DEVELOPMENT OF A
HIGH ENERGY TOTAL ABSORPTION SPECTROMETER

A Thesis

Submitted to

Faculty of Graduate Studies, University of Manitoba, in partial fulfillment of the requirements of the Degree of Master of Science.

By

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A B S T R A C T

The development of a scintillation spectrometer is described in which use is made of a large sodium iodide crystal surrounded by a plastic phosphor as an anticoincidence shield.

The low energy performance of this spectrometer is evaluated by studying the spectra of several gamma ray sources. The high energy performance is evaluated by studying cosmic radiation up to an energy of 200 Mev. It is shown that the anticoincidence shield is some 30% efficient in reducing the Compton portion of low energy spectra and greater than 95% efficient in the higher energy region.

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TABLES

1. INTRODUCTION

The lower energy portion of any gamma ray spectrum taken with a scintillation spectrometer is considerably enhanced due to higher energy gamma rays losing only part of their energy in the detecting phosphor. Reduction of this lower energy portion has been effected by increasing the physical size of the phosphor, hence increasing the probability of total absorption, and by surrounding the phosphor with an anticoincidence shield, the pulses from which are placed in anticoincidence with those from the phosphor.

The following thesis describes the construction and results obtained from the conjunction of these two systems, a large sodium iodide (thallium activated) crystal surrounded by an anticoincidence shield of scintillating plastic. This apparatus was designed to study the neutral compon ent of cosmic radiation. It was further hoped that the completed instrument might be useful as a total absorption spectrometer for low energy gamma ray work.

2. PREVIOUS WORK

Naqui (1) using a 1 inch by 1 inch cylindrical N a I (TI) crystal in anticoincidence with a shield of scintillating plastic reports a reduction of the Compton portion of gamma ray spectra to 35% of the unshielded value. Using a 4 inch cylindrical well type N a I(TI) crystal completely surrounded by a tank of liquid scintillator, Naqvi (2) reports a reduction in the Compton portions of gamma ray spectra to 20% of the unshielded value. A typical ratio of maximum photopeak counting rate to average Compton counting rates is given as 50 : 1 for Cs^{137} and Zn^{65} spectra.

Olde and Brannen (3) using an unshielded cylindrical Na I (Tl) crystal 4 inches long by 5 inches in diameter and highly collimated gamma ray beams report a reduction in average Compton background to 30% of that of a cylindrical crystal 1 inch long by 1-1/2 inches in diameter. They give the ratio of maximum photopeak to average Compton counting rates as 10 : 1 for Cs^{137} and Zn^{65} spectra.

Results obtained with 9 inch by 9 inch NaI (Tl) crystals similar to the one discussed in this thesis were presented at the Large Crystal Spectrometry Symposium held at Cincinatti, in May 1958 (4). H. Lazar (4) noted typical resolutions of 12 - 13% for the Cs^{137} 662 Kev photopeak with the source external to the crystal, resolutions being somewhat worse when the source was quite near one of the three 5 inch photomultipliers viewing the crystal. With the source inside the crystal, the ratio of photopeak to average Compton counting rates for Cs^{137} was given as 40 : 1. Chapman (4) reported a resolution of 12.5% for the Cs^{137} photopeak using three 5" photomultipliers, with the ratio of photopeak to average Compton counting rates being 12 : 1, (source exterior to the crystal). Use of seven small photomultipliers gave a resolution of 15% but increased the ratio of photopeak to average Compton counting rates to 40 : 1.

H. A. May (4) noted a non-uniformity in a particular crystal and a variation in properties of different crystals under identical conditions. This would imply a dependence of results on the particular crystal used.

R. Hoffstader and A.W. Knudsen (5) using a similar crystal, have found a linear relationship between pulse height and incident electron energy for electrons up to 600 Mev. The Stanford linear accelerator was used as the source of these high energy electrons.

3. THE TOTAL ABSORPTION SPECTROMETER

a. General Description

The spectrometer consists of a large NaI (Tl) crystal mounted in a thin aluminum case. Three photomultipliers view the crystal through a glass light pipe. The outputs of these photomultipliers are electronically summed, amplified and sorted as to pulse height.

Surrounding the crystal is a scintillating plastic viewed by eleven photomultipliers. The outputs from these photomultipliers are summed, amplified and put into anticoincidence with those from the crystal.

b. The Sodium Iodide Crystal

The crystal is a Harshaw Chemical Co. full ingot with dimensions as given in Fig. 1. As sodium iodide tends to absorb water and give off free iodine, it was necessary to do all work on mounting the crystal inside a dry box to prevent clouding of the crystal surface. Plate I is a photograph of the crystal inside the dry box.

Before the crystal was mounted, its surface was ground with number 120 emery cloth until clear and clean. This surface was then polished with number 240 emery cloth. During the grinding and polishing procedures, care was taken not to produce local frictional heating to prevent cracking or chipping the crystal.

To keep the crystal moisture free while in use, it was enclosed in an airtight mounting. This mounting was constructed of aluminum due to its low density and atomic number. Glass light pipes allowed the plane faces of the crystal to be viewed by photomultipliers. Optical joints were made between the crystal and light pipes with a thin layer of Dow Corning D.C. 200 silicone grease, viscosity 10^6 centistokes.

Work was done with the crystal in two different mountings. The first mounting was mechanically weak and was used to find the best geometrical arrangement of photomultipliers viewing the crystal. It is designated as the temporary mounting. The second, mechanically stronger, is designated as the permanent mounting.

c. The Temporary Mounting

The crystal was first optically coupled to the two glass light pipes shown in Fig. 2. A thin layer of silicone grease was then smeared over the remaining crystal surface and this was dusted with powdered aluminum oxide to act as a reflector. An aluminum shell of wall thickness .005 inches was shaped to the proper size and fitted over the crystal assembly. The glass-metal joints were sealed with Apiezon Q vacuum wax and the system was evacuated by thrusting a hollow needle connected to a vacuum pump, through the wall of the shell. This hole was sealed by Apiezon Q during withdrawal of the needle.

d. The Permanent Mounting

The permanent mounting of the crystal consists of an aluminum spinning of dimensions given in Fig. 3 coupled to a single glass light pipe. Plate 2 is a photograph of the crystal in the permanent mounting. The assembly of the mounted crystal is shown in Fig. 4.

The following procedure was followed in mounting the crystal. The crystal was placed, conical end down, inside the aluminum spinning. The plane end of the conical portion of the crystal rested upon the hollowed aluminum disc shown in Fig. 4. Aluminum oxide powder was packed between the crystal and spinning up to the level of the lip of the spinning. A 9-1/4 by 9-3/4 inch O-ring was packed between the crystal and spinning to hold the powder in place. The plane end of the base was cleaned free of powder and optically coupled to the glass light pipe shown in Fig. 4. A 10-1/2 by 11 inch O-ring was placed between the glass and the lip of the spinning. This served to make the system airtight when the two were pressed together by bolting together the two aluminum rings shown in Fig. 4.

e. The Anticoincidence Shield

The anticoincidence shield is a plastic phosphor, type N E 102, obtained from Nuclear Enterprises Ltd. The shield consists of four sections (Fig. 5a), a cylindrical base plate 6 inches thick and

26 inches in diameter, two identical hollow cylinders of outer diameter 26 inches, inner diameter 16 inches and height 11-1/4 inches and a top plate 1 inch thick by 26 inches in diameter.

Four slots were cut into the bottom of one of the hollow cylinders (Fig. 5b) allowing this section to fit over the arms of the stand which was constructed to support the plastic and crystal. The cables feeding the photomultipliers inside the anticoincidence shield enter through one of these slots.

Plates 3, 4 and 5 show three steps in the construction of the shield. All joints between section of the shield were optically coupled with D.C. 200 silicone grease. All other surfaces of the shield were covered with a layer of white tape of good reflectivity supplied by Nuclear Enterprises Ltd. Windows were left in the tape for the placement of photomultipliers. To ensure light tightness, several layers of white, then black, paint were sprayed over the tape on the interior surfaces of the shield. The exterior surfaces were covered by a double layer of aluminum foil and a double layer of black wallpaper. The slots in the plastic wall were taped with reflecting tape and then filled with Apiezon Q. Plate 6 shows this final assembly with the photomultipliers in position.

f. The Stand

Fig. 6a is a diagram of the stand with crystal and plastic in position. Plate 3 is a photograph of the stand with the crystal, its photomultipliers and the base plate of the plastic in position.

The stand has four legs of 2 inch by 1 inch channel iron. These are bent inward at a height of 40 inches to form four 9-1/2 inch arms. The bends were welded for rigidity. For support, the legs were bolted to two horizontal rings of 2 inch by 2 inch angle iron, inner diameter 30 inches. A 13 inch section of 1/2 inch aluminum rod, threaded at both ends, was bolted to each arm as in Fig. 6a. An aluminum ring, hollowed to fit the crystal, was then fitted over the free ends of these aluminum rods and bolted down.

Figure 6b shows the device used to support the plastic shield. Strips of 2 inch by 1 inch channel iron are slotted, and bolted through the slots to each leg of the stand. Upon these strips rests a ring of 2 inch by 2 inch angle iron which supports the plastic shield.

g. Electronics

Fig. 7 is a block diagram of the electronic apparatus associated with the spectrometer. Photomultiplier tube pulses arising from events in the crystal are fed directly to the grids of separate cathode followers in the detector heads, thence through co-axial cables to the mixer where the pulses are electronically summed. From the mixer, the sum pulse is fed either through an amplifier to a 100 channel kicksorter or through another amplifier to the single channel analyser and scalar.

Pulses arising from events in the plastic shield are fed to another mixer through separate cathode followers. The sum pulse is amplified and fed through co-axial cable to the gate pulse generator which activates the anticoincidence circuits in the 100 channel kicksorter or the single channel analyzer.

110 volt a.c. power is supplied to all units from two Sorenson A.C. Voltage Regulators Model 2000 G. Stabilized power

supplies of conventional design were built at the University to supply the detector heads, mixers, single channel analyzer and gate pulse generator.

Photomultipliers used are:

DuMont type K 1328	16 inches in diameter
DuMont type 6364	5-1/4 inches in diameter
DuMont type 6363	3 inches in diameter
Dumont type 6292	2 inches in diameter

High voltage supplies to the photomultipliers were built by Hamner Electronics Inc. Two of the 5 inch tubes viewing the crystal are controlled by a Hamner model N 401 with associated potentiometer, the third by a Hamner model 530. The tubes viewing the plastic are controlled by twelve, 10 megohm potentiometers fed by another Hamner model N 401 high voltage supply. Stability of these supplies is quoted by the manufacturer as 3 p.p.m. for an input voltage variation of one volt.

The non-overloading amplifiers used with the single channel analyzer and in the plastic circuit are a combination of Fairstein and Chase - Higinbotham designs similar to that produced by Hamner Electronics Inc. Model N 301. This type of amplifier produces a positive output pulse. As the 100 channel requires a negative input pulse, another amplifier was obtained from Franklin Electronics, Model 358. This amplifier, using double delay line clipping, produces both a positive and a negative output pulse and was used to feed the 100 channel kicksorter.

The single channel pulse height analyzer and scalar were both built at the University and are conventional design. The 100 channel kicksorter was recently obtained by the University from Computing Devices of Canada Ltd., Model W 475.

The mixers and gate pulse generator (Figs. 8 & 9) were both designed by Dr. K.I. Roulston of the Physics Department. Two mixers were built, one designed to sum a maximum of four channels and the other to sum a maximum of twelve channels.

The gate pulse generator delivers a square negative pulse of amplitude - 40 volts and duration variable from 5 to 50 microseconds, upon receiving a positive input pulse with amplitude greater than a predetermined value.

4. PERFORMANCE OF THE SPECTROMETER

a. Arrangement of Photomultipliers

With the crystal in the temporary mounting, resolution tests were made on the 662 Kev line of a Cs^{137} gamma ray source for the following arrangements of photomultiplier tubes.

(a) One 5 inch tube co-axial with the crystal facing into the cylindrical base of the crystal.

(b) One 5 inch tube optically coupled to the cylindrical base of the crystal by a short light pipe as in Fig. 10a.

(c) One 3 inch tube co-axial with the crystal facing into the conical end of the crystal.

(d) Systems a and c simultaneously, the output pulses summed in a mixer.

(e) Three 5 inch tubes facing into the cylindrical base, the output pulses summed in a mixer.

(f) Systems c and e simultaneously, the output pulses all summed in a mixer.

(g) One 16 inch tube optically coupled to the cylindrical base of the crystal by a short light pipe as in Fig. 10b.

In all cases, the photomultipliers and light pipes were coupled to the glass light pipes of the temporary mount with D.C. 200 silicone grease. Figure 11 shows the various source geometries used in studying the crystal. The collimator is a lead block 3 inches by 4 inches by 5 inches with a 1 inch hole bored in a long direction. Table I gives the resolutions obtained with the various source positions and tube geometries.

TABLE I

TUBE GEO-METRY	POSITION OF SOURCE (Cs^{137})					
	Axially above Cone		Radially		Axially below Base	
	Non Coll	Coll	Non Coll	Coll	Non Coll	Coll
a)	21%	19%	29%	33%	35%	43%
b)	23%	21%	20%	20%	26%	27%
c)	50%	70%	40%	35%	45%	35%
d)	26%	43%	24%	26%	30%	24%
e)	14%	14%	13.5%	13.5%	17%	16%
f)	21%	---	15%	15%	14%	14%
g)	43%	---	---	---	---	---

Obviously the choice of photomultiplier arrangement lay between systems e and f. System e was chosen for the following reasons.

Stability may be maintained more easily in three tubes than in four.

Cosmic ray studies were to be attempted with the conical end of the crystal pointing upwards. System e gives the least mass above the crystal and the best resolution of energy entering the conical end of the crystal.

Were system f chosen, an increase of ten inches in the wall length of the anticoincidence shield would be necessary to enclose the extra photomultiplier and detector head. This would increase both the cost of the shield and the problems in viewing it with photomultipliers.

Only one arrangement of photomultiplier tubes on the plastic shield has been tried. A light pipe of scintillating plastic, diameter 14 inches, minimum thickness 2 inches with one flat and one concave face was obtained from Nuclear Enterprises to couple the 16 inch photomultiplier (DuMont K 1328) to the base plate of the plastic shield. Four 5 inch photomultipliers (DuMont 6364) were mounted symmetrically outside the rim of the 16 inch tube. Six 2 inch tubes (DuMont 6292) were symmetrically mounted facing into the sides of the 1 inch top plate of the shield. Figure 12 shows a cross section of the shield with this photomultiplier arrangement.

This arrangement is also shown in Plate 6.

Individual voltages of these photomultipliers were adjusted until, with no gamma source present, each tube gave the same counting rate above a certain arbitrarily chosen discrimination level. An increase in counting rate from each tube when a Cs^{137} gamma source was brought near showed the ability of the photomultipliers to detect events in plastic in the 600 Kev range.

b. Low Energy Studies

(i) Without Anticoincidence

With the crystal in the permanent mounting Cs^{137} spectra were taken with the source in the various positions shown in Fig. 11. It was impossible to use the previously described collimator to collimate the gamma ray beam into the base of the crystal as it would not fit between the photomultipliers coupled to the base. In this case only, a section of lead pipe 4 inches long by 1 inch in diameter and 1/8 inch wall thickness was used as the collimator.

Fig. 13 shows typical Cs^{137} spectra obtained with the source geometries indicated. In each case, the curve presented is the difference between the spectrum obtained with the source in its designated position and the background curve obtained with the source absent. The horizontal scale is presented in volts as read from the single channel pulse height analyzer. The vertical scale is presented in arbitrary units. In obtaining these spectra and all spectra presented later, care was taken to record sufficient counts that the error on each plotted point due to statistical variation would be negligible. Points were plotted at one volt intervals along the spectra.

