes between each radiation level. A mobile fixture
was used to apply bias (battery) to the devices at all times except during
electrical parameter measurements. Remote measurements were performed using a
Lorlin Impact 100, a Tektronix 178/577 curve tracer, a Tektronix 3260 IC
tester, or a bench fixture. Occasionally, custom-built test circuits were
used to simulate the circuit application of the devices tested.

D. TESTING AT THE BOEING COMPANY

A number of integrated circuits (ICs) were tested for JPL at the Boeing
Radiation Effects Laboratory (BREL). Complex large-scale integrated (LSI)
devices—such as analog/digital (A/D) converters, memories, and micro-
processors—were irradiated with the BREL Dynamitron or Cobalt-60 sources and
tested on a Tektronix 3260 computerized IC tester. Most of these tests were
non-in situ. The test programs were specified by JPL personnel. The data
developed were then sent to JPL for analysis.

SECTION V

DATA PRESENTATION

The information presented in this section represents the results of combining and analyzing the data contained in Volumes I and II. The information is presented graphically in the following sequence with the Volume I data presented first, followed by the Volume II data.

A. ANALYSIS OF COMBINED DATA

B. COMPARISON OF RADIATION SENSITIVITIES OF DEVICES OF A GIVEN TYPE AND DIFFERENT MANUFACTURERS

C. COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

D. COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

E. COMPARISON OF RADIATION SENSITIVITIES VS TIME (DATE CODES)

F. COMPARISON OF THE EFFECTS OF ELECTRON AND GAMMA RAY TOTAL-DOSE IONIZING RADIATION

Where the parameter values are not expressed in such terms of measurement change (delta values) as transistor leakage currents or integrated circuit gain, the initial mean values are also given at the bottom of the graph. As the graph format varies for each type of analysis, a discussion of the graphical presentation is included in each section. The vendor code descriptions are given in Appendix A. The parameter descriptions are given in Appendix B. However, the reader is referred to Volumes I and II for a detailed discussion of the electrical test parameters.

A. ANALYSIS OF COMBINED DATA

To increase the effective sample size and show the variability between test results, this analysis combines all of the tests for the given manufacturer, device type, and test conditions.

The mean values of the combined test data are plotted as points on the graph at each total-dose level. These points are then connected by a straight line. To indicate the variability of the combined data, the mean ± one-sigma (σ) values are represented by horizontal bars. These bars are then connected by a vertical line. The device type, the manufacturer, the number of tests that are being combined, and the total number of devices included are shown in the graph heading. In addition, the test conditions are included where practicable.

The ground rules for combining the test data required that all of the tests represent the same device type, manufacturer, test conditions, and total-dose values.

1.   Volume I Data

The bipolar transistor gain ($1/h_{FE}$) data are presented at two collector current (I_C) test values. Under certain circumstances, mean ± sigma bars may overlap. In this case, the upper curve sigma values are represented by a short bar and the lower curve sigma values by a longer bar (see Figure 5-1).

Because of the extreme variability of the transistor leakage currents, the sigma bars for these parameters were not included on the graphs.

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 8
No. OF DEVICES: 34
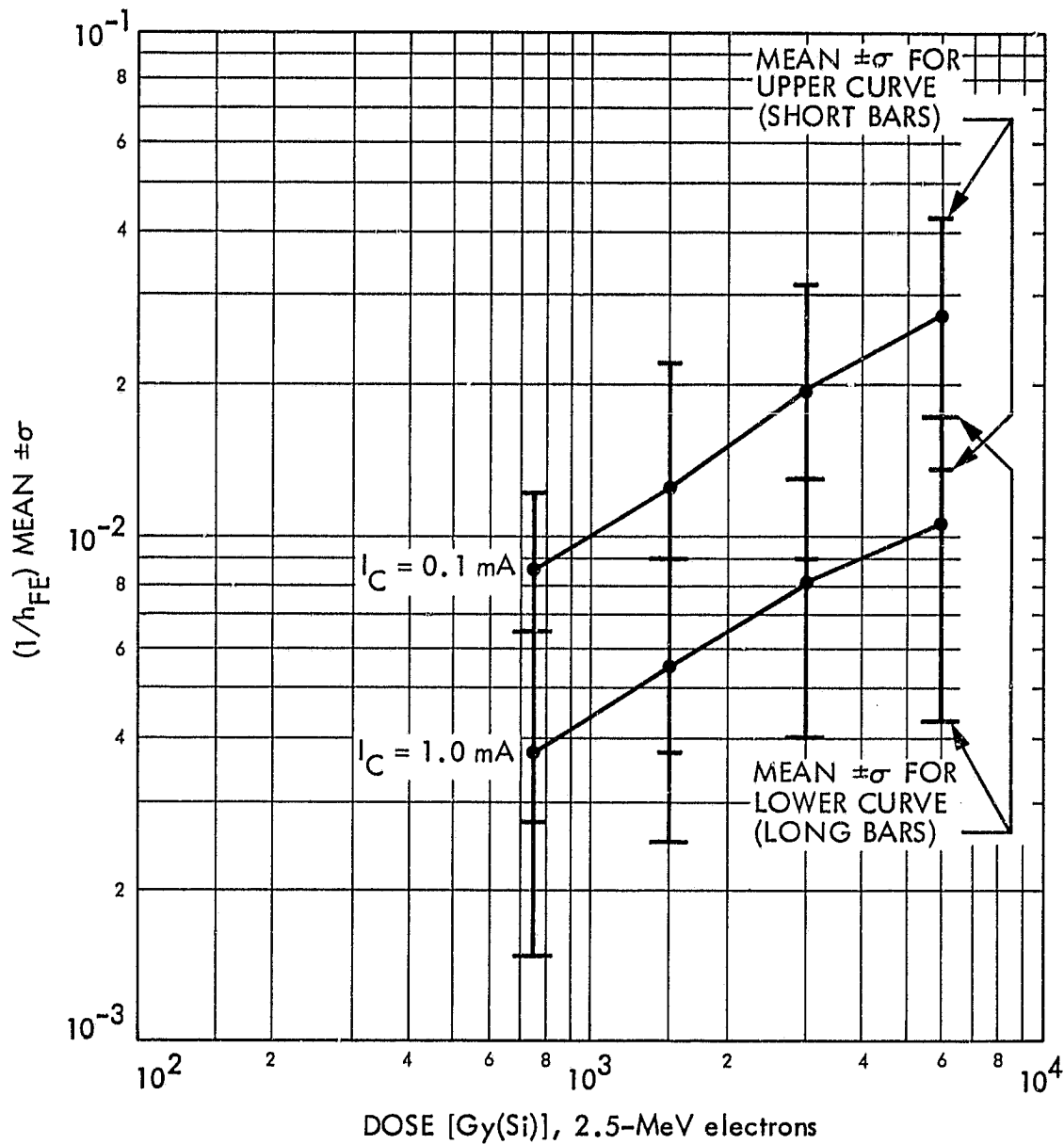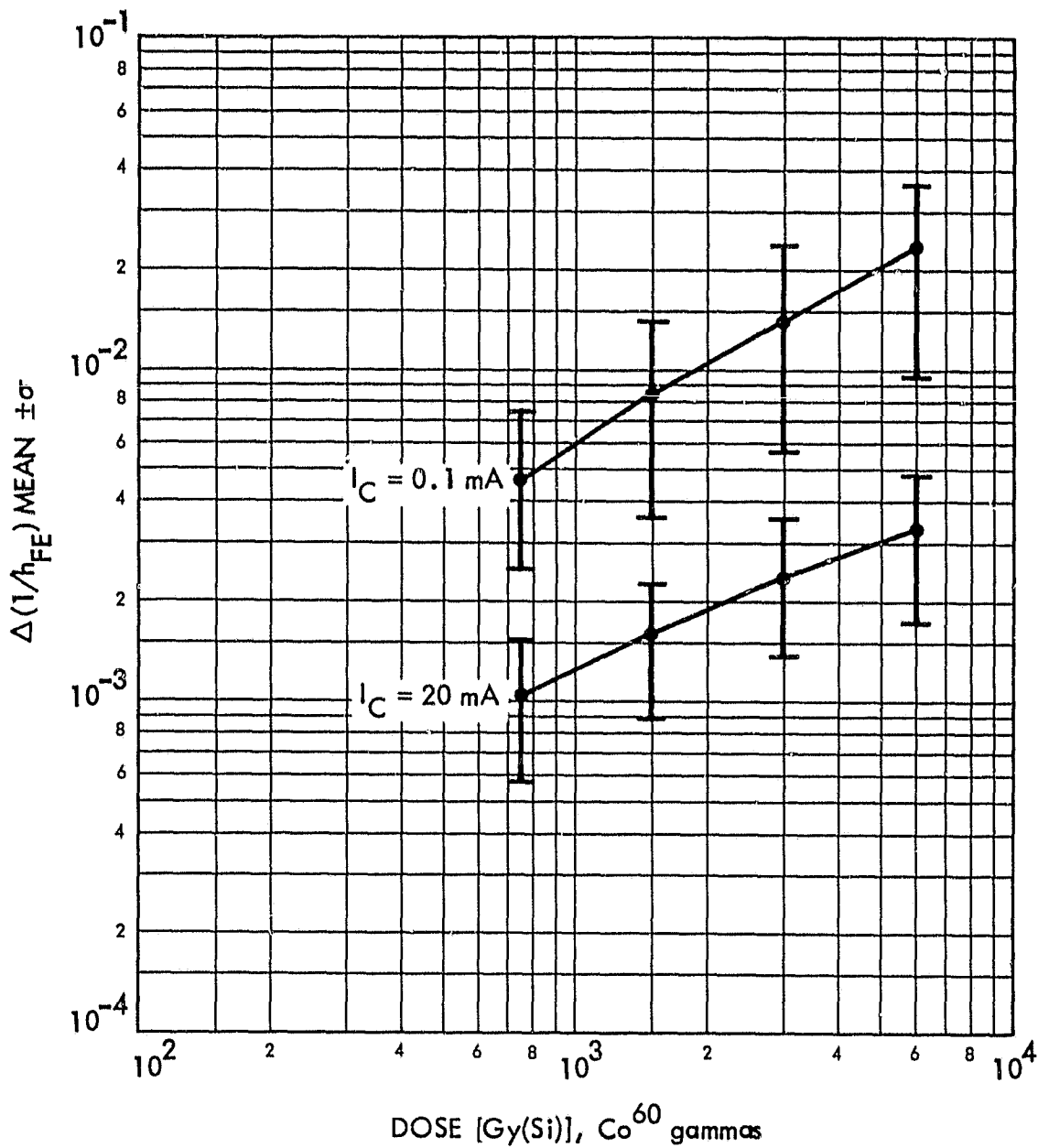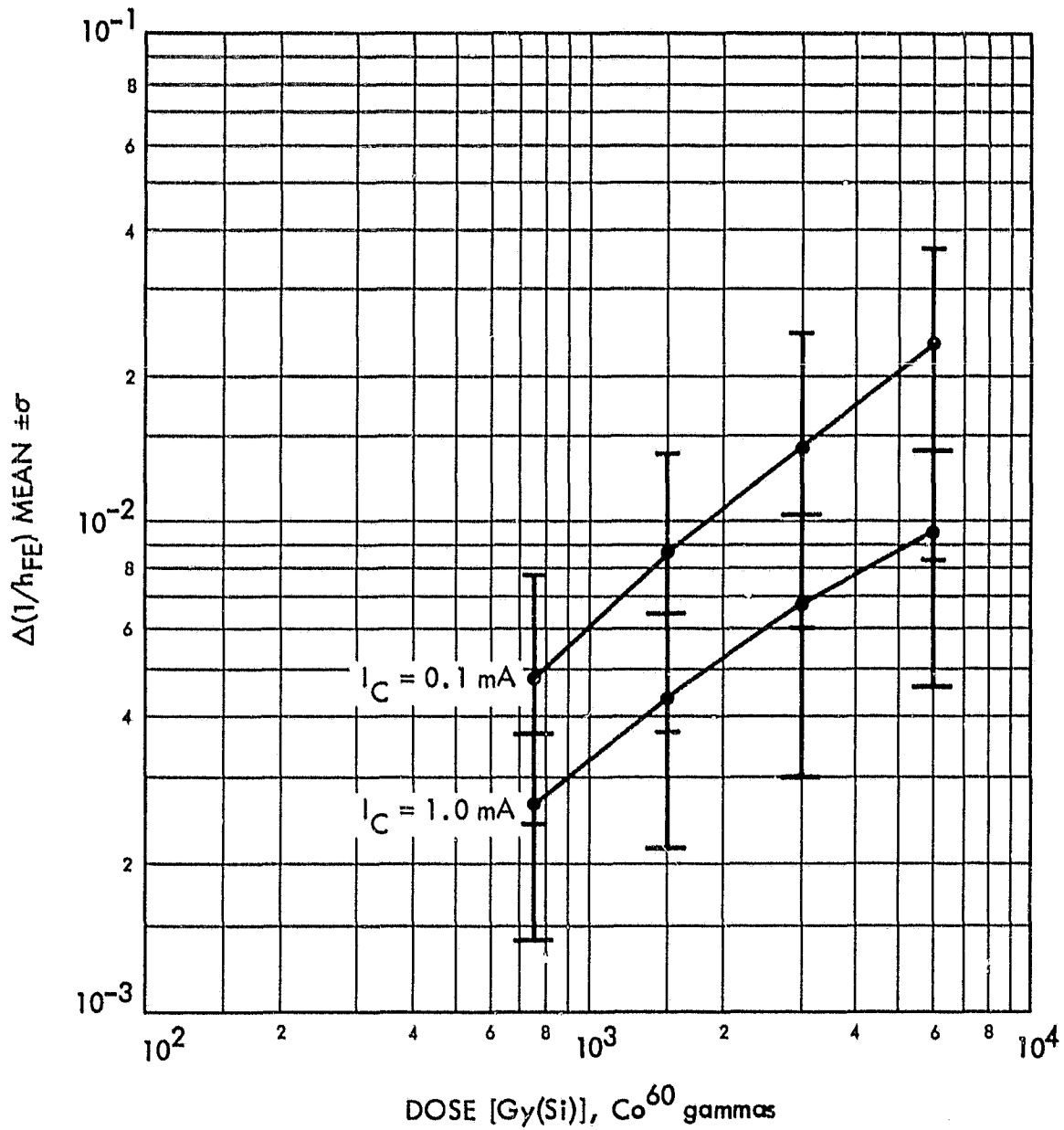TEST CONDITIONS: V_{CE} = 0.5 V (SATURATED)

Figure 5-1.   Example of a Transistor Graph With Data
              That Overlap

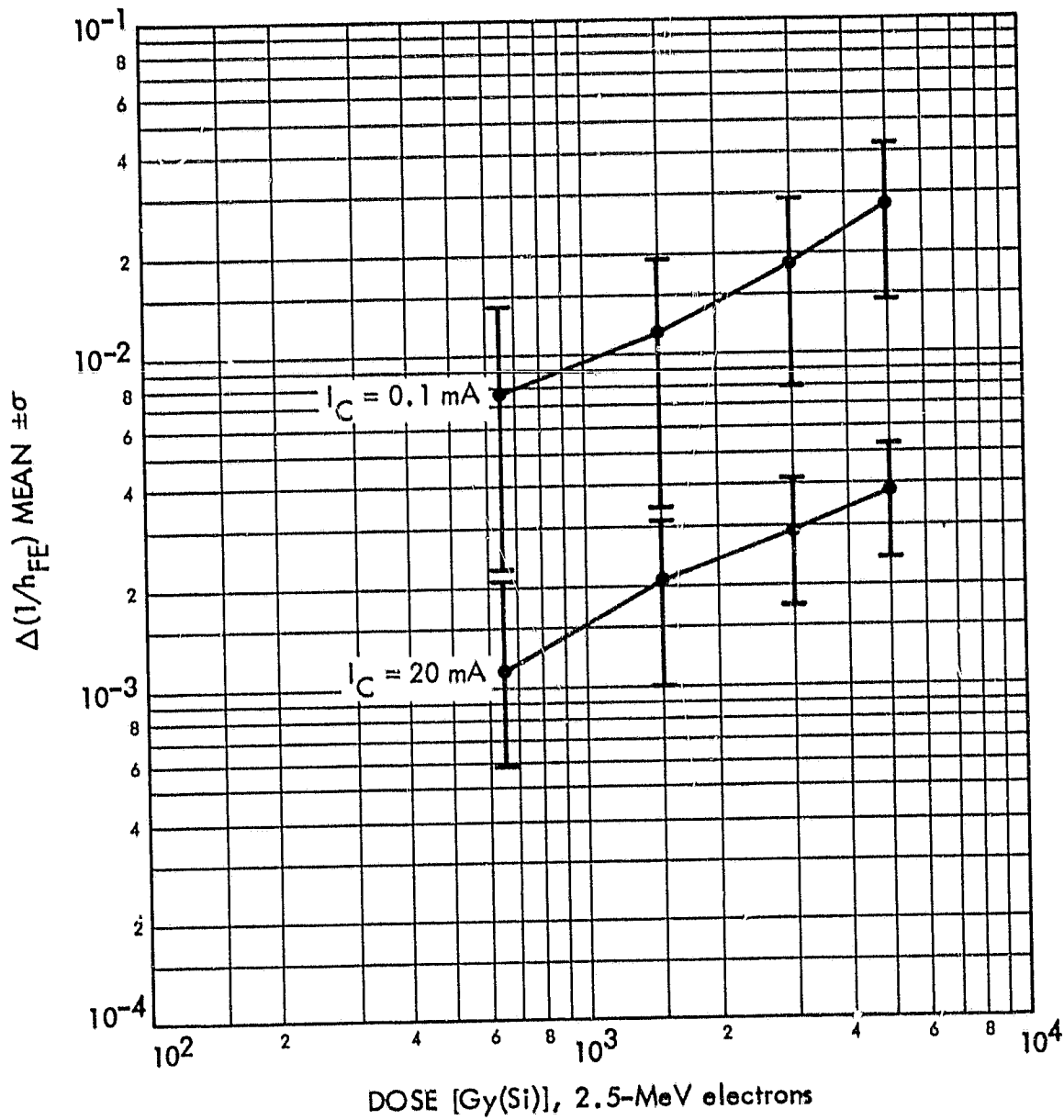COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 7

No. OF DEVICES: 23

TEST CONDITIONS: V_{CE} = 20 V
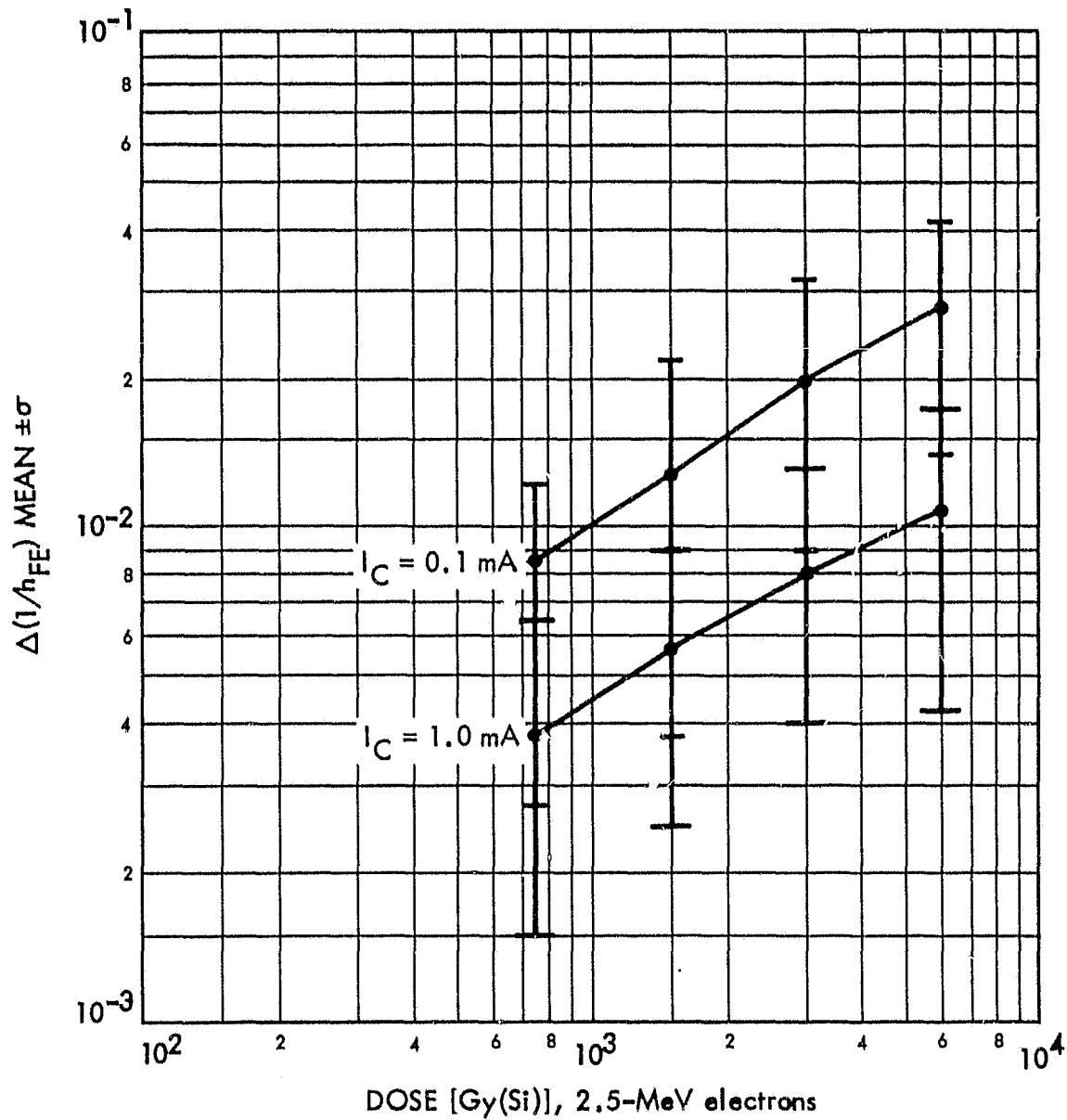
COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 7

No. OF DEVICES: 23

TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

Y-axis: $\Delta(1/h_{FE})$ MEAN $\pm\sigma$

X-axis: DOSE [Gy(Si)], Co^{60} gammas
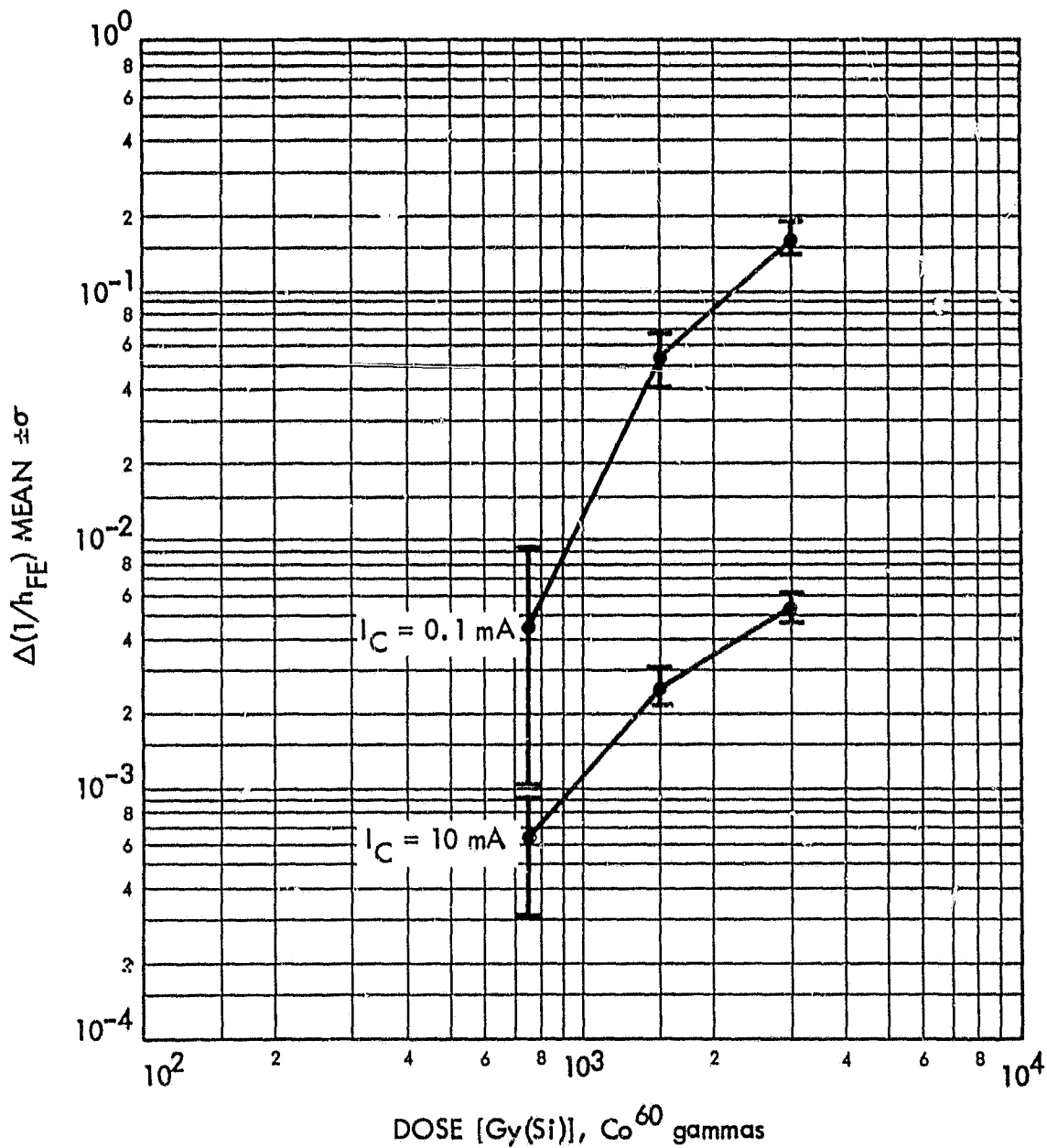
$I_C = 0.1$ mA

$I_C = 1.0$ mA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 8
No. OF DEVICES: 34
TEST CONDITIONS: $V_{CE} = 20$ V

$I_C = 0.1$ mA

$I_C = 20$ mA

$\Delta(1/h_{FE})$ MEAN $\pm \sigma$
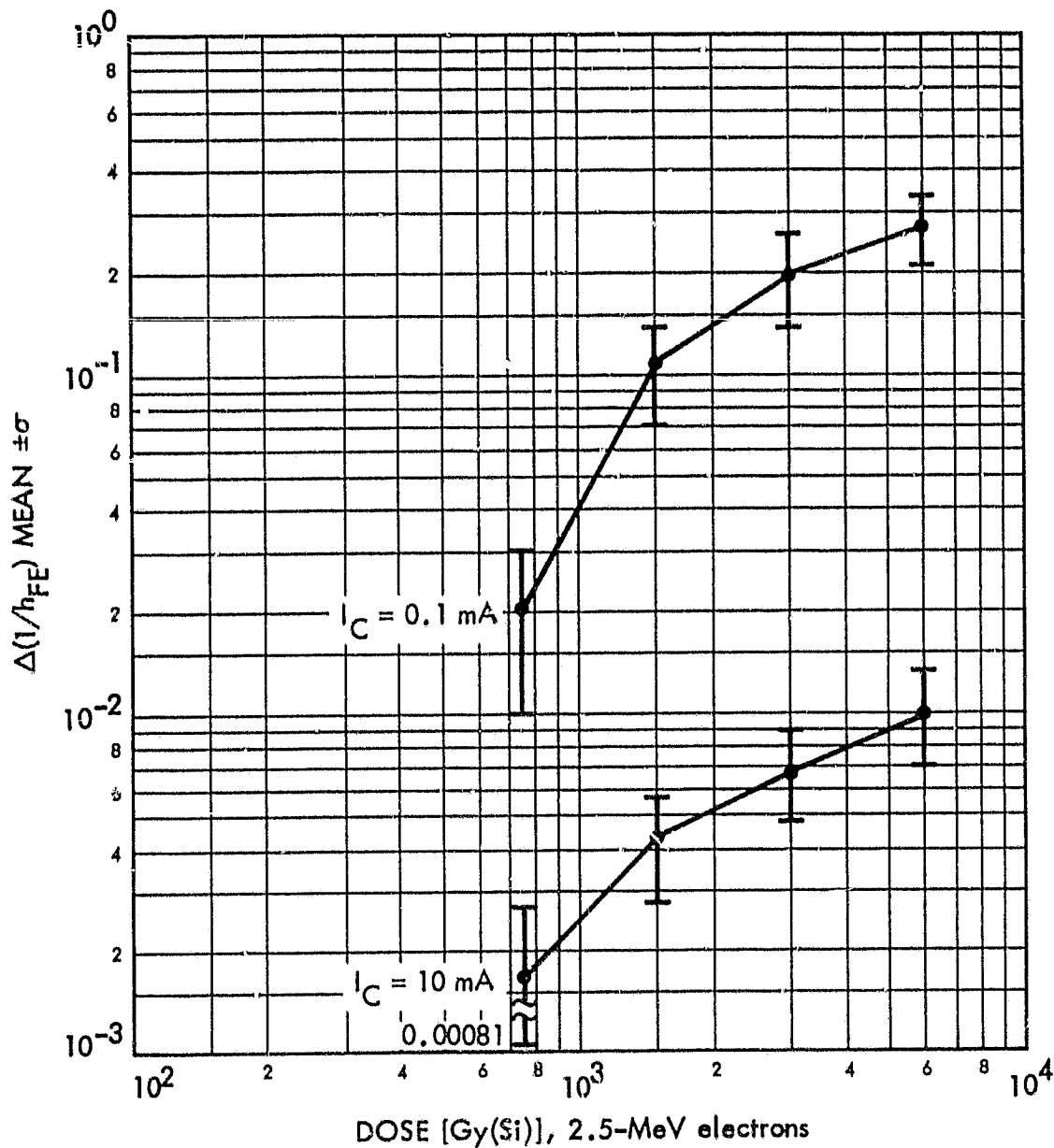
DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 8
No. OF DEVICES: 34
TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

Y-axis: $\Delta(1/h_{FE})$ MEAN $\pm \sigma$

$I_C = 0.1$ mA

$I_C = 1.0$ mA

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2432 NPN LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 3

No. OF DEVICES: 24
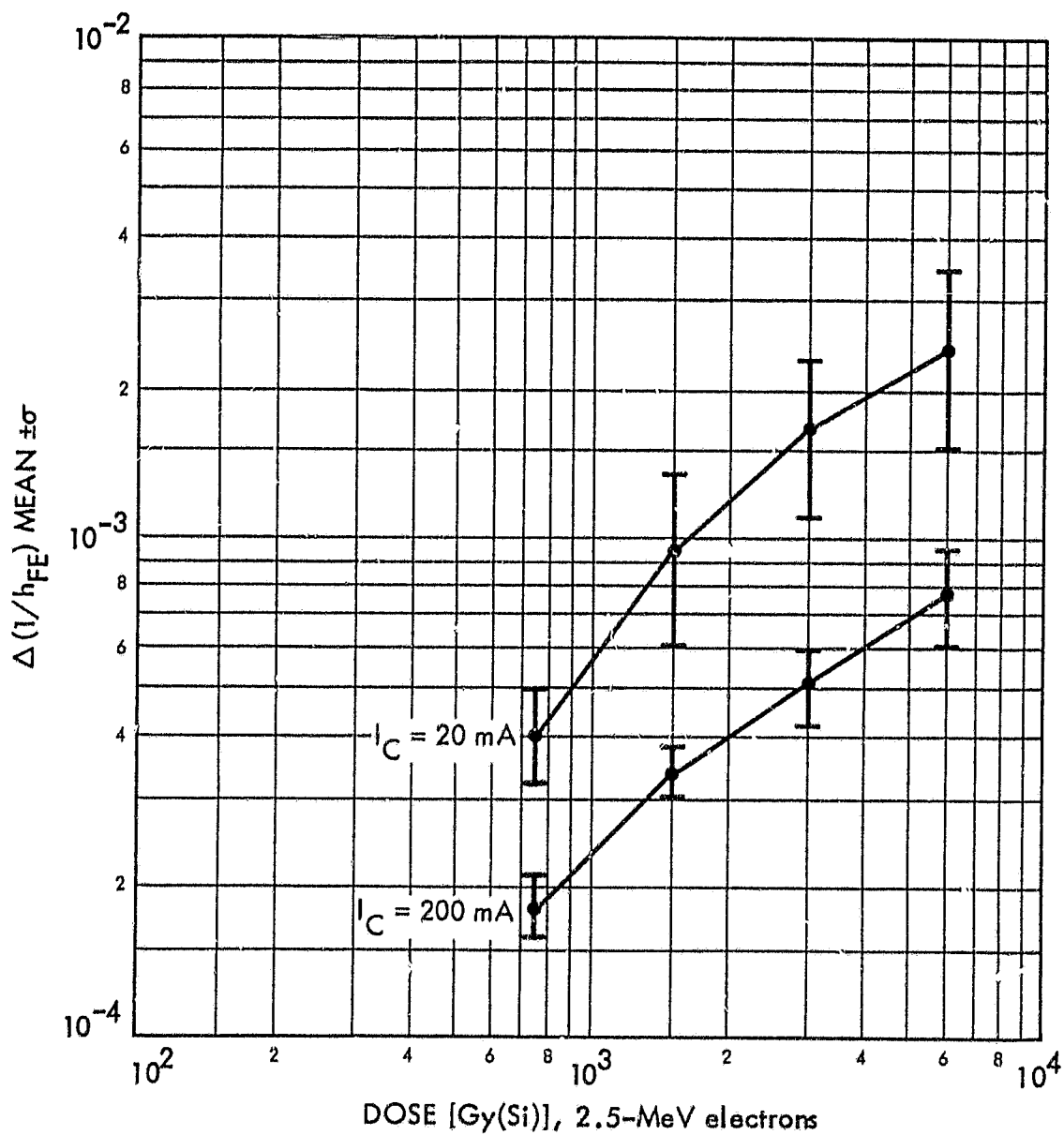
TEST CONDITIONS: $V_{CE} = 10$ V

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2432 NPN LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 4
No. OF DEVICES: 28
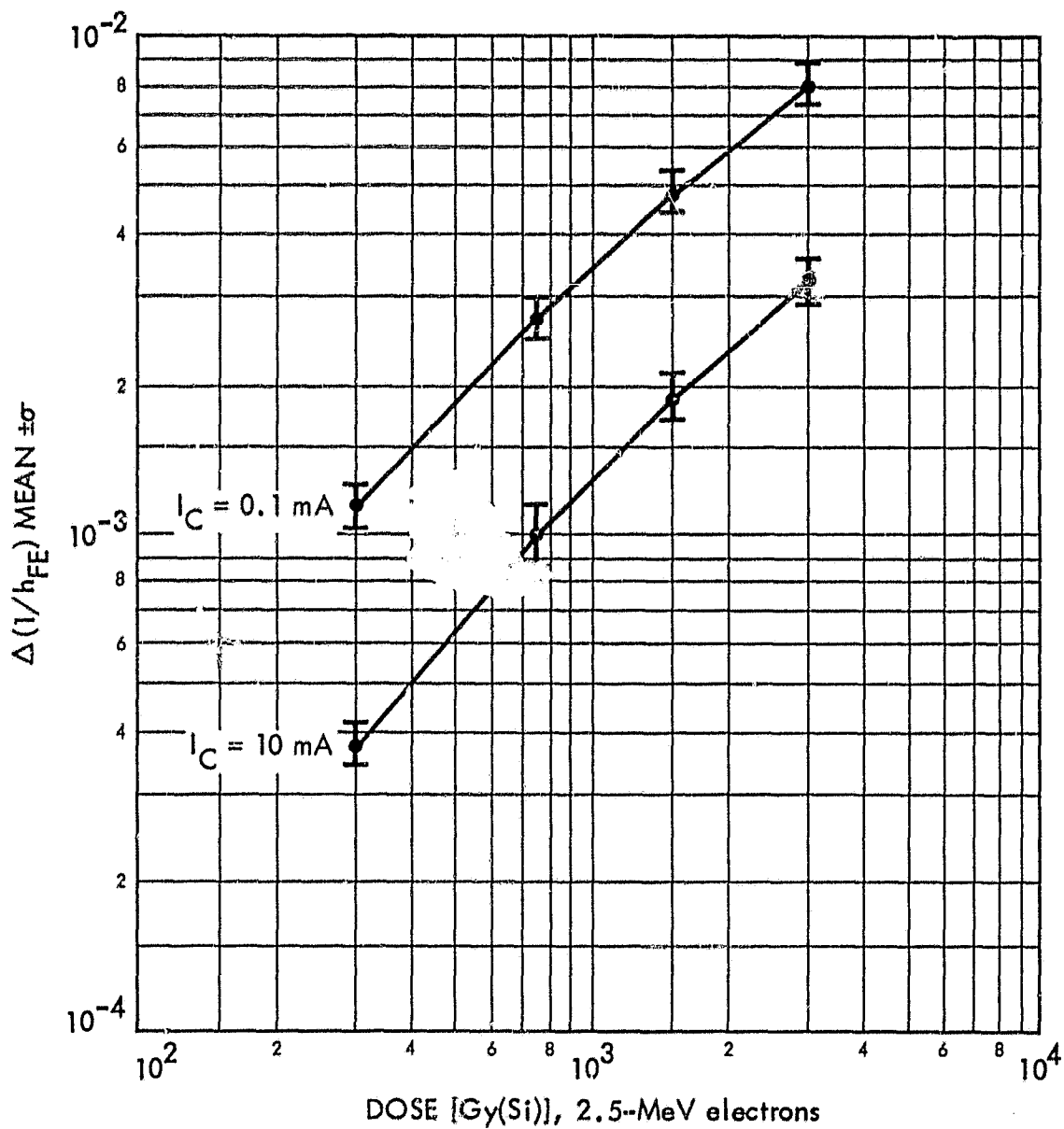TEST CONDITIONS: $V_{CE} = 10$ V

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2658 NPN POWER TRANSISTOR

MFG: SOD   No. OF COMBINED TESTS: 4

No. OF DEVICES: 22

TEST CONDITIONS: V_{CE} = 0.2 V (SATURATED)

