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Development of Directional Detector for High Energy Neutrons

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I. Introduction

The measurement of energies and directions of neutrons at the top of the atmosphere is important for investigating the origin of certain components of the trapped radiation. Singer and others, for example, have proposed that the decay of albedo neutrons from the atmosphere may constitute a source of trapped protons in the inner radiation belt.

A program is underway to investigate albedo neutrons, first at balloon altitudes and then from satellites. In preparation for this the research reported herein concerned the development of a suitable directional detector in the energy range 40-120 Mev.

II. Neutron Detection

Neutrons, being uncharged, cannot be detected directly by most standard counters, which are sensitive to ionization. Since neutrons interact almost entirely through nuclear processes, neutron detectors generally involve the detection of charged secondary particles resulting from nuclear interactions of the incident neutrons. Such detectors include Boron trifluoride counters, fission counters and proton recoil counters.

Boron trifluoride and fission detectors employ specific reactions of positive Q and are insensitive to particles other than neutrons. However, they are not directional and are not suitable for high energies.

The proton recoil process is inherently directional and retains reasonable efficiency at high energies. In the ideal case proton recoils from a pure hydrogen target are analyzed with respect to energy and direction. This information gives the direction of the incident neutron if the energy is known and vice versa. An example of such a detector is the liquid hydrogen bubble chamber. For natural radiation, however, bubble chambers suffer from the impossibility of triggering them by random events. Nuclear emulsions contain a low percentage of hydrogen and are not readily adapted to satellite telemetry.

In the system considered in this report proton recoils generated by neutrons incident upon a hydrogenous material were analyzed by a set of scintillation counters. Since the target material used (scintillation plastic) contained carbon as well as hydrogen it was necessary to provide a means of identifying proton recoil events. At 90 Mev, for example, 25% of all neutron-induced events are pure recoils.

In addition, the problem is complicated by the fact that instead of an ideal collimated beam of pure neutrons the detector would be exposed to radiations of all kinds and from all directions. Thus the detector would be called upon to select neutron-induced events from all others while an anticoincidence counter will permit charged particles to be eliminated. Further selection is required to differentiate neutrons from gamma rays.

III. Proton Recoil Neutron Detector System

A. General Description

The counter geometry developed in the present research is shown to half scale in Fig. 1. In the case of the counters labeled "convertor" and "de/dx", the photomultipliers view diffusely reflecting surfaces below the corresponding counters. The entire system is surrounded by plastic scintillator fluor which is viewed by two photomultipliers above and one below. This scintillator functions as an anticoincidence detector to eliminate charged particles.

A block diagram of the associated circuitry is shown in Fig. 2. A neutral particle event is defined by a coincidence between the convertor and de/dx counters in the absence of a coincident pulse in the anticoincidence counter. When such an event occurs three gates are opened which permit the height-to-width convertors to respond respectively to the pulses in the convertor, de/dx, and energy counters. Although positive pulses from the last dynode in each tube are used to operate the trigger circuits, negative pulses from the anodes are read out via the height-to-width convertors to avoid distortion due to pulsing of the trigger circuits.

The resolving time of the two-fold coincidence circuit is: 90 nanoseconds and the anticoincidence dead time is 450 nanoseconds. There is sufficient delay in the coincidence gate to permit the anticoincidence to lag by 15 nanoseconds relative to the two-fold coincidence and still eliminate the output.

Proton recoils are selected from other neutral-produced events by requiring certain relationships between pulse heights in the three counters. In particular the de/dx output must be appropriate for a proton of the observed energy in the energy counter. In addition, the pulse height in the convertor must be appropriate for a proton of the observed energy originating somewhere within the convertor. Recoils originating in the energy counter and proceeding backward through the system will not generally show the correct relationship of pulse heights. Similarly, gamma rays will not be able to imitate recoil protons.

B. Detectors

All scintillators in the system consist of "polyfluor" plastic fluor manufactured by Semi-Elements, Inc. This material, which has a polystyrene base, has an H-C ratio of 1:1. The anticoincidence and the energy counter are painted with Nuclear Enterprises white reflector paint. In the case of the convertor and de/dx counters, which are not viewed directly by their photomultipliers, the bottom surfaces are machined but not polished or painted; light diffuses out of the scintillators and illuminates the walls of the cavities viewed by the photomultipliers.

