Title

THE DESIGN AND PERFORMANCE OF A HIGH-RESOLUTION HIGH-RATE AMPLIFIER SYSTEM FOR NUCLEAR SPECTROMETRY

Permalink

https://escholarship.org/uc/item/91c8w47q

Authors

Goulding, F.S.
Landis, D.A.
Pehl, R.H.

Publication Date

1967-05-01

UCRL-17560

Cy 2

University of California

Ernest O. Lawrence Radiation Laboratory

THE DESIGN AND PERFORMANCE OF A HIGH-RESOLUTION HIGH-RATE AMPLIFIER SYSTEM FOR NUCLEAR SPECTROMETRY

F. S. Goulding, D. A. Landis and R. H. Pehl

May 1967

Submitted to Gatlinburg Conference
On Semi-Conductor Detectors and
Associated Circuits, May, 1967

UCRL-17560
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

THE DESIGN AND PERFORMANCE OF A HIGH-RESOLUTION HIGH-RATE AMPLIFIER SYSTEM FOR NUCLEAR SPECTROMETRY

F. S. Goulding, D. A. Landis and R. H. Pehl

May 1967

FOREWARD

This is one of a series of papers presented at the Gatlinburg Conference on Semi-Conductor Detectors and Associated Circuits (May, 1967). Taken together, the papers represent a general summary of some of the recent advances in this area at LRL, Berkeley.

THE DESIGN AND PERFORMANCE OF A HIGH-RESOLUTION HIGH-RATE AMPLIFIER SYSTEM FOR NUCLEAR SPECTROMETRY*

By F. S. Goulding, D. A. Landis and R. H. Pehl

Introduction

Improvements in electronic noise in preamplifiers, and the availability of germanium exhibiting a Fano factor of about 0.1, have made possible the achievement of an energy resolution of 2 keV or smaller in germanium gamma-ray spectroscopy in the 1 MeV energy region. This represents a factor of 2 to 3 improvement in the course of the last two years and has resulted in increasing emphasis on other factors such as the effect of counting-rate upon resolution. We might also mention in passing that it has also resulted in some attention being paid to the rise-time sensitivity of pulse shaping networks, as the detector rise-time fluctuations are rather large in detectors drifted to 1 to 1.5 cm depth. It is quite possible to observe poor energy resolution if a rise-time sensitive shaping network (such as delay-line with RC integrator) is used with such detectors.

The purpose of this paper is to present a brief outline of a system developed, and now in fairly general use at LRL, Berkeley for high-resolution γ-ray spectroscopy, and to discuss some of the results achieved.

1. Description of System

A. Amplifiers and Preamplifiers

The approach adopted here toward improving the high counting-rate performance of detector-spectrometers systems is fairly straightforward in concept. It is similar to a system worked on by

---

*This work was carried out as part of the program of the Nuclear Chemistry Instrumentation Group of the Lawrence Radiation Laboratory supported by AEC Contract No. W-7405-eng-48.

Strauss and his collaborators(1) but it is designed as a more general purpose system. The linear amplifier part of the system (shown in Fig. 1) is designed to develop unipolar pulses with a single short differentiator (1μsec) while all other unavoidable differentiating time constants are made very long (>0.1sec). For the integrator, required to improve the signal-to-noise ratio, we have chosen to use a modified version of the active integrator.(2) We thereby obtain the almost Gaussian-shaped pulse shown in Fig. 3A --a shape which experience has shown to be very nearly optimum from the point of view of resolution with all practical detector-F.E.T. preamplifier combinations. No switching of the shaping time constants is provided in the amplifier. This results in an economical design, avoids the problem of controls being incorrectly set by inexperienced operators, and provides a fixed pulse shape which simplifies pile-up rejection. A fast output pulse is also provided (Fig. 3B) by the amplifier for use in timing and coincidence experiments, and for pile-up rejection purposes.

The major design problem in the main amplifier is the removal of the 120∿ power supply ripple from the output. Since all the later stages are capable of passing frequencies as low as about 1 cycle/sec power supply ripple is a more serious problem than in more conventional amplifiers. It is avoided by careful attention to decoupling in the constant current sources used as transistor loads in the operational amplifier stages which form the basis of the amplifier.

The single unwanted differentiating time constant, which cannot be avoided in the system, is due to the feedback network $R_1 C_F$ in the charge sensitive preamplifier. To correct this, pole-zero cancellation(3) is used, the amount being adjustable with a preset control mounted on the front panel. Unfortunately, the resistor R1 generally does not behave as a pure resistor at high frequencies as its value is usually a few hundred MΩ and distributed capacities are in the fractional pF region. In fact, close examination of the waveform at the output of the charge sensitive stage reveals a picture like that of Fig. 2A. The main decay time-constant is determined by $R_1 . C_F$, but a second (or multiple) time constant is present during the first (5 to 50μsec) part of the decay. Since a single pole-zero cancellation can only correct for a single RC differentiator, the result is a short overswing on the output pulse of the amplifier. The remedy we have adopted consists of modifying a standard high-valued resistor (e.g., Pyrofilm) as shown in Fig. 2B.* The resulting resistor element is a very small (~10mil square) and distributed effects are negligible. The result is a very clean amplifier output pulse with no short-term overswings on which further pulses might ride at high counting rates.

The following points on the preamplifier-detector combination are also worthy of note:

(a) The detector is dc coupled to the F.E.T. This permits the use of the feedback voltage to monitor detector leakage. It also reduces stray capacities on the F.E.T. gate as compared with ac coupled systems.

---

*This method was suggested and executed by W. L. Hansen.

Furthermore, our experience has been that damage to F.E.T.'s, due to high voltage transients, has been completely eliminated with this mode of connection.

(b) A delay time-constant box is inserted in the detector voltage supply line. Also included in this box is provision to inject a test pulse through the detector capacity. By matching the pulser peak height at the amplifier output to that of a known γ-ray peak, a direct measure of detector capacity can be made and its variation with voltage determined.

(c) The F.E.T. is mounted together with a power Zener diode on a high thermal resistance (∿300°C/W) post which mounts onto the liquid nitrogen cooled part of the system. Adjustment of the Zener current allows optimization of the F.E.T. temperature.

(d) Connection DE to the feedback network is made with heavy braid. AB and BC are fine (∿2mil) nickel wires, which reduce stray capacity on the gate and also reduce heat flow from B to A or C. With this arrangement, temperature of resistor R_1 and capacitor C_F remains close to room temperature. This avoids the large change in value which occurs when certain types of high-valued resistors are cooled.

B. Pile-up Rejector and Linear Gate

With correct adjustment of the pole-zero preamplifier decay correction, excellent results like those shown in Figs. 4, 5, and 6 are realized using the amplifier to drive a pulse-height analyzer (the results in Figs. 4, 5 and 6 were obtained with a very fast successive approximation ADC of our own design). Some degradation of resolution occurs at high rates, typical numbers for this particular detector being <2 keV FWHM at 1Kc/S and 5 keV at 50 kc/S. This is a vast improvement in performance as compared with earlier systems used in our laboratory. However, as is evident in Fig. 6, trash between peaks is very significant at high counting rates. We also find, of course, that the results depend to a large extent on the quality of the input and dead time circuits of the particular type of analyzer used for the test.

In order to produce a significant improvement in these results, the pile-up rejector system shown in block form in Fig. 7 has been designed. The slow output signal from the amplifier, used for pulse-height analysis, passes through a linear gate to the analyzer only when the pile-up rejector signifies that the pulse is "uncontaminated" by other pulses. The pile-up rejector makes the decision based on examining the fast output pulse from the amplifier. Its logic circuits perform three tests on a pulse before allowing it to be regarded as valid:

a) The pulse being considered must not have been preceeded by another in a time interval shorter than an adjustable inspection time (variable from 5 to 25μsec).

b) No pulse must occur during the rise time and for 0.5μsec after the peak of the pulse being considered.

c) The pulse being considered must not contain a significant slow component. Since detectors vary in rise-time the allowable "slowness" of a pulse is adjustable by the user.

Only if these three conditions are met is the pulse allowed to pass through the linear gate into the analyzer.

Preceeding the linear gate, it is very necessary to re-establish the pulses on zero baseline as the linear gate would otherwise chop the base-line error and produce modulation of the pulse-height at the gate output to the analyzer. The circuit shown in Fig. 8 is used to correct the baseline. For negative input pulses it behaves as a White emitter-follower containing Q1 and Q2 with diode CR1 coming into conduction. During the input pulse capacitor C1 acquires charge, due to its supplying the current in R1, and following the pulse, a slight positive overswing of the voltage at the base of Q1 will occur. This causes the current in Q1 to become smaller than its equilibrium value, tending to turn off Q4 and causing Q3 to pass an increased current. This rapidly restores the voltage at the base of Q1 to its equilibrium value, recharging C1 in the process. The circuit holds the baseline accurate to about 2mV when driven by -5V pulses at 50% duty factor. The linearity of the circuit has also been shown to be excellent at levels in the millivolt range.

