FACILITY FORM 602

N66-11201 (ACC[illegible]	(THRU)
19 (PAGES)	1 (CODE)
(NASA CR OR TMX OR AD NUMBER)	09 (CATEGORY)

X-636-65-241

NASA TM X-55305

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GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

MAY 18, 1965

NASA

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-636-65-241

EFFECTS OF GAMMA RADIATION ON SCR'S USED IN SWITCHING MODE AND IN APPLICATION TO ATTITUDE CONTROL MOTOR DRIVE BRIDGE

by

Gail D. Smith

EFFECTS OF GAMMA RADIATION ON SCR'S USED IN SWITCHING MODE AND IN APPLICATION TO ATTITUDE CONTROL MOTOR DRIVE BRIDGE

SUMMARY

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A study of the effect of Cobalt 60 gamma radiation upon silicon controlled rectifiers (SCR) during repetitive pulsing is presented. Six electrical characteristics of each SCR were tested before, during, and after radiation exposure. All of these characteristics are shown graphically as a function of the total accumulated dose with the SCR's both in and out of the radiation field. These curves reveal appreciable changes in the characteristics with total accumulated dose and some evidence of dose rate effect. It is concluded that all observed changes are within design capability. That is, SCR circuits can be designed to reliably perform the desired functions in a gamma field of 2 x 10^6 rads per hour for a total dose of 6.6 x 10^6 rads.

Author

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INTRODUCTION

This report is being written primarily to inform the advanced orbiting solar observatory (AOSO) project office of the findings to this date of the silicon controlled rectifier (SCR) radiation study. An extensive study is being conducted of high power SCR's during and after exposure to various radiation fields. The SCR's in this study are irradiated in three different modes:

(1) Biased

(2) Unbiased

(3) Switched on and off several hundred times per second.

This report covers only the portion concerned with the SCR's being switched on and off during radiation. Thus, the purpose of this report is to determine the effect of radiation upon the SCR's while being turned on and off as they are in the AOSO inertia wheel motor drive bridge circuit.

While being turned on and off in the radiation field, various parameters of the SCR's were continuously monitored with a multichannel oscilloscope. Static tests were conducted by use of variable voltage regulated power supplies, an electrostatic microammeter, a multirange milliammeter, and a digital voltmeter. Automatic digital print out or paper punch equipment was not employed because of the short time period allotted to circuit design. This would have required the design of a system for digitalizing current in the low nano-ampere range and the use of memory storage elements to remember the firing voltage and current after the SCR had fired and thereby lost the desired information.

MOTOR DRIVE BRIDGE

The optical axis of observation of the solar observatory is oriented by rotating inertia wheels on three separate mutually perpendicular axes. The desired orientation is attained and retained by controlling the rate of rotation of these wheels. Each of the three motors used to drive the inertia wheels is controlled in a circuit similar to that of Figure 1. A bridge circuit is employed to enable the dc motor to be driven in either the clockwise or counterclockwise direction by a single power source. All transistors and both silicon controlled rectifiers are operated in the off condition except when an input signal is present at one of the inputs.

To obtain clockwise rotation, a series of square pulses are injected at input C (clockwise). These pulses are negative with respect to the positive side of the 28 volt power source. Each of these pulses turn transistor Q1 on which turns Q2, Q3 and SCR 1 on. Thus current flows from the positive side of the power source through SCR 1, M1, Q3, and R12. This current of approximately 10 amperes causes the motor M1 to rotate its inertia wheel in the clockwise direction. At the end of the pulse transistors, Q1, Q2, and Q3 go off. As Q3 goes off the anode current through SCR 1 is reduced below the holding current and causes this SCR to go off.

Counterclockwise rotation is obtained by introducing a similar train of pulses at input CC. Each of these pulses turn on Q6, Q5, Q4, and SCR 2. Thus current flows through SCR 2, M1, Q4, and R12. This current now flows through the motor in the opposite direction to that for the clockwise case thus driving the inertia wheel in the counterclockwise direction. The transistors and SCR's turn off in the same manner as for the clockwise portion of the circuit. A turn on pulse should not be introduced at both inputs simultaneously because a very high current would surge through SCR 1 and Q4 and also through SCR 2 and Q3. Such a current would destroy the usefulness of several components in a very short period of time. This also reveals that it is imperative that the SCR's go off at the end of each pulse. For example, if SCR 1 does not go off when the input signal is removed, then when Q4 is turned on by a counterclockwise input a destructive current is allowed to surge through SCR 1 and Q4.

When input pulses are introduced at one of the inputs, they appear at a constant rate of 960 pulses per second. The rate of rotation of the motor or inertia wheel is controlled by pulse width modulation (PWM). That is, the motor speed is controlled by controlling the length of time current is allowed to flow through the motor each period. The width of the pulse can be modulated from approximately 2 to 98%.

TEST CIRCUIT

The circuit of Figure 2 was used to simulate the circuit of Figure 1 during irradiation of the SCR's. Resistor R5 is used for the load in the bridge circuit instead of a motor and consists of a 5 ohm, 10 ampere potentiometer. The negative supply biases the transistors and SCR's off. A positive pulse is introduced at input C which turns Q1, Q2, Q3 and SCR 1 on. Thus current flows through

SCR 1, R5 and Q3. Resistor R5 is adjusted to give a current of 10 amperes. At the end of this square pulse Q1, Q2, and Q3 go off. SCR 1 also turns off because Q3 reduces the anode current below the holding current. After a short dwell time, a positive pulse is presented at input CC which causes Q6, Q5, Q4, and SCR 2 to turn on. This allows current to flow through resistor R5 in the opposite direction to that for a positive pulse at input C. At the end of the pulse the SCR and transistors go off as before. After another similar dwell time another turn on signal appears at input C. This cycle is repeated at a rate of approximately $1KH_z$.

This method of testing with the circuit of Figure 2 differs from operation of the actual circuit of Figure 1 in two respects. The square input pulse appears alternately at the two inputs whereas in the satellite a long train of pulses appear at one input at a time. Also the width of the input pulses are held constant. The reason for these deviations is to maintain approximately equal heating and aging of the two irradiated SCR's.

