A NEW DEVELOPMENT: THE GEIGER-MULLER RADIOISOTOPE SNOW GAGE

A Thesis

Presented in Partial Fulfillment of the Requirements for the

DEGREE OF MASTER OF SCIENCE

Major in Electrical Engineering

in the

UNIVERSITY OF IDAHO GRADUATE SCHOOL

by

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May, 1967

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This thesis of Harvey Macy Waldron III for the Master of Science degree, "A New Development: The Geiger-Muller Radioisotope Snow Gage,"

A. has been reviewed in rough draft form and preparation of the final draft is recommended; permission is granted to proceed with the final examination upon submission of two final draft copies to the Graduate School:

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BIOGRAPHICAL SKETCH OF THE AUTHOR

Harvey M. Waldron, III was born September 16, 1942, in San Diego, California. Being the son of a naval officer, he received schooling in all four corners of the United States, including Hawaii, and finally graduated from Moscow High School in 1960. The following September he enrolled at the University of Idaho in electrical engineering and received the degree, Bachelor of Science in Electrical Engineering, in June of 1965. That same month he accepted a research staff position with the Engineering Experiment Station and simultaneously entered the Graduate School of the University of Idaho.

The author has been engaged in radiation snow gage research and development since 1961. He has presented papers on these activities to the American Nuclear Society, The Institute of Electrical and Electronic Engineers, and the American Geophysical Union. Research work in this field is the basis of this thesis.

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ACKNOWLEDGMENT

The author wishes to express his most sincere appreciation to Professor George A. McKean, Department of Electrical Engineering for his assistance and technical advice during this investigation. Gratitude is also expressed to Professor George Hespelt, Department of Electrical Engineering, and Professor Paul F. Dierker, Department of Mathematics, for their kindness in reviewing this thesis.

ABSTRACT

Since about 1947, the use of radioactive isotopes had been known to be adaptable to the measurement of water contained in snow packs. Early investigations of these measurement techniques were unsuccessful because the Geiger-Muller detector, the detector readily available at that time, is a device incapable of energy discrimination.

Energy discrimination is achievable by the use of scintillation detectors resulting in the present use of these devices as radiation snow gages. However, the scintillation systems have the disadvantages of high cost and complex maintenance as compared to Geiger-Muller systems.

Mechanical energy discrimination, using collimation techniques, makes possible use of the non-energy-discriminant Geiger-Muller systems for snow gaging. This paper discusses such a system that has been developed and tested. Design emphasis is placed on energy discrimination and electronic dead-time correction methods. Laboratory and field test data are presented to show predictable performance characteristics. All evidence to date indicates that the Geiger-Muller snow gage may be preferable, considering the combined aspects of accuracy and costs, to either the scintillation snow gage or the pressure pillow.

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CHAPTER I

INTRODUCTION

Throughout the world the efficient control and utilization of water resources have become increasingly important. A major area of interest in this field is in the mountain snow pack water storage areas. With information on snow pack water content made frequently available, it is possible to forecast the amount of water being released in order to plan and operate irrigation projects, hydroelectric plants, flood control programs, and water conservation facilities.

In the past, to obtain the required data for accurate forecasts, it has been necessary to send men and equipment into mountain snow storage areas each winter. The required information was then collected by taking core samples of the snow, which are physically weighed for water content. The snow tube method of collecting the required data has proved to be time consuming, expensive, and insufficiently accurate. Also it was not practical to live in the snow storage areas during the winter; therefore, important data during critical flooding periods were not available.

A variety of methods to replace snow tube readings has been and is being used to measure the amount of snow pack water content. Among the various methods used, not counting the snow tube, are the pressure pillow, pressure diaphragm, snow-filled capacitor, and various types of nuclear radiation detectors.

In the opinion of this author, of the various methods just mentioned, the nuclear radiation detector currently holds the greatest promise as a replacement for the antiquated snow tube readings. The main drawbacks of the nuclear radiation detector in the past have been its high cost and circuit complexity.

The purpose of this study was to develop a radiation detector that would retain the benefits of past radiation systems and reduce its cost to a point where the system would be economically feasible. This study deals with such an examination and the development of an economical Geiger-Muller radiation snow gage system.

CHAPTER II

ATTENUATION THEORY AND THE SCINTILLATION SNOW GAGE

In approaching the problem of designing radiation snow gages, it is necessary to look carefully at attenuation theory and the basic principle behind the successful operation of the scintillation snow gage.

The purpose of this section is to study in detail the radiation attenuation equation and look at the reasons for the conception of the current scintillation snow gage, paying particular attention to the theory of operation and its disadvantages.

I. ATTENUATION THEORY

The operation of the radioisotope snow gage is based on the theory that as radiation passes through the snow pack, its attenuation is proportional to the snow pack water content. In developing the theory around which a snow gage may be designed, it is necessary to discuss the problem which might be involved in the interaction of this radiation with the snow pack.

Nuclear radiation sources emit basically alpha, beta, x, and gamma radiation. Since alpha and beta radiation do not penetrate appreciable quantities of water mass, they preclude the discussion of such radiation. Also x-rays are lower in energy than most gamma radiation; therefore, it is only necessary to consider gamma radiation in further discussions.

The basic property of the absorption of gamma-rays is the exponential decrease in the intensity of radiation as a homogeneous beam of gamma-radiation passes through mass. The equation (1.1) for the attenuation of gamma radiation is

$$I = I_o e^{-\mu x} \tag{1.1}$$

where the equation parameters are defined by

I_o = initial intensity of impingent radiation

I = radiation intensity after attenuation

μ = total linear absorption coefficient

x = length of radiation travel through absorber

It is necessary to define precisely the conditions under which equation (1.1) is valid. These conditions are (1) the gamma-rays are monoenergetic, i.e., the beam is homogeneous; (2) the beam is collimated and of small solid angle; (3) the traverse dimensions of the absorber are small compared to its thickness and greater than the beam. These conditions are shown in Figure 1. This arrangement provides a narrow collimated beam and is spoken of as "good geometry."[1]

The total absorption coefficient, μ, in equation (1.1) is composed of three parts as expressed by

$$\mu = \tau + \xi + k \tag{1.2}$$

where τ, ξ and k are partial coefficients described as follows:

τ = coefficient due to photoelectric effect (low photon energies)

ξ = coefficient due to Compton effect (0.5 to 10 mev energies)

k = coefficient due to positron-electron pair production (energies greater than 10 mev)

Since the energy levels of Cobalt-60 are only 1.1 and 1.3 mev, the attenuation by the snow pack can be assumed entirely due to Compton effect. Gamma attenuation by pair production effects are almost

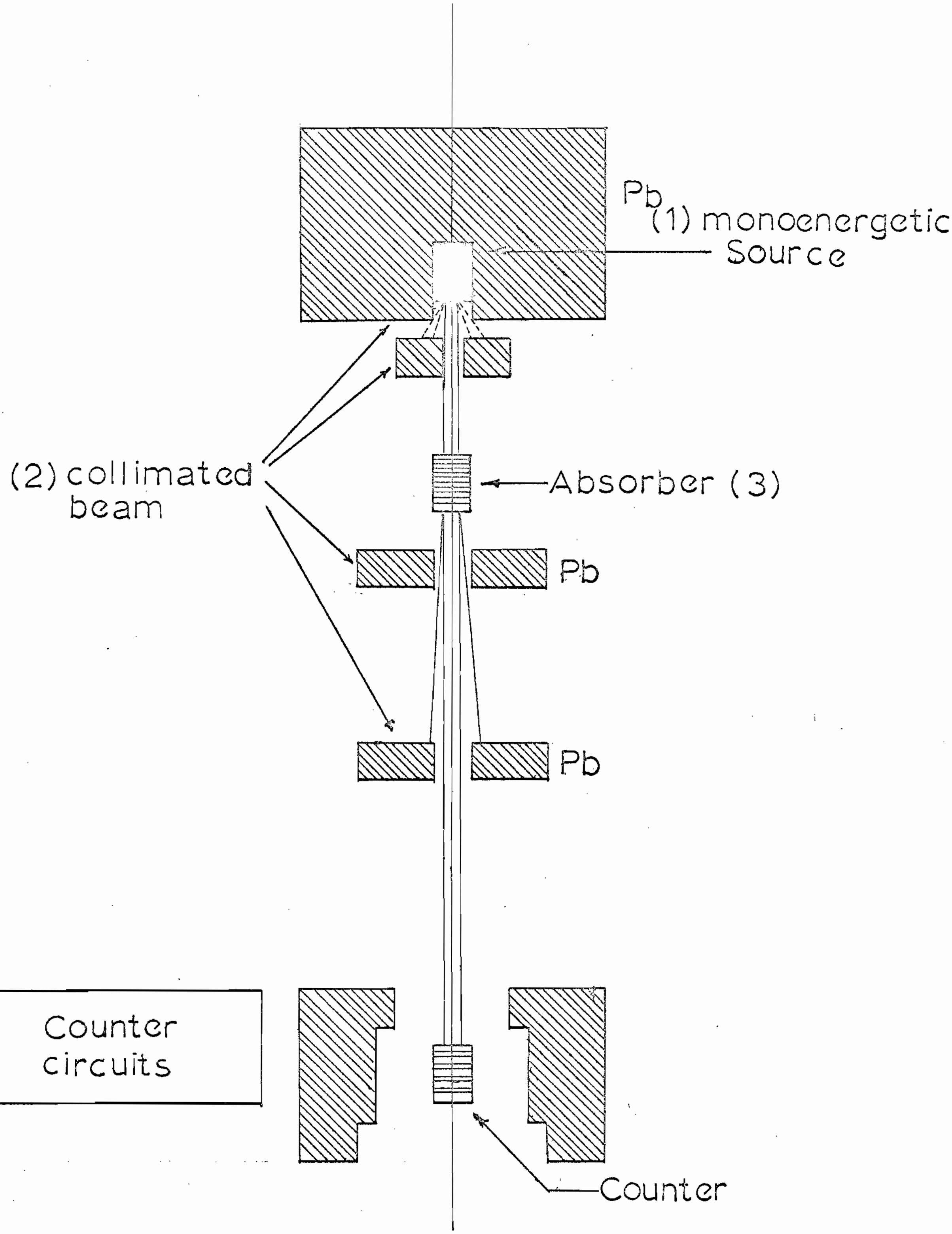


FIGURE 1
good geometry

nonexistent and attenuation due to photoelectric effect is so small as to be considered negligible.[2]

To show that radiation attenuation by snow is a practical method of determining snow pack water content, it is necessary to write equation (1.1) on a mass basis. Solving of this mass equation will then specify the conditions that must be met if nuclear radiation is to be used by a radioisotope snow gage. Therefore, rewriting equation (1.1)

$$I = I_o e^{-\mu_m x_m} \tag{1.3}$$

where the new parameters are defined by

μ_m = the total mass absorption coefficient $= \frac{\mu}{\rho}$

ρ = the mass density, mass per unit volume, of the absorber

x_m = the mass thickness of the absorber = x

Since the mass absorption coefficient, μ_m, is a function of both photon energy, E, and the atomic number of the absorber, Z, the mass absorption coefficient can be rewritten as

$$\mu_m = F(E,Z) \tag{1.4}$$

The relationship between μ and μ_m, the narrow-beam absorption coefficient may be expressed now as

$$\mu = \rho F(E,Z) \tag{1.5}$$

If the mass density, ρ, is expressed as mass per unit volume, $\rho = M/V$, and the volume of the absorber, V, is expressed as the product of absorber thickness, x, and absorber cross-section, A, then equation (1.5) may be written as

$$\mu = \frac{M}{V}F(E,Z) = \frac{M}{Ax}F(E,Z) \tag{1.6}$$

Placing the expression in equation (1.6) in equation (1.1) gives

$$I = I_o e^{-\mu x} = I_o e^{-\frac{M}{A}F(E,Z)} \quad (1.7)$$

Examination of equation (1.7) shows what conditions must be met in order to measure accurately the water equivalent of a snow pack with a radioisotope snow gage. For a given amount of snow, a fixed water equivalent, the exponent of e in equation (1.7) must be a constant. This requires: (1) that the mass, M, of water in the beam of radiation must remain fixed; (2) the area, A, of the absorber in the beam must not vary; and (3) the function, F (E,Z) must be a constant.

The first two of the above conditions are met if the radiation is cylindrically collimated. The last condition, that F (E,Z) be an appropriately selected constant, was satisfied when the Cobalt-60 source of gamma radiation was selected.[5]

II. SNOW-WATER EQUIVALENT

With the understanding gained in the previous section, Attenuation Theory, it is now necessary to look at a particular application, snow-water equivalent. The problem is that if a radiation measurement is made of a snow pack to determine its water equivalent, will the same result occur when the same amount of liquid water is measured?

Extensive testing at the University of Idaho laboratories[4] has shown some attenuation differences do occur as the snow-water absorber changes in physical state. This can best be explained by looking at the entire spectrum of Colbalt-60. Figure 2 shows a typical spectrum of this radioisotope.