2. Experimental Results

Experimental results demonstrating the performance of the system used with three different detectors are given in Figs. 9 - 17. Most of the results were obtained with an excellent 5cc planar detector made from a Hoboken pulled crystal. The following characteristics were measured on this detector using the complete amplifier and pile-up rejector system:

(a) γ-resolution at low rates on 1.33 Mev line = 1.90 keV

Pulser resolution = 1.35 keV

Fano factor F = .08

(A series of measurements give values of F in the range .08 to 0.1)

(b) Resolution change at high rates (with complete system):

Rate	Resolution
1Kc/S	2.0 keV
5Kc/S	2.2 keV
10Kc/S	2.3 keV
25Kc/S	2.45 keV
50Kc/S	2.65 keV

(The counting rate quoted here is the total input γ-rate; the pile-up rejector inspect time was set to about 20 μsec and the analyzer counting rate was about 12Kc/S at 50Kc/S input rate.)

Figs. 9, 10 and 11 should be compared with Figs. 4, 5, and 6. They illustrate that, while causing no degradation in the spectrum at low rates, the pile-up rejector cleans up the spectrum considerably at high counting rates. The background between the 1.16 and 1.13 MeV lines in Figs. 11 and 6 shows this very clearly. Figs. 12 and 13 further illustrate the effectiveness of the pile-up rejector (and quality of the detector).

The low energy tailing on the 1.33 MeV line is seen to be very small at 25Kc/S. The next two figures (14 and 15) are illustrations of the peak to Compton ratios of achieved with different types of detectors.* They are to be compared with Fig. 9 for the 5cc planar detector. The best measured resolutions were:

5cc planar (capacity 8pF) - 1.9 keV
15cc double drift (capacity 13pF) - 2.2 keV
40cc coaxial (capacity 45pF) - 2.9 keV

While these results were obtained on detectors made from our best material, we quote them as an illustration of performance which can be achieved when good material is available.

A more complex spectrum taken at a moderately high counting rate with the planar detector is shown in Fig. 16; this shows that the resolution becomes 1.65 keV at about 400 keV. The lower energy performance of the system is illustrated in Fig. 17, showing that the system achieves 1.27 keV at 120 keV. Although one might expect some degradation in resolution at low energies due to the effect of noise on the base-line corrector, very little indication of this effect is present at the energy of ^{57}Co. For lower energies there is little justification for using the pile-up system.

3. Conclusion

This work has demonstrated that a relatively simple approach to the high counting rate problems in γ-ray spectroscopy can yield excellent results if executed with care. More complex schemes may be developed to further improve on performance, but the system described here has already allowed experimenters to use counting rates more than 10 times higher than previously, with virtually no sacrifice of energy resolution.

*A 40cc coaxial detector made on Hoboken pulled crystal material and a 15cc double drift unit (i.e., planar drifted from both sides to a depth of 1.3 cm leaving a slice about 2mm thick of p-type material between the two drifted regions).

4. Acknowledgements

We wish to express our thanks to S. Wright, W. Maertens and L. Schifferle for much of the constructional work and testing of the system. G. Saucedo and R. Cordi constructed the detectors used here and D. Malone designed the detector holders and cooling systems.

References

(1) M. Strauss - Argonne National Laboratory - Private Communication.

(2) E. Fairstein and J. Hahn; Nucleonics 24, 54 (1966).

(3) C. N. Nowlin and J. L. Blankenship; Rev. Sci. Instr. 36, 1830 (1965).

Figures

Figures (Continued)

13. As Figure 12 but vertical scale increased by a factor of 50

14. 15cc Double-Drift detector; ^{60}Co at 1 Kc/S (with pile-up rejector system)

15. 40cc Coaxial detector; ^{60}Co at 10 Kc/S (with pile-up rejector system)

16. 5cc Planar detector - ^{177m}Lu at 5 Kc/S (with pile-up rejector system)

17. 5cc Planar detector - ^{57}Co at 2.5Kc/S (with pile-up rejector system)

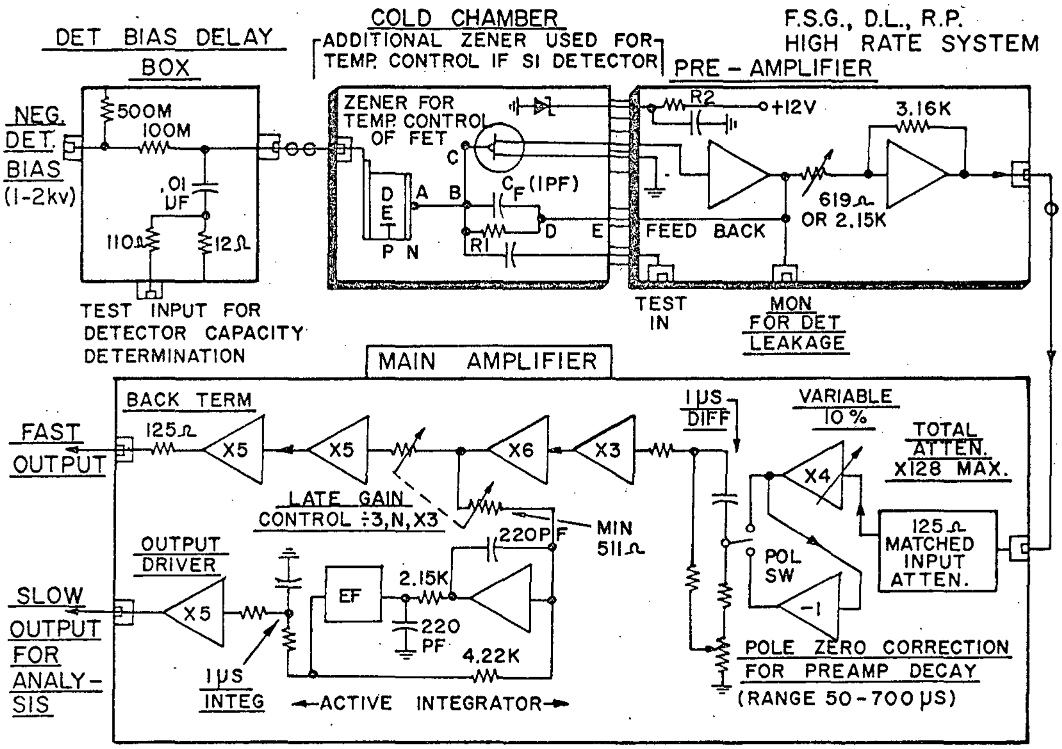


FIG.1
ESSENTIAL FEATURES OF HIGH RATE SYSTEM

XBL 675-1468

Fig. 1.

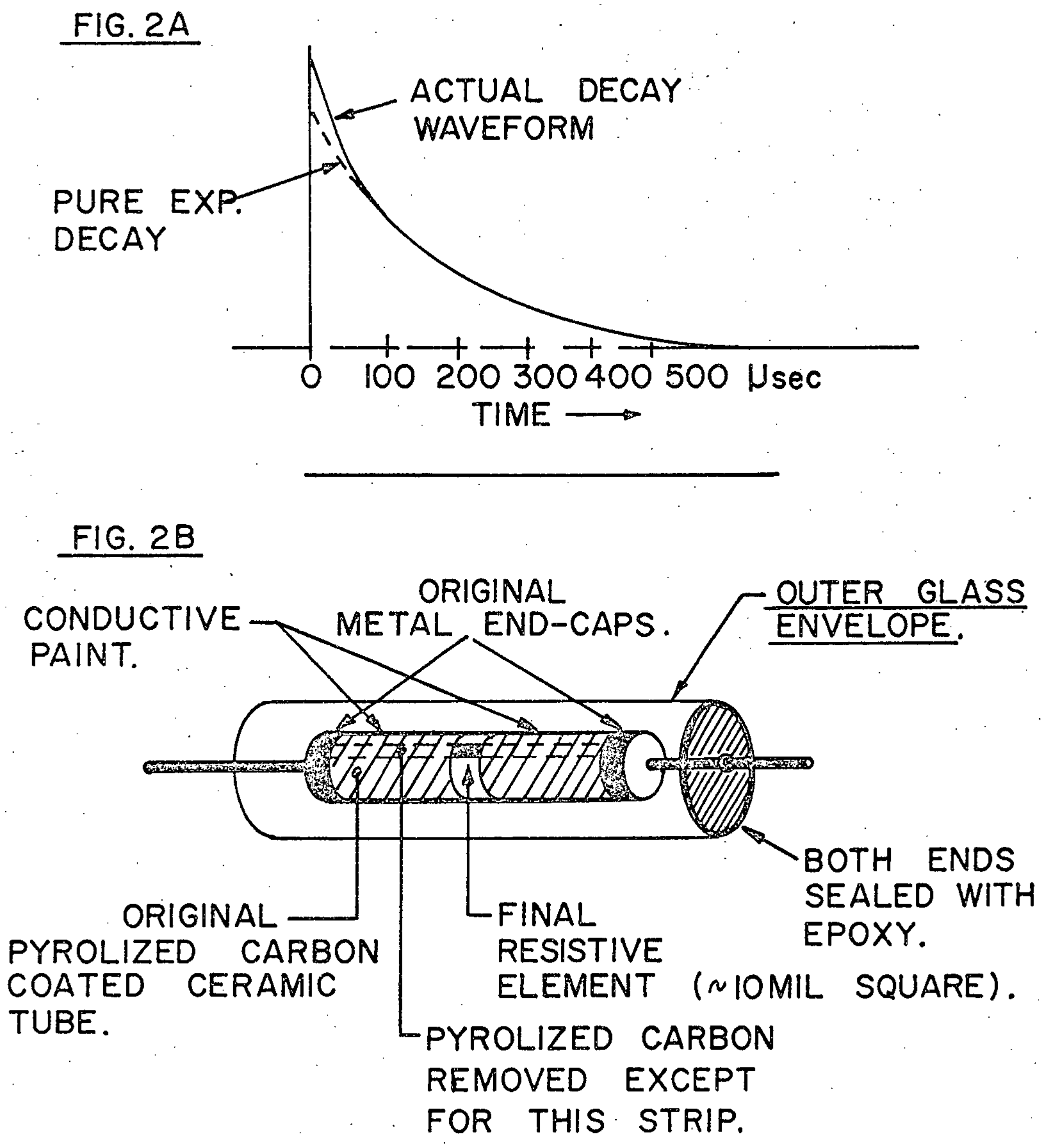


FIG. 2

SHOWING MULTIPLE TIME-CONSTANT DUE TO RI AND CONSTRUCTION OF RESISTOR TO ELIMINATE EFFECT.