Plot: $\Delta(1/h_{FE})$ MEAN $\pm\sigma$ versus DOSE [Gy(Si)], 2.5-MeV electrons, with curves labeled I_C = 20 mA and I_C = 200 mA.
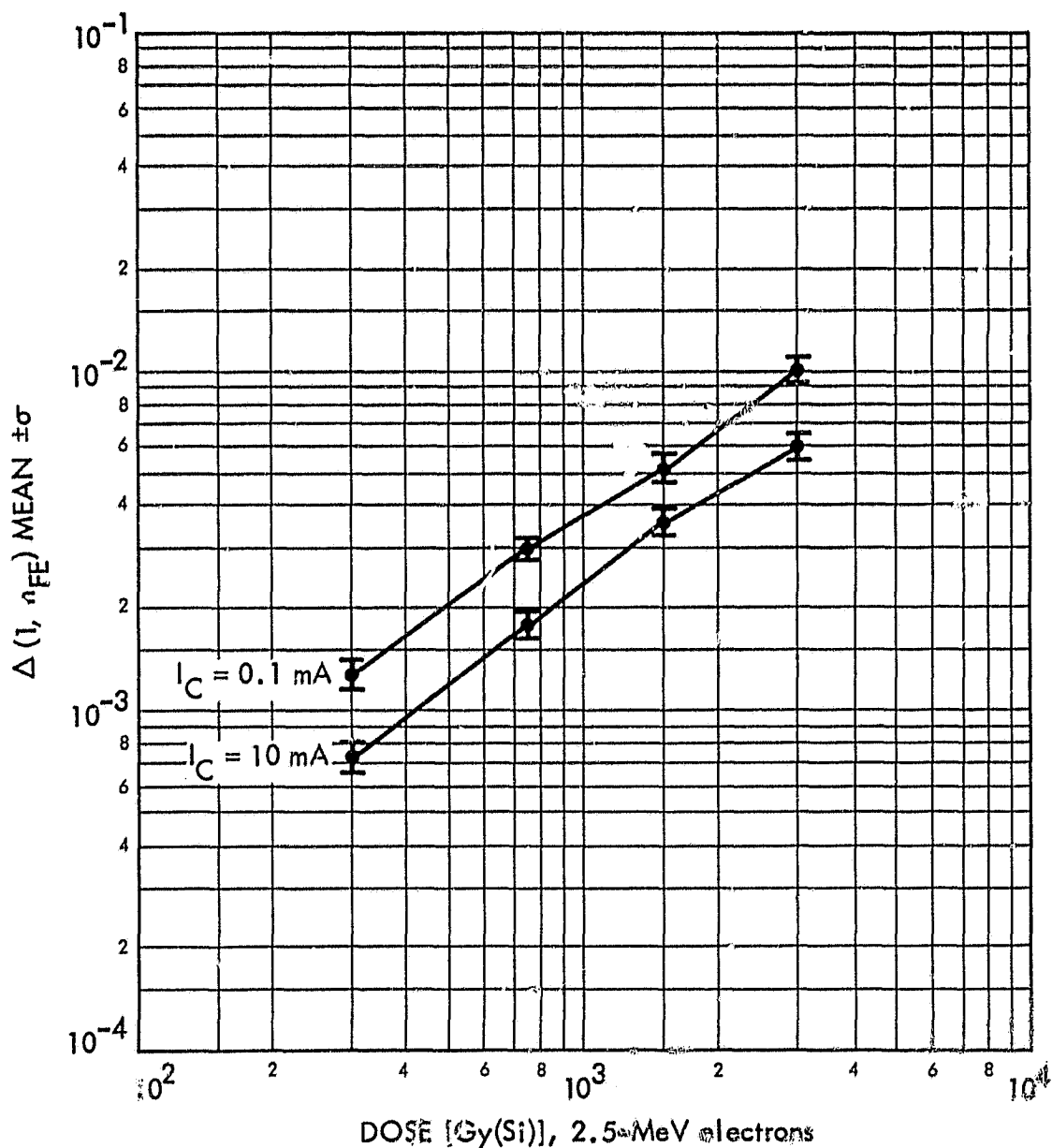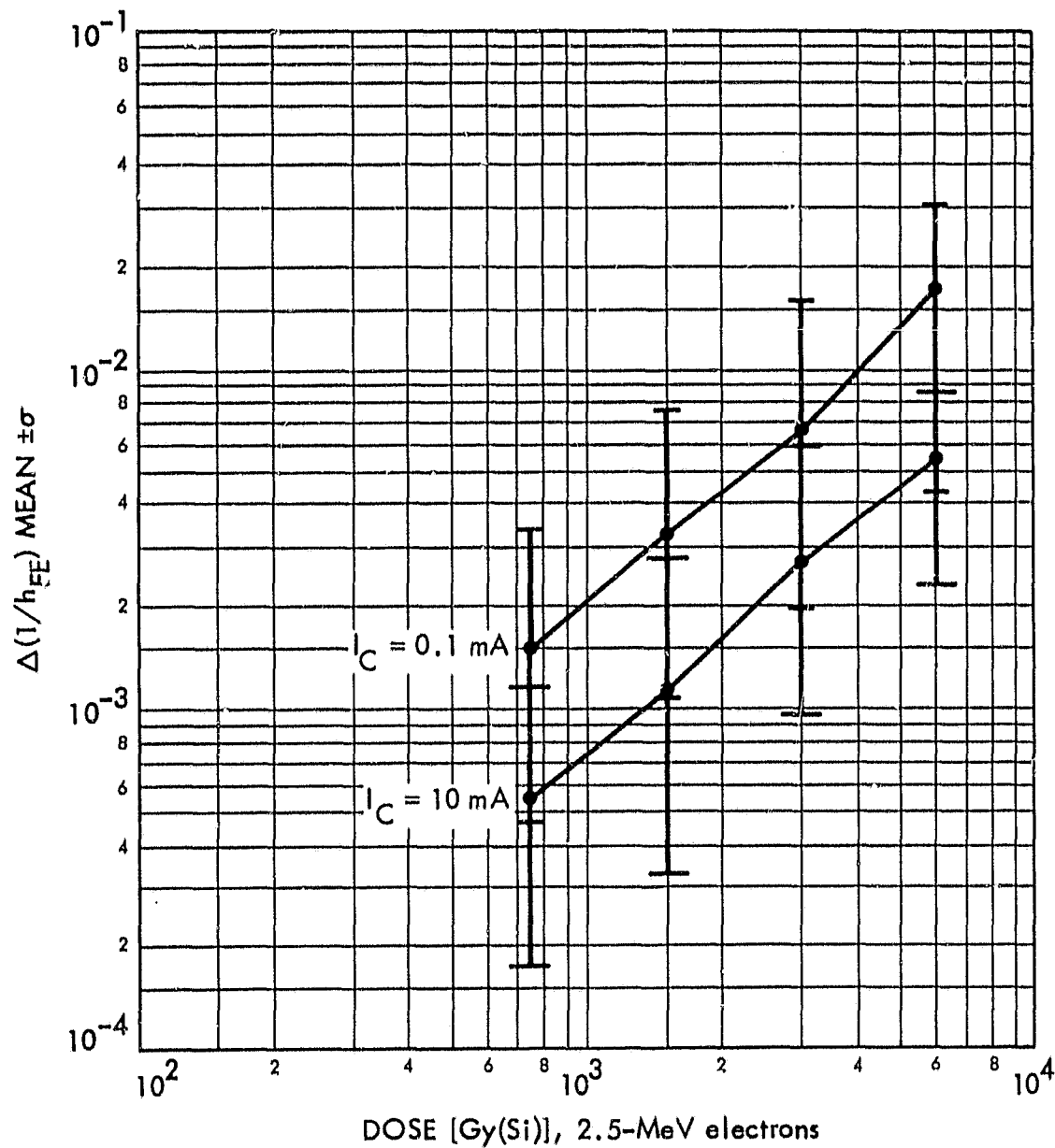
COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2905 PNP LOW-POWER TRANSISTOR

MFG: RAY   No. OF COMBINED TESTS: 4

No. OF DEVICES: 24

TEST CONDITIONS: $V_{CE} = 20$ V

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2905 PNP LOW-POWER TRANSISTOR
MFG: RAY   No. OF COMBINED TESTS: 4
No. OF DEVICES: 24
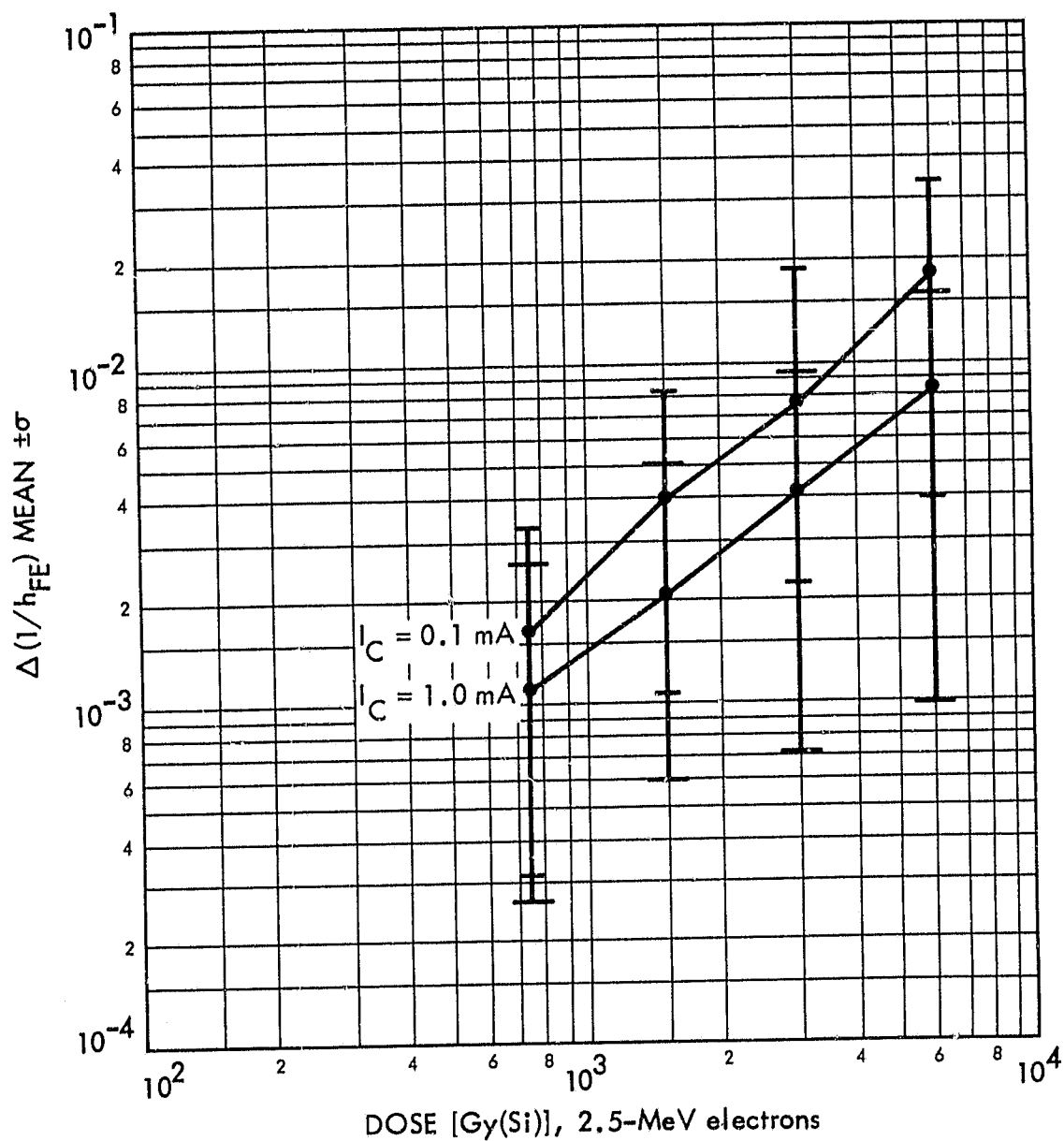TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 3
No. OF DEVICES: 14
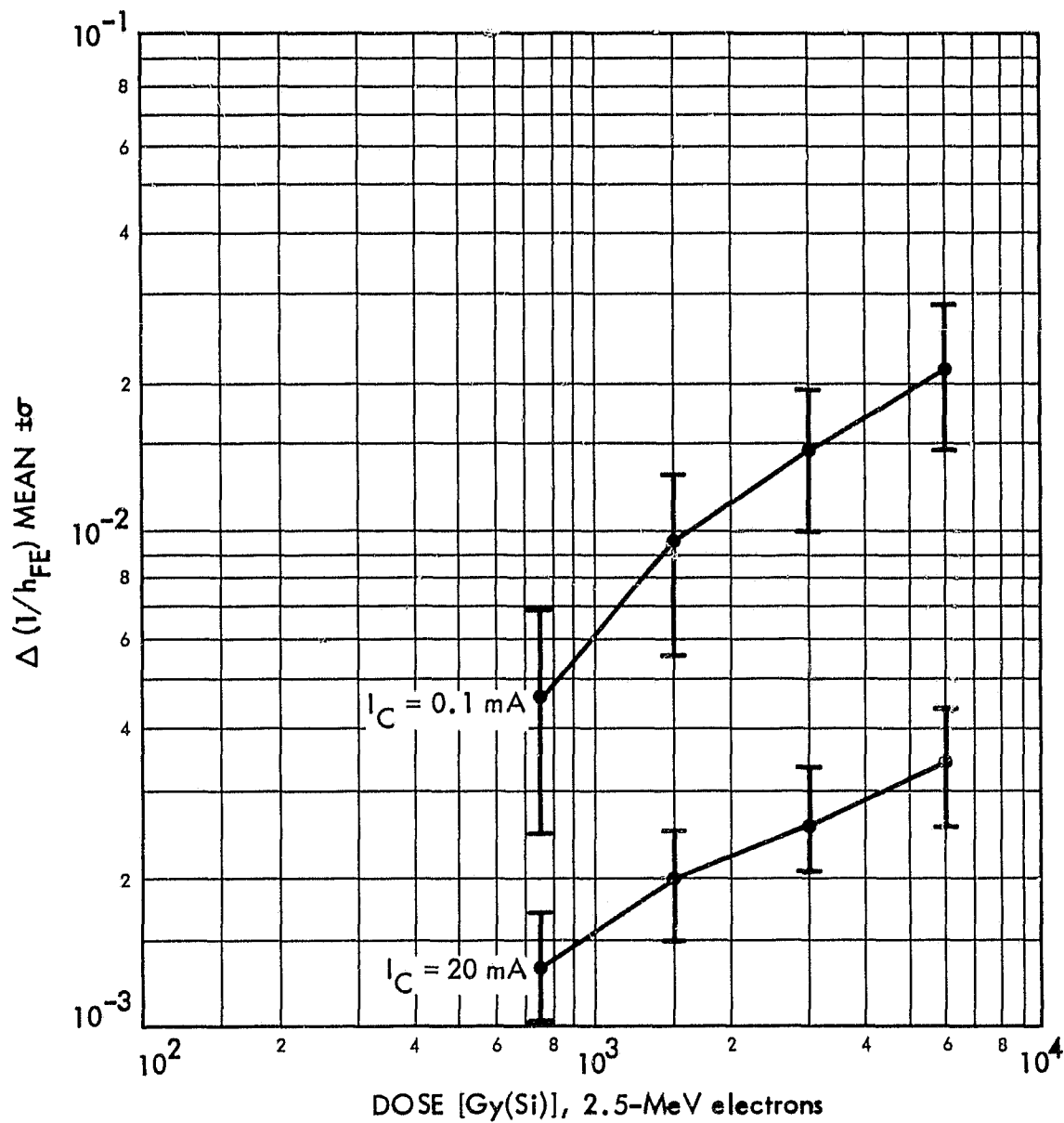TEST CONDITIONS: $V_{CE} = 20$ V

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 3
No. OF DEVICES: 14
TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

Y-axis: $\Delta(1/h_{FE})$ MEAN $\pm\sigma$

$I_C = 0.1$ mA

$I_C = 1.0$ mA

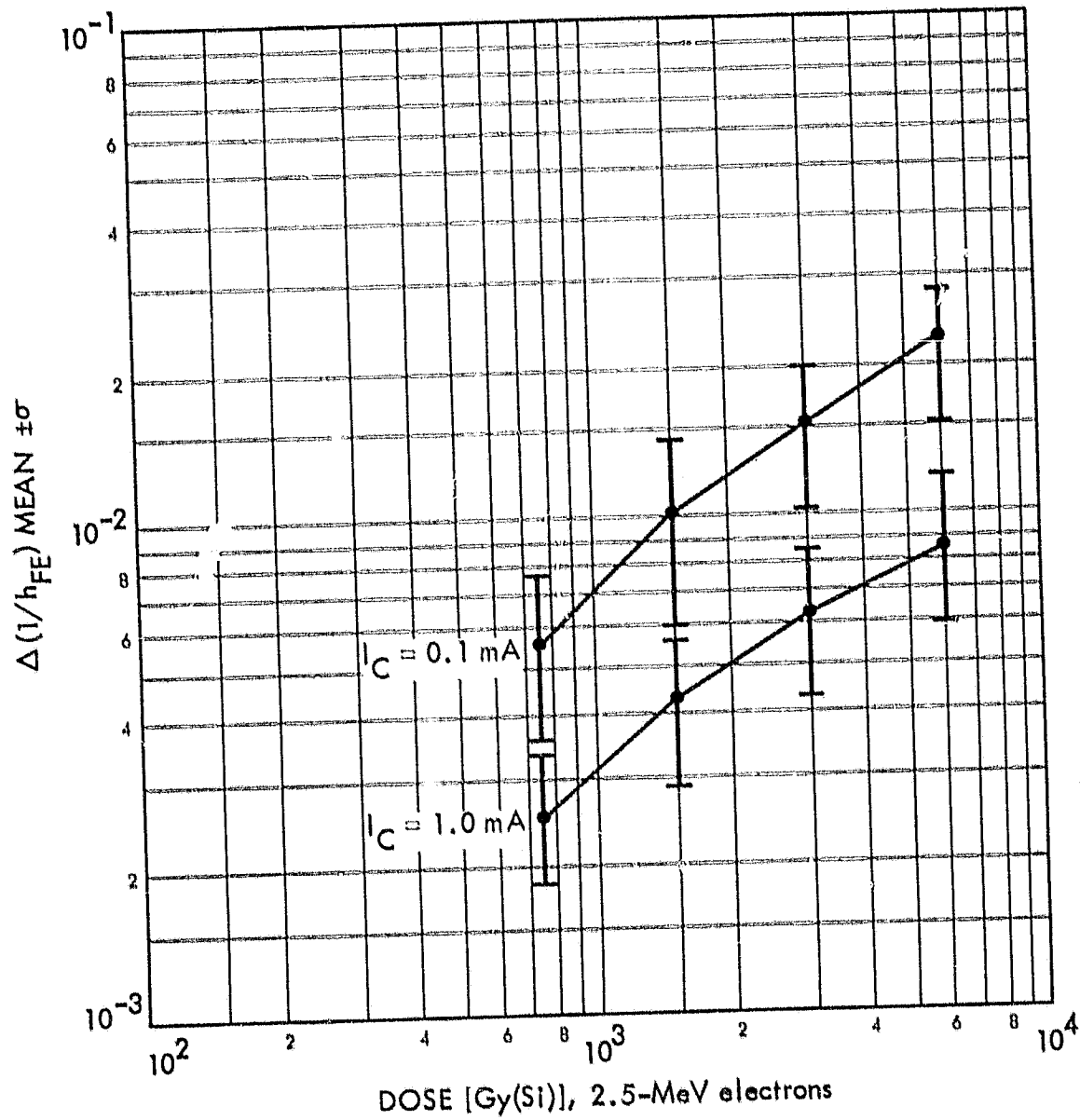DOSE [Gy(Si)], 2.5–MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2920 DUAL NPN TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 7
No. OF DEVICES: 27
TEST CONDITIONS: $V_{CE} = 20$ V
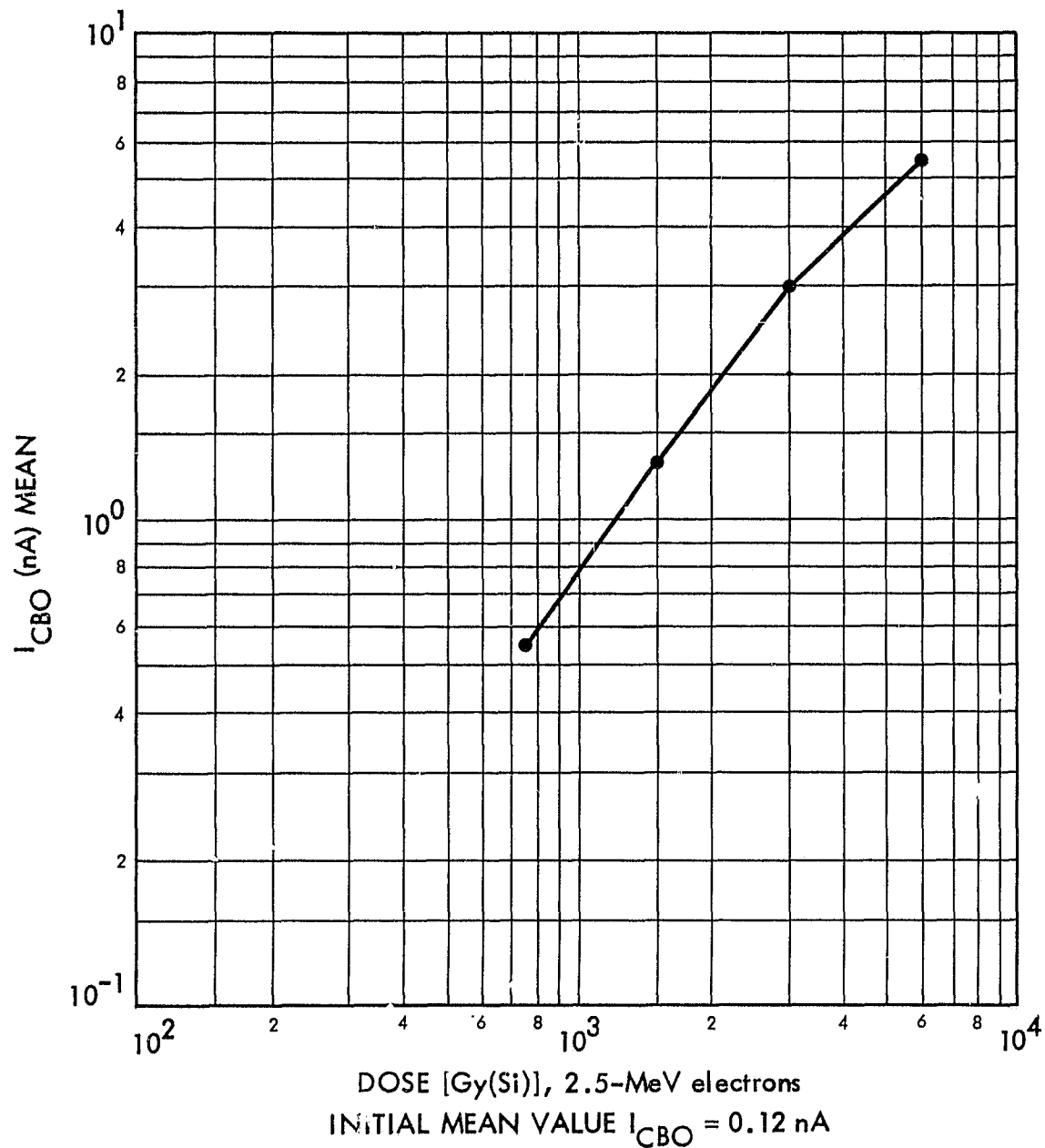

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2920 DUAL NPN TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 7

No. OF DEVICES: 27

TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

DOSE [Gy(SI)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2920 DUAL NPN TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 4

No. OF DEVICES: 14

TEST CONDITIONS: $V_{CB} = 30$ V

DOSE [Gy(Si)], 2.5-MeV electrons

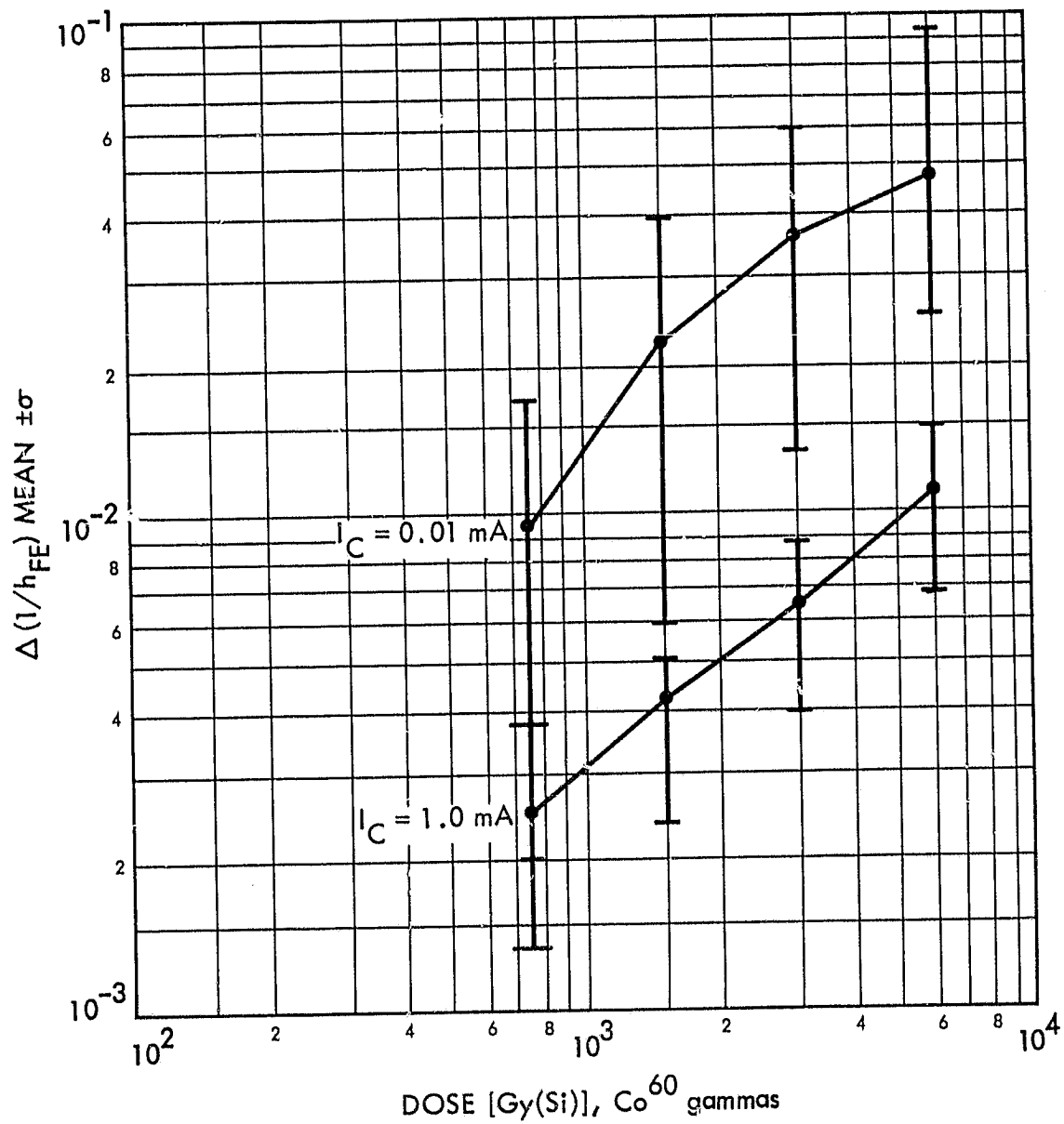INITIAL MEAN VALUE $I_{CBO} = 0.12$ nA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2975 NPN LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 7

No. OF DEVICES: 28

TEST CONDITIONS: $V_{CE} = 5$ V

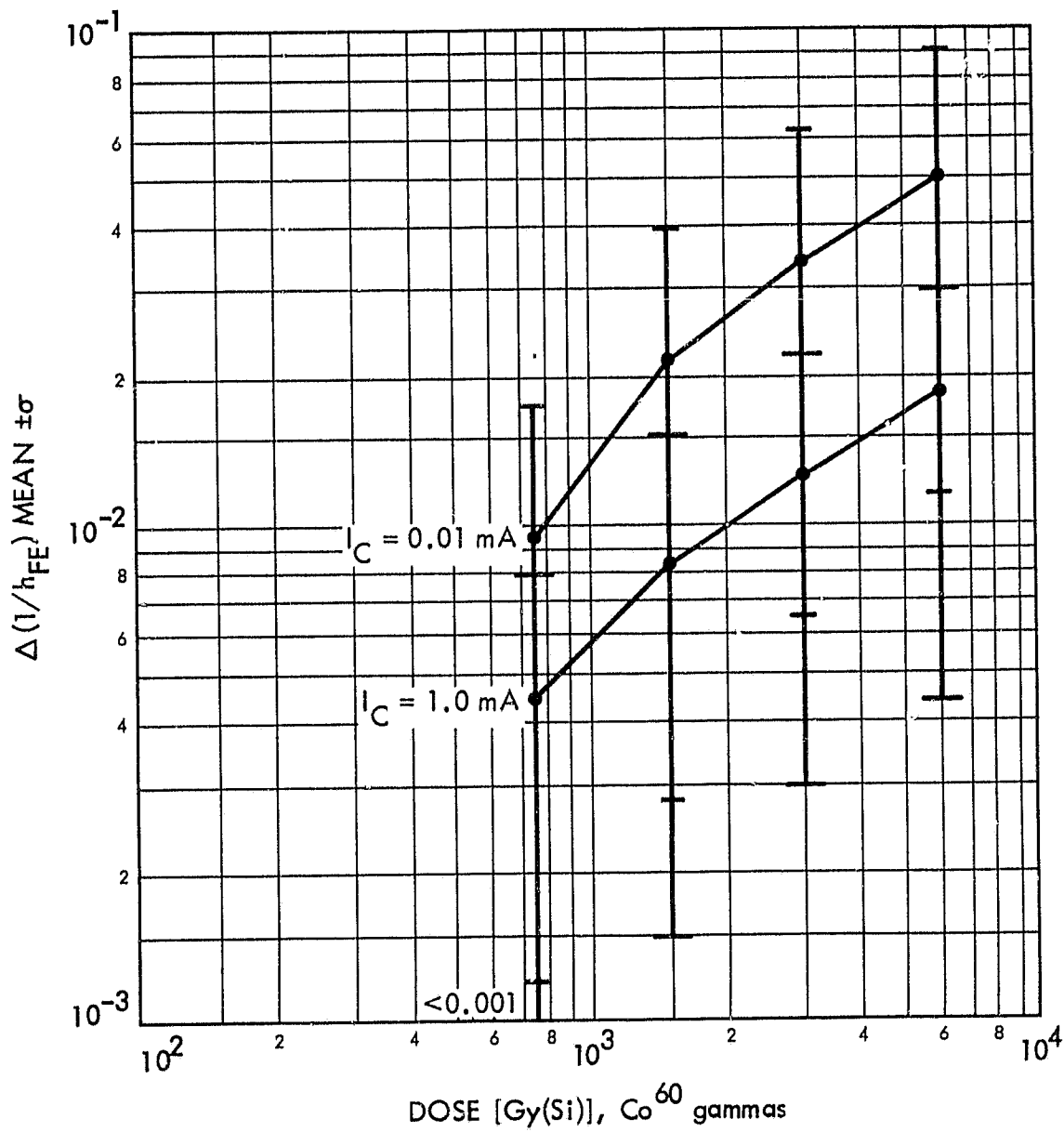DOSE [Gy(Si)], Co^{60} gammas

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N2975 NPN LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 7

No. OF DEVICES: 28

TEST CONDITIONS: $V_{CE} = 0.35$ V (SATURATED)

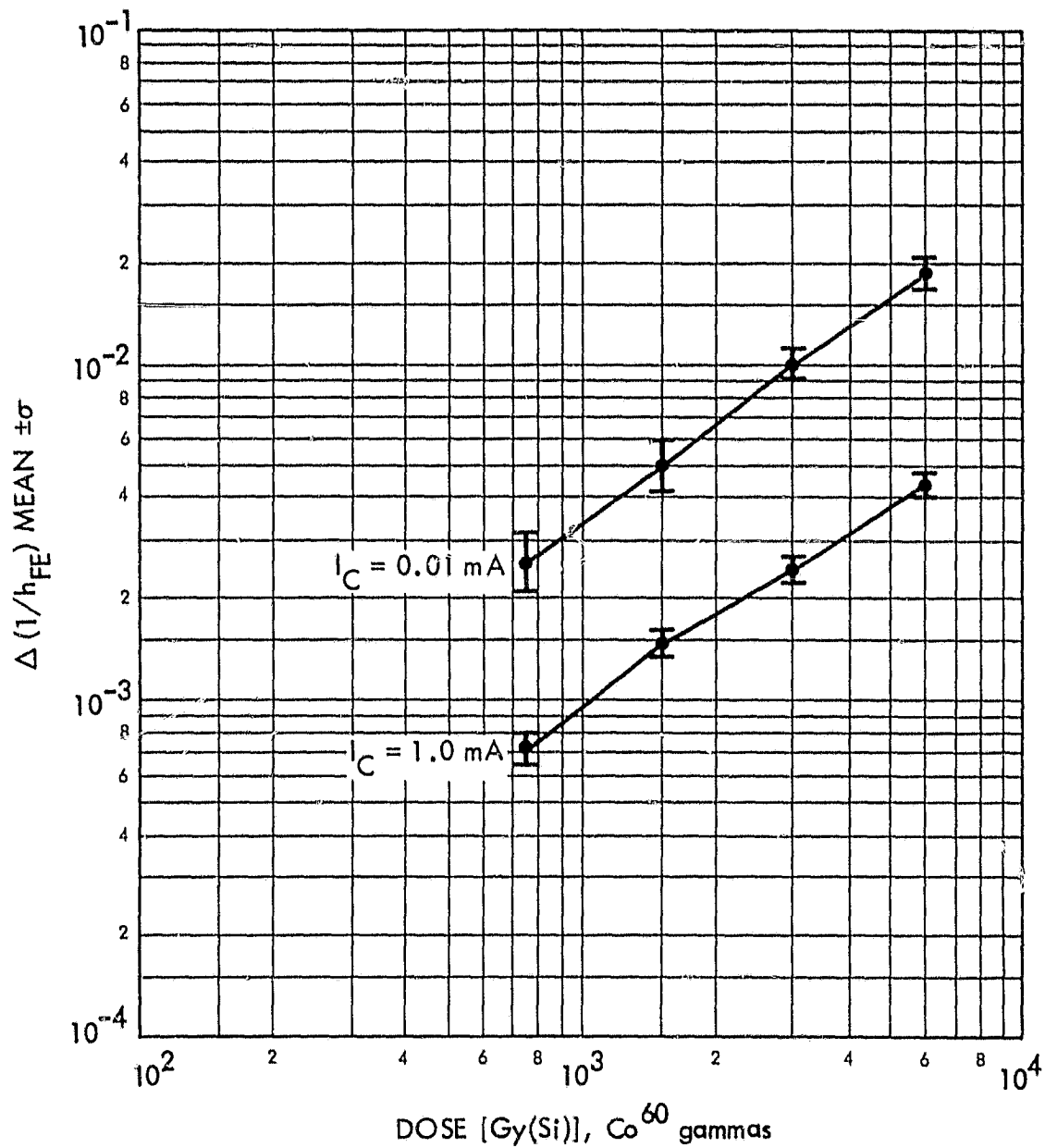DOSE [Gy(Si)], Co^{60} gammas

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N3350 PNP LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 3

No. OF DEVICES: 24

TEST CONDITIONS: $V_{CE} = 0.5$ V (SATURATED)

Y-axis: $\Delta (1/h_{FE})$ MEAN $\pm\sigma$

$I_C = 0.01$ mA

$I_C = 1.0$ mA

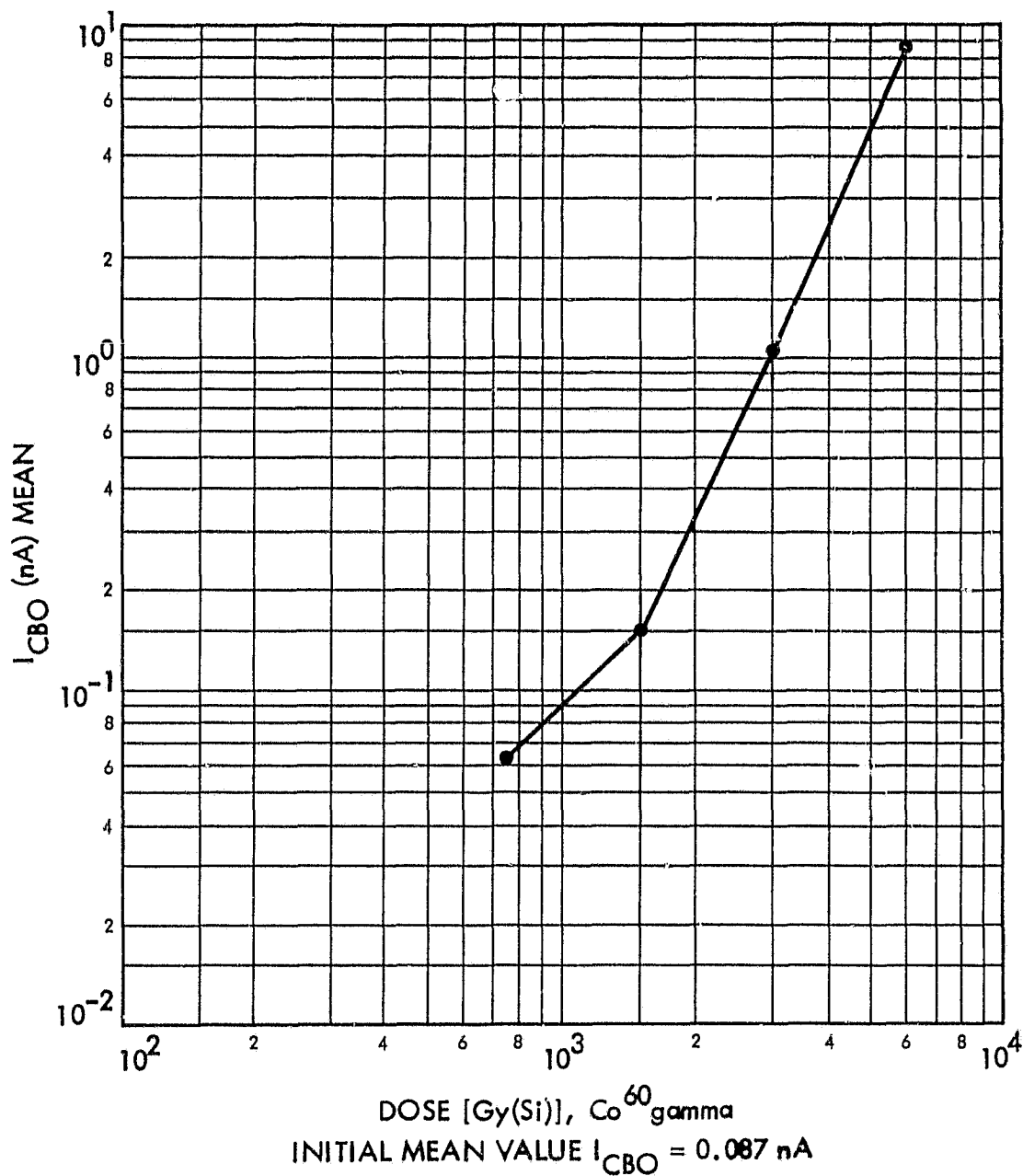X-axis: DOSE [Gy(Si)], Co^{60} gammas

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N3350 PNP LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 5

No. OF DEVICES: 40

TEST CONDITIONS: $V_{CB} = 20$ V

DOSE [Gy(Si)], Co^{60} gamma

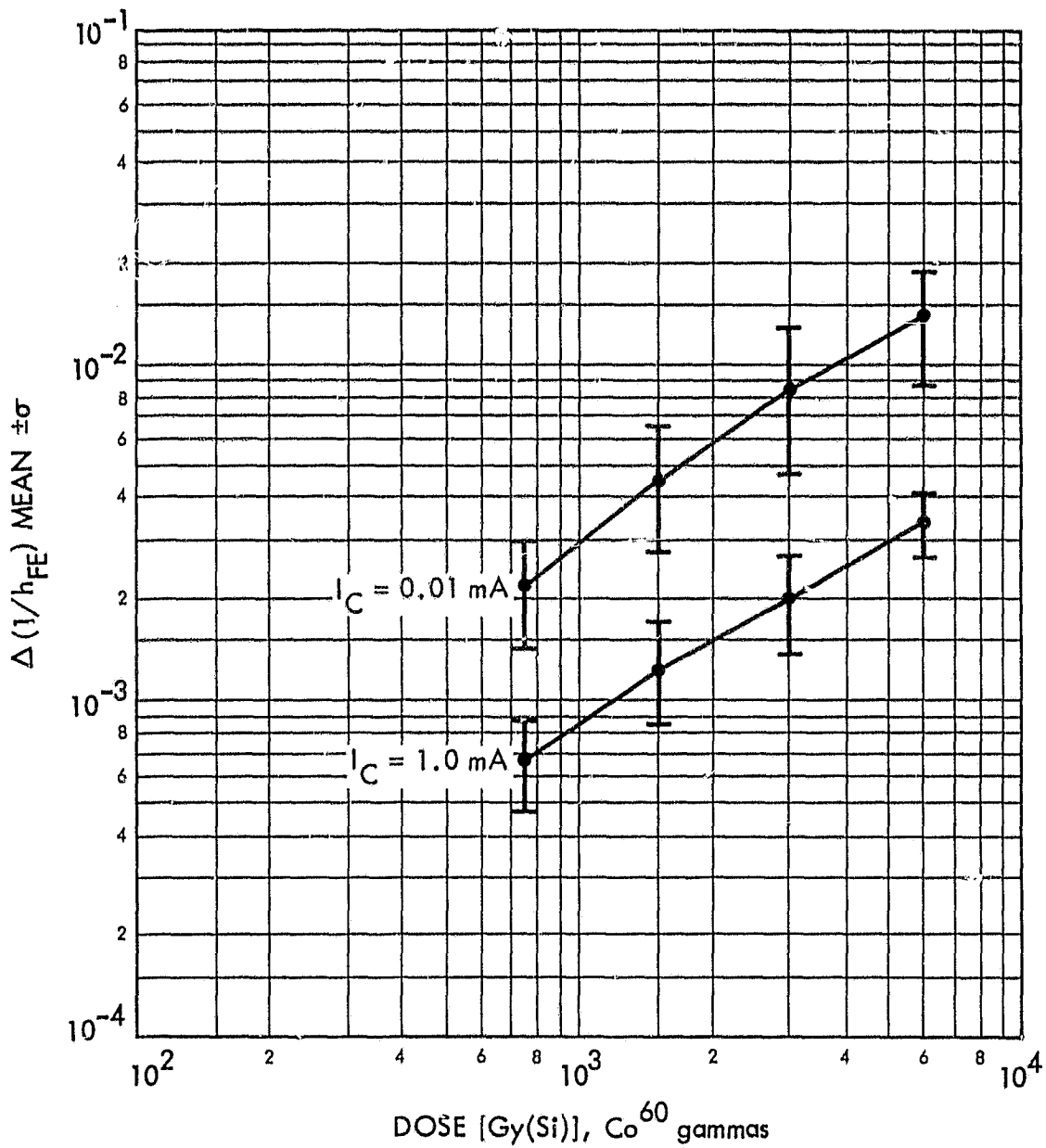INITIAL MEAN VALUE I_{CBO} = 0.087 nA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N3799 PNP LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 3
No. OF DEVICES: 24
TEST CONDITIONS: $V_{CE} = 20$ V