The resolutions of all three counters were checked with cosmic ray μ-mesons selected by external counters and absorbers. Pulse height spectra showed spreads (FWHM) of 10-15% or roughly .5 Mev in the case of the convertor, for example. It would be possible to improve the resolution by experimenting with the light collection geometry, but in view of other more fundamental causes of spreading, such a study was not deemed necessary.

The detectors are viewed by EMI 9514S two-inch thirteen-stage photomultipliers selected by the manufacturer for good signal-to-noise ratio. The use of these tubes eliminated the need for amplifiers and simplified the problem of stability under varying environmental conditions. Pulses from the tubes are in the range of several volts and circuit thresholds are approximately one-half volt.

C. Electronics

The circuitry is completely transistorized in anticipation of balloon and satellite work. In Fig. 2, the "Trigger circuits" are complementary pair univibrators which act as discriminators and which provide the coincidence circuit with standardized pulses. The coincidence circuit is a standard diode Rossi-type gate with a resolving time of 90 nanoseconds as determined by the trigger pulses. These circuits are shown in detail in Figs. 3 and 4.

In the height-to-width convertor (Fig. 5) the negative photomultiplier pulses are passed through a shunt gate to an emitter follower. The emitter follower charges a capacitor through a series diode. The resulting discharge sawtooth cuts off a transistor and causes a positive square pulse of length determined by the amplitude of the sawtooth to appear on its collector. This pulse is then amplified and eventually converted to digital form for readout.

The readout system comprises a set of indicator lights giving each pulse height in digital form. These lights are recorded on continuously moving film by a camera constructed specially for the purpose. Each pulse height is allocated five lights so the data is quantized in steps of one part in thirty two. The presence of a coincidence gate is indicated by a separate light and various other parameters are also recorded on the film. The entire circuit power requirement exclusive of the indicator lights is .75 watt.

IV. Calibration Methods

Although a measurement of the type contemplated in this project does not require extremely precise calibration, it is necessary to insure that a pulse height can be translated into energy loss within 10% accuracy in order to make full use of the counter resolution.

Two major methods were used to effect calibration: (a) finding the response to cosmic ray μ-mesons, and (b) obtaining a de/dx vs E counter response curve for charged particles which stop in the E-counter. Method (a) is simplest to undertake, but it gives only one point on the response curves. It is most useful as a rapid check on the photomultiplier settings. Method (b) is most important because it gives the very pulse height correlation that will be used to single out the recoil protons from background. To be sure of the absolute energy response the correlation curve so obtained must be fitted to the minimum ionizing (μ-meson) pulse heights with the use of a theoretical de/dx vs E relationship modified by scintillator response.

Calibration data are not included in this report because the work is still in progress. Preliminary data indicate the feasibility of these calibration methods and they have been used in analyzing the neutron data obtained to date.

V. Results of Measurement

No runs have yet been made to obtain the data eventually desired, that is, the neutron albedo flux at the top of the atmosphere. However, a number of runs have been made at Albuquerque and at Sandia Crest. The system had an effective overall efficiency of approximately 1%. To analyse the results the data points were plotted on a graph of de/dx vs. E counter responses. A typical plot is shown in Fig. 6. It will be noted that the points tend to lie along a curve similar to the theoretical de/dx - E curve. These events may thus be identified as proton recoils (after comparison with μ-meson points). The separate group of points lying below the curve is caused by gamma rays. Some scattered points may be due to scattered particles traveling backwards.

It will be seen that the apparatus does single out recoil protons fairly well. It should also be noted tha backward-going recoils originating in the E-counter will lie on a curve with approximately a reversed slope.

A preliminary measurement was made to determine the directional response. An indication of the result is given by the fact that the ratio of upward-pointing counting rate to downward-pointing counting rate was eight to one. In this energy range one would expect very few neutrons to be traveling upwards, so this ratio probably reflects the front-to-back sensitivity ratio. Thus roughly one out of eight events is ambiguous as to direction.