XBL 675-1469

Fig. 2.

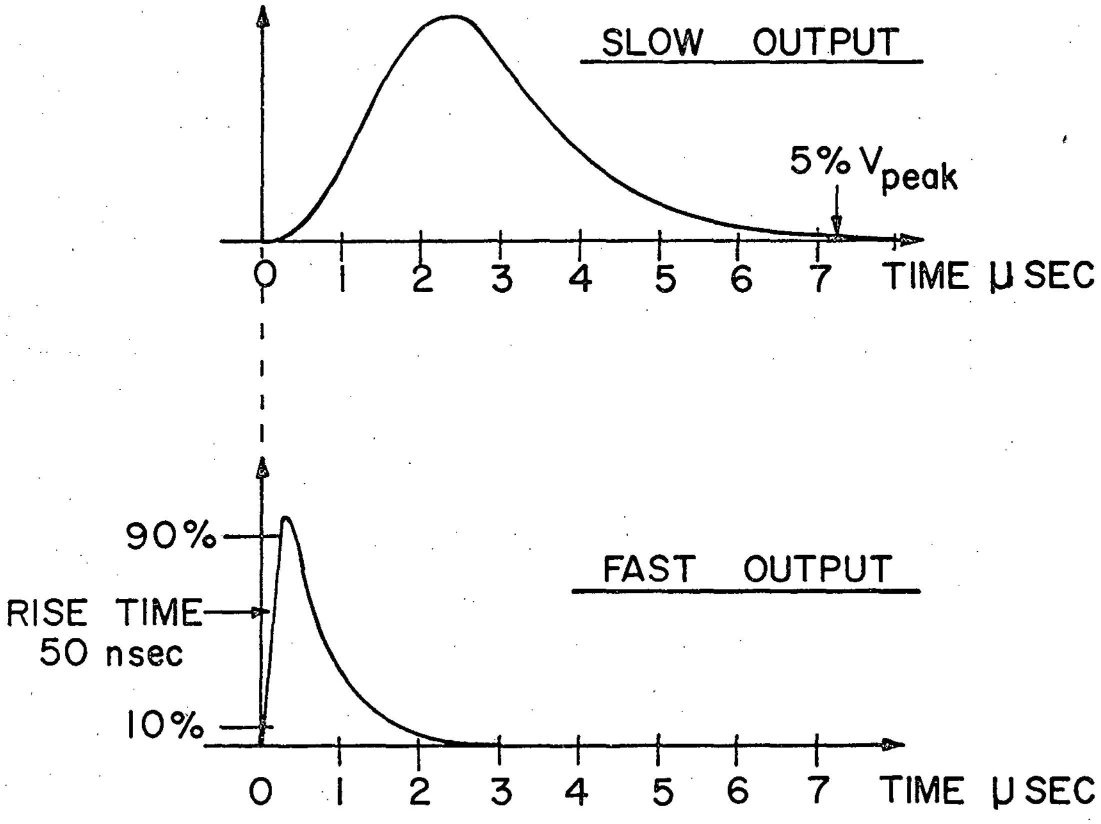
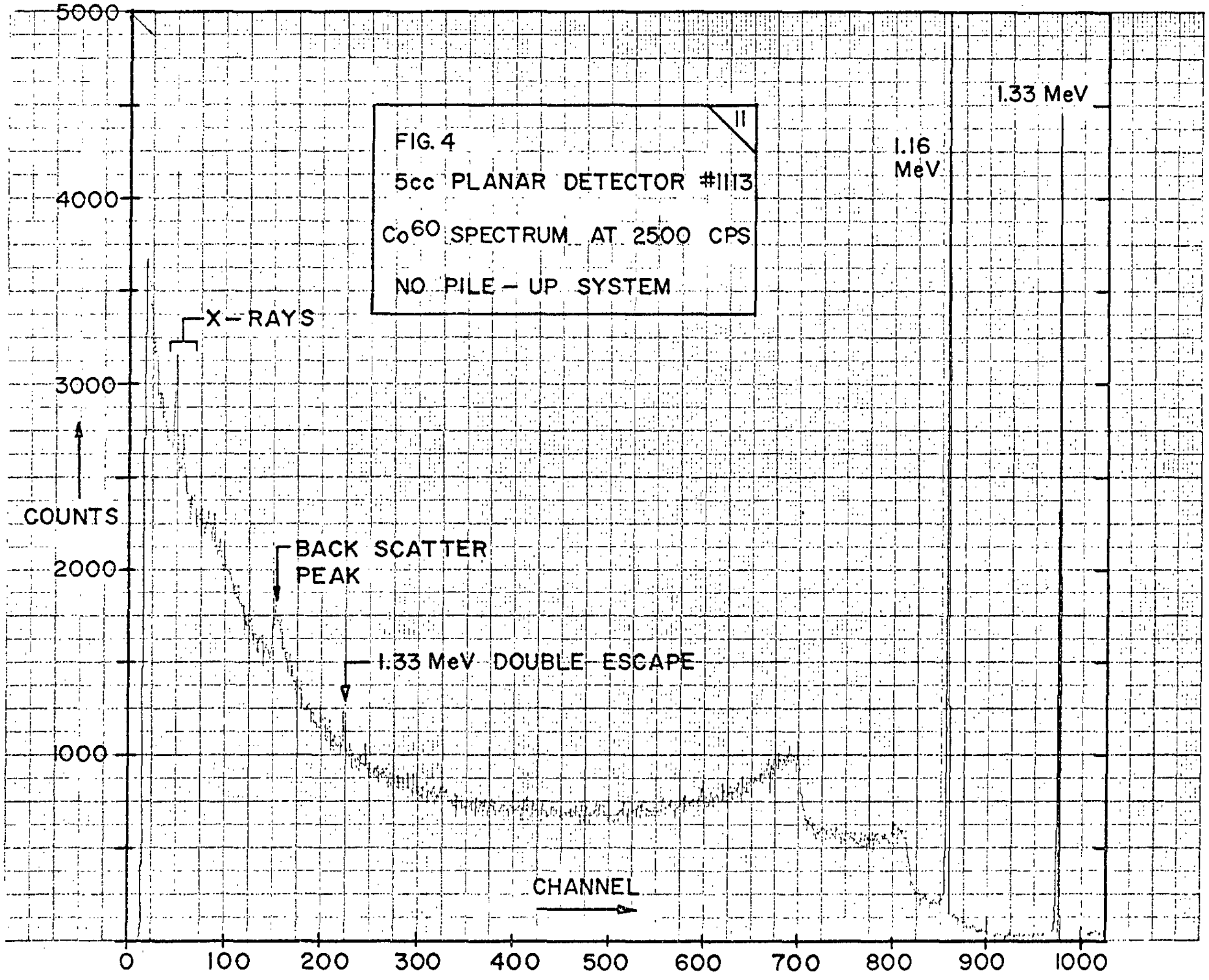