This figure shows that there is a difference between the two spectral plots when comparing snow and water. Therefore, if an entire

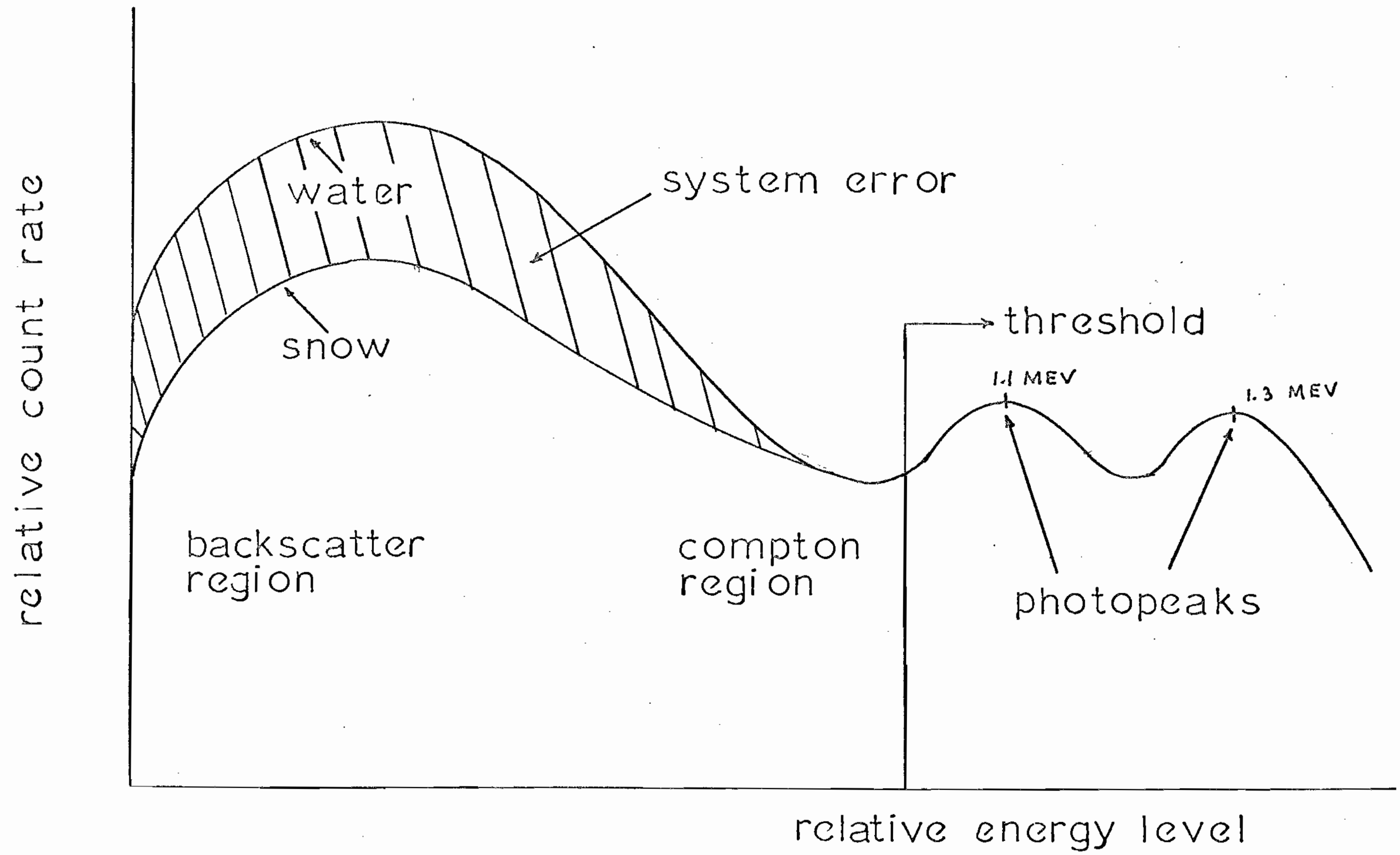


FIGURE 2

cobalt-60 spectra following attenuation by snow and water spectrum were used for counting, the error of the system would be proportional to the area difference between the two spectral plots. It can be seen that the photopeak region, which represents the principal energies of photons emerging from the radioactive source, is the most desirable portion of the Colbalt-60 spectral plot since, in this region, the plots are identical for snow and water.

III. SCINTILLATION SYSTEM

In the previous section it was found that errors due to count rate differences between snow and water could be minimized by counting pulses due only to high energy photons. Of the various radiation detectors this may be accomplished rather easily by a scintillation detector, since there is a linear dependence between energy of the impingent photons on the detector and the height of the corresponding output pulse; therefore, electronic "energy discrimination" techniques can be used. For this reason a scintillation type radiation detector was developed and perfected by the University of Idaho for measuring snow-water equivalent at remote sites. A block diagram and typical site installation of the basic scintillation radioisotope snow gage are shown in Figure 3.

In the design and development of the scintillation system, or any other type of radiation detector, environmental conditions pose the greatest problem. All water storage measurements are made at remote mountain locations, generally inaccessible for 10 months of the year. The result is that (1) battery operation is mandatory, (2) the system power consumption must be low, (3) the coded information must be transmitted, and (4) the temperatures affecting the system will be as low as -30°C.

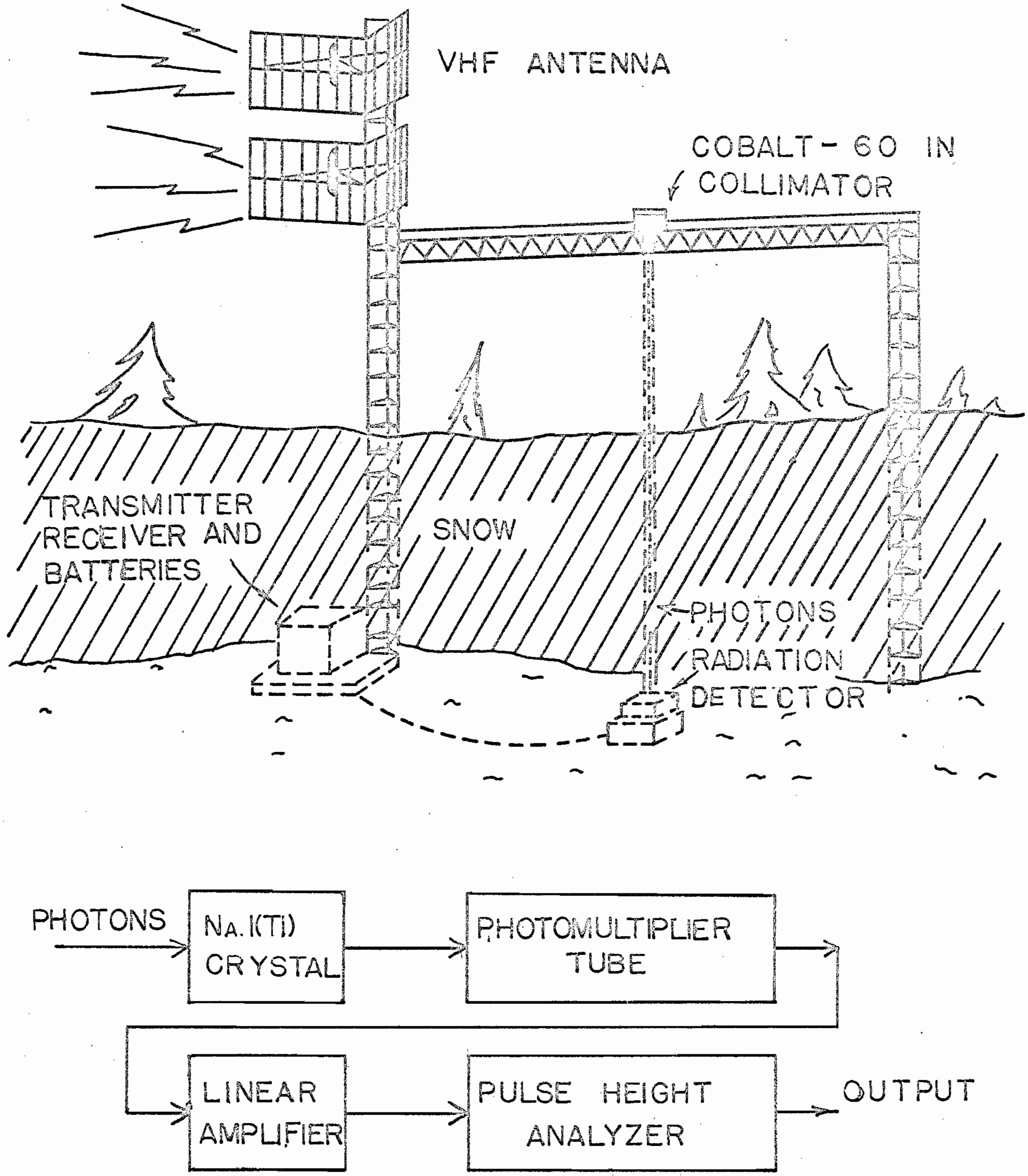


FIGURE 3
the radioisotope snow gage

The complexity of the scintillation type detector caused considerable difficulties in its development because of the above requirements. These difficulties are discussed below.

NaI(Tl) crystal. The crystal is highly hygroscopic; therefore, it is necessary to encapsulate the crystal for protection from moisture. Problems developed when this arrangement was used over the wide temperature ranges because the crystal would separate from its transparent faceplate causing opaque optical voids. When this occurs, the photomultiplier tube sees fewer photon created light scintillations, resulting in an uncalibrated system. This problem has been brought under control, but still is not satisfactorily solved.[6]

Photomultiplier (PM) tube. The PM tube is used to convert the scintillations from the crystal to electrical pulses at its output. It is a very high gain device, and its stability basically determines the overall accuracy of the system. Tests at the University of Idaho[4] have shown the PM tube to be very temperature dependent, and its gain does not remain constant over long periods of time. In the opinion of this author, the PM tube is the main drawback of this system and, in any future development of the scintillation system, it will be the limiting factor.

Linear amplifier and pulse height analyzer. These devices had to be transistorized because of the power requirements. This required complex temperature compensation of the transistor circuits because of the wide temperature range involved. This resulted in a very expensive and complex electronic system.

Since the development of the radiation snow gage, three of these scintillation gages have been in operation for the past two years in the Clearwater Basin.[6,7] The snow gages have had no operational failures but, due to the associated high cost and complex circuitry of the scintillation type system, it has not been economically feasible to expand the present system to include other watershed areas.

CHAPTER III

PRELIMINARY DESIGN AND ANALYSIS OF A GEIGER-MULLER SYSTEM

Although the scintillation snow gage operation has been quite satisfactory, the associated high cost and complex circuitry have stimulated this study to reexamine the Geiger-Muller System.

In this chapter, the basic development of the Geiger-Muller system into an operational snow gage device is discussed. Detailed analysis of the various parts of the system are covered in later chapters.

I. THE ORIGINAL GEIGER-MULLER (G-M) SYSTEM

The Geiger-Muller (G-M) radiation detector is the system which was used in the very first radiation snow gage. One of these original types of systems was built by the University of Idaho[8] during the initial investigations of radiation snow gages. The main purpose of such a study was to take advantage of the associated low cost and simple circuitry required by such a system.

In the original G-M system, radiation is detected by a Geiger-Muller tube, a thorough study of which revealed the following problems:

1. A G-M tube has a relatively large dead-time. This dead-time is the period required by the tube to "recuperate" after a radioactive photon bombardment, so it is able to measure the next sequential bombardment. Because the dead-time is fixed in a given tube, this limits the maximum count rate measureable since, at high count rates, some counts will go undetected while the tube is dead.
2. The G-M tube is incapable of energy discrimination;

therefore, the tube will not delete the unwanted portions of an isotope spectrum. The system will produce a count rate proportional to the area under an entire spectral plot which evidently will vary according to the quality of the measured snow pack.

To illustrate these two problems, Figure 4 shows a semi-logrithmic plot of the calibration curves taken from both a scintillation-type snow gage and an original type of G-M snow gage. With the scintillation system set to measure only the photo-peak energies of radiation, as shown earlier in Figure 2, a straight-line plot results which is also the mathematically ideal case. However, the G-M calibration curve shows two departures from the ideal case:

1. At low water levels, the high radiation intensities cause count rate loss resulting from the tube dead-time. This flattened curve slope infers a decrease in resolution at low water levels.
2. At high water levels, the large amounts of snow cause radiation scatter which cannot be rejected by the G-M tube. This flattened curve slope results in decreased resolution at high water levels.

The simplicity and stability of the G-M system made it quite attractive, but because of these two errors, the primitive G-M system was unusable for snow gaging. Work along this line was then abandoned until 1965.