It is evident from these curves that collimation of the gamma ray beam into the crystal cone gives not only the best resolution but also the highest ratio of photopeak maximum counting rate to average Compton counting rate. Poorest resolution and ratio of photopeak to Compton counting rates are obtained with the source beneath the flat end of the crystal.

Several spectra were taken with the gamma ray beam collimated radially into the crystal to determine the dependence of photopeak pulse height on radial position. Table 2 shows this dependence, 0°, 120° and 240° being the radial positions of the three photomultipliers viewing the crystal.

TABLE 2

Radial Position of Source	Cs^{137} Photopeak Pulse Height
0°	41.4
60°	38.0
120°	42.0
180°	36.2
240°	39.4
300°	35.2
360°	41.4

It is seen that if the collimated gamma radiation enters the crystal directly above one of the photomultipliers, the photopeak pulse height is somewhat higher than that produced when the radiation enters the crystal radially between the photomultipliers. This spread in photopeak pulse height helps explain the poor resolution of this spectrometer when compared to one utilizing a much smaller crystal.

Figures 14 to 17 are spectra taken with gamma ray sources of Na^{22}, Zn^{65}, Co^{60}, and Sb^{124}. The background has been subtracted from each of these curves. The corresponding photopeak energies are indicated on the spectra.

II. With Anticoincidence

Low energy studies using the anticoincidence shield were made with the source outside the shield collimated into the crystal. The best low energy results, by others, were obtained with the source inside a well cut into the crystal. As this crystal is to be used primarily for high energy studies, a well cannot be used. With the source outside the shield all radiation must pass through some plastic before reaching the crystal. The major result of this, is the production of a large number of gating pulses unrelated to most of the pulses in the amplitude range under study.

Consider a typical situation where only pulses in a given amplitude range are being passed by the single channel analyzer. A gamma ray may now cause an event in both the plastic and the crystal. If the pulse from the crystal is not in the amplitude range under study, then the gating pulse from the plastic serves no useful function. However, this gating pulse may produce an accidental cancellation of one of the crystal pulses under study. Background and cosmic radiation striking the plastic may also produce accidental cancellations.

The effect of these were eliminated in the following manner. The photopeak maximum is a well defined point where no cancellations should occur. As a result, any diminishment of the photopeak is due to accidental cancellations. If the spectra obtained with and without anticoincidence are replotted with the photopeaks normalized the effect of accidental cancellations is eliminated.

Figures 18 and 19 show Zn^{65} and Na^{22} spectra with and without anticoincidence with normalized photopeaks. A typical Zn^{65} spectrum taken with a 1 inch by 1-1/2 inch cylindrical sodium iodide crystal is shown for comparison purposes.

iii. Discussion

With the gamma ray beam collimated into the cone of the crystal, the mean resolution of the Cs^{137} 662 Kev photopeak by this instrument is 14%. A typical resolution of this same photopeak by a 1 inch by 1-1/2 inch NaI crystal would be about 9%. The poorer resolution of the large crystal could be attributed to the non-localization of scintillation light in the crystal. Table 2 shows that events, of a given energy, taking place in the crystal directly above one of the photomultipliers, produce output pulses of a greater amplitude than those produced by events of the same energy, taking place elsewhere in the crystal. Thus, gamma rays from a monoenergetic source may produce output pulses in a limited range of amplitudes. This effect appears as a broadening of the photopeak under study. Obviously this effect is much reduced in the spectra of a smaller crystal.

The resolution of the present instrument might be improved by extreme collimation of the incident gamma radiation. This would have the effect of localizing the scintillation light in the crystal. Another method of improving the resolution might be to view the crystal with a single photomultiplier with a uniform photocathode of sufficient diameter to cover the entire base of the crystal. This should eliminate the necessity of localizing the scintillation light. Neither of these methods were experimentally demonstrated due to the lack of a suitable collimator in the first instance and lack of a suitable photomultiplier in the second.

The worth of this spectrometer for low energy work may be shown in the comparison of a Zn^{65} spectrum taken with this instrument, with one obtained from a scintillation spectrometer using a 1 inch by 1-1/2 inch NaI crystal as the detector (Fig. 18).

The following figures may be derived from the spectra presented in Fig. 18.

$$\frac{\text{Area under Compton portion of spectrum:}}{\text{Area under total spectrum}}$$

Large crystal	$\frac{49}{100}$
Large crystal with anti-coincidence shield	$\frac{43}{100}$
Small crystal	$\frac{79}{100}$

$$\frac{\text{Area under Compton portion - large crystal spectrum:}}{\text{Area under Compton portion - small crystal spectrum}}$$

Large crystal alone	$\frac{29}{100}$
Large crystal with anti-coincidence shield	$\frac{21}{100}$

The latter figures have been presented with the spectra normalized by equalizing the counting rates at the photopeak maxima.

Two main conclusions may be drawn from these figures. Only 20% of the events which occur in the smaller crystal make up the photopeak, whereas more than 50% of the events which occur in the larger crystal make up the photopeak. If the spectra be plotted with the maximum photopeak counting rate normalized as in Fig. 18, the area under the Compton portion of the spectrum taken from the large crystal spectrometer is only 29% of that taken from the small crystal spectrometer. This figure is improved to 21% by use of the anticoincidence shield with the large crystal spectrometer. Thus, a large percentage of the Compton portion of a gamma ray spectrum may be eliminated by the use of the total absorption spectrometer described in this thesis.

Typical ratios of maximum photopeak counting rate to average Compton counting rate for gamma radiation collimated into the cone of the crystal are:

Cs^{137},	7 : 1
Zn^{65},	5 : 1
Na^{22},	4.5 : 1 (511 Kev photopeak)

with output from the crystal in anticoincidence with that from the anticoincidence shield, the Zn^{65} and Na^{22} ratios both increased to 7.5 : 1. Anticoincidence also decreased the area under the non-photopeak portions of the Zn^{65} and Na^{22} spectra by 30%. Hence the anticoincidence shield is about 30% efficient in the lower energy range.

The efficiency of the anticoincidence shield is dependent on the bias setting of the gate pulse generator. Only input pulses with amplitude greater than the minimum determined by this bias setting may trigger an output pulse. Ideally, if all input pulses could trigger an output pulse, the anticoincidence shield would be 100% efficient. However, a large number of low energy events occur in the plastic due to background radiation. It is necessary to bias out most of these lower energy pulses to prevent a high percentage of accidental cancellations. In this process, many of the lower energy pulses which would produce truly anticoincident cancellations are lost. As a result, the efficiency of the anticoincidence shield is poor for low energy studies.

c. High Energy Studies

i. Without Anticoincidence

All high energy studies were carried out in the Cosmic Ray Laboratory located on the roof of the science building, University of Manitoba. The laboratory was built of wood and the thickness of building material in the roof was kept to a minimum. Gagne (6) showed that for events in the NaI crystal of energy greater than 50 Mev, the effect of the roof is negligible.

Fig. 20 is a comparison of activity in this laboratory with activity in the basement of the Science Building in the 0 to 5 Mev range. As may be expected, the K^{40} 1.47 Mev and Pb^{208} 2.6 Mev peaks are enhanced in the basement where the surrounding concrete of the walls and ceilings are more likely to contain these radio elements. However in the higher energy region, cosmic radiation is attenuated by the building and above 3 Mev, more events are noted on the roof.

The high energy curves without anticoincidence were taken with the single channel analyzer arrangement. Care was taken to prevent saturation in the photomultipliers at higher energies by running the tubes at low voltages. As a general criterion it was assumed a given pulse was not saturated if the photomultipliers could deliver a pulse ten times larger.

This apparatus was calibrated in terms of the .511 and 1.28 Mev photopeaks in the Na^{22} spectrum. With the photomultiplier

iii. Discussion

The broad peak occurring in the differential energy spectrum with a maximum at 80 Mev is due to the loss of energy in the crystal of singly charged relativistic particles (mostly mu mesons) passing through the crystal predominantly in a vertical direction. As most of these particles pass directly through the crystal, interactions with the anticoincidence shield are quite probable. As a result, the peak should be eliminated by anticoincidence. There is a neutral cosmic ray component which will not interact with the shield on entering. This will produce some counts in the region of the peak.

A 95% reduction of counting rate in the region of the peak was obtained using anticoincidence. If the true number of events in that energy range were zero, the efficiency of the anticoincidence shield would be 95%. As the neutral component produces some counts the efficiency of the anticoincidence shield is greater than 95%.

As events of energy greater than 1 Bev have been detected by the crystal and the efficiency of the anticoincidence shield is greater than 95% in the high energy range, this instrument should provide means for viewing the neutral component of high energy cosmic radiation, the charged component being eliminated by the anticoincidence shield.

voltage set so that saturation would not occur in the desired energy range, amplifier gain was set to a high enough value to display the Na^{22} peaks. The sodium energies calibrated an energy scale at this amplifier setting. The amplifier gain was then decreased by a known factor increasing the energy scale by this factor. This method of calibration was used for energies up to 200 Mev.

Fig. 21 shows the differential energy distribution of events in the 0 to 200 Mev energy range.

Using the broad peak which occurs with maximum at 80 Mev. as a calibration point, events with energy greater than 1 Bev were detected by the crystal.

II. With Anticoincidence

High energy studies with anticoincidence were done using the 100 channel kicksorter. To satisfy the delay requirements of the kicksorter, the pulse from the gate pulse generator was lengthened to six microseconds. As one could bias out a large portion of the very low energy pulses, accidental cancellation factors were negligible, less than .1% in general.

Figure 22 is a semi logarithmic plot of frequency of events V.S. channel number on the 100 channel kicksorter. The lower curve is taken with the plastic in anticoincidence with the crystal. The upper curve is taken with no anticoincidence. Channel 50 corresponds to an energy of 80 Mev on this graph.

5. CONCLUSIONS

The mean resolution of the Cs^{137} 662 Kev photopeak by this instrument is 14%, with the gamma radiation collimated into the cone of the crystal. This rather high value may be partly attributed to the non-localization of scintillation light in the crystal.

The area under the Compton portion of a Zn^{65} spectrum taken with this instrument is, at worst, some 30% of that taken with an instrument utilising a 1 inch by 1-1/2 inch crystal as the detector. However, the anticoincidence shield is only some 30% efficient in the lower energy region.

In the high energy region, the anticoincidence shield proved better than 95% efficient. Events of energy greater than 1 Bev have been detected by the instrument. Thus, the instrument should prove useful as a total absorption spectrometer for high energy work.

6. REFERENCES

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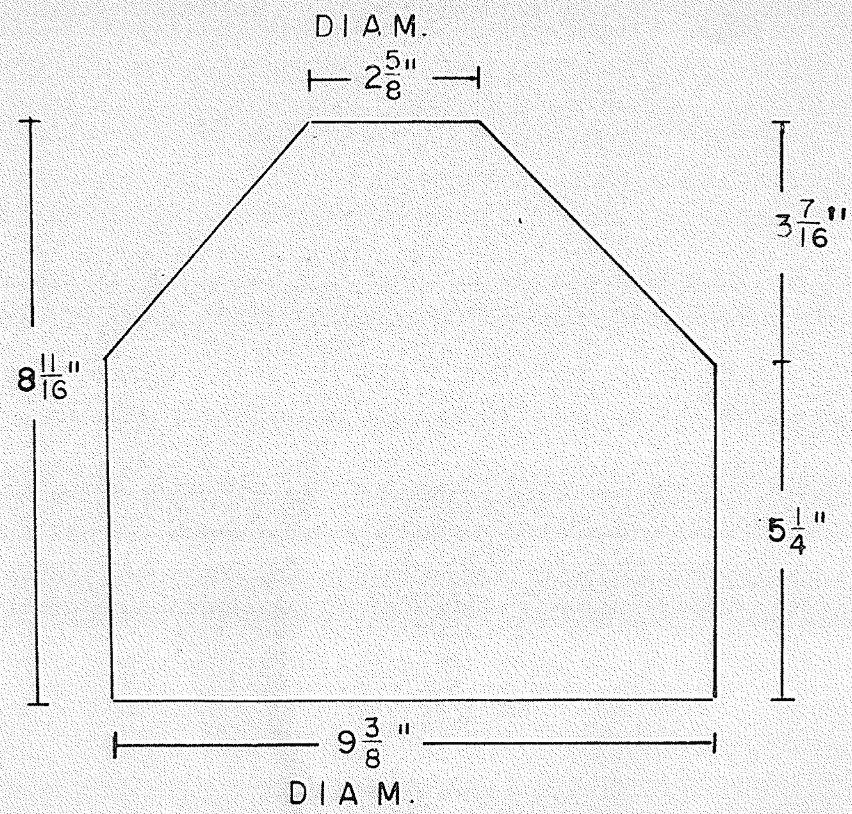
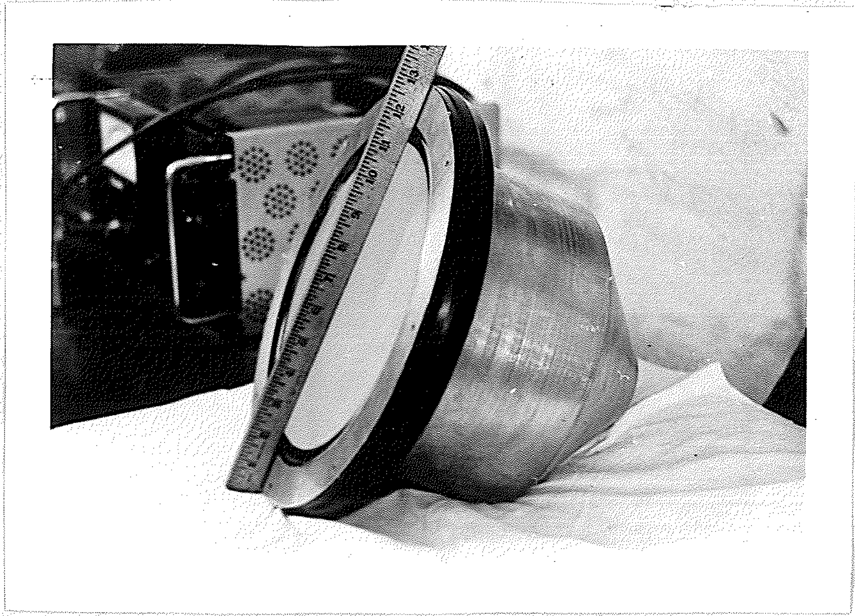