Attempts are being made to determine how seriously the events in carbon will complicate the analysis and runs are being made with different H-C ratios to determine this. Preliminary results indicate that the contributions to the measured recoils from carbon and from hydrogen are roughly the same. This result is in agreement with our theoretical estimates.

VI. Future Plans

The research will be continued under a NASA grant with the aim of developing a balloon-borne package and undertaking several flights. Detailed calibration runs will be taken to insure correct data analysis. The balloon data will be analyzed to determine high energy neutron albedo flux and, if possible, spectrum shape.

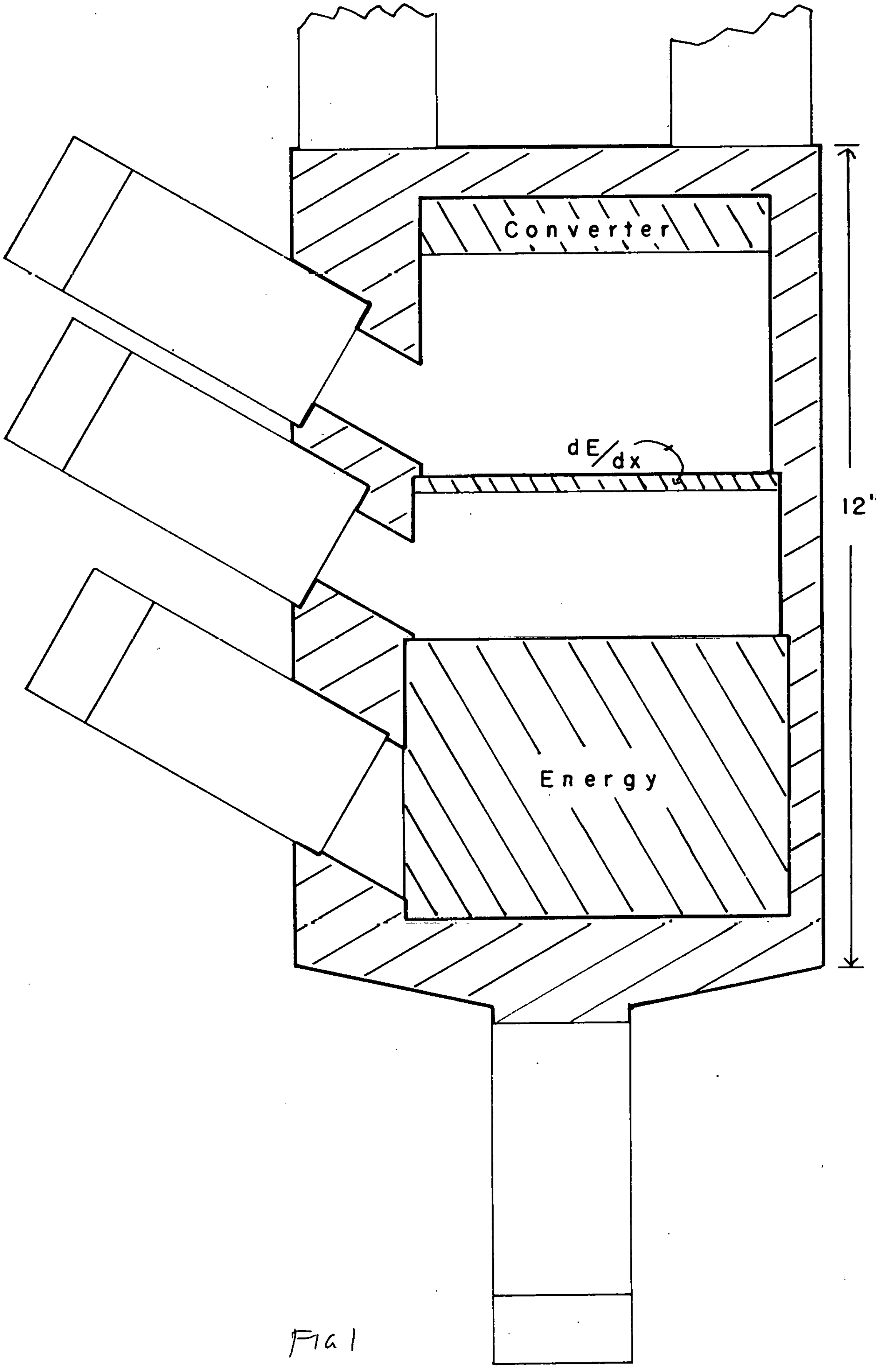
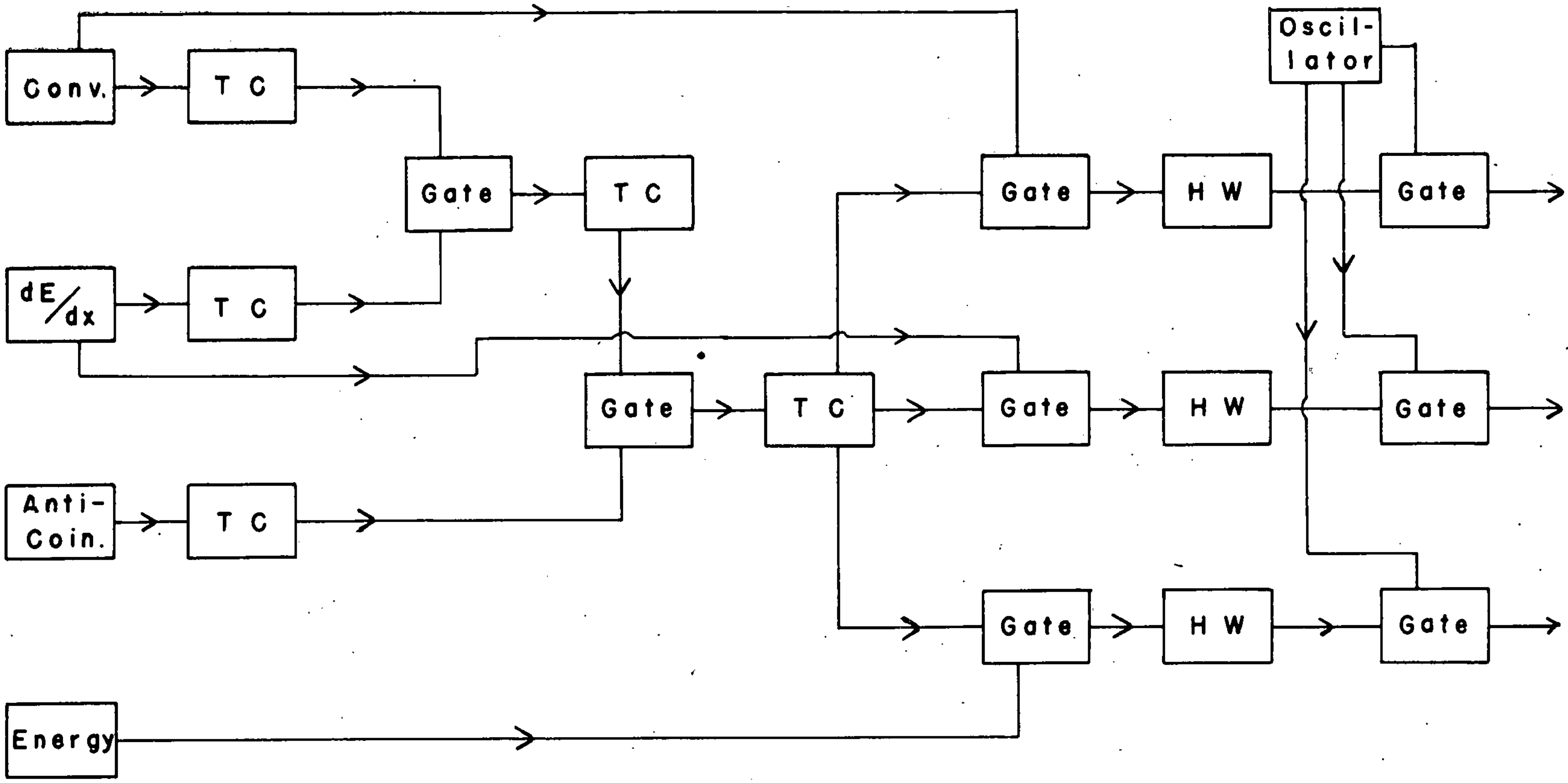