FIG. 3
AMPLIFIER OUTPUT PULSE SHAPES

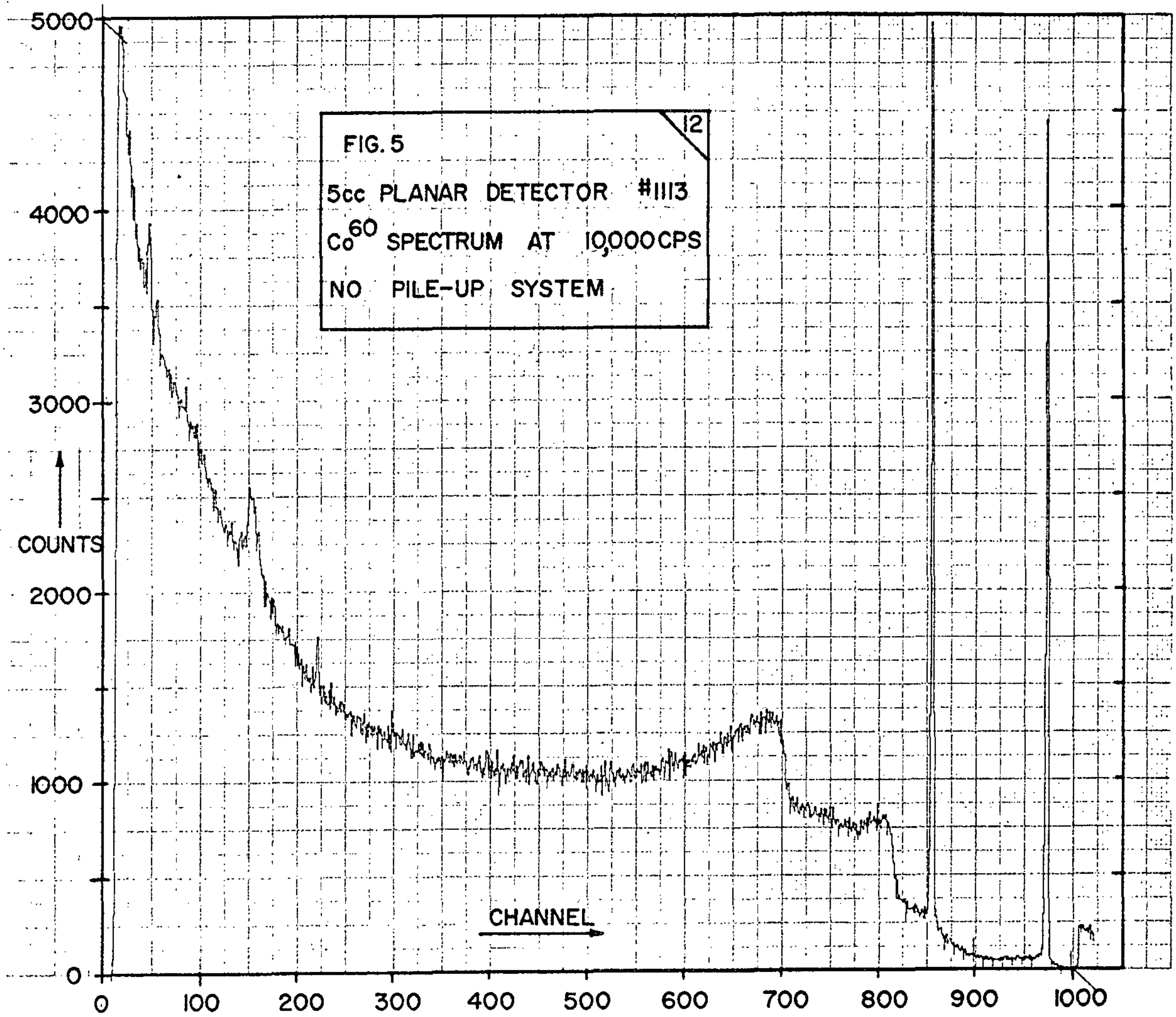
XBL 675-1470

Fig. 3.



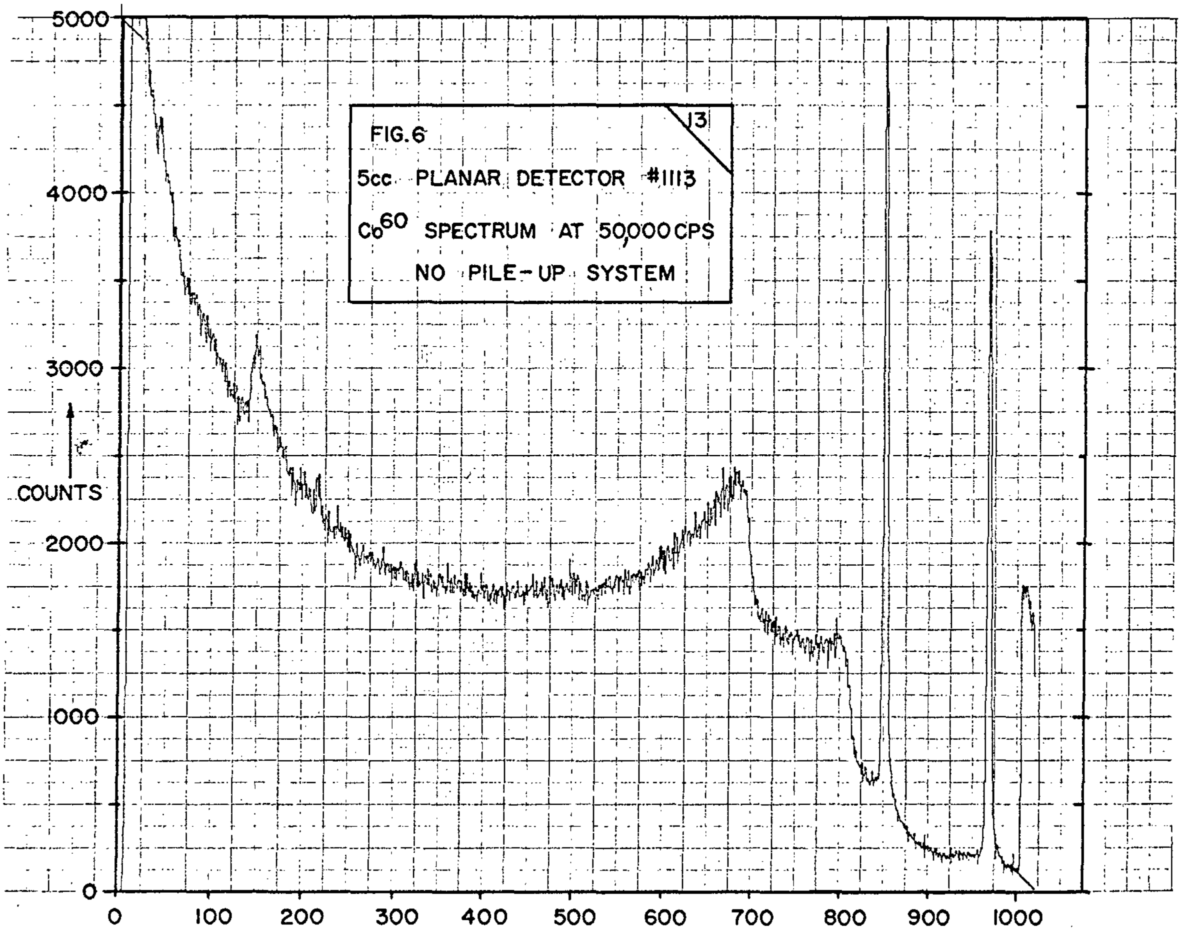
XBL 675-1471

Fig. 4.



XBL 675-1472

Fig. 5.



XBL 675-1473

Fig. 6.

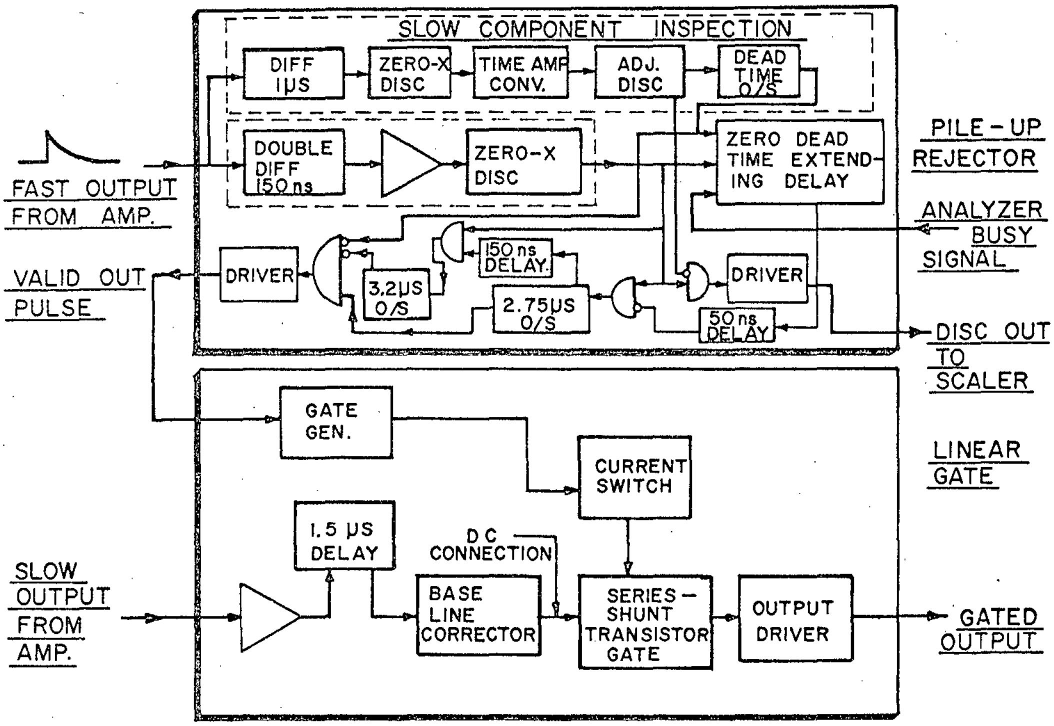


FIG. 7
BLOCK DIAGRAM OF PILE-UP REJECTOR AND GATE

XBL 675-1474

Fig. 7.