FIG I CRYSTAL DIMENSIONS
PLATE I CRYSTAL



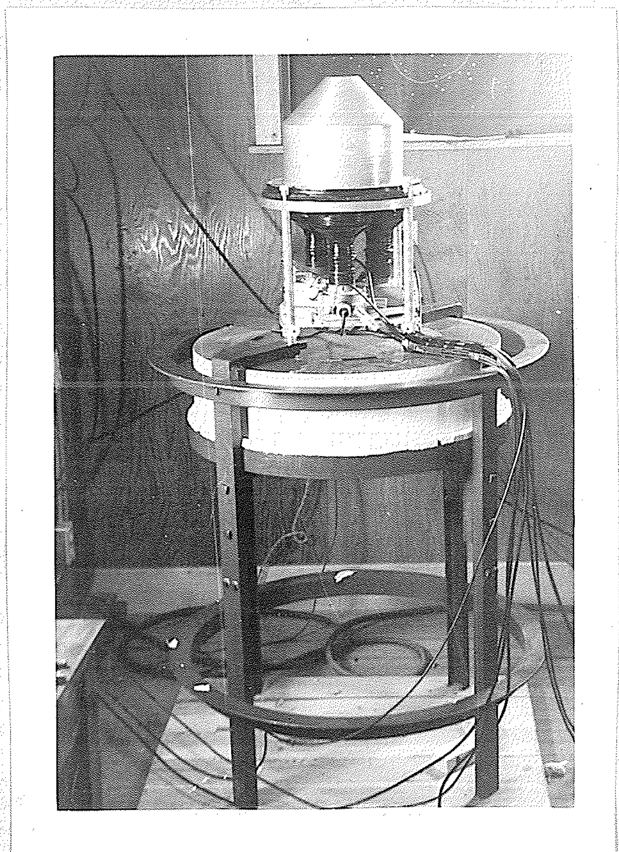
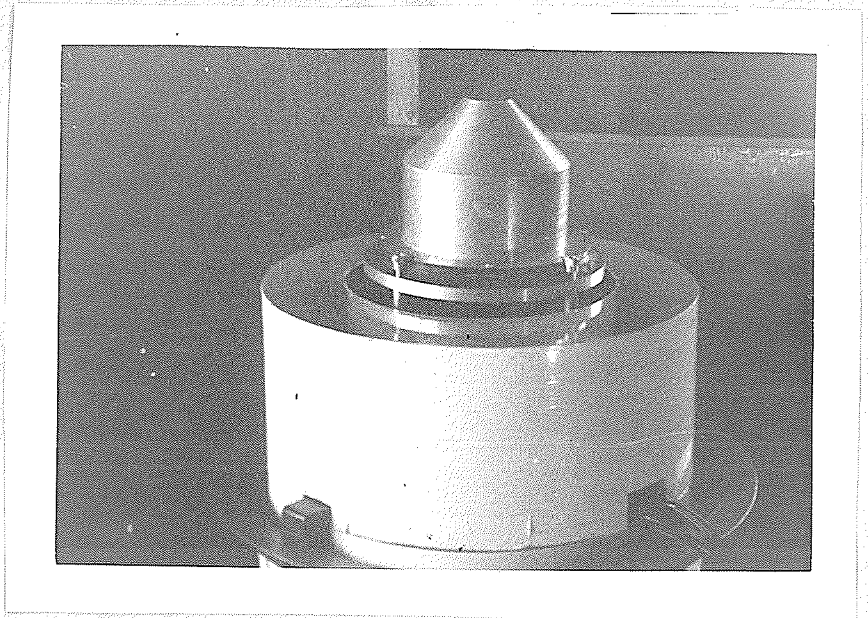


PLATE 2

PLATE 3



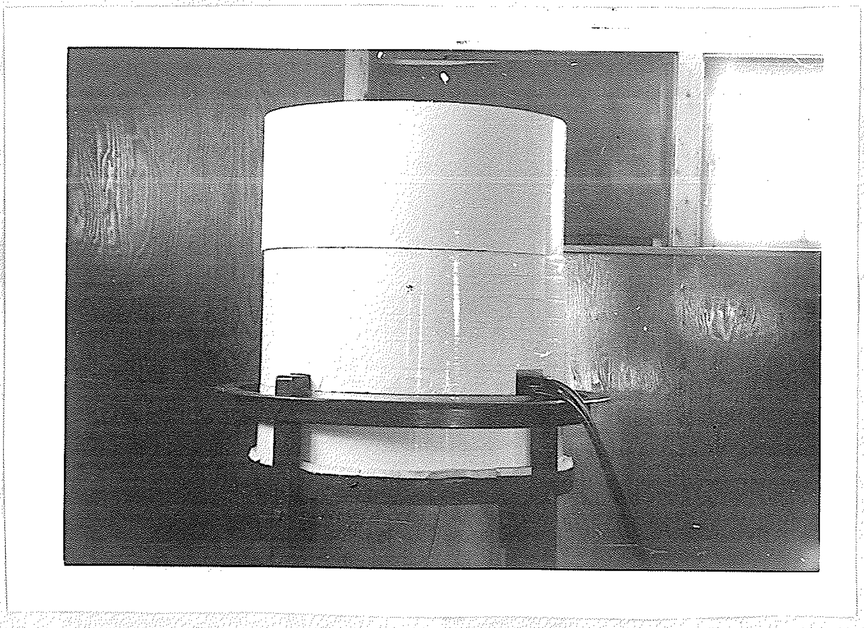


PLATE 4
PLATE 5

AUG 59

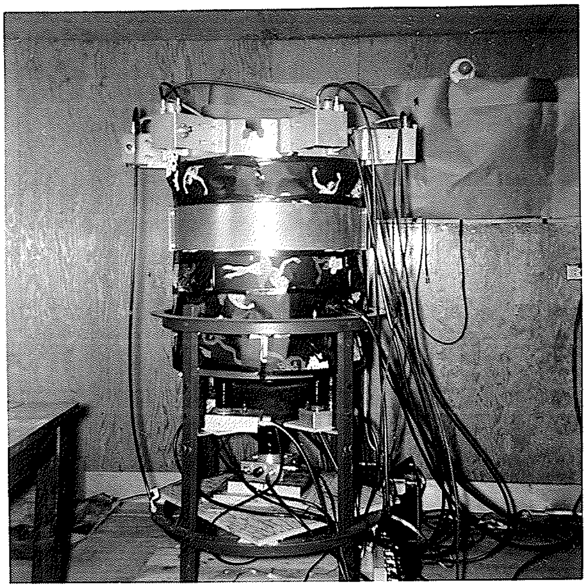
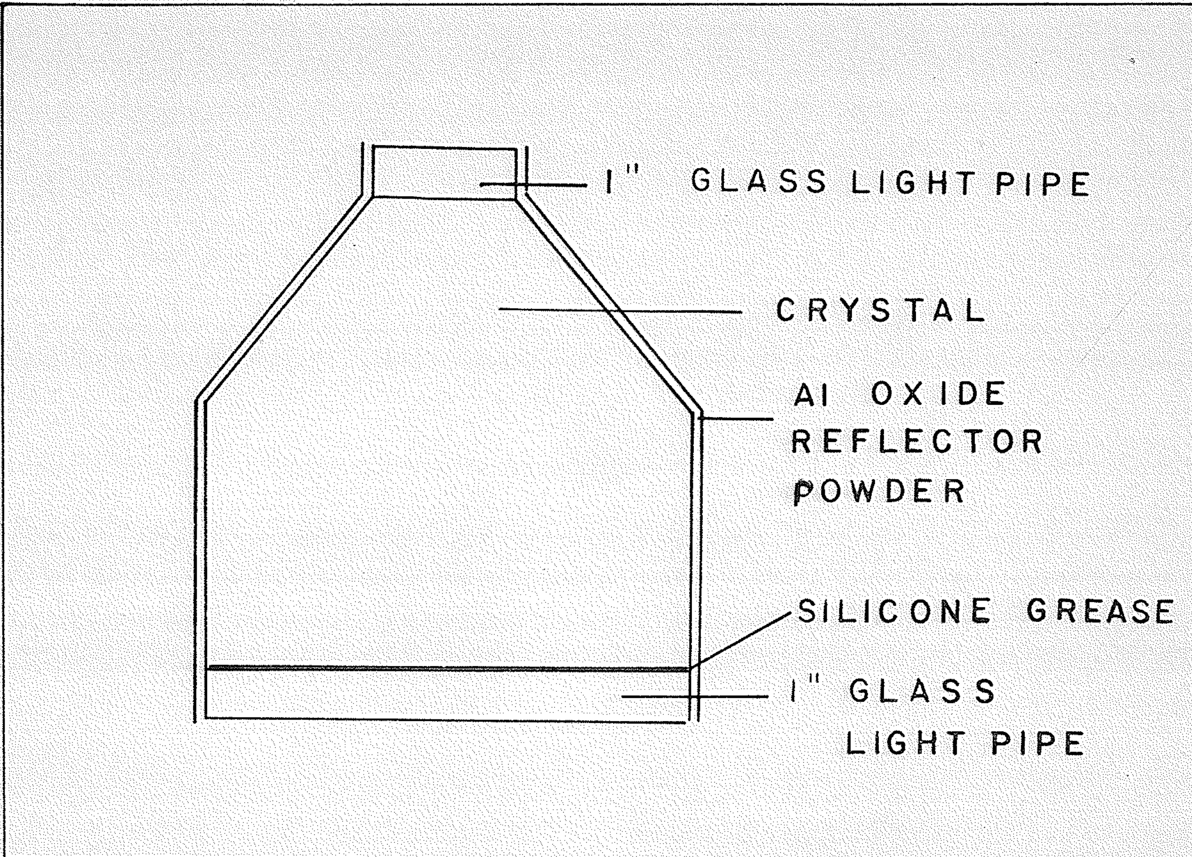


PLATE 6



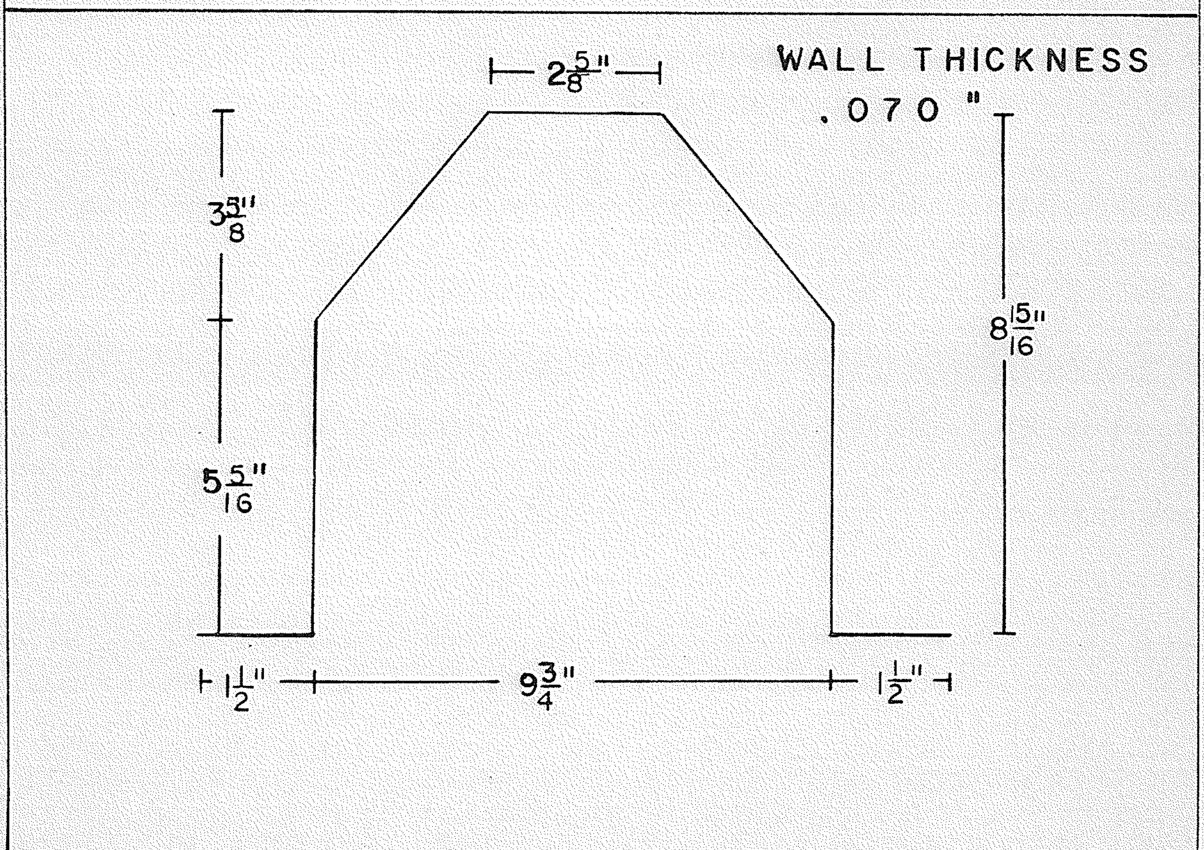


FIG 2 TEMPORARY MOUNTING

FIG 3 ALUMINUM SPINNING

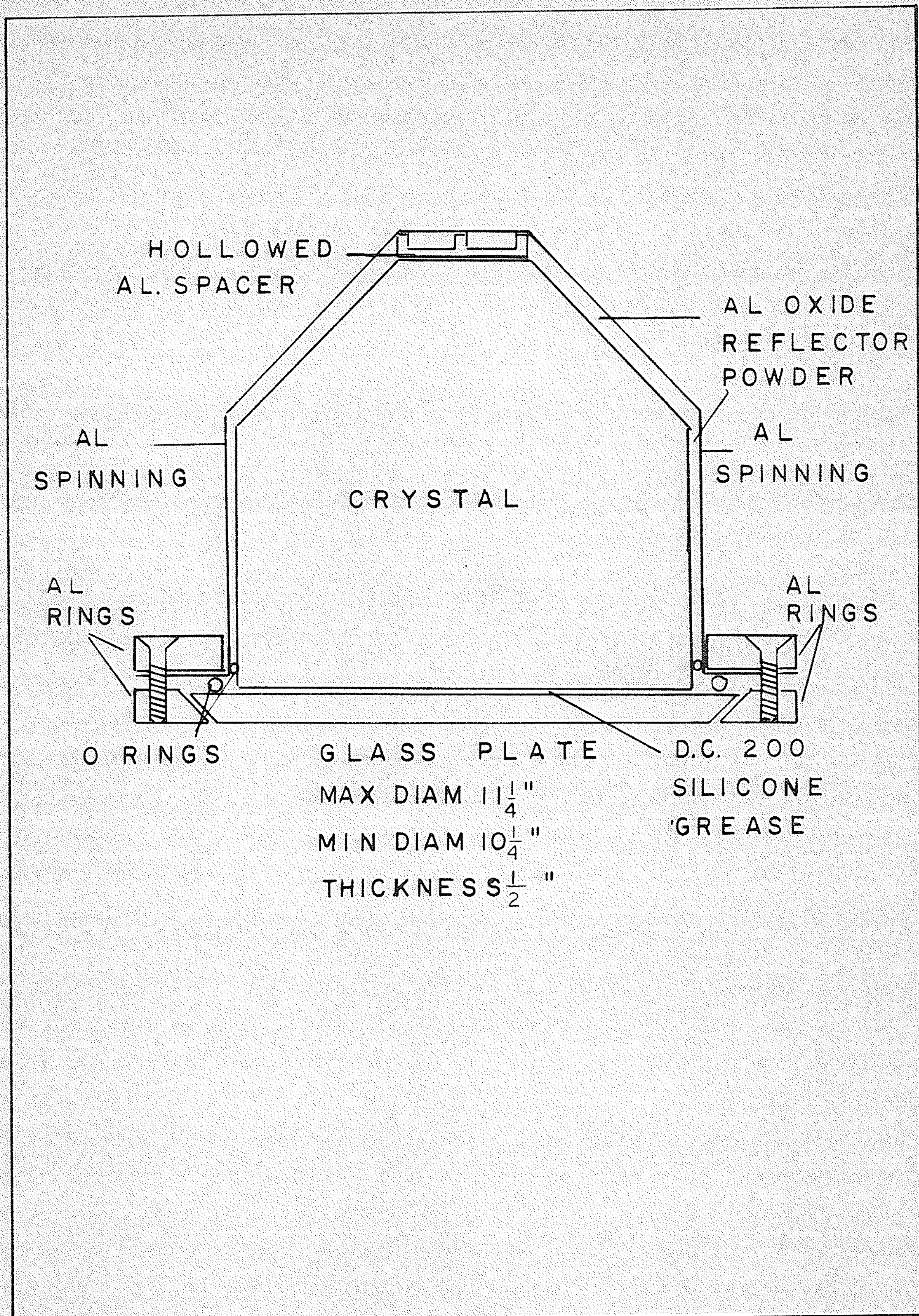
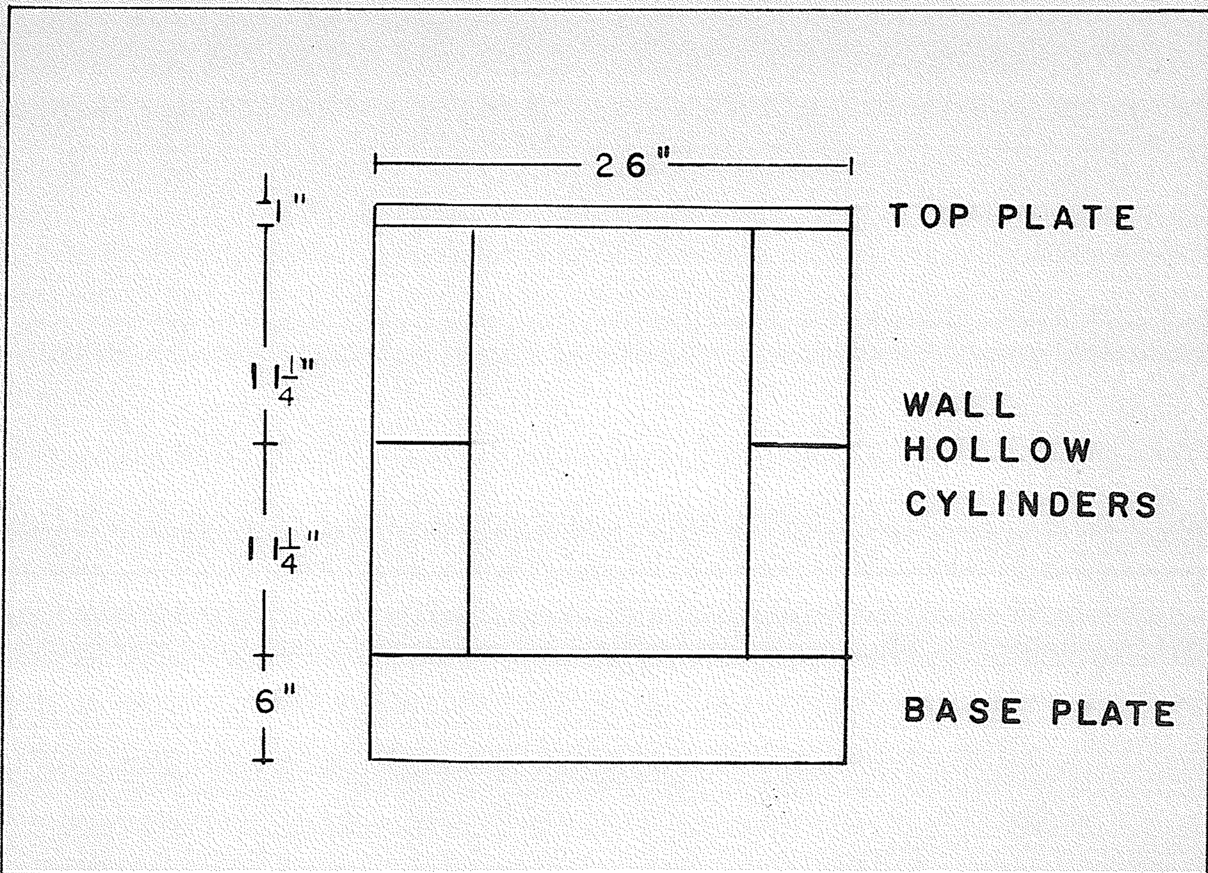