II. IMPROVED GEIGER-MULLER SYSTEM

If the two inherent G-M system problems could be solved; namely,

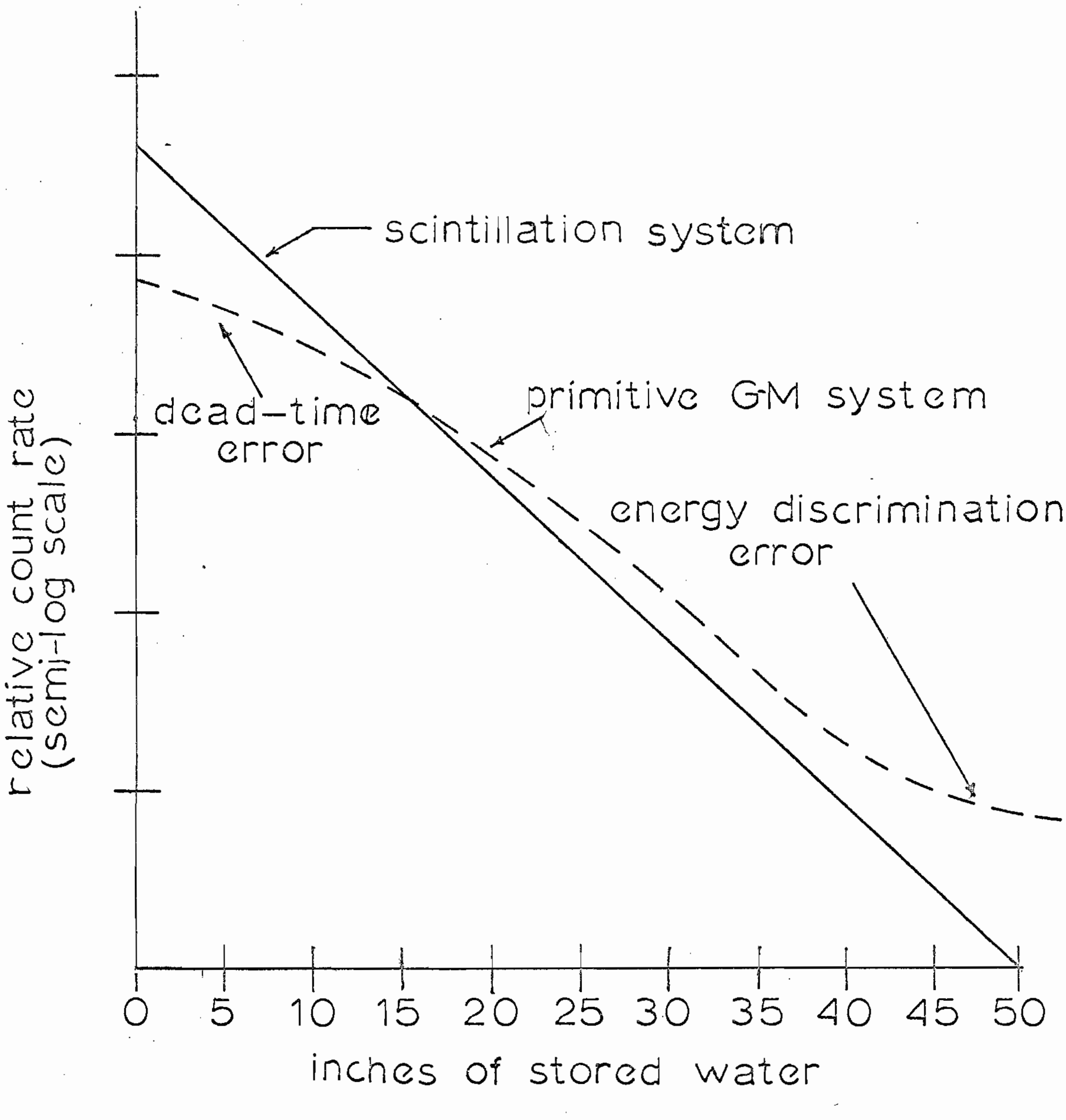


FIGURE 4
SNOW GAGE CALIBRATION CURVES

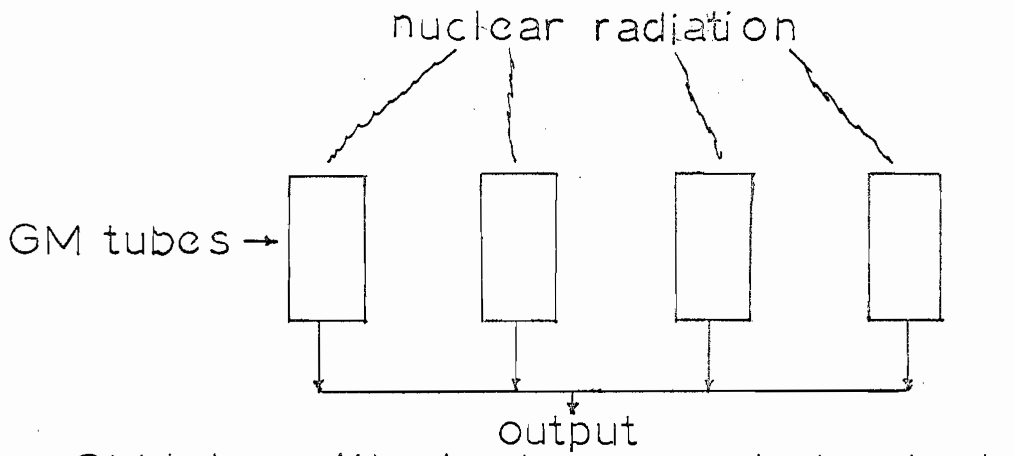
the maximum count rate capability limited by dead-time effects, and the discrimination against unwanted radiation energy levels; the G-M snow gage would have the same accuracy and resolution as the scintillation system. The added advantages would be reducing cost and circuit complexity. These problems were solved during this study and are briefly analyzed below.

Dead-time problem. The G-M tube has a maximum counting rate which limits the strength of the radiation source that can be used, thus limiting the amount of stored water that can be measured. An obvious but misleading solution is to group several G-M tubes together and combine their outputs to form a single electrical signal as shown in Figure 5. Unfortunately, this solution increases the dead-time rather than decreasing it; that is, although the maximum counting rate capability has increased, so has the dead-time increased.

To permit the simultaneous use of several G-M tubes without increasing system dead-time, each G-M tube output was modified as shown in Figure 6. The output of each tube is applied to a separate wave-shaping circuit. Each wave-shaping circuit generates a pulse of extremely short time duration whenever the G-M tube conducts; this short pulse eliminates the system dead-time caused by the long quenching, or extinguishing time of the tube. Finally, all of the reshaped outputs are combined to form a single output for counting purposes. This method allows the use of several tubes to increase count rate capability while simultaneously reducing dead-time.

Energy discrimination problem. As mentioned before, a G-M tube is incapable of discriminating against various radiation energy levels and

FIGURE 5



GM tubes with simply connected outputs

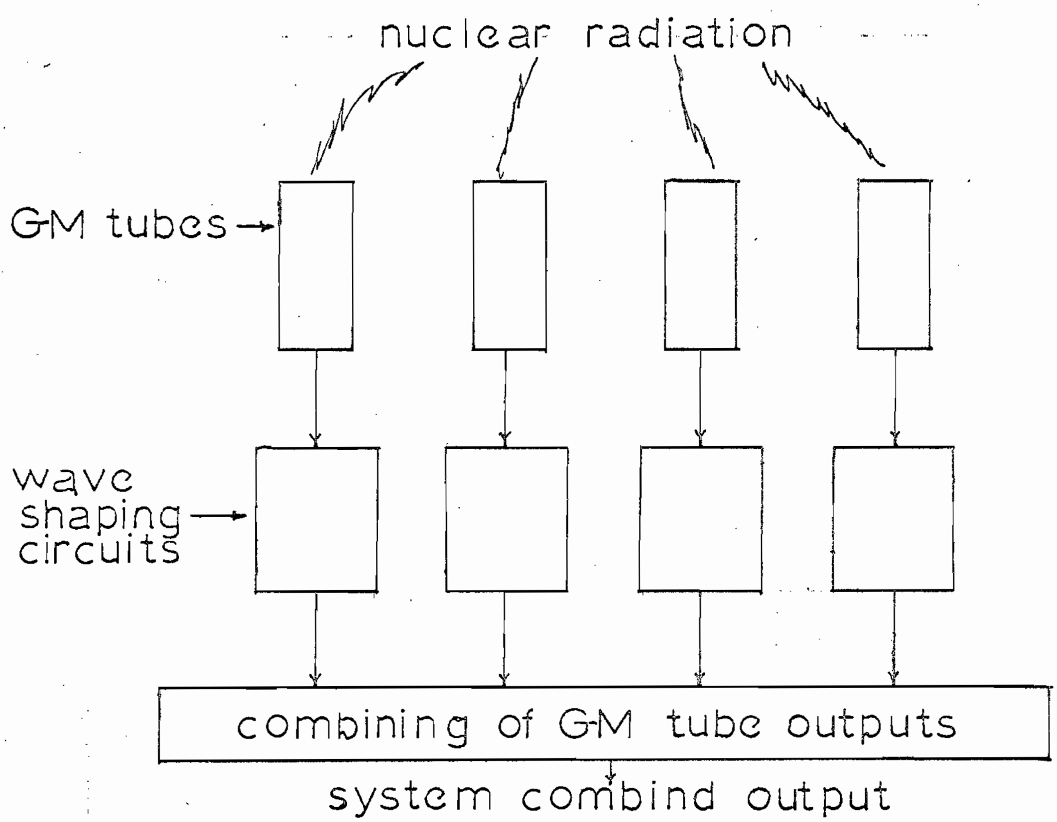


FIGURE 6

GM tubes combined for dead time correction hence counts an entire radiation spectrum. To reduce or eliminate the errors due to "low energy counting," a method of energy discrimination must be incorporated. Since this cannot be accomplished electrically by the G-M tube, a method of mechanical discrimination was developed.

If proper geometry is established, low energy radiation is reduced greatly. Figure 7a shows a typical snow gage configuration. When a radiation particle, or photon, leaves the source, it always possesses photopeak energy. If the particle is unattenuated due to lack of collision with water molecules, it travels directly to the detector along path 1 and is measured. If it is attenuated by molecular collision, it loses energy and is scattered, or changes direction, as shown in path 2. This particle traveling along path 2 can suffer additional collisions before leaving the snow pack and might be deflected into a path such as 3. Evidently, path trajectories such as 3 are of the type which cause "low energy counting" and it is desirable to eliminate or minimize these occurrences.

The number of path 3 type trajectories that will be measured can be greatly reduced by collimating the G-M detector. As shown in Figure 7b, detector collimation causes the effective radiation beam to approximate a cylindrical configuration more closely than in the uncollimated case shown in Figure 7a. Testing of this technique indicated that all discernible "low energy counting" was eliminated.

The result is that the improved G-M system is a low cost, simple, electronic snow gage that retains the advantages of the past radiation snow gages and becomes economically feasible.

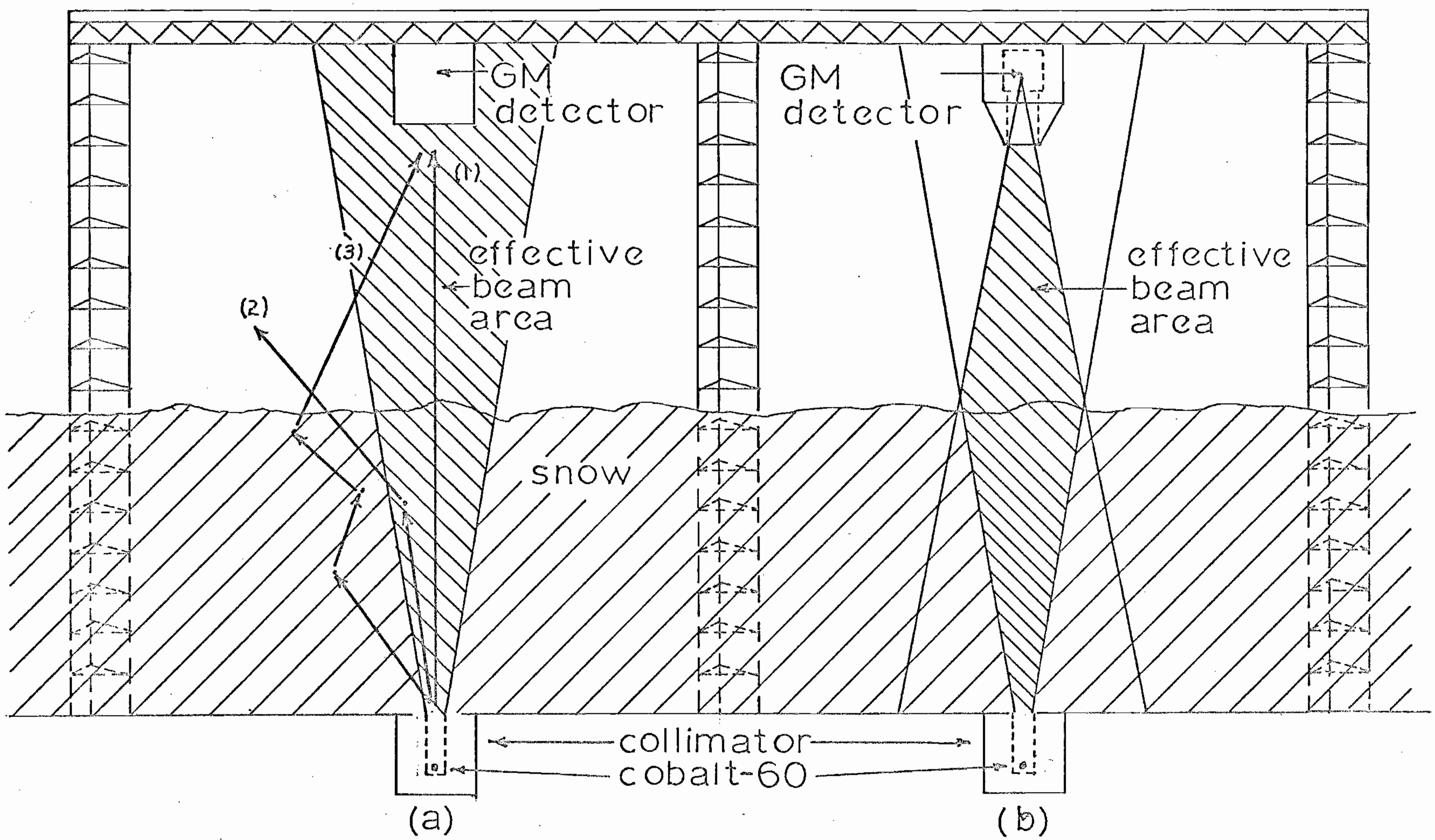


FIGURE 7

effect of geometry on errors of low energy counting

CHAPTER IV

FINAL DESIGN OF THE GEIGER-MULLER SNOW GAGE

The preceding chapter presented a discussion concerning a theoretical Geiger-Muller snow gage. Using the information thus gained, a detailed analysis of the Geiger-Muller tubes, high voltage power supply, dead-time correction techniques, and collimation, Figure 8, will now be discussed.