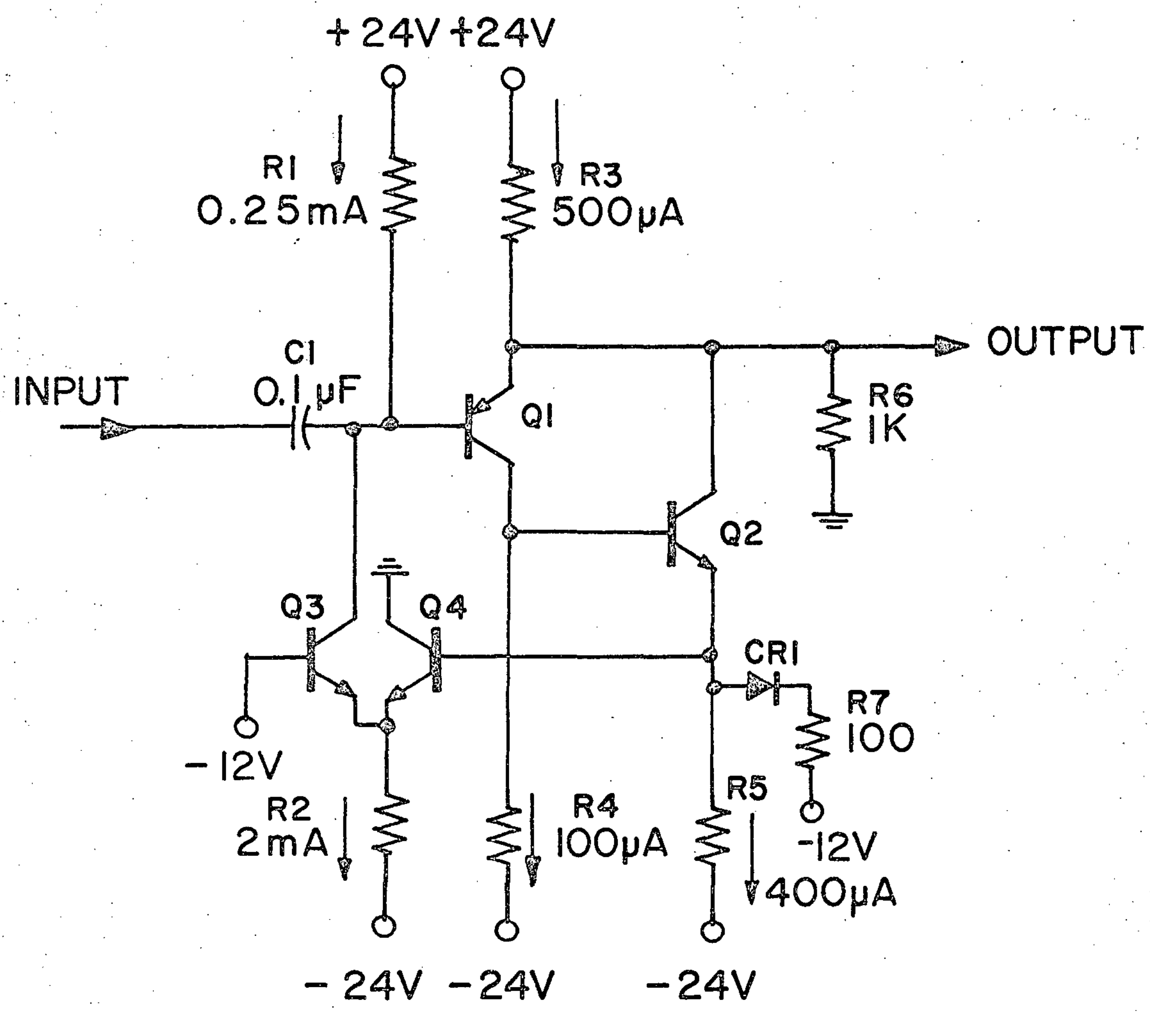
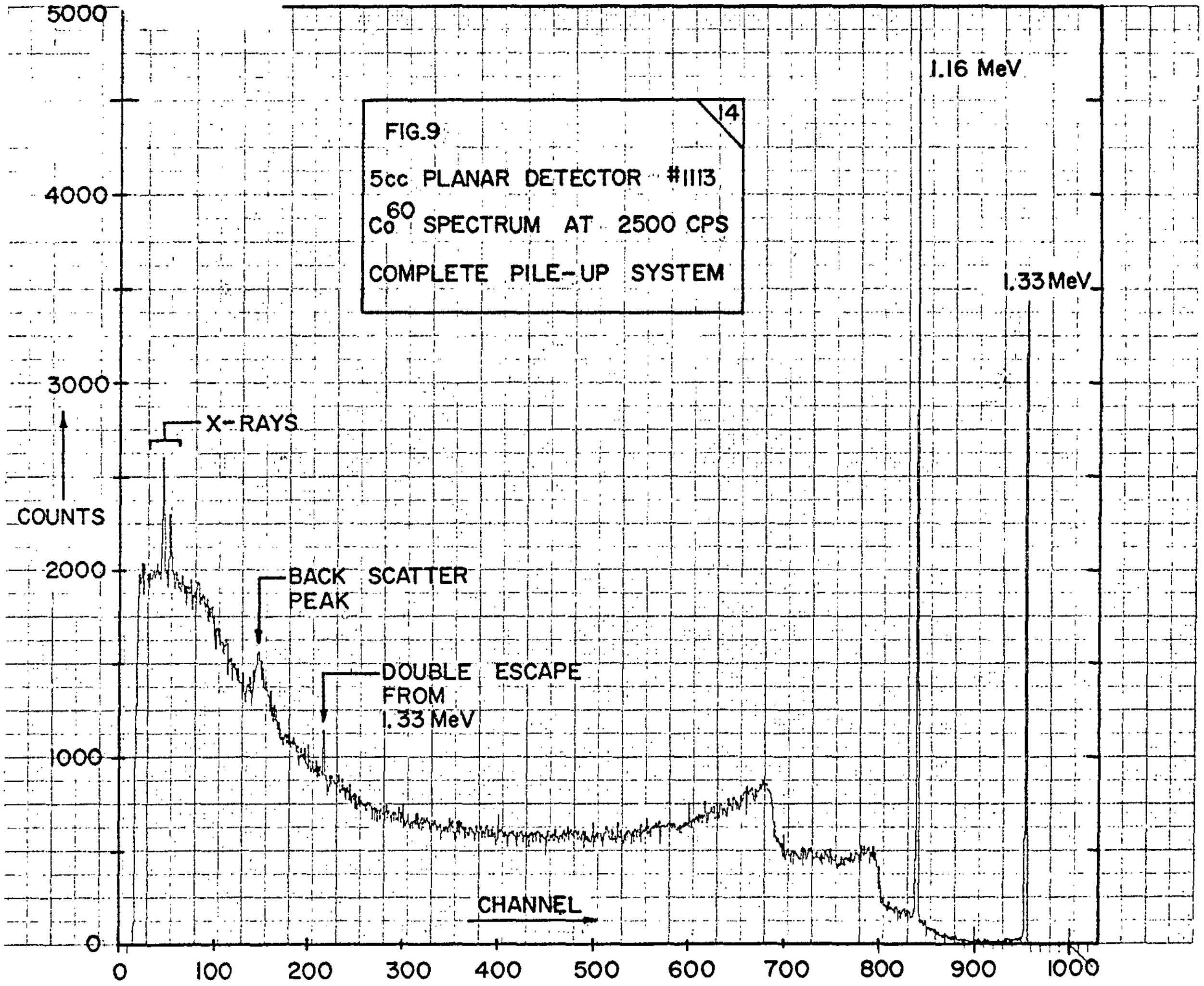


FIG. 8

BASE-LINE CORRECTOR CIRCUIT

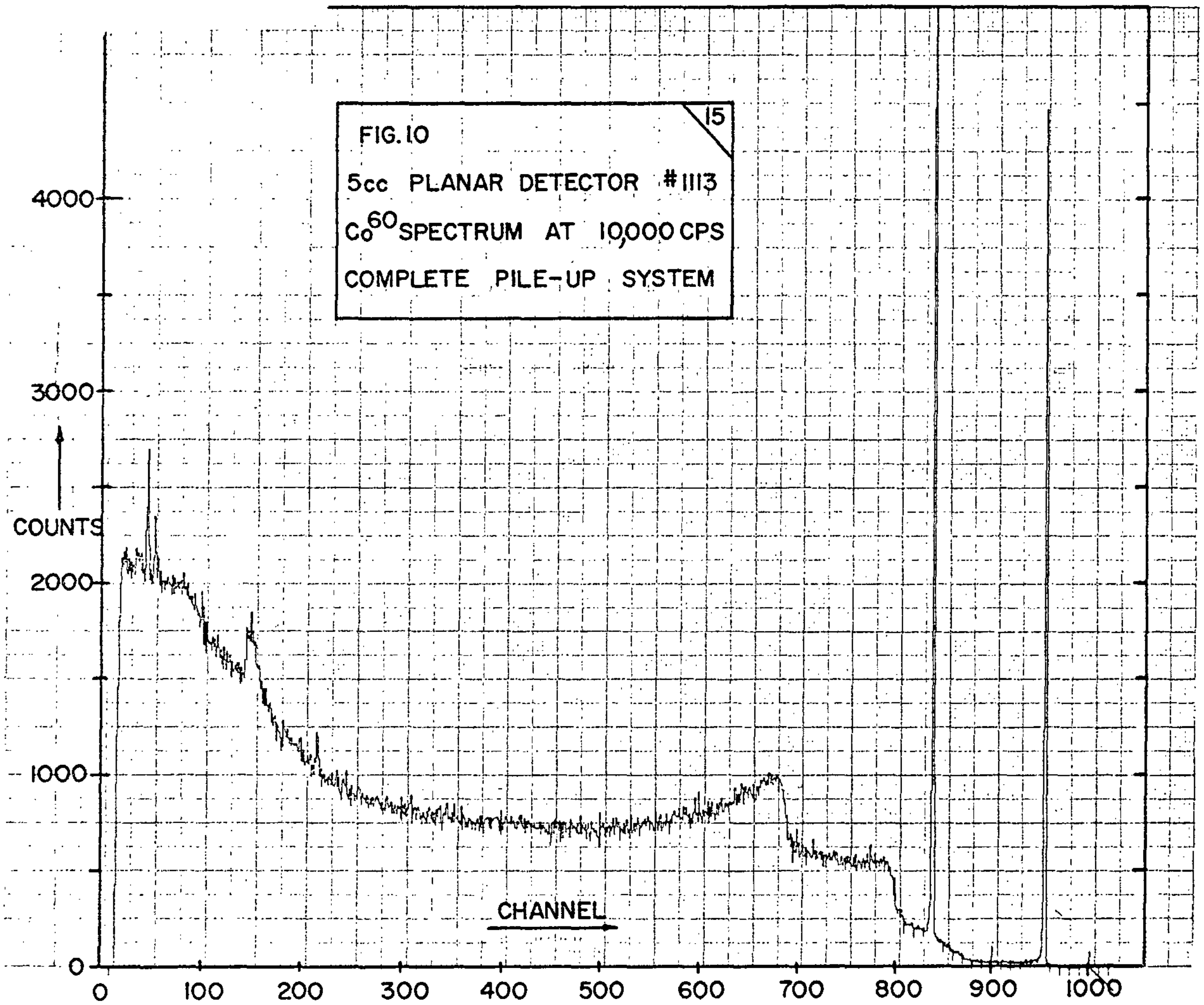
XBL 675-1475

Fig. 8.