FIG 4 PERMANENT MOUNTING



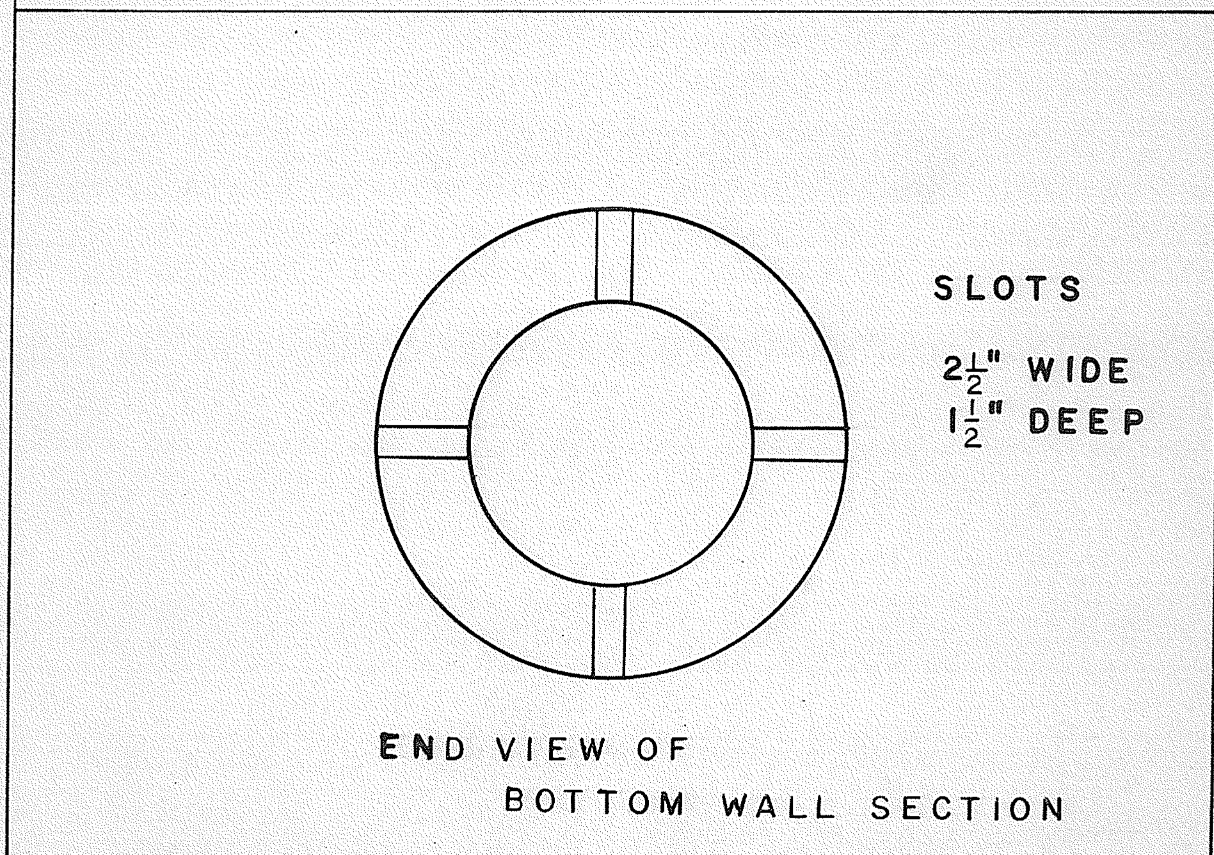


FIG 5a PLASTIC SHIELD
5b END VIEW

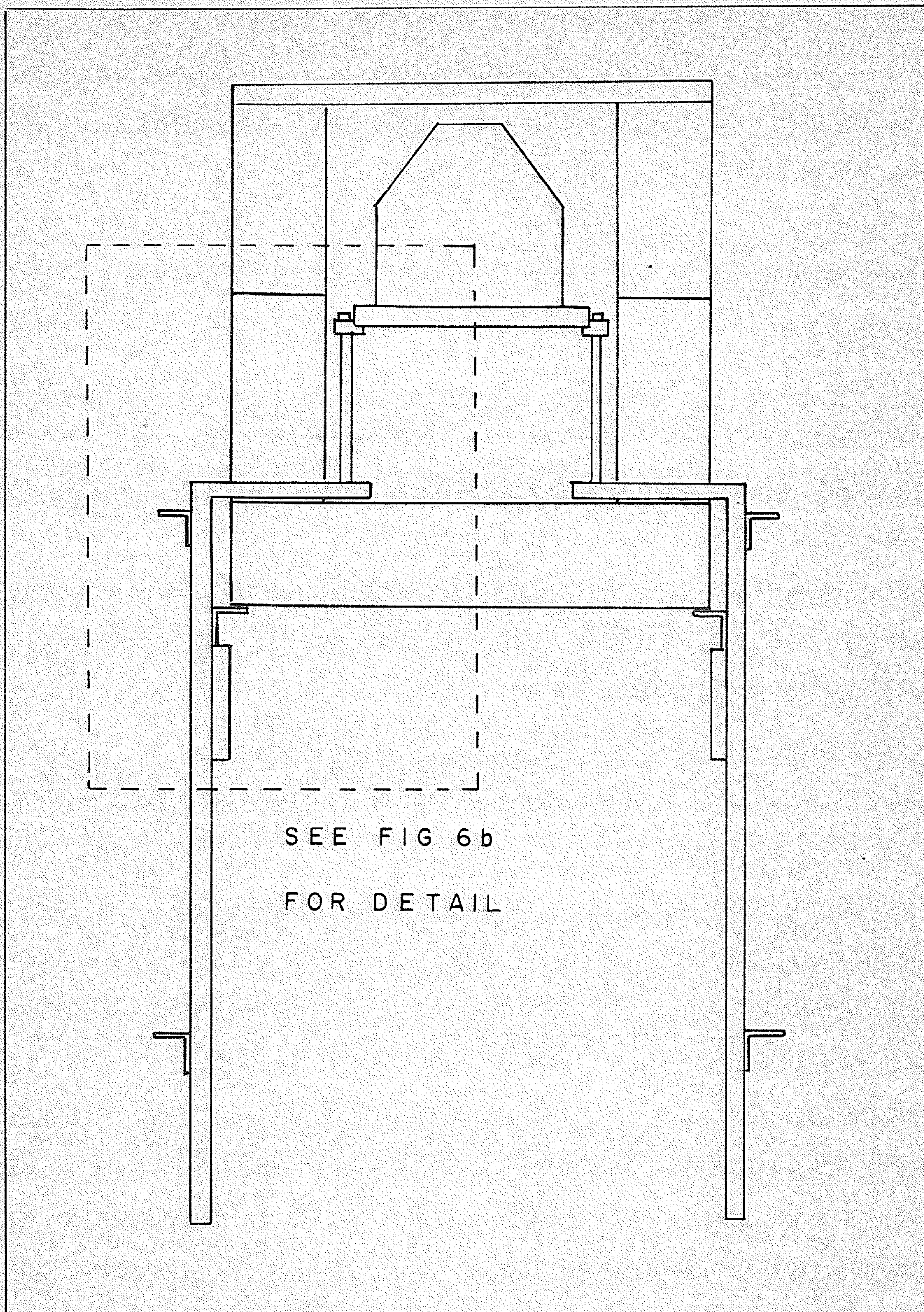


FIG 6a STAND

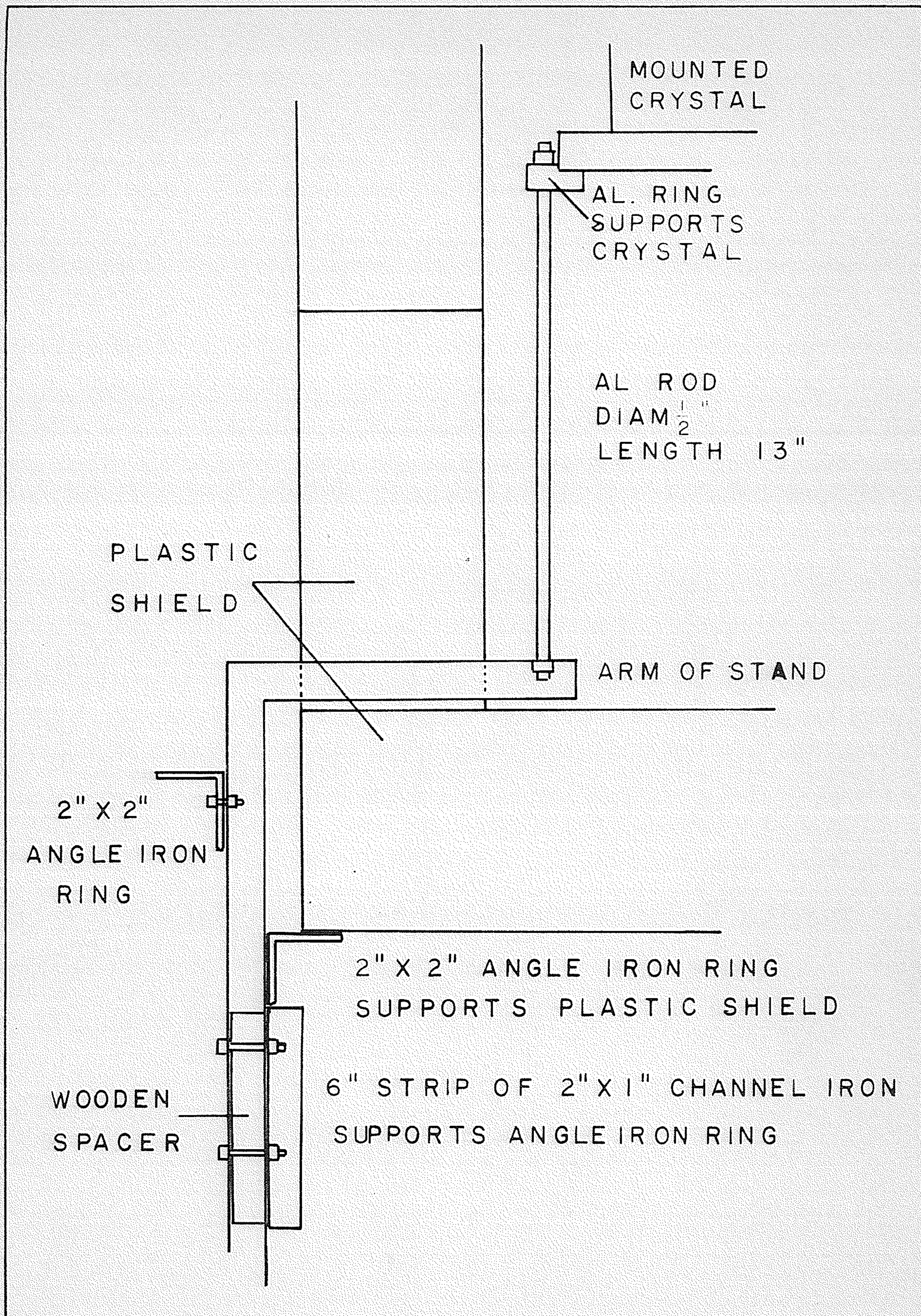