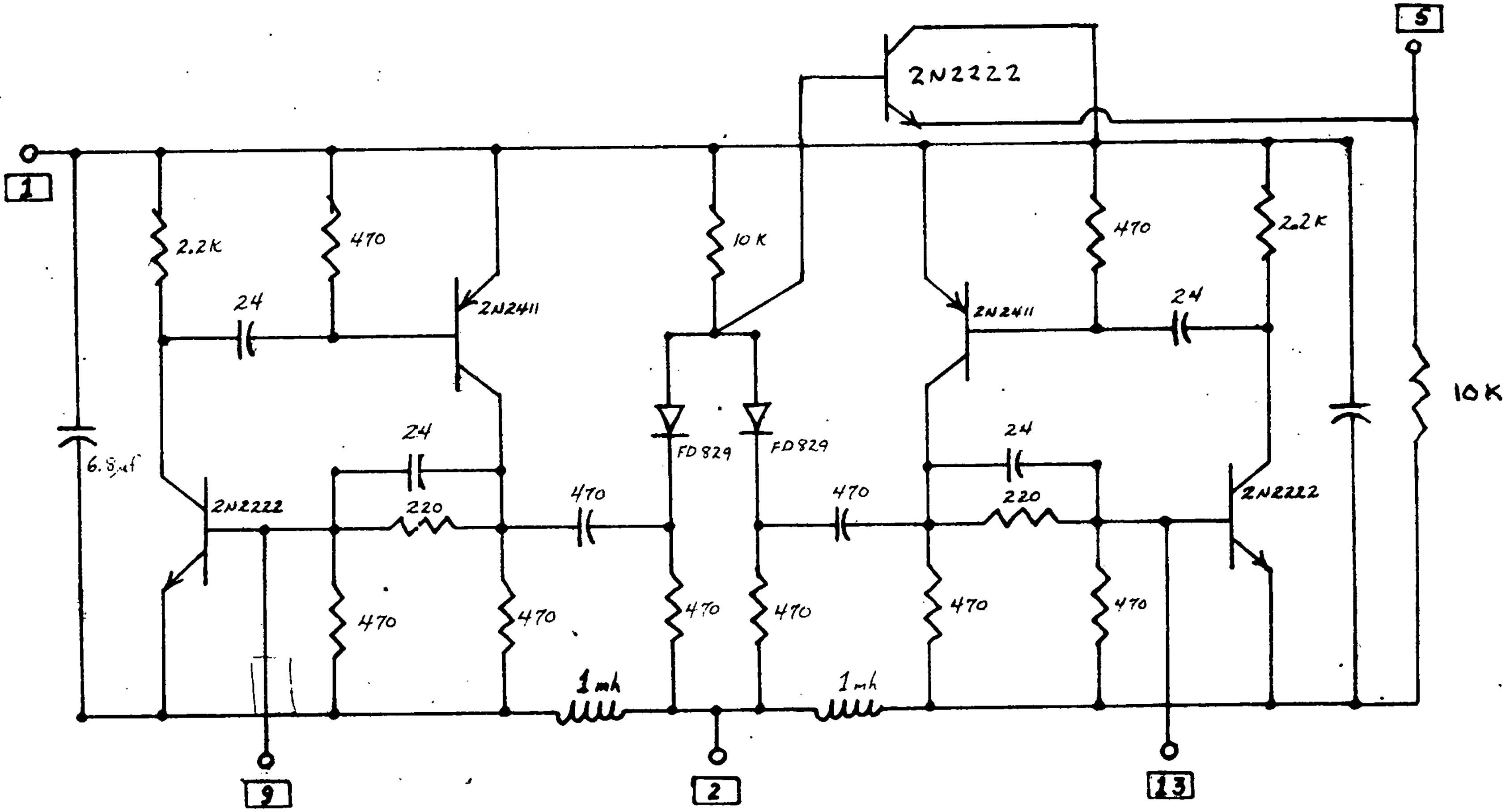
Fig 1



T C - Trigger Circuit

H W - Height to Width