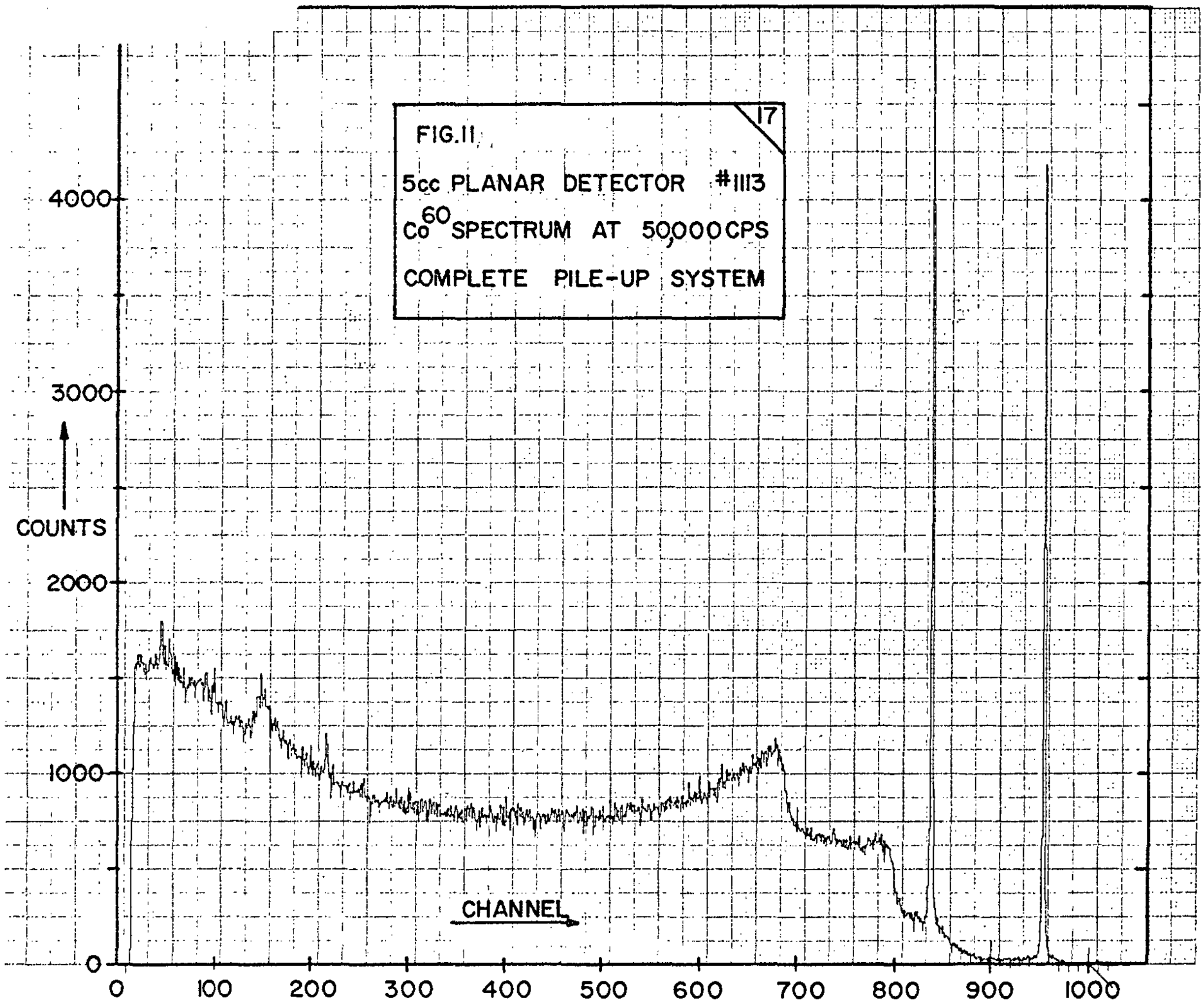
XBL 675-1476

Fig. 9.



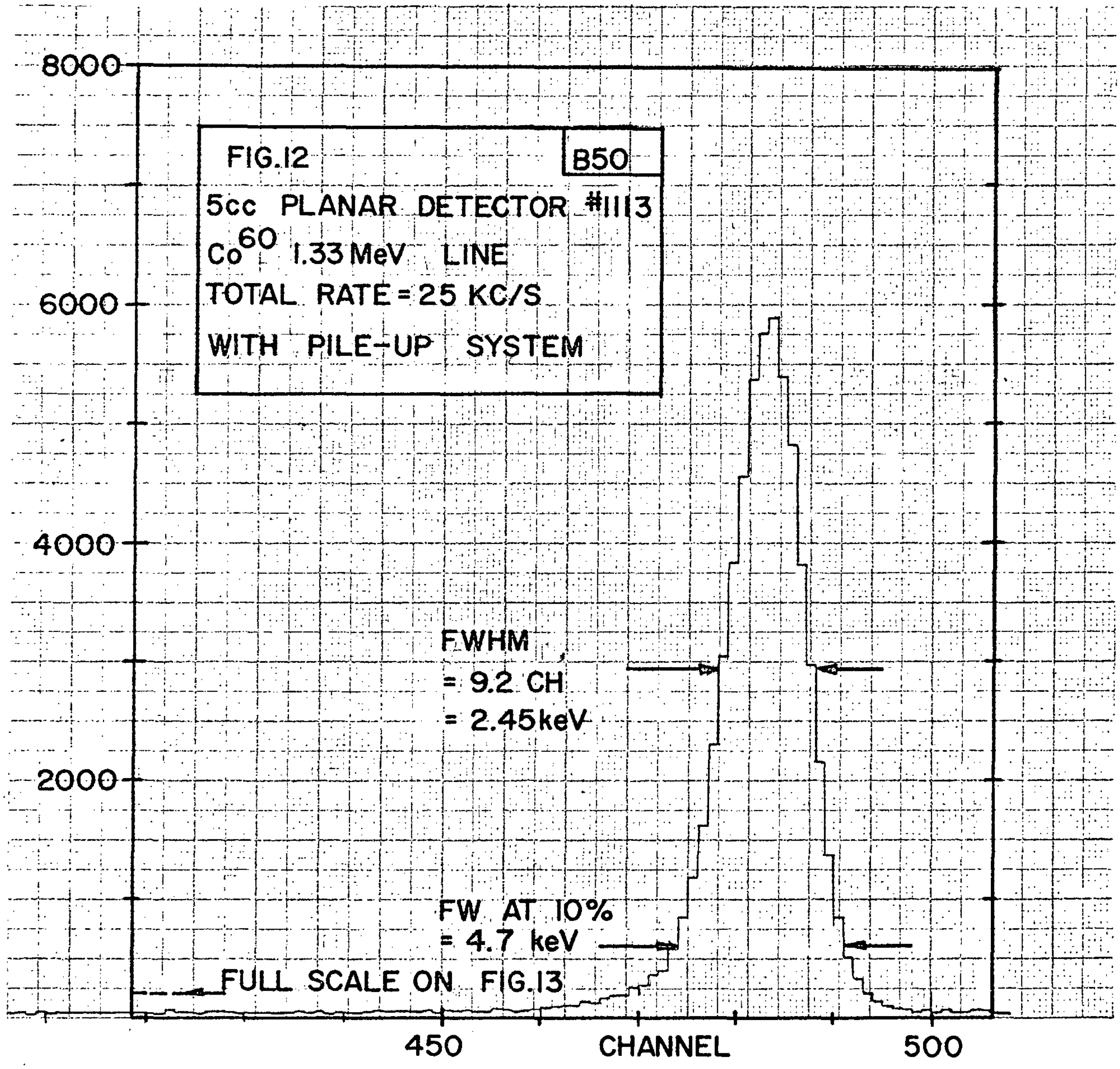
XBL 675-1477

Fig. 10.