FIG 6b DETAIL OF STAND

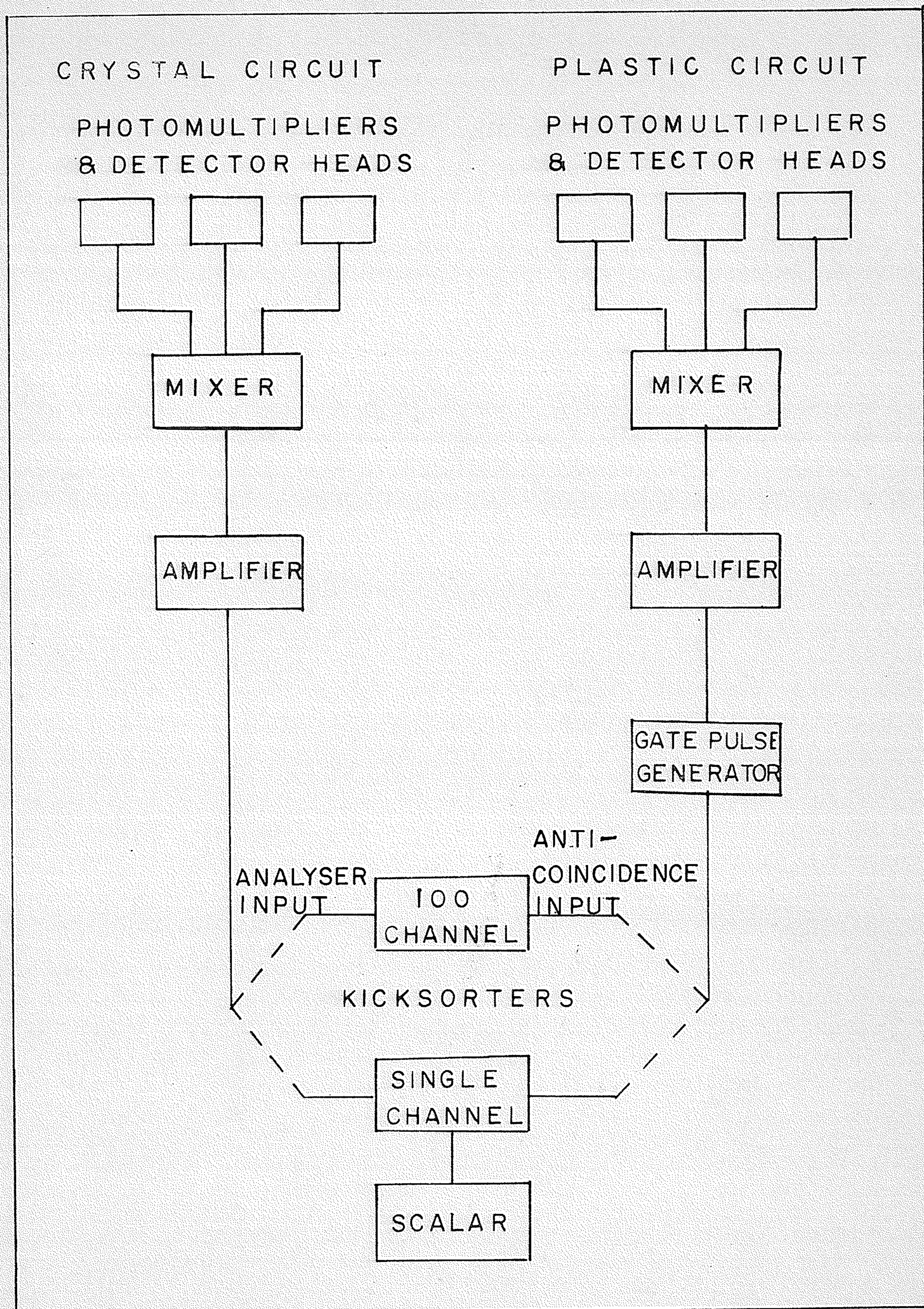


FIG 7 BLOCK DIAGRAM OF ELECTRONICS

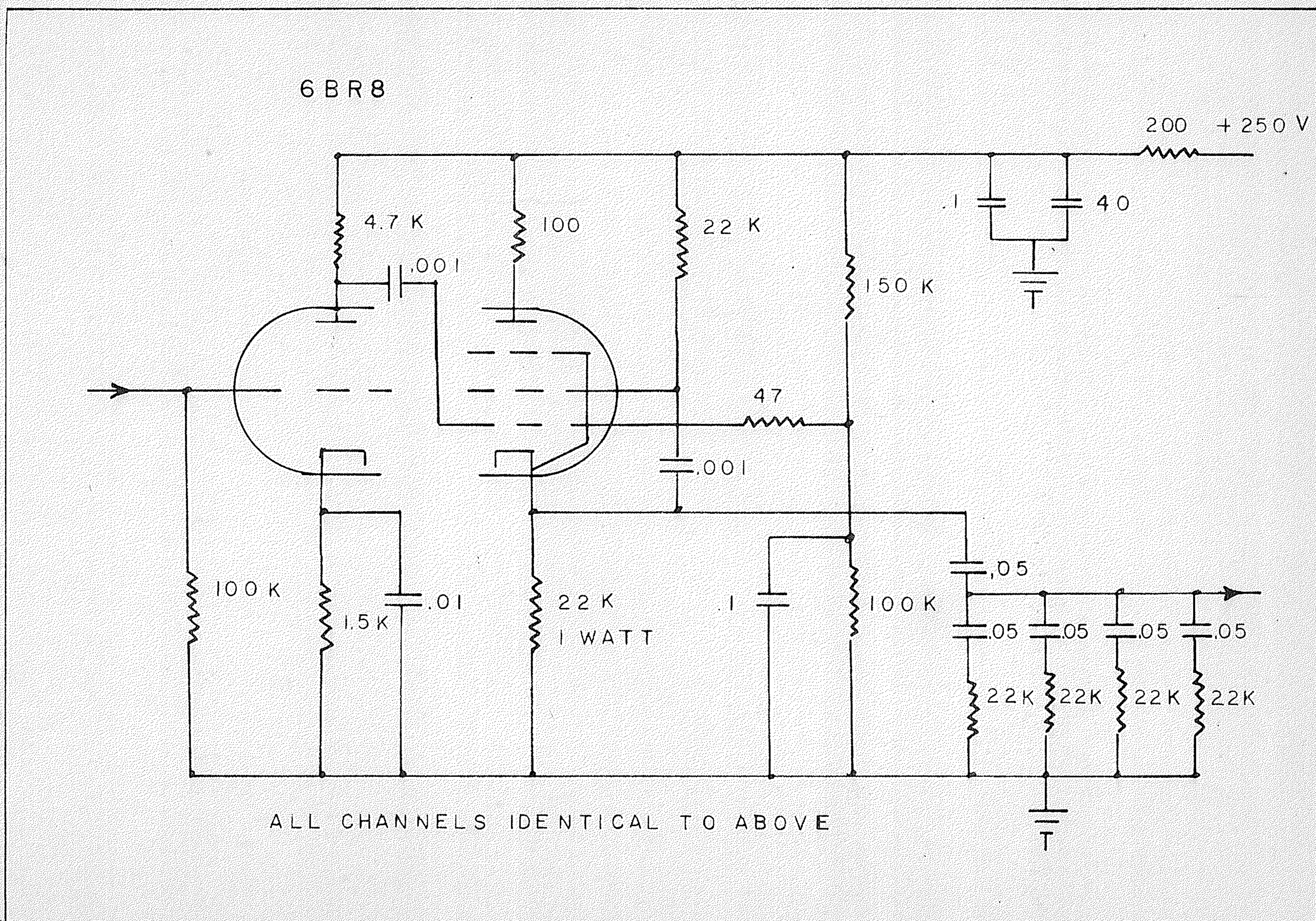
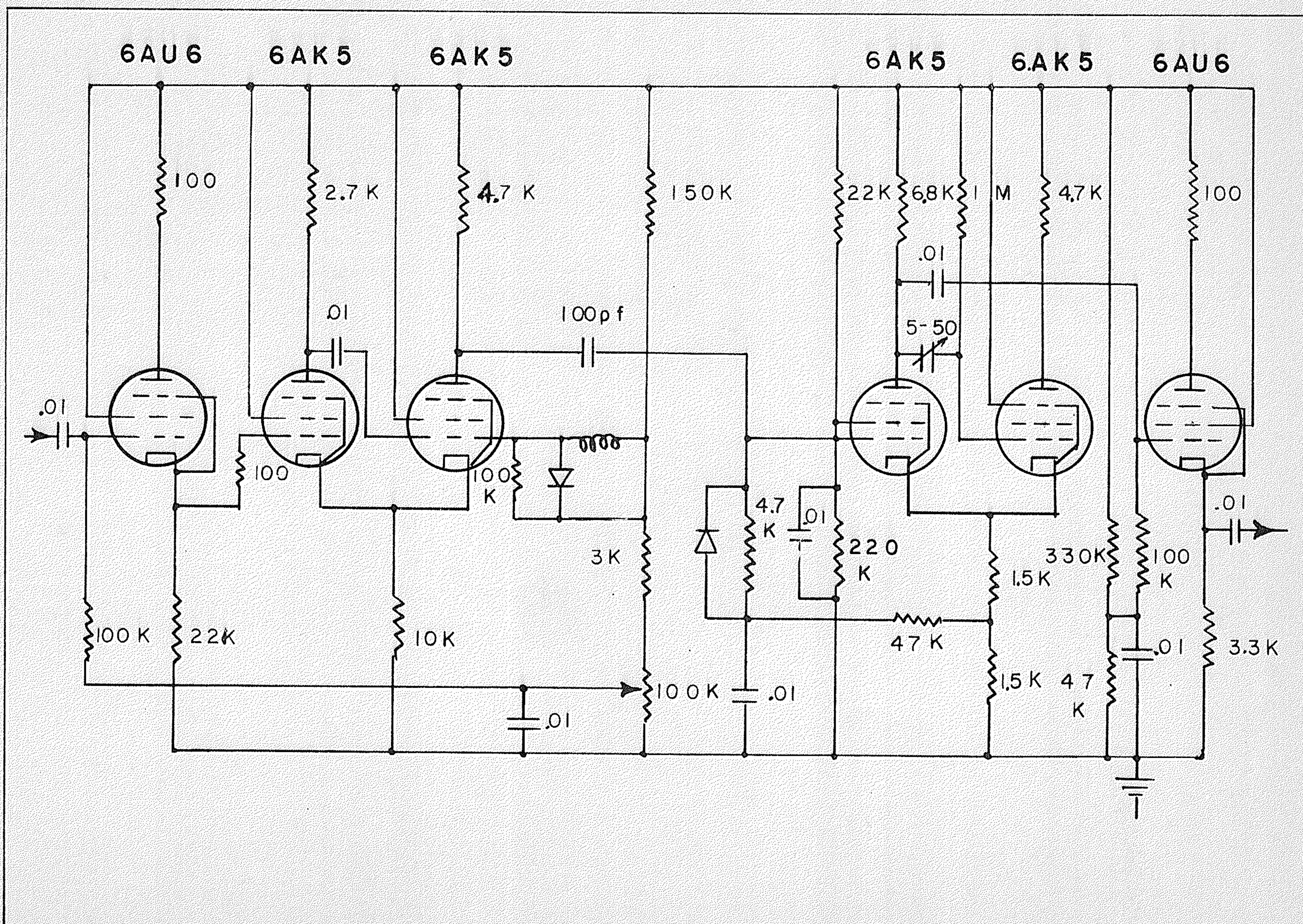