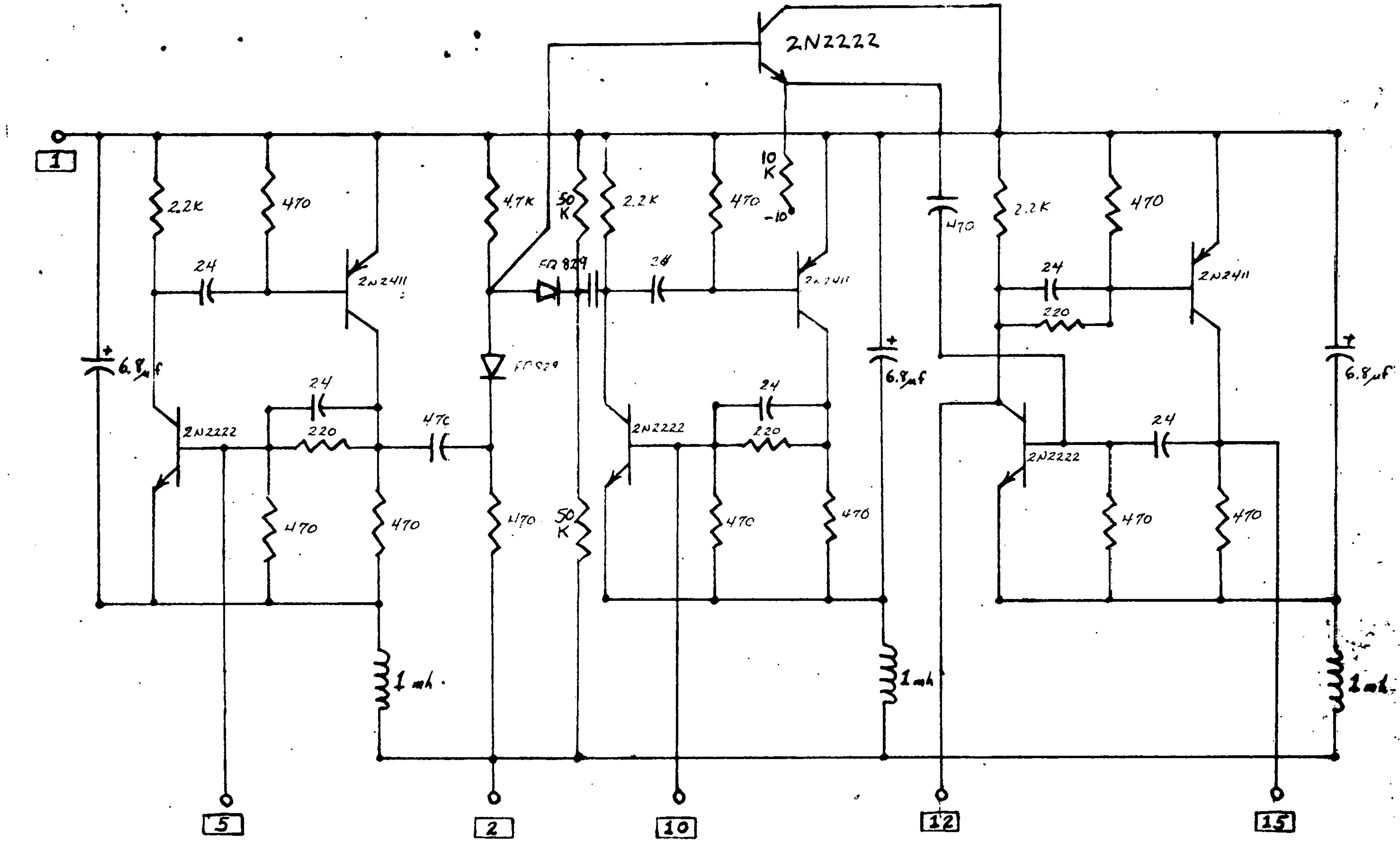
FIG 2



Pin	Function
1	Ground
2	−10 V
5	Coincidence out
9	Coincidence in
13	Coincidence in