I. GEIGER-MULLER TUBES

The heart of the system is the Geiger-Muller (G-M) tube. After evaluation of the types of G-M tubes available, Appendix A, it was decided to use the Amperex 76NB3, Appendix B. This particular tube had the least dead-time, 100 μs, and the largest count rate capability, 1700 cps, of any tube currently available on the market. But still, at its maximum counting rate as a single tube, it was not possible to obtain satisfactory statistical accuracy at high water content levels.

<u>Number of tubes</u>. The main problem in using G-M tubes is their maximum count rate capability. Since increasing source strength to increase count rate is not an answer, the only solution is to increase the number of G-M tubes used for counting by the system. Figure 9 illustrates experimentally why the system count rate will increase when the number of tubes is increased.

If there is some constant beam of radiation flux (photons) as shown and tube A is placed in its path, its output will be proportional to the radiation flux density. For example, the output may be 1000 cps. Now if tube B is placed in the radiation path, its output will also be

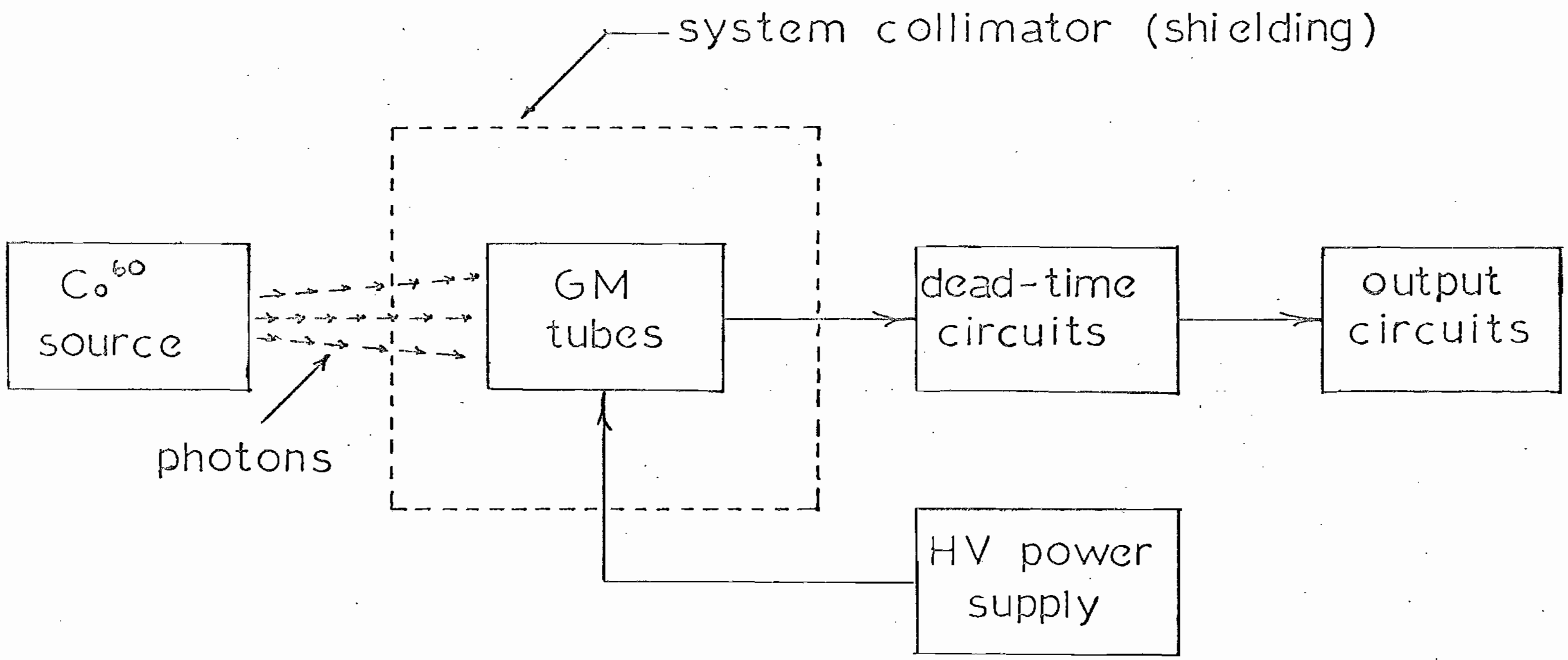


FIGURE 8
block diagram of the geiger muller snow gage

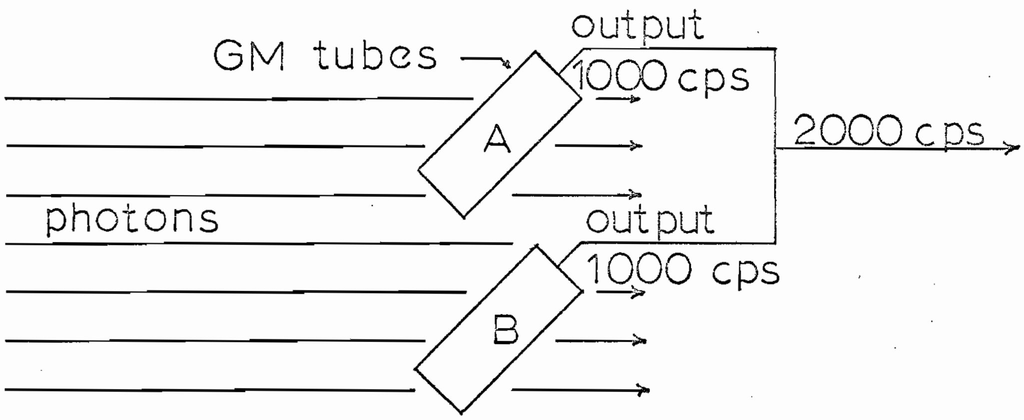
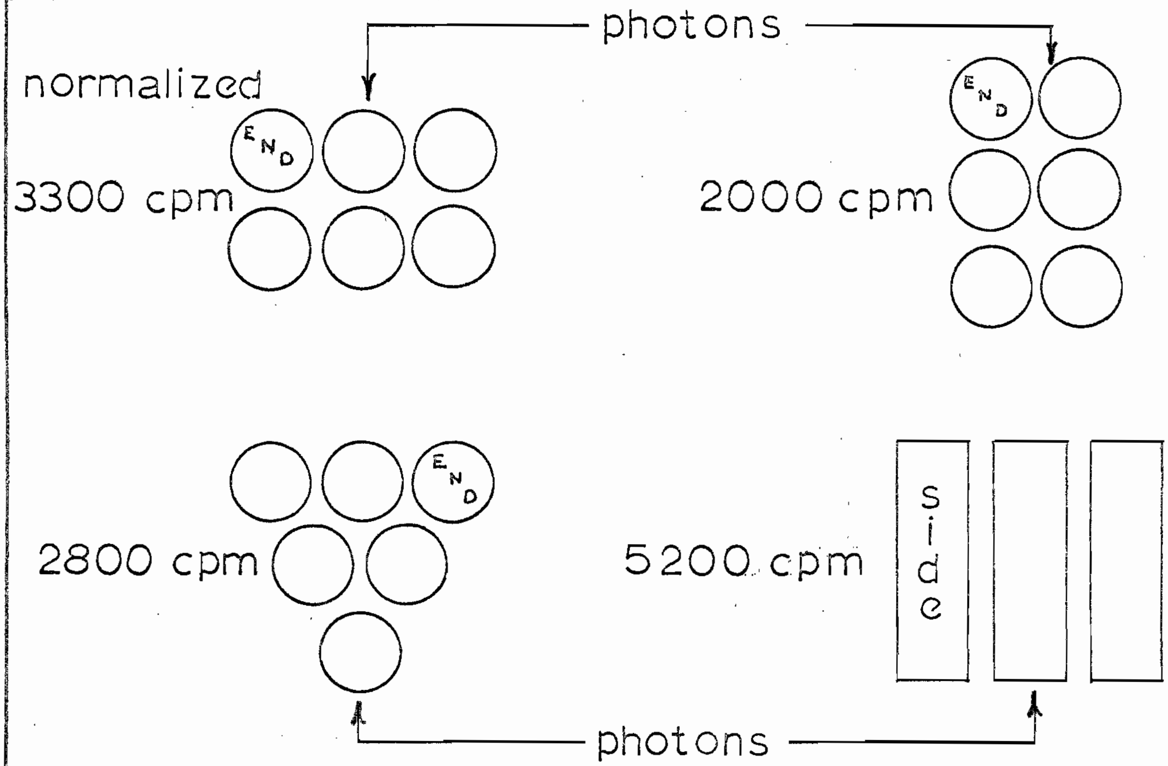


FIGURE 9

count rate vs. the number of tubes



(tube geometry vs. count rate)

FIGURE 10

effect of tube geometry on count rate

proportional to the radiation flux density or 1000 cps. If both these outputs are combined the system output will now be 2000 cps, but there has been no increase in the radiation flux; therefore, the system count rate has been increased by increasing the number of tubes.

The number of tubes finally selected for any particular system is determined by the source strength to be used, the snow pack water content levels that are expected, and the statistical accuracy required, the latter being discussed in Appendix D.

Tube geometry. The next problem that must be solved is how should this group of G-M tubes be arranged and placed in the radiation beam to obtain the maximum radiation flux capture. The reason for this interest is that the system cost and size have been increased to improve statistical accuracy. Every count lost due to poor tube geometry is a loss of money and system performance.

Laboratory tests were performed assuming a maximum practical collimated beam of radiation 4 inches by 4 inches. A group of six tubes was then placed in the radiation beam at different angles and positions as shown in Figure 10. The information obtained in this test showed that placing the tubes on end in the radiation beam almost doubled the count rate output as compared to other positions, i.e., maximum radiation capture occurred in this position.

Group plateau. The G-M tube as discussed in Appendix A is a radiation sensitive tube. When low voltage levels are applied to the tube no multiplication of the ionization current occurs and the tube has no output. As the voltage level is increased, the output of the tube increases until a point is reached where increases in voltage cause only very slight changes in count rate output. This region is called the "Geiger tube plateau."

The tube selected for the system, the 76NB3, has an advertized plateau length in excess of 125 volts, as cited in Appendix B. But each tube of the same type does not have the same plateau length or position.

Since it is not practical to build a high voltage power supply for each G-M tube, thereby taking advantage of operating on the best portion of its plateau region, it is necessary to determine what operating voltage is suitable for the entire group of G-M tubes.

The particular plateau region for the group of tubes used in this study was determined by experimentation, the results of which are shown in Figure 11, to have a length of 100 volts. The best operating point, by inspection, is about 900 volts.

This information is necessary for designing a high voltage power supply for the system, presented in a later section.

<u>Temperature range</u>. The specifications for the 76NB3, given in Appendix B, indicate that the operating temperature of the G-M tubes is from -55°C to 75°C.