FIG 8 CIRCUIT DIAGRAM OF MIXER

FIG 9 CIRCUIT DIAGRAM OF
GATE PULSE GENERATOR



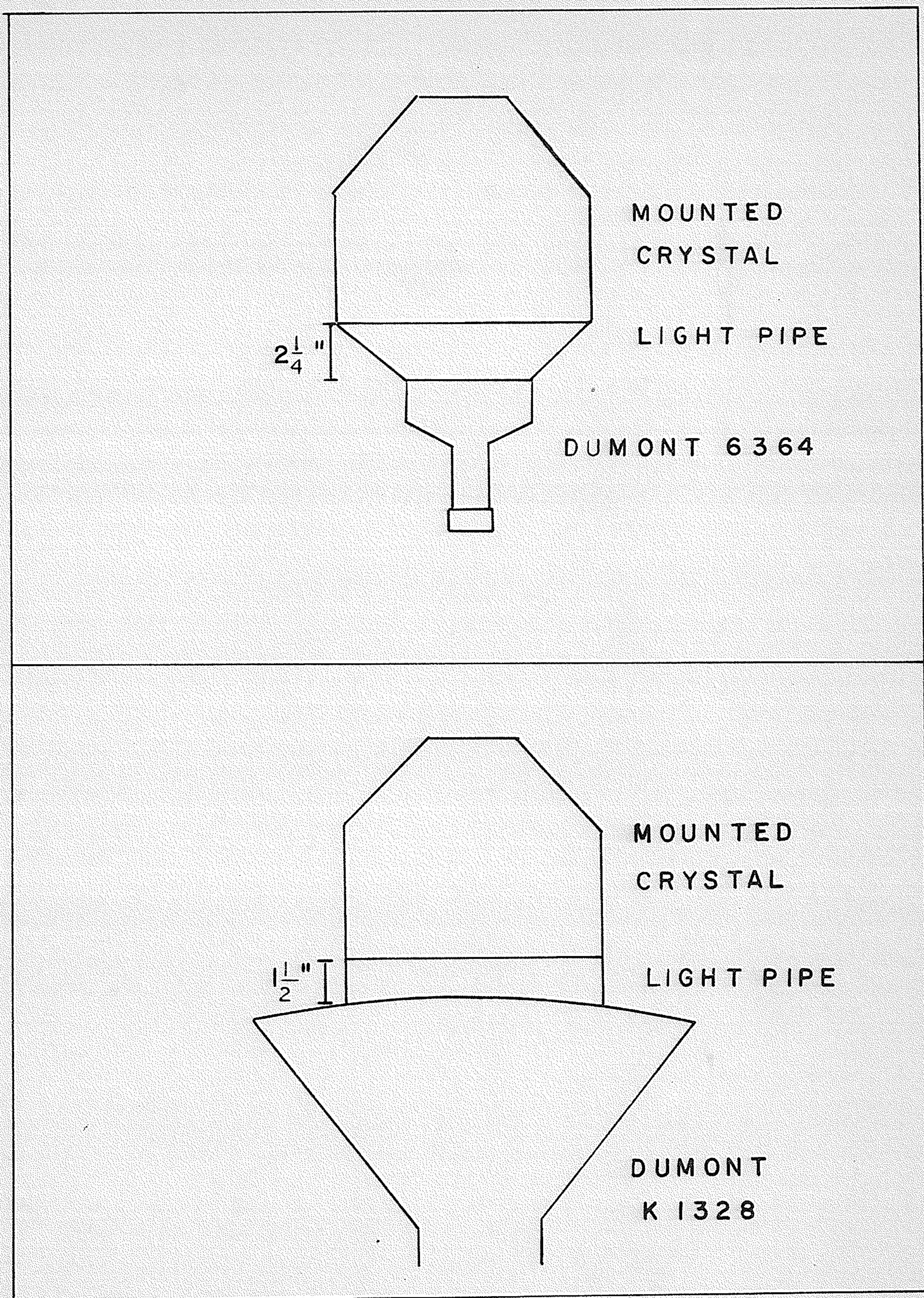


FIG 10 LIGHT PIPES USED WITH TEMPORARY MOUNTING

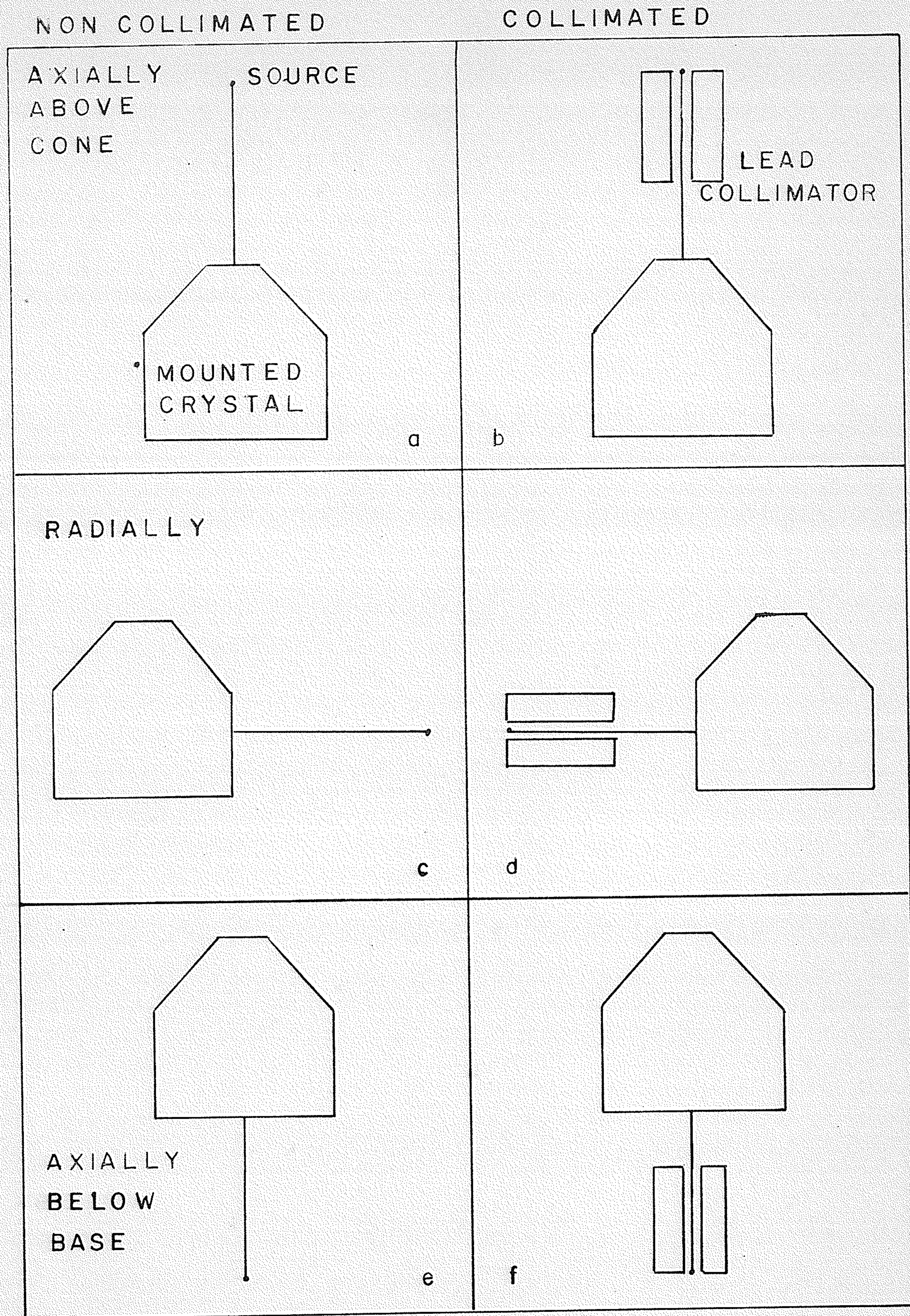


FIG II SOURCE POSITIONS

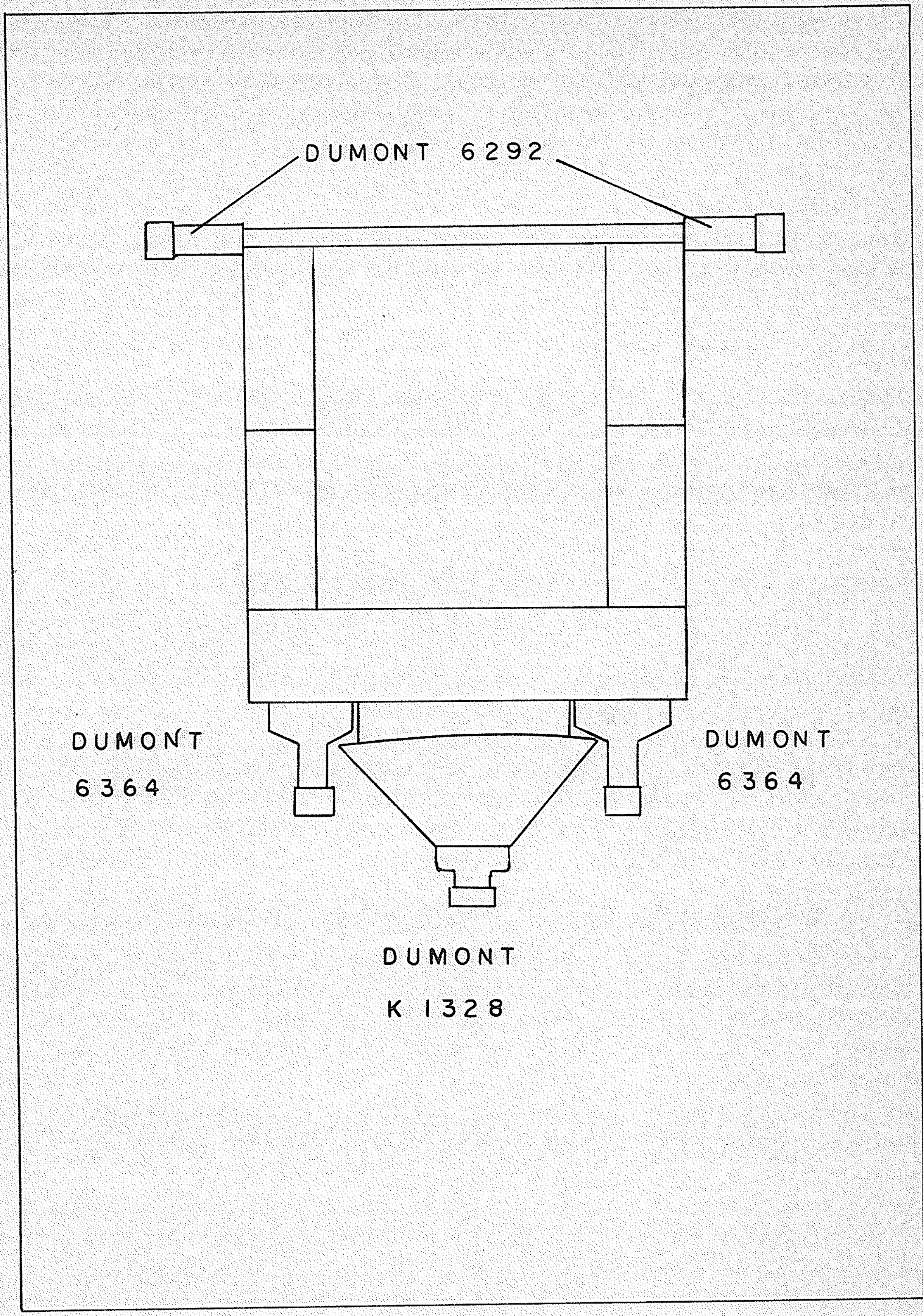


FIG 12 PHOTOMULTIPLIER ARRANGEMENT ON PLASTIC SHIELD

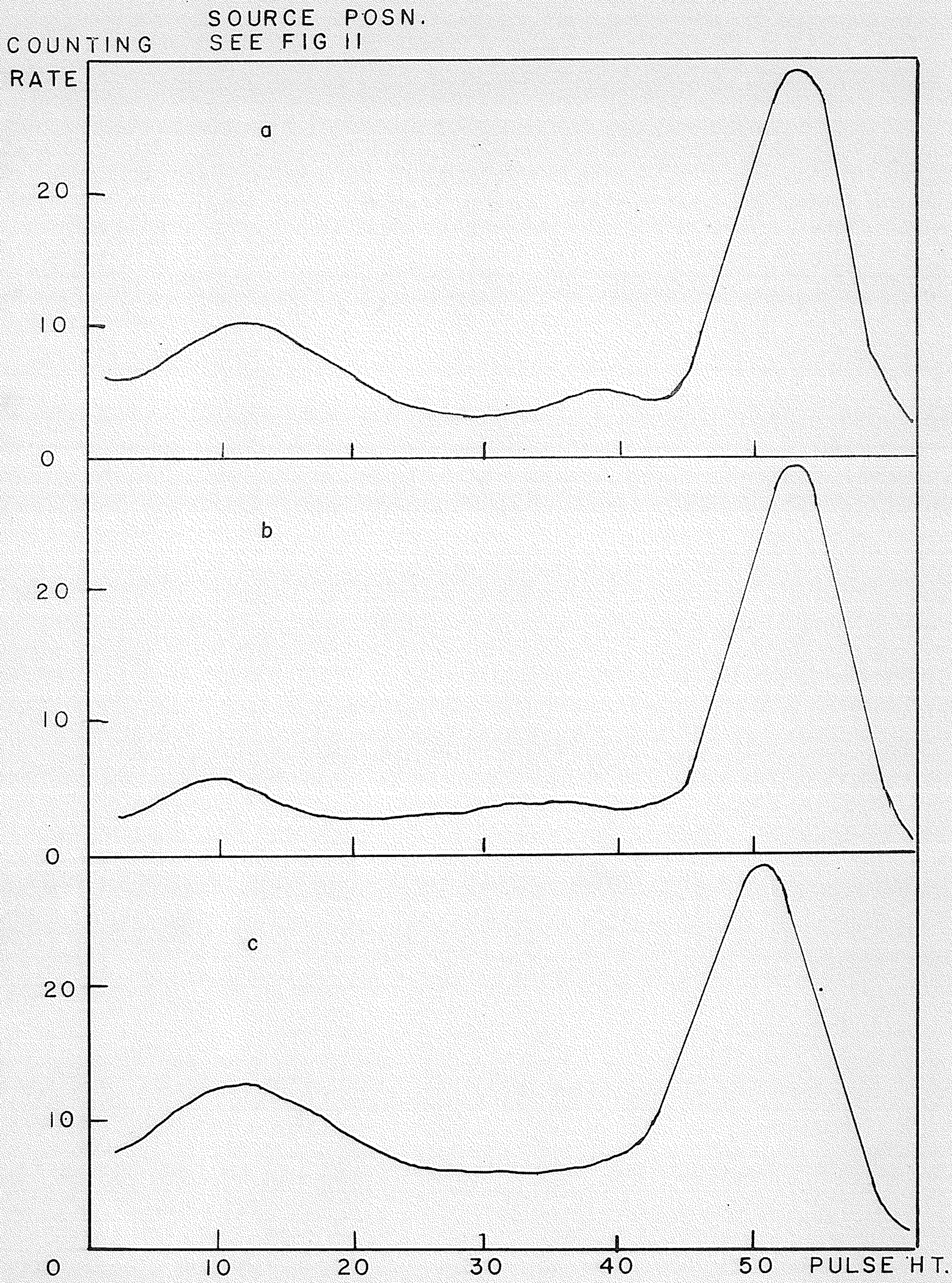