Board no. 1

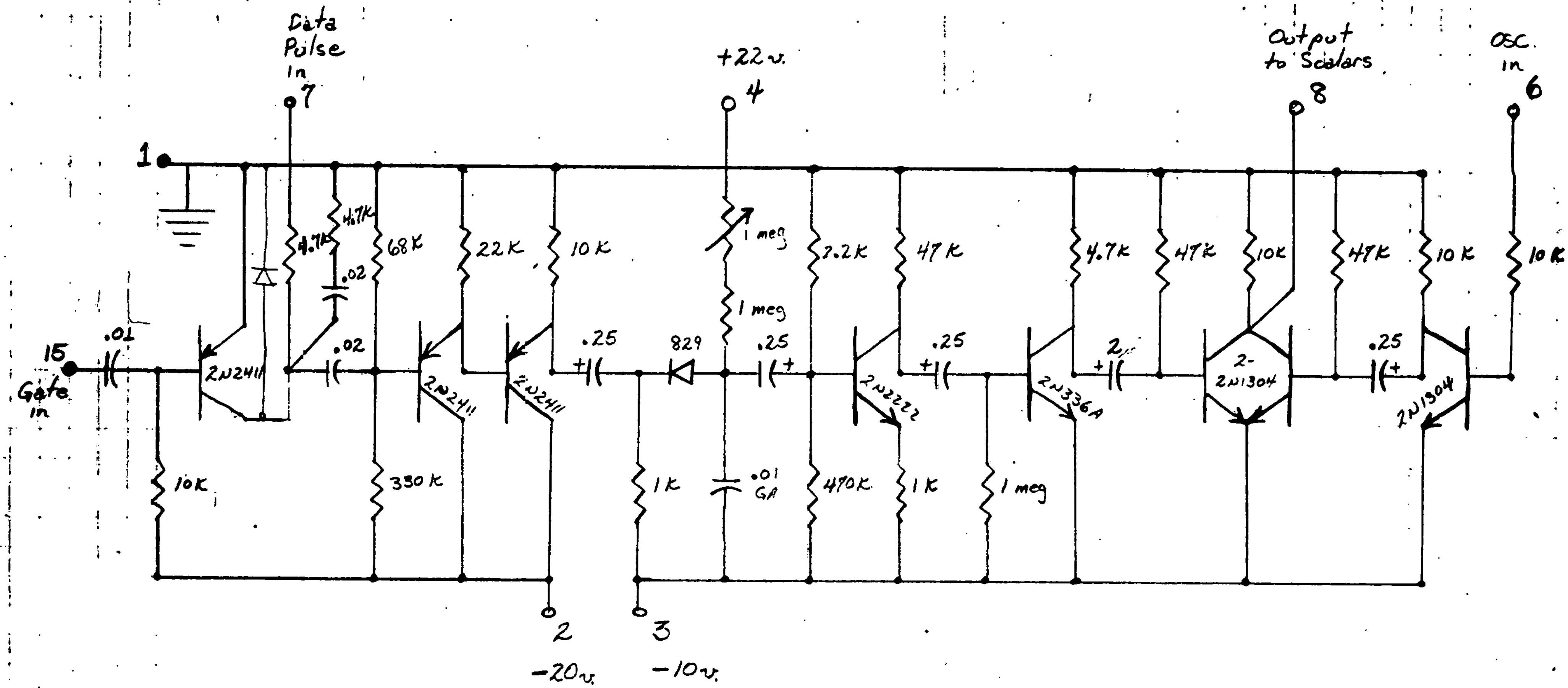
FIG. 3



Board no. 2

Fig. 4

Pin	Function
1	Ground
2	-10V
5	Coincidence in
10	Anticoincidence in
12	Out to "Reset" one-shot
15	Out to Gates



Board No. 3 (Connectors 3,4,&5)