A temperature test was performed on the group of G-M tubes from -29°C to 30°C to prove that no problems would develop under varying temperature conditions. During the test particular attention was paid to the plateau region. The results in Figure 12 showed that the tube count rate pivoted about the plateau point of 900 volts with larger variations occurring along the plateau ends. The test indicated that if the operation of the tubes is around the plateau point of 900 volts in an unstable temperature atmosphere, there will be little effect on the system output count

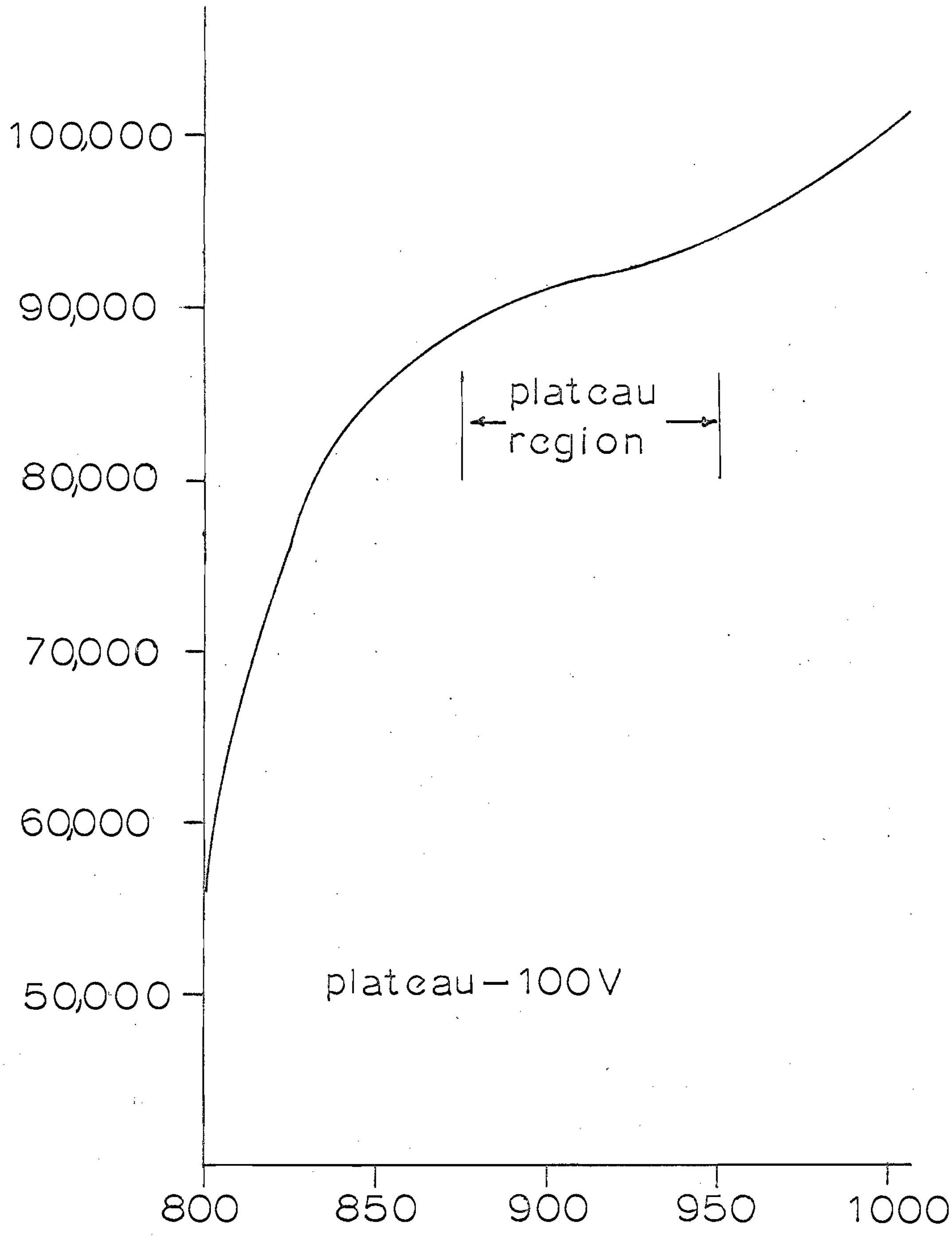


FIGURE 11

geiger plateau region for six 76N/B3 tubes

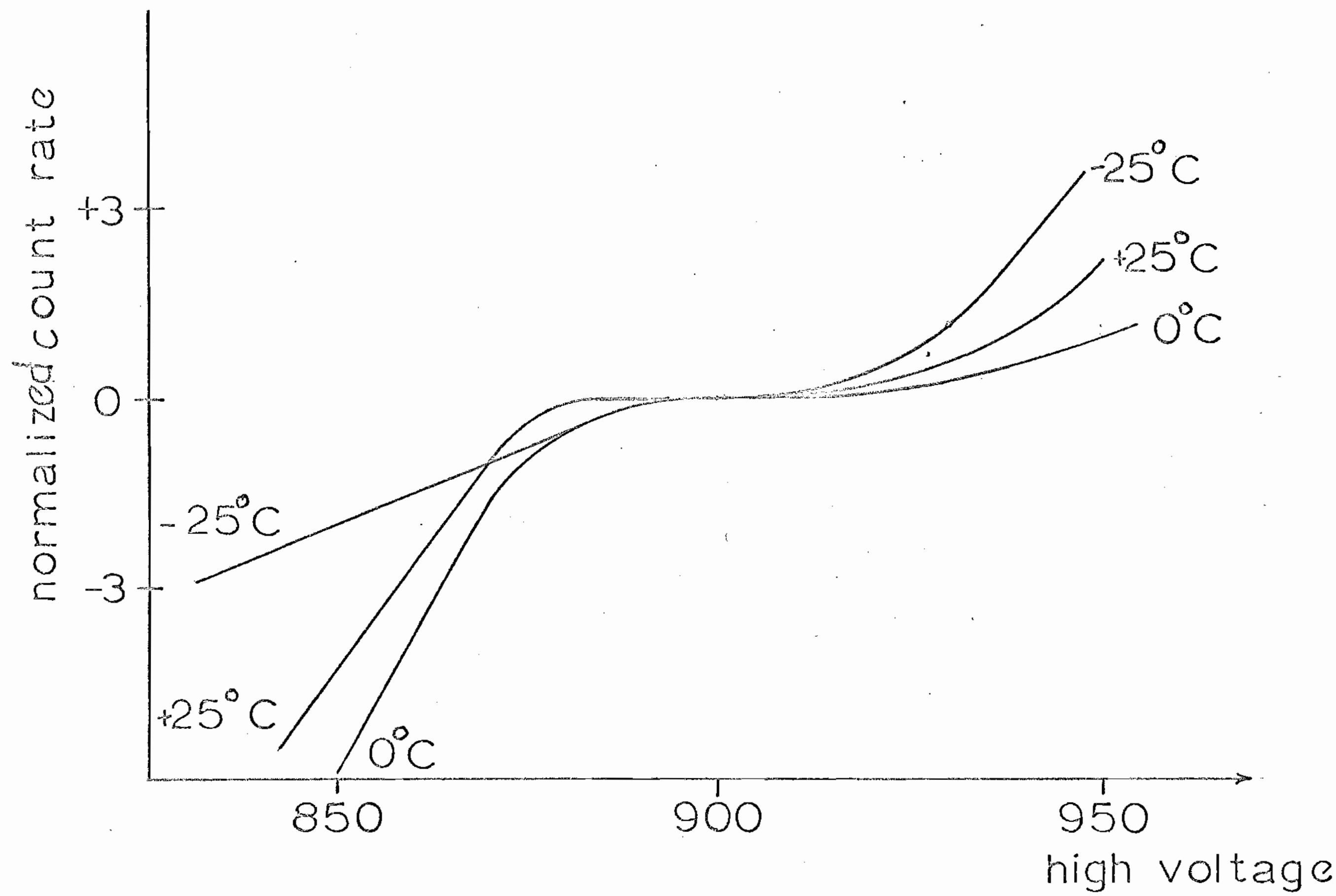


FIGURE 12
temperature vs. count rate

rate.

II. HIGH VOLTAGE POWER SUPPLY

As mentioned in the previous section, the G-M tube requires a high voltage power supply for operation. In designing such a power supply, or obtaining a commercial unit, it is important to realize that, when the G-M tube conducts, it becomes a current demanding device. The greater the conduction rate, the greater the current demand from the high voltage (HV) power supply. Therefore, the HV power supply must not only be able to supply the necessary potential to the tubes, but also any current demanded by the system.

The high voltage selected for operation by the system is determined by the point on the plateau region, Figure 11, it is selected to operate. This point is selected such that, over the various temperature ranges expected, the least amount of shift occurs on the plateau region. The advantage is that the count rate variation due to changes in the system parameters is held to a minimum.

Commercial power supply. During the first year of operation, a commercial high voltage power supply was selected for use in the system. The DC-DC Converter, cited in Appendix E, required an input voltage of 60 VDC at 65 milliamps. The output was a regulated 1440 VDC at 120 uamps. For operation in conjunction with the 76NB3 G-M tubes it was necessary to reduce the voltage to 900 VDC and regulate it by using a + 900 VDC voltage regulator (V-R) tube.

During the winter of 1965-1966 when the commercial power supply was used in the system, several problems arose that needed to be corrected.

1. The unit did not operate reliably at the low temperatures encountered during operation in the field.
2. The operating point on the plateau region was limited by the voltage regulator tubes that were available on the market. In this particular case a +900 VDC V-R tube was used.
3. The high voltage unit drew 70% of the current required by the system. If a unit could be built that required less current, it would be an advantage, due to the remote application of the system and the necessity of battery power.
4. The oscillator within the DC-DC converter was quite noisy. It created a high frequency that was hard to shield against. The frequency from the DC-DC converter coupled into the output circuitry and resulted in miscounting of the data pulses (cross talk).

<u>New HV power supply</u>. The replacement unit, built for use during the winter of 1966-1967, was designed to help correct the problems that occurred with the commercial HV power supply.

The high voltage power supply was a transistorized unit as shown in Figure 13. The basic idea behind its operation is that there is a blocking oscillator for the input circuit with a variable resistor, R_R, to control the output amplitude. The signal is then fed through a transformer into a voltage doubler circuit. It is then filtered and the output is a constant DC potential that is regulated by what value of R_R is selected. The problems solved with this unit are:

1. The output potential was very stable over the test range of $-20^{\circ}C$ to $+25^{\circ}C$.

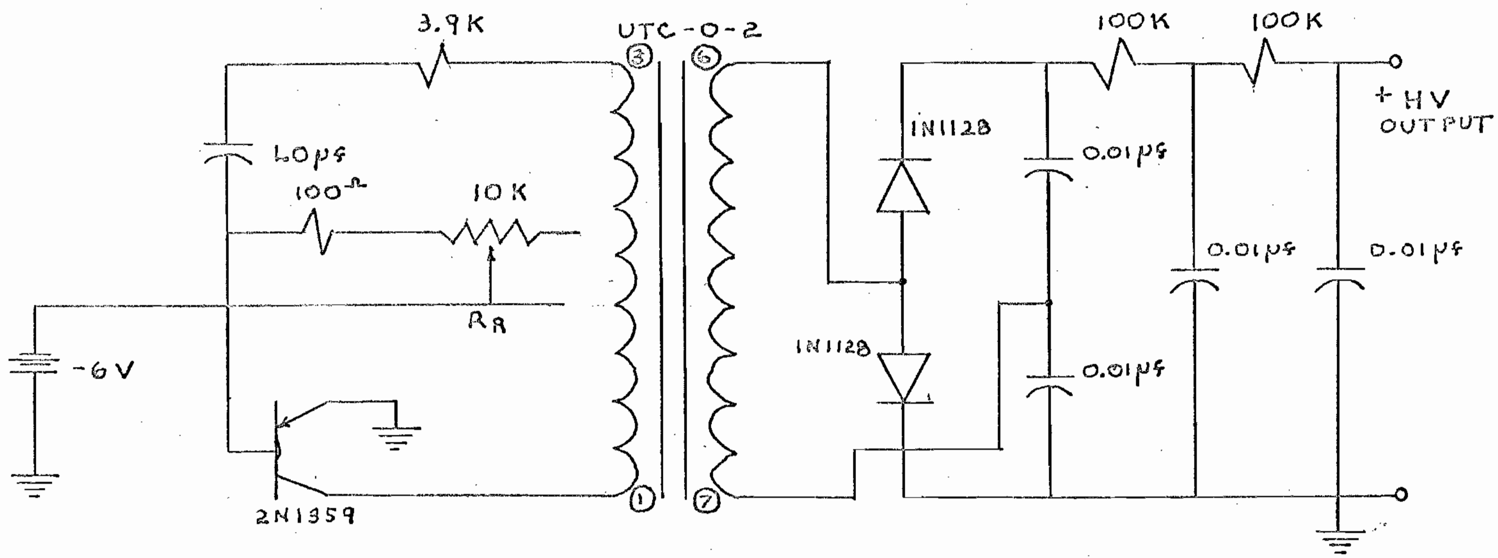


FIGURE 13

high voltage power supply

2. Because the HV power supply can now be regulated from 700 VDC to 975 VDC the selection of an operating point on the plateau region can now be made for best system operation.
3. The power supply required only 30 ma or about 50% less than the previous unit.
4. The blocking oscillator was carefully shielded from the other circuits and no cross talk problems now exist.

The new high voltage power supply was installed in the G-M system just before the winter of 1966-1967. Since the unit was easily adjustable, the output voltage was varied and a plot was made of voltage vs. count rate, Figure 14. From these data an operational point of 925 volts was selected. The advantages are the small variation in count rate between 875 volts and 950 volts. This operating point is also in the temperature stable region of the G-M tubes.

III. DEAD-TIME CORRECTION TECHNIQUES

The G-M tube has a maximum counting rate which limits the strength of the radiation source that can be used, thus limiting the amount of stored water that can be measured. An obvious solution that has been mentioned is to group several G-M tubes and to combine their outputs to form a single electrical signal. But this solution has also increased the system dead-time, and the maximum counting rate capability has not really increased as desired. Therefore, it will be necessary to employ some type of dead-time correction to obtain any benefit from tube grouping.