FIG 13 Cs^{137} SPECTRA

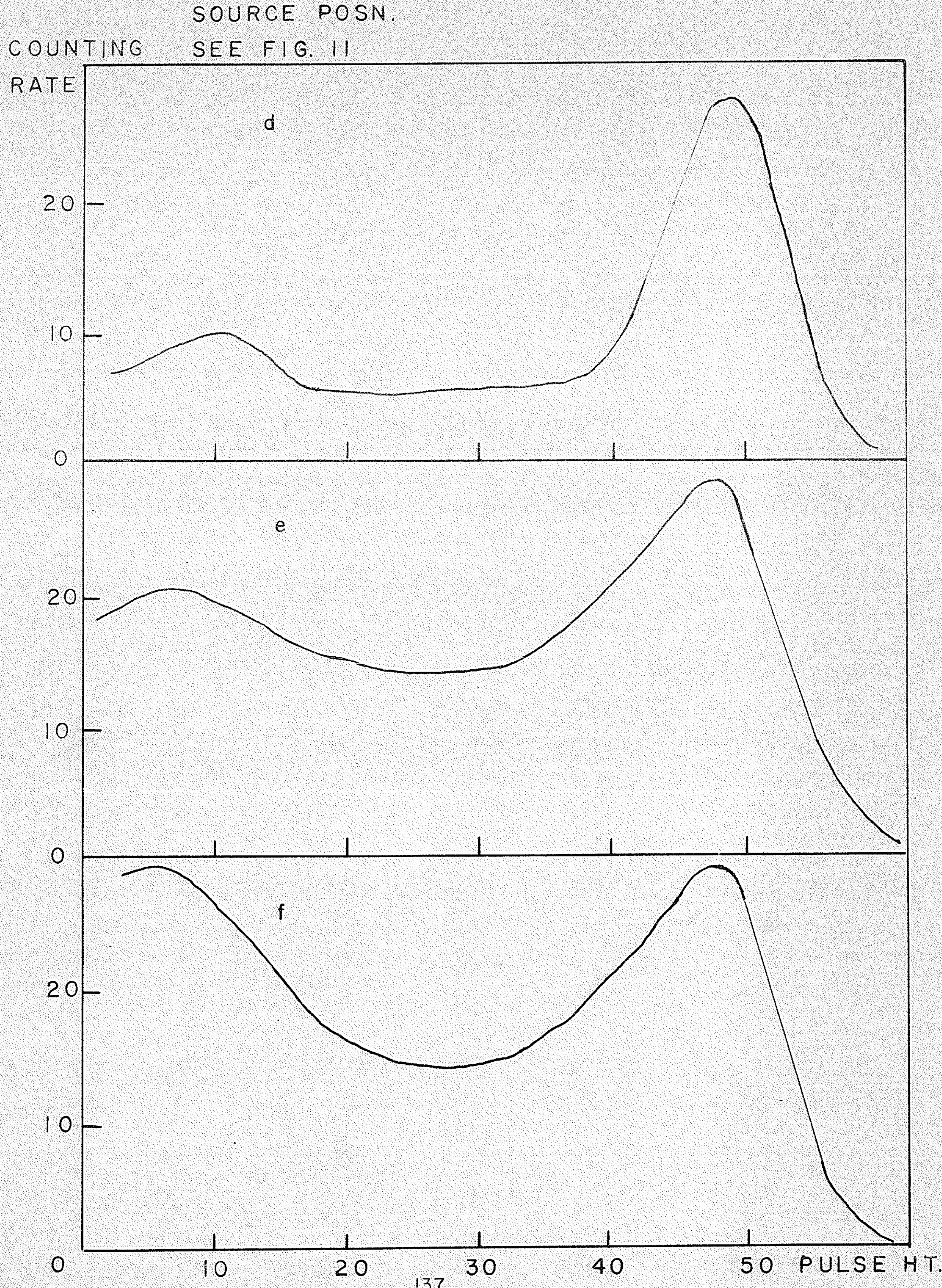


FIG 13 contd Cs^{137} SPECTRA

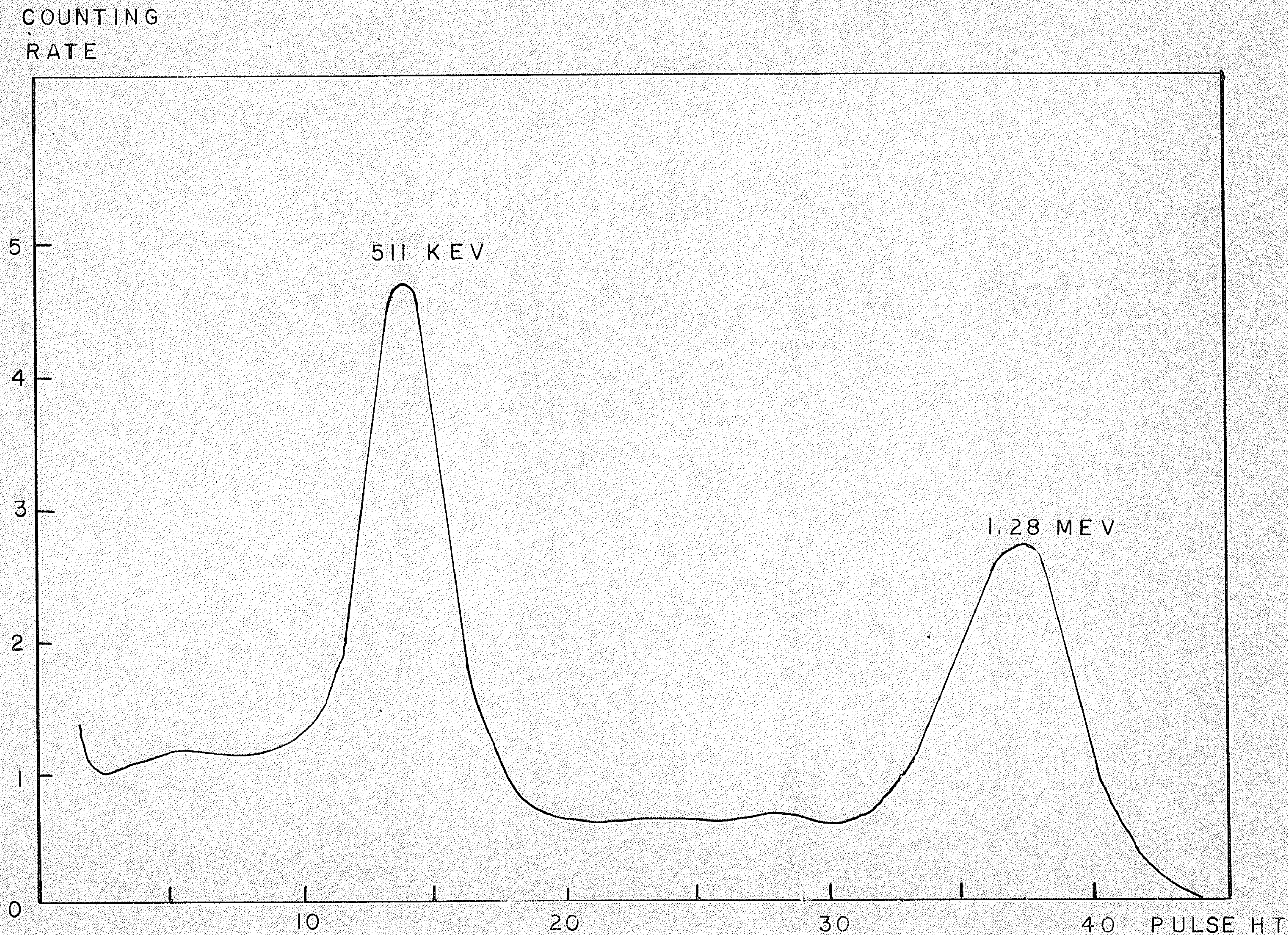


FIG 14 Na SPECTRUM

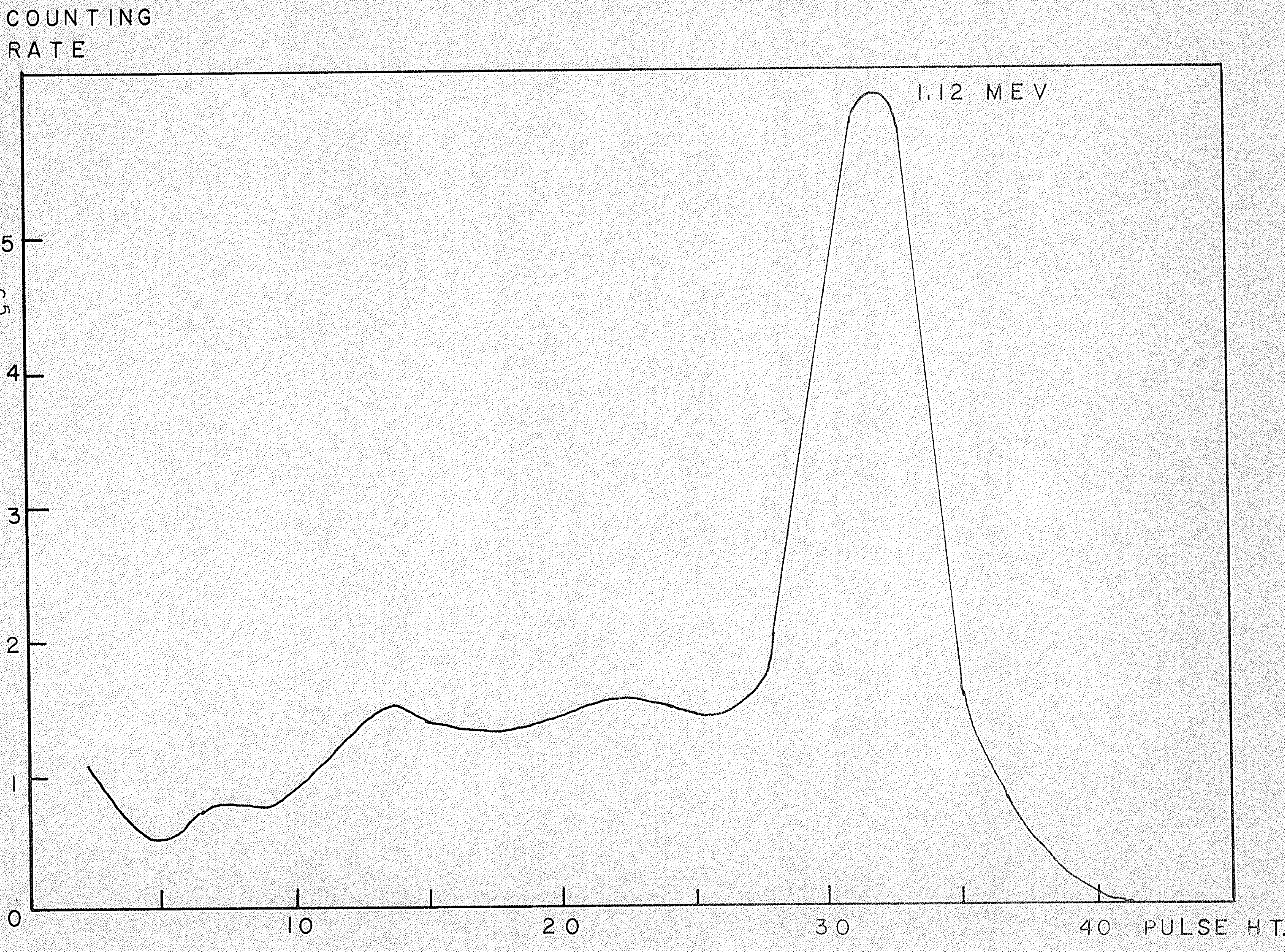


FIG 15 Zn^{65} SPECTRUM

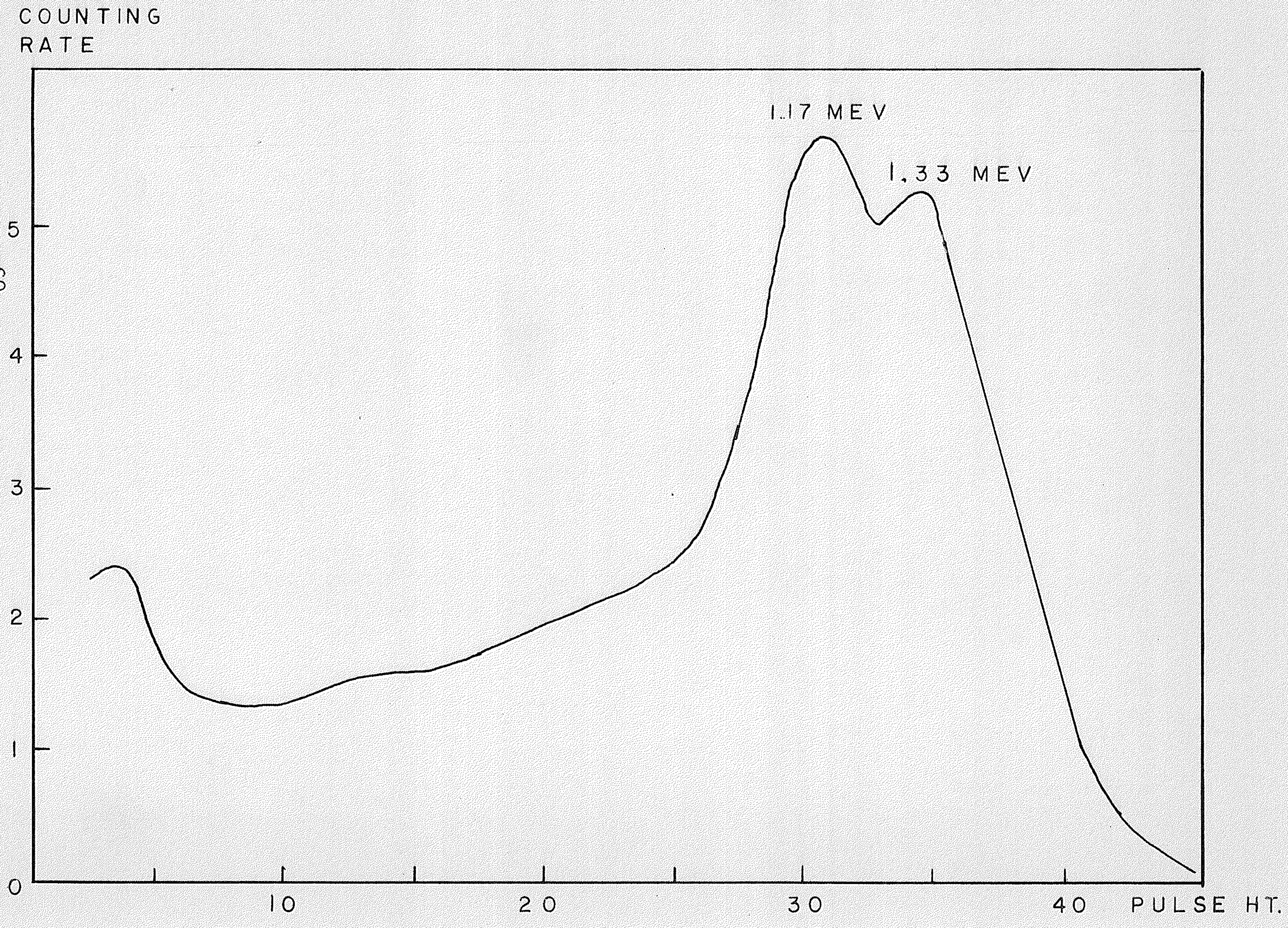


FIG 16 Co^{60} SPECTRUM

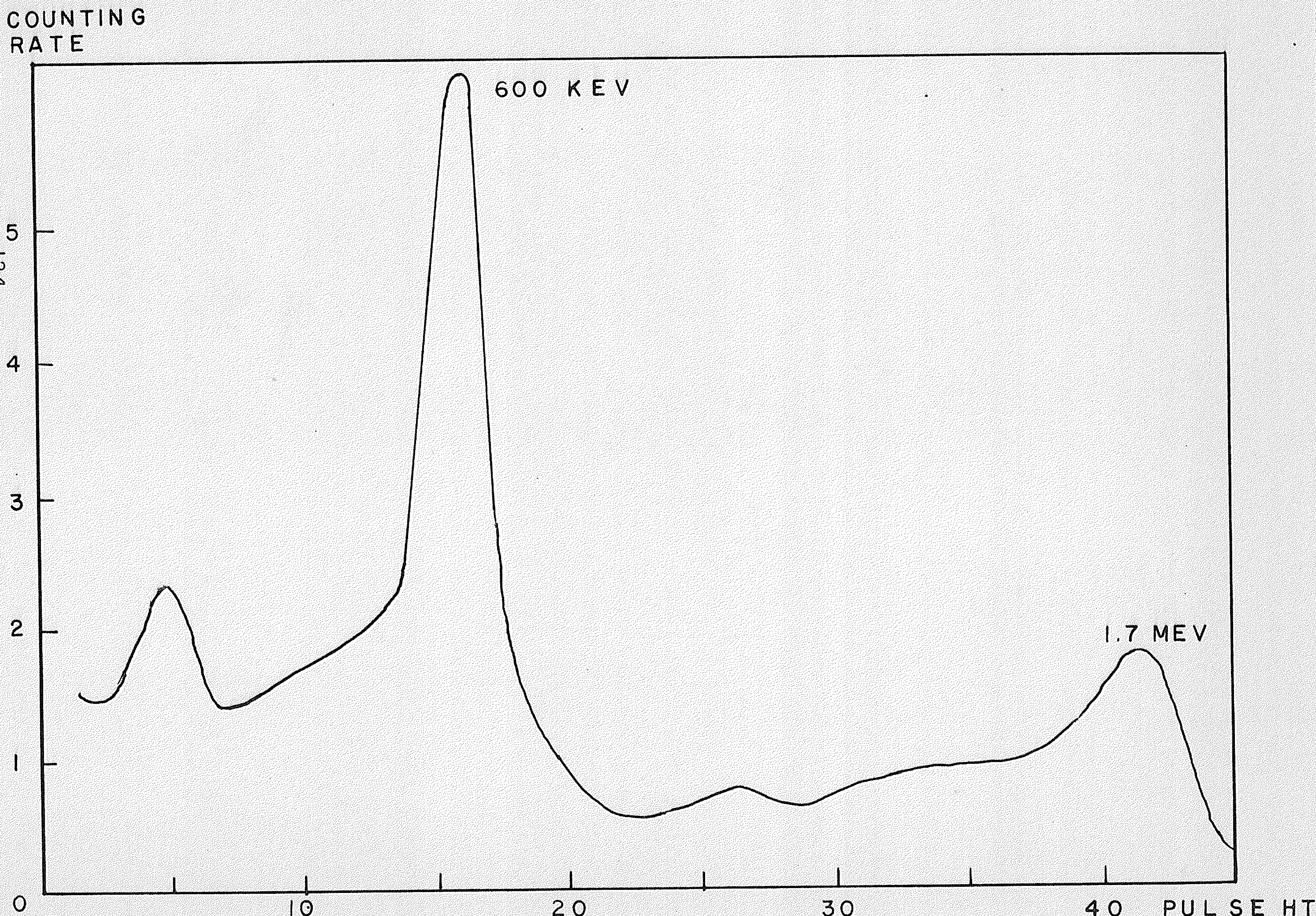