Height to Width Converter

Fig 5

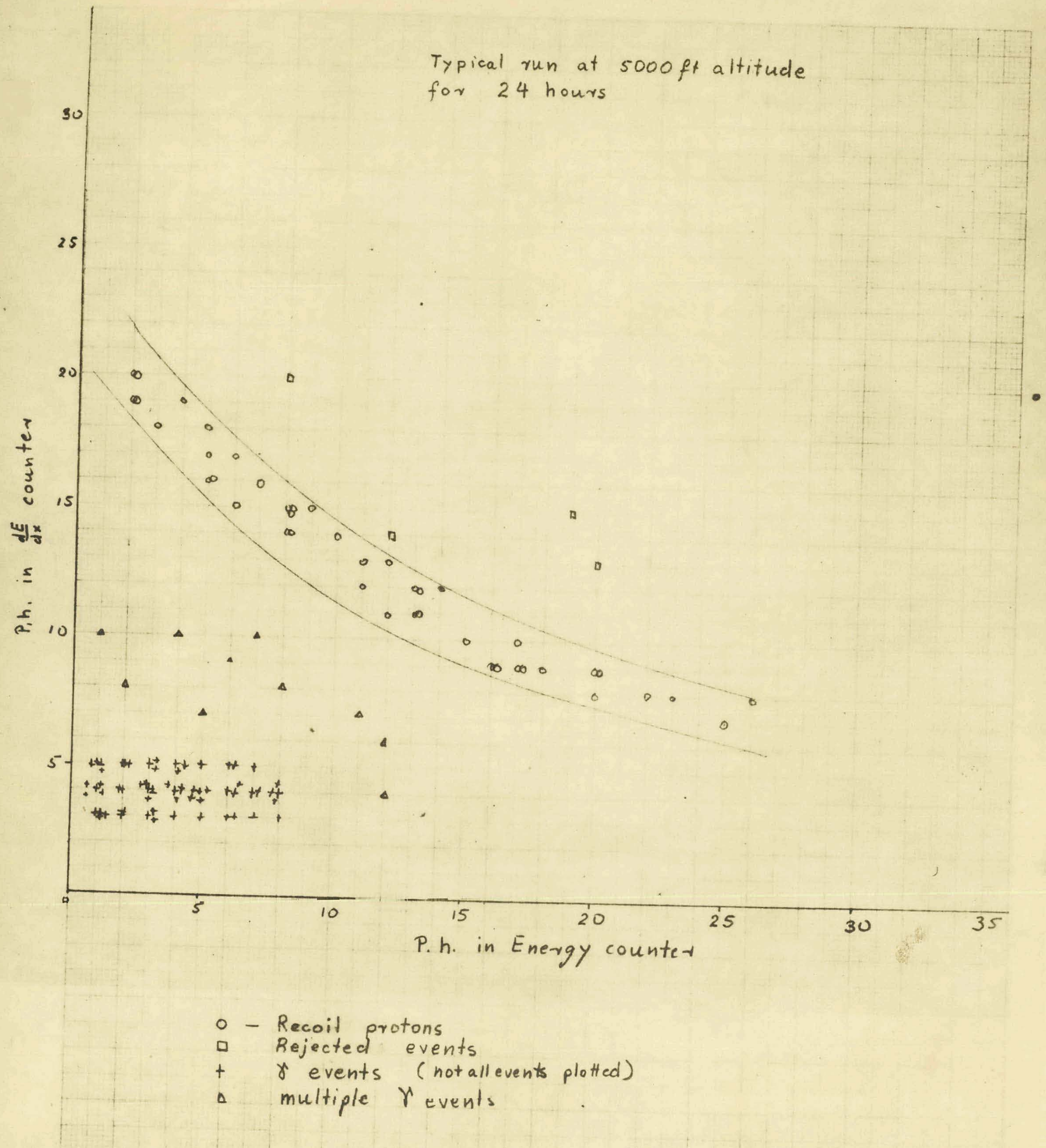

Typical run at 5000 ft altitude for 24 hours
30
25
20
15
10
5
0
P.h. in $\frac{dE}{dx}$ counter
5
10
15
20
25
30
35
P.h. in Energy counter
○ – Recoil protons
□ Rejected events
+ γ events (not all events plotted)
Δ multiple γ events

FIG 6

F rm AEC-426

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