PARAMETER TESTING

Periodically during the radiation study the forward blocking current (I_{FB}), reverse blocking current (I_{RB}), dc gate trigger voltage (V_{GT}), dc gate trigger current (I_{GT}), forward on voltage (V_F), and holding current (I_H) were measured for each SCR. The forward blocking current is the anode current with the positive side of a 28 volt supply connected to the anode, and the negative to the cathode with the gate open. Similarily the reverse blocking current is the anode current with the negative side of the 28 volt supply connected to the anode and the positive to the cathode with open gate. The dc gate trigger voltage and dc gate trigger current are the dc voltage and current required at the gate to turn the SCR on with a 28 volt supply and a load (approximately 2.7 ohms) to give an anode current of 10 amperes. The forward on-voltage is the anode to cathode voltage while conducting a current of 10 amperes with open gate. The holding current is the minimum forward anode current required to hold the SCR in the "on" state with an open gate.

TEST PROCEDURE

The SCR's and temperature sensors were mounted on a small aluminum heat sink. Lead wires, fifteen feet long, were connected to the assembly for remote operation, testing and temperature monitoring. The pre-radiation measurements were made of the six aforementioned SCR parameters. The assembly was then placed in the Cobalt-60 radiation field while being operated as described for the circuit of Figure 2 and monitored with meters and an oscilloscope. After some period of time in the radiation chamber the six parameters were measured again. The devices were removed from the radiation field and tested once again. Then the SCR assembly was placed in the Cobalt 60 field for another period of operation and testing. This cycle was repeated until a total dose of approximately 6.6 x 10^6 rads were received.

RADIATION SOURCE

All radiation tests were conducted by use of a Cobalt 60 gamma cell. This source emits two gamma rays (1.1733 and 1.3 328 MEV) at approximately equal rates. The dose rate in the test chamber is 2 x 10^6 rads per hour. Reference (a) indicates that one rad of these gamma rays is approximately equivalent to 3 x 10^7 electrons. Thus the dose rate in the test chamber is approximately equivalent to 6 x 10^{13} electrons per hour.

DISCUSSION OF TEST RESULTS

The test results are shown graphically in Figures 3 through 9. More unpublished test findings are available from the extensive study of SCR's in radiation environments mentioned in the introduction. Frequent reference is made to this more extensive study to reveal the maximum and minimum parameter variation for a large number of SCR's.

The pictures of the oscilloscope traces shown in Figure 3 were taken during operation of the SCR's in the radiation field. The dose rate is 2 x 10^6 rads per hour and the total dose received is recorded for each picture. The curves of this figure reveal details of the circuits (Figure 2) operation. When the clockwise input signal (trace V_{IN} at Q1) is received Q3 and SCR 1 are turned on. The collector voltage of Q3 (trace V_{CE} Q3) rapidly reaches its saturation voltage. At the same time the voltage across Q4 (trace V_{CE} Q4) goes up to the supply voltage minus the saturation voltage of SCR 1. The load current (trace I_{LOAD}) gradually climbs to its preset peak of 10 amperes. At the end of the input pulse (trace V_{IN} at Q1) Q3 goes off. Note the rapid fall of load current. This sudden change in current through the 15 foot leadwires and load resistor gives an inductive kick (trace V_{CE} Q3 and trace V_{CE} Q4). Immediately after this kick (at 100 μs) the two collector voltages begin to settle at a value equal to the supply voltage minus the anode to cathode drop of SCR 1. At this instant SCR 1 turns off and both collector voltages rapidly attain a voltage determined by the leakage resistance of Q3, Q4, SCR 1, and SCR 2. During the time when these components are off, the leakage resistance of the SCR's is approximately a thousand times that of the reverse biased transistors Q3 and Q4.

The cathode to gate voltage required to turn the SCR on with a 28 volt anode supply and a 2.7 ohm load is shown in Figure 4. These curves reveal a pronounced increase with total dose of radiation in the gate voltage required to fire the SCR. Tests on a large number of SCR's reveal no change for some and an increase of as much as 3.5 percent per megarad for others. These curves reveal a marked decrease in the gate firing voltage upon entering the radiation field and a corresponding increase upon being removed from the field. Similar tests with several SCR's reveal that some do not change whereas others change as much as 5 percent for a field of 2 x 10^6 rads per hour.

The gate current required to turn the SCR on with a 28 volt anode supply and a 2.7 ohm load is shown in Figure 5. These curves reveal the gate triggering current to increase with total dose of radiation received. Similar tests on several SCR's reveal that some do not change in this respect whereas others increase as much as 3.5 percent per megarad. A change in this firing current is sometimes observed upon entering or leaving the radiation field however the change is usually very small.

The anode to cathode voltage with an anode current of 10 amperes is shown in Figure 6. The "on" voltage increases approximately linearly with total dose. The increase in this voltage upon removing it from the radiation field is small and is frequently not detected.

The minimum value of forward anode current required to maintain the device in the "on" state is shown in Figure 7. This holding current increases with total dose and approximates a straight line. Some SCR's reveal no change in this parameter whereas others increase as much as 5.5 percent per megarad. The change upon removing the devices from the radiation field is small and frequently indistinguishable.

The forward blocking current is shown in Figure 8. This indicates a large increase in current upon being placed in the radiation field and a corresponding decrease upon being removed from the field. Auxiliary studies reveal this change to be related to the dose-rate as well as the total dose. The current change while in the radiation field is indictive of the findings of auxiliary studies. That is, for some SCR's, this current does not change, for some it changes irregularly and rapidly, and for some it depends upon the manner driven electrically while in the radiation field. Further studies are planned to determine the effect of bias, repetition rate and anode current upon this and other SCR parameters. The SCR's with the high rate of change in this current are of concern because it would become impossible to hold them off once they are turned off. The magnitude of blocking current at which this failure occurs depends upon the circuit design, magnitude of the supply voltage, and gate trigger current.

The reverse blocking current is shown in Figure 9. These curves reveal a large increase in the current upon being placed in the radiation field and a decrease upon being removed from the field. Auxiliary studies point toward a relationship between this change and the dose rate as well as the total accumulated dose.