<u>A grouping of two G-M tubes.</u> Two G-M tubes of the type selected

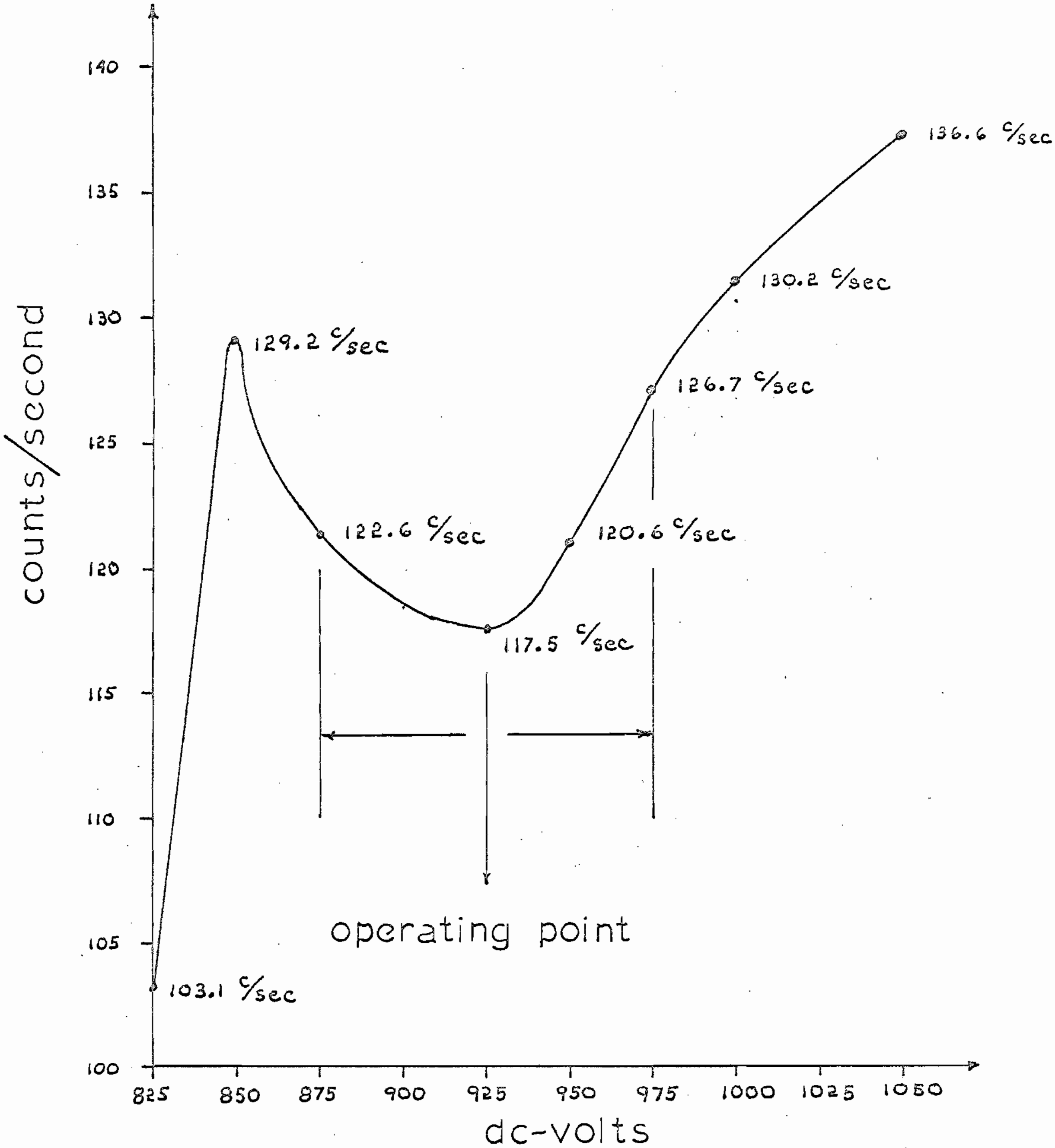
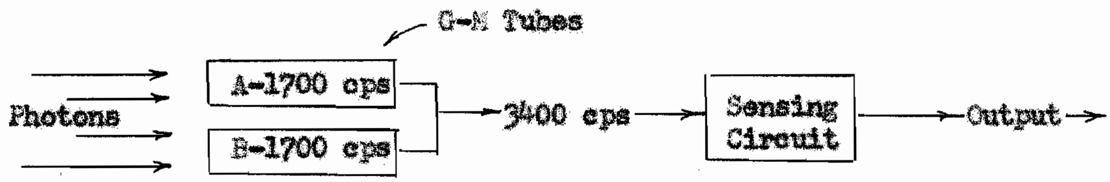


FIGURE 14

voltage vs. countrate

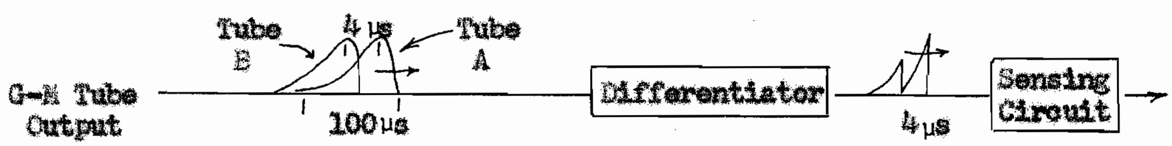
for the system are combined so that their outputs form a single electrical signal.



The tubes are placed in a beam of photons whose intensity is proportional to 1700 counts per second (cps) or 3400 cps for the tube group. This particular G-M tube, Appendix B, has a count rate limit of 1700 cps or the tubes total dead-time is 590 microseconds.

For example, assume that the sensing circuit receiving the pulse output of the G-M tubes is only able to receive one pulse at a time. Under this condition tube A or tube B can receive only 1700 photons per second but not both tubes. The reason is that the sensing circuit requires 590 microseconds to recover before the circuit can react to the next incoming pulse. The result is that the number of tubes has been increased without a corresponding increase in system count rate.

A solution to this problem is to feed the output pulses, from the G-M tubes into a differentiating circuit with a dead-time of only 4 microseconds, that is, the second tube can now conduct only 4 microseconds later and be recorded by the sensing circuit



The result is that the system can now respond to a second photon in only 4 μsec. However, if a third pulse arrives before 98 usec, the remaining dead-time required by tube A, it will be missed by the system. To show that something has been gained by using this technique, it is necessary to look at Poisson's Equation.

Probability. It is known that the emission of particles from a radioisotope is random. If the half-life of the material is reasonably long, Poisson's law can be used to describe this random distribution.

Poisson's law is given by

$$Pn(t) = \frac{(\alpha t)^n e^{-\alpha t}}{n!} \qquad (4.1)$$

Where pn(t) is read as the probability of getting n-events, disintegration in this case, during a time t when α is the average rate of disintegrations. Equation (4.1) can be shown in another form as

$$P[n](t) = \sum_{r=o}^{x} \frac{(\alpha t)^n e^{-\alpha t}}{n!} \qquad (4.2)$$

where it is now concerned with the probability of x or less events occurring in some time t.

Under the first condition the two tubes were electrically tied together and placed in a radiation flux intensity of 3400 counts per second. If, at time t = 0 tube A conducts, the probability of tube B conducting in 590 μsec is found from equation (4.2)

$$1 - P_o(t) = \sum_{r=o}^{o} \frac{(2)^o e^{-2}}{0!} = 1 - 0.135 = .865$$

$\alpha t = (3700)(590)(10^{-6})$

$\alpha t = 2$, or the probability of not more than 0 events occurring in 590 μsec is only 13.5% of the time. Therefore, 86.5% of the time tube A does not conduct because of its dead-time and the count is missed. This is quite significant and a solution must be found to solve this problem.

Looking at the second condition, the output is fed into a sensing circuit with only a 4 μsec dead-time. Therefore, if tube A conducts at t = +0 the probability that tube B will conduct in less than 4 usec is found by using equation (4.2)

$$Po(t) = \sum_{r=o}^{o} \frac{(\alpha t)e^{-\alpha t}}{0!} \qquad \begin{aligned} \alpha t &= .0136 \\ Po(t) &= 0.985 \end{aligned} \qquad (4.4)$$

or the probability of 0 events occurring is 98.5%.

The conclusion that can now be drawn is that, if the output is fed into a sensing circuit with only a 4 μsec dead-time, only 1.5% of the incoming pulses will be missed by the system.

Table I shows the probability of 0, 1, and 2 events occuring in 25 μsec, 50 μsec, and 100 μsec, using the values for the 76NB3 dead-time.

Table I
Probability of X-events Occurring at 1700 cps

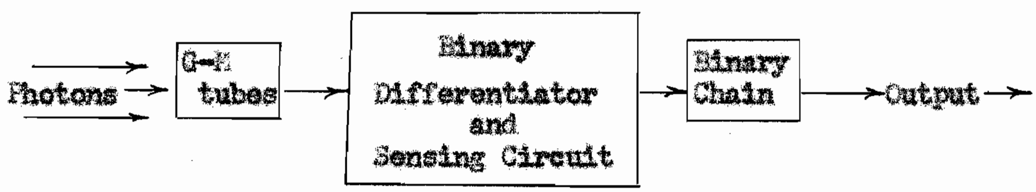
	0 events	1 event	2 events
25 μsec	0.958	0.041	0.00172
50 μsec	0.918	0.078	0.0065
100 μsec	0.842	0.143	0.0242

Due to the random nature of the disintegrations, the fact will have to be accepted that some data pulses will be lost. But, the loss of only 1.5% can not be considered significant under the condition of a sensing circuit with a 4 μsec dead-time.

It has been determined that if a sensing circuit with a dead-time of only 4 μsec is used to collect data pulses from the G-M tubes, very few pulses will be lost at maximum radiation flux levels. As the radiation flux level is decreased due to snow pack attenuation, the probability of losing a data pulse will be so small that it can be considered nonexistent.

Data collection. Building a sensing circuit that has a dead-time of only 4 μsec would be possible, but first it may prove to be an advantage to look at the overall system requirements. The "Timed Count Data Conversion System"[16] is to be used by the G-M system to collect the data pulses. In this system the initial random count rate is divided by a large factor to produce a "regularizing" effect on the output count rate. The reason for the large division ratio is to reduce the count rate to a point where the information can be transmitted from the remote site and remain within the bandwidth requirements of the radio transmitter.

The large division ratio is accomplished through the use of a binary chain. The first binary, if designed properly, can also be used as the sensing circuit for the G-M tubes. This was done and the final circuit configuration would be as shown with a count rate limit of 3400 cps.



IV. COLLIMATION

It was mentioned in an earlier chapter that a G-M tube is incapable of discriminating against various radiation energy levels and hence counts an entire radiation spectra. To prevent system errors due to "low energy counting" a set of collimators was designed and built to be used in the Improved G-M System.

G-M tube collimator. The main purpose of this collimator was to shield against the low radiation energy levels in the Compton Region as discussed in Appendix C. The most economical shielding material available is lead. Therefore, the design was based on construction using this material.

The design criteria for collimator construction are as follows:

1. The G-M tubes, for proper shielding, are to be completely enclosed by the lead shield.
2. The amount of lead used to obtain a certain amount of attenuation should be held to a minimum. Therefore, (a) the G-M tubes should be bunched together to obtain the smallest possible volume; (b) all associated electronic circuitry should be removed to the outside of the collimator to further decrease the required internal volume.
3. The collimator geometry should be designed to obtain the best approximation to the ideal situation as shown in Figure 7b.
4. The main purpose of this study was to prove the feasibility of such a system. Therefore the amount of shielding used in the study system should not be held to a minimum, or, maximum shielding should be used when constructing the collimators, thus insuring good geometry.

The G-M collimator designed using the above conditions is shown in Figures 15, 16, and 17. It can be seen that the maximum lead depth was selected to be $3\frac{1}{2}$ inches which resulted in a total weight of 1200 lbs. Therefore, the G-M collimator was divided into two pieces for easier handling.