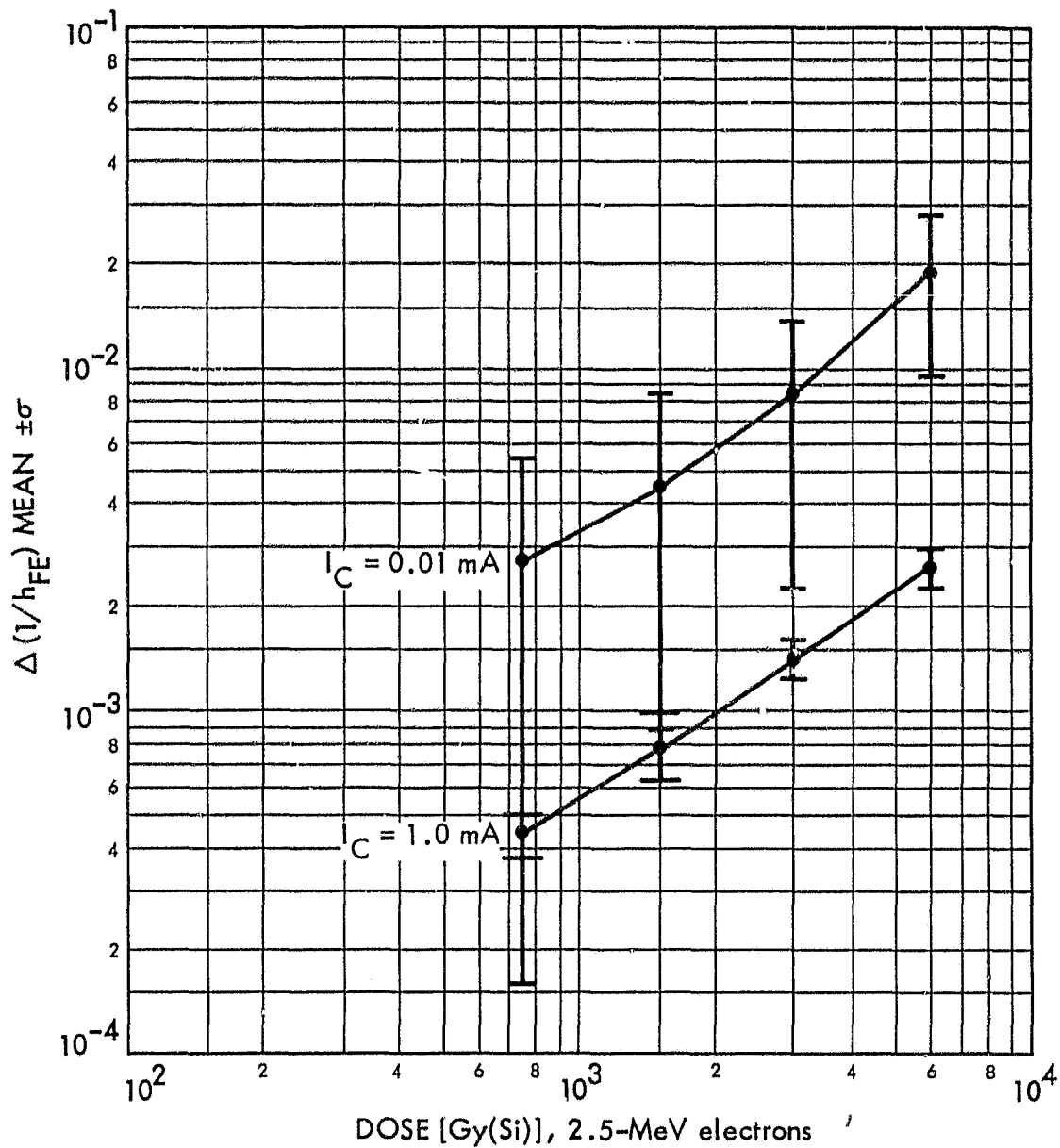DOSE [Gy(Si)], Co^{60} gammas

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N3799 PNP LOW-POWER TRANSISTOR

MFG: TIX   No. OF COMBINED TESTS: 3

No. OF DEVICES: 24

TEST CONDITIONS: $V_{CE} = 20$ V
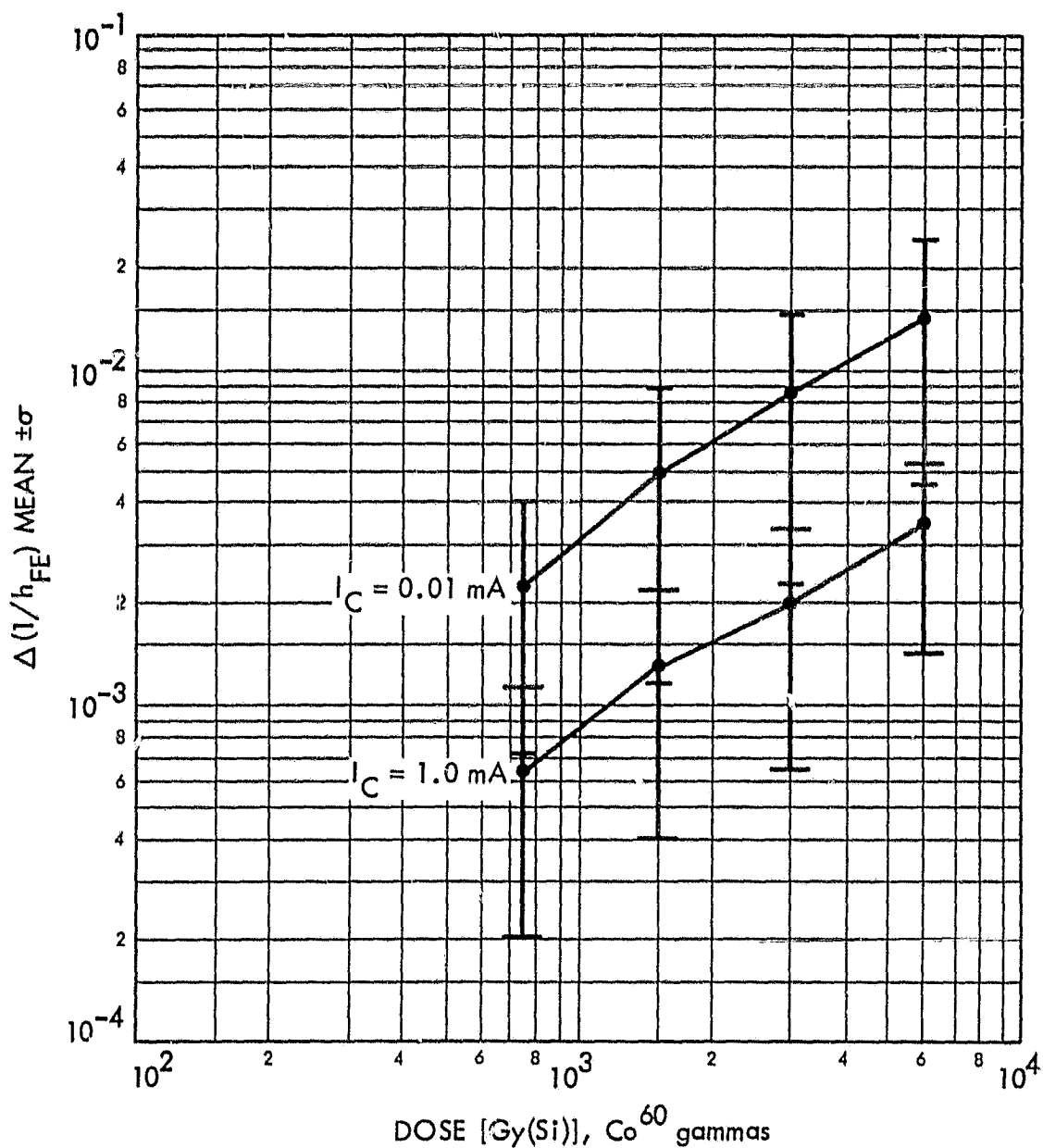

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N3805 PNP LOW-POWER TRANSISTOR
MFG: TIX   No. OF COMBINED TESTS: 6
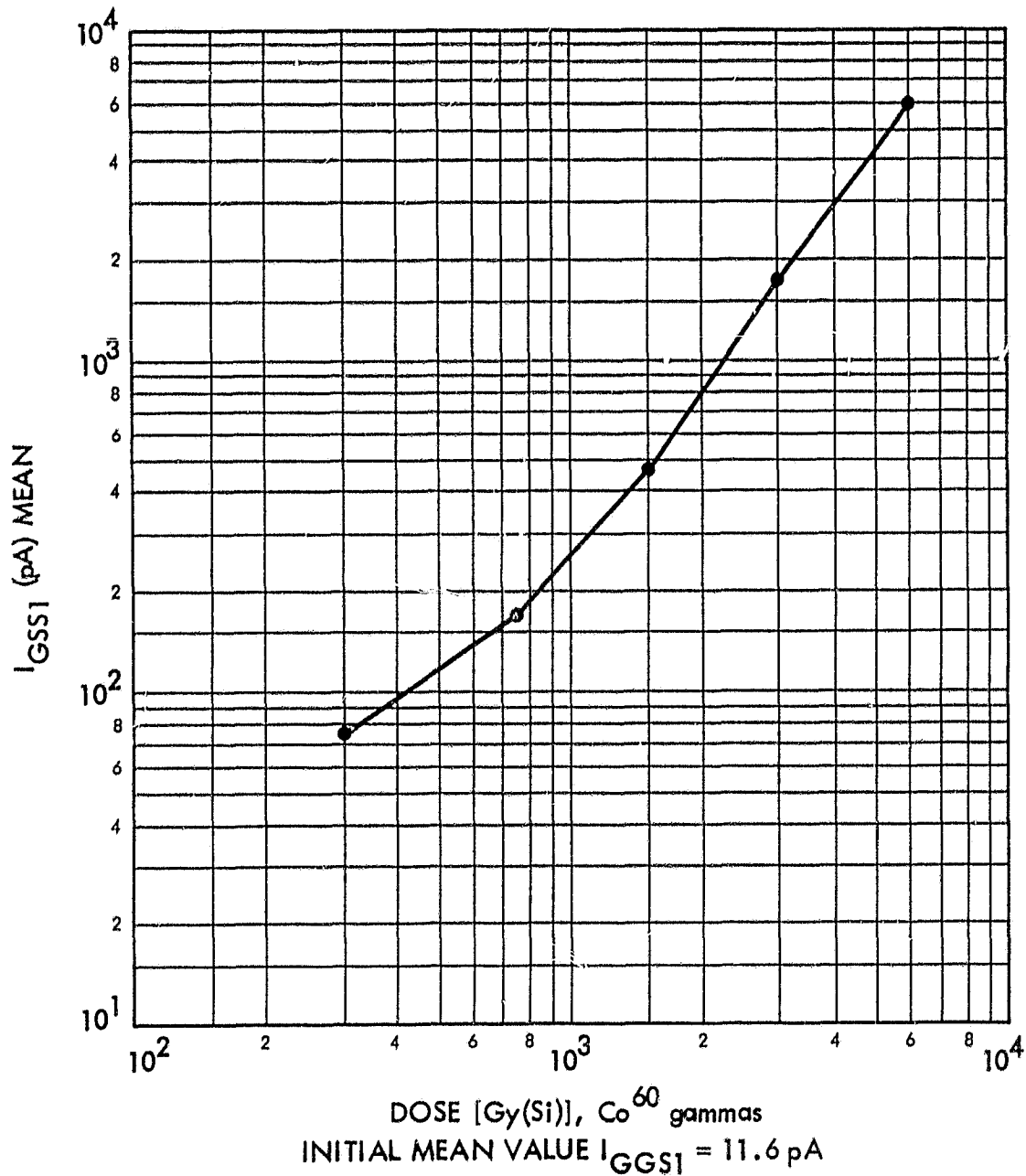No. OF DEVICES: 32
TEST CONDITIONS: $V_{CE} = 16$ V

$\Delta(1/h_{FE})$ MEAN $\pm\sigma$

$I_C = 0.01$ mA

$I_C = 1.0$ mA

DOSE [Gy(Si)], Co^{60} gammas

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET

MFG: SIL   No. OF COMBINED TESTS: 4

No. OF DEVICES: 18

DOSE [Gy(Si)], Co^{60} gammas

INITIAL MEAN VALUE I_{GGS1} = 11.6 pA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET
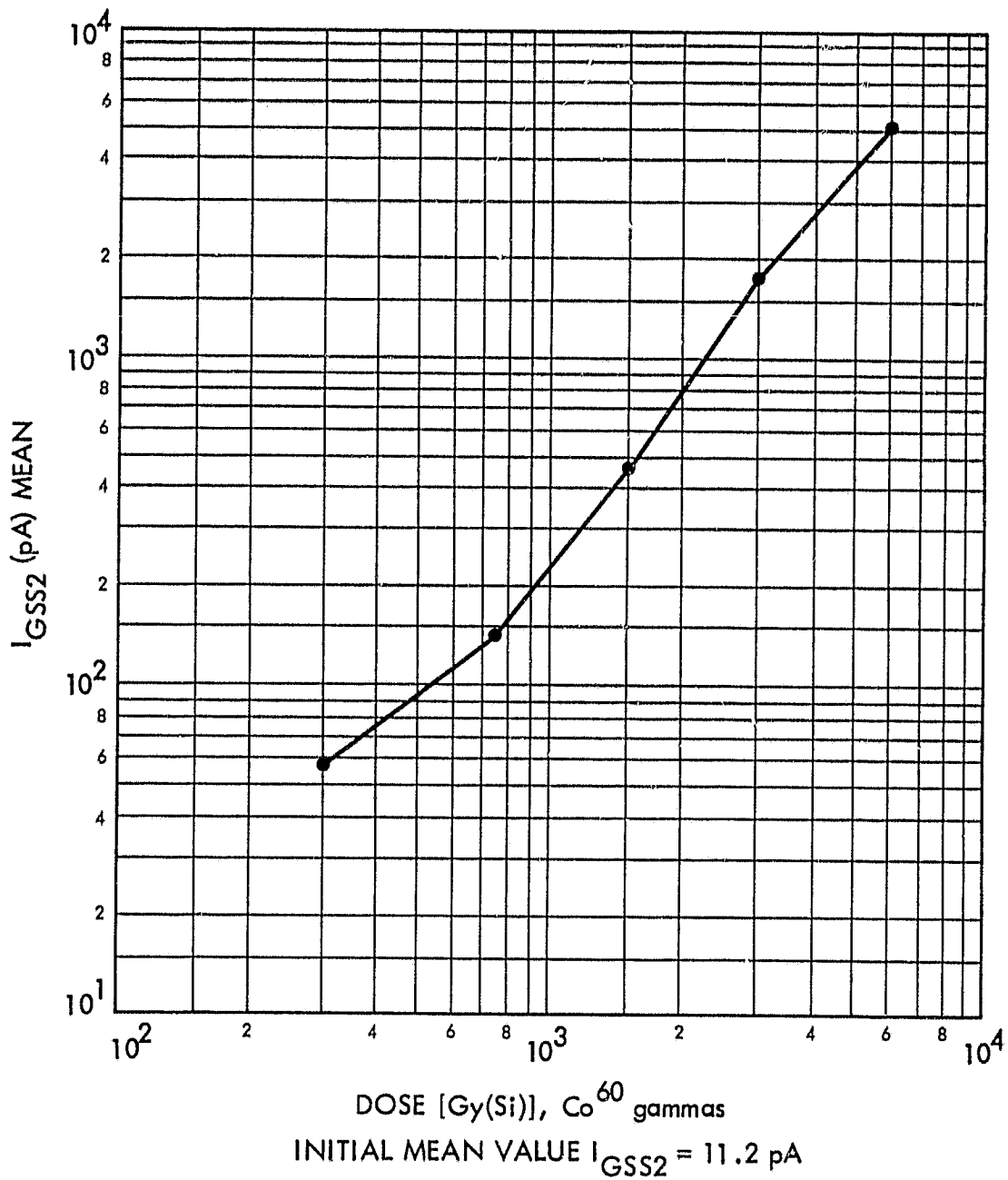
MFG: SIL   No. OF COMBINED TESTS: 4

No. OF DEVICES: 18

DOSE [Gy(Si)], Co^{60} gammas

INITIAL MEAN VALUE I_{GSS2} = 11.2 pA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET
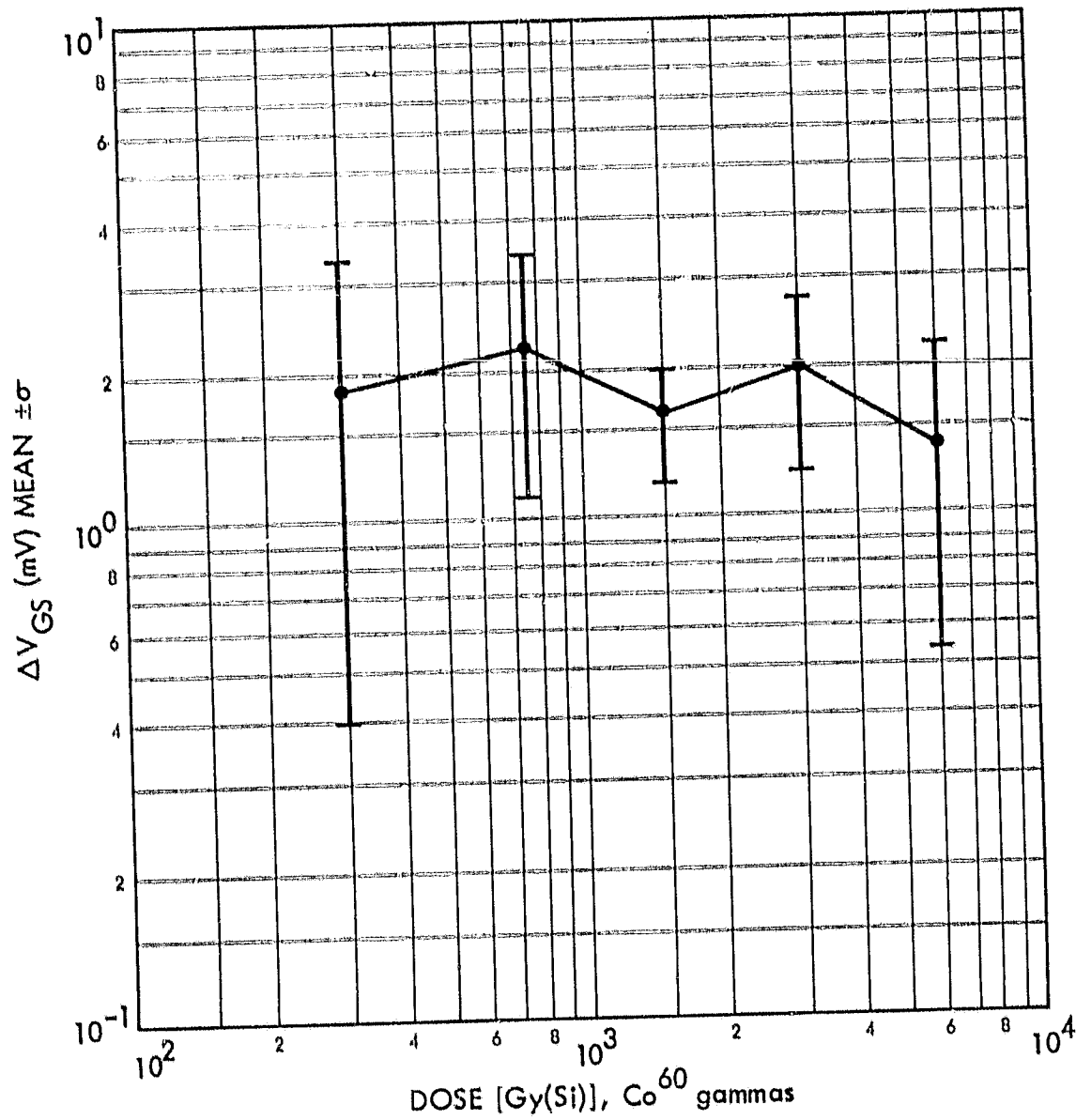
MFG: SIL   No. OF COMBINED TESTS: 4
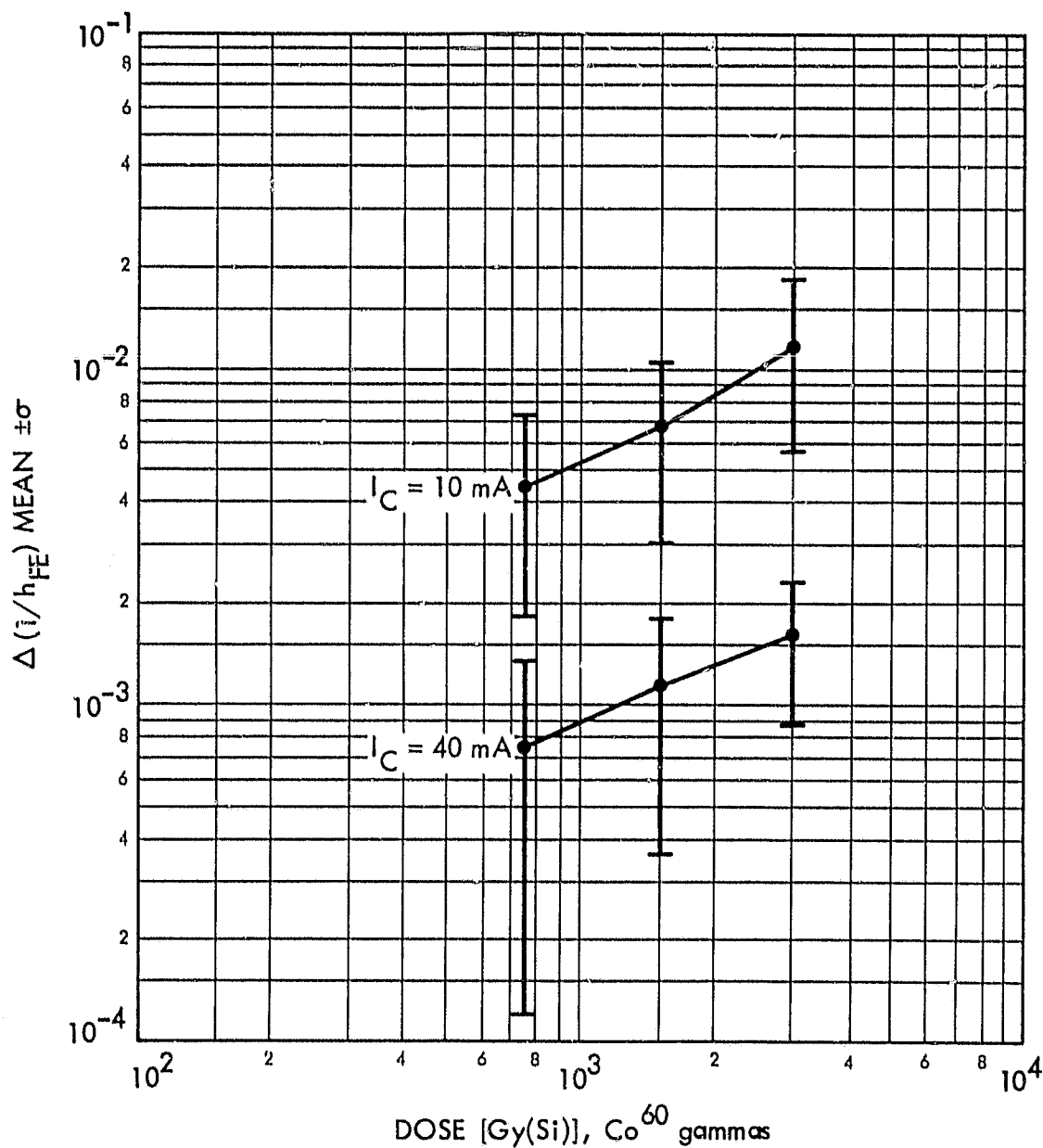
No. OF DEVICES: 19

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: MQ2905 QUAD PNP LOW-POWER TRANSISTOR
MFG: MOT   No. OF COMBINED TESTS: 5
No. OF DEVICES: 32
TEST CONDITIONS: $V_{CE} = 2.4$ V

2. Volume II Data

The Volume II combined data are presented as a single curve for each parameter on a separate graph. Where there was a catastrophic failure for one of the tests included in the combined data, the total-dose where the failure was detected is indicated at the bottom of the graph. Because the test conditions were complex, they are not included on the graphs, except those for the gain parameters.
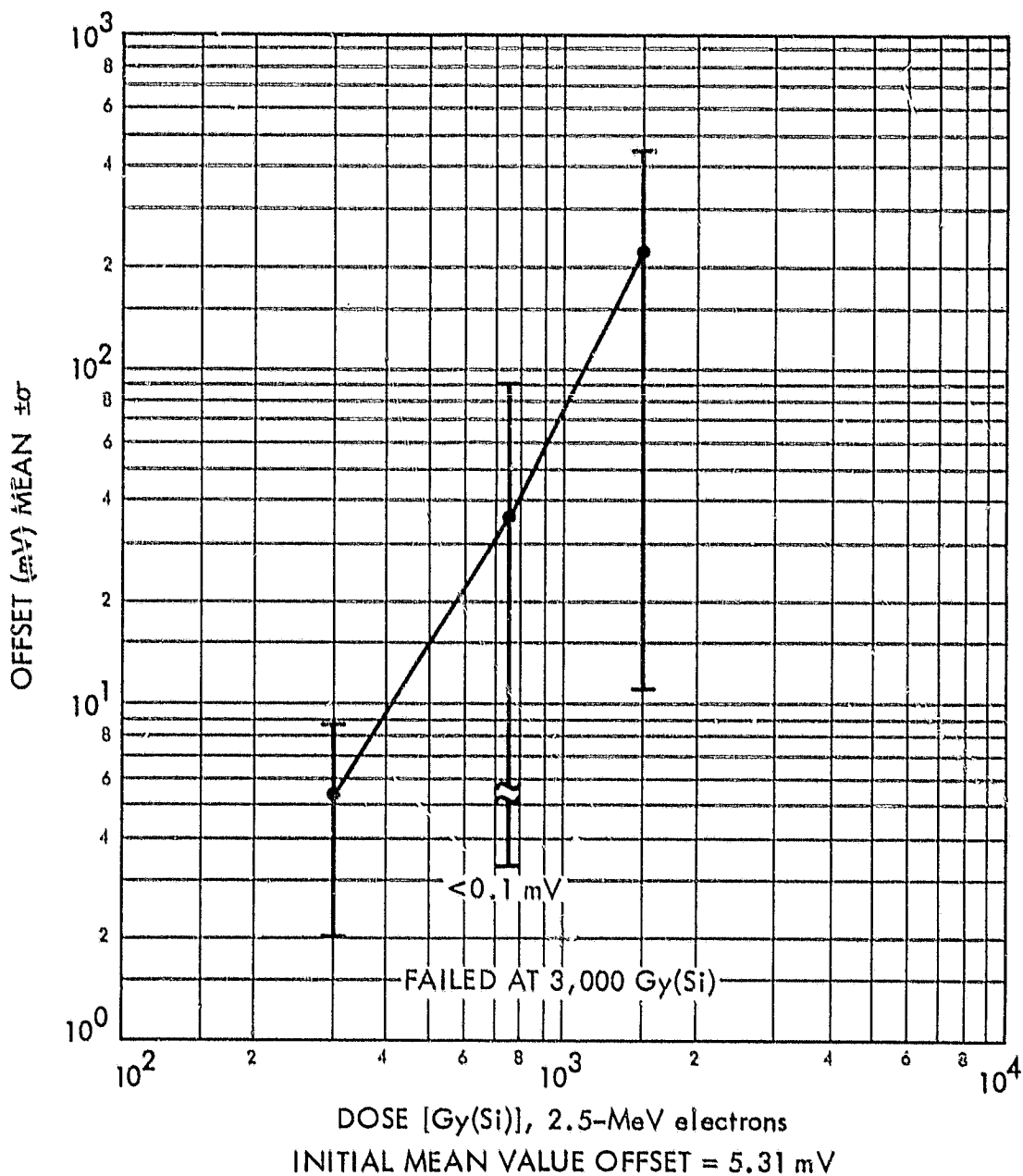
COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: AD571 ANALOG/DIGITAL CONVERTER, 10-BIT
MFG: ADI   No. OF COMBINED TESTS: 5
No. OF DEVICES: 29

DOSE [Gy(Si)], 2.5-MeV electrons
INITIAL MEAN VALUE OFFSET = 5.31 mV

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: AD571 ANALOG/DIGITAL CONVERTER, 10-BIT
MFG: ADI   No. OF COMBINED TESTS: 6
No. OF DEVICES: 29

DOSE [Gy(Si)], 2.5-MeV electrons
INITIAL MEAN VALUE OFF ERROR (LSB) = 0.496

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: AD571 ANALOG/DIGITAL CONVERTER, 10-BIT
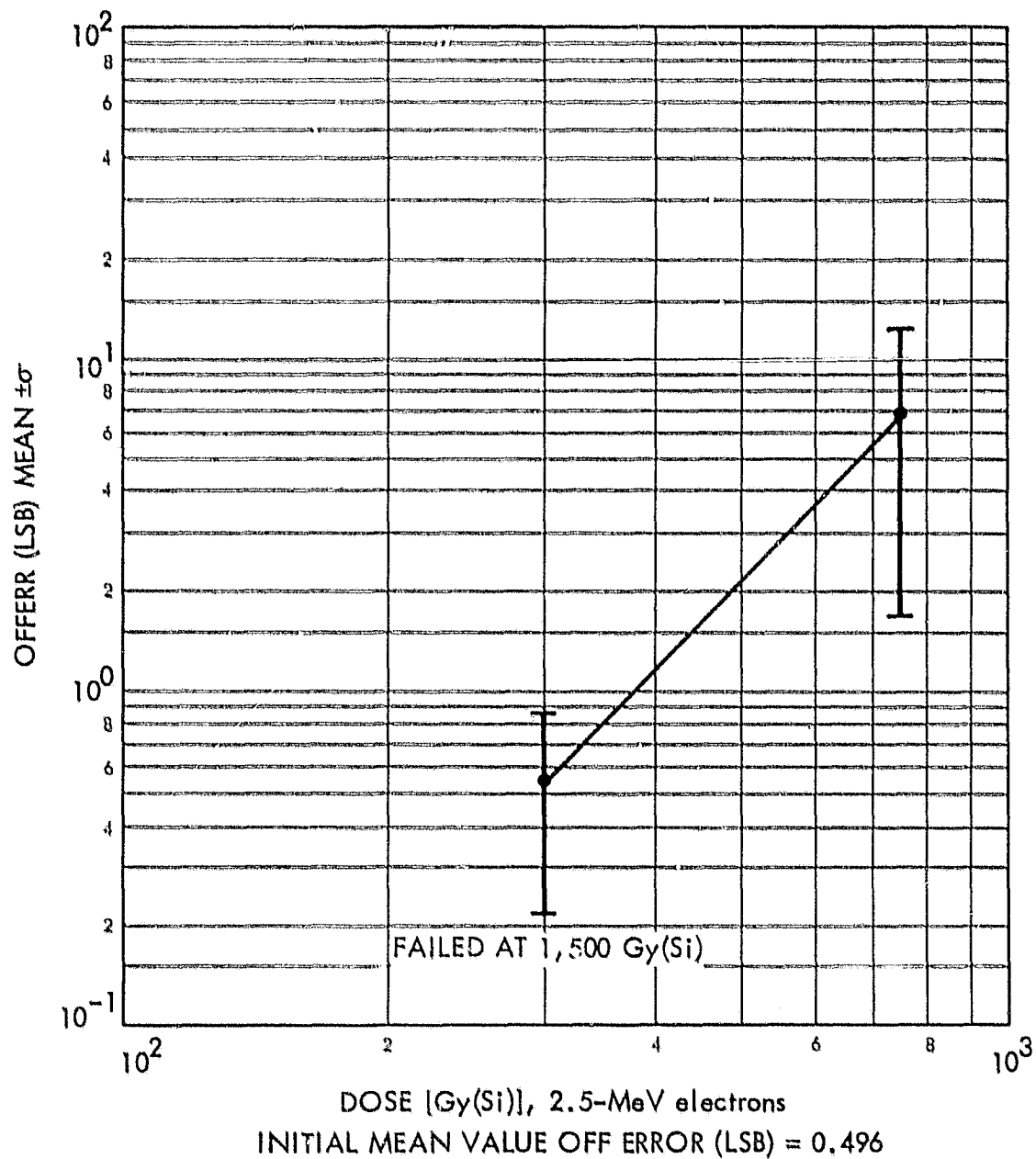
MFG: ADI   No. OF COMBINED TESTS: 6

No. OF DEVICES: 24

FAILED AT 1,500 Gy(Si)

NONLIN (LSB) MEAN $\pm \sigma$

DOSE [Gy(Si)], 2.5-MeV electrons

INITIAL MEAN VALUE NONLIN (LSB) = 0.53

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: AD571 ANALOG/DIGITAL CONVERTER, 10-BIT
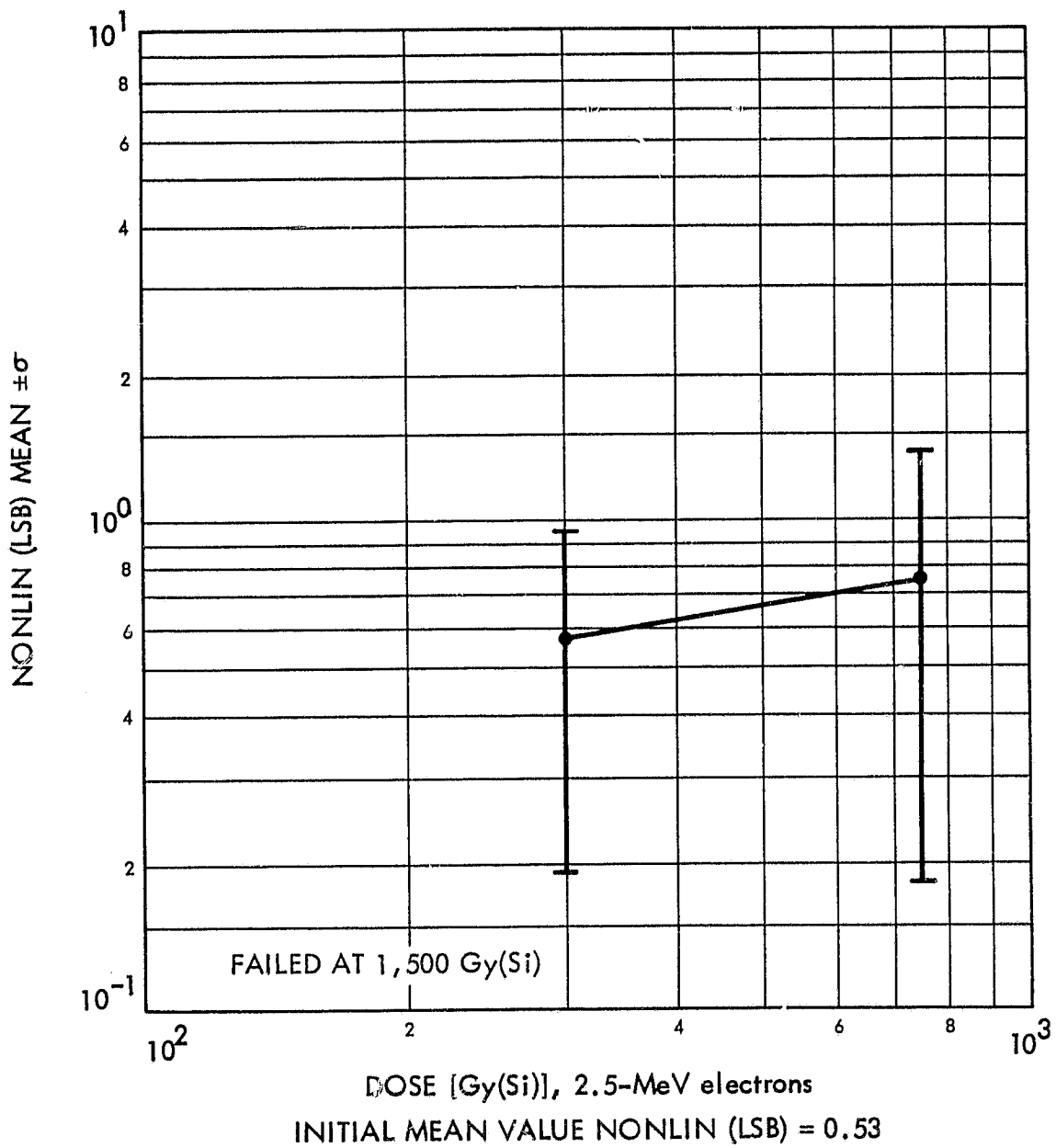
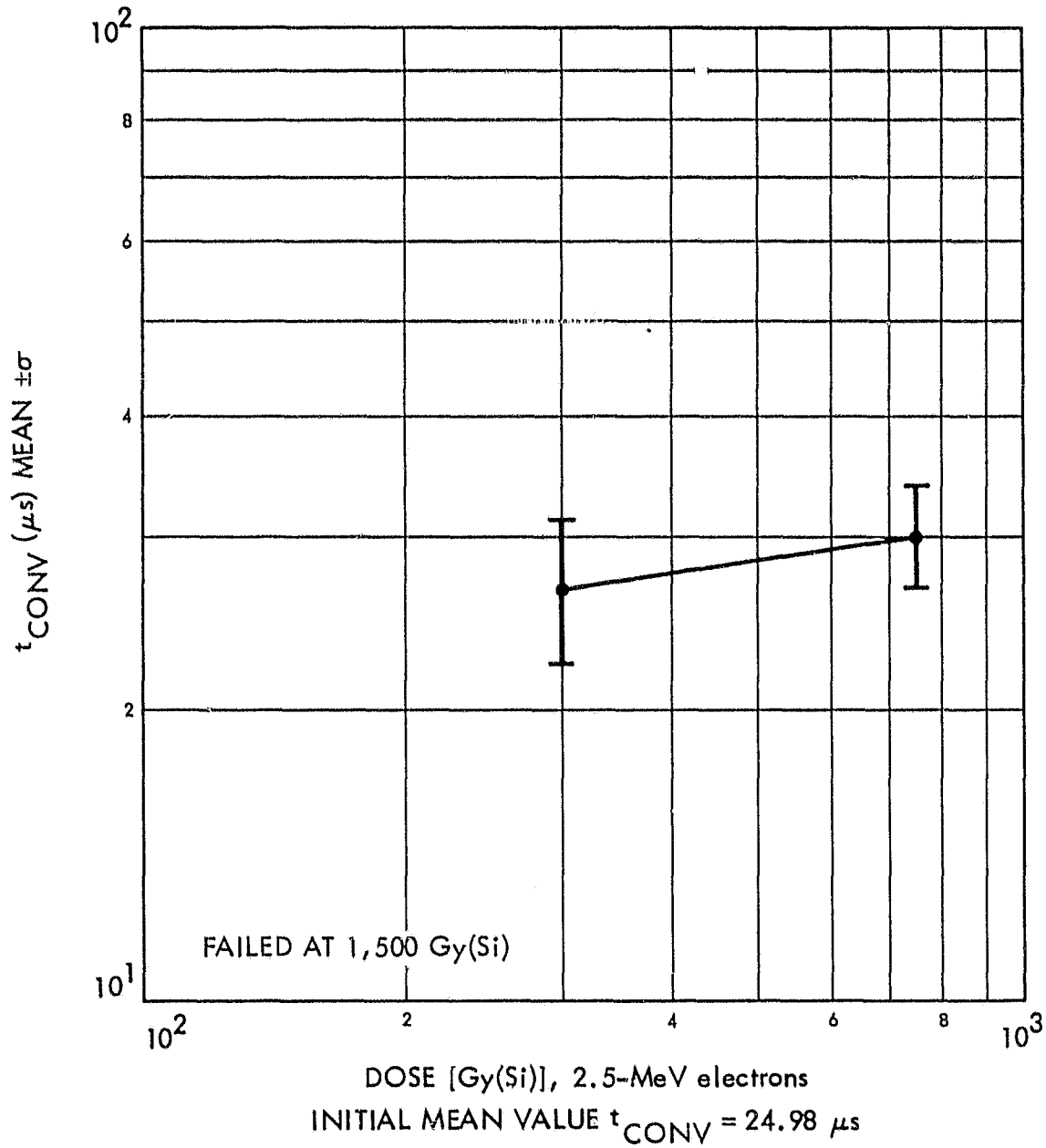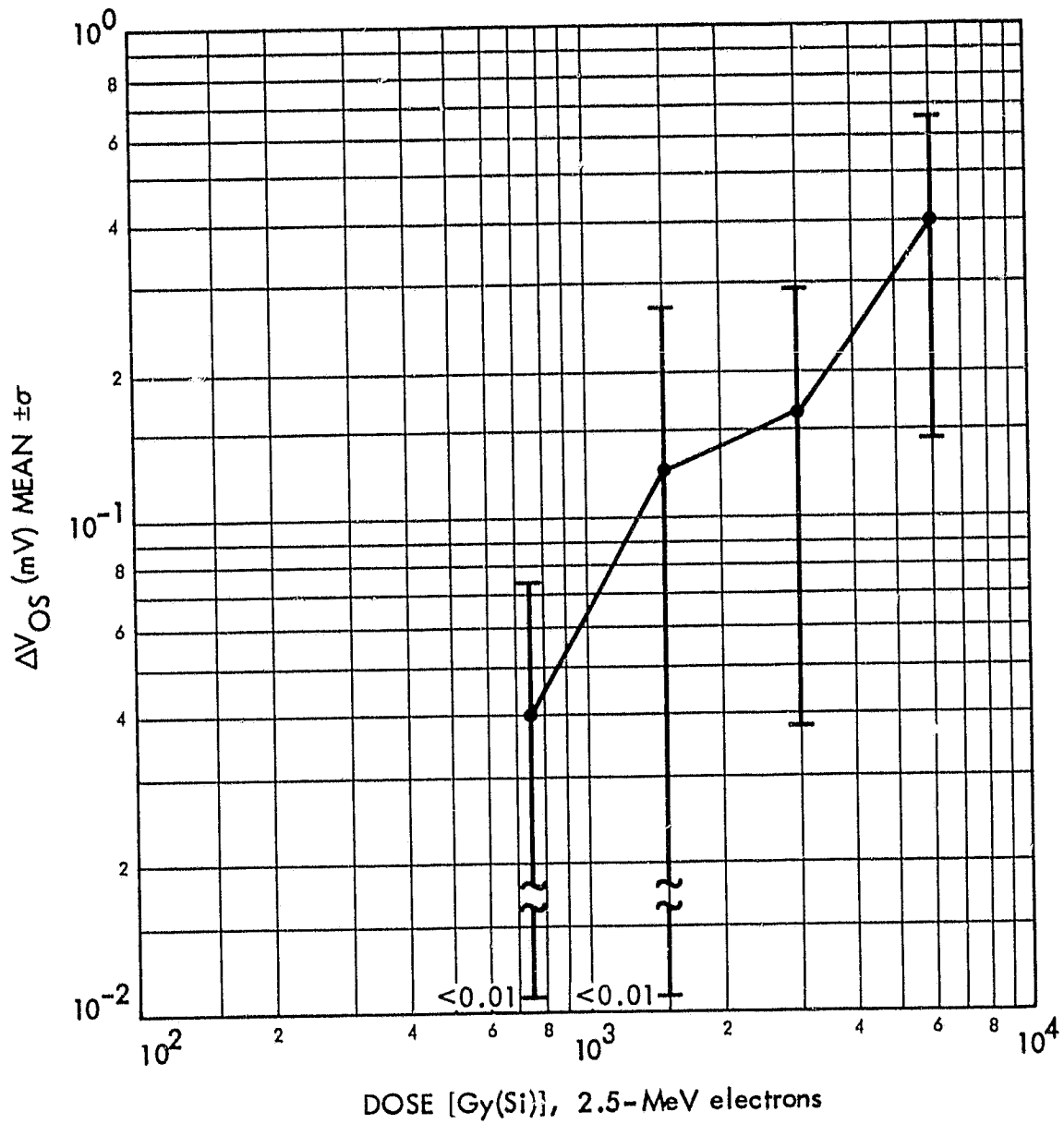MFG: ADI   No. OF COMBINED TESTS: 6