FIG 17 Sb^{124} SPECTRUM

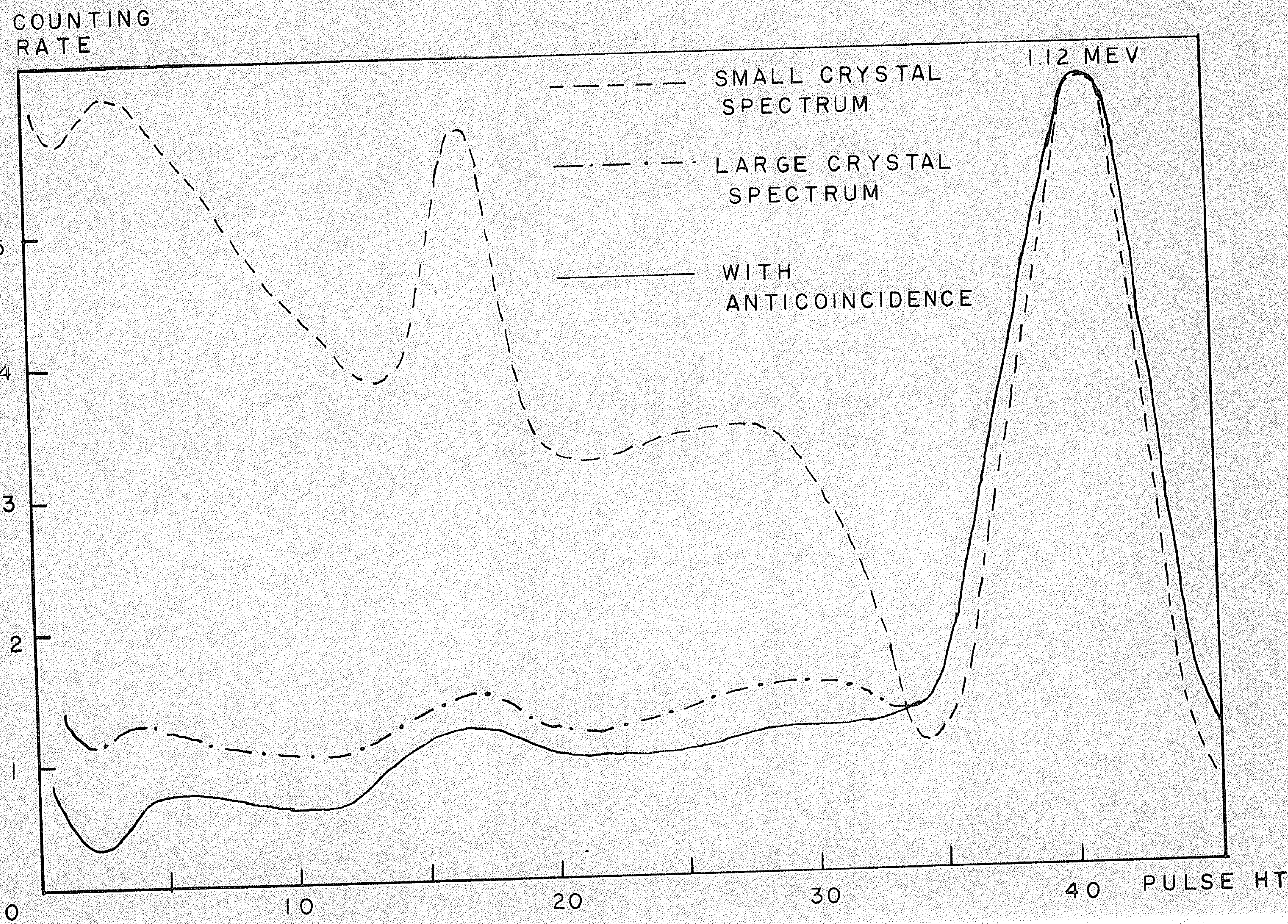


FIG 18 Zn^{65} SPECTRA

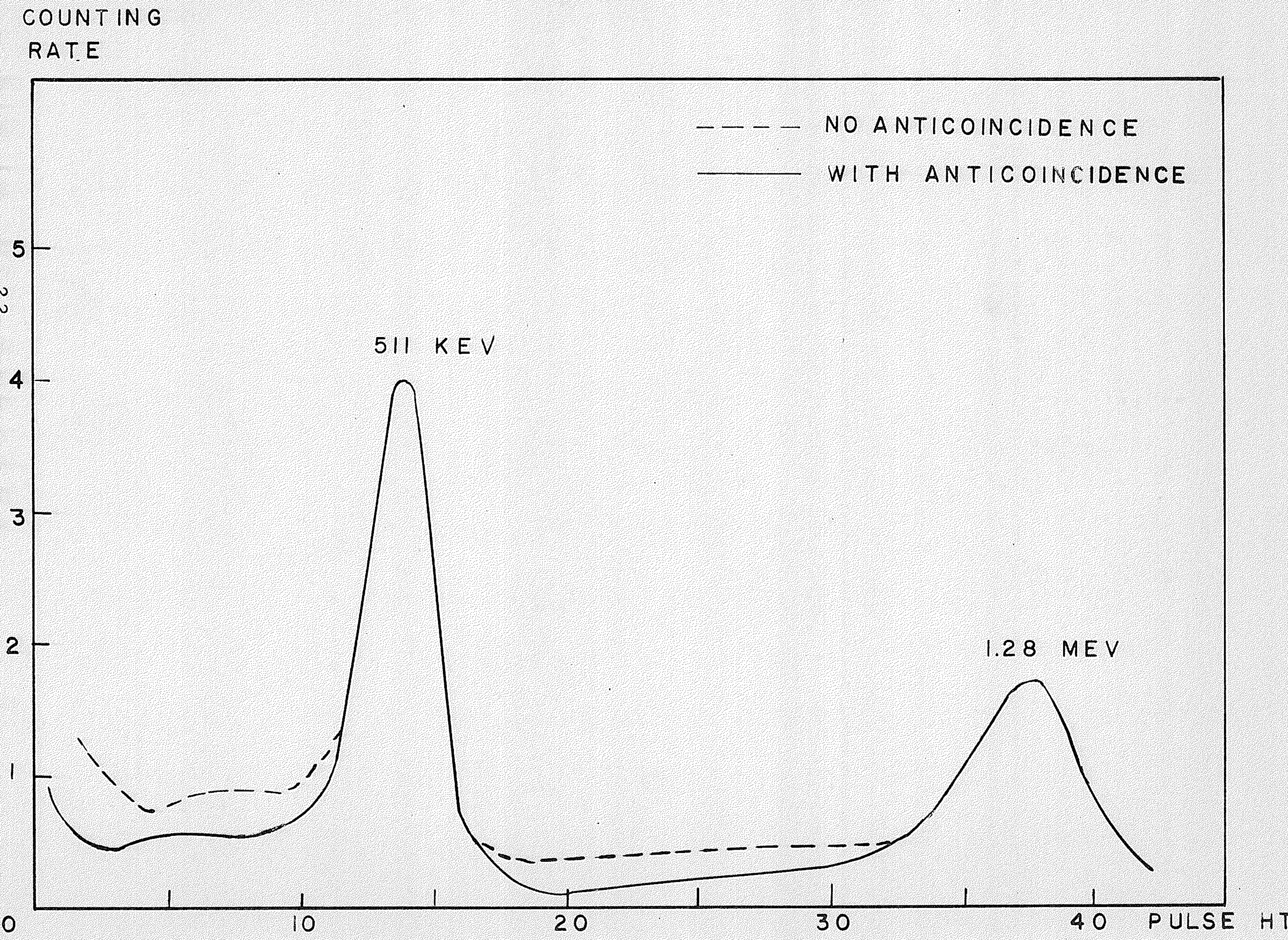


FIG 19 Na^{22} SPECTRA

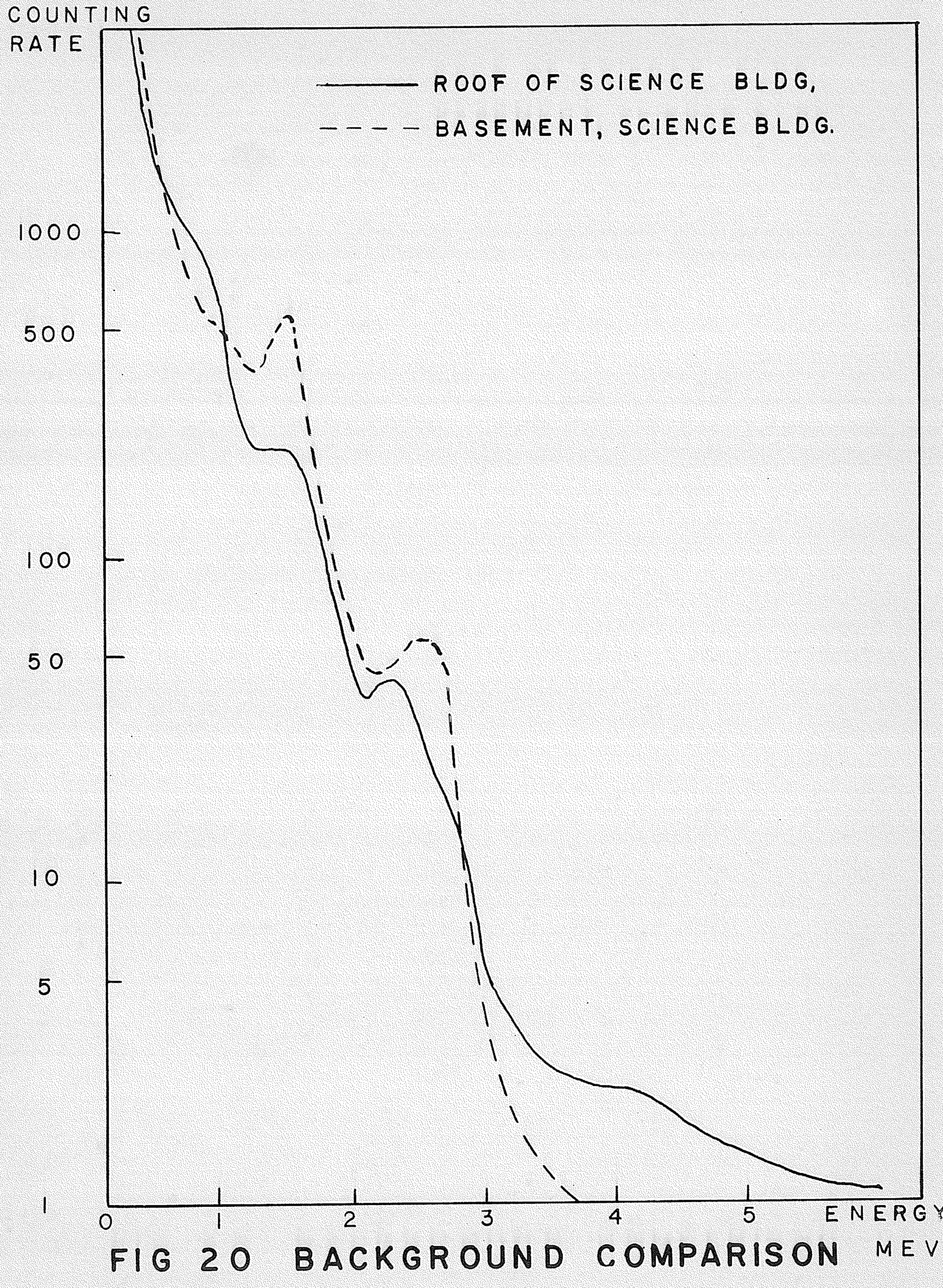


FIG 20 BACKGROUND COMPARISON

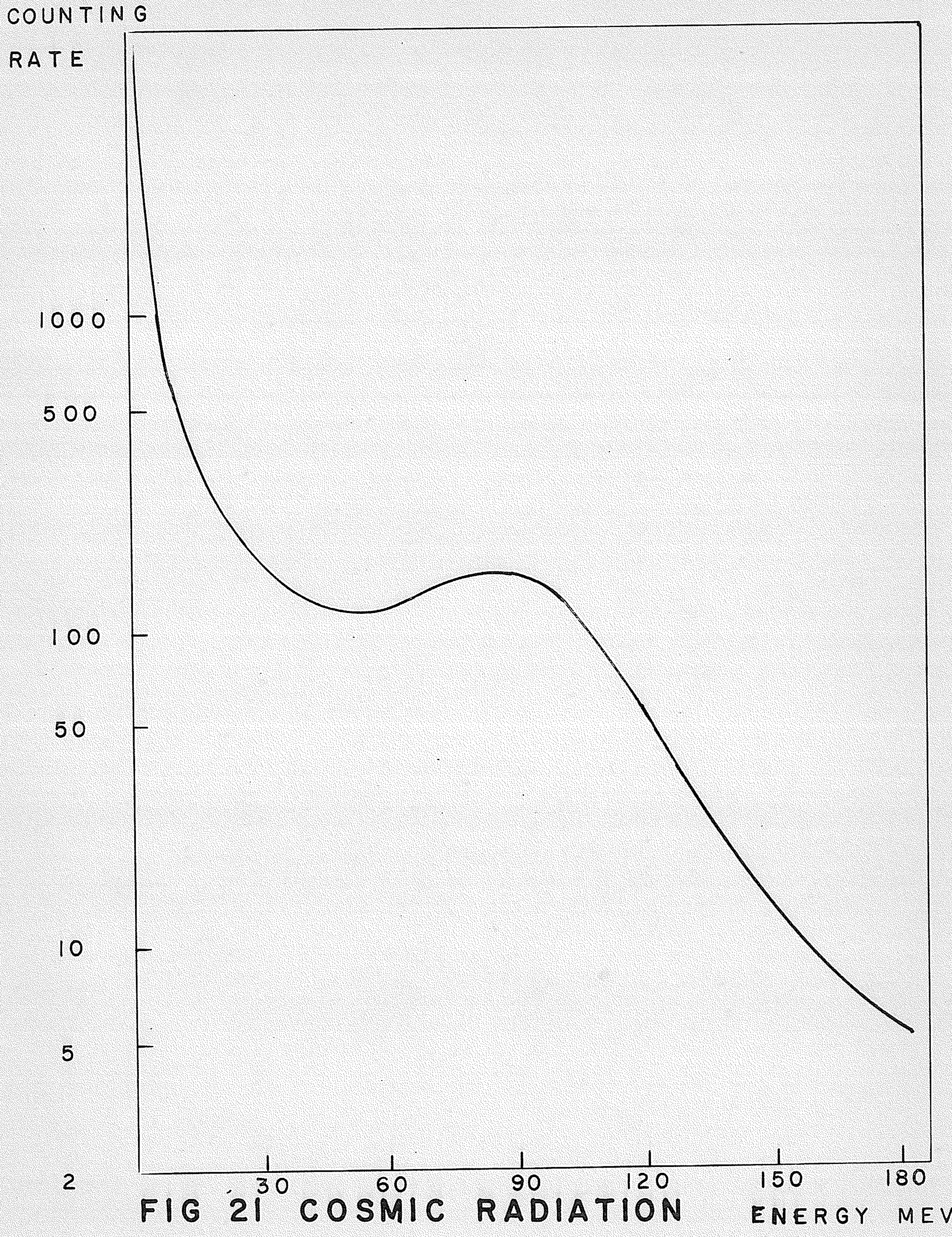


FIG 21 COSMIC RADIATION

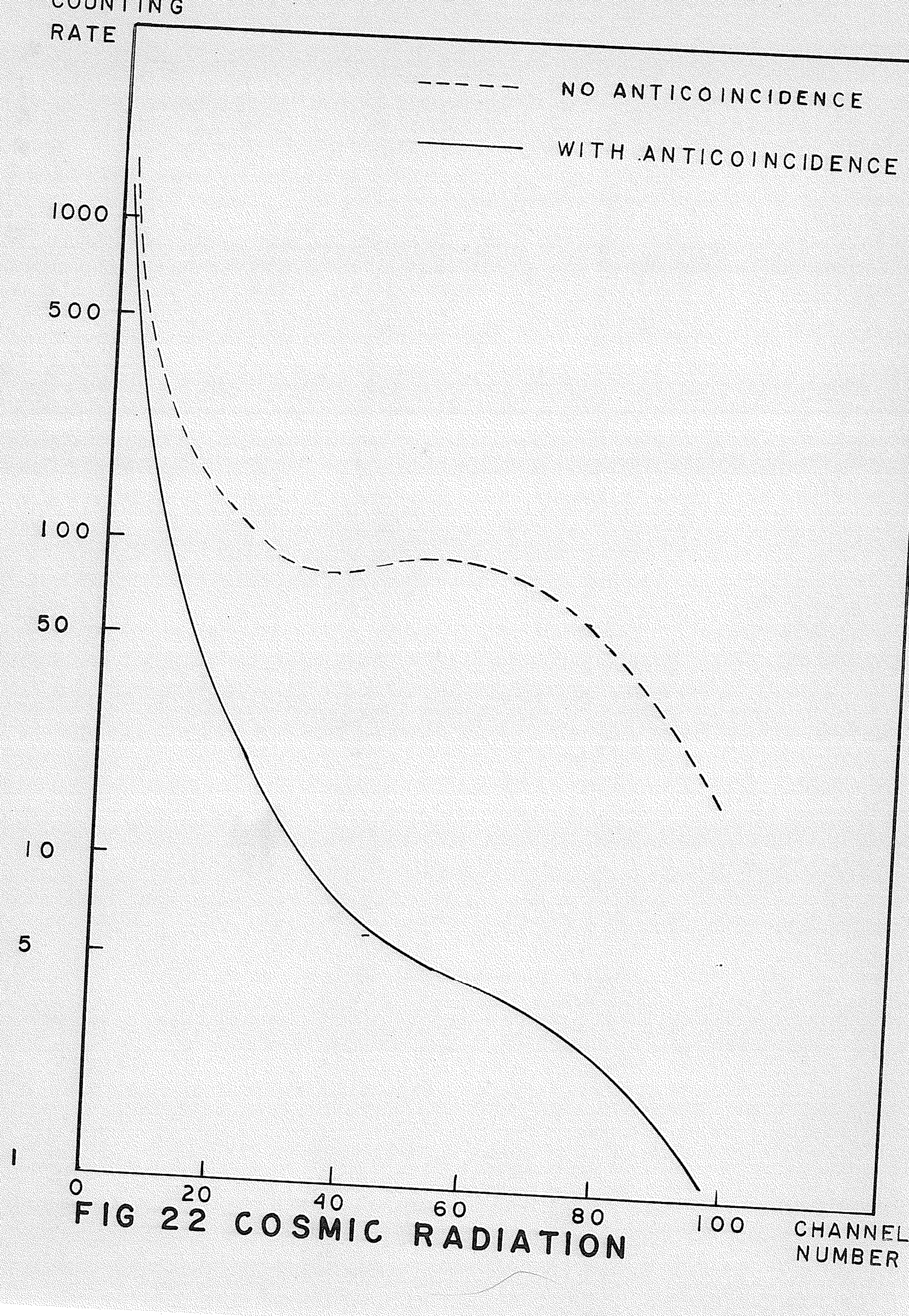


FIG 22 COSMIC RADIATION