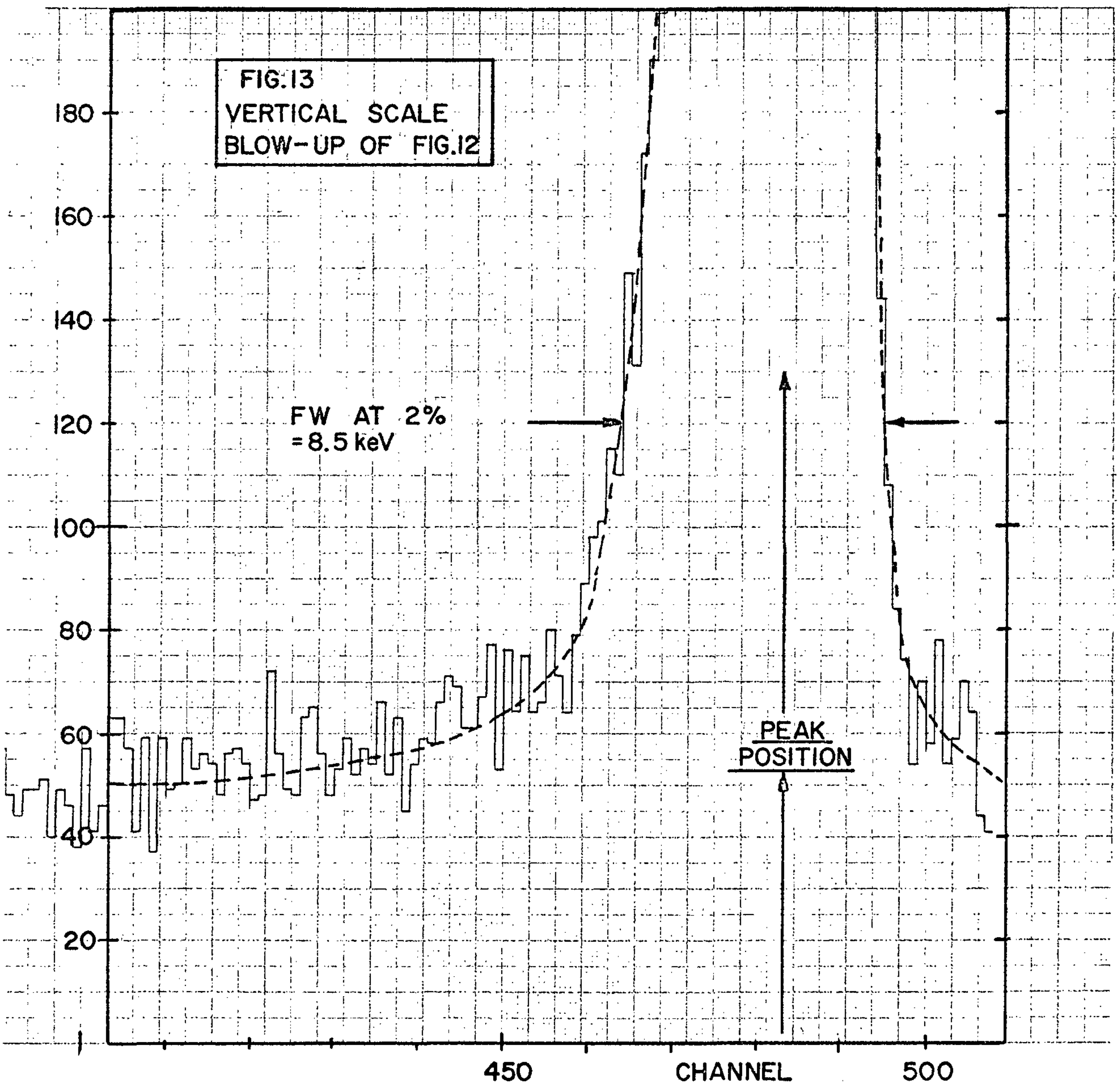
XBL 675-1478

Fig. 11.



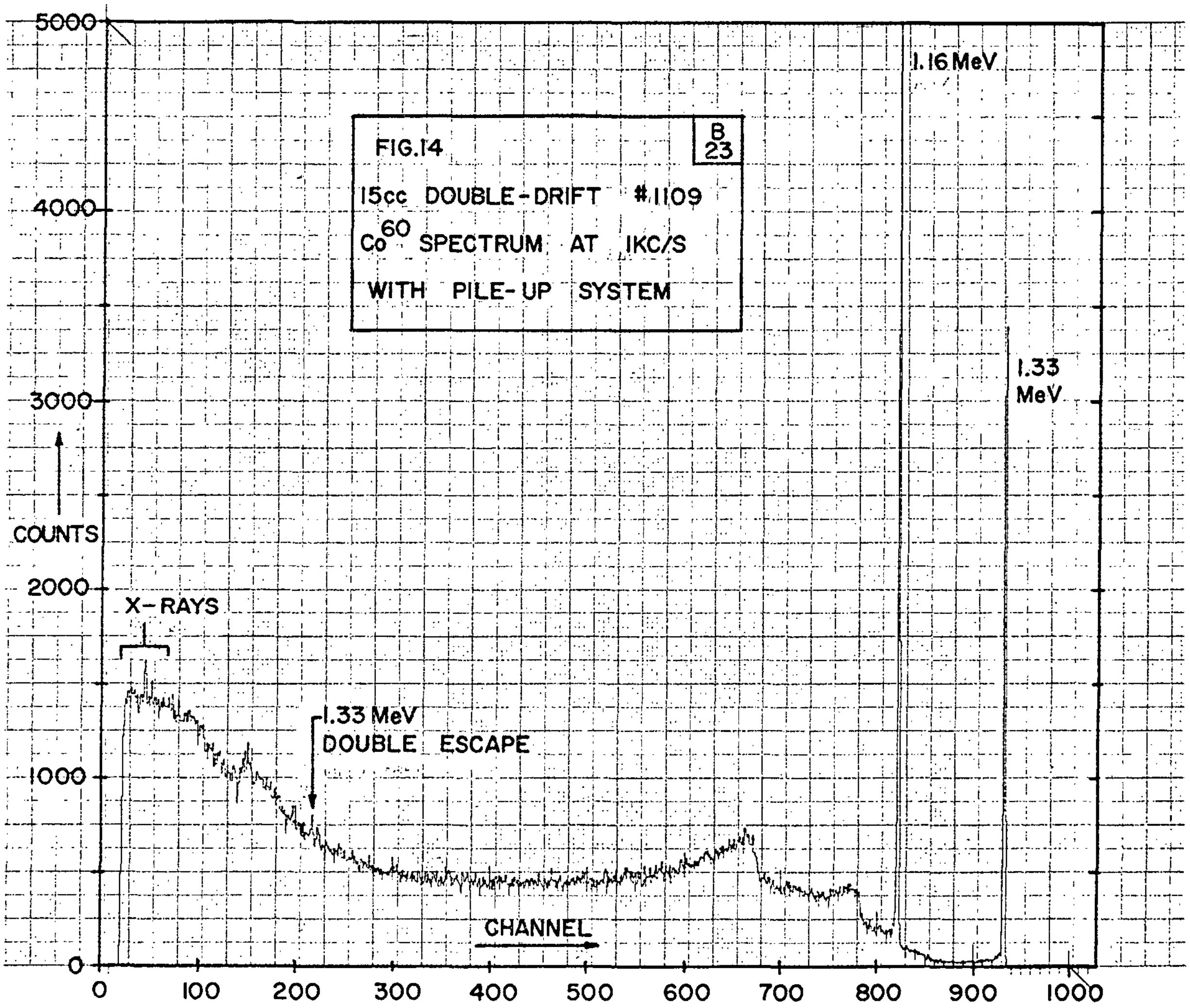
XBL 675-1479

Fig. 12.