It was shown in Appendix C that the low energy radiation to be

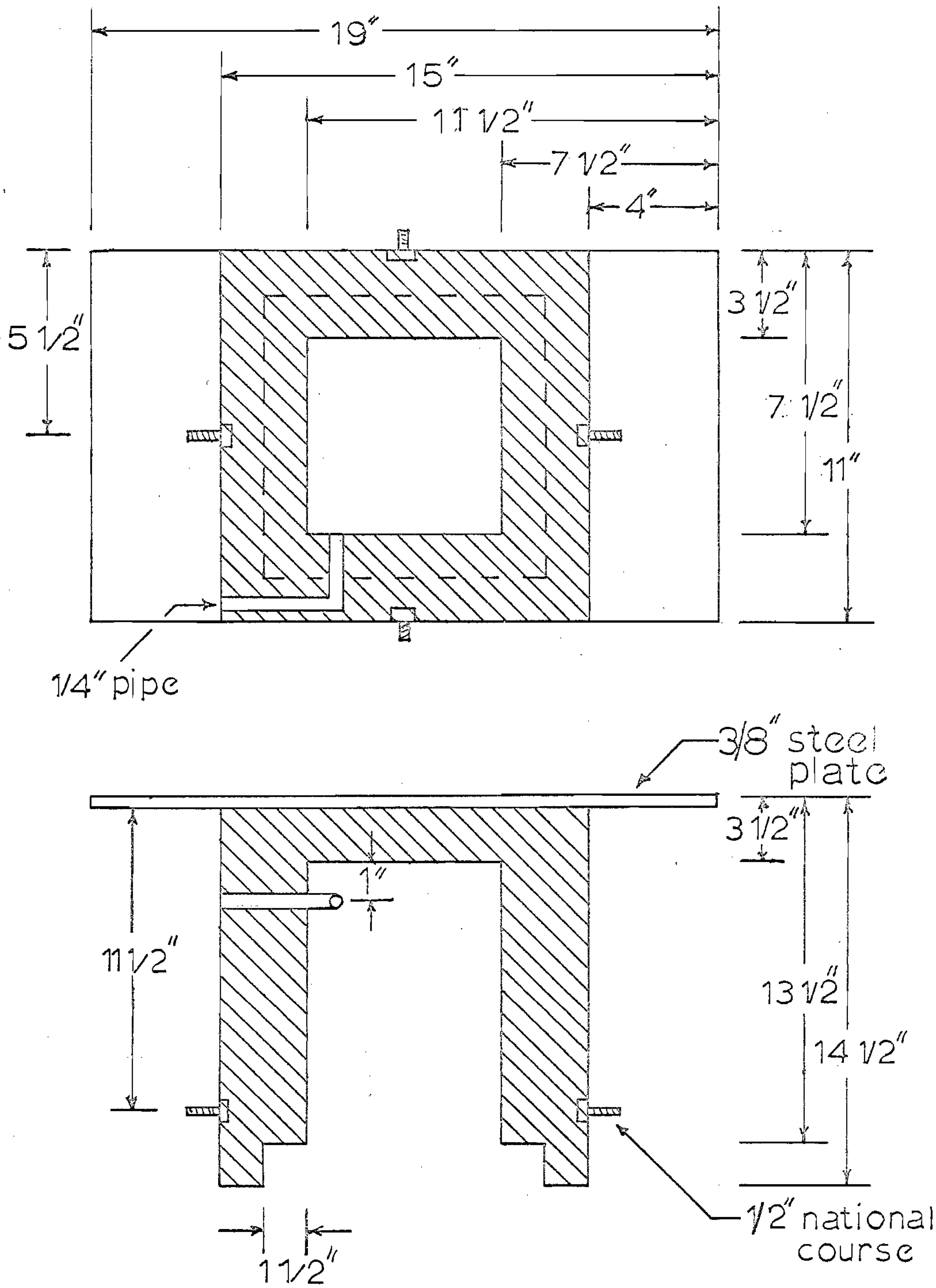


FIGURE 15

GM collimator—upper section

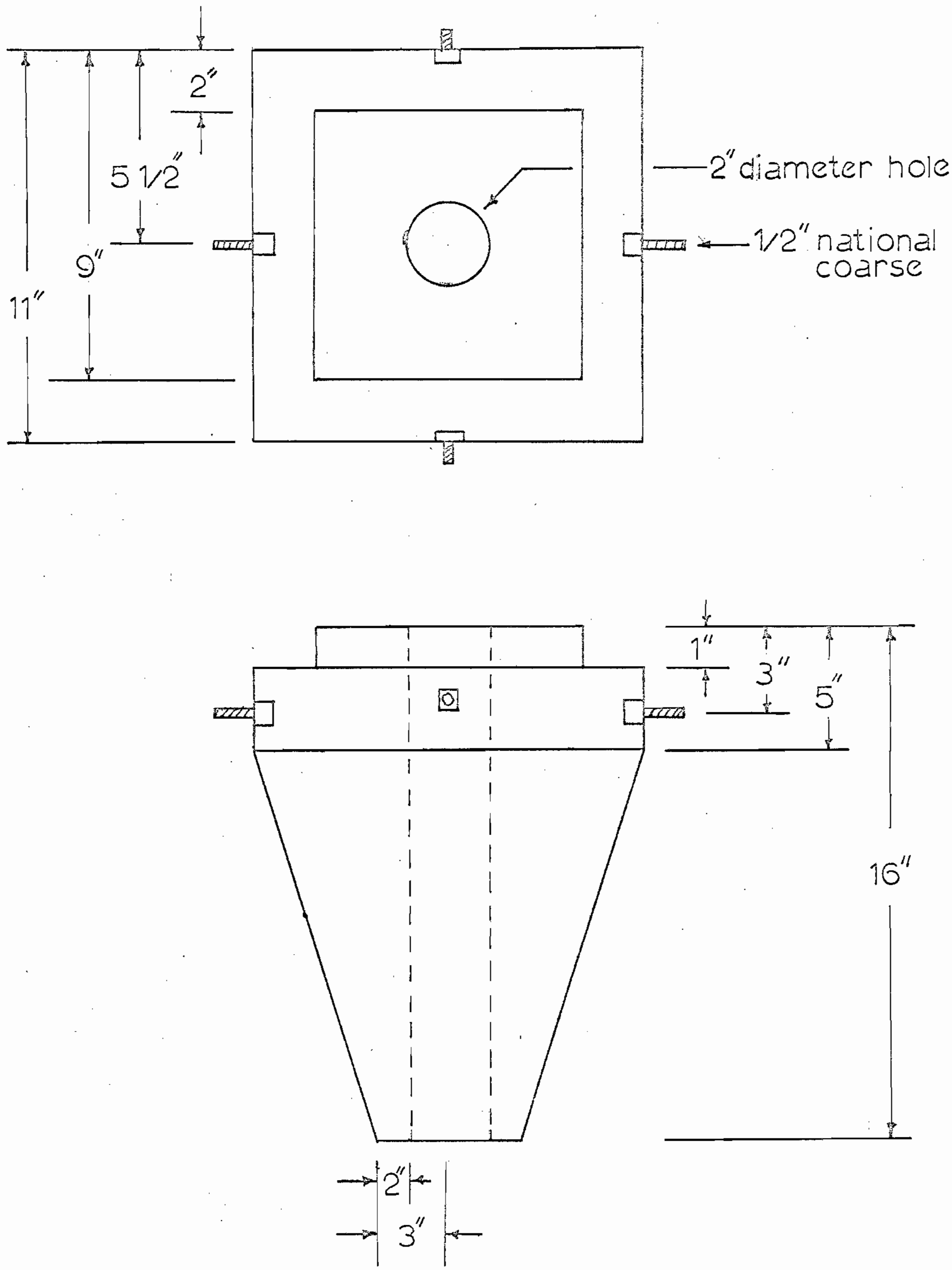


FIGURE 16
G-M collimator–lower section

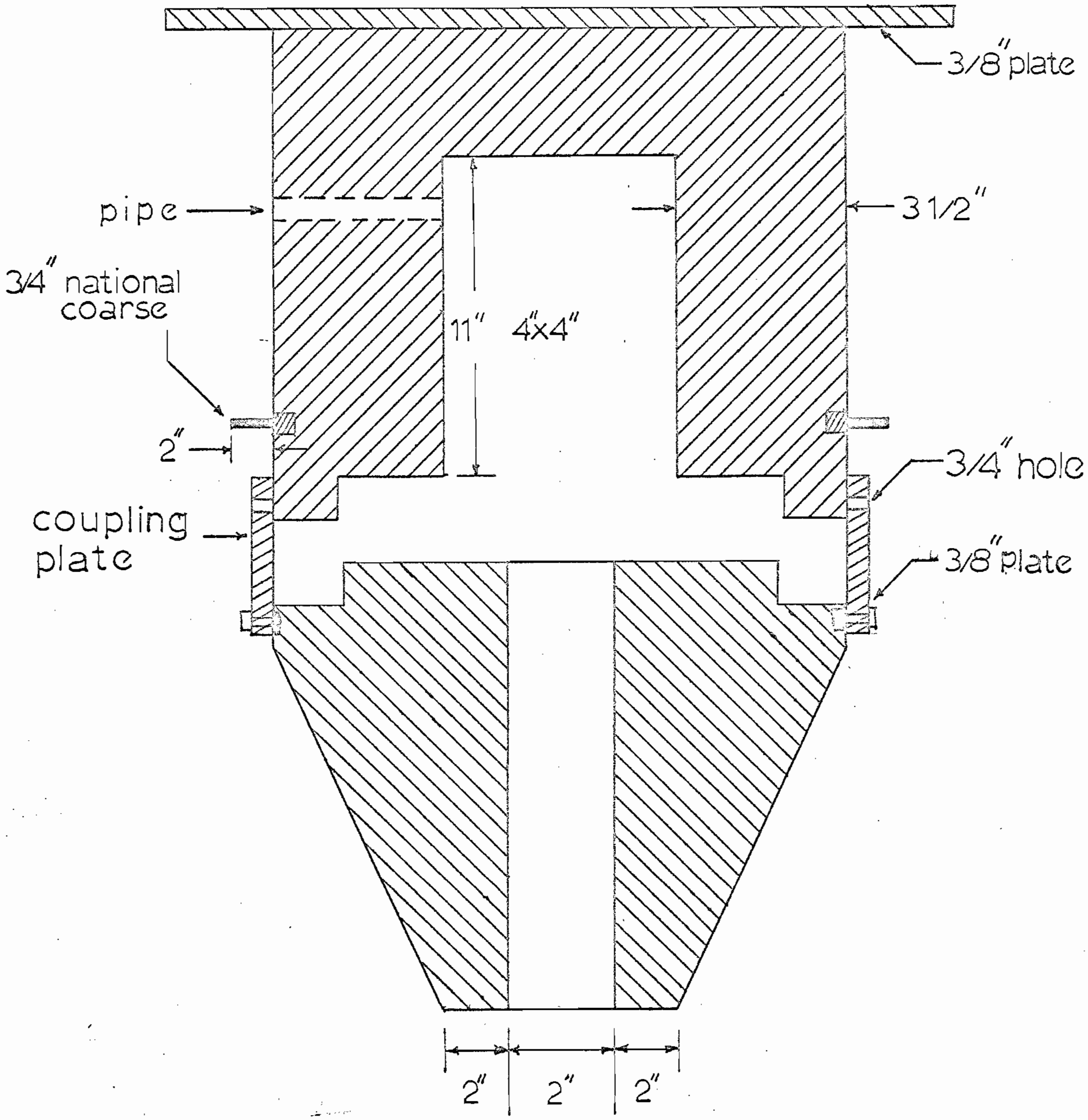


FIGURE 17
total GM collimator

shielded against has an energy of 0.74 mev or less. Using the nomogram, Figure C-2, the attenuation due to $3\frac{1}{2}$ inches of lead is 1×10^{-4}. But the majority of the low energy photons coming from the snow pack will encounter more than 10 inches of lead due to the collimator design. This results in an attenuation of better than 1×10^{-10}.

If at zero water content the count rate at the G-M tube of "low energy radiation" is 6000 cps, the resulting counts arriving at the G-M tubes will be 6×10^{-7} cps or nonexistent. The point to note is that the "low energy counting" does not create a problem until high water content levels are reached, 10 inches or greater. In this range the counts have been reduced to 600 cps or less; therefore, even greater attenuation will occur.

Source collimator. The second collimator designed to complete the ideal geometric system is used to hold the radioactive source. The main purpose of this collimator is to tightly collimate the radiation flux emitting from the source. Also it serves as a source container to protect personnel from the radiation during handling.

The source collimator constructed for the study system is shown in Figure 18. The length shown was determined by geometry considerations, while the hole size is based on the diameter of the radioactive source. This is the smallest radiation beam practical.

V. DESIGNING A SYSTEM

There are an infinite number of combinations that can occur when designing any particular system. Before designing a particular snow gage, it is necessary to define various important parameters and, with these

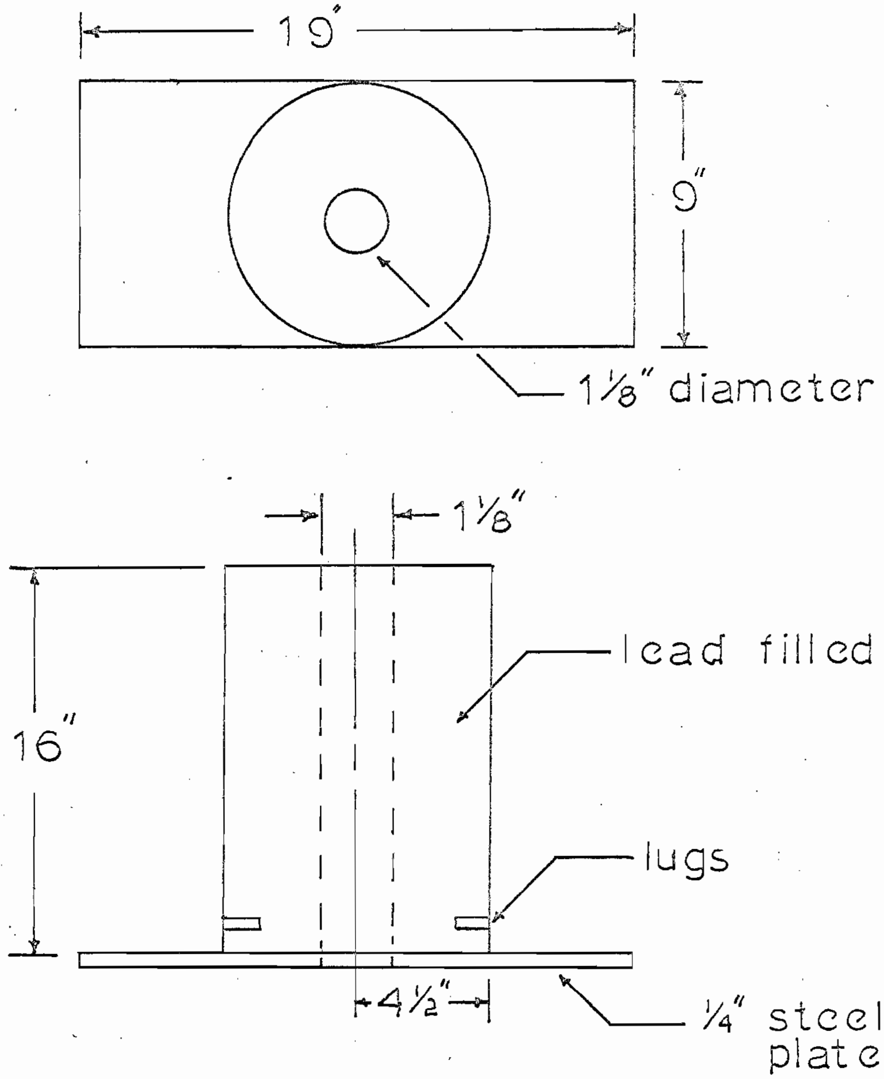


FIGURE 18
source collimator

available, it is possible to design a unique system. The examples that follow are special cases, but the technique is applicable for any design.

System I. A six tube 76NB3 G-M system is to be placed at a remote site. The information received should have an accuracy of ± 0.25 inch with a .90 confidence level at the maximum water count. The radio equipment is capable of transmitting data pulses for 150 seconds, and the maximum water content expected at the site is 50 inches.

The two nomograms available in Appendixes C and D will be used in solving this problem.

1. Using the statistical nomograph in Appendix D for a 0.9 confidence level and a ± 0.25 inch (4% count error), the required total events by the system at maximum water level is 1800 counts.

2. The six 76NB3 G-M tubes have a count rate limit of 1500 cps each, using less than actual saturation, or the maximum system capability is 9000 cps.

3. The counting time of the system is 150 seconds. At maximum water content, it is necessary to receive from the system

$$\frac{1800}{150} = 12 \text{ counts per second}$$

4. The radiation attenuation from 9000 cps to 12 cps is

$$\frac{12}{9000} = 1.3 \times 10^{-3}$$

5. Using the nomogram in Appendix C for lead vs. attenuation and 1.3 mev for the Cobalt-60 gamma energy, the required lead to attenuate 1.3×10^{-3} is 4.3 inches. The relationship between lead and water is

$$10.1" \; H_2O = 1" \; Pb$$

or the system can measure

$$(10.1)(4.3) = 43.5" \text{ of water } \pm 0.25"$$

This is the system that was designed and built for this study. The final circuit diagram is shown in Figure 19.

System II. The following design is to determine a limit on the theoretical snow pack water content the G-M system can measure. The specifications are selected as a possible limit, but some variations may occur to suit different situations.

1. Maximum error of $\pm \frac{1}{2}"$ at a .90 confidence level.
2. Maximum number of G-M tubes is eleven. A greater number would result in collimators too large for practical use.
3. The radio equipment can count data pulses for a maximum of 250 seconds.
   a. 550 counts must then be collected at maximum water level for the required accuracy.
   b. 16,500 counts per second are received from the system at zero water level. This is determined by the number of G-M tubes.
   c. Counts per second to be collected at maximum water level are
   $$\frac{550}{250} = 2.2 \text{ cps}$$
   d. Radiation attenuation is
   $$\frac{2.2}{16,500} = 1.3 \times 10^{-4}$$
   e. Lead required to attenuate a 1.3 mev gamma photon 1.3×10^{-4} is about 6 inches.

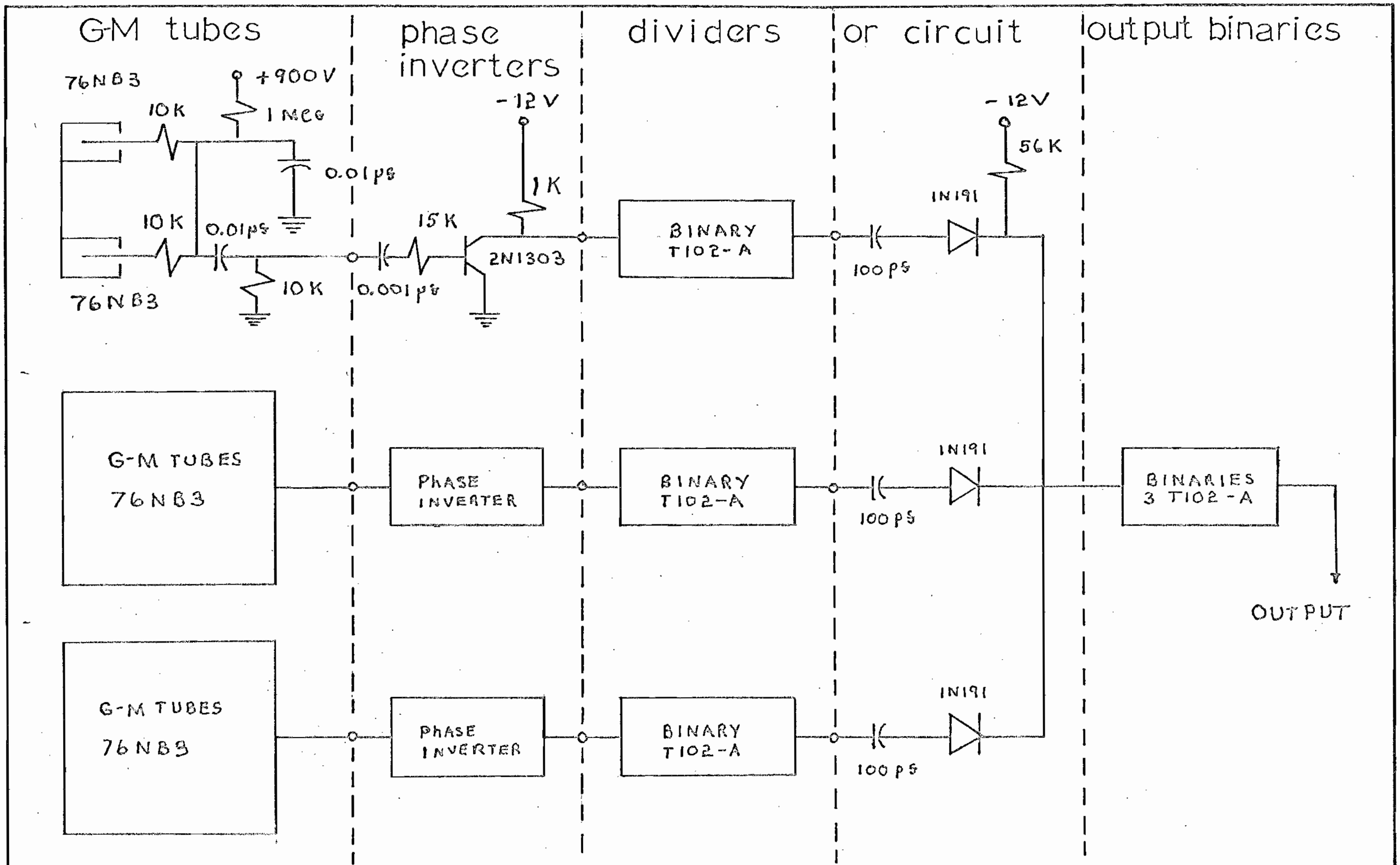


FIGURE 19
the geiger-muller electrical system

Therefore, the practical limit of the improved G-M radiation snow gage is 60 inches $\pm \frac{1}{2}$ inch of snow pack water content.

CHAPTER V

LABORATORY AND FIELD RESULTS OF THE GEIGER-MULLER SNOW GAGE SYSTEM

The theoretical analysis and design of a system, as given in Chapter IV, provide the necessary information about the correct approach required to accomplish a goal. However, the final proof of any system design is its construction and the actual laboratory and field testing of the device. Many times the effects not taken into consideration by theory become evident as problems under actual operating conditions.

I. LABORATORY TESTING

The main goal of the Geiger-Muller system redesign was to solve the two original system problems; namely, (1) system dead-time at high counting rates, zero water equivalent, and (2) low energy counting at high snow pack water content levels. It has been theorized that if these problems could be solved, the G-M system would then have the same accuracy as the more expensive scintillation snow gage.

The system designed in Chapter IV was set up in the laboratory to simulate actual field conditions. A series of tests on the effects of attenuation due to lead, water, and snow were performed on the gage. The purpose of these tests was to determine if the techniques used to solve the dead-time and energy discrimination problems were effective.

The normalized calibration curves for lead, water, and snow, using two different radioisotope source strengths, conformed to the ideal linear curves as shown on the semi-logarithmic plot of Figure 20a. These straight line calibration functions indicate that both of the earlier problems were solved satisfactorily. Moreover, the fact that the curves remain parallel as source strength is changed substantiates the claim of achieving good system geometry. Also Figure 20b shows that the per cent of error in measuring snow pack water equivalent has been improved considerably compared to the early G-M system. This indicates that the low energy photons due to Compton attenuation have been successfully shielded against by employing the current collimator design.

The effect of geometry on system parameters. The successful operation of the G-M system at high water content levels is based on achieving "good geometry." Therefore, the proper alignment of the collimators to achieve essentially a cylindrical radiation flux beam is quite critical.

Since alignment is critical, it is necessary to determine what would happen if the collimators were not properly aligned initially during site installation or the alignment changed during the snow season. To study this effect, the system was aligned in the laboratory. The position angle of the source collimator was then varied. The system count rate and the calibration curves were then obtained as shown in Figure 21 and 22.

The information available from these plots is: (1) the count rate decreases rapidly if the collimators become unaligned; (2) when installing the gage at the site, if the calibration curves are not ideal, "good geometry" has not been achieved as can be seen by the non-linear plots that occur. The information gained from these plots indicates that the support towers have to be designed to handle any expected snow or wind loading during the winter to retain proper collimator alignment.

II. FIELD OPERATION

After the G-M system was built and laboratory tested the system

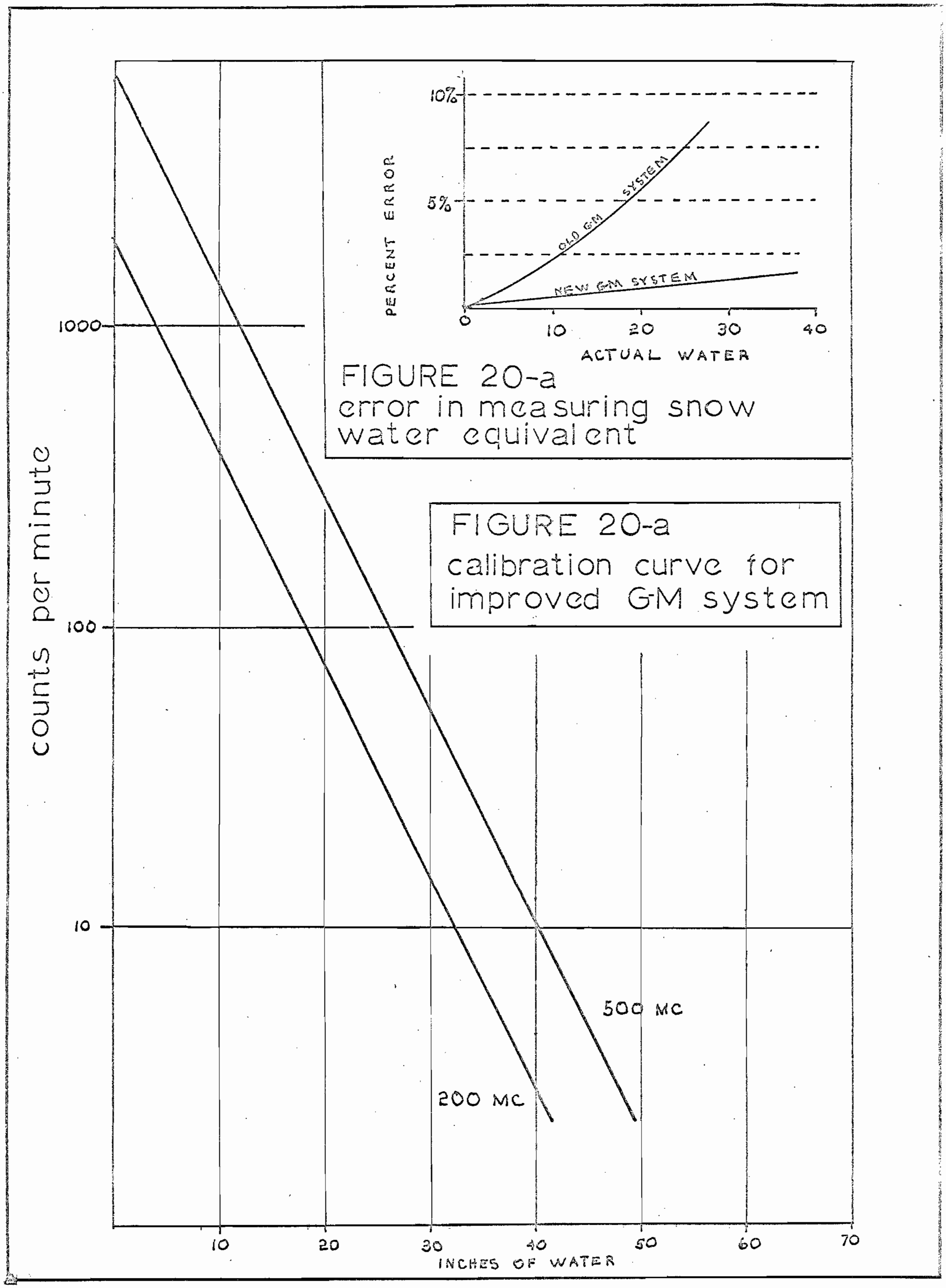


FIGURE 20-a
error in measuring snow water equivalent

FIGURE 20-a
calibration curve for improved G-M system