CONCLUSIONS

The observed changes in SCR parameters due to gamma radiation of the total accumulated dose and dose rate employed in these tests are considered to be within design capability. That is, SCR circuits can be designed to reliably perform the desired functions before and after receiving 6.6 x 10^6 rads of 1 to 2 MEV gamma rays while in a 2 x 10^6 rad per hour field. The maximum and minimum change in parameters are given to enable the designer to predict parameter values after a perscribed radiation history. Total accumulated doses greater than 6.6 x 10^6 rads may reveal turn off or more properly hold off problems. That is, the forward leakage of some units may become so high that the SCR will not remain off with the full supply voltage across it. Further studies are being conducted of this problem and the details should be available soon.

REFERENCE

(a) Correlation of Proton to Neutron and Electron to Photon Radiation Damage in Transistors and Diodes by G. L. Keister, Document No. D2-90407, The Boeing Co., Seattle, Washington.

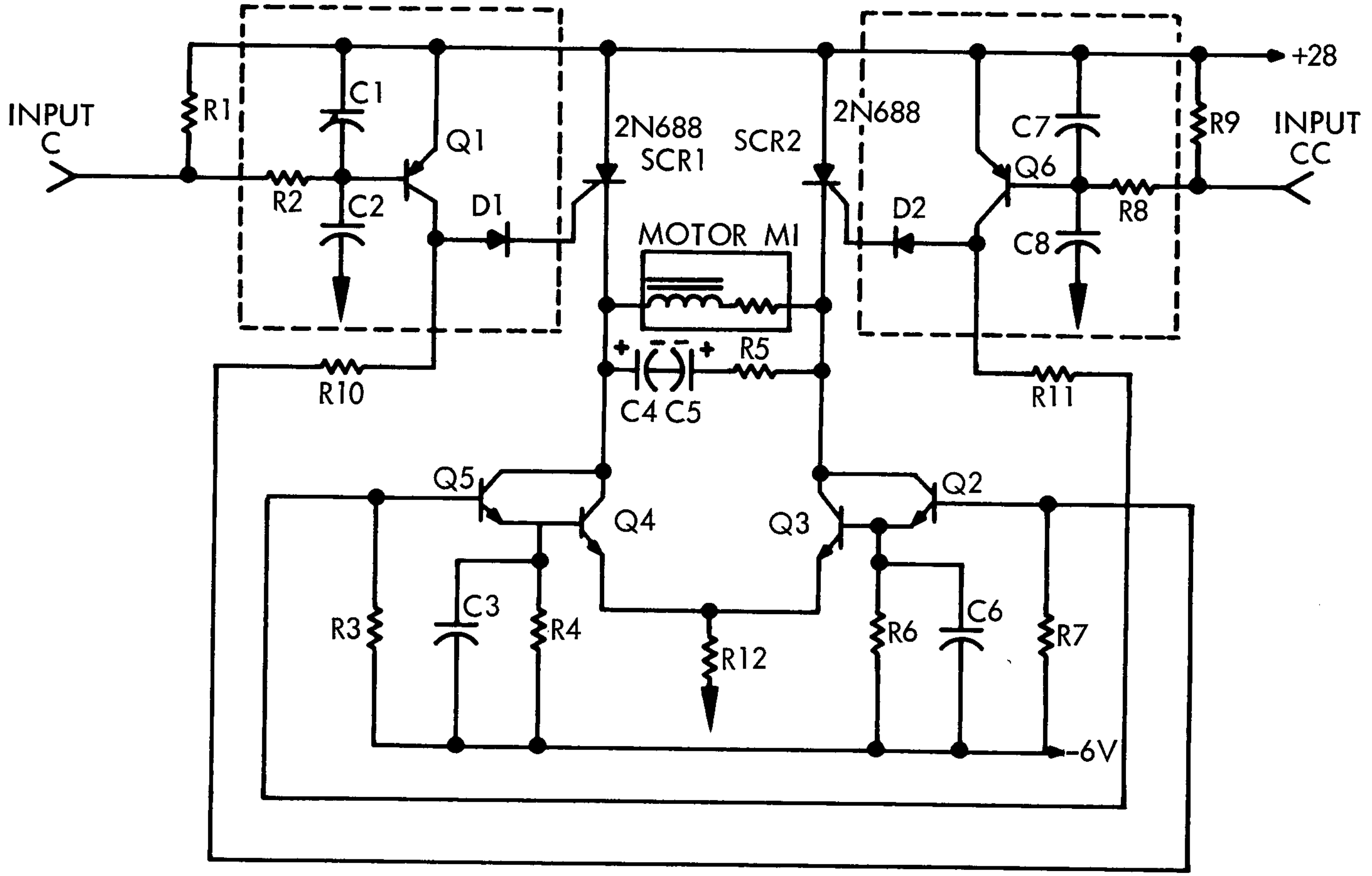

Figure 1 – Motor Drive Bridge Circuit

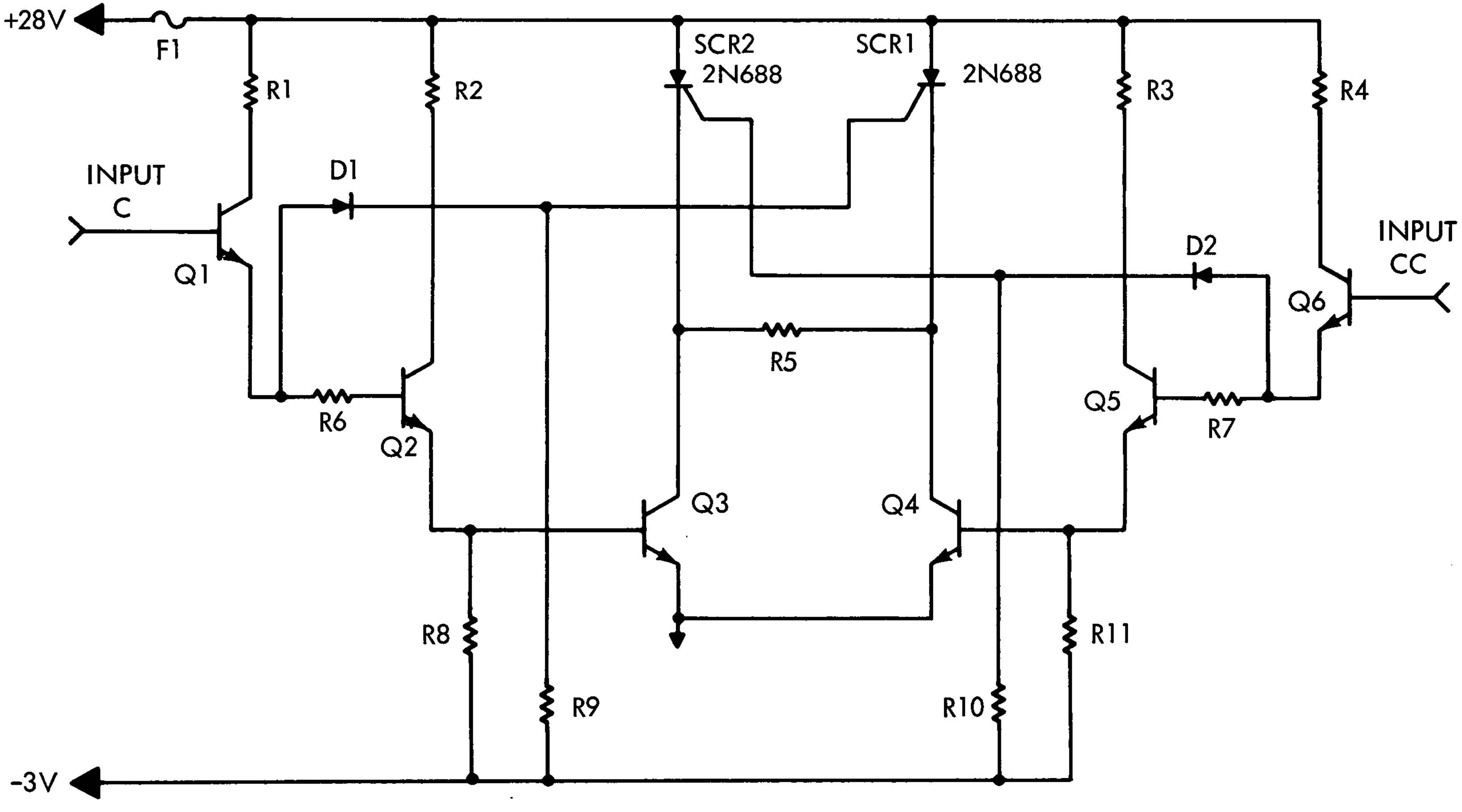

Figure 2 – Test Circuit to Simulate Motor Drive Bridge

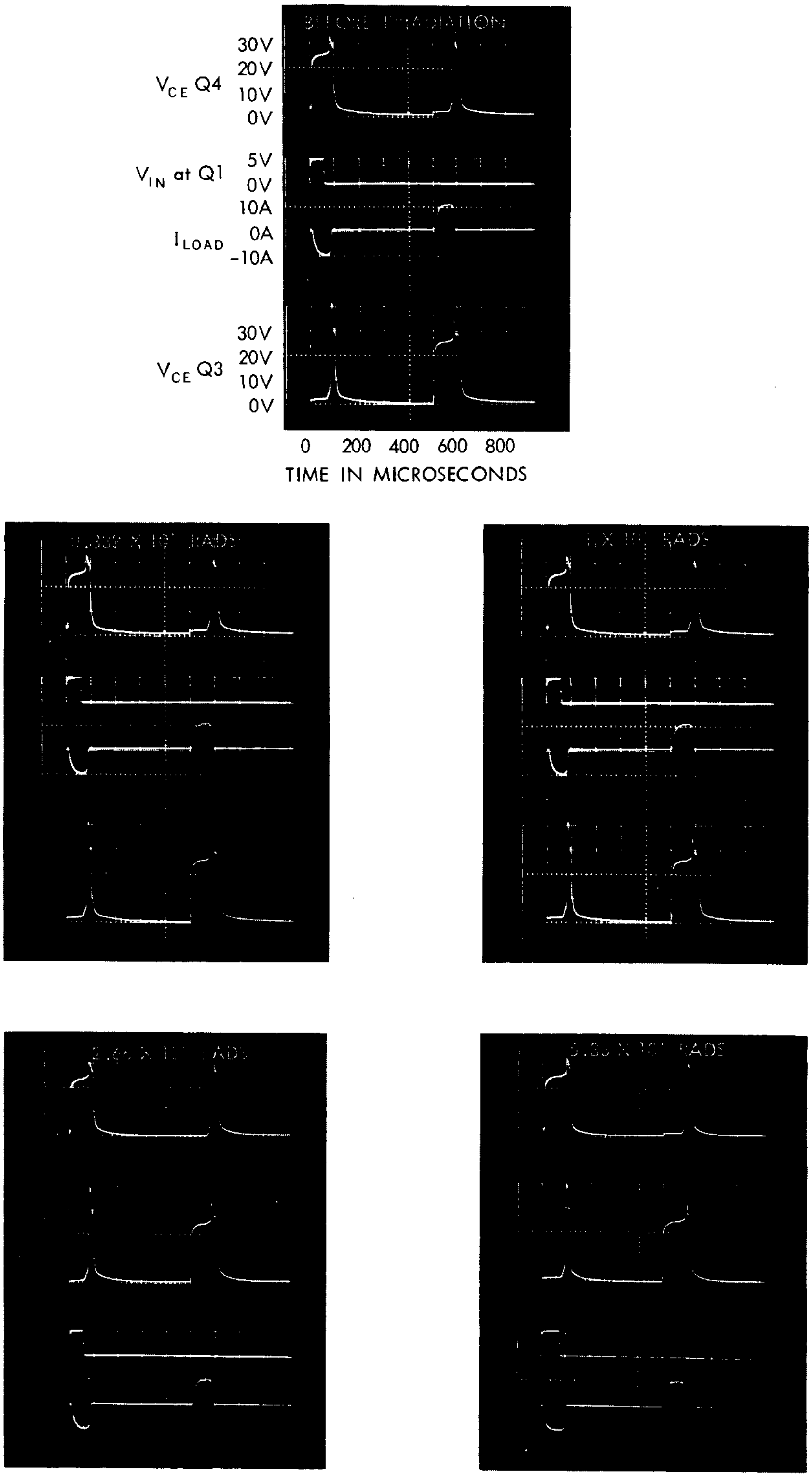

Figure 3 – Oscillograms of Test Circuit During Irradiation Studies

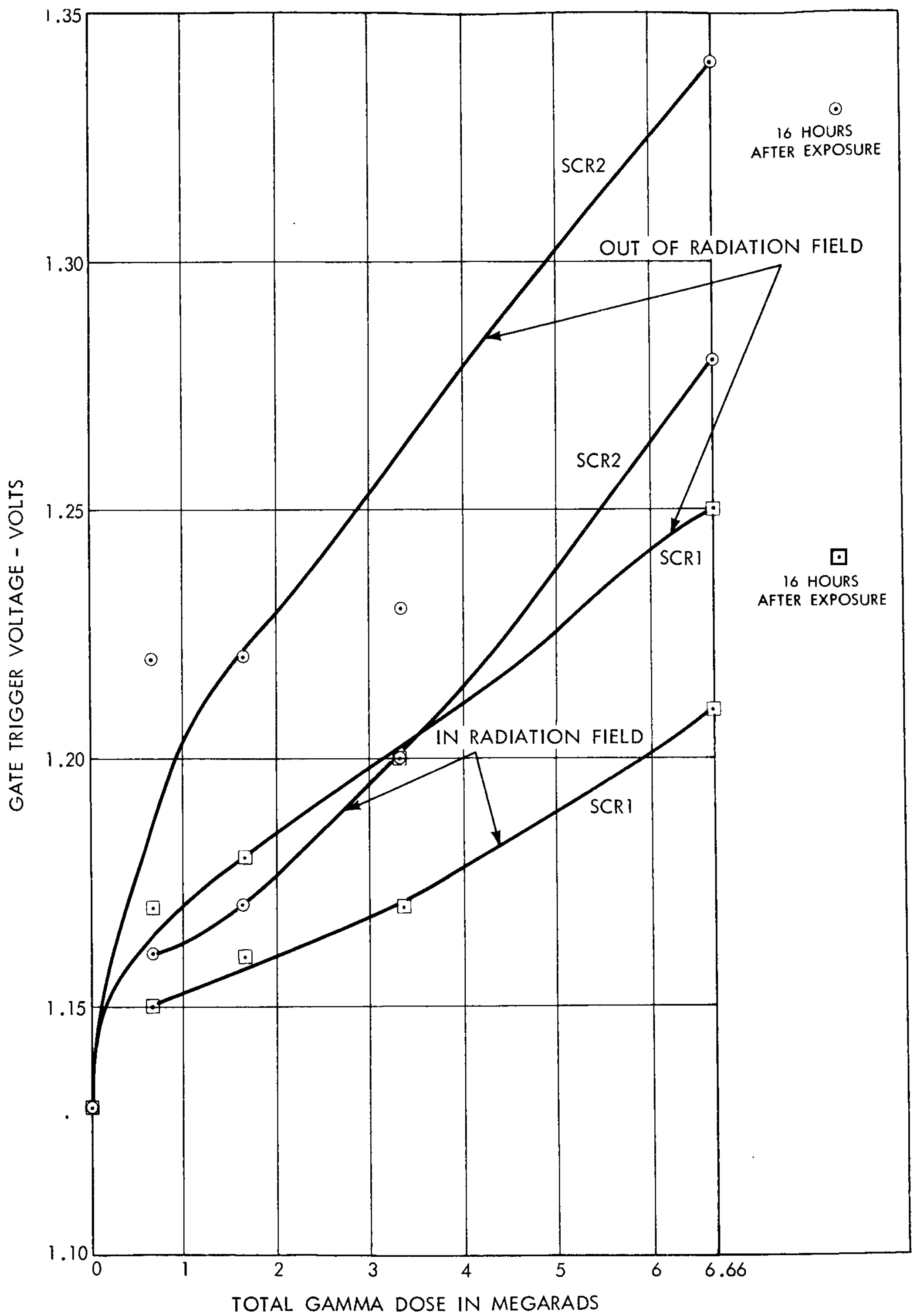

Figure 4 – Gate Trigger Voltage vs Total Gamma Dose

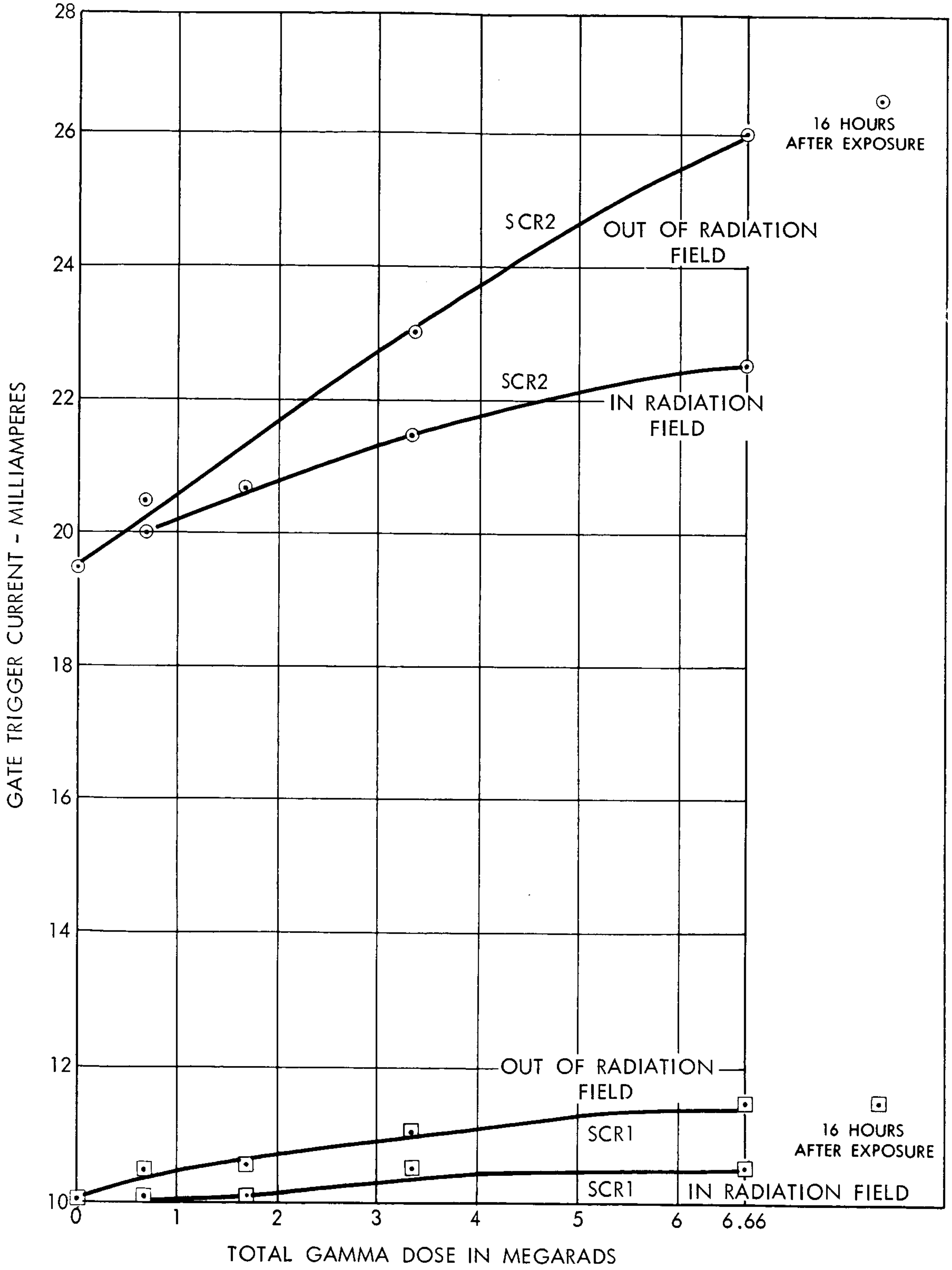

Figure 5 – Gate Trigger Current vs Total Gamma Dose

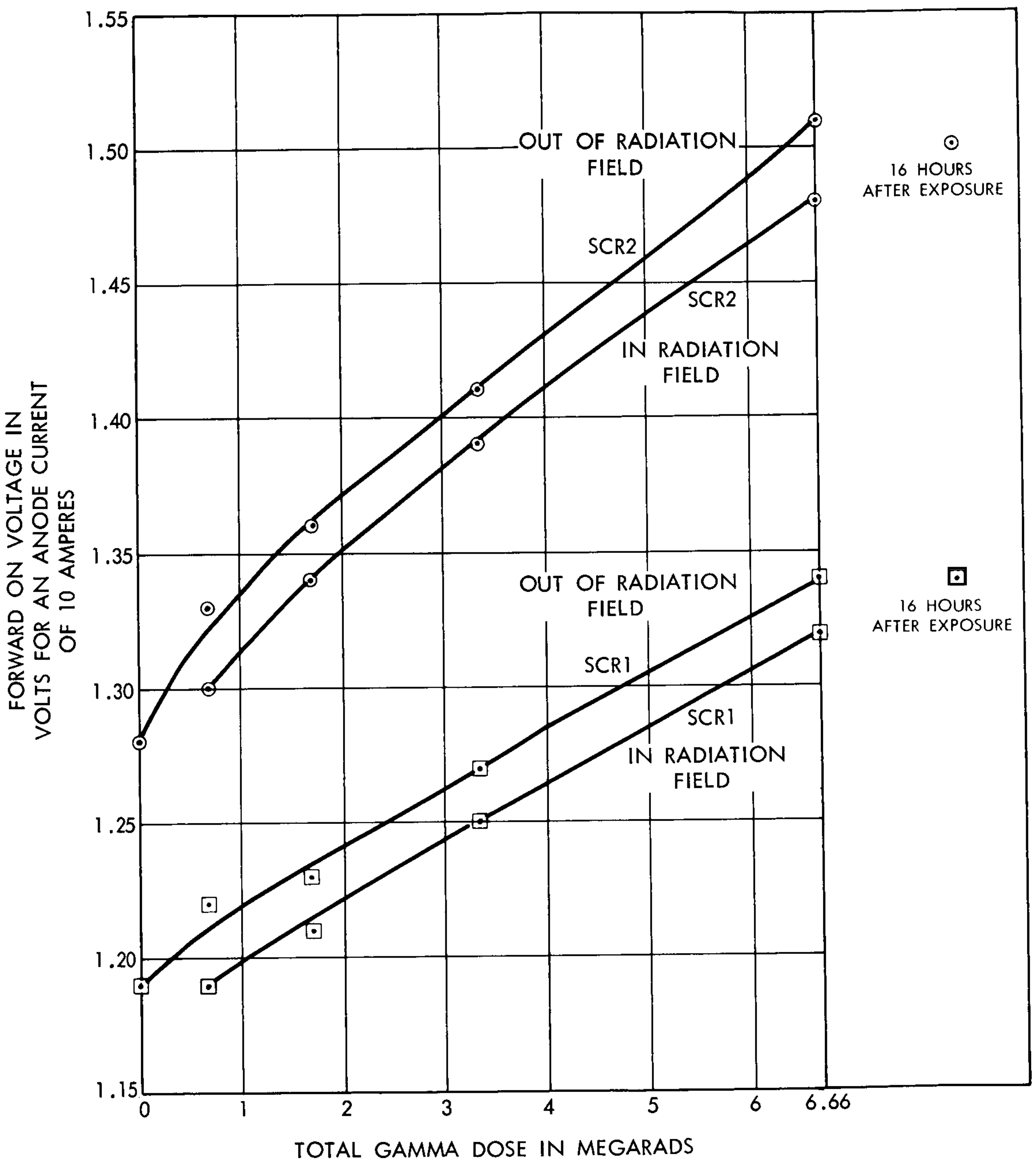

Figure 6 – Forward On Voltage vs Total Gamma Dose

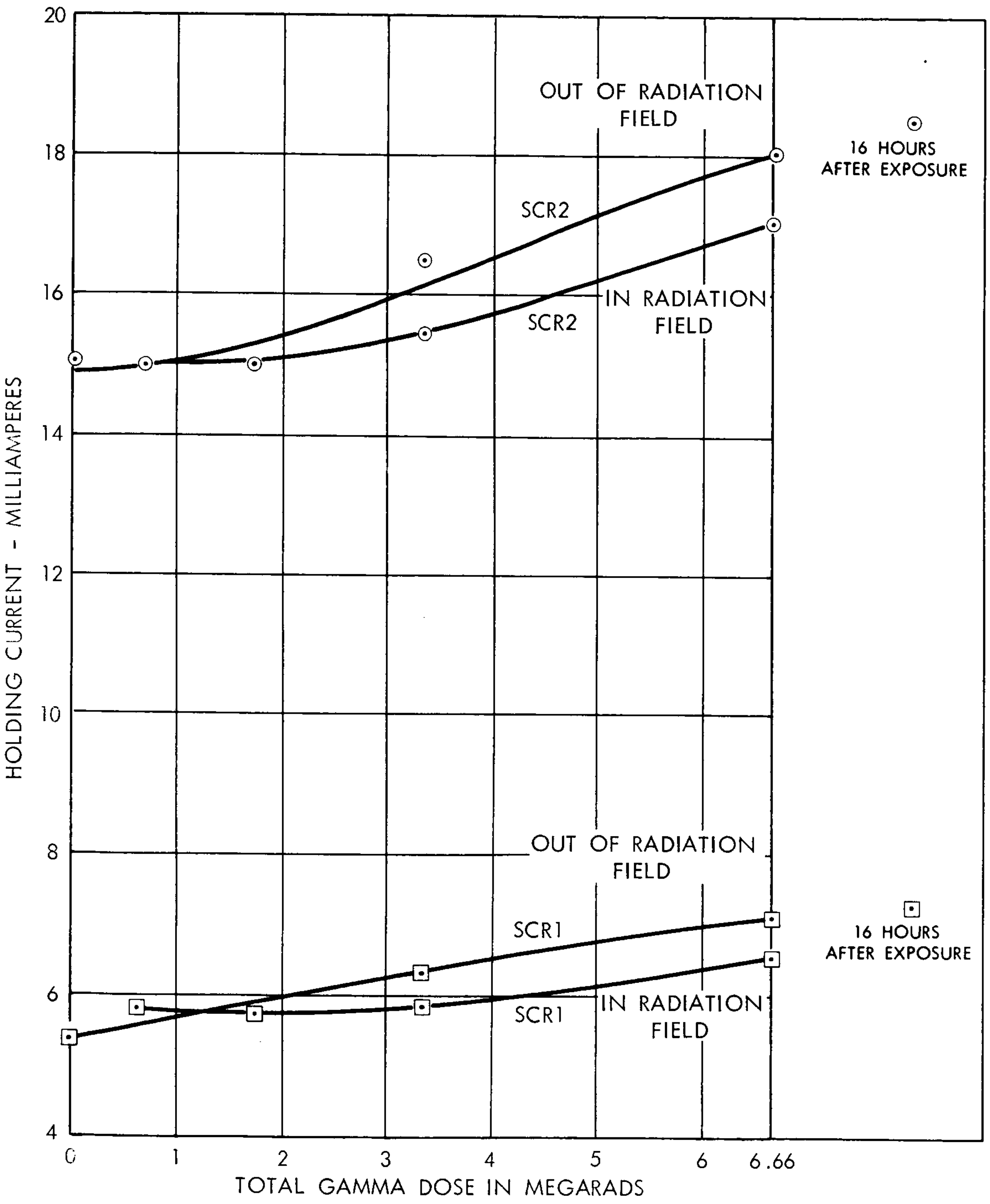

Figure 7 – Holding Current vs Total Gamma Dose

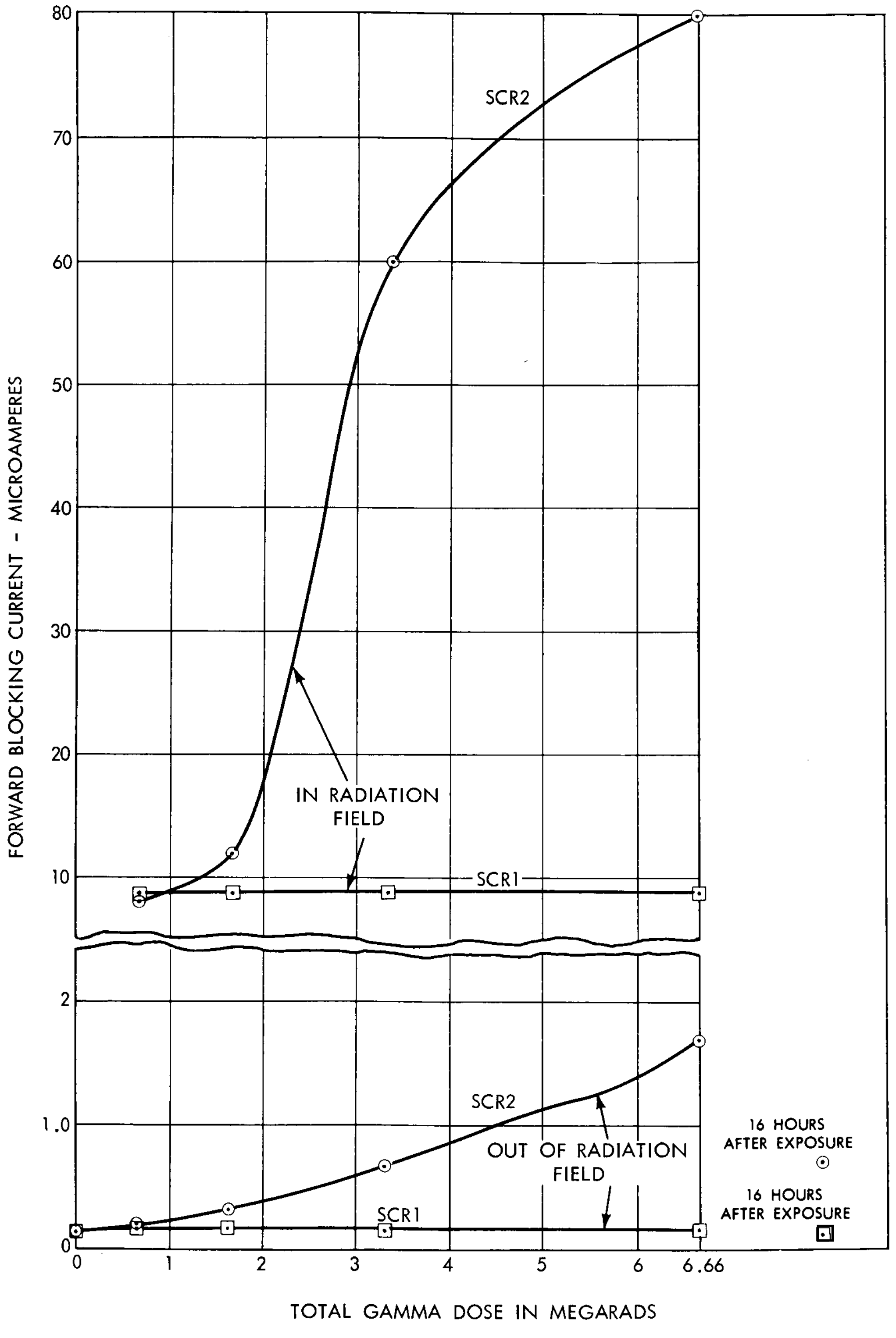

Figure 8 – Forward Blocking Current vs Total Gamma Dose

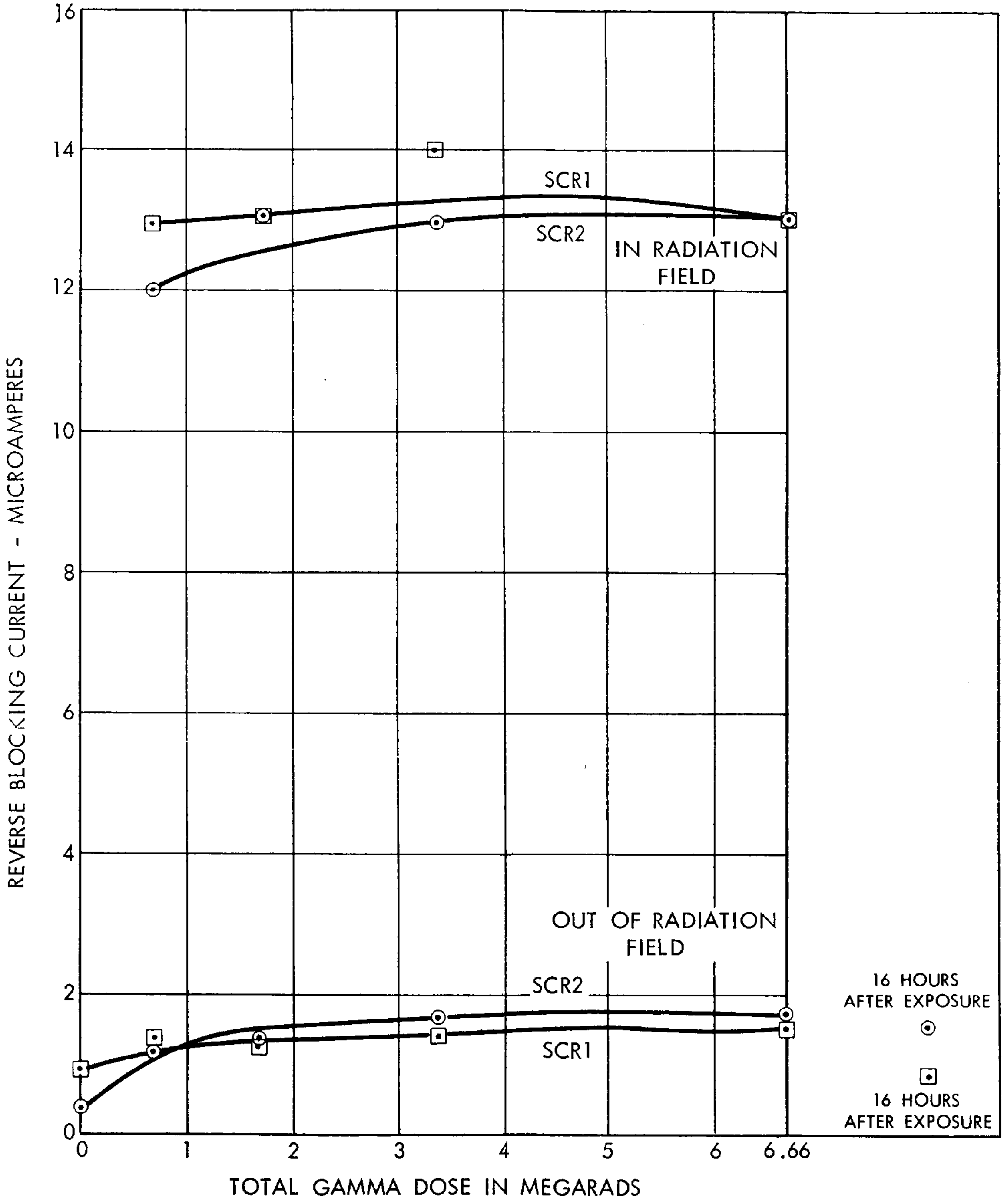

Figure 9 – Reverse Blocking Current vs Total Gamma Dose