No. OF DEVICES: 24

FAILED AT 1,500 Gy(Si)

DOSE [Gy(Si)], 2.5-MeV electrons

INITIAL MEAN VALUE t_{CONV} = 24.98 μs

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM108 OPERATIONAL AMPLIFIER RAD HARD
MFG: NSC   No. OF COMBINED TESTS: 6
No. OF DEVICES: 19

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM108 OPERATIONAL AMPLIFIER RAD HARD
MFG: NSC   No. OF COMBINED TESTS: 6
No. OF DEVICES: 19

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM108 OPERATIONAL AMPLIFIER RAD HARD
MFG: NSC   No. OF COMBINED TESTS: 6
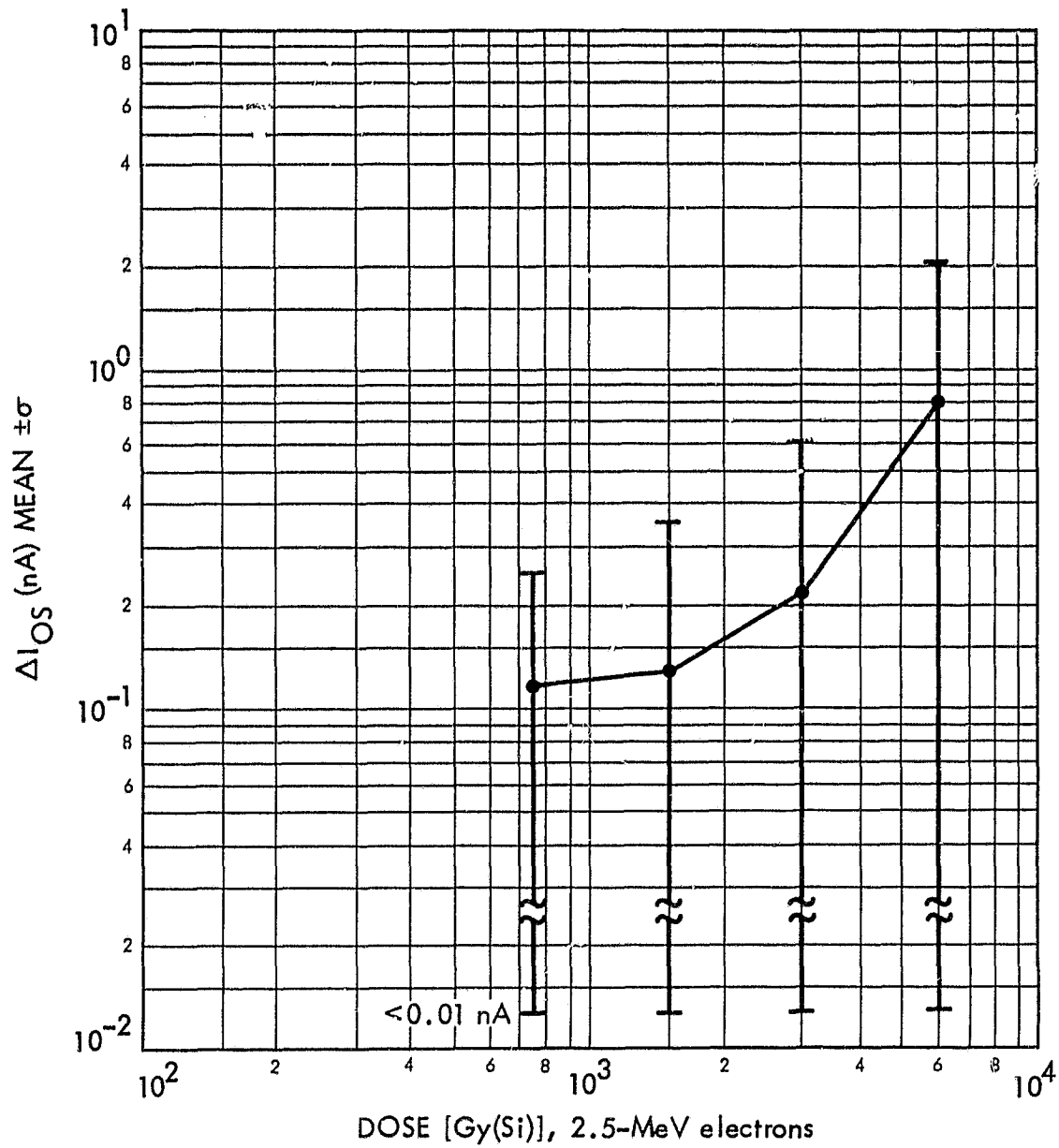No. OF DEVICES: 19

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM108 OPERATIONAL AMPLIFIER RAD HARD
MFG: NSC   No. OF COMBINED TESTS: 5
No. OF DEVICES: 16
TEST CONDITIONS: 10 kΩ LOAD = 1 mA

DOSE [Gy(Si)], 2.5–MeV electrons

INITIAL MEAN VALUE + GAIN = 124 dB

FAILED AT
6,000 Gy(Si)

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM108 OPERATIONAL AMPLIFIER RAD HARD
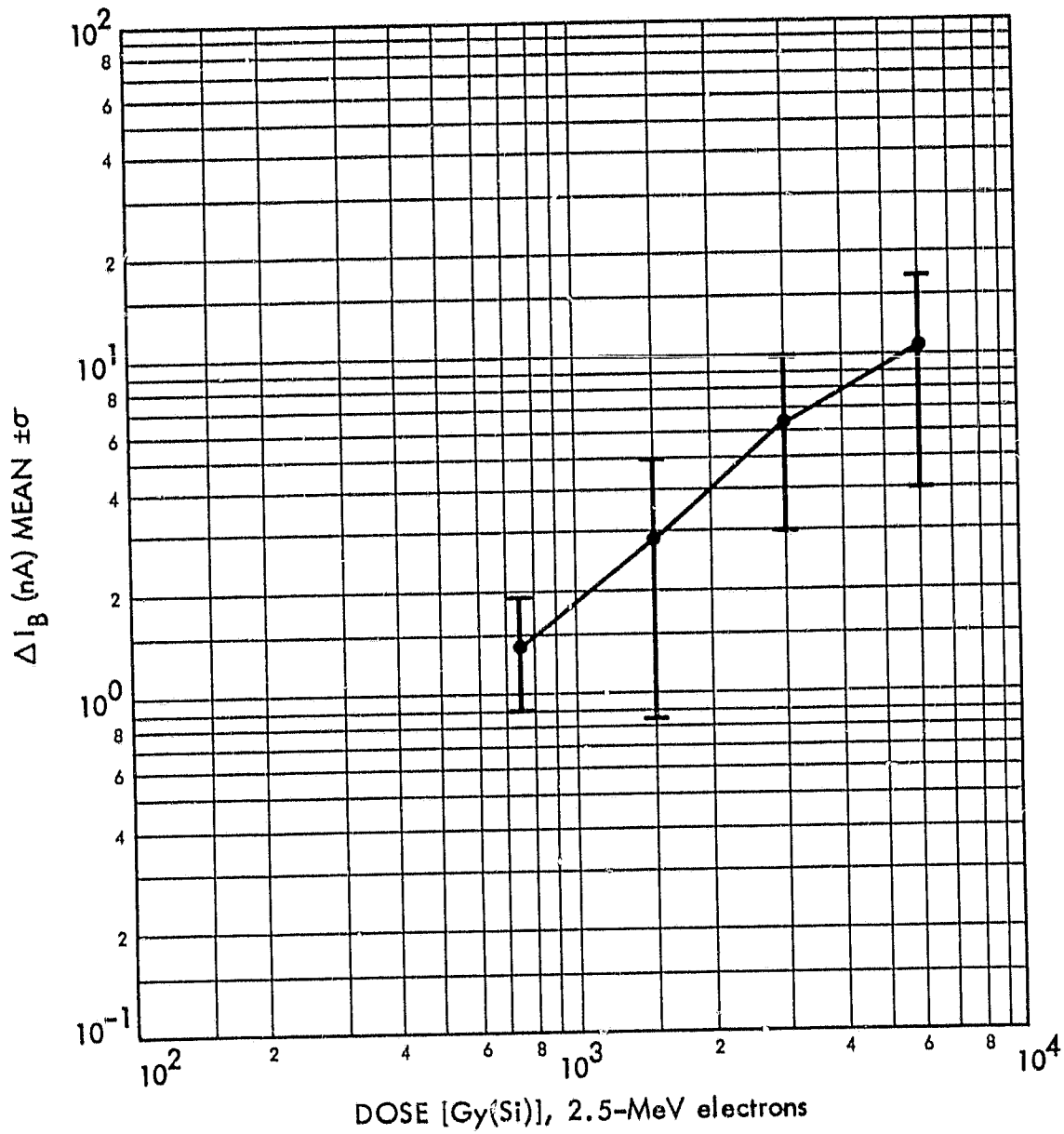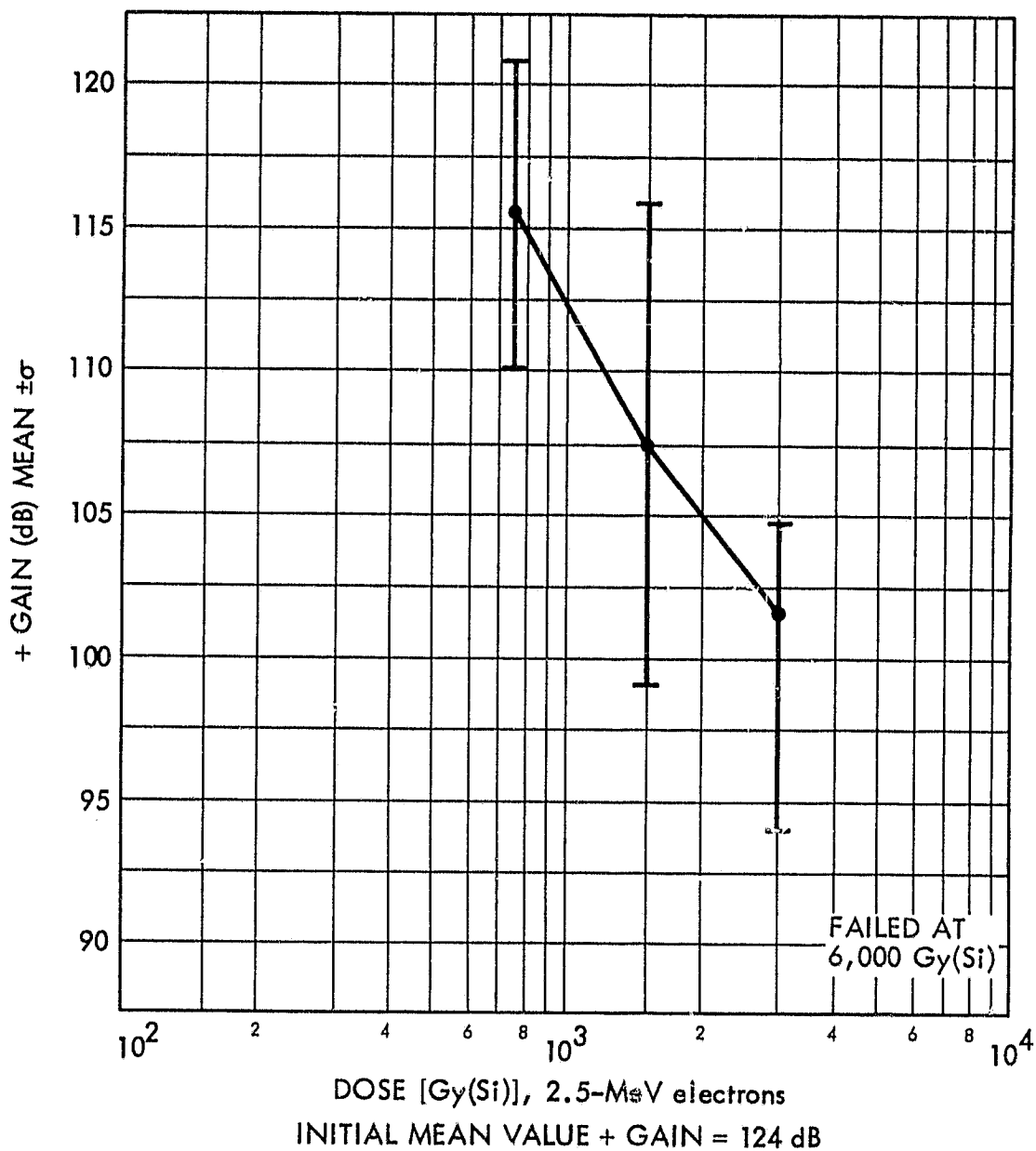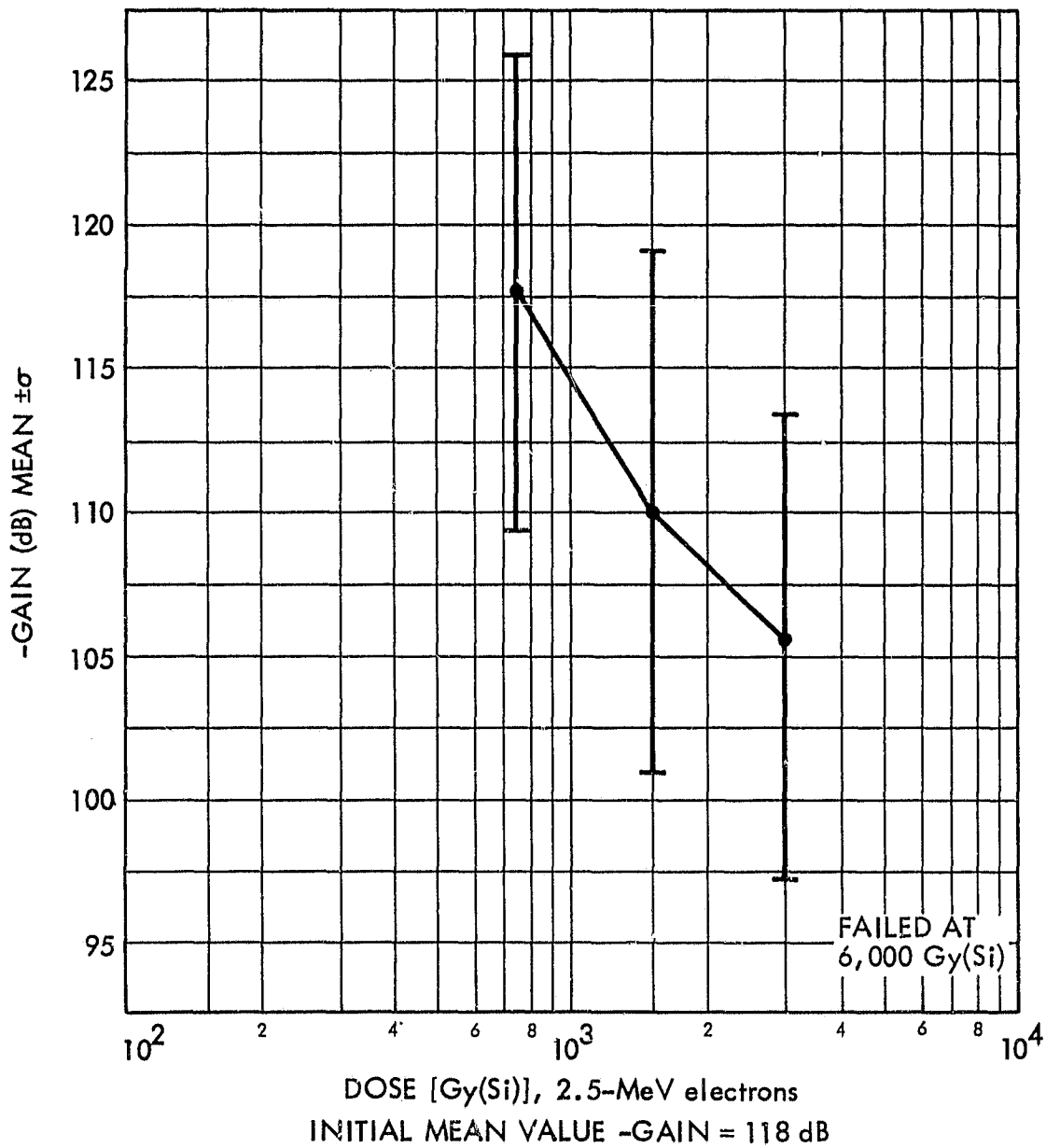MFG: NSC   No. OF COMBINED TESTS: 5
No. OF DEVICES: 16
TEST CONDITIONS: 10 kΩ LOAD = 1.0 mA

-GAIN (dB) MEAN ±σ

FAILED AT
6,000 Gy(Si)

DOSE [Gy(Si)], 2.5-MeV electrons
INITIAL MEAN VALUE -GAIN = 118 dB

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LMIII COMPARATOR

MFG: AMD   No. OF COMBINED TESTS: 4

No. OF DEVICES: 31

DOSE [Gy(Si)], 2.5–MeV electrons

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COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LMIil COMPARATOR

MFG: AMD   No. OF COMBINED TESTS: 3

No. OF DEVICES: 24

DOSE [Gy(Si)], 2.5–MeV electrons
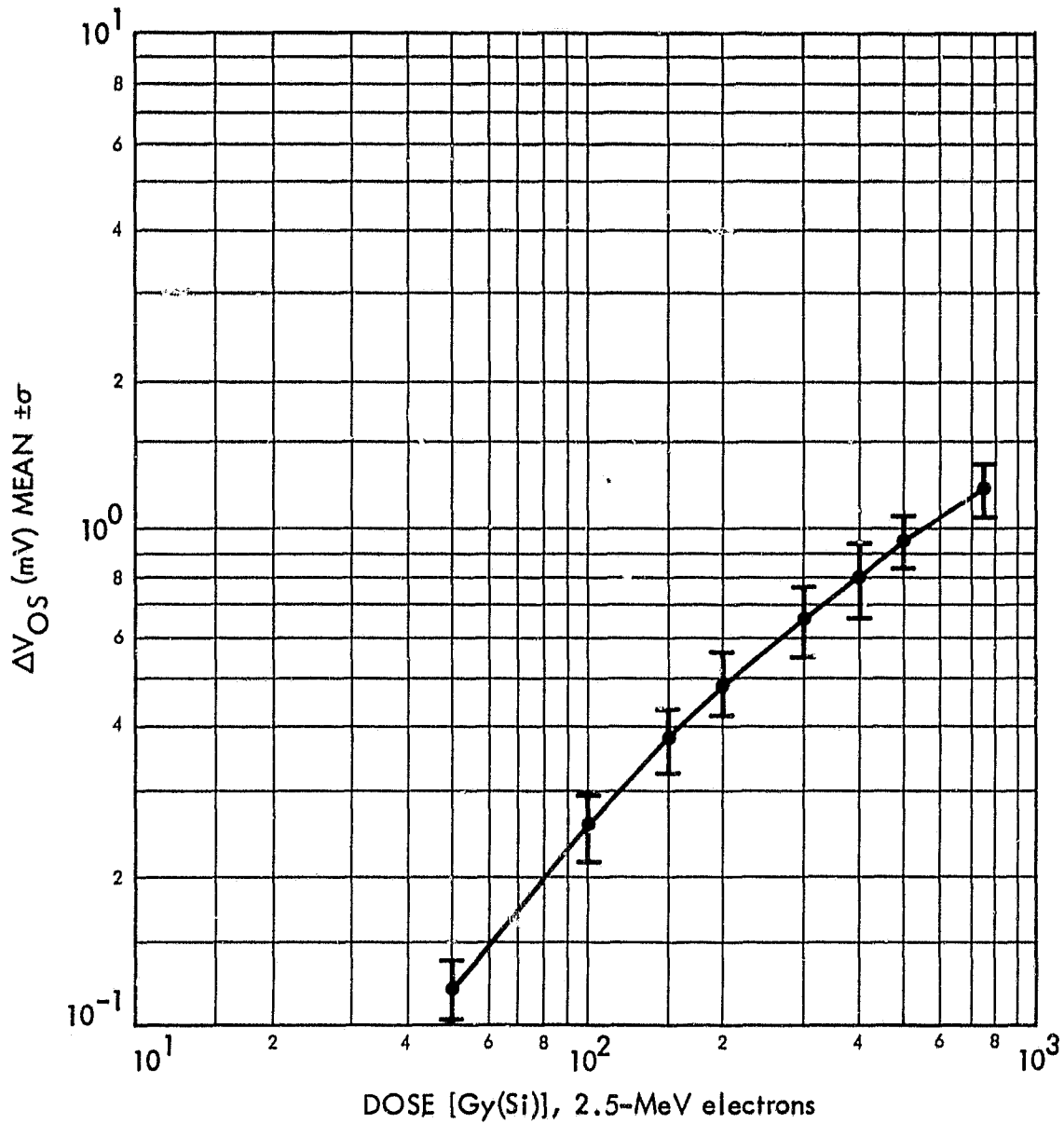
COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LMIII COMPARATOR
MFG: AMD   No. OF COMBINED TESTS: 4
No. OF DEVICES: 31

DOSE [Gy(Si)], 2.5-MeV electrons

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COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LMIII COMPARATOR
MFG: AMD   No. OF COMBINED TESTS: 13
No. OF DEVICES: 112

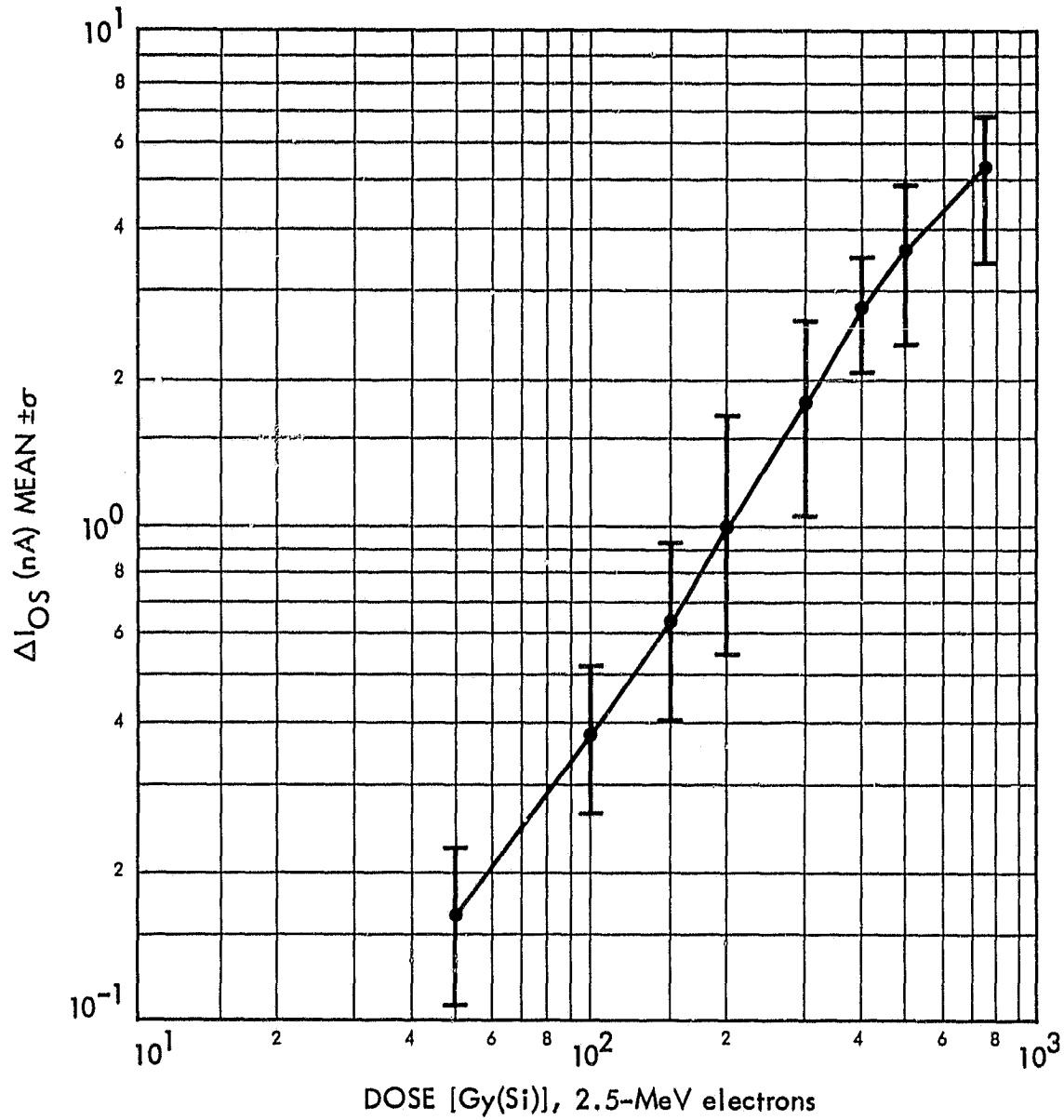DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A-SINGLE MANUFACTURER

DEVICE TYPE: LMIII COMPARATOR

MFG: AMD   No. OF COMBINED TESTS: 13

No. OF DEVICES: 112
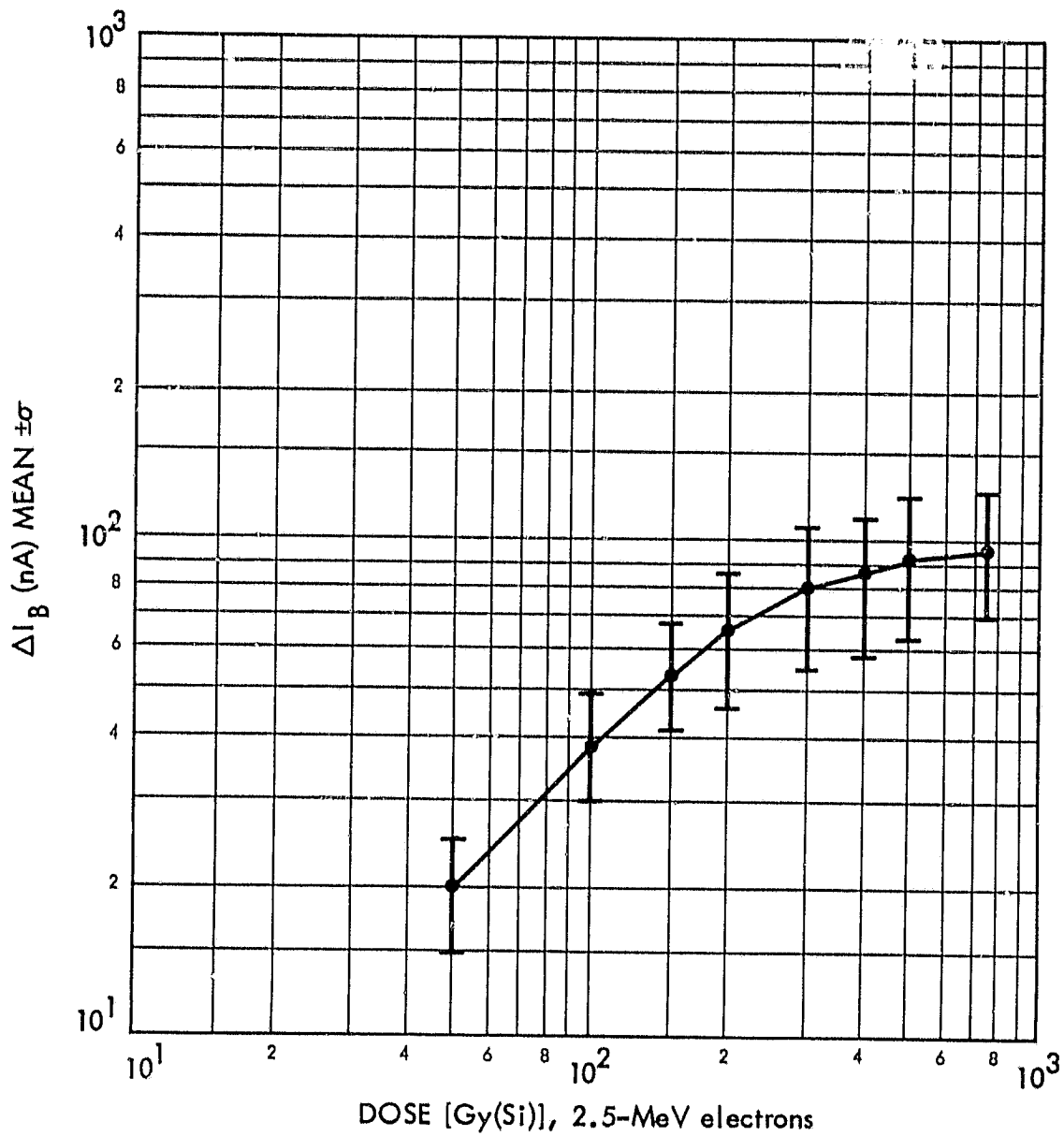

DOSE [Gy(Si)], 2.5-MeV electrons

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COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LMIII COMPARATOR

MFG: AMD   No. OF COMBINED TESTS: 13

No. OF DEVICES: 112

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER
DEVICE TYPE: LM119 DUAL COMPARATOR
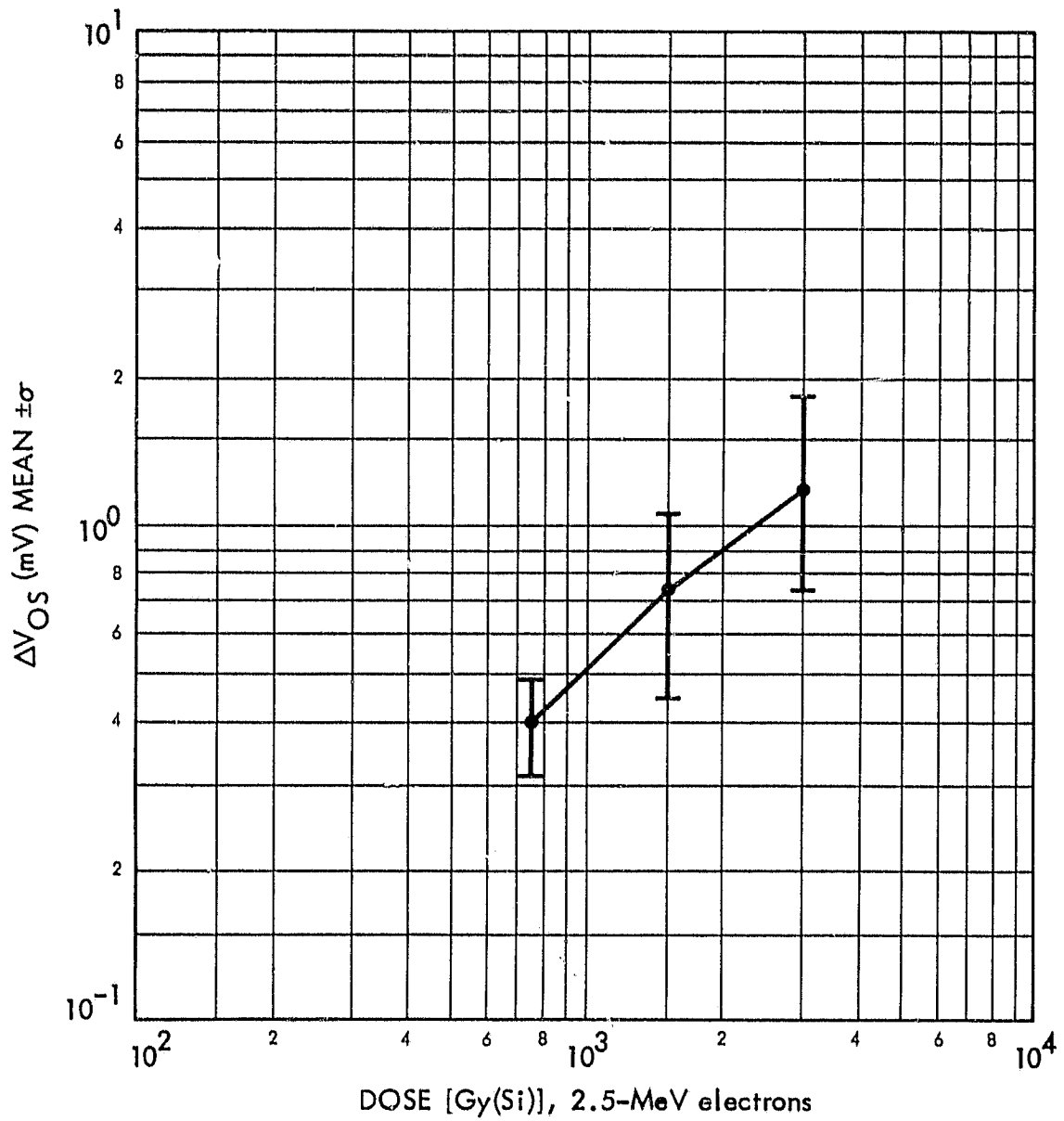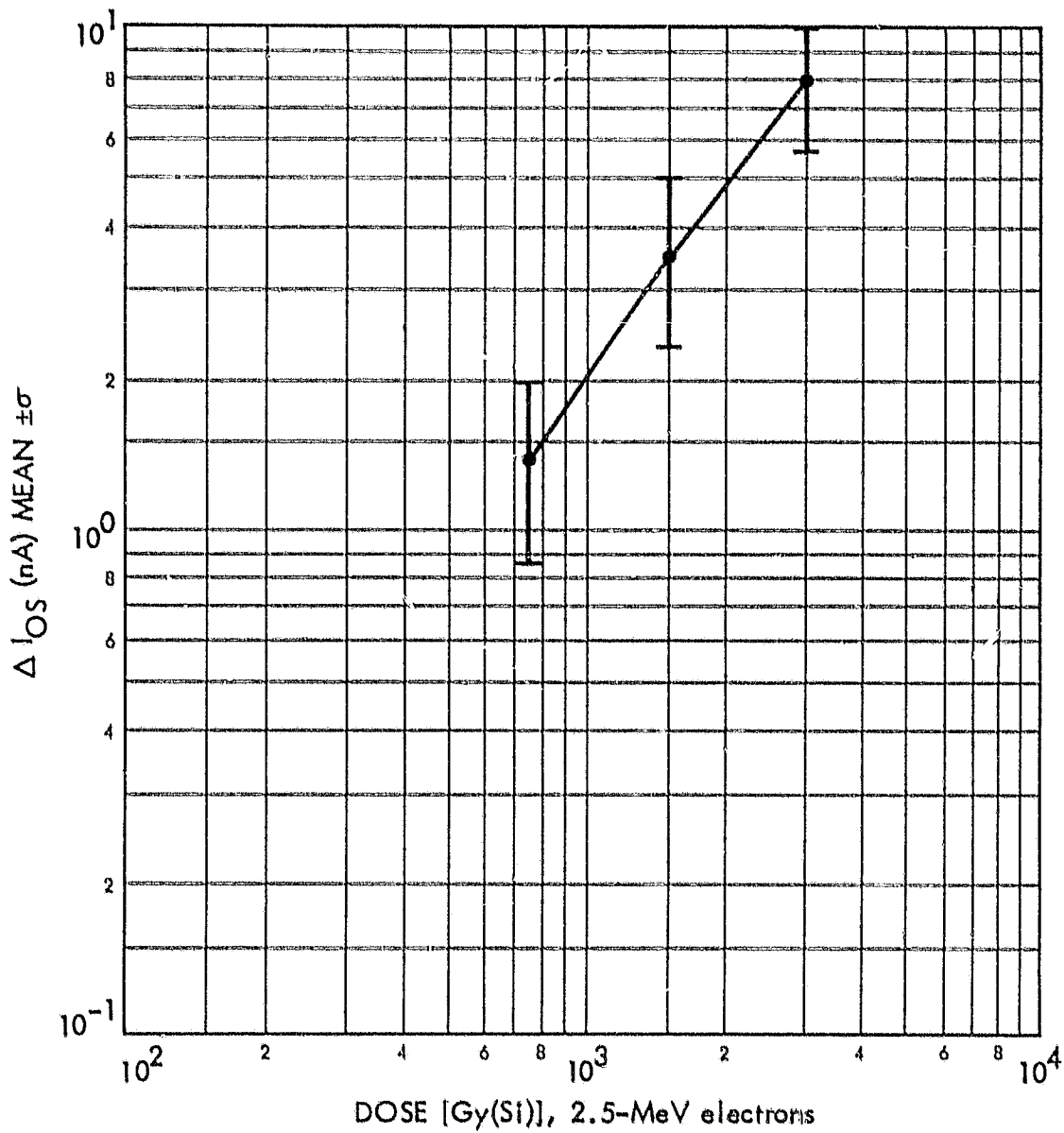MFG: AMD   No. OF COMBINED TESTS: 14
No. OF DEVICES: 56