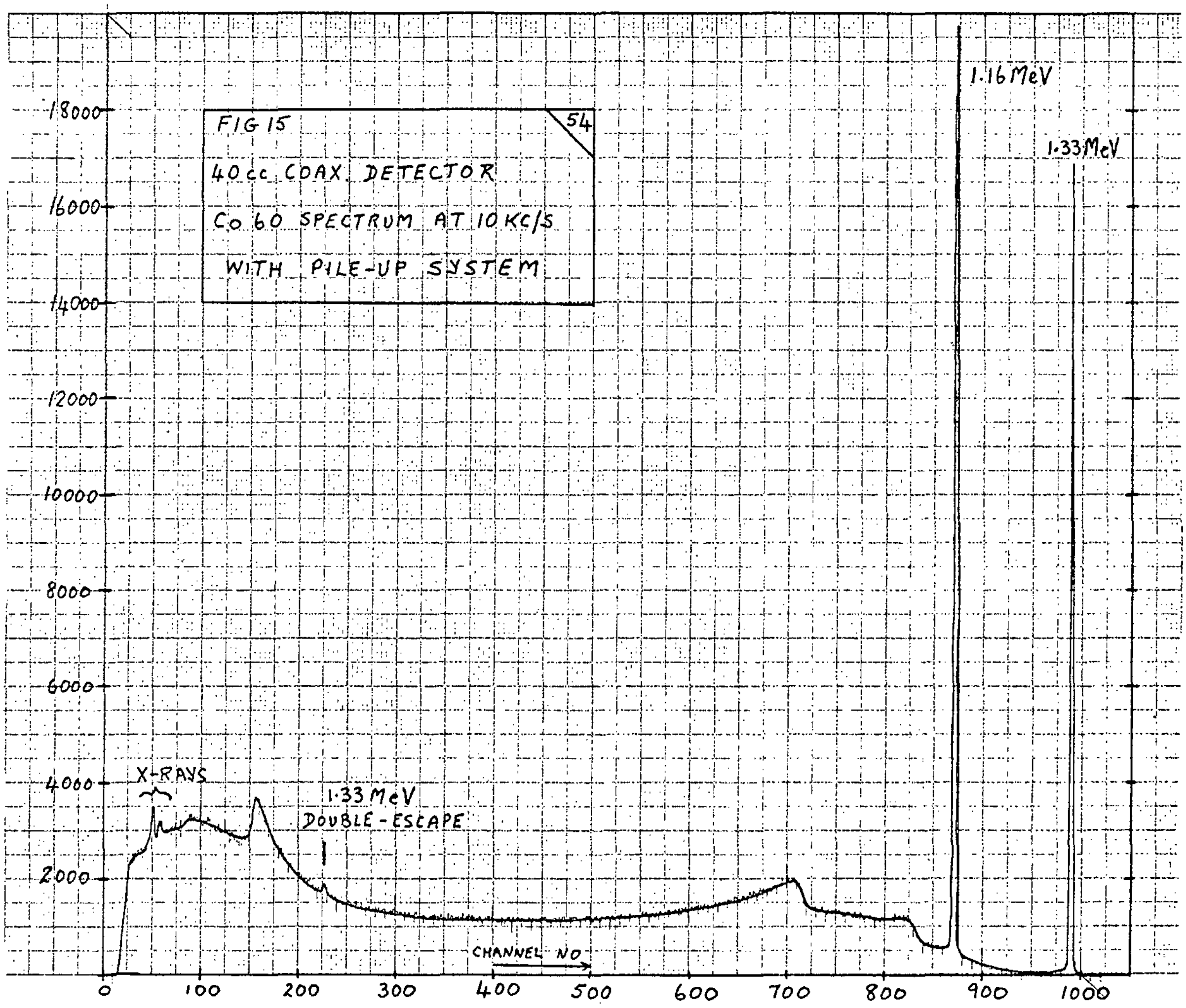
XBL 675-1480

Fig. 13.



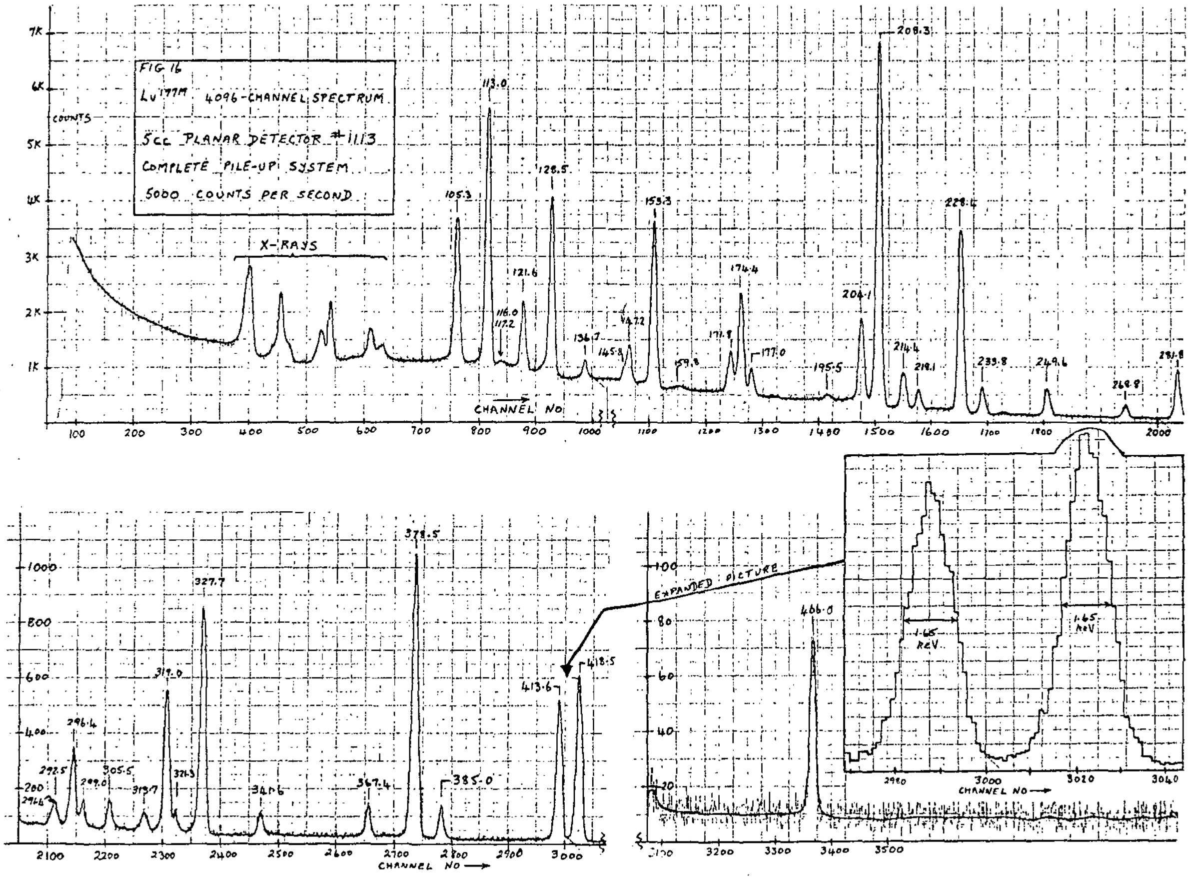
XBL 675-1481

Fig. 14.



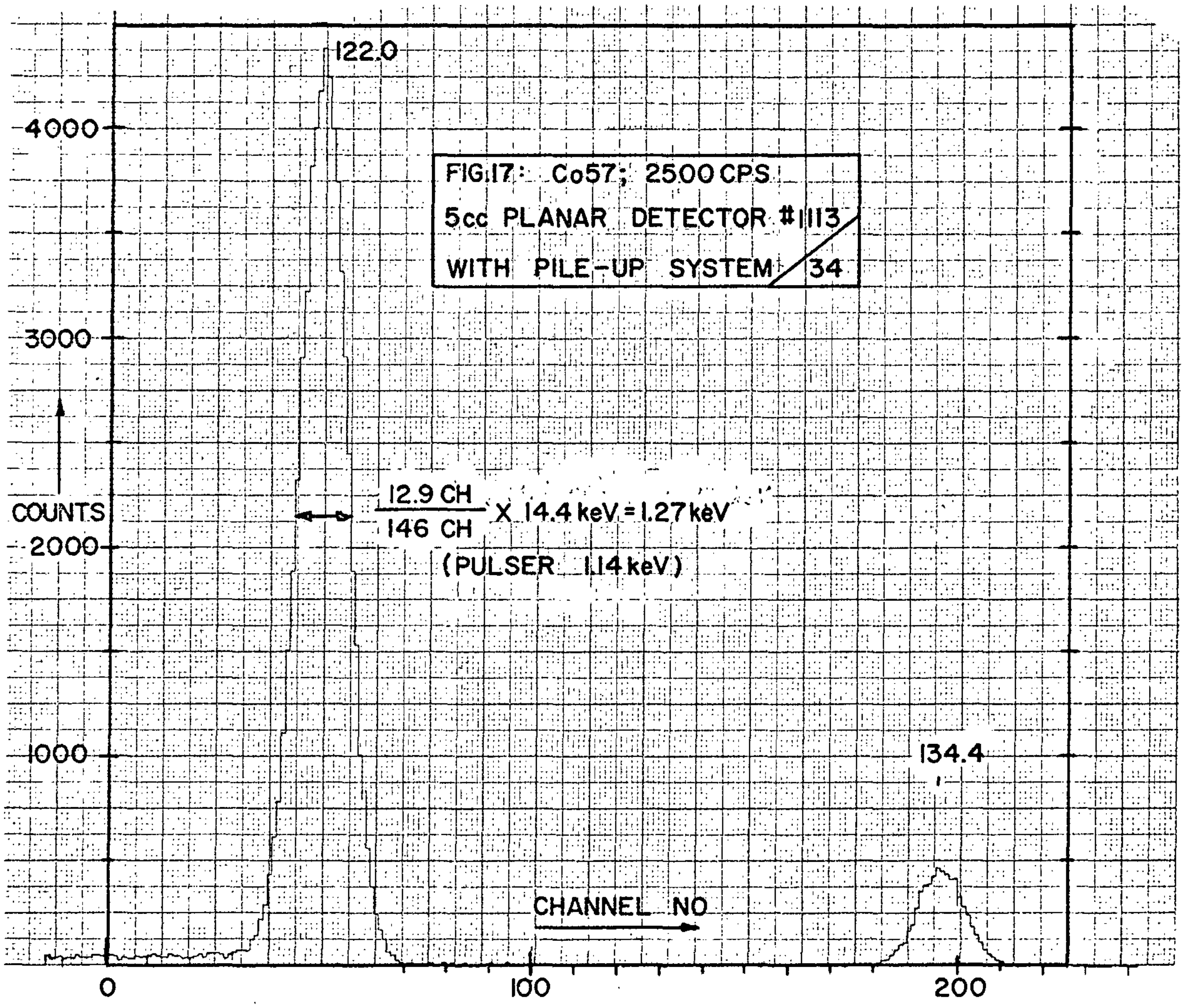
XBL 675-1482

Fig. 15.



XBL 675-1483

Fig. 16.



XBL 675-1484

Fig. 17.