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GPO PRICE $ ______

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Hard copy (HC) #2.00

Microfiche (MF) .50

ff 653 July 65

FACILITY FORM 602

N66 25577	
(ACCESSION NUMBER)	(THRU)
41	1
(PAGES)	(CODE)
CR-65354	14
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

Enclosure (2) to
0-71000/5L-86

FINAL REPORT

LTV BETA-GAMMA SPECTROMETER

MODEL BG-1

Report No. 0-71000/5R-23

August 1965

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INTRODUCTION

The Nuclear Sciences Group of the LTV Research Center under contract NAS9-4013 has completed fabrication of an LTV Beta-Gamma spectrometer and mock-up in space prototype configuration for the National Aeronautics and Space Administration's Manned Spacecraft Center in Houston. The device, developed by the LTV Research Center prior to this contract, can measure simultaneously the spectra of electrons and bremsstrahlung. Since the radiation received by an astronaut due to electrons impinging upon a spacecraft may result from bremsstrahlung and direct electrons penetrating the walls of the spacecraft, such a device offers several advantages over a combination of devices necessary to perform the same function in space. This concept has also proven quite useful in the laboratory in measurements of electrons scattered by foils, where bremsstrahlung would normally produce exceptionally high backgrounds.

Photographs of the spectrometer and its accessories are shown in Figures 1, 2, 3, and 4. The spectrometer is 2.7 inches in diameter, 14.3 inches in length, weighs 2.2 pounds, and consumes approximately 4.5 watts with its present inefficient low voltage power supply. It is a prototype device and is neither space qualified, nor does it contain the interface electronics required between the detector output and a spacecraft telemetering system, since this varies greatly from one system to another. The space qualified unit will consume less than 1 watt. The output of the device is in the form of two separate channels of linear pulse height information compatible with a Radiation Counter Laboratories multichannel pulse height analyzer. In conjunction with an appropriate selective storage unit, both beta and gamma spectra may be stored in separate sections of the analyzer memory simultaneously. Specific operating instructions are given in the manual which accompanies the spectrometer.

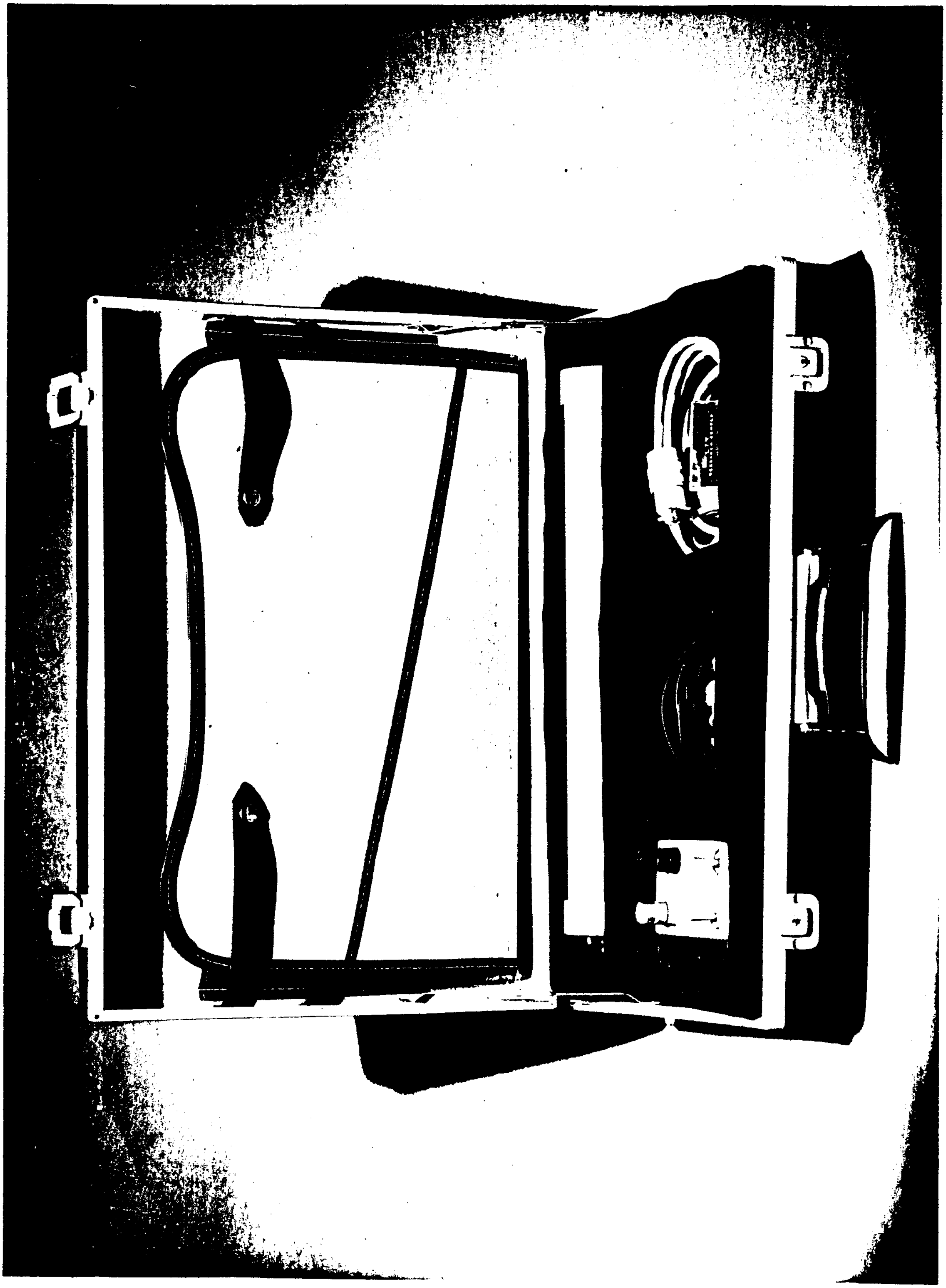


Figure 1 LTV Beta-Gamma Spectrometer and Accessories

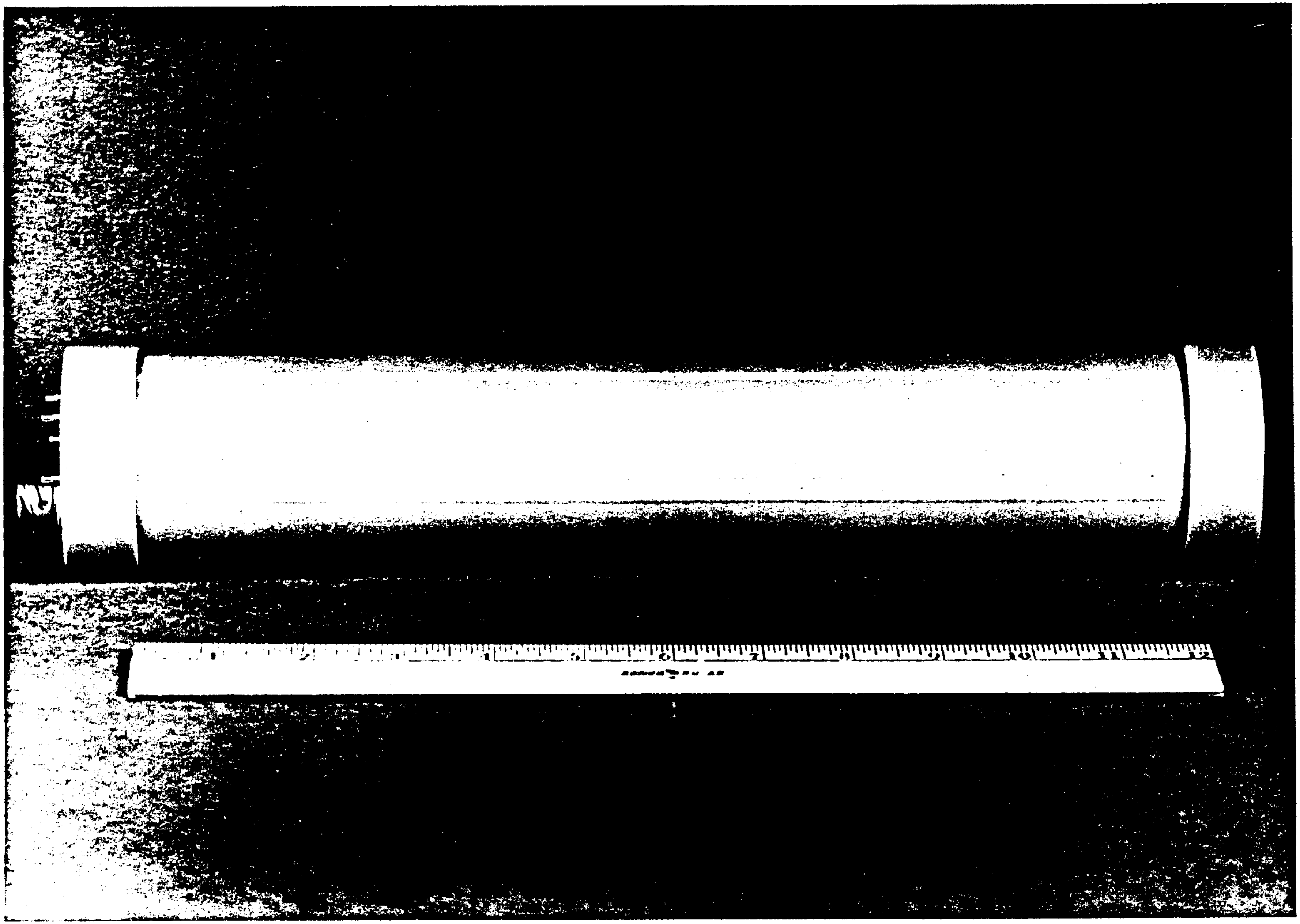


Figure 2 Spectrometer Side View

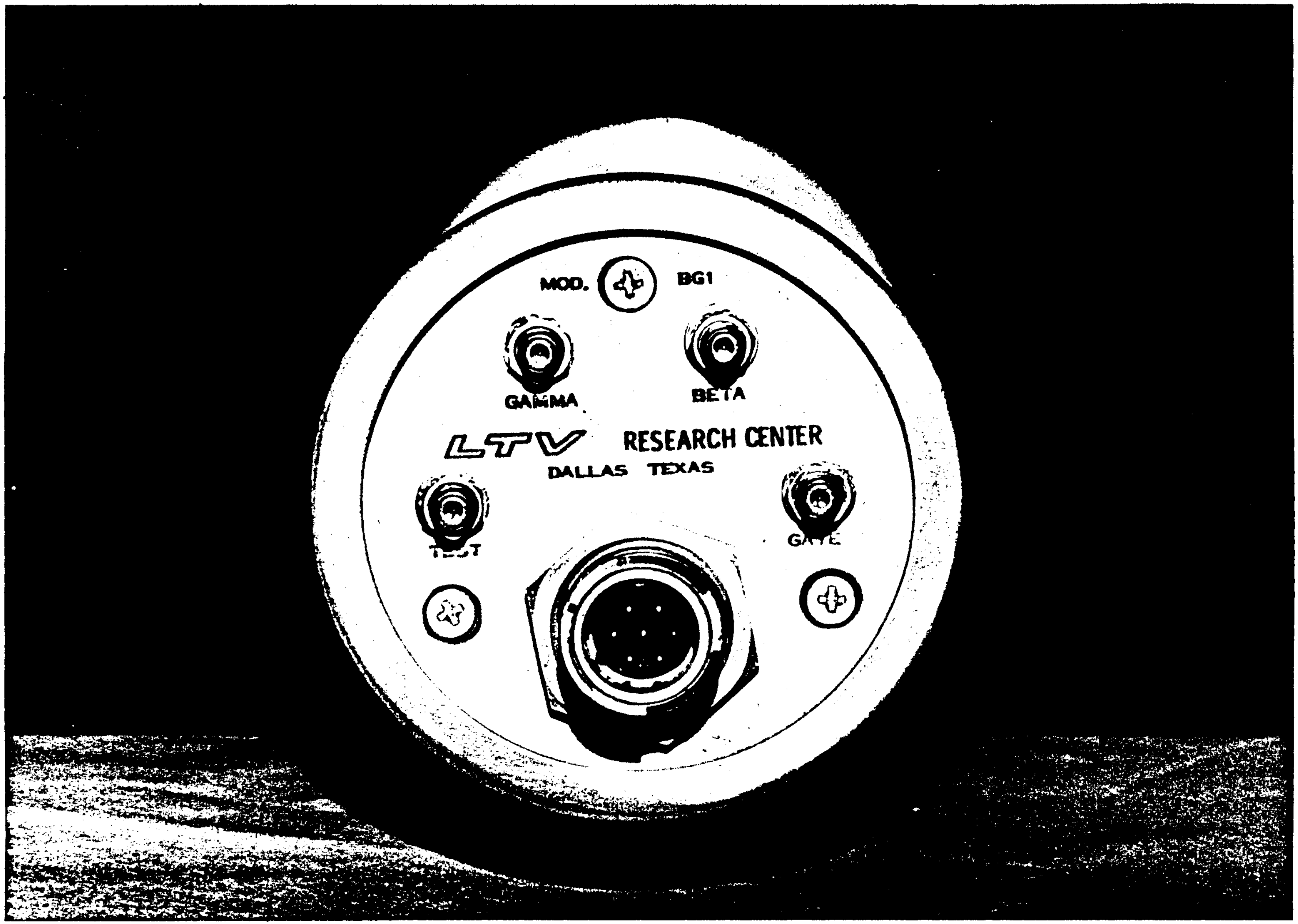


Figure 3 Spectrometer End View

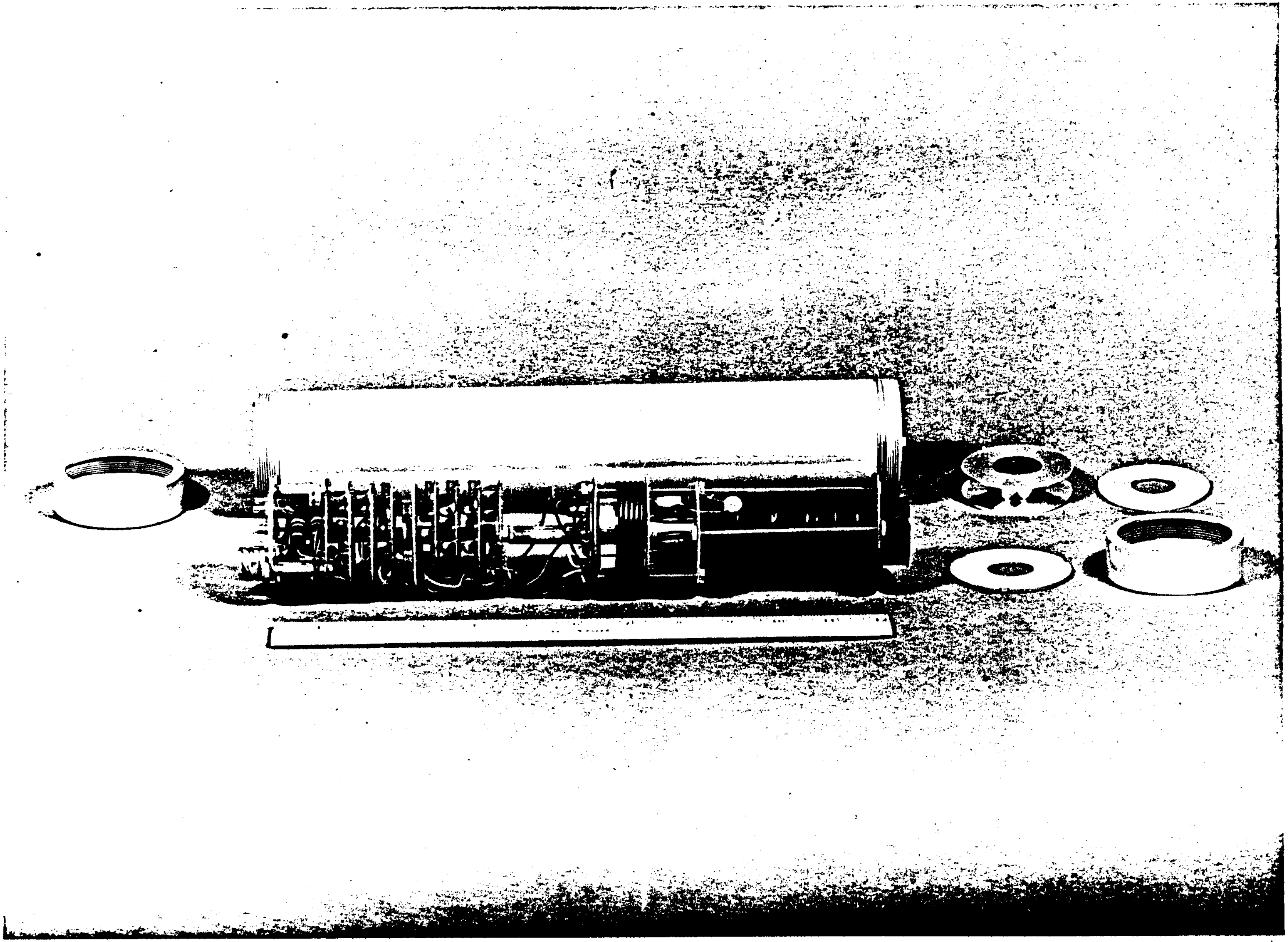
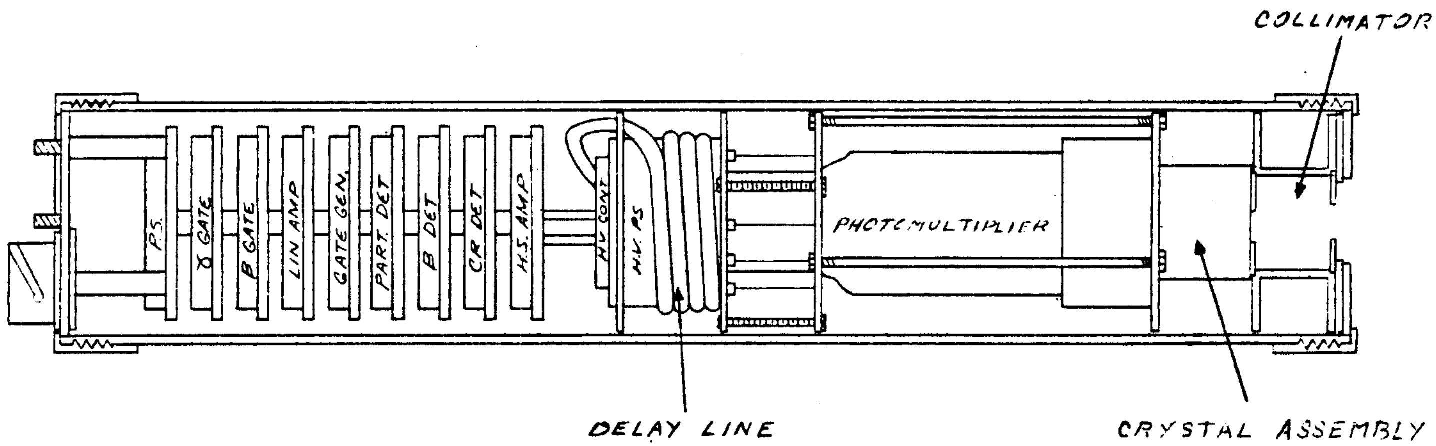


Figure 4 Spectrometer Exploded View

THEORY OF OPERATION

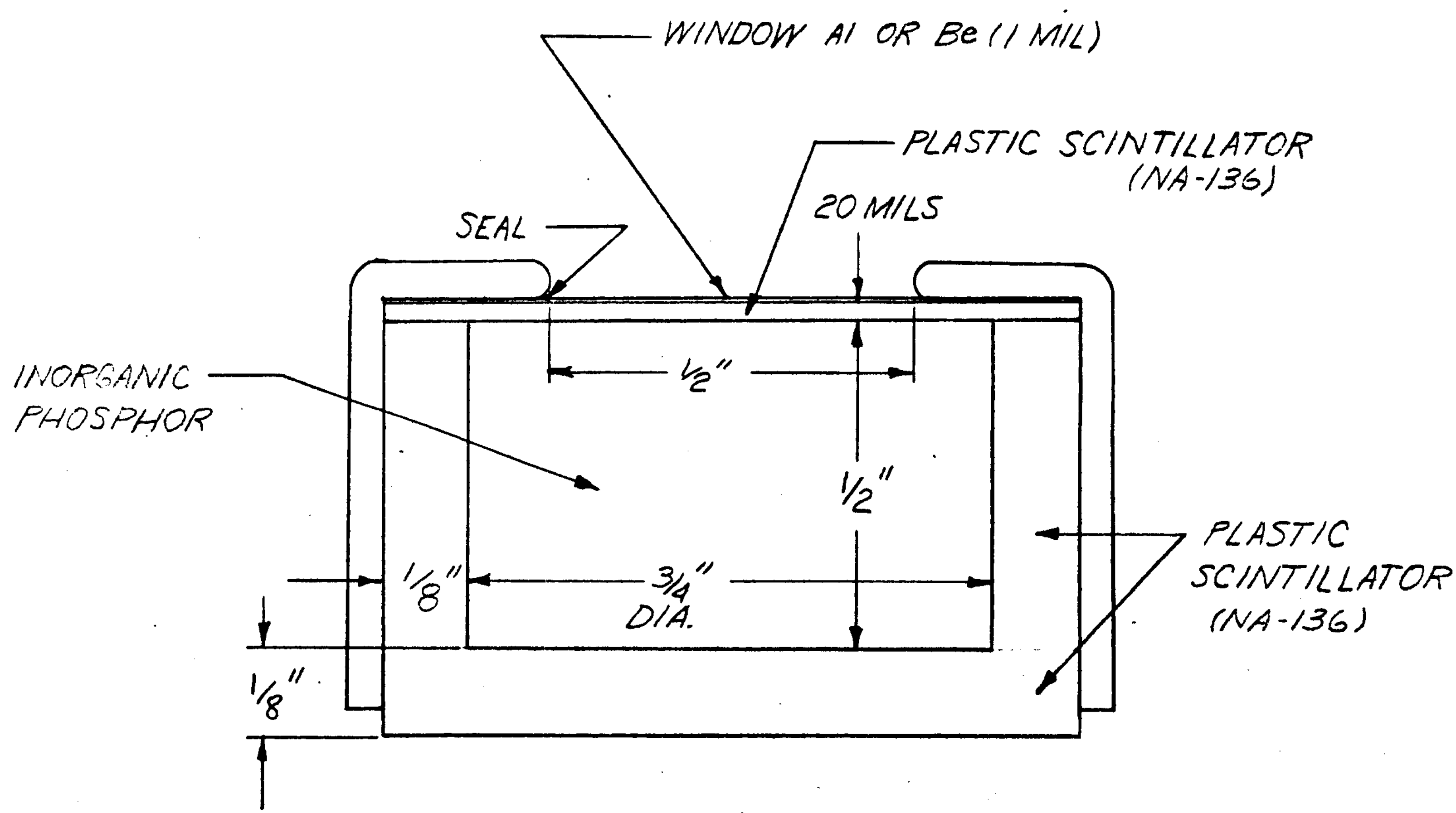
The LTV Beta-Gamma Spectrometer, Model BG-1, shown in Figure 5, is designed to measure electrons and electromagnetic radiation in the energy range 0.5 to 4.0 MeV. It is further designed to eliminate cosmic ray background. These functions are accomplished through the use of a complex scintillation crystal assembly composed of two phosphors with different phosphorescent decay times. The crystal assembly is shown in Figure 6. The center crystal, CsI(Tl), has a relatively slow phosphorescent decay time of 1.1 μs. It is completely surrounded by a NA-136 plastic phosphor with a decay time of less than 3 ns. When a charged particle traverses the plastic a very fast pulse is produced at the anode of the photomultiplier tube, while one passing through the CsI(Tl) produces a much longer pulse. When a particle loses energy in both crystals a fast and slow component are produced at the anode. The anode signal then enters a shorted or near shorted delay line with a delay time t_d of approximately 7 ns. The signal is inverted and reflected at the termination of the line and returns to cancel all but the first 14 ns of the pulse. This process is shown quite clearly by the sketches of oscilloscope traces in Figure 7. The upper curve represents a pulse with both a fast and slow component as would be produced by a beta entering the crystal through the collimator, while the lower curve represents a pulse with only a slow component as would result from a gamma interaction in the center crystal only. It should be noted that the resultant signal in both cases has a negative component approximately 14 ns in duration while only the beta pulse has a positive component.

The negative portion of a signal is detected and utilized to activate the logic in the spectrometer, indicating the presence of an interaction in the



LTV BETA GAMMA SPECTROMETER
MODEL BG-1

FIGURE 5

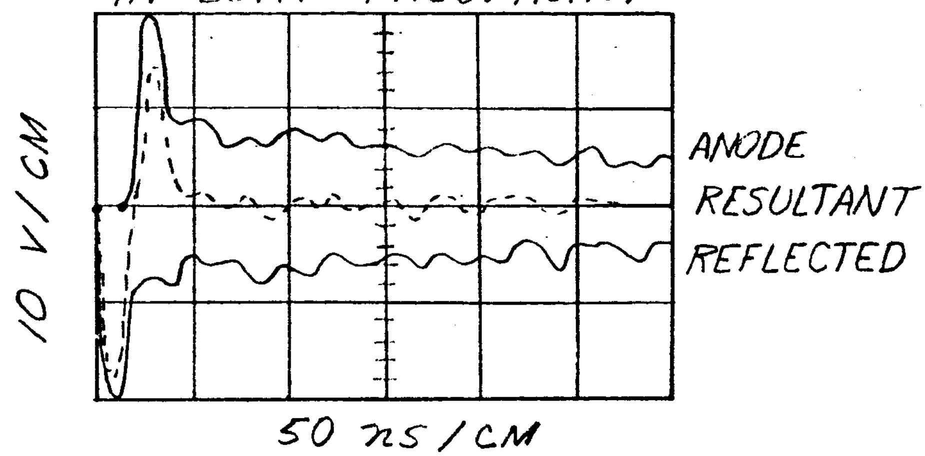


CRYSTAL ASSEMBLY

FIGURE 6

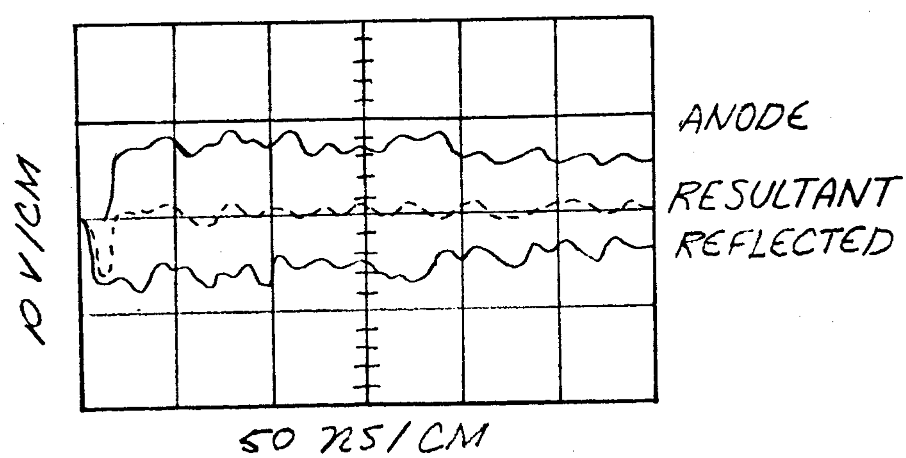
BETA PULSE

(RESULTING FROM AN INTERACTION IN BOTH PHOSPHORS)



GAMMA PULSE

(RESULTING FROM AN INTERACTION IN THE CsI(Tl) ONLY)



SIGNALS FROM CRYSTAL ASSEMBLY

FIGURE 7

crystal. The positive portion of a signal, being present only with a beta or other charged particle, is used to separate these particles from gammas. In addition, analysis of the positive component with both an upper and lower level discriminator distinguishes cosmic rays from betas. The manner in which these functions are accomplished is described as follows:

(1) Electron Detection: When an electron enters the detector via the collimator, shown in Figure 5, it traverses the thin plastic crystal and is absorbed in the CsI(Tl). An analog signal from the last dynode of the photomultiplier is amplified, split, and enters two linear gates. Simultaneously, the signal from the anode enters the recognition circuit just following the delay line. Since the electron penetrated the thin plastic crystal, a fast positive pulse generates a routing signal and opens the Beta linear gate.

(2) Bremsstrahlung Detection: When a photon has an interaction in the CsI(Tl), with the exception of minor wall effects, no energy is lost in the surrounding plastic. In this case no positive pulse is received from the anode circuit so the logic circuit recognizes the signal as a gamma and opens the Gamma linear gate.

(3) Cosmic Ray Elimination: When a cosmic particle enters the crystal it must either pass through the thin plastic scintillator behind the collimator or the thicker plastic surrounding the CsI(Tl). In either case, if the particle is less energetic than minimum ionizing, it will lose more energy in the plastic than an electron and, thus, the amplitude of the fast positive pulse from the recognition circuit will be greater than that produced by an electron which passes only

through the thin plastic. Pulse amplitude discrimination of the pulse is used to eliminate the cosmic rays. The near minimum ionizing protons, which will lose the same energy in the thin plastic as an electron, will lose more energy in the CsI(Tl) than the electrons of interest, thus, producing no background.

DESCRIPTION OF SPECTROMETER COMPONENTS

COLLIMATOR SYSTEM

The collimator is shown in Figure 5. The apertures are made of tantalum, a high density material, to minimize scattering. The dimensions of the collimator system were chosen to be consistent with the electron intensities which would be received inside a space craft in the Gemini orbit. In determining the collimator geometry, one utilizes the following approximate relationship:

$$CN \simeq \frac{F\, a_1\, a_2}{8 \pi d^2}$$

C = count rate per channel

N = number of channels

F = omnidirectional flux

a_1 = area of first aperture

a_2 = area of second sperture

d = distance between apertures

The following dimensions are used in the collimator furnished with the spectrometer:

a_1 = $1\ cm^2$

a_2 = $1\ cm^2$

d = $1.6\ cm$

The effectiveness of the collimation is discussed in the final section of this report.

SCINTILLATION CRYSTAL ASSEMBLY

The specially designed crystal assembly, shown in Figure 6, uses CsI(Tl) and NA-136 scintillators. The size of the crystal assembly was chosen to be consistent with the bremsstrahlung and electron intensities expected in the Gemini orbit. The center crystal, used as the energy determining element, was made of CsI(Tl), since this is a dense scintillator with a long decay constant and good temperature characteristics. The CsI(Tl) crystal was highly polished and set into a well of polished NA-136 and optically coupled using Dow-Corning clear silicon grease. The wall thickness of the well is one eighth inch on the sides and bottom. A twenty mil thick NA-136 scintillator was similarly coupled to the top of this assembly and fitted into a polished aluminum case with a one half inch diameter hole in the top for an electron window. Two sheets of 1/2 mil aluminum foil were placed over the crystal to cover the electron window. This gives a total thickness of one mil for the aluminum light shield, and eliminates light leaks due to pin holes. The scintillation crystal assembly was manufactured at LTV using commercially available scintillators. The scintillation crystal assembly was coupled to the phototube with Dow-Corning clear silicone grease.

PHOTOMULTIPLIER TUBE

The phototube utilized for this particular spectrometer is the RCA 2060. This is electrically equivalent to the RCA 6199 and its ruggedized versions. It is a 10 stage tube with a nominal gain of 6×10^5 at 1000 volts and a transit speed time of 3 to 5 ns. It is operated with negative high voltage on the photocathode, thus, leaving the anode and last dynode near ground potential. The anode is utilized for the high speed recognition circuitry while the last dynode is utilized for the linear signal. A magnetic shield around the phototube is maintained at the potential of the photocathode through a filter isolation circuit. This electrostatically isolates the photocathode from external sources of noise.

HIGH VOLTAGE

The high voltages for the phototube are supplied by a Pulse Engineering Corp. Model P5400 power supply, which is a DC to DC convertor operating from plus 24 to 32 volts DC, and supplying proper voltages for the phototube. It is a highly stabilized space qualified unit of compact dimension and low power consumption. The desired high voltage is set using an external feed back network, and is presently adjusted for approximately 925 volts on the photocathode. A trimming potentiometer is available for approximately a 10 volt change in the photocathode voltage. A wider range of voltages may be obtained by changing the zener diode D_1 on the high voltage control board.

DETECTOR ELECTRONICS

Linear Amplifier - The linear amplifier has two stages and a gain which may be varied from 5 to 200 by changing the feedback characteristics of the first amplifier stage. This makes the noise output level proportional to the gain of the system allowing improved signal to noise ratio for lower gain settings. Adjustment is made with a 25 turn trimming potentiometer. The DC feedback for the stage is constant, giving constant DC stability. The linearity of the amplifier was measured using an RIDL Mercury pulser, and a Victoreen SCIPP 1600 channel analyzer. The results are shown in Figure 8 and indicate a linearity over the entire dynamic range much better than the required 1%. The output of the amplifier is a positive pulse of 5 volts maximum amplitude when terminated in 50 ohms. The amplifier noise level is typically less than 20 mv., peak to peak.

High Speed Circuits - This section describes four basic high speed circuits: the high speed amplifier, the Cosmic Ray detector, the Beta detector, and the Particle detector. The signal from the anode of the photomultiplier, after being delay line clipped, enters the high speed amplifier which has a 50 ohm input impedance and a gain of approximately 80. The amplifier rise and fall times are approximately 5 ns each. It is a three stage non-inverting circuit biased to amplify positive pulses preferentially.

The output of the amplifier is fed into the Cosmic Ray detector board and the Beta detector board. In order to provide isolation and additional gain, each detector board has an input amplifier. These are non-inverting amplifiers with approximate gains of 2 and 8 for the Cosmic Ray and Beta circuits respectively. The amplifier outputs drive high speed Schmidt trigger circuits for pulse height discrimination. The Schmidt trigger circuits feed pulse shaping circuits to provide standardized outputs for the logic elements.

The high speed amplifier output on the Beta detector card is also fed into the Particle detector card where it is amplified and inverted. This inverted output is fed into a Schmidt trigger discriminator and pulse shaping circuit. The reason for the invertor is to provide a logic output for gamma rays, interacting only in the main crystal. Pulses from this type interaction have only a slow decay component, and, since they are delay line clipped, only the positive portion or leading edge of the fast pulse is available. This requires detection of pulses corresponding to a very few photo-electrons leaving the photomultiplier tube cathode. The statistical variation in the actual number leaving the photocathode, for a given energy gamma ray, is the reason for the relatively slow cutoff of the low energy end of the gamma spectrum.

Logic Circuits - The gate generator and control logic is constructed entirely of industrial integrated circuits (with military equivalents) and passive components. The logic is such that the Particle and Cosmic Ray detectors control the triggering of the monostable gate generator. A trigger is produced only if a Particle detector pulse is generated in the absence of a Cosmic Ray detector pulse.

The final two gates in the gate control logic are triggered by the outputs of the monostable gate generator and the Beta detector pulse and the monostable gate generator and the complement of the Beta detector pulse. The former opens the Beta gate and the latter the Gamma gate. There is feed back from the logic output such that a gate pulse is generated for a specified time (the gate generator period) for one and only one type particle, regardless of input changes during this period (approximately three microseconds). This eliminates the possibility of dual analysis of a particular pulse and the gate width is sufficient to allow proper analysis of the peak by most analyzers. Since both gates are closed, and only open when the proper logic is generated, it is not necessary to have delay line amplifiers and long gate times.

Linear Gate Circuits - The linear gate circuits, for both Beta and Gamma signals, have gate circuits followed by line driving amplifiers capable of being opened by internal or external command. In addition, the Beta circuit generates a positive 10 volt pulse for the duration of the gating period. All outputs are capacitively coupled to provide maximum compatibility with an RCL analyzer with minimum power supply complexity. The linear outputs are capable of driving a 50 ohm load to 5 volts full scale. They have a 50 ohm output impedance for maximum termination flexibility.

Test Features - The spectrometer is provided with two basic test features. These are an input for an external pulser and external control of the linear gates. The Test input is coupled into the linear amplifier at the junction of the amplifier input and the photomultiplier output. This provides the capability of checking all of the amplifiers in the spectrometer. Since the linear gates are normally closed, it is necessary to use the external gate control when using the test input. The external gate control is also helpful in determining the total spectrum of interactions in the scintillation crystal.

CALIBRATION

This section contains data taken with the spectrometer to illustrate its linearity as a function of radiation energy and response as a function of count rate. In addition curves are supplied showing the response function of the detector to various gamma sources and an electron beam.

ENERGY LINEARITY

Various sets of data have been taken to show that the spectrometer system is linear with respect to pulse amplification. The first set, shown in Figure 8, is a check of the linear amplifier, independent of the rest of the circuit. The response of the amplifier to input pulse height is plotted for amplifier gains of approximately 10 and 200. Any nonlinearities are imperceptible on the graph.

The second set of data, shown in Figure 9 is a linearity check of the entire electronic system, using a mercury pulser. The pulser was connected to the spectrometer Test input so that pulses passed through the linear amplifier, the linear gate circuits of both the beta and gamma channels, an RCL selective storage unit, and into an RCL pulse height analyzer. As before, no nonlinearities are observable on these plots.

Finally, the system was checked for linearity with electron and gamma sources. These results are shown in Figure 10. The electron data were obtained in two ways, with internal conversion electron sources and the LTV Research Center's 3 MeV Van de Graaff accelerator. The gamma data were obtained using a series of gamma sources with well known energies. Both plots are linear; however, it should be noted that the electron calibration curve is displaced from the gamma curve due to partial absorption of the electrons in the aluminum and thin plastic windows over the CsI(Tl) crystal.

AMPLIFIER LINEARITY
(X-21 ATTENUATION OF PULSER AT TEST INPUT)

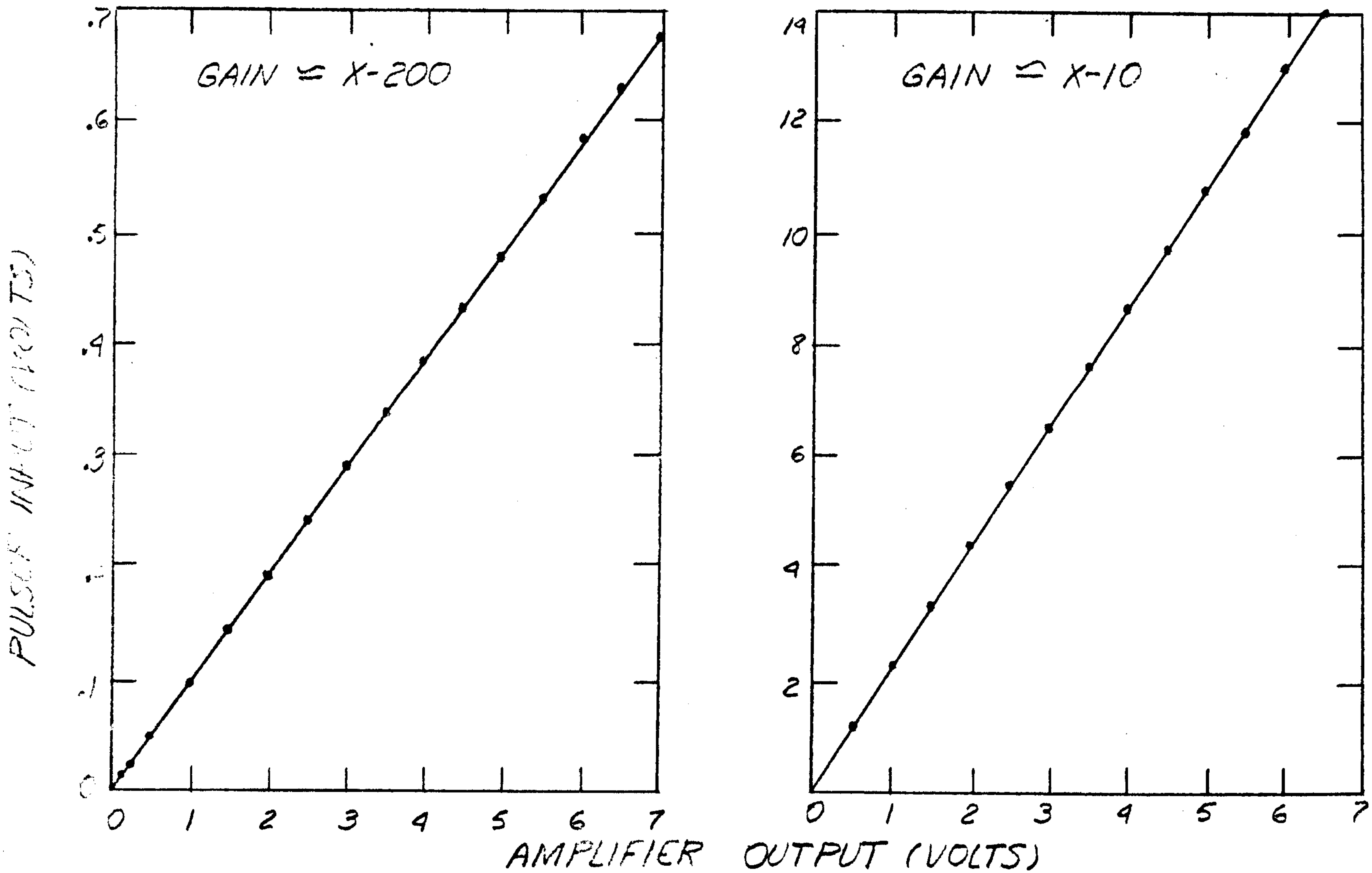


FIGURE 8

ELECTRONIC SYSTEM LINEARITY

PULSER IN AT TEST INPUT

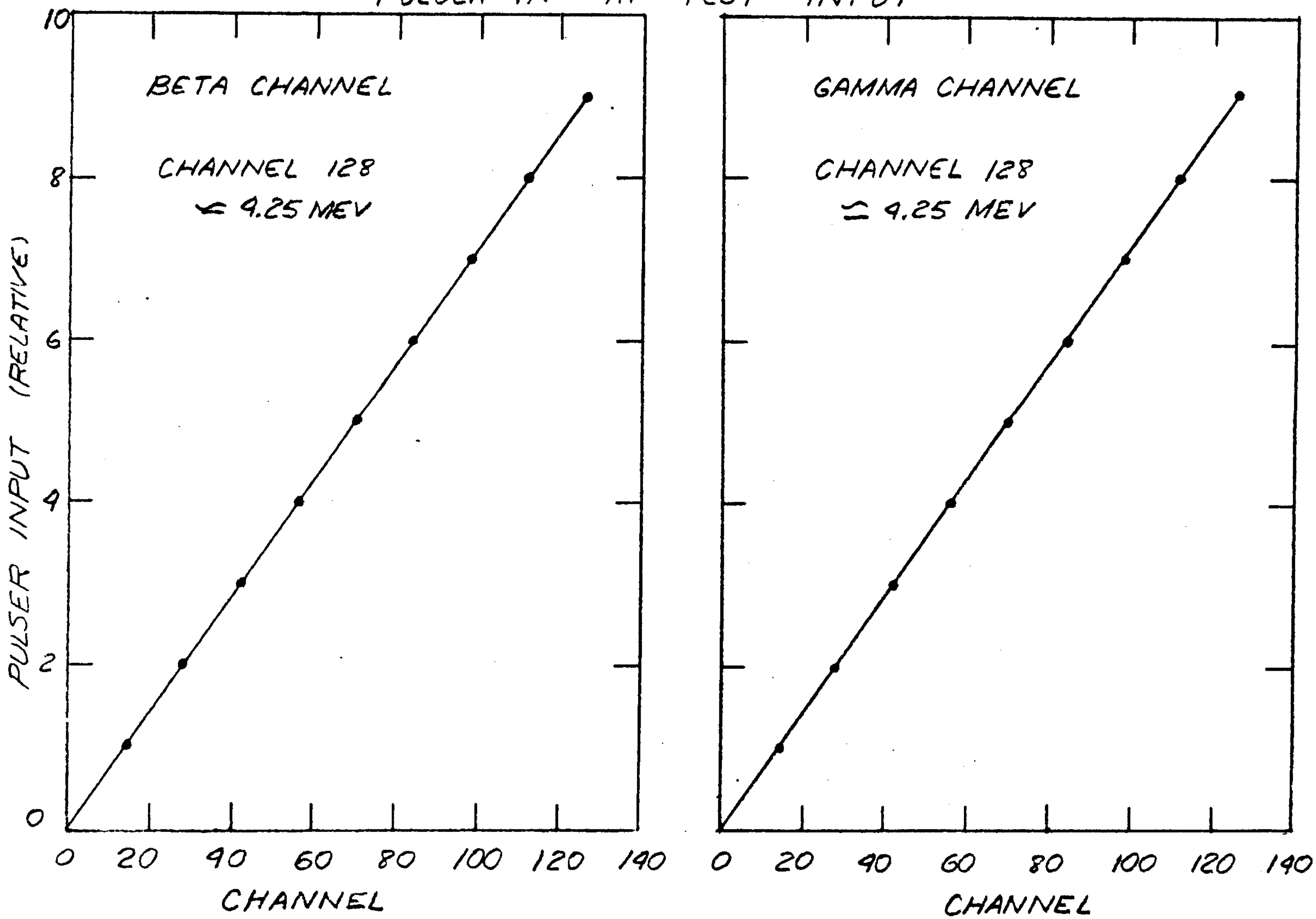
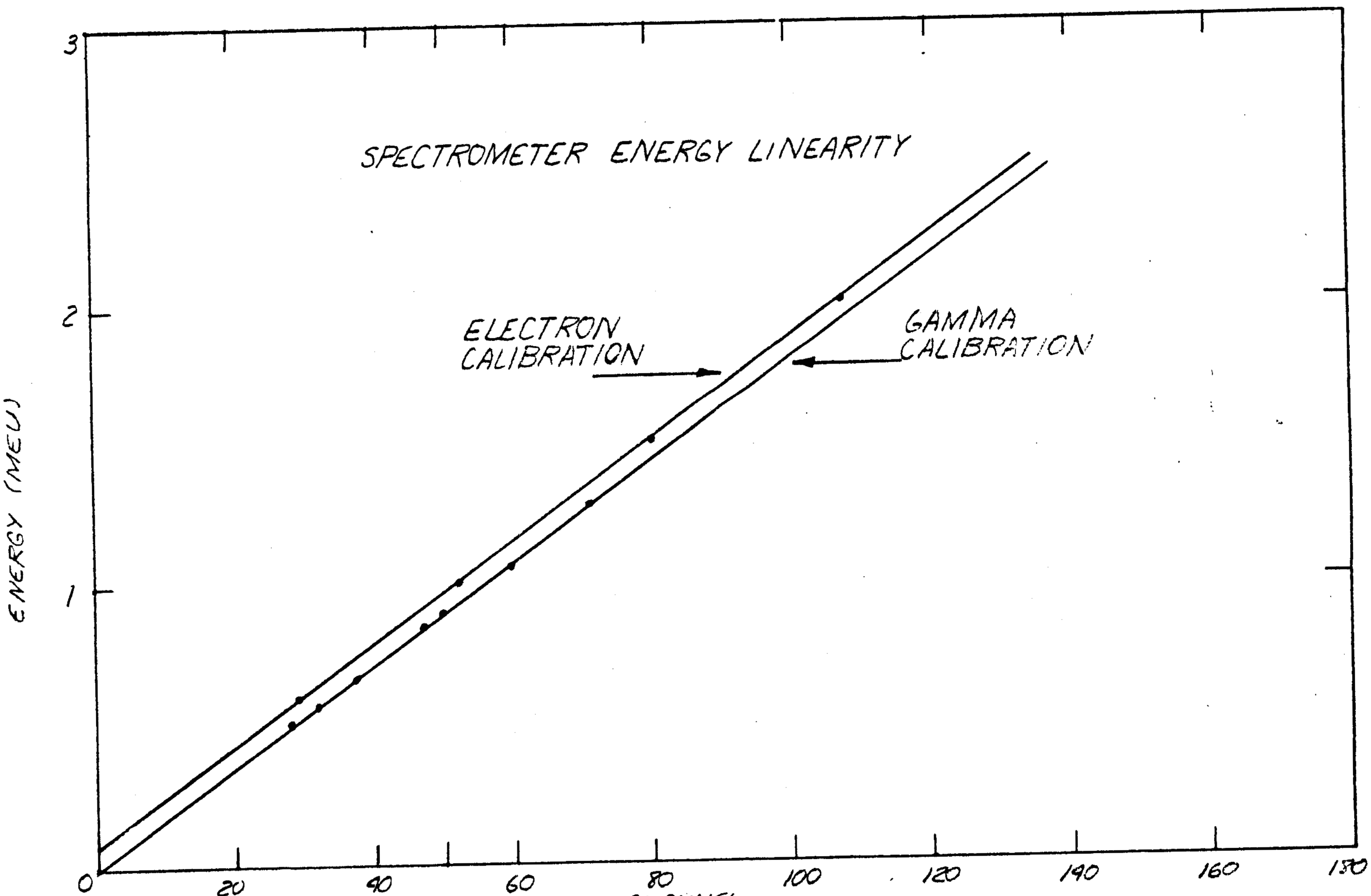


FIGURE 9



SPECTROMETER ENERGY LINEARITY
ELECTRON CALIBRATION
GAMMA CALIBRATION
ENERGY (MEV)
0
1
2
3
20
40
60
80
100
120
140
160
180
CHANNEL

FIGURE 10

FLUX CALIBRATION

A measure of the linearity of the spectrometer to count rate is shown in Figure 11. These data were taken by placing a Cs^{137} source at fixed distances from the spectrometer crystal to vary the count rate in a known manner. The curve is seen to have a true inverse square relationship, illustrating linearity, to count rates of approximately 500 counts per second, where it begins to deviate slightly.

ANGULAR EFFICIENCY

The relative efficiencies as a function of incident angle have been measured both for betas and gammas. The function for betas, shown in Figure 12 was measured with a Cs^{137} source in air along an arc 4 inches from the center of the inside collimator aperture. The strength of the source was approximately 2.5 μc and the counter was biased to count only the internal conversion electrons.

The gamma angular distribution, Figure 13 was measured along a 12 inch radius circle about the center of the crystal. A 100 μc Cs^{137} source was used for this measurement.

REPRESENTATIVE SPECTRA

Data have been taken with gamma and internal conversion electron sources and the LTV 3 MeV Van de Graaff accelerator to show the response of the spectrometer to monoenergetic beams. The electron data from the Van de Graaff is shown in Figure 14. Both the internal conversion electron spectra and the gamma spectra from Cs^{137} and Bi^{207} sources are shown in Figures 15 and 16 respectively. The gamma rays from a Na^{22} source are shown in Figure 17. In addition, a thick target bremsstrahlung spectrum is shown in Figure 18.

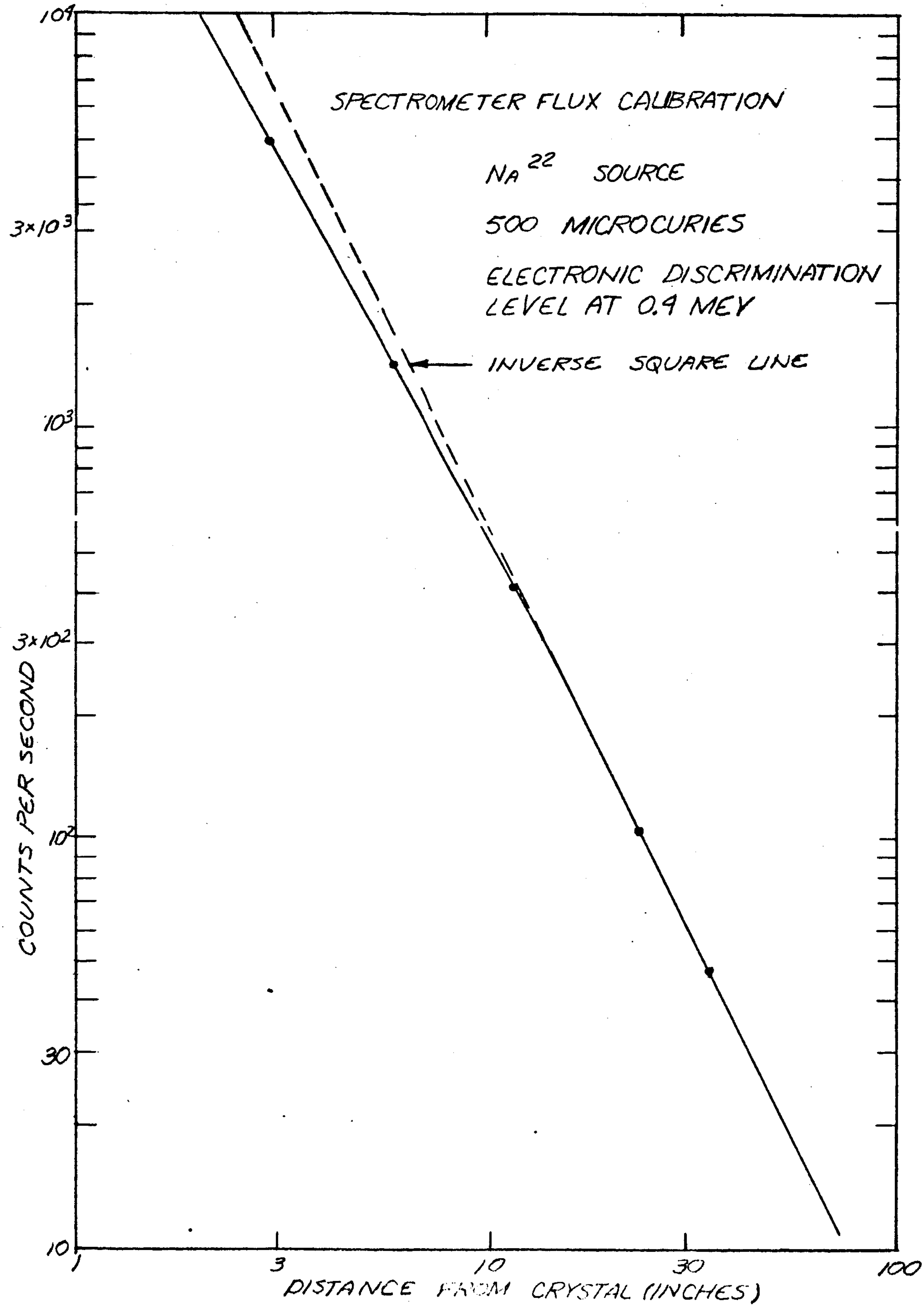
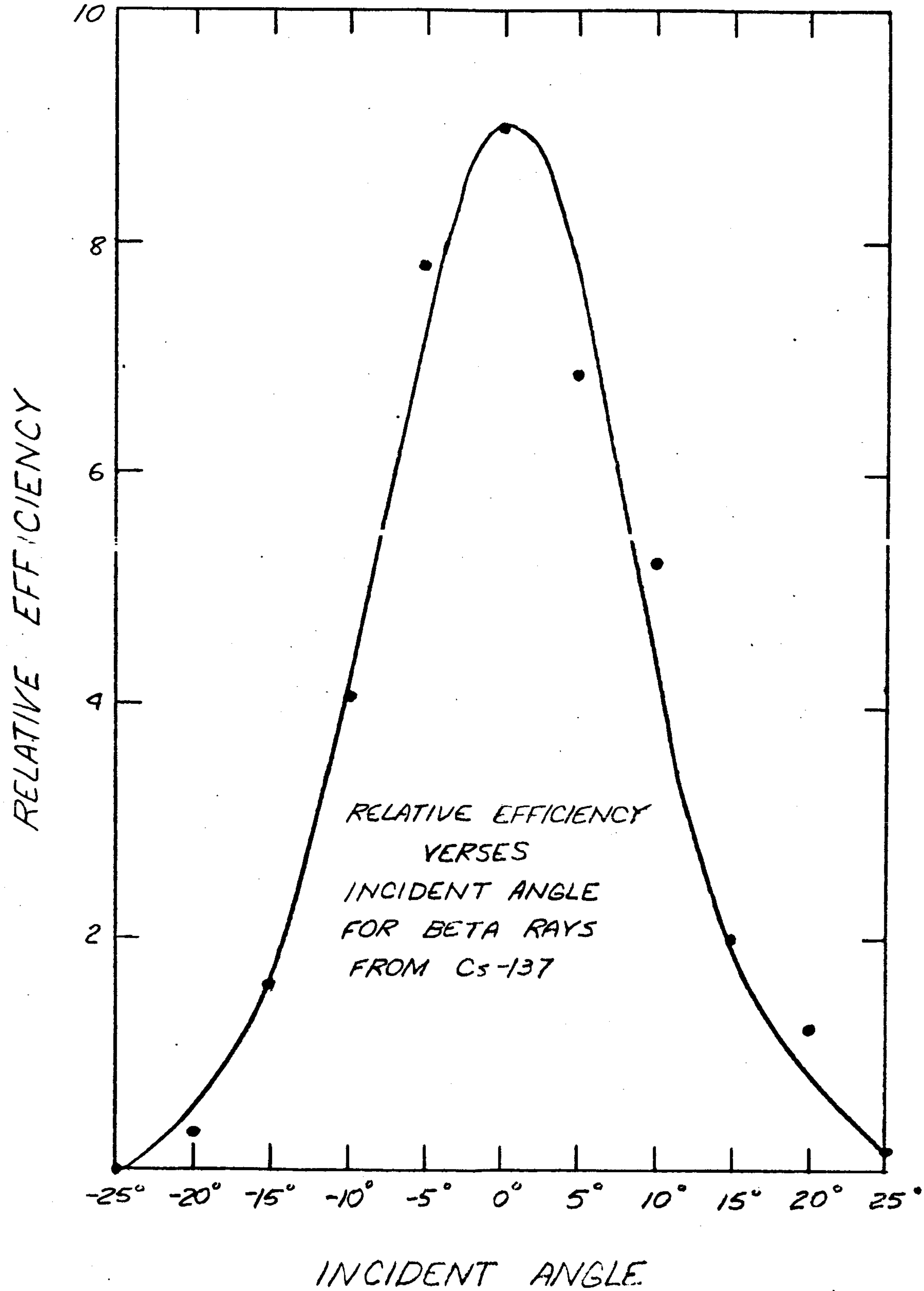

SPECTROMETER FLUX CALIBRATION
NA 22 SOURCE
500 MICROCURIES
ELECTRONIC DISCRIMINATION
LEVEL AT 0.4 MEV
INVERSE SQUARE LINE
10⁴
3×10³
10³
3×10²
10²
30
10
COUNTS PER SECOND
1
3
10
30
100
DISTANCE FROM CRYSTAL (INCHES)

FIGURE 11



10
8
6
4
2
RELATIVE EFFICIENCY
RELATIVE EFFICIENCY
VERSES
INCIDENT ANGLE
FOR BETA RAYS
FROM Cs-137
-25° -20° -15° -10° -5° 0° 5° 10° 15° 20° 25°
INCIDENT ANGLE

FIGURE 12

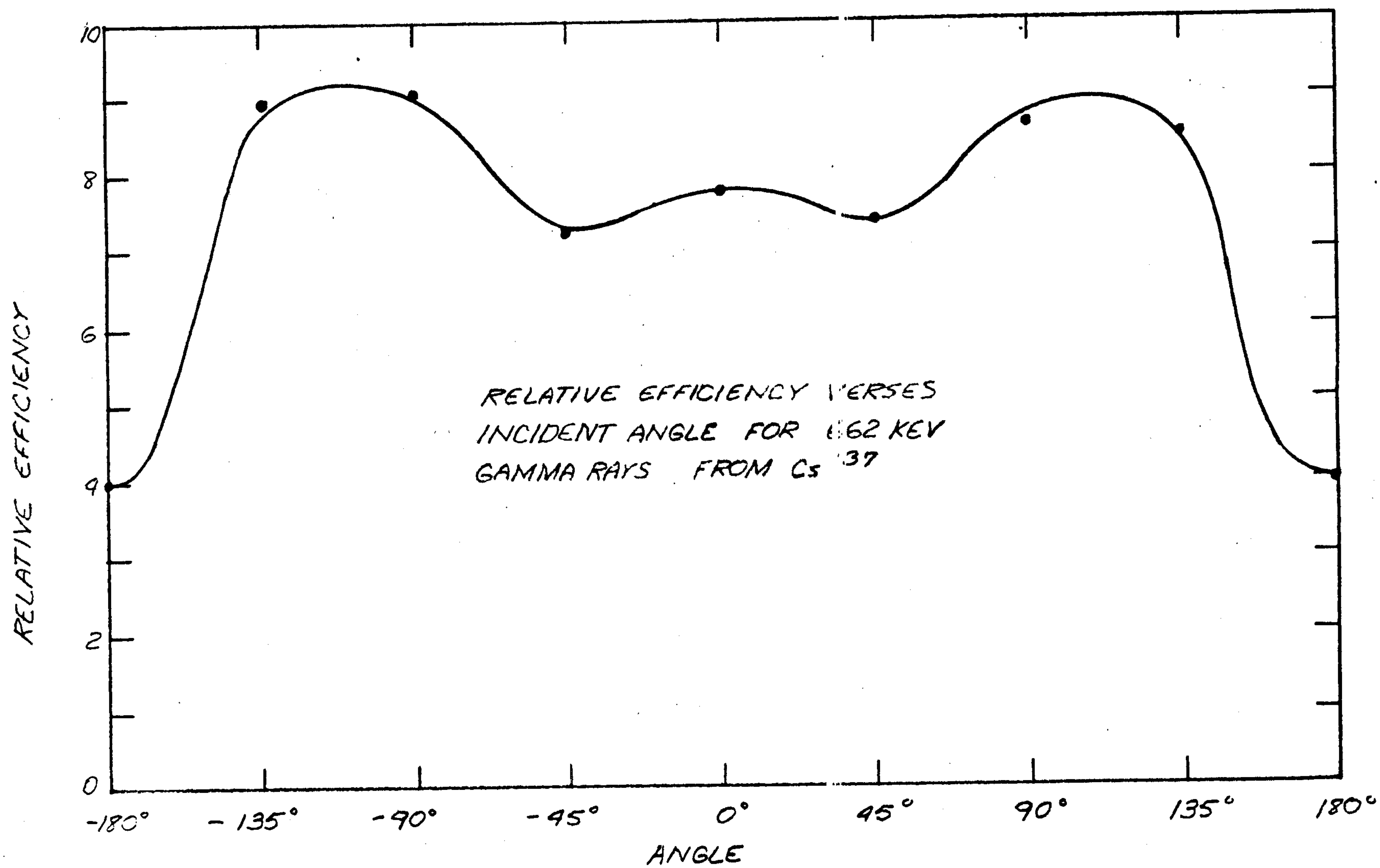

RELATIVE EFFICIENCY VERSES
INCIDENT ANGLE FOR 662 KEV
GAMMA RAYS FROM Cs 137
RELATIVE EFFICIENCY
0
2
4
6
8
10
-180°
-135°
-90°
-45°
0°
45°
90°
135°
180°
ANGLE

FIGURE 13

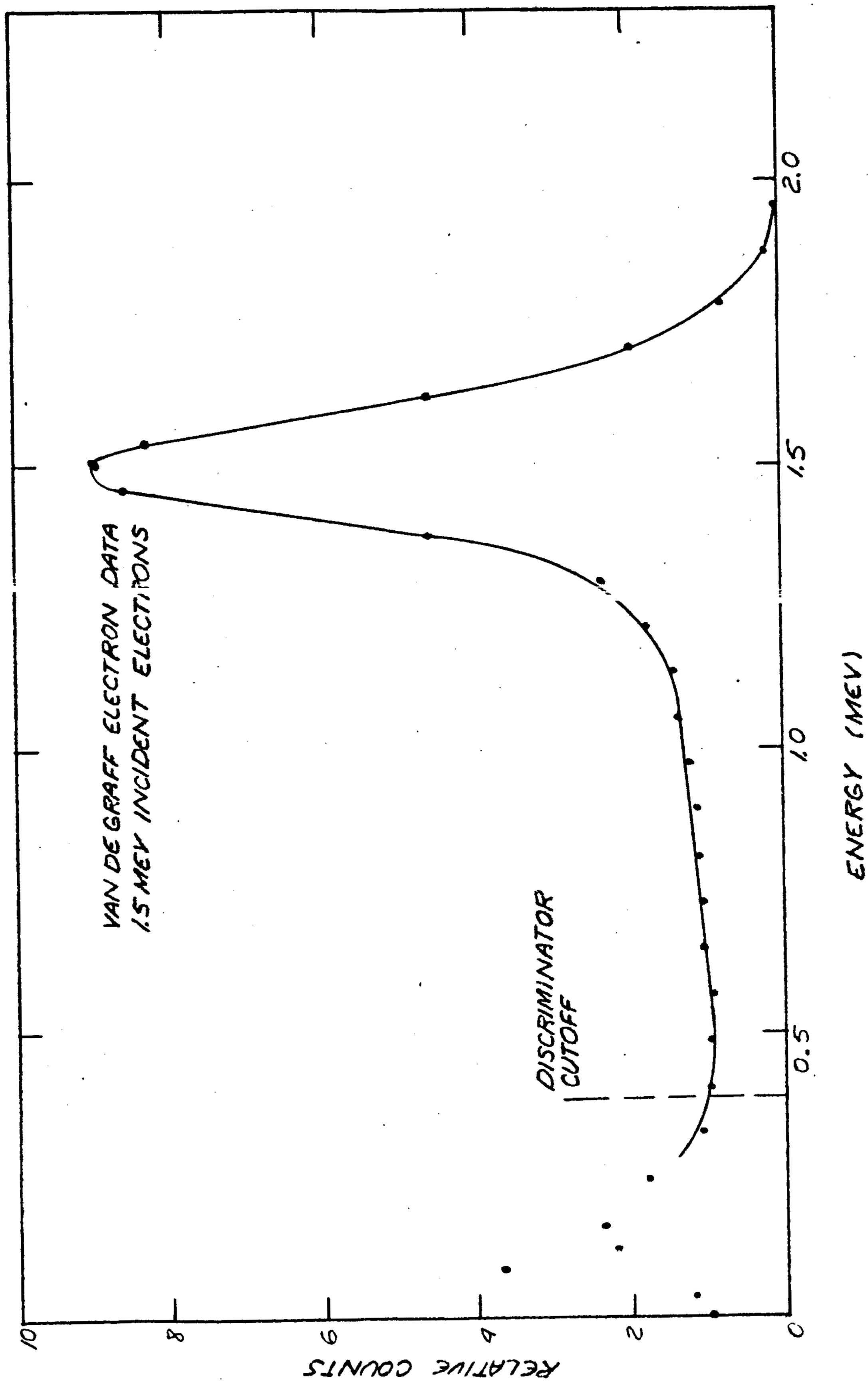

VAN DE GRAFF ELECTRON DATA
1.5 MEV INCIDENT ELECTRONS
DISCRIMINATOR CUTOFF
0.5
1.0
1.5
2.0
ENERGY (MEV)
0
2
4
6
8
10
RELATIVE COUNTS

FIGURE 14

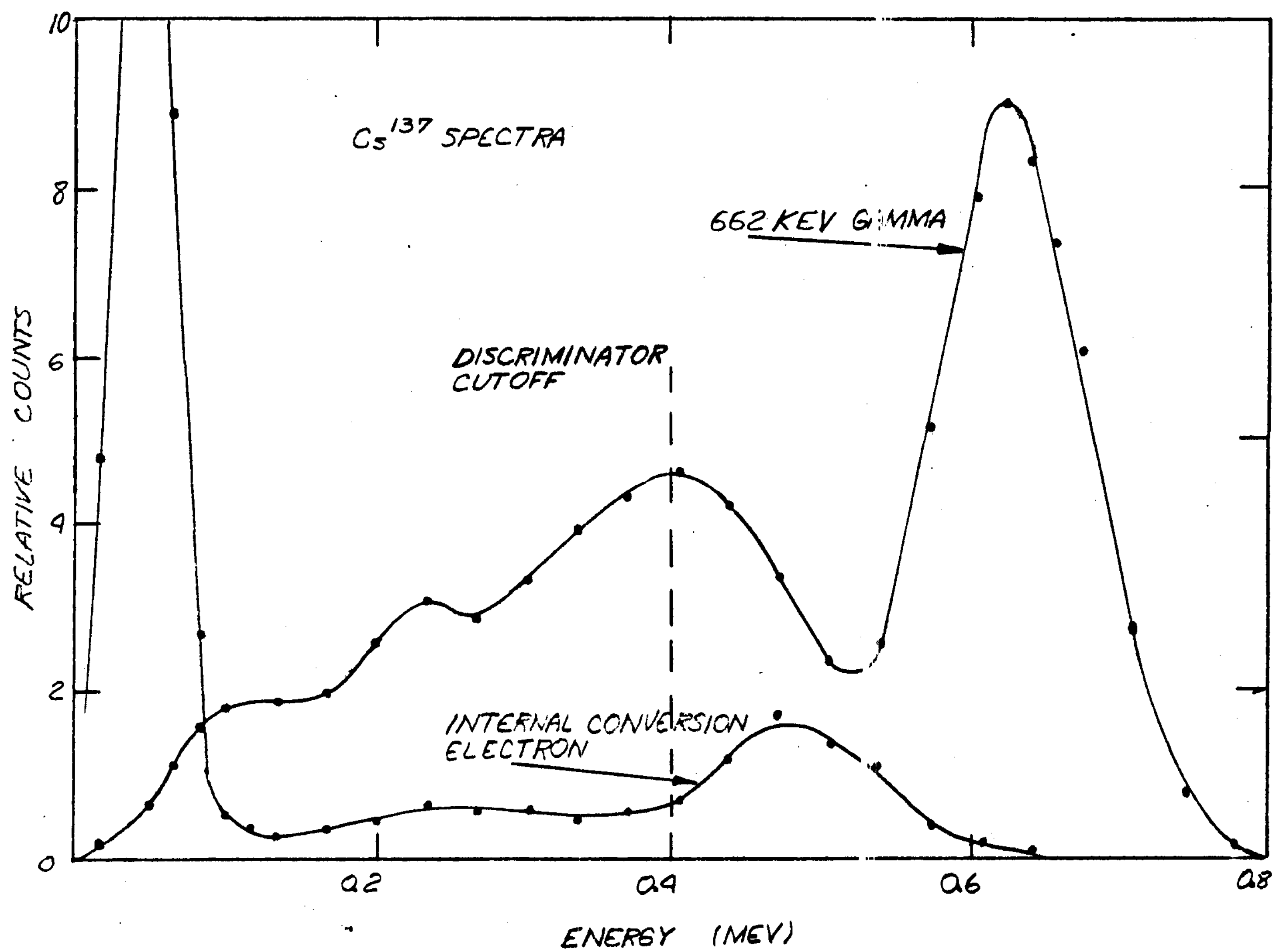
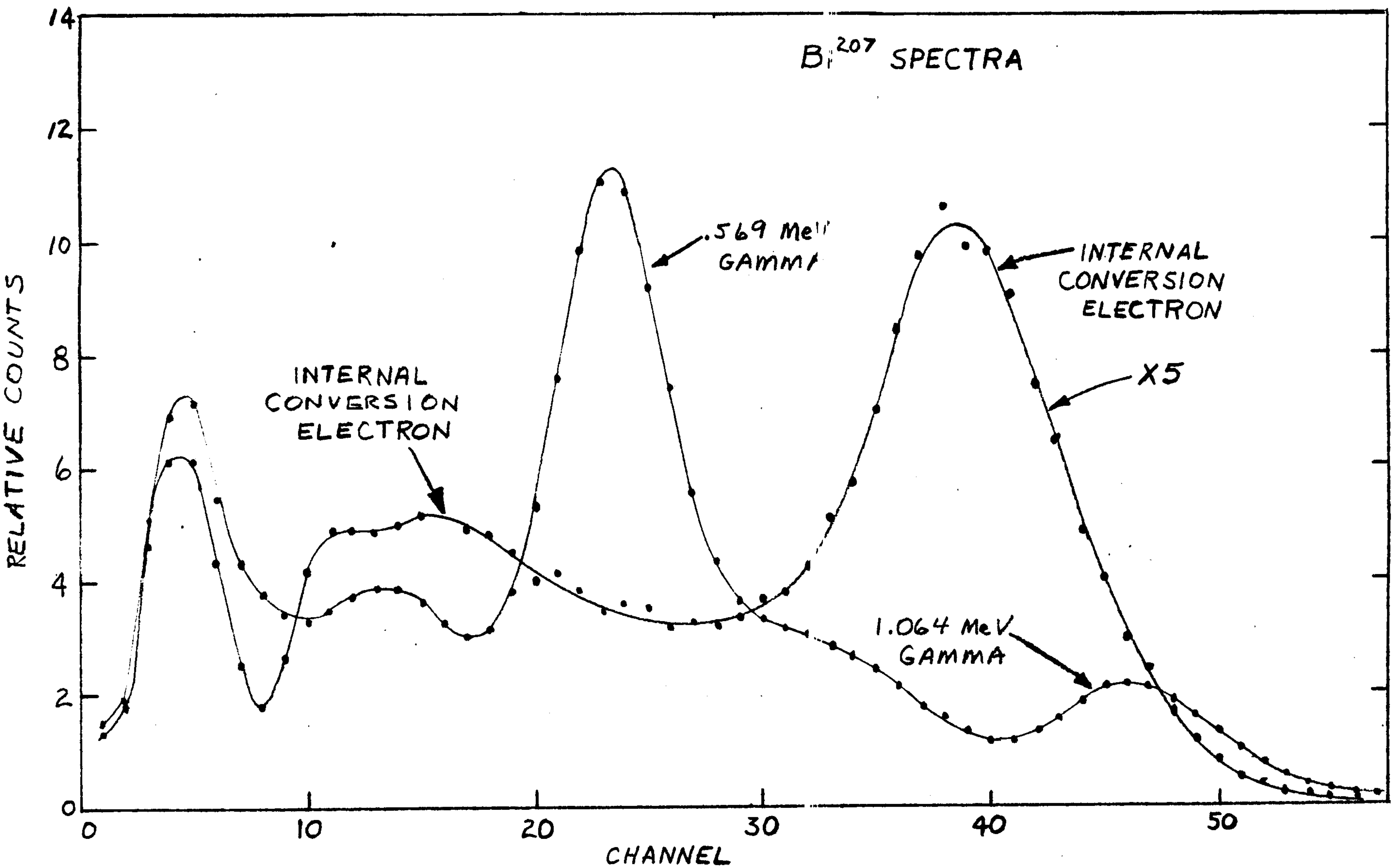
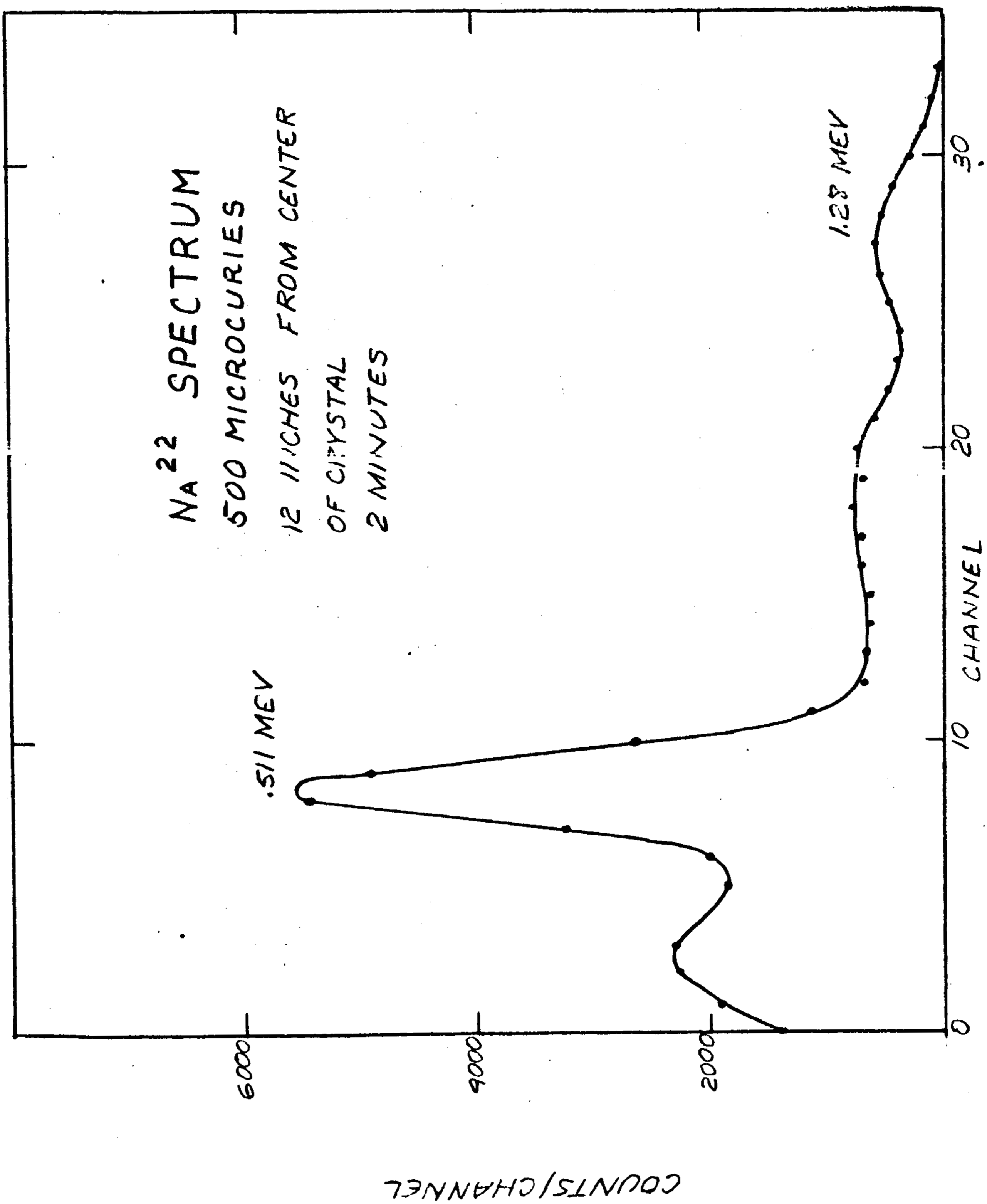

Cs^{137} SPECTRA
662 KEV GAMMA
DISCRIMINATOR CUTOFF
INTERNAL CONVERSION ELECTRON
RELATIVE COUNTS
ENERGY (MEV)
0
2
4
6
8
10
0.2
0.4
0.6
0.8

FIGURE 15



Bi^{207} SPECTRA
.569 MeV GAMMA
INTERNAL CONVERSION ELECTRON
INTERNAL CONVERSION ELECTRON
X5
1.064 MeV GAMMA
RELATIVE COUNTS
CHANNEL
0
2
4
6
8
10
12
14
0
10
20
30
40
50

FIGURE 16



Na^{22} SPECTRUM
500 MICROCURIES
12 INCHES FROM CENTER
OF CRYSTAL
2 MINUTES
.511 MEV
1.28 MEV
0
10
20
30
CHANNEL
6000
4000
2000
COUNTS/CHANNEL

FIGURE 17

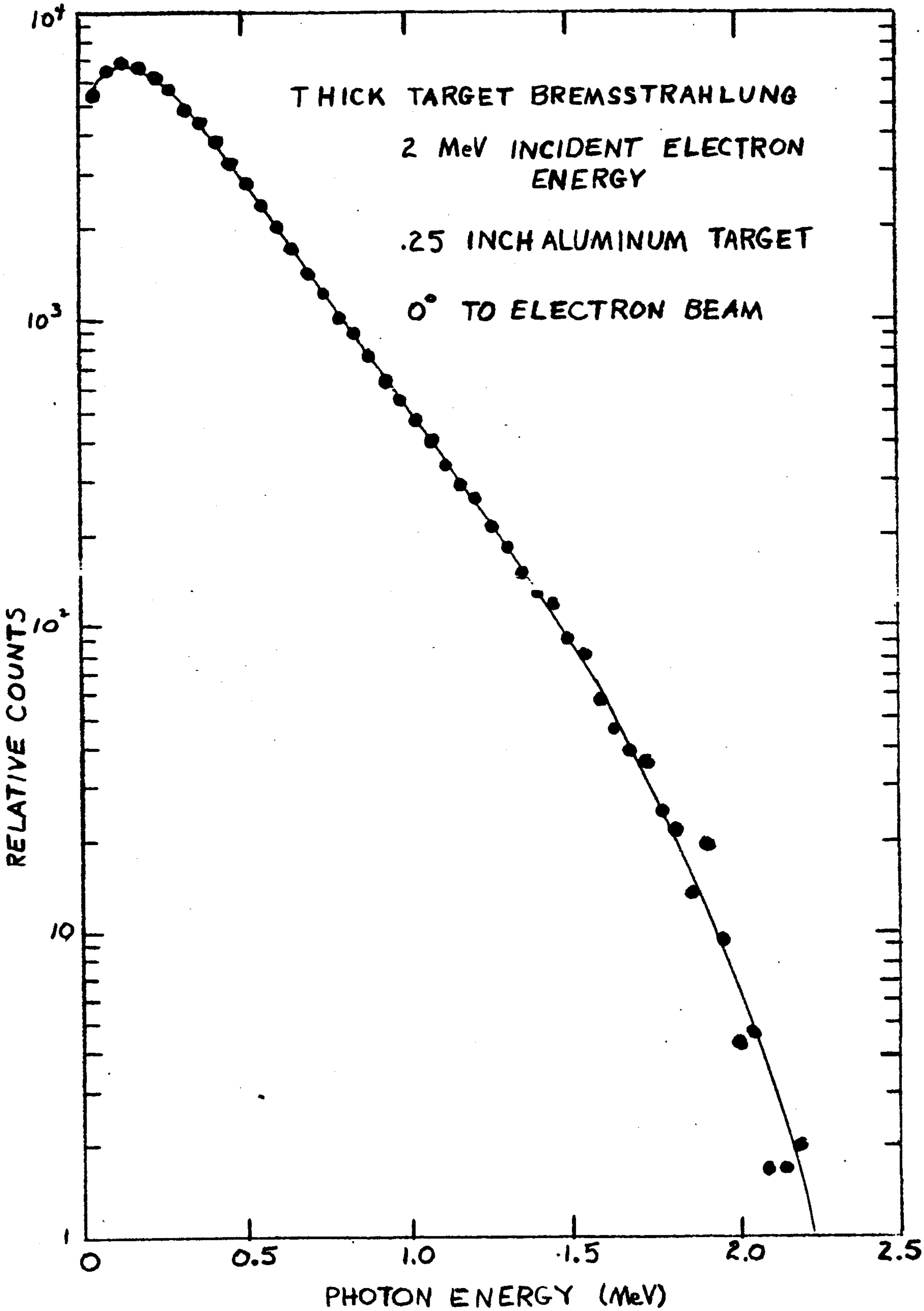

THICK TARGET BREMSSTRAHLUNG
2 MeV INCIDENT ELECTRON ENERGY
.25 INCH ALUMINUM TARGET
0° TO ELECTRON BEAM
RELATIVE COUNTS
10⁴
10³
10²
10
1
0
0.5
1.0
1.5
2.0
2.5
PHOTON ENERGY (MeV)

FIGURE 18

CONCLUSIONS

If is felt that the LTV Beta-Gamma Spectrometer, having been proven in the laboratory, has a wide range of applications. Now, in space prototype configuration, it is especially suited for the field of space radiation measurements where its simplicity and resulting weight and power reduction over separate systems are significant.

LTV RESEARCH CENTER

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