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM119 DUAL COMPARATOR

MFG: AMD   No, OF COMBINED TESTS: 14

No. OF DEVICES: 56

DOSE [Gy(Si)], 2.5–MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM119 DUAL COMPARATOR
MFG: AMD   No. OF COMBINED TESTS: 14
No. OF DEVICES: 56
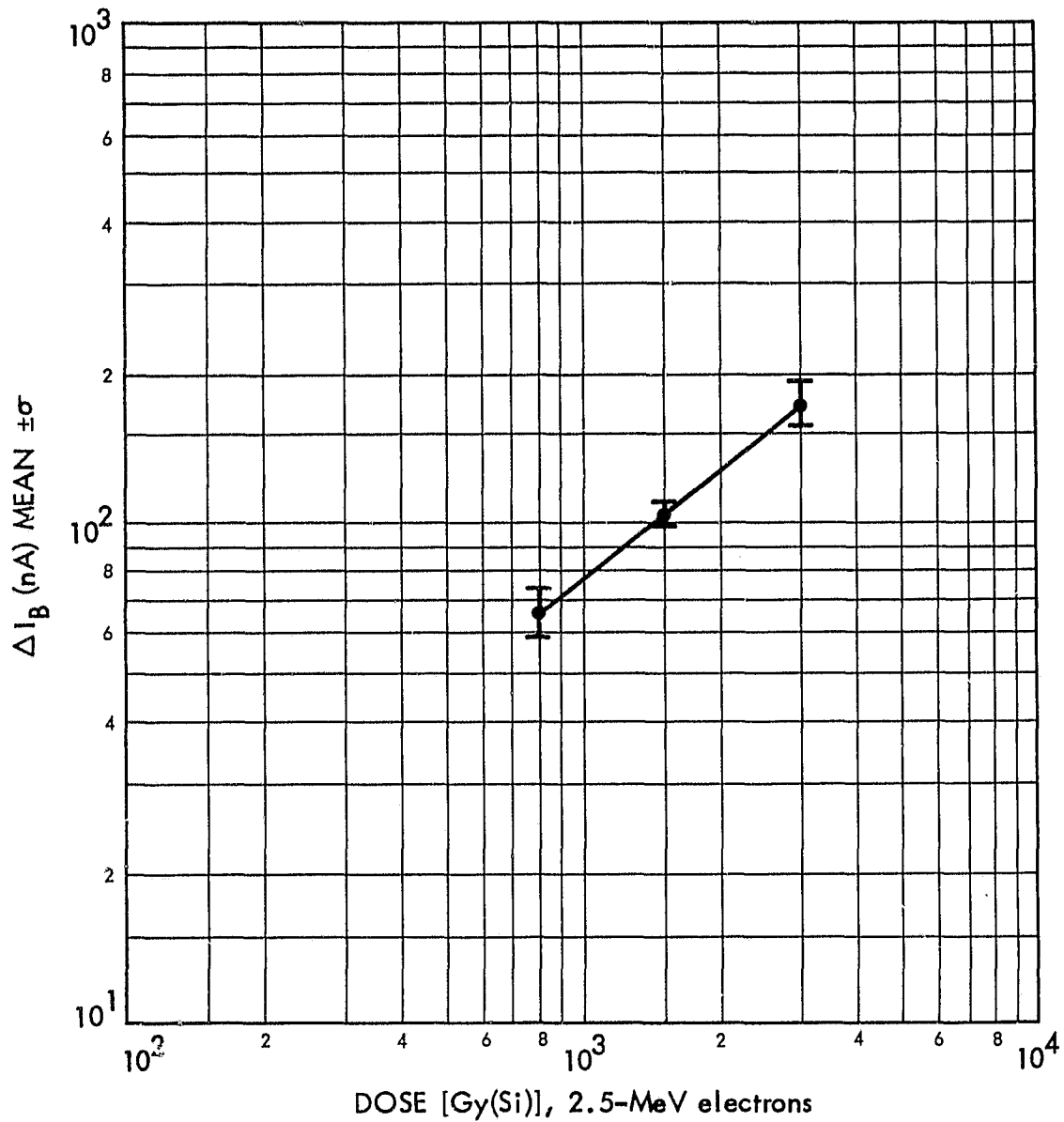

DOSE [Gy(Si)], 2.5–MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM119 DUAL COMPARATOR
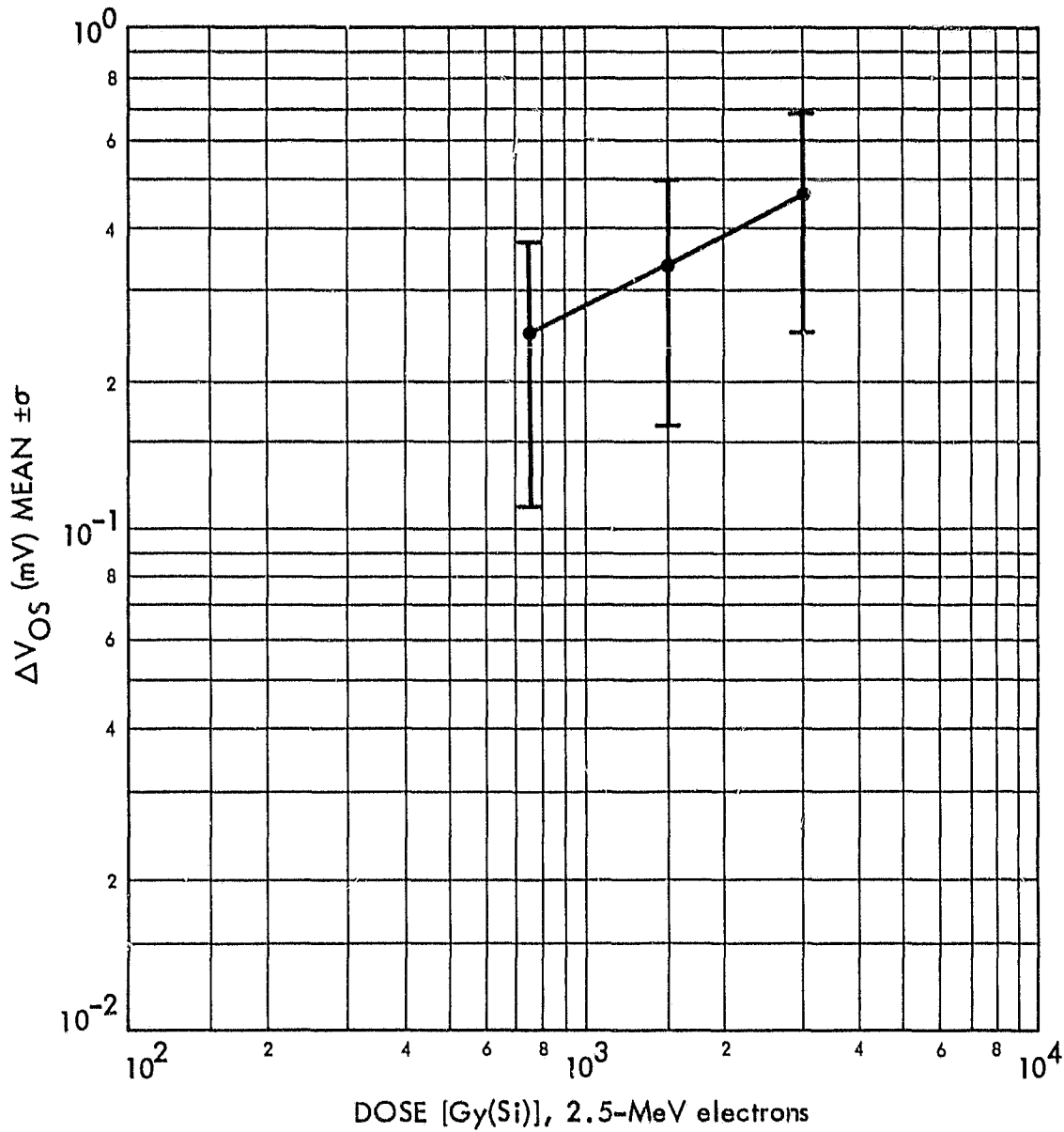MFG: AMD   No. OF COMBINED TESTS: 14
No. OF DEVICES: 56

DOSE [Gy(Si)], 2.5-MeV electrons

INITIAL MEAN VALUE I_{SINK} = 16.8 mA

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM139 QUAD COMPARATOR
MFG: AMD   No. OF COMBINED TESTS: 13
No. OF DEVICES: 52

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM139 QUAD COMPARATOR
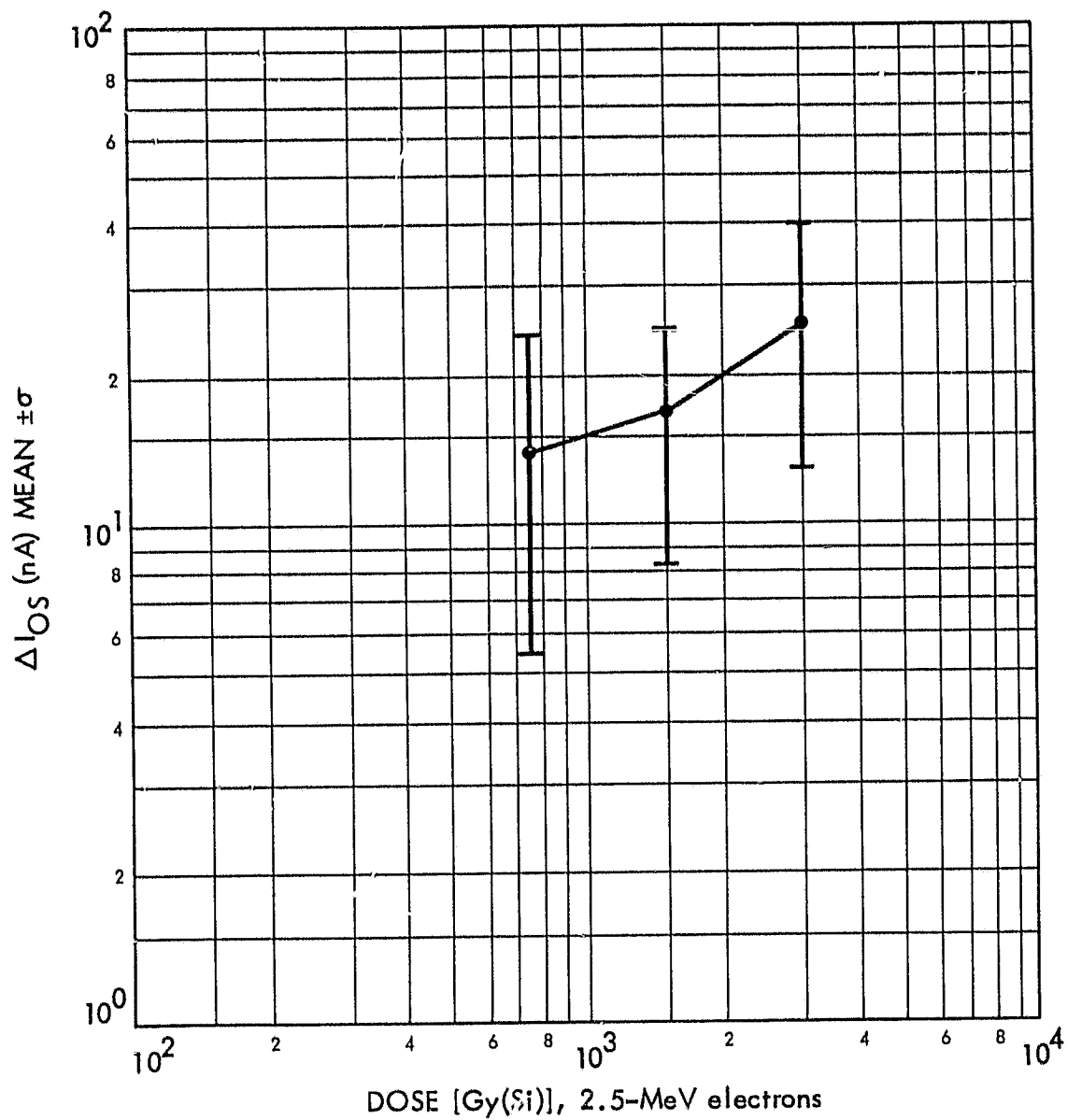
MFG: AMD   No. OF COMBINED TESTS: 12

No. OF DEVICES: 48

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

DEVICE TYPE: LM139 QUAD COMPARATOR
MFG: AMD   No. OF COMBINED TESTS: 12
No. OF DEVICES: 48

DOSE [Gy(Si)], 2.5-MeV electrons

COMBINED DATA FOR ALL TESTS FOR A SINGLE MANUFACTURER

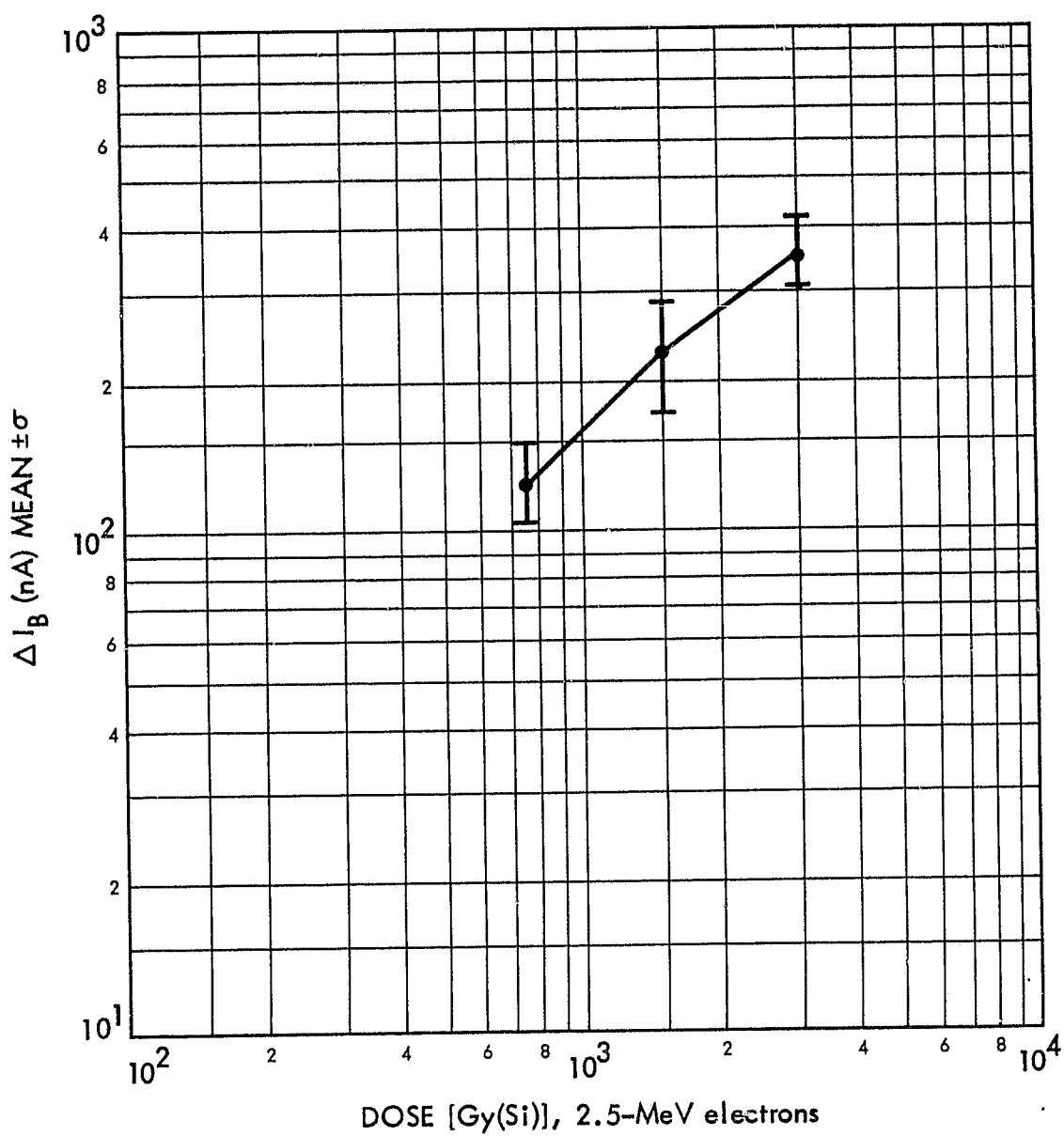DEVICE TYPE: LM139 QUAD COMPARATOR
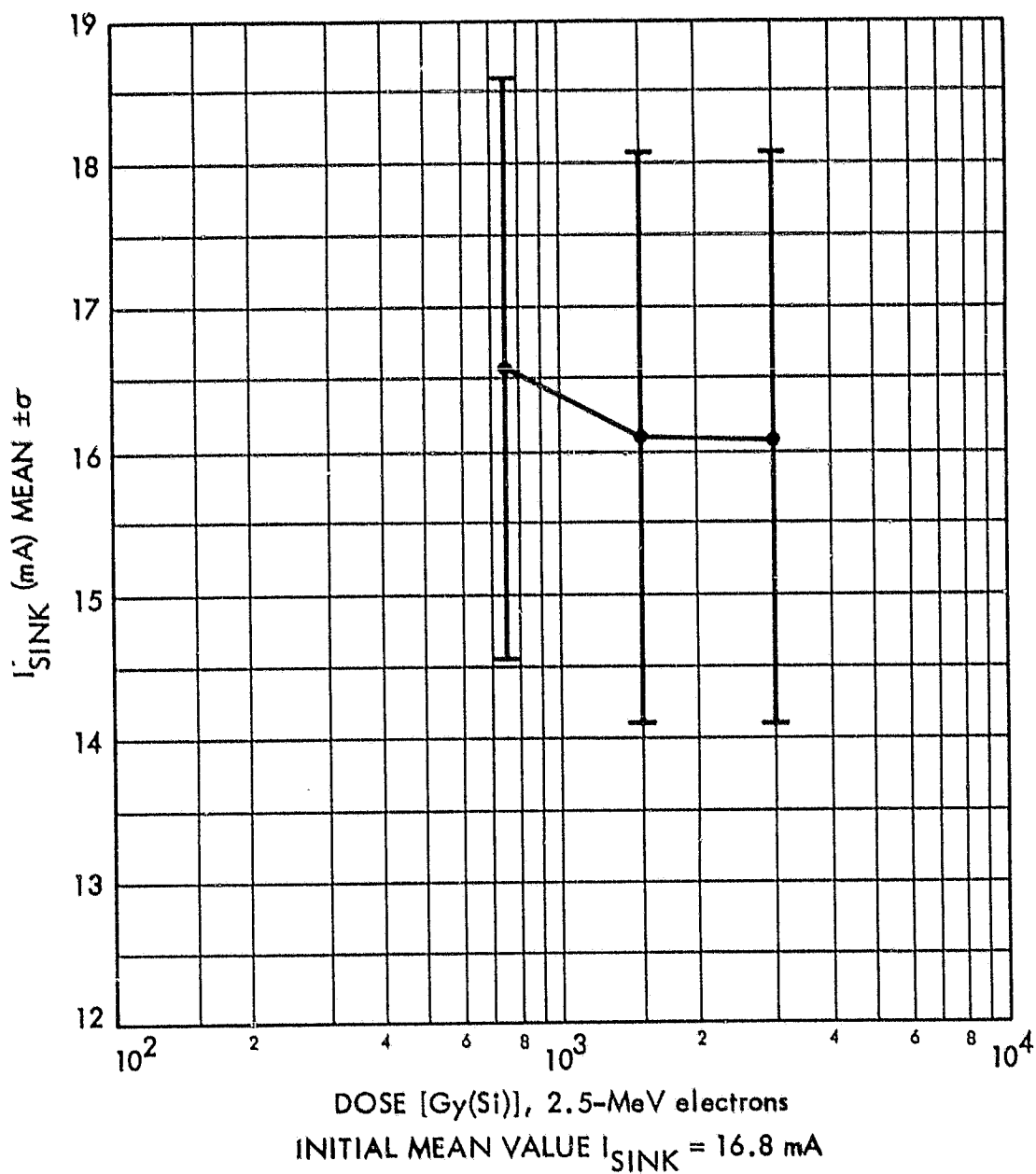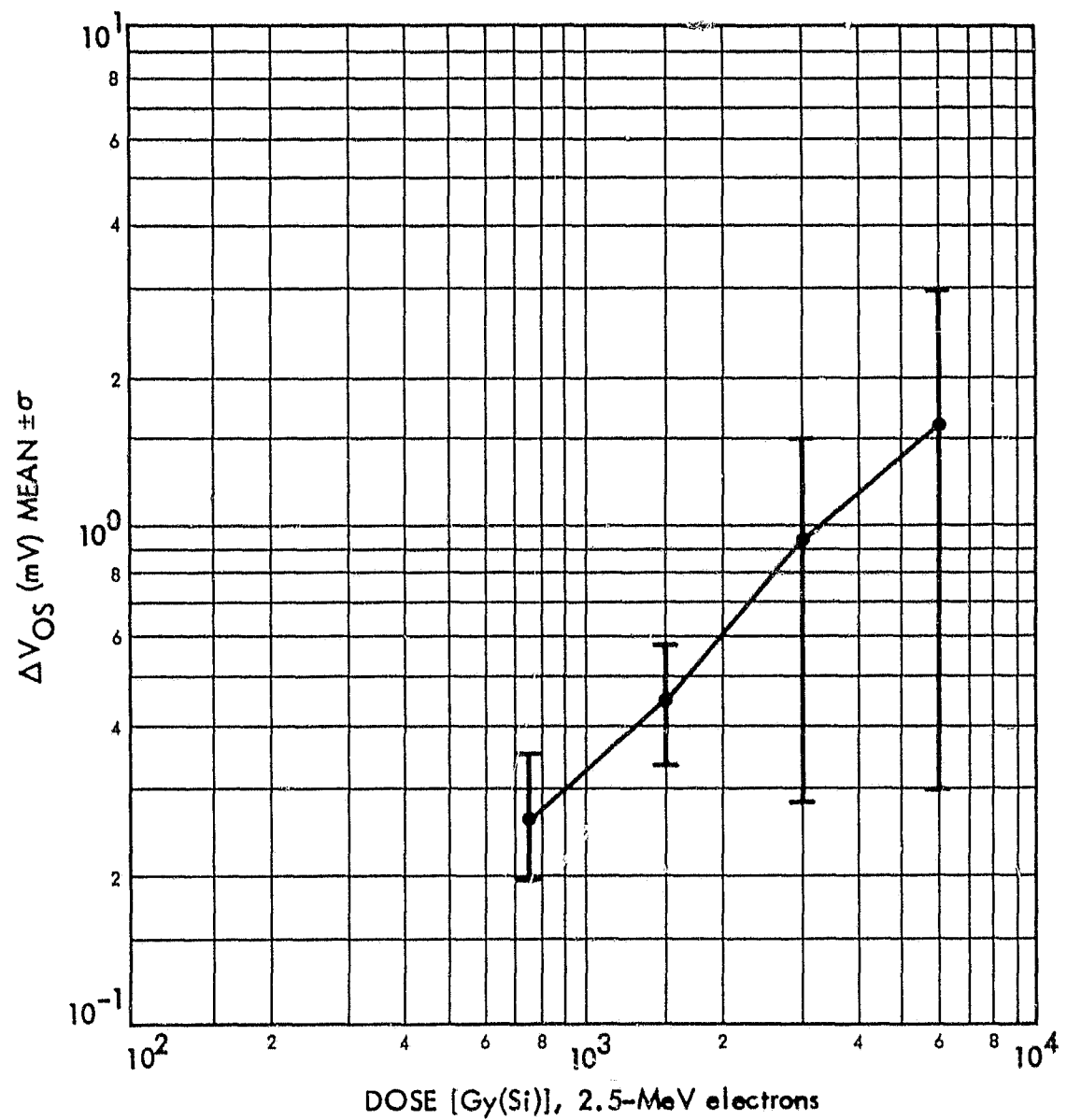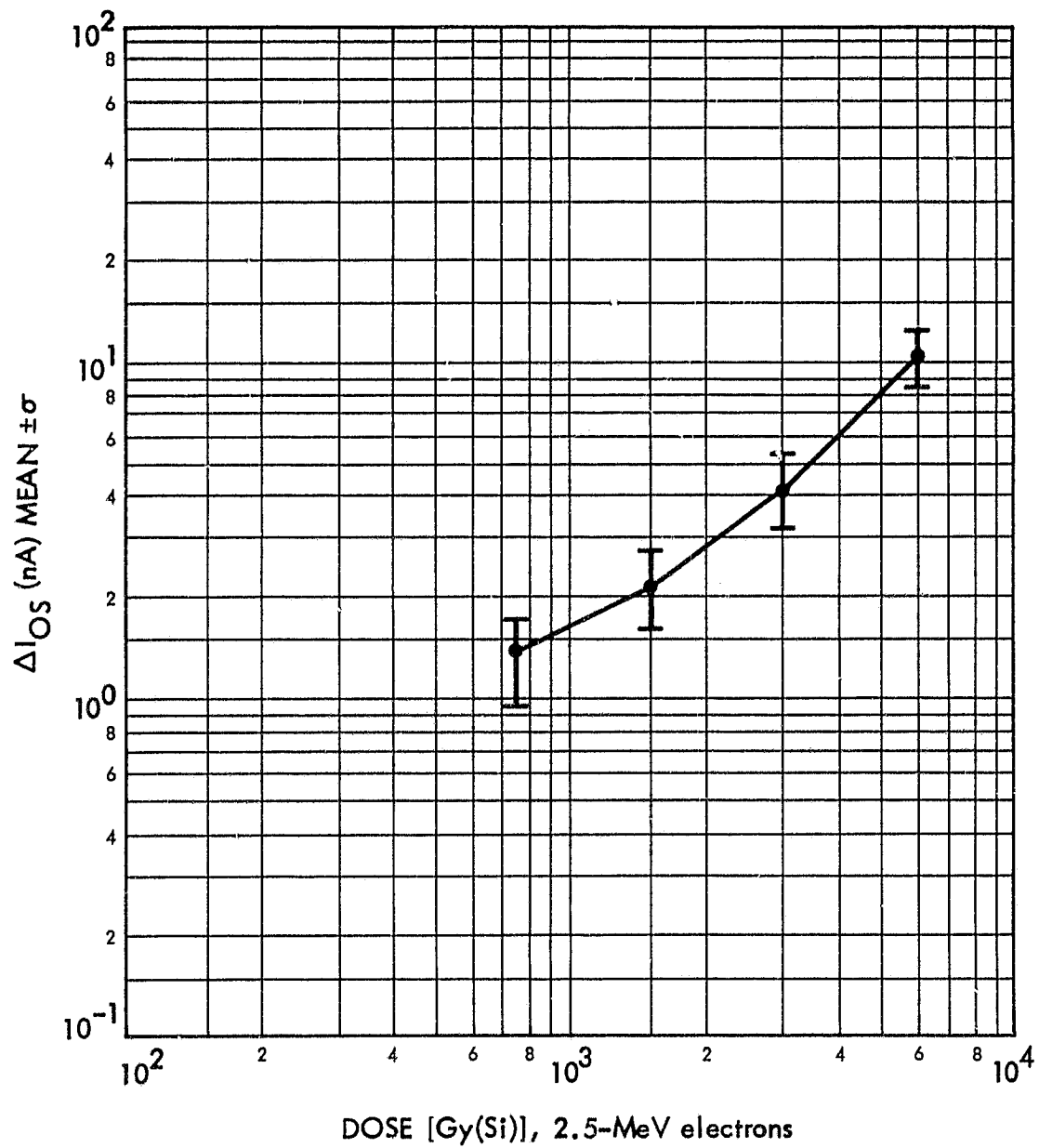
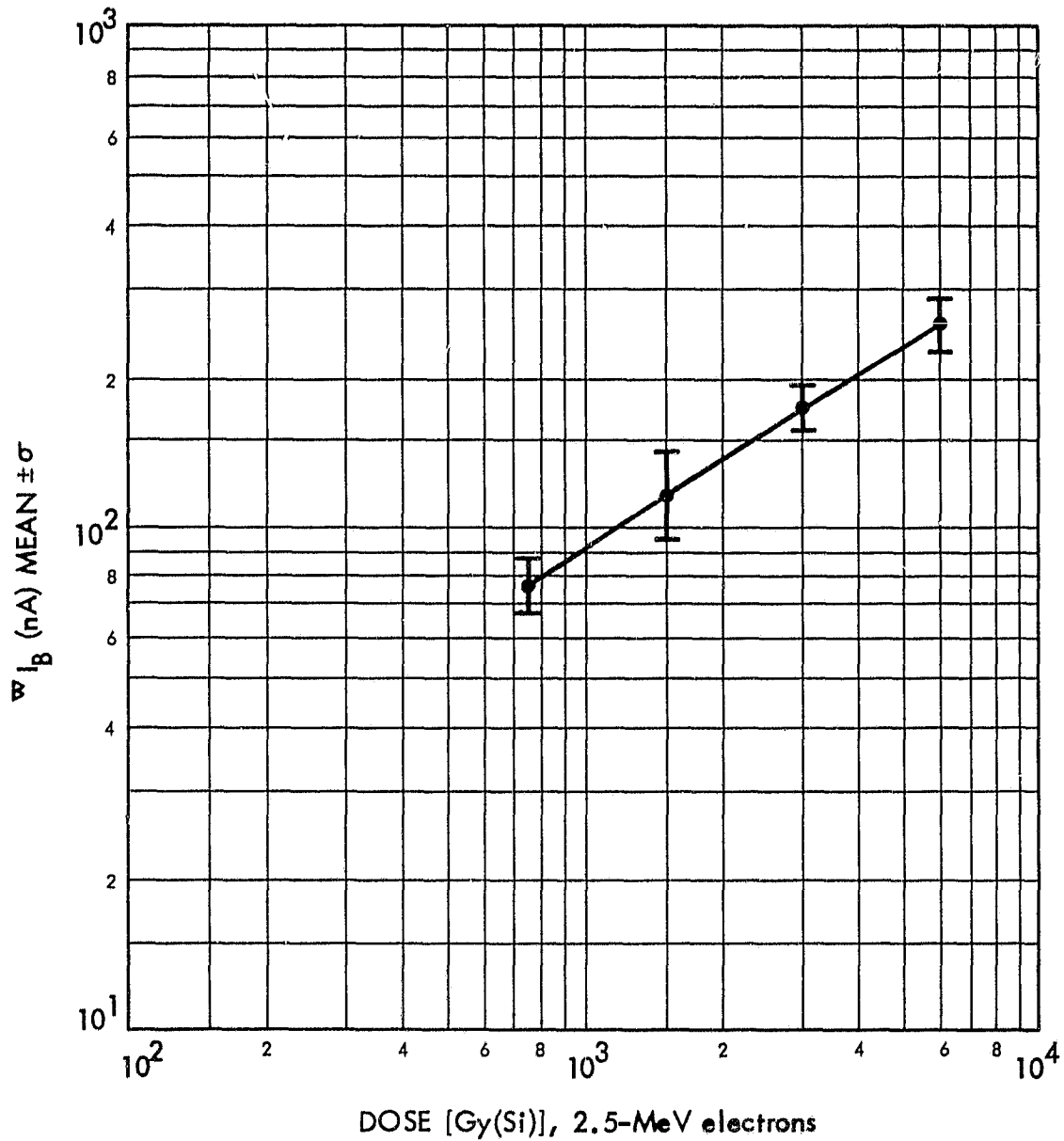MFG: AMD   No. OF COMBINED TESTS: 12

No. OF DEVICES: 48

DOSE [Gy(Si)], 2.5-MeV electrons

INITIAL MEAN VALUE I_{SINK} = 15.8 mA

B.   COMPARISON OF RADIATION SENSITIVITITES OF DEVICES OF A GIVEN TYPE AND
      DIFFERENT MANUFACTURERS

The analysis in this section compares the total-dose radiation
sensitivitites of devices of a given type and of different manufacture when
exposed to the same test conditions. This comparison is made by plotting the
sensitivitites on the same graph. In all cases, the data available were
enough to compare the devices of a given type from only two different
manufacturers.

This analysis is intended to point out the range of sensitivitites to
total-dose radiation. Sensitivity to radiation is a close function of the
manufacturing processes. Minor changes in a process can have major effects on
the sensitivity; therefore, it is imperative to test samples from the
manufacturers periodically.

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS

DEVICE TYPE: 2N918 NPN LOW-POWER TRANSISTOR

$I_C = 10 \ \mu A$ $V_{CE} = 5 \ V$

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
MOT	6	7/20/79	7925	▲
FAS	4	4/25/80	7840	●
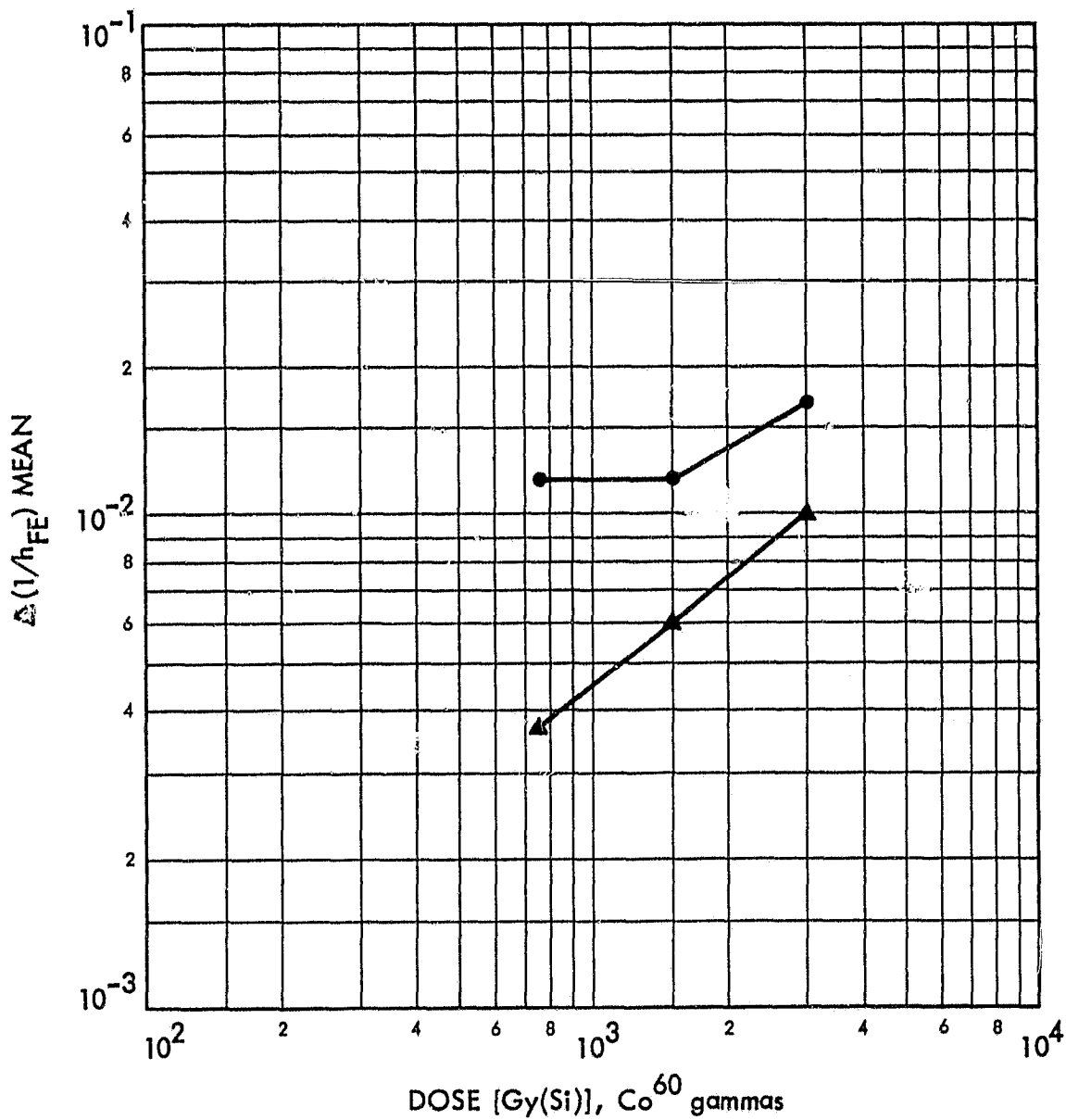
Y-axis: $\Delta (1/h_{FE})$ MEAN

X-axis: DOSE [Gy(Si)], Co^{60} gammas

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS
DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR

$I_C = 0.1$ mA $V_{CE} = 20$ V

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
TIX	4	5/4/79	7917A	▲
FAS	3	3/4/80	7939	●
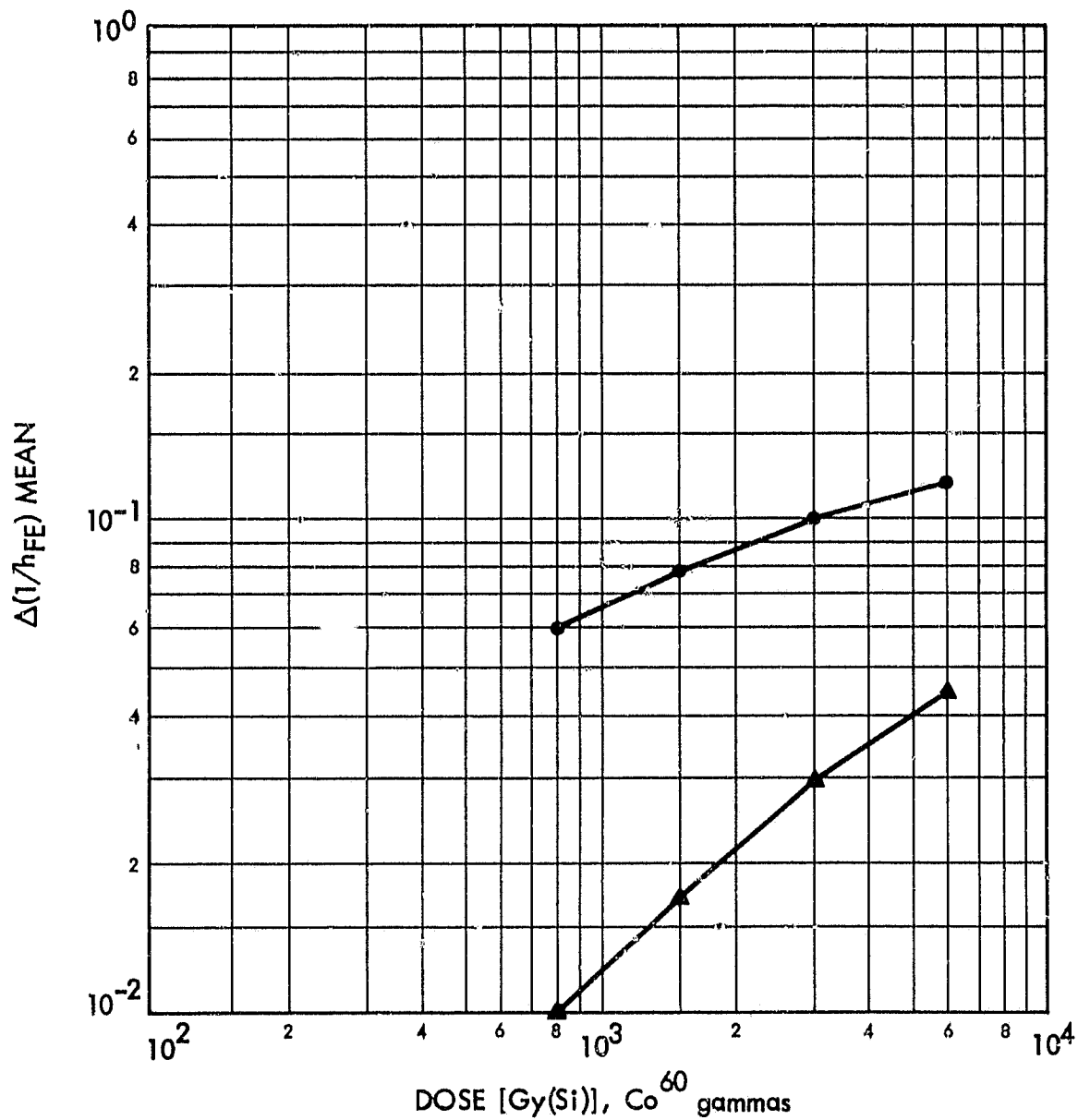
DOSE [Gy(Si)], Co^{60} gammas

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS

DEVICE TYPE: 2N2905 PNP LOW-POWER TRANSISTOR

$I_C = 0.1$ mA $V_{CE} = 20$ V

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
TIX	4	1/17/79	NONE	▲
RAY	8	7/2/80	7737	●
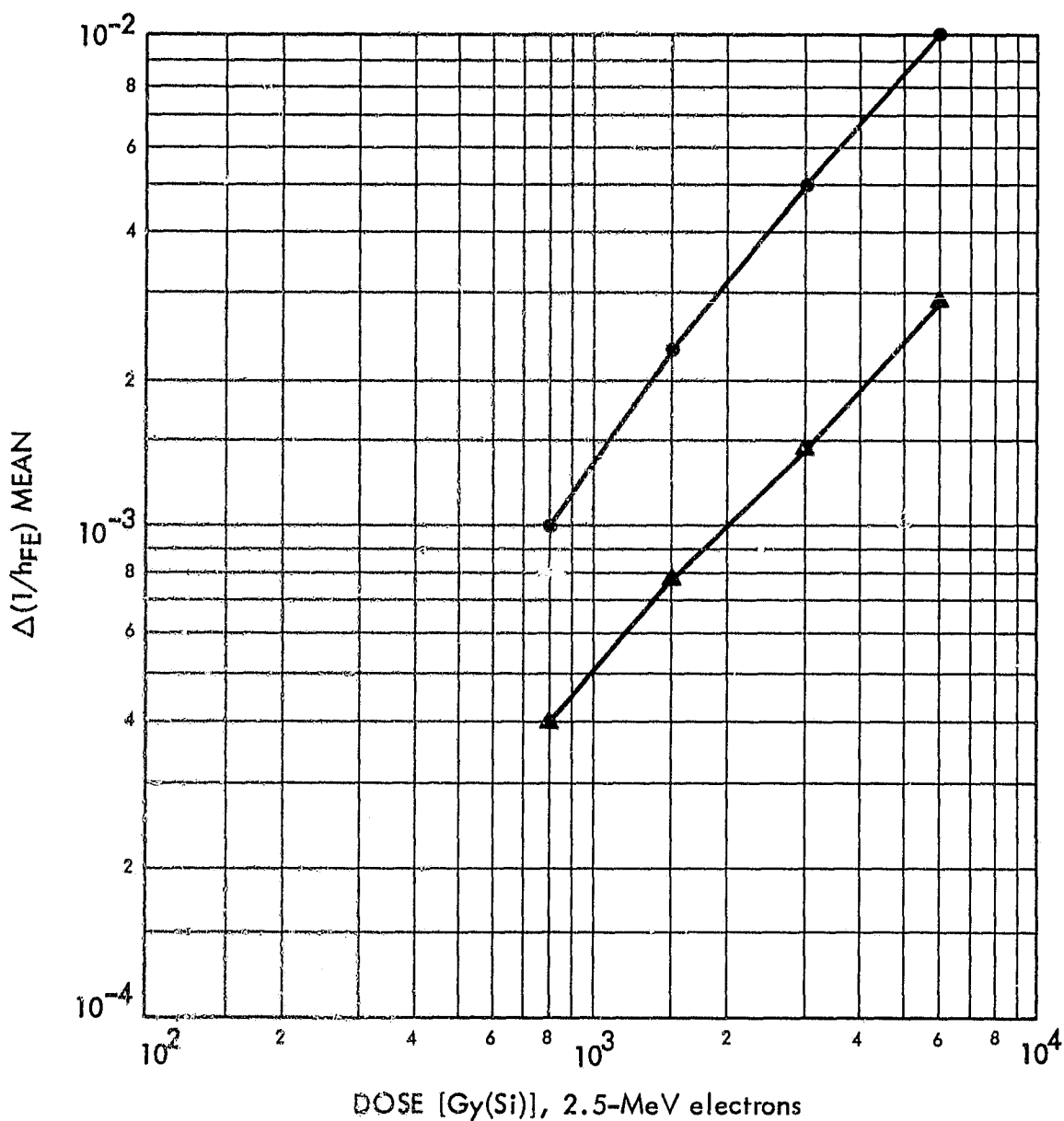
$\Delta(1/h_{FE})$ MEAN

DOSE [Gy(Si)], 2.5-MeV electrons

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR

$I_C = 0.1$ mA $V_{CE} = 20$ V

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
TIX	4	2/15/79	NONE	▲
FAS	3	4/10/80	7925	●

DOSE [Gy(Si)], 2.5-MeV electrons

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RADIATION SENSITIVITIES BETWEEN MANUFACTURERS
DEVICE TYPE: LM 108 OPERATIONAL AMPLIFIER

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
AMD	5	5/10/79	NONE	●
PMI	5	9/12/79	7710/773	▲

DOSE [Gy(Si)], 2.5-MeV electrons

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS
DEVICE TYPE: LM 108 OPERATIONAL AMPLIFIER

MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
AMD	5	5/10/79	NONE	●
PMI	5	9/12/79	7710/773	▲

DOSE [Gy(Si)], 2.5–MeV electrons

RADIATION SENSITIVITIES BETWEEN MANUFACTURERS
DEVICE TYPE: LM 108 OPERATIONAL AMPLIFIER

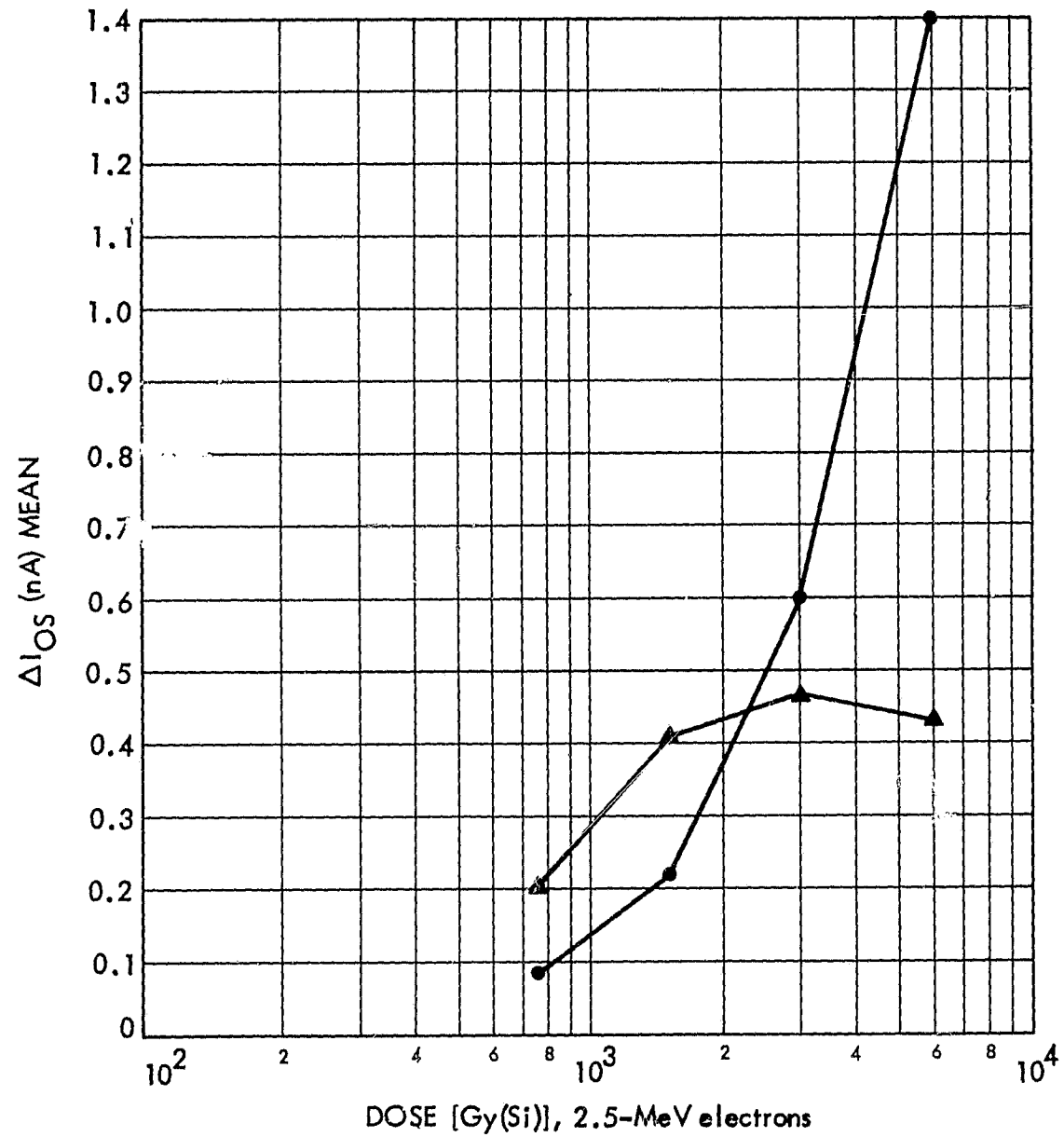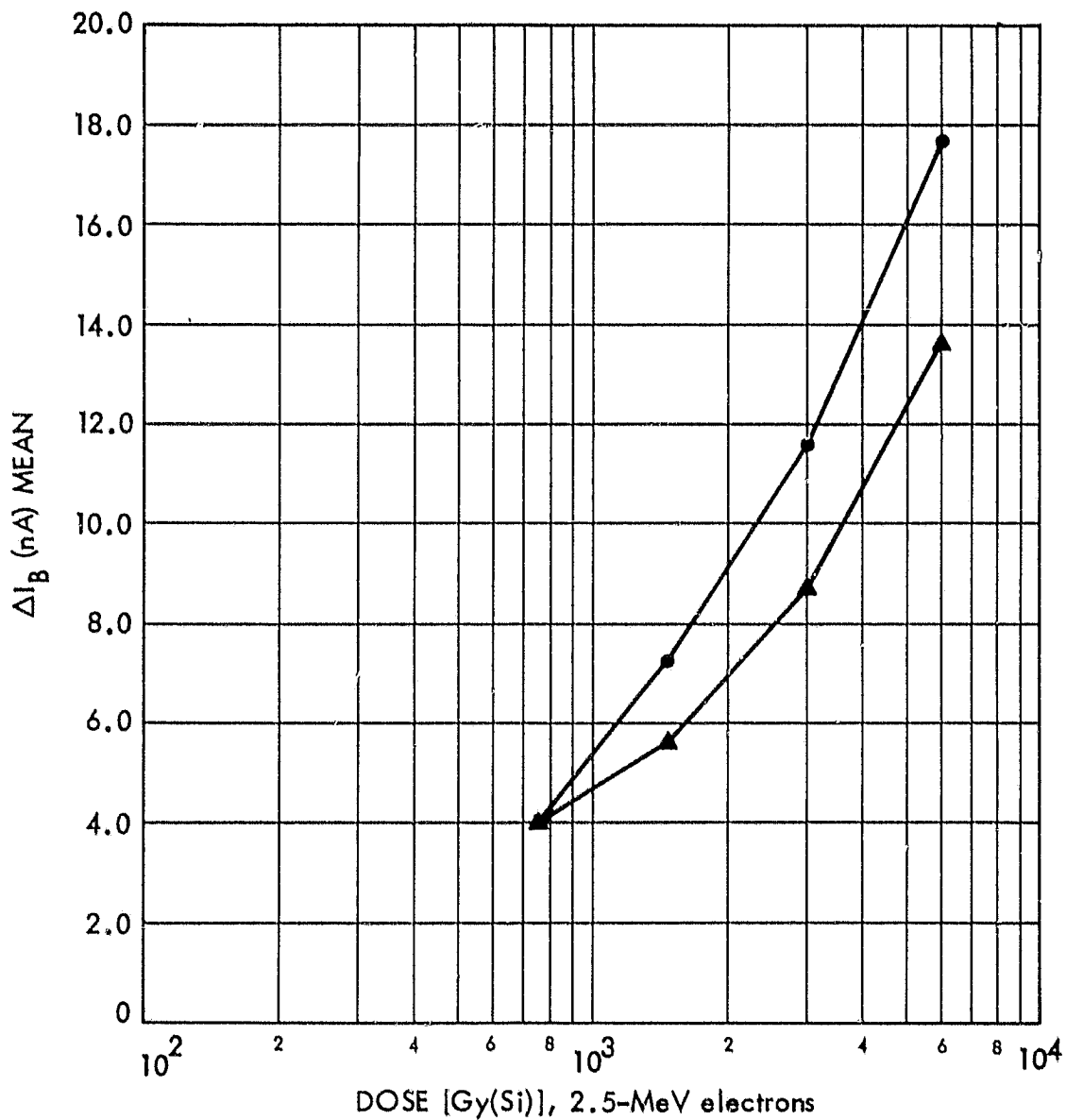| MFG	No. OF DEVICES	TEST DATE	DATE CODE	SYMBOL
AMD	5	5/10/79	NONE	●
PMI	5	9/12/79	7710/773	▲

DOSE [Gy(Si)], 2.5-MeV electrons

C.   COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

The purpose of the analysis in this section is to show the variability of data from many different tests, where the devices all have the same date code. As the device type, manufacturer, test conditions, and date codes are all the same for the data on a given graph, the difference in the radiation sensitivity between the data plots is due to variability within the manufacturer's lot. Each curve on the graph represents the results of a separate test. The range of test dates are included in the heading for each graph.

To indicate the variability of the data presented by the curves, the range of the one-sigma values is shown (i.e., the one-sigma values are bounded by upper and lower bars on the vertical lines). These bars are shown only at the highest and lowest dose values.

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 20$ V

DATE CODE: 7917A   TEST DATES: 5/4/79 TO 5/9/79

DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR
MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 20$ V
DATE CODE: 7917A   TEST DATES: 5/4/79 TO 5/9/79

DOSE [Gy(Si)], 2.5-MeV electrons
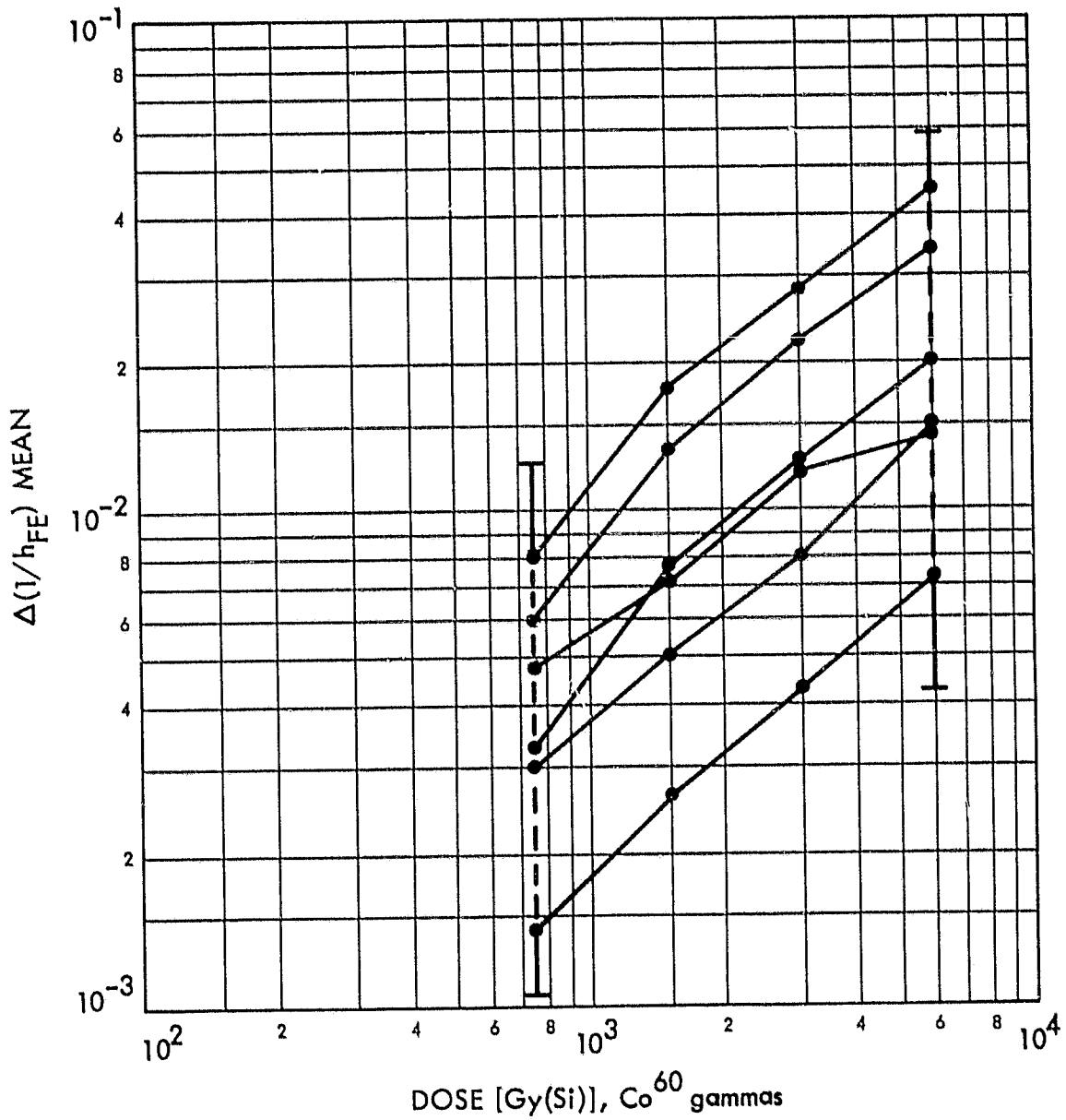
COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2432 NPN LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 10$ V

DATE CODE: 8102   TEST DATES: 3/18/81 TO 3/31/81

DOSE [Gy(Si)], Co^{60} gammas

Y-axis: $\Delta(1/h_{FE})$ MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2432 NPN LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 10$ V

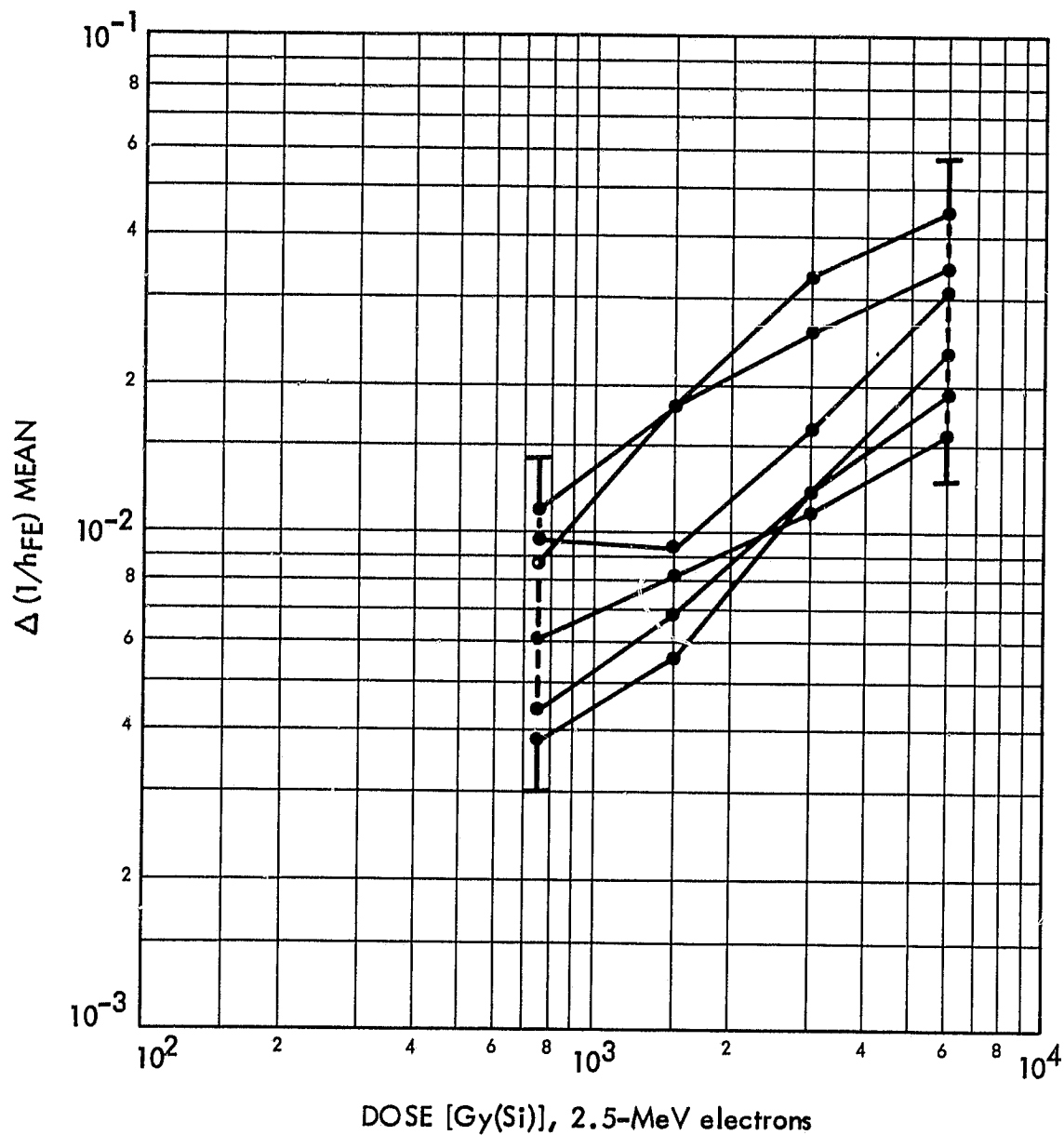DATE CODE: 8102   TEST DATE: 3/31/81

DOSE [Gy(Si)], 2.5-MeV electrons

y-axis: $\Delta(1/h_{FE})$ MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2905 PNP LOW-POWER TRANSISTOR

MFG: RAY   TEST CONDITIONS: I_C = 0.1 mA, V_{CE} = 20 V

DATE CODE: 7737   TEST DATES: 7/2/80 TO 7/20/80

DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2905 PNP LOW-POWER TRANSISTOR

MFG: RAY   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 20$ V
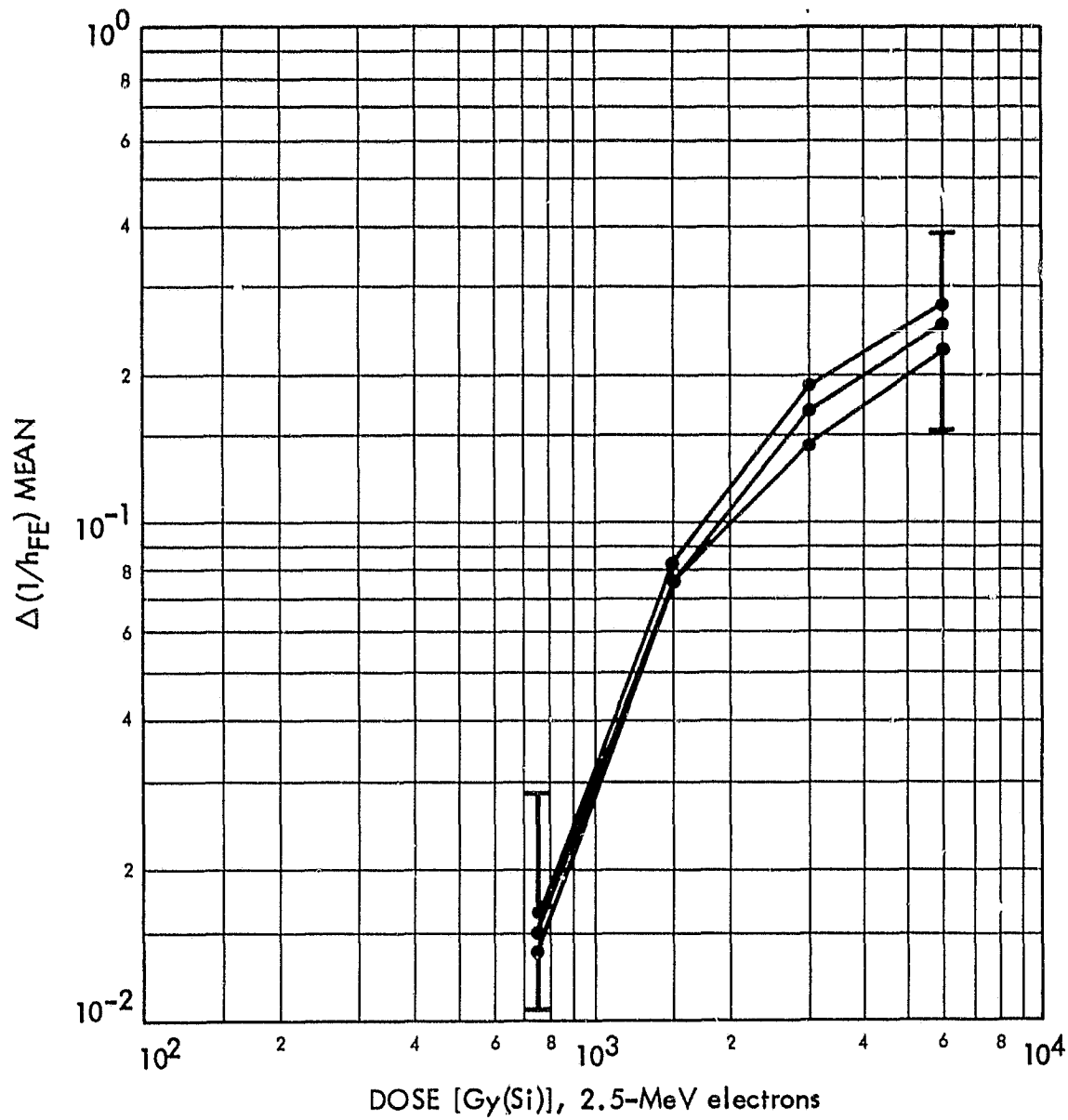
DATE CODE: 7737   TEST DATE: 7/8/80

DOSE [Gy(Si)], 2.5-MeV electrons
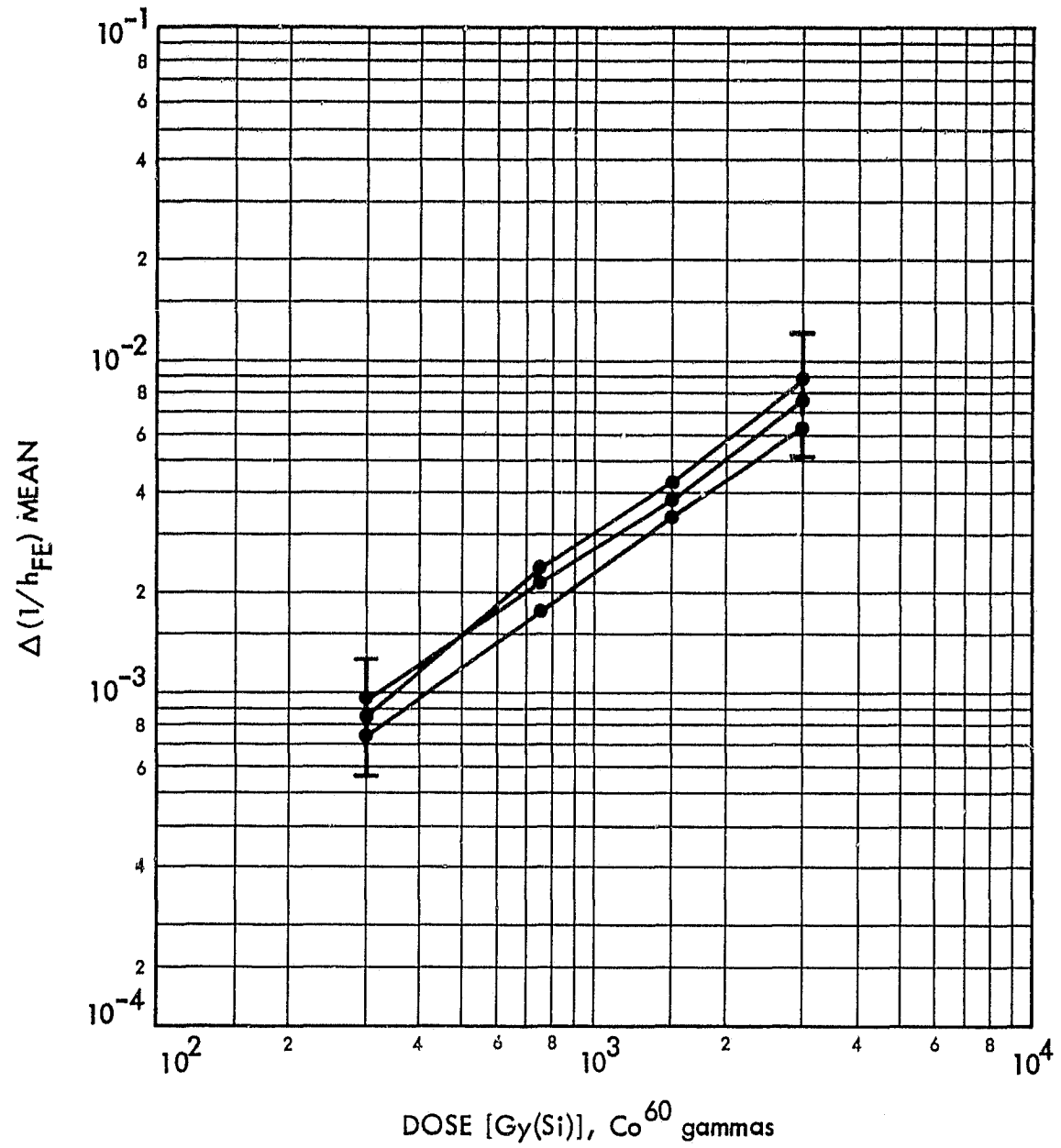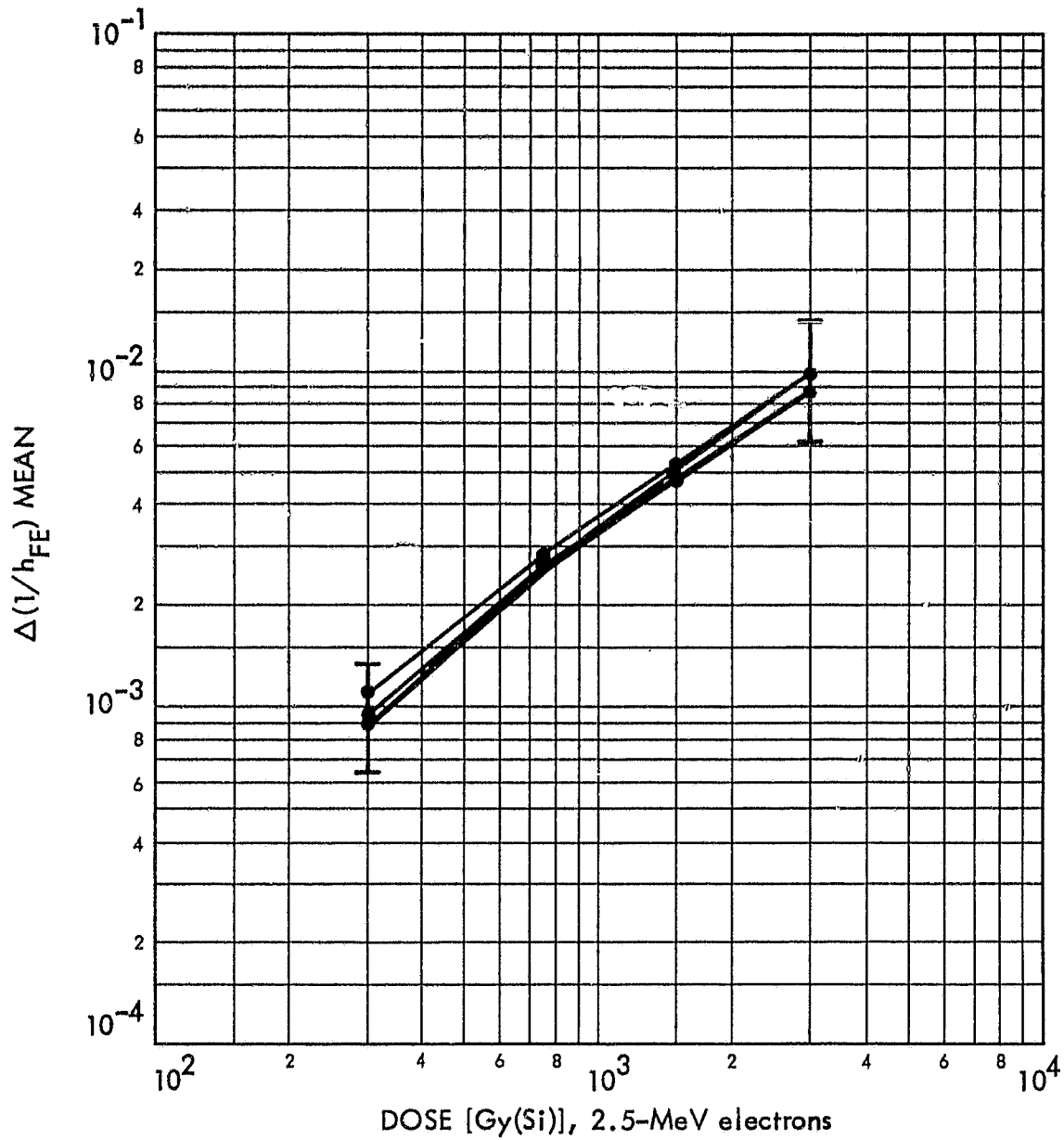
COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $V_{CB} = 40$ V

DATE CODE: 7522A   TEST DATE: 12/10/79

I_{CBO} (nA) MEAN

DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N3350 PNP LOW-POWER TRANSISTOR
MFG: TIX   TEST CONDITIONS: $I_C = 0.01$ mA, $V_{CE} = 0.5$ V
DATE CODE: 7834A   TEST DATE: 4/9/80

DOSE [Gy(Si)], Co^{60} gammas
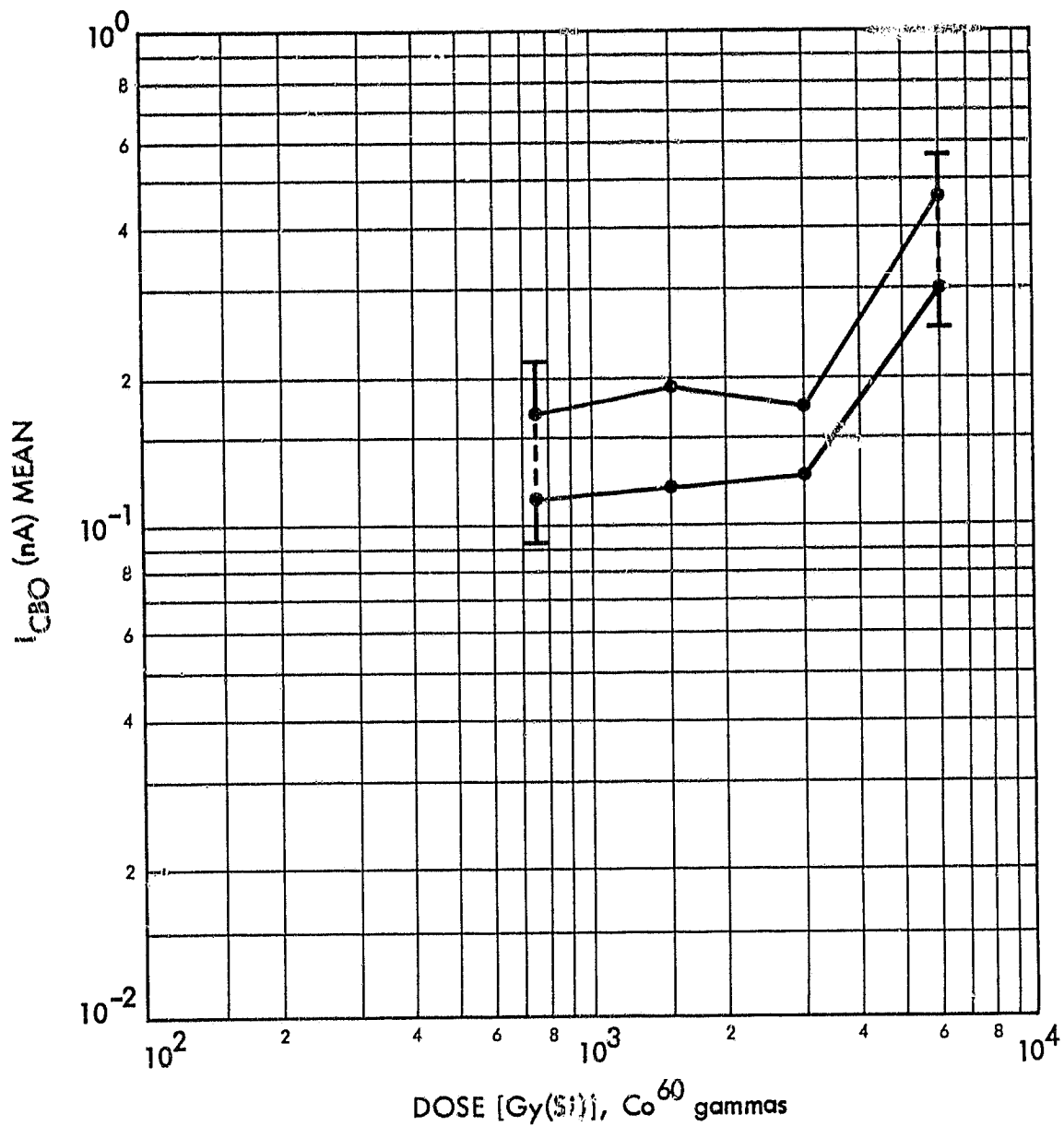
COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N3350 PNP LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $I_C = 0.01$ mA, $V_{CE} = 0.5$ V

DATE CODE: 7834A   TEST DATE: 4/15/80

DOSE [Gy(Si)], 2.5-MeV electrons

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N3350 PNP LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $V_{CE} = 20$ V

DATE CODE: 7935   TEST DATE: 11/7/79

DOSE [Gy(Si)], Co^{60} gammas

I_{CBO} (nA) MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N3700 NPN LOW-POWER TRANSISTOR
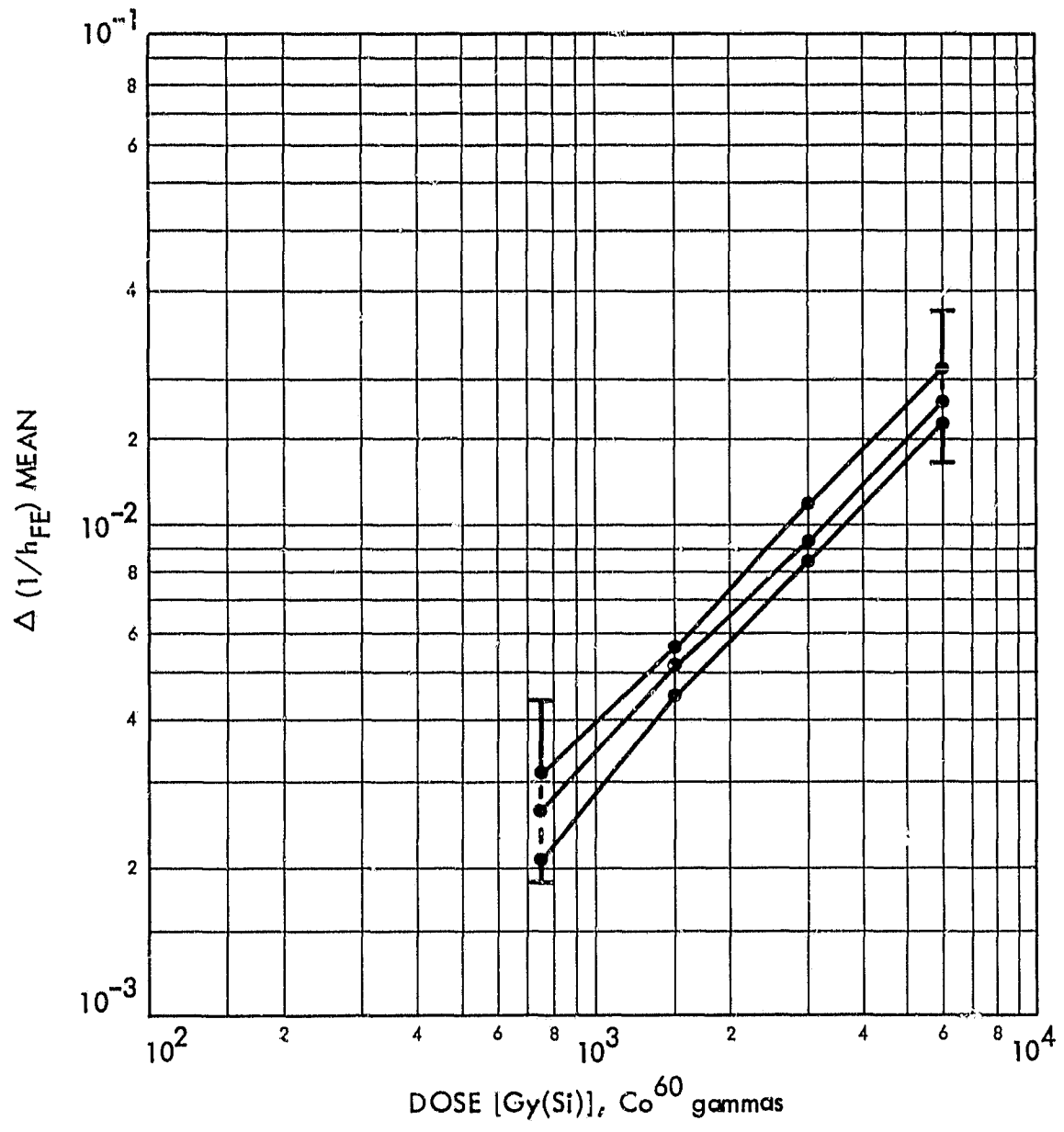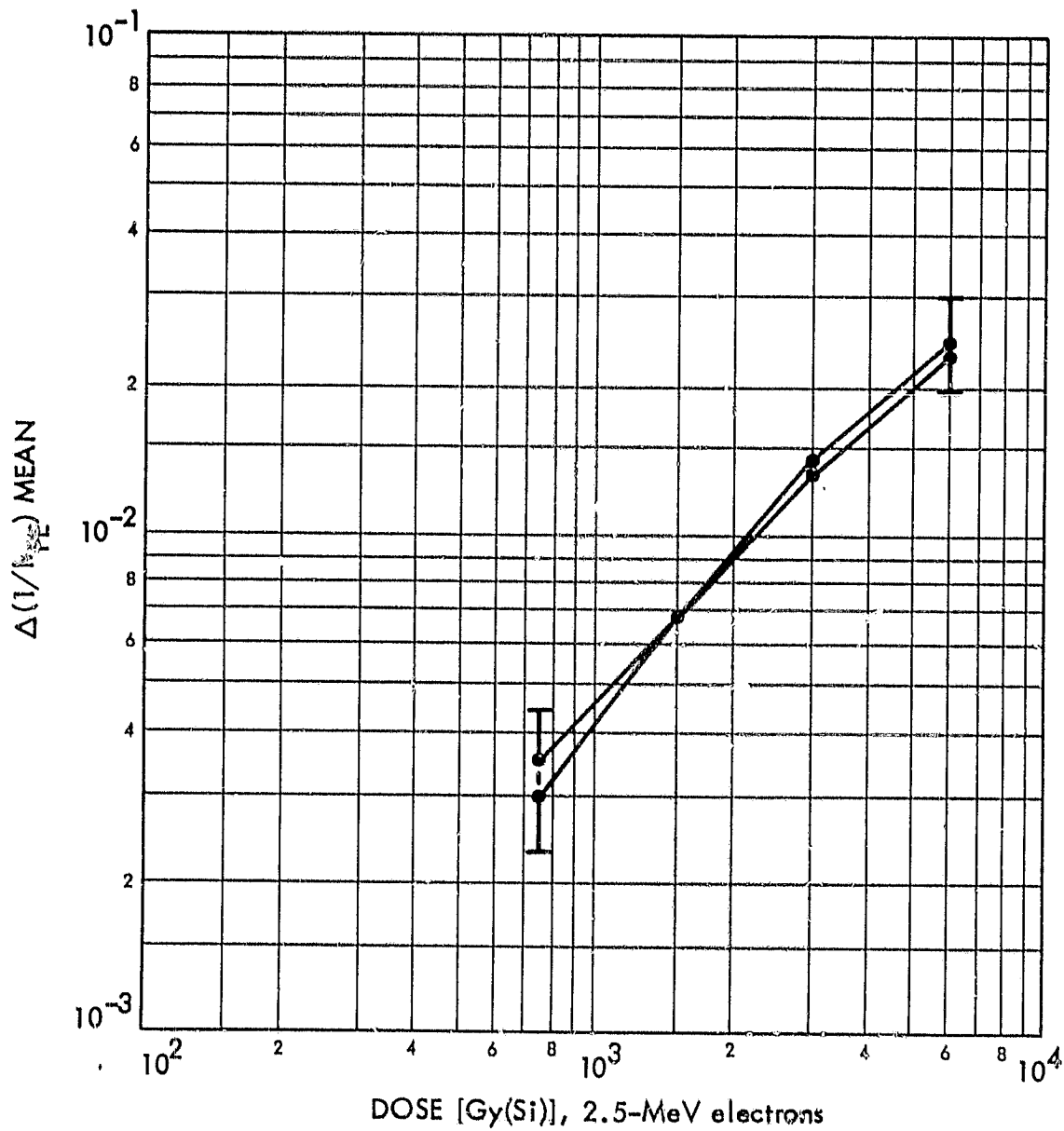
MFG: TIX   TEST CONDITIONS: $I_C = 1.0$ mA, $V_{CE} = 20$ V
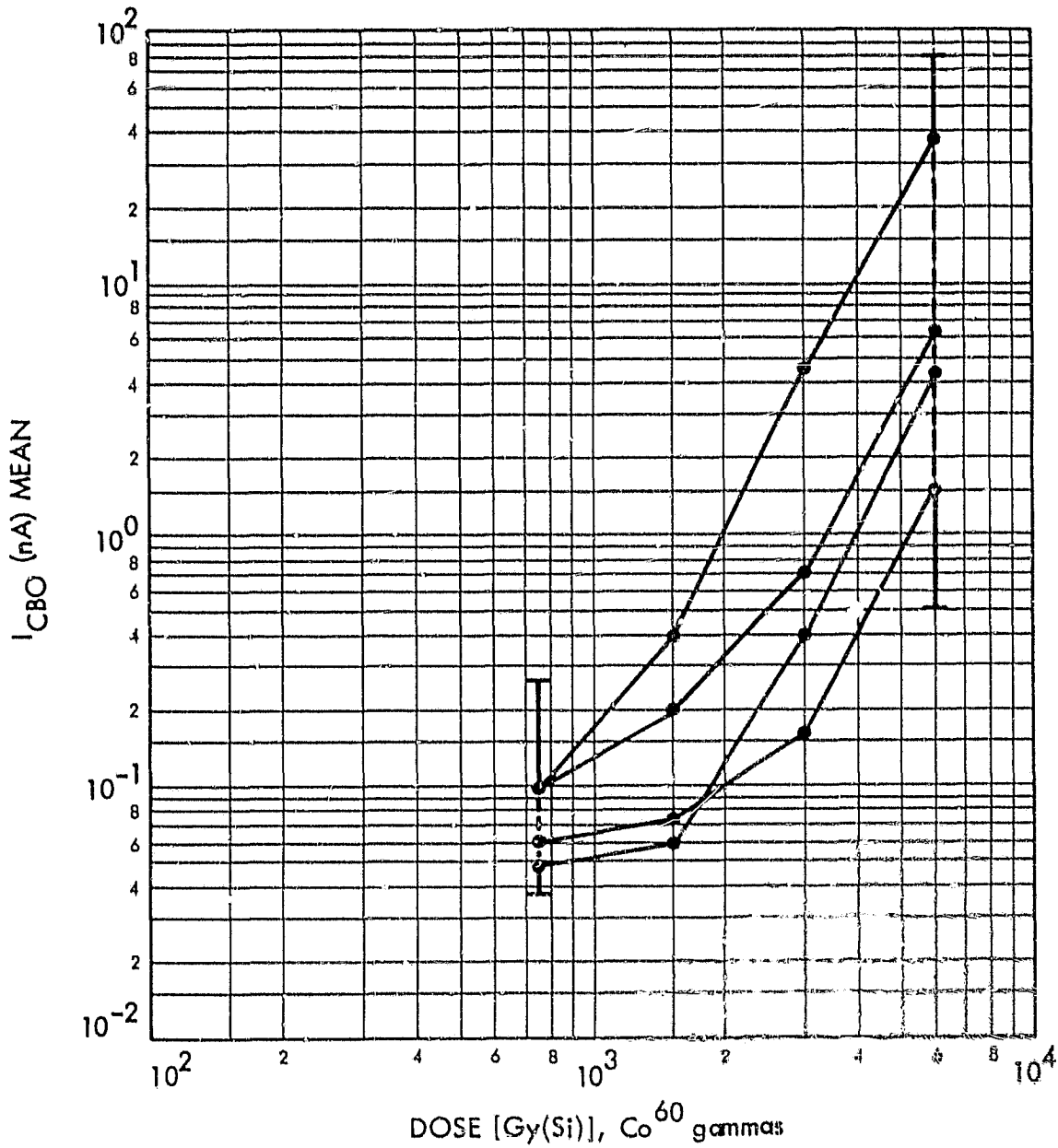
DATE CODE: 7920A   TEST DATE: 6/11/79
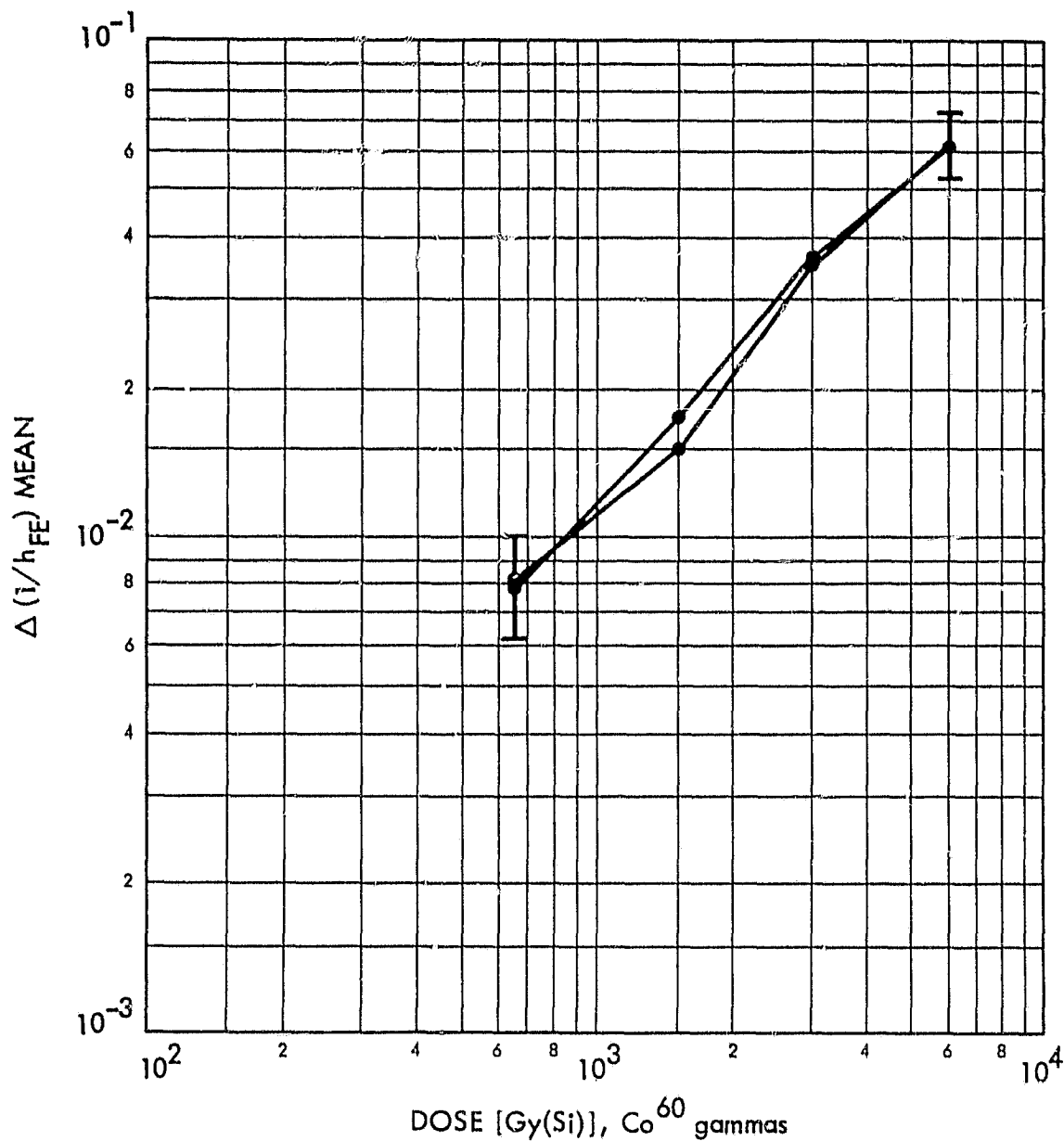
Y-axis: $\Delta (i/h_{FE})$ MEAN

X-axis: DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET

MFG: SIL   TEST CONDITIONS: $V_{GS} = 10$ V, $V_{DS} = 0$

DATE CODE: 7947   TEST DATE: 2/22/80

DOSE [Gy(Si)], Co^{60} gammas

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COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: 2N6483 DUAL N-CHANNEL FET
MFG: INL   TEST CONDITIONS: $V_{DS} = 10$ V, $V_{DS} = 0$
DATE CODE: 7915   TEST DATE: 6/19/79

DOSE [Gy(Si)], Co^{60} gammas

I_{GSS} (nA) MEAN
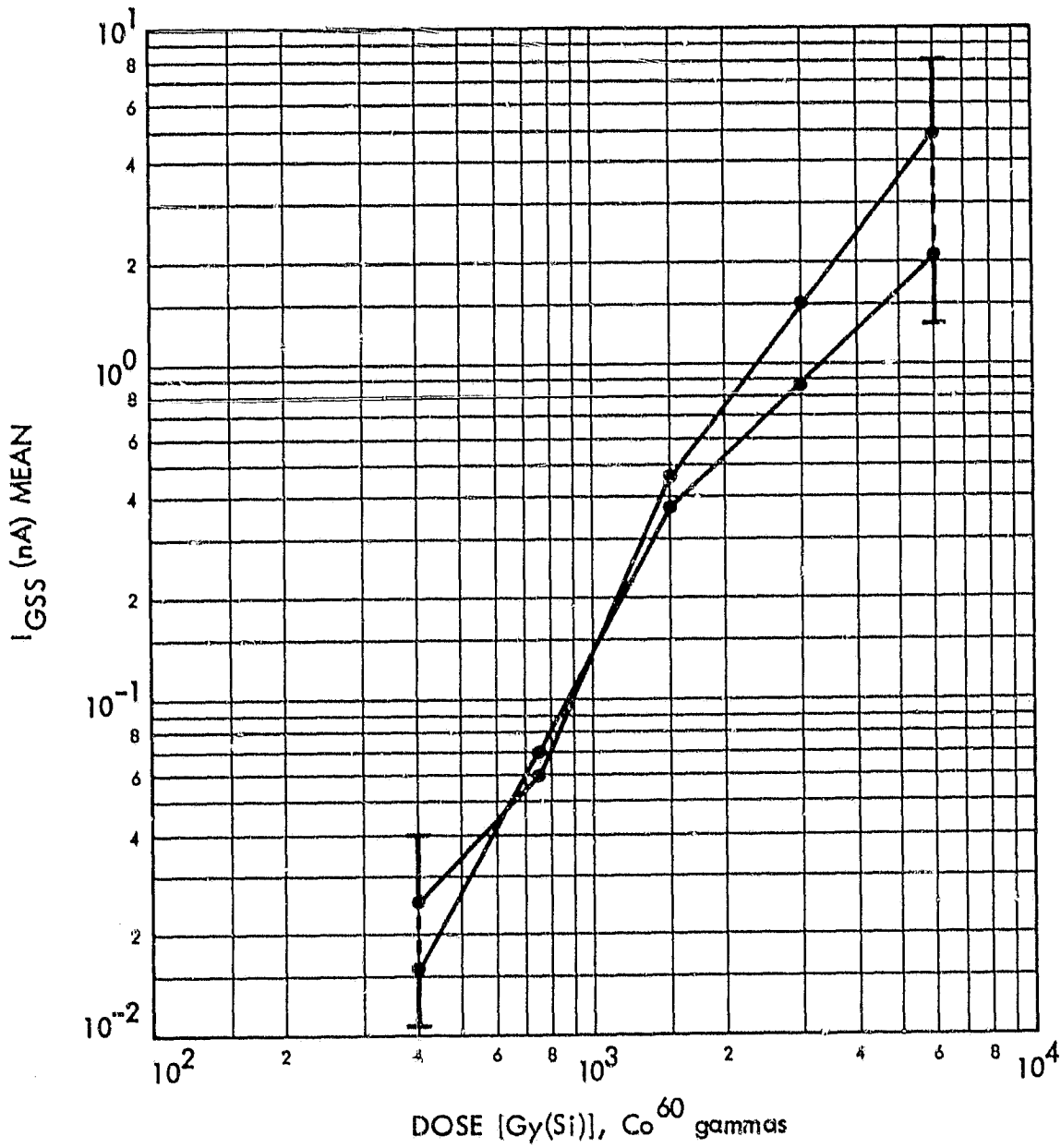
COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: MQ2219 QUAD NPN TRANSISTOR

MFG: MOT   TEST CONDITIONS: $I_C = 2.0$ mA, $V_{CE} = 0.1$ V

DATE CODE: 7940   TEST DATE: 11/16/79

DOSE [Gy(Si)], Co^{60} gammas

y-axis: $\Delta (1/h_{FE})$ MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: MQ2905 QUAD PNP TRANSISTOR

MFG: MOT   TEST CONDITIONS: $I_C = 2.0$ mA, $V_{CE} = 2.4$ V

DATE CODE: 7938   TEST DATE: 10/26/79
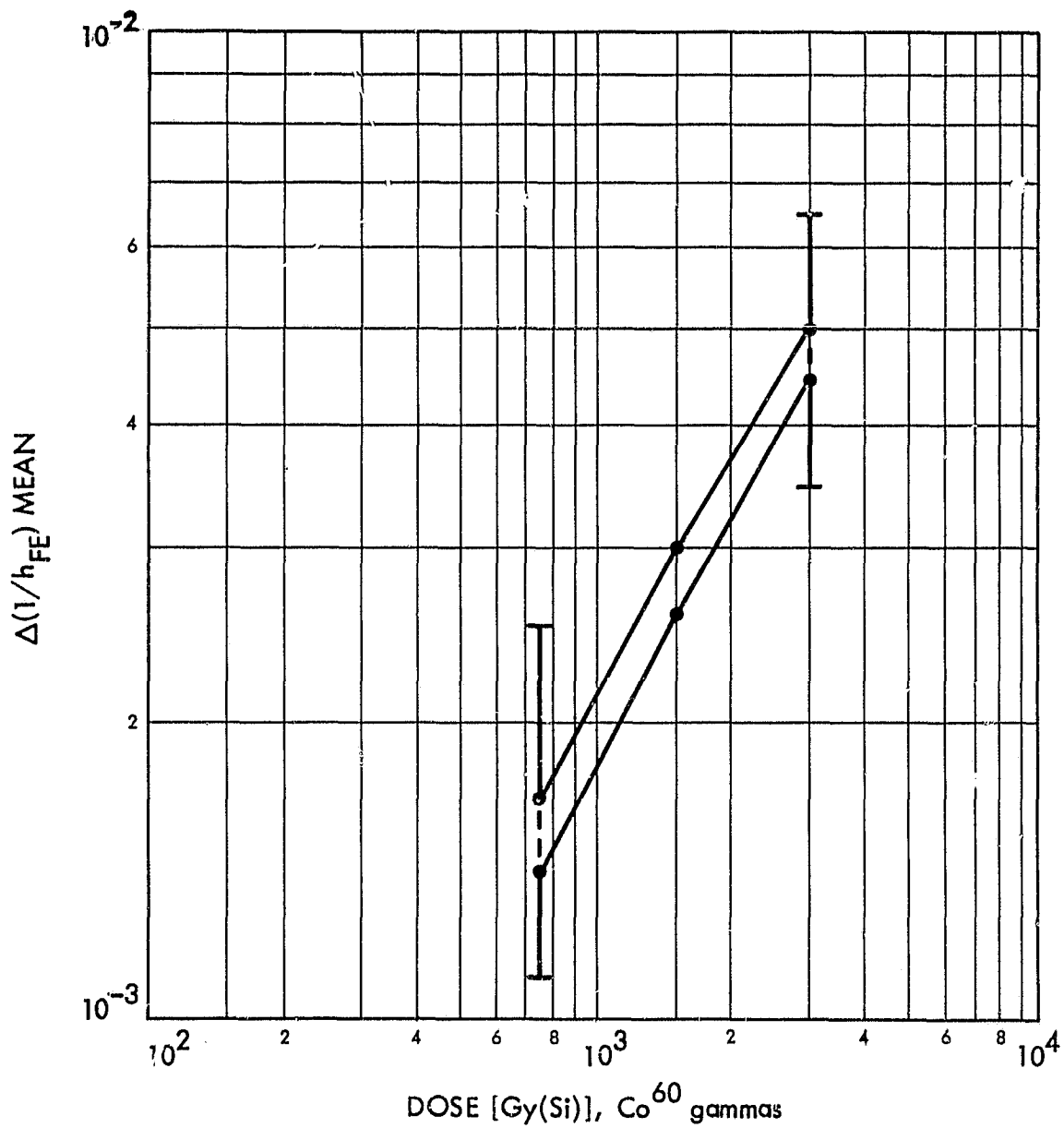
DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: MQ2905 QUAD PNP TRANSISTOR
MFG: MOT   TEST CONDITIONS: $I_C = 2.0$ mA, $V_{CE} = 2.4$ V
DATE CODE: 7951   TEST DATE: 1/23/80
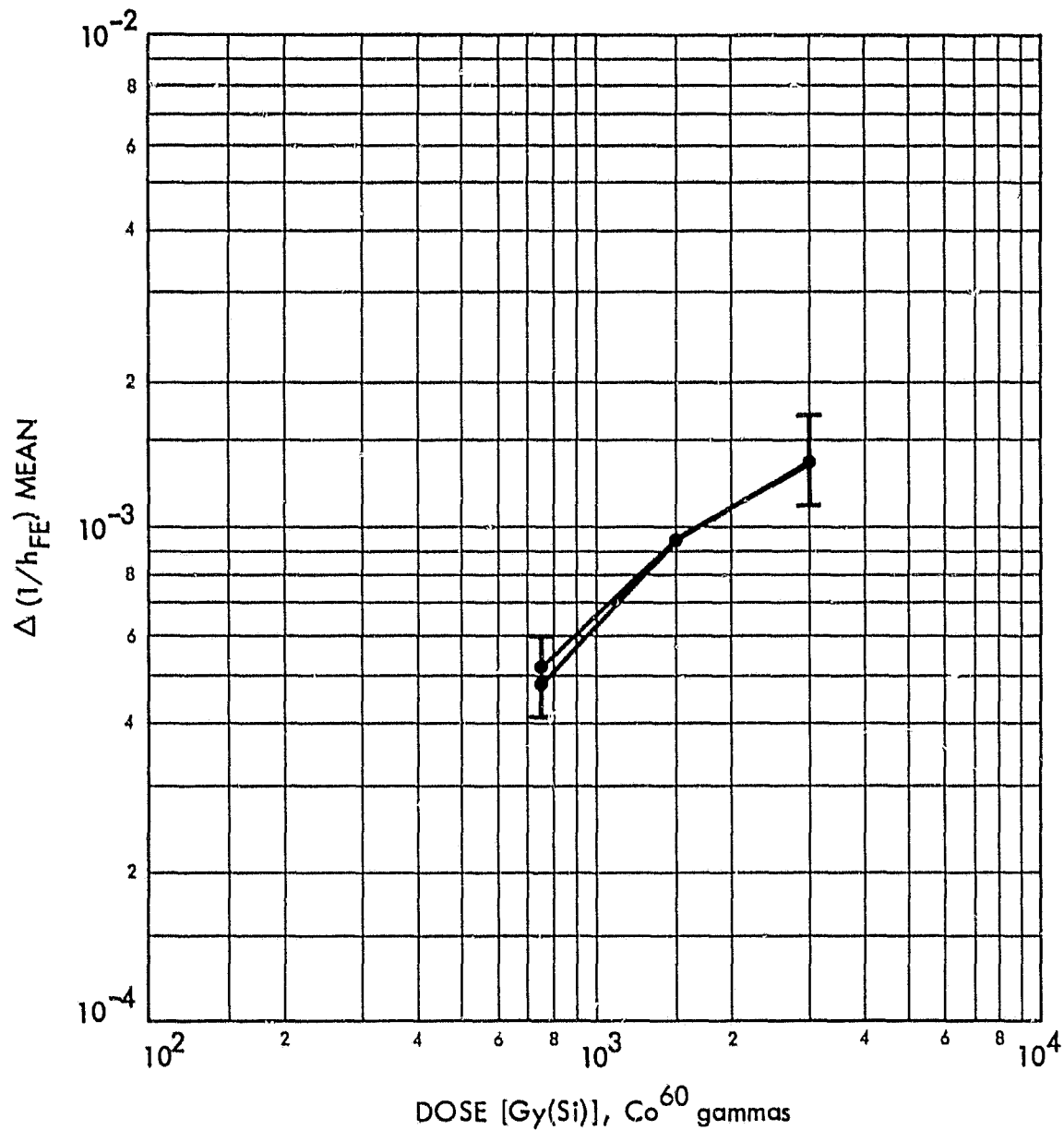
$\Delta (1/h_{FE})$ MEAN vs. DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: U401 DUAL N-CHANNEL FET

MFG: SIL   TEST CONDITIONS: $V_{GS} = 10$ V, $V_{DS} = 0$
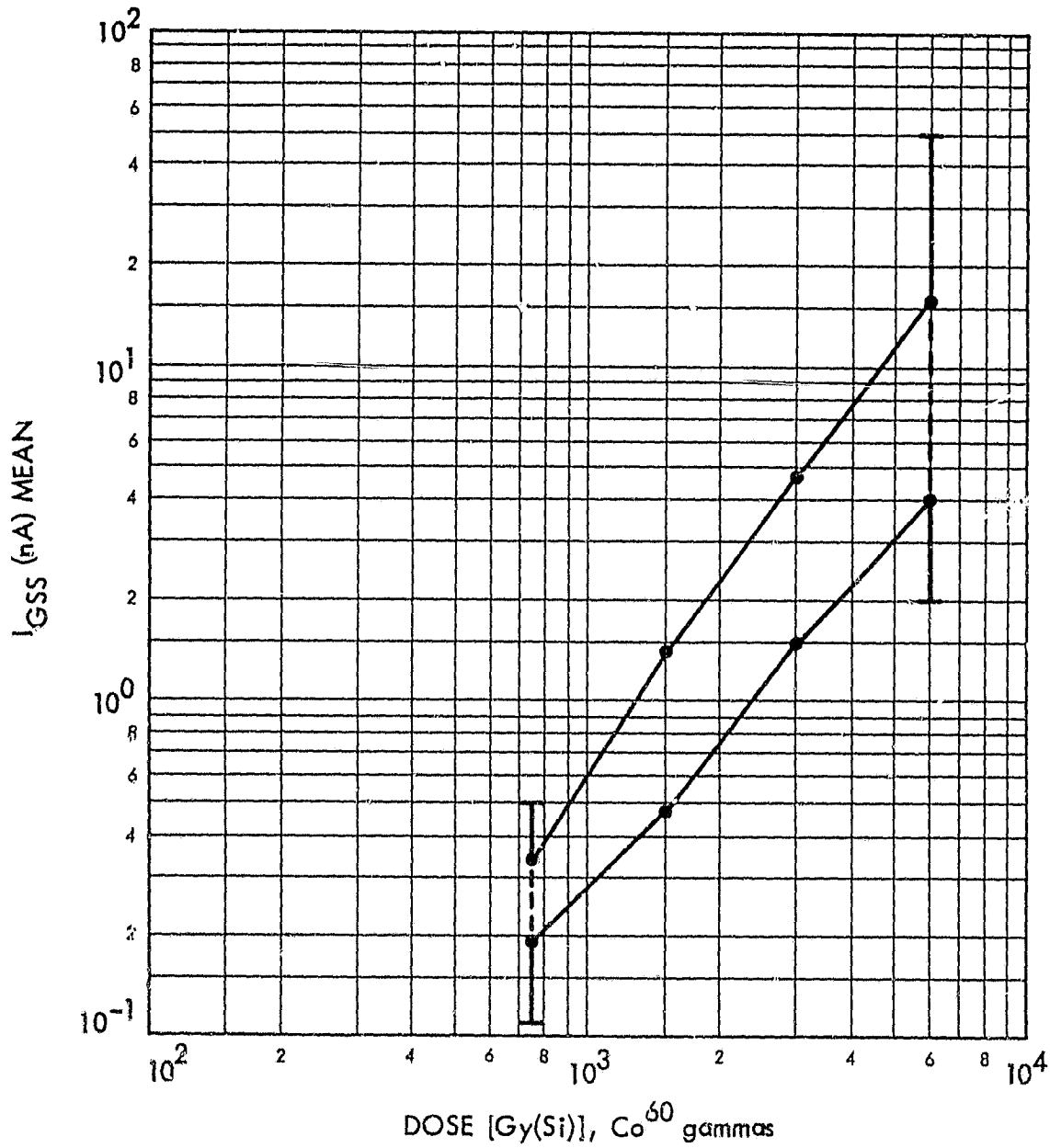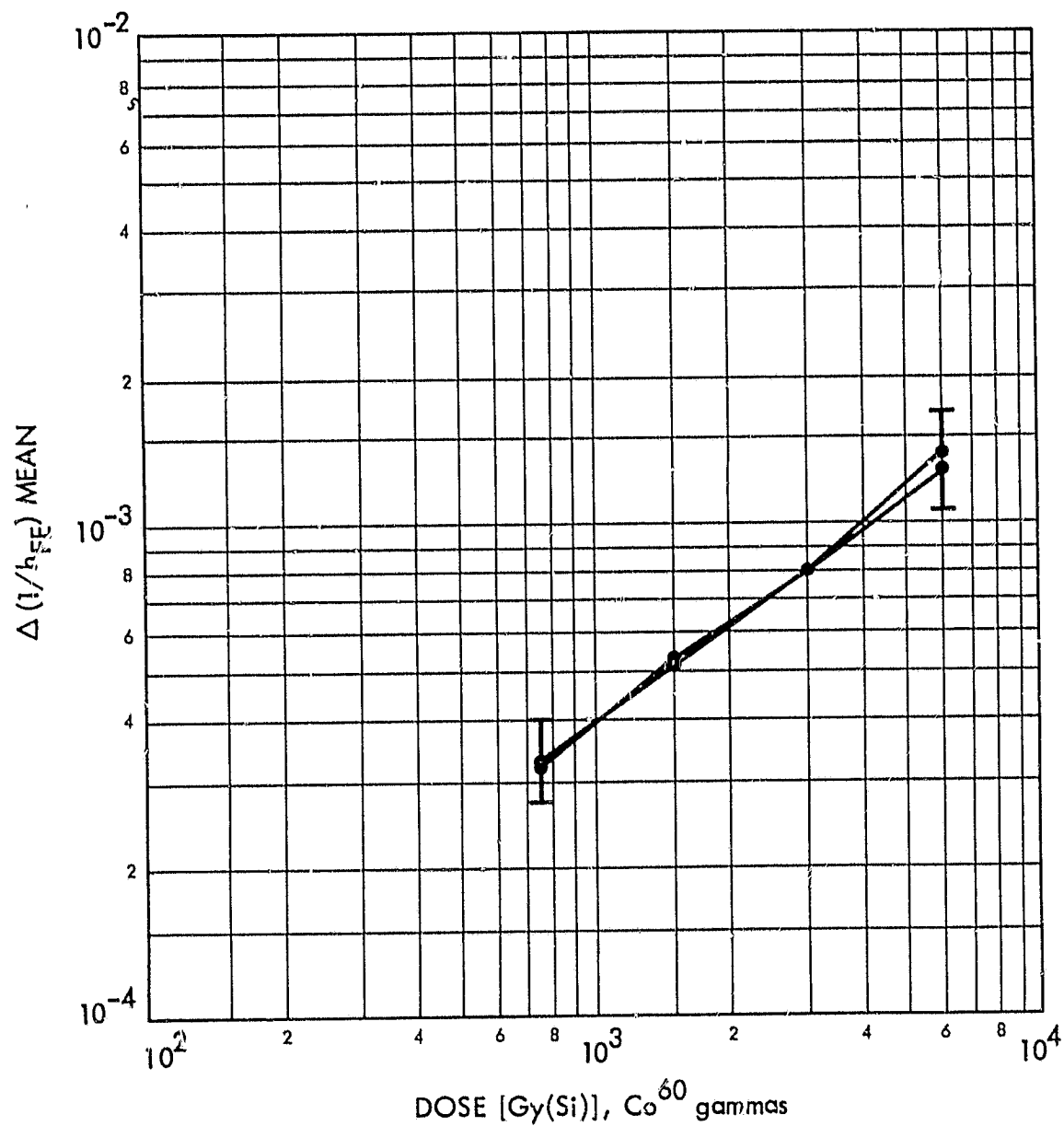
DATE CODE: TEST DATE: 3/6/81

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: LMIII COMPARATOR
MFG: AMD
DATE CODE: 7922   TEST DATE: 10/16/79

DOSE [Gy(Si)], 2.5-MeV electrons

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: LMIII COMPARATOR

MFG: AMD

DATE CODE: 7922   TEST DATE: 10/16/79

DOSE [Gy(Si)], 2.5-MeV electrons

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: LMIII COMPARATOR

MFG: AMD

DATE CODE: 7922   TEST DATE: 10/16/79

DOSE [Gy(Si)], 2.5-MeV electrons

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: DG 129 FET SWITCH

MFG: SIL

DATE CODE: 7738   TEST DATE: 7/5/79

$I_{D(OFF)}$ (nA) MEAN

DOSE [Gy(Si)], Co^{60} gammas

COMPARISON OF MULTIPLE TESTS FOR A SINGLE DATE CODE

DEVICE TYPE: DG129 FET SWITCH

MFG: SIL

DATE CODE: 7738   TEST DATE: 7/5/79

DOSE [Gy(Si)], Co^{60} gammas

C-2

D.   COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

The purpose of the analysis in this section is to show the variability of data from many different tests, where the devices are all from the same procurement lot. As the device type, manufacturer, test conditions, and procurement lot are all the same for a given graph, the difference in the radiation sensitivity between the data plots is due to variability within the manufacturer's lot. Each curve on the graph represents the mean value of a separate test. The range of test dates are included in the heading for each graph.

To indicate the variability of the data presented by the curves, the range of the one-sigma values is shown (i.e., the one-sigma values are bounded by upper and lower bars on the vertical lines). These bars are shown only at the highest and lowest dose values.

COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N2222 NPN LOW-POWER TRANSISTOR
MFG: TIX   TEST CONDITIONS: $V_{CB} = 15$ V
LOT NUMBER: 22698   TEST DATES: 2/28/79 TO 5/8/79
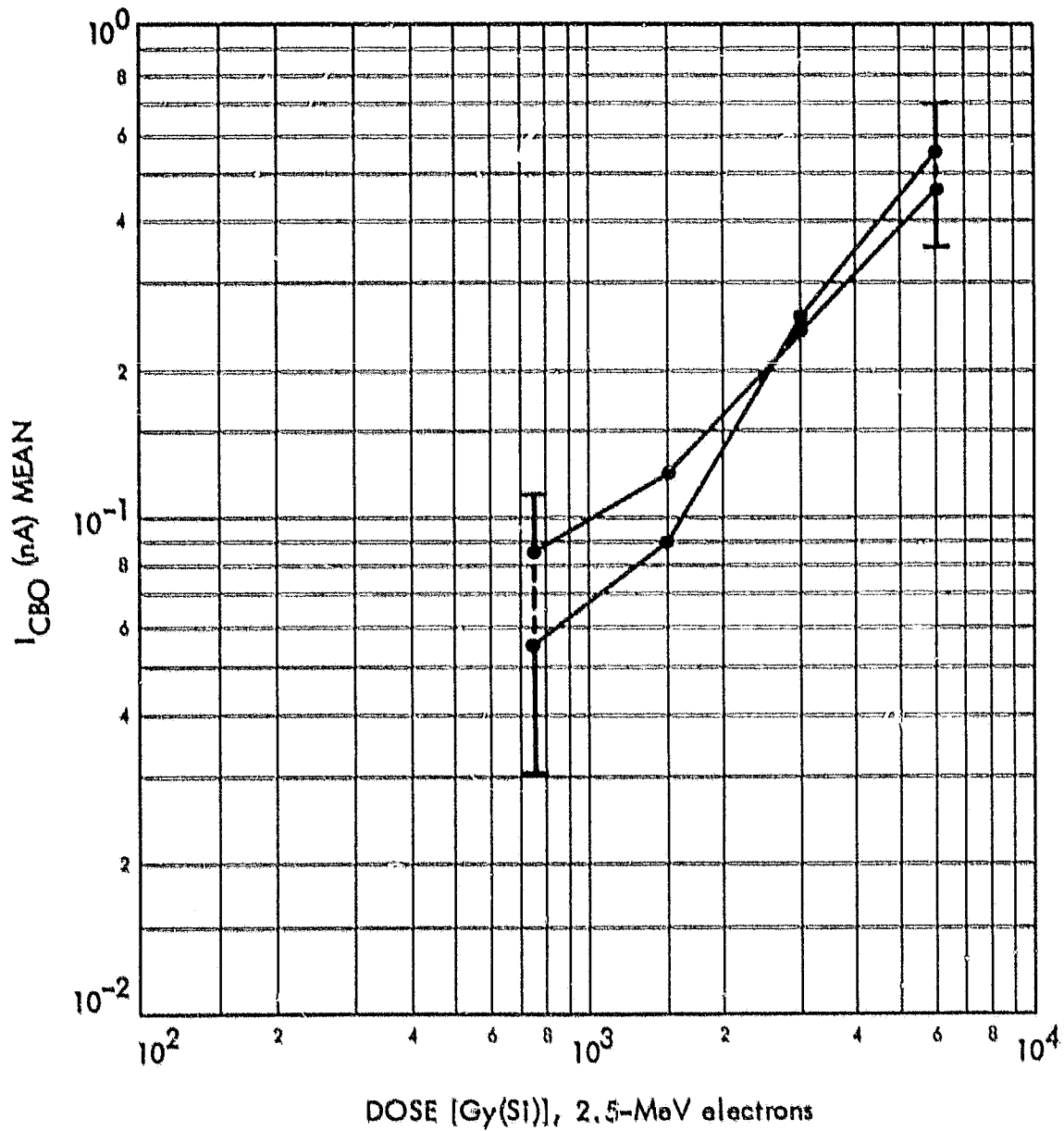
DOSE [Gy(Si)], 2.5-MeV electrons

Y-axis: I_{CBO} (nA) MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR
MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 20$ V
LOT NUMBER: DR28834   TEST DATE: 2/15/79

DOSE [Gy(Si)], 2.5-MeV electrons

COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N2907 PNP LOW-POWER TRANSISTOR
MFG: TIX   TEST CONDITIONS: $V_{CB} = 40$ V
LOT NUMBER: DR28834   TEST DATE: 12/10/79
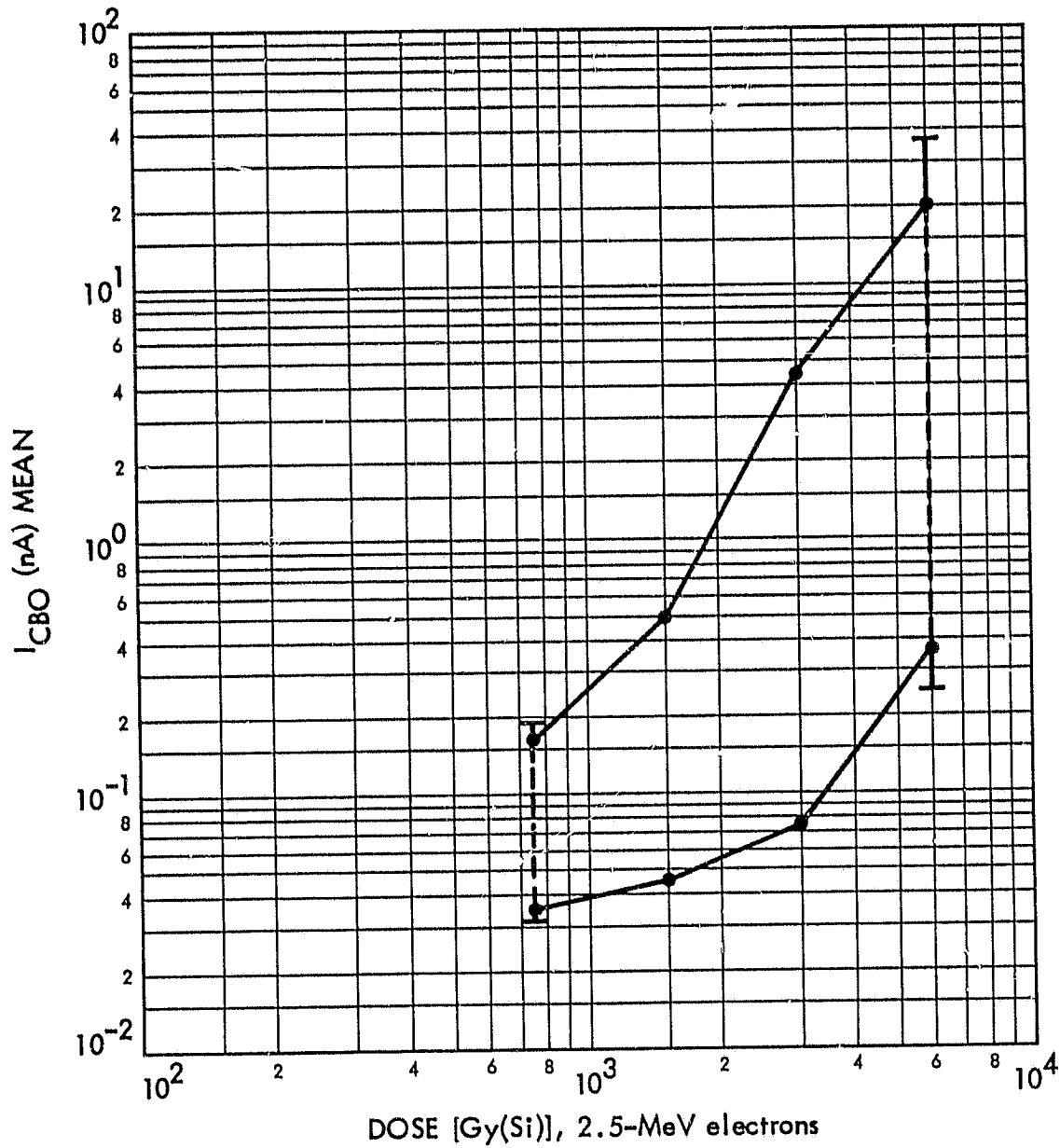
DOSE [Gy(Si)], 2.5-MeV electrons

(y-axis) I_{CBO} (nA) MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N2920 DUAL NPN LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $I_C = 0.1$ mA, $V_{CE} = 20$ V

LOT NUMBER: DR27600   TEST DATES: 2/8/79 TO 2/15/79

DOSE [Gy(Si)], 2.5-MeV electrons
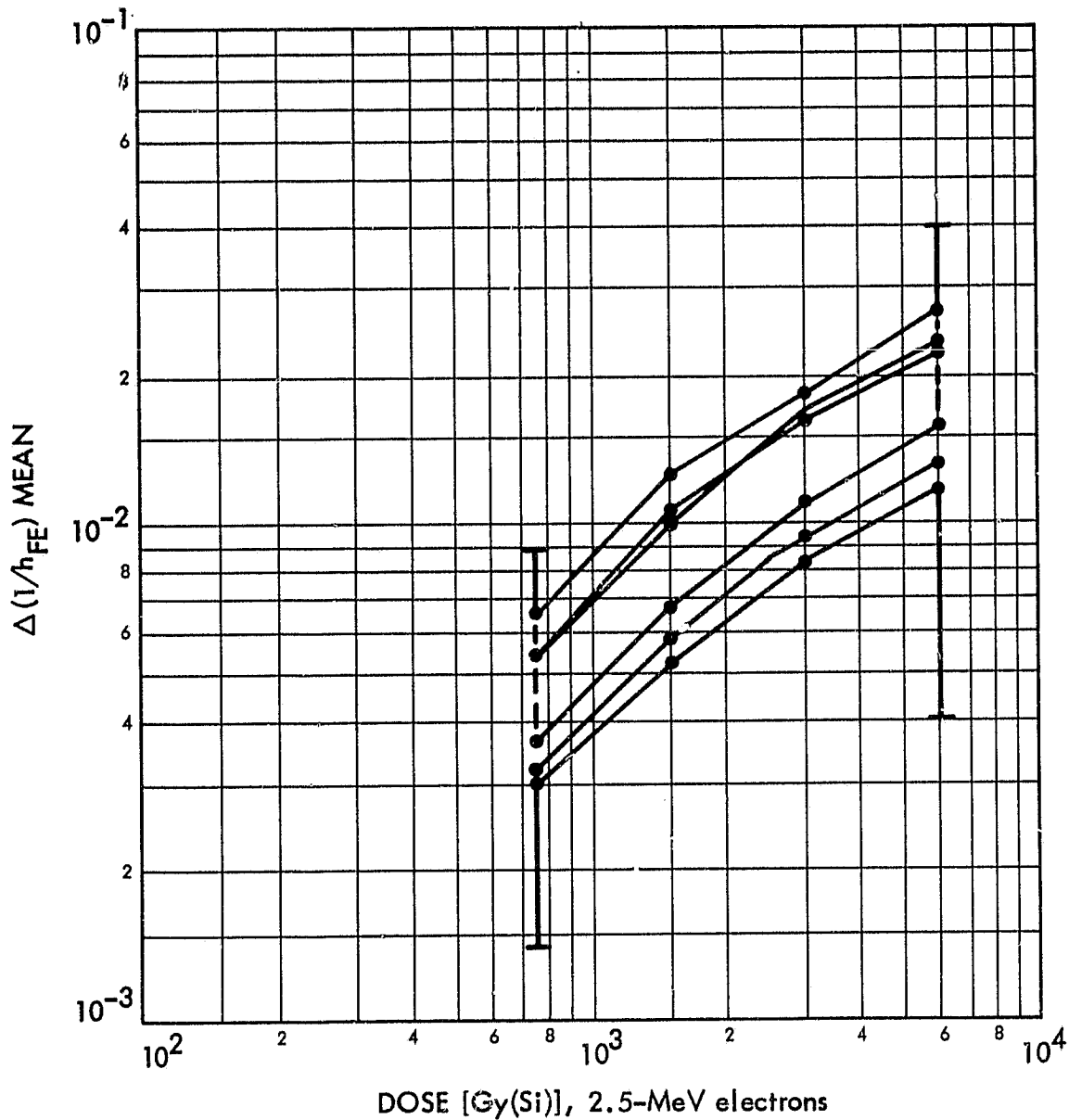
COMPARISONS OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N2920 DUAL NPN LOW-POWER TRANSISTOR

MFG: TIX   TEST CONDITIONS: $V_{CB} = 30$ V

LOT NUMBER: DR27600   TEST DATE: 2/20/79
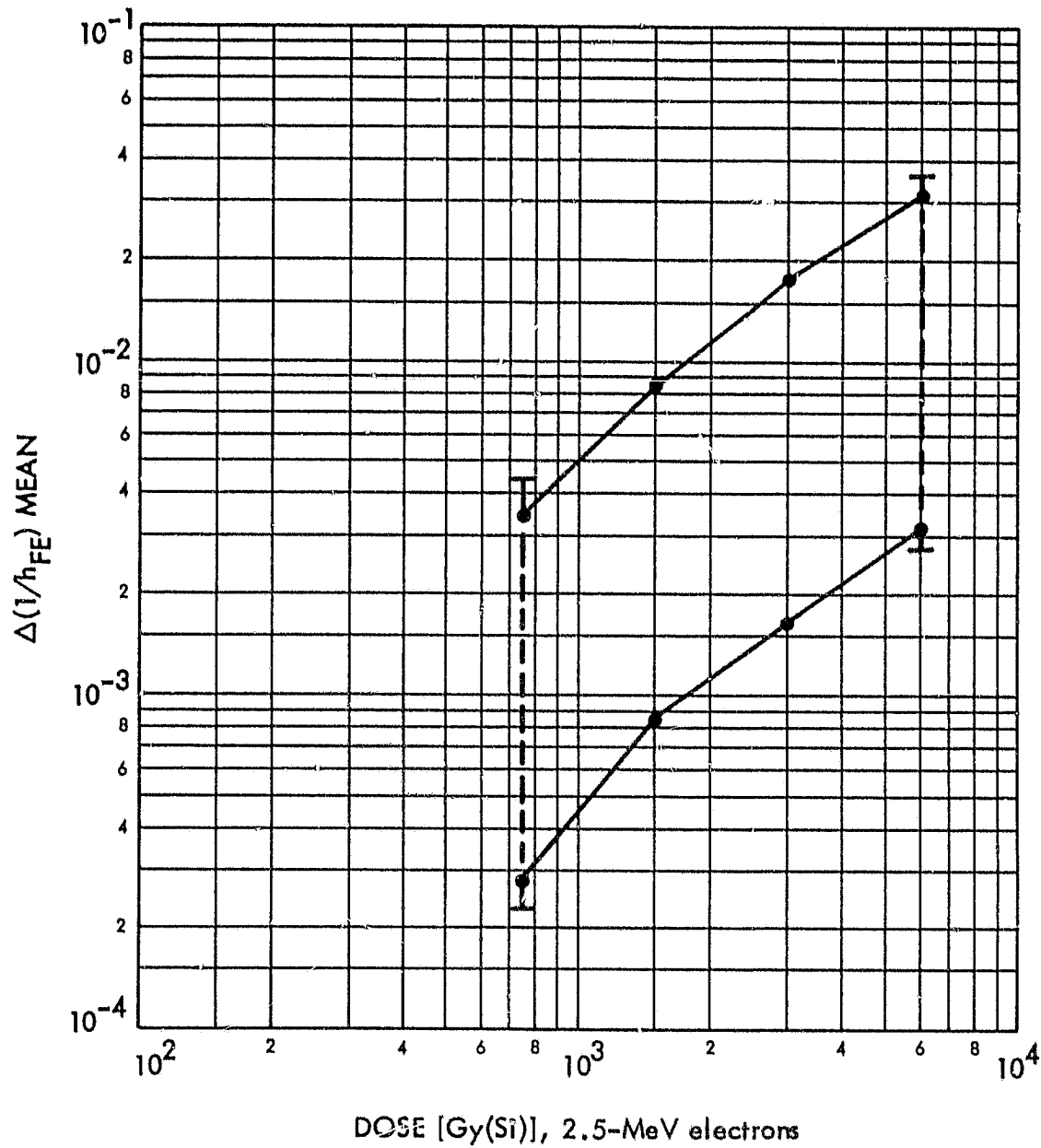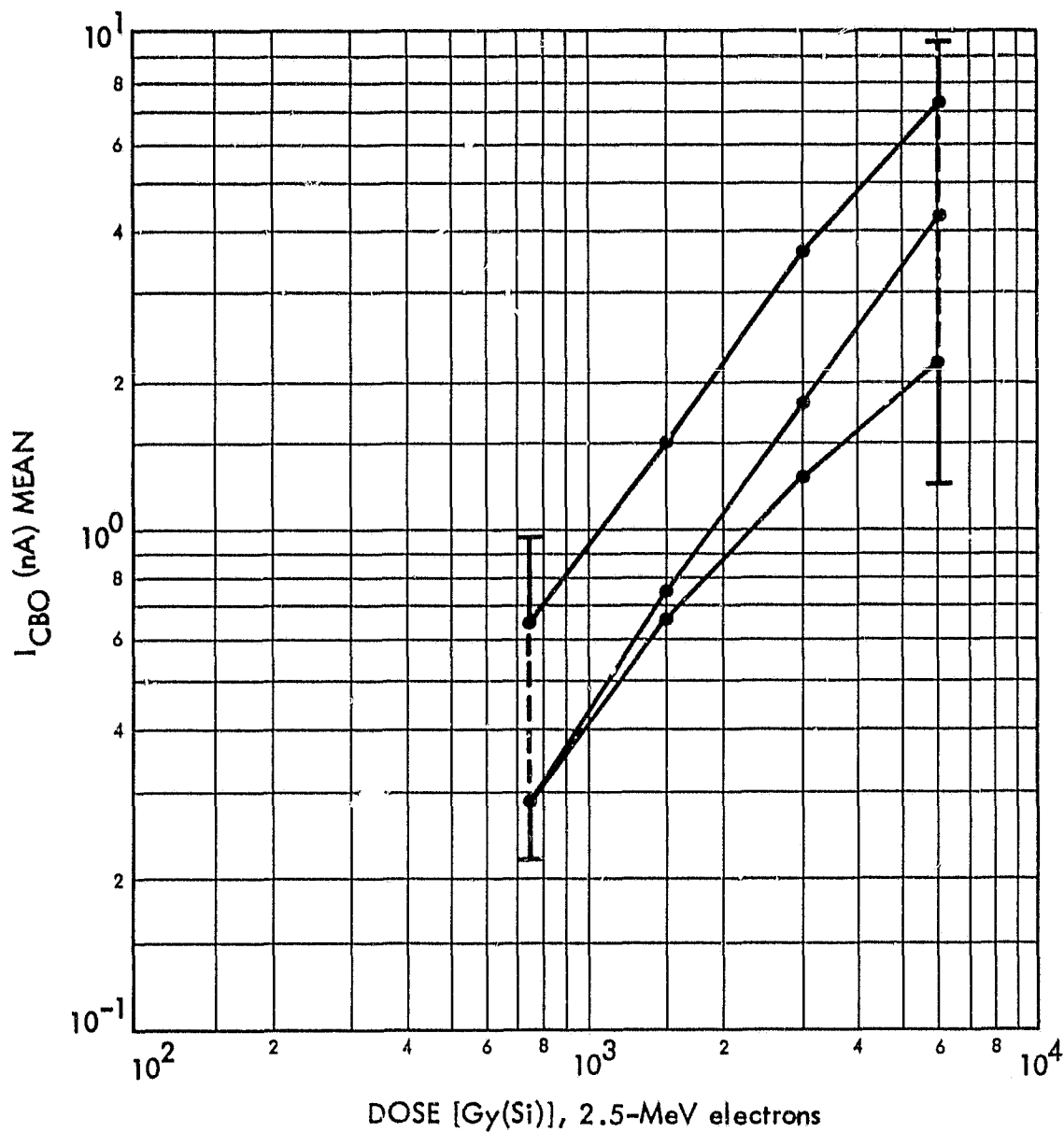

DOSE [Gy(Si)], 2.5-MeV electrons

Y-axis: I_{CBO} (nA) MEAN

COMPARISON OF MULTIPLE TESTS FOR A SINGLE LOT

DEVICE TYPE: 2N3700 NPN LOW-POWER TRANSISTOR

MFG: MOT   TEST CONDITIONS: $I_C = 1.0$ mA, $V_{CE} = 20$ V

LOT NUMBER: DR10499   TEST DATE: 1/16/79

DOSE [Gy(Si)], 2.5-MeV electrons
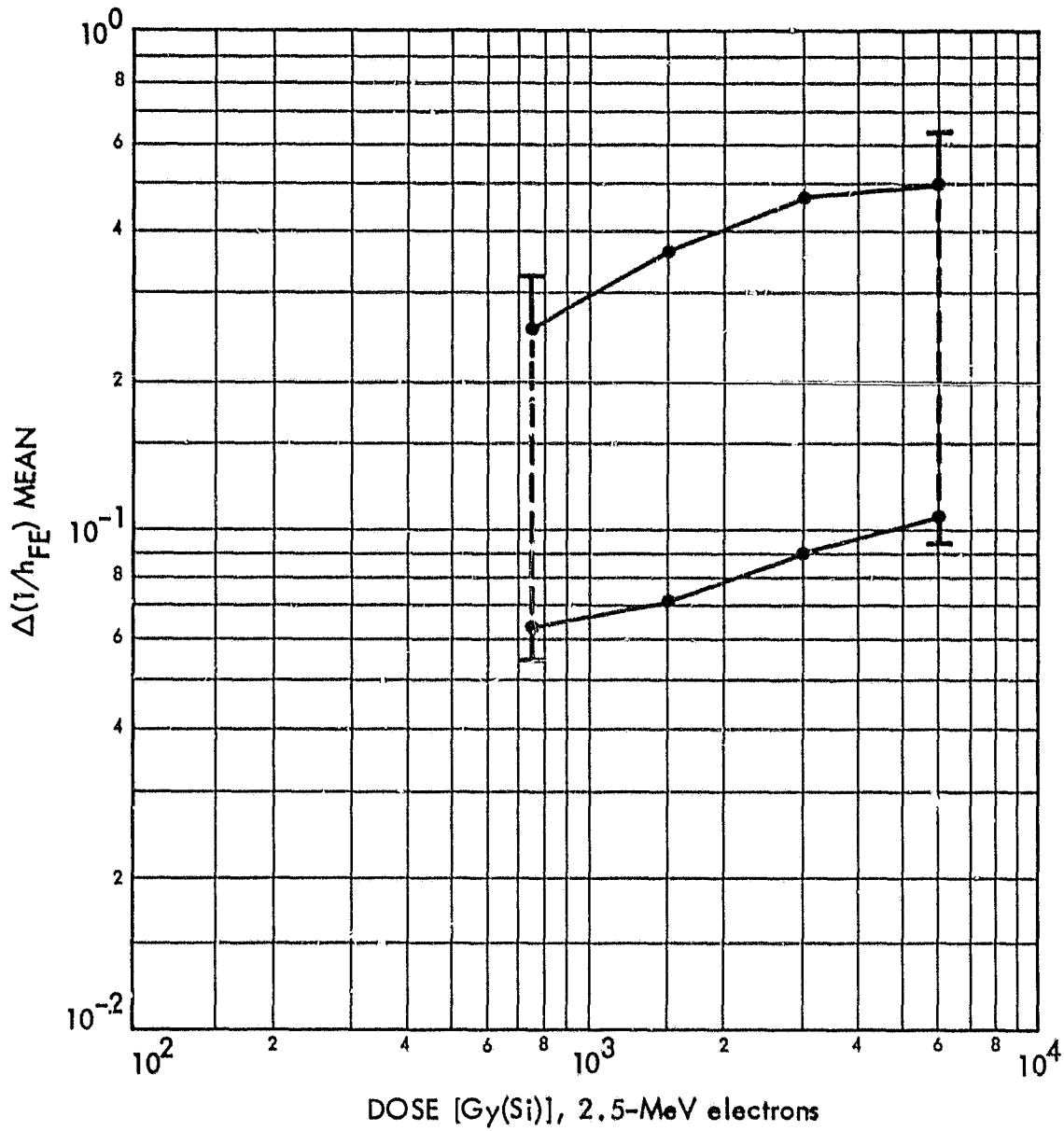
E.   COMPARISON OF RADIATION SENSITIVITIES VS TIME (DATE CODES)

The purpose of this analysis is to demonstrate the difference in radiation sensitivity between samples of a given device type fabricated at different times (date codes).* As the device type, manufacturer, and test conditions are all the same for a given graph, the difference in the radiation sensitivity between the data plots is due to variability in the manufacturer's processing steps when the devices are fabricated at different times.   There were data available for plotting only two time points on each graph.

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*The date code generally indicates the date that the device was sealed (packaged) and does not necessarily indicate the date that the die was processed. Normally, the first two numbers indicate the year, and the second two numbers the week of the year. For example, a date code of 8122 indicates the 22nd week of 1981. Occasionally, a manufacturer will follow the number with a proprietary letter, or omit the first number.

RADIATION SENSITIVITIES vs TIME (DATE CODES)

DEVICE TYPE: 2N2432 NPN LOW-POWER TRANSISTOR

MFG: TIX $I_C = 0.1$ mA, $V_{CE} = 10$ V

DOSE = 6000 [Gy(Si)], 2.5-MeV electrons

DATE CODE	No. OF DEVICES	TEST DATE
7525A	4	5/2/79
8102	8	3/31/81

Y-axis: $\Delta(1/h_{FE})$ MEAN $\pm \sigma$

X-axis: DATE CODES — 7925A, 8102

RADIATION SENSITIVITIES vs TIME (DATE CODES)

DEVICE TYPE: 2N2946 PNP LOW-POWER TRANSISTOR

MFG: TIX $I_C = 0.1$ mA, $V_{CE} = 20$ V

DOSE = 6000 [Gy(Si)], 2.5-MeV electrons

DATE CODE	No. OF DEVICES	TEST DATE
7519A	4	5/18/79
7746A	9	12/6/79

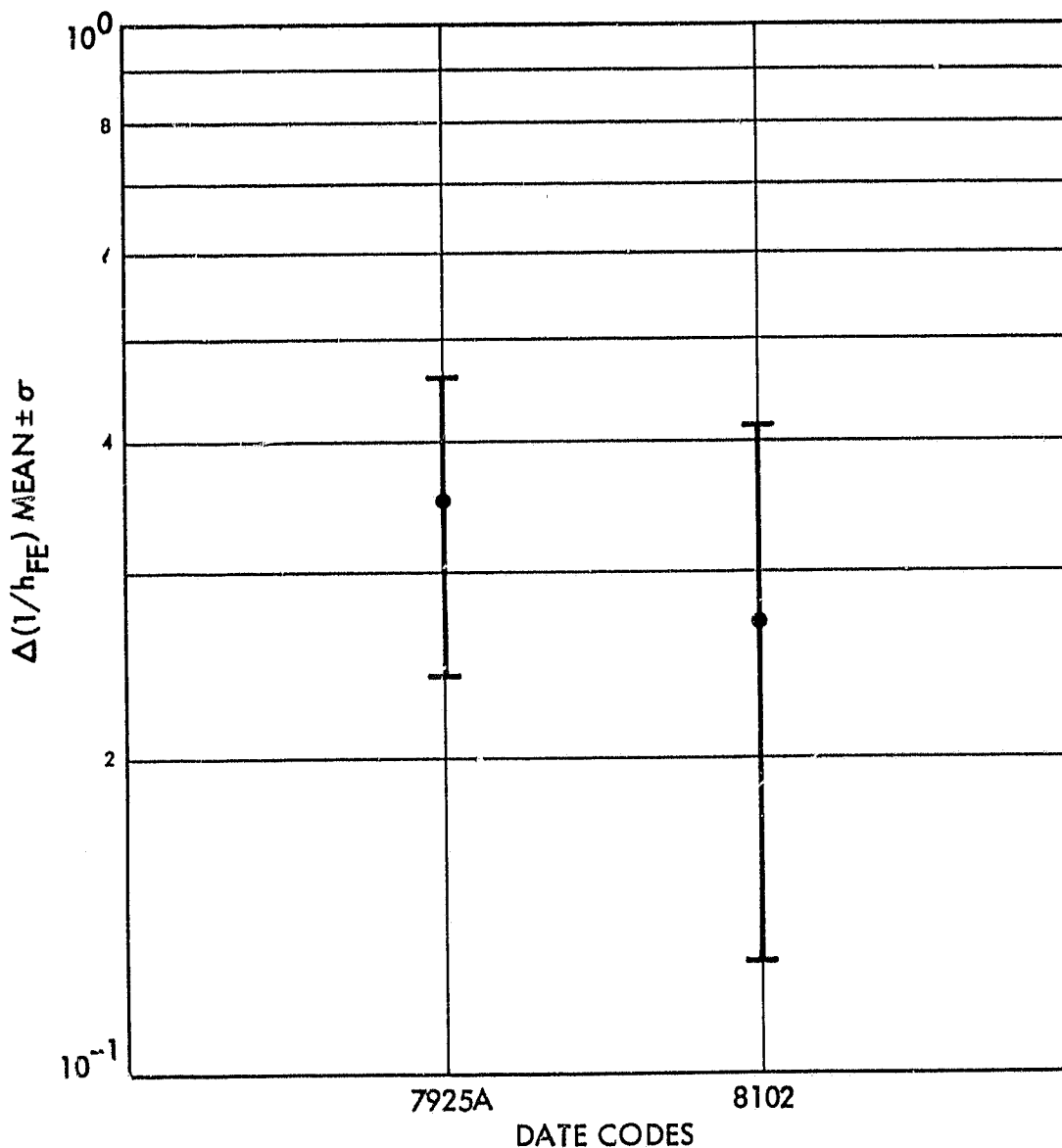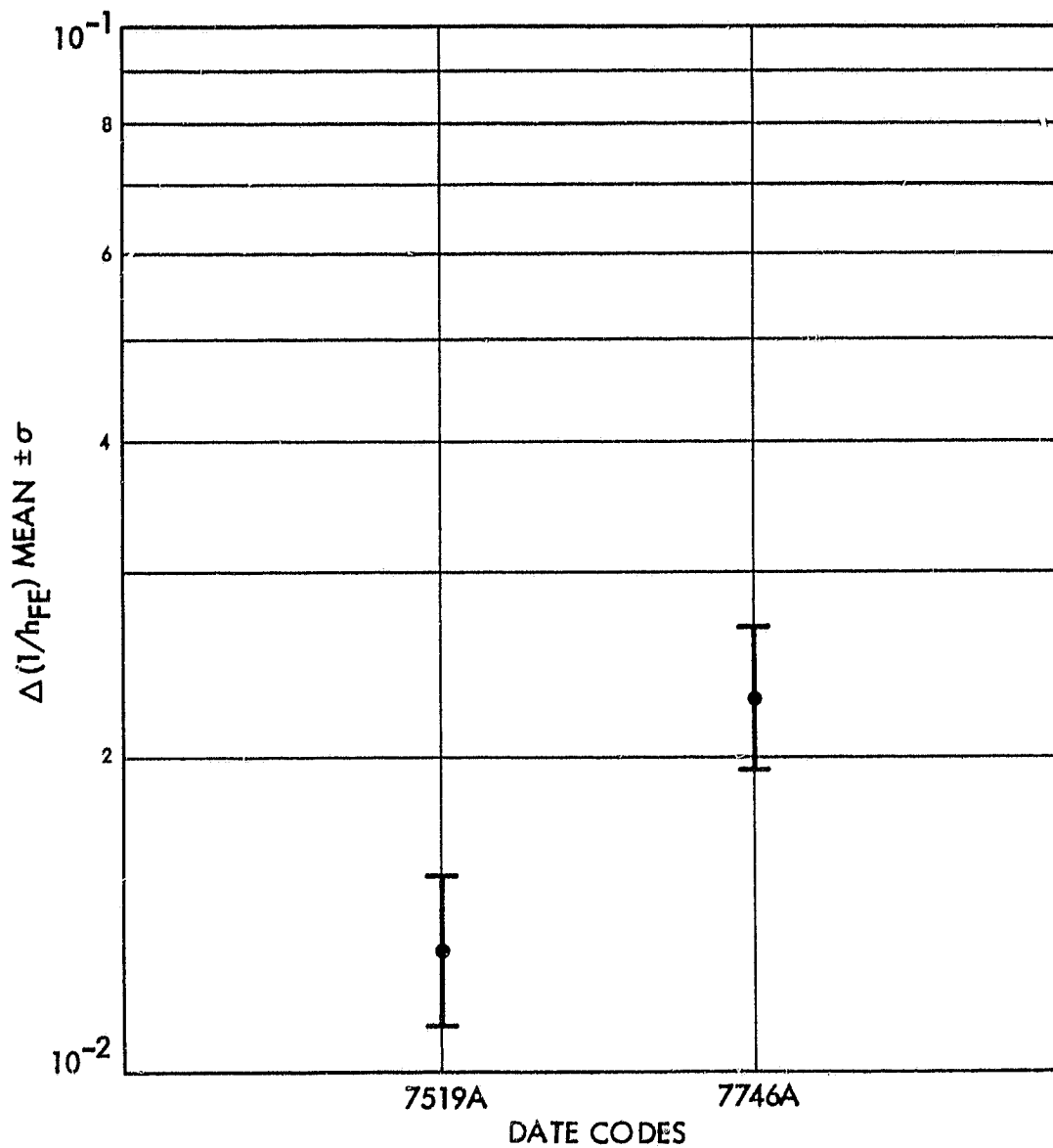## RADIATION SENSITIVITIES vs TIME (DATE CODES)

DEVICE TYPE: 2N3251 PNP LOW-POWER TRANSISTOR

MFG: MOT $I_C = 1.0$ mA, $V_{CE} = 20$ V

DOSE = 6000 [Gy(Si)], 2.5-MeV electrons

DATE CODE	No. OF DEVICES	TEST DATE
7946	6	1/2/80
8006	6	3/11/80

RADIATION SENSITIVITIES vs TIME (DATE CODES)

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET

MFG: SIL   DOSE = 6000 [Gy(Si)], Co^{60} gammas

DATE CODE	No. OF DEVICES	TEST DATE
7623	4	9/26/79
7947	5	2/22/80

RADIATION SENSITIVITIES vs TIME (DATE CODES)

DEVICE TYPE: 2N5196 DUAL N-CHANNEL FET

MFG: SIL   DOSE = 6000 [Gy(Si)], Co^{60} gammas

DATE CODE	No. OF DEVICES	TEST DATE
7623	4	9/26/79
7947	5	2/22/80

F. COMPARISON OF THE EFFECTS OF ELECTRON AND GAMMA RAY TOTAL-DOSE IONIZING RADIATION

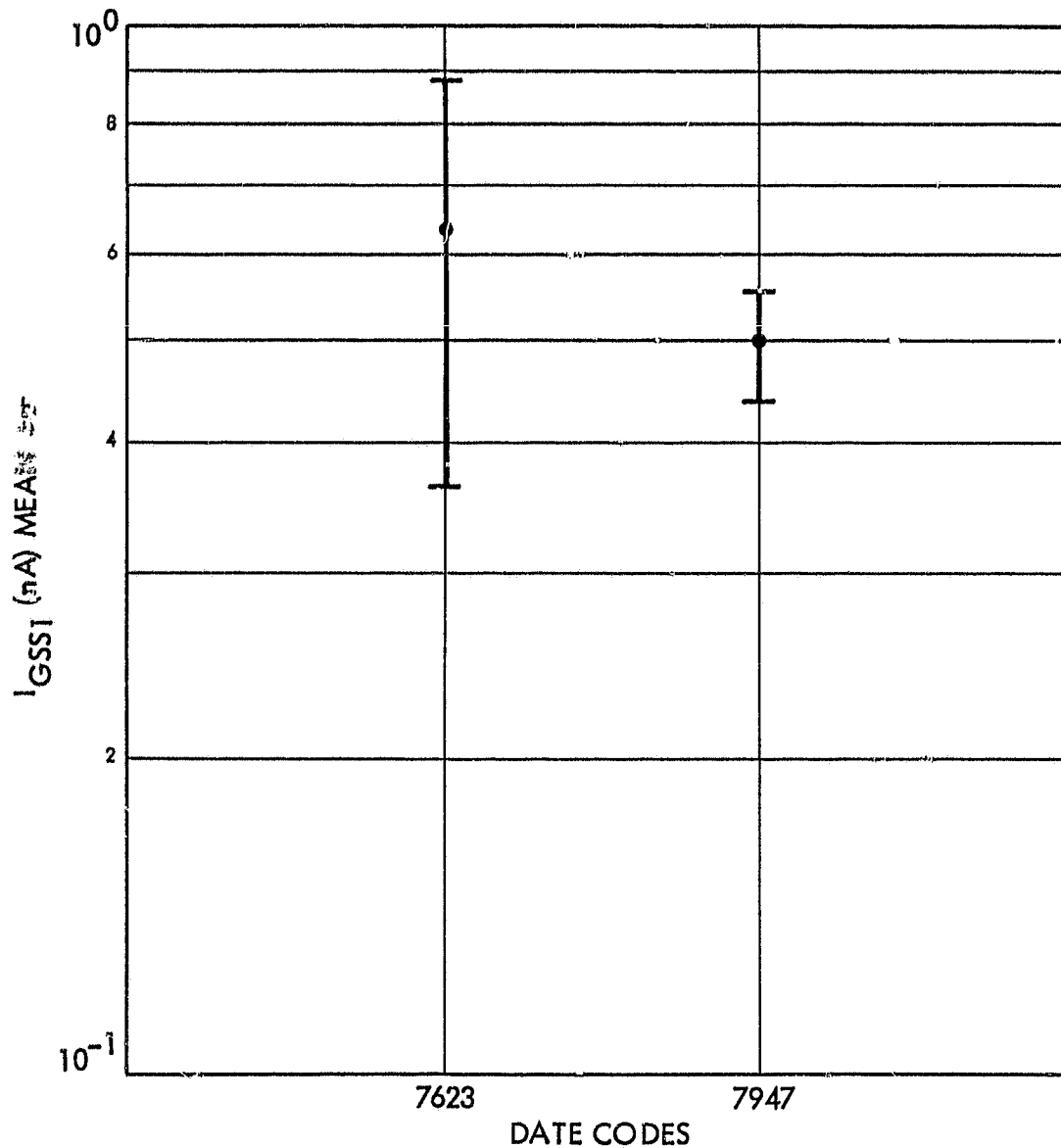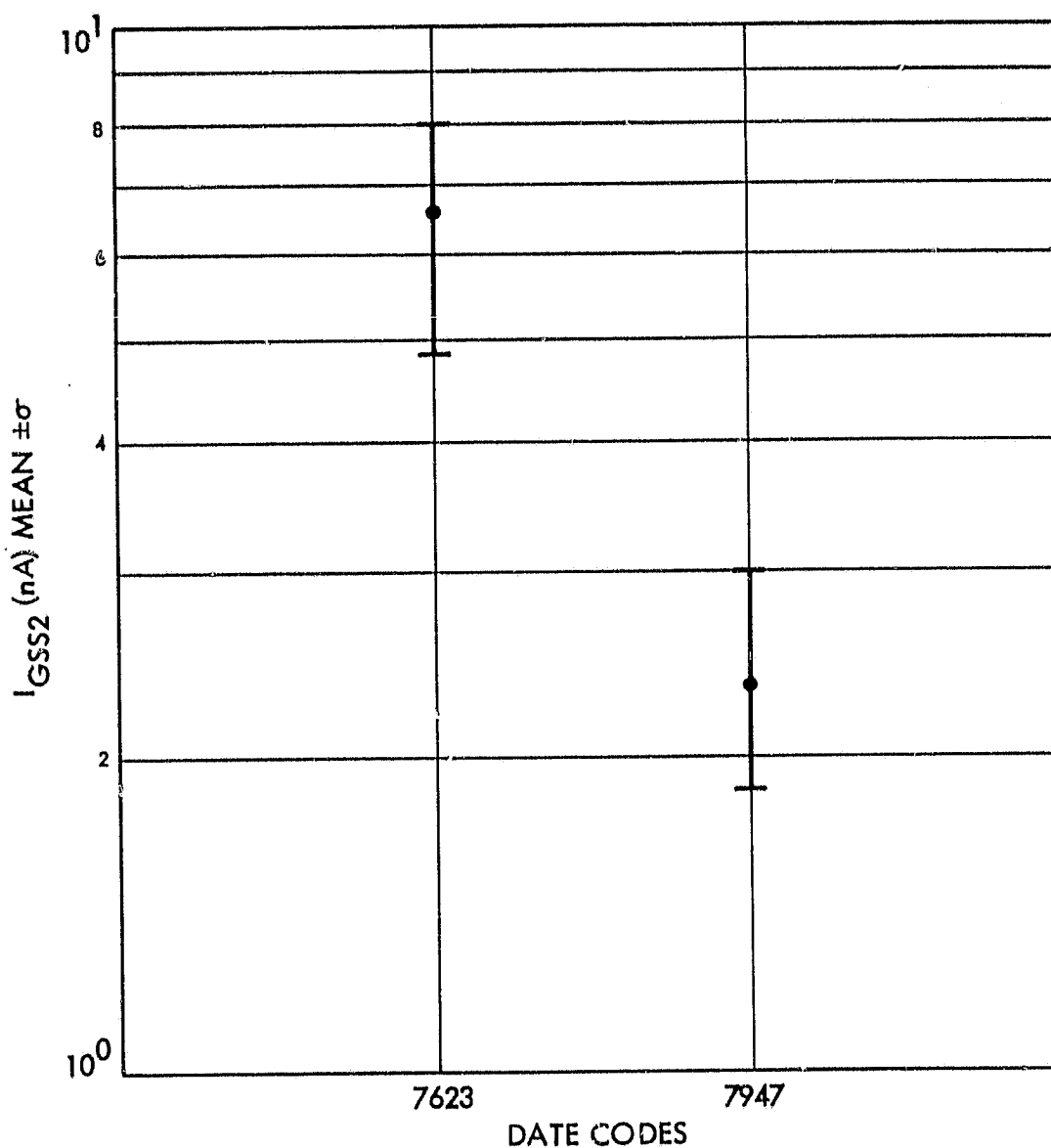A comparison of the total ionizing dose (TID) responses of selected transistors has been made, using the JPL Cobalt-60 gamma ray source and the JPL Dynamitron. The Cobalt-60 source provides 1.33-MeV and 1.17-MeV gamma rays, with a component of low-energy secondary electrons; the Dynamitron provides a continuous 2.5-MeV electron beam. Both sources have been properly calibrated with dosimetry traceable to NBS standards.

The radiation response of a large variety of transistors irradiated to the same total dose with either electrons or gamma rays is equal. However, the response of some transistors and integrated circuits when irradiated with electrons is greater than when irradiated with gamma rays. This difference arises from the fact that electrons also introduce permanent lattice damage. This damage is manifest as a decrease in minority carrier lifetime, τ. For transistors having a wide base (a low frequency), the effect of the degradation in lifetime is significant. Furthermore, the n-type base of PNP transistors is more strongly damaged than the p-type base of NPN transistors.

Some recent data* taken by JPL have been used to construct the curve for PNP transistors shown in Figure 5-2 and the curve for NPN transistors shown in Figure 5-3. For each transistor type (characterized by a point on the frequency X-axis), a sample of eight or more devices from a given wafer lot was tested in one source, and another sample from the same wafer lot was tested in the other source. It is seen that there is considerable difference in the amount of damage $\Delta(1/h_{FE}) = K\phi$, where K is a damage constant and ϕ is the dose, sustained by PNP transistors with $f_{ab} < 200$ MHz. However, there is little difference in the damage ratios for the low-power and high-power

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*D. K. Nichols, W. E. Price, M. K. Gauthier, "A Comparison of Radiation Damage in Transistors from Cobalt-60 Gamma Rays and 2.2-MeV Electrons," IEEE Trans. on Nuc. Sci., NS-29, No. 6, Dec. 1982.
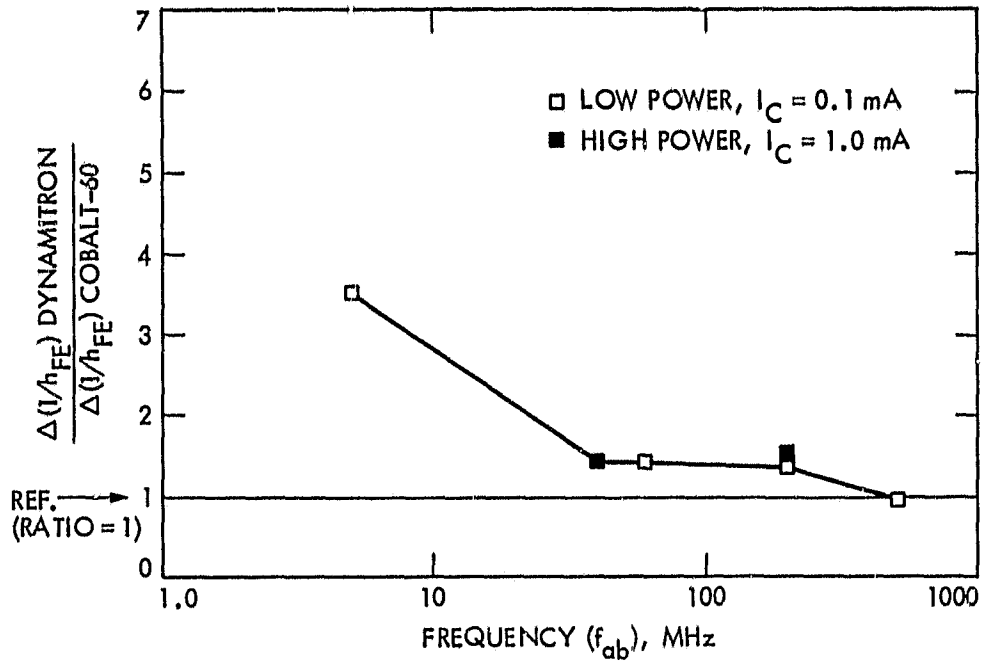
Figure 5-2. A Comparison of h_{FE} Degradations of PNP
Transistors Using 2.5-MeV Electrons and
Cobalt-60 Gamma Rays (150 krad)

Figure 5-3. A Comparison of h_{FE} Degradations of NPN
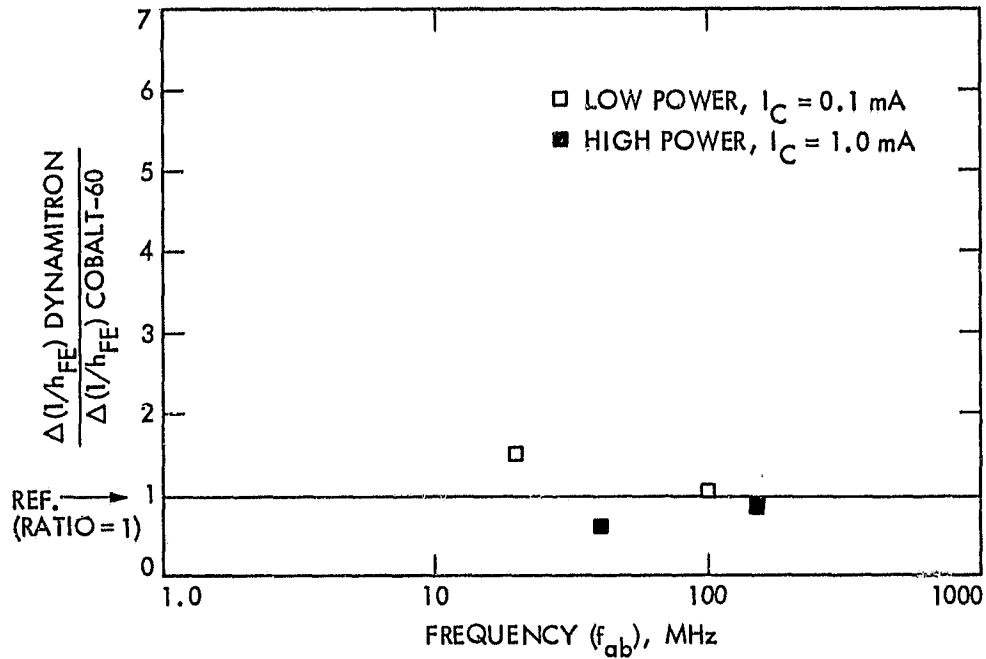Transistors Using 2.5-MeV Electrons and
Cobalt-60 Gamma Rays (150 krad)

devices. The data of Figure 5-3 reveal that damage ratios for NPN transistors are smaller (as expected) and extend up to a lower frequency limit than those for PNP transistors.

These results may be used by the reader to make more realistic comparisons between data on devices taken in both sources.

APPENDIX A

VENDOR IDENTIFICATION CODE LIST

ADI   Analog Devices, Inc.

AMD   Advanced Micro Devices Corporation

FAS   Fairchild Semiconductor

INL   Intersil, Inc.

MOT   Motorola, Inc., Semiconductor Products Division

NSC   National Semiconductor Corporation

PMI   Precision Monolithics, Inc.

RAY   Raytheon Company

SIL   Siliconix Devices, Inc.

TIX   Texas Instruments, Inc.

APPENDIX B

SEMICONDUCTOR DEVICE ELECTRICAL PARAMETER
SYMBOLS AND ABBREVIATIONS

ΔI_B*	input bias current
ΔI_{OS}	offset current
ΔV_{OS}	offset voltage
f_{ab}	alpha cutoff frequency
GAIN	voltage gain
h_{FE}	common-emmitter static forward current transfer ratio
I_C	collector current
I_{CBO}	collector cutoff current open emitter
$I_{D(OFF)}$	drain cutoff current
I_{GSS}	reverse gate current
$I_{S(OFF)}$	source cutoff current
I_{SINK}	output sink current
NONLIN	nonlinearity
OFFERR	offset error
OFFSET	offset voltage
t_{CONV}	conversion time
V_{CE}	collector emitter voltage
V_{DS}	drain source voltage
V_{GSS}	gate-source voltage

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*Δ is the difference between the subject measurement and the

initial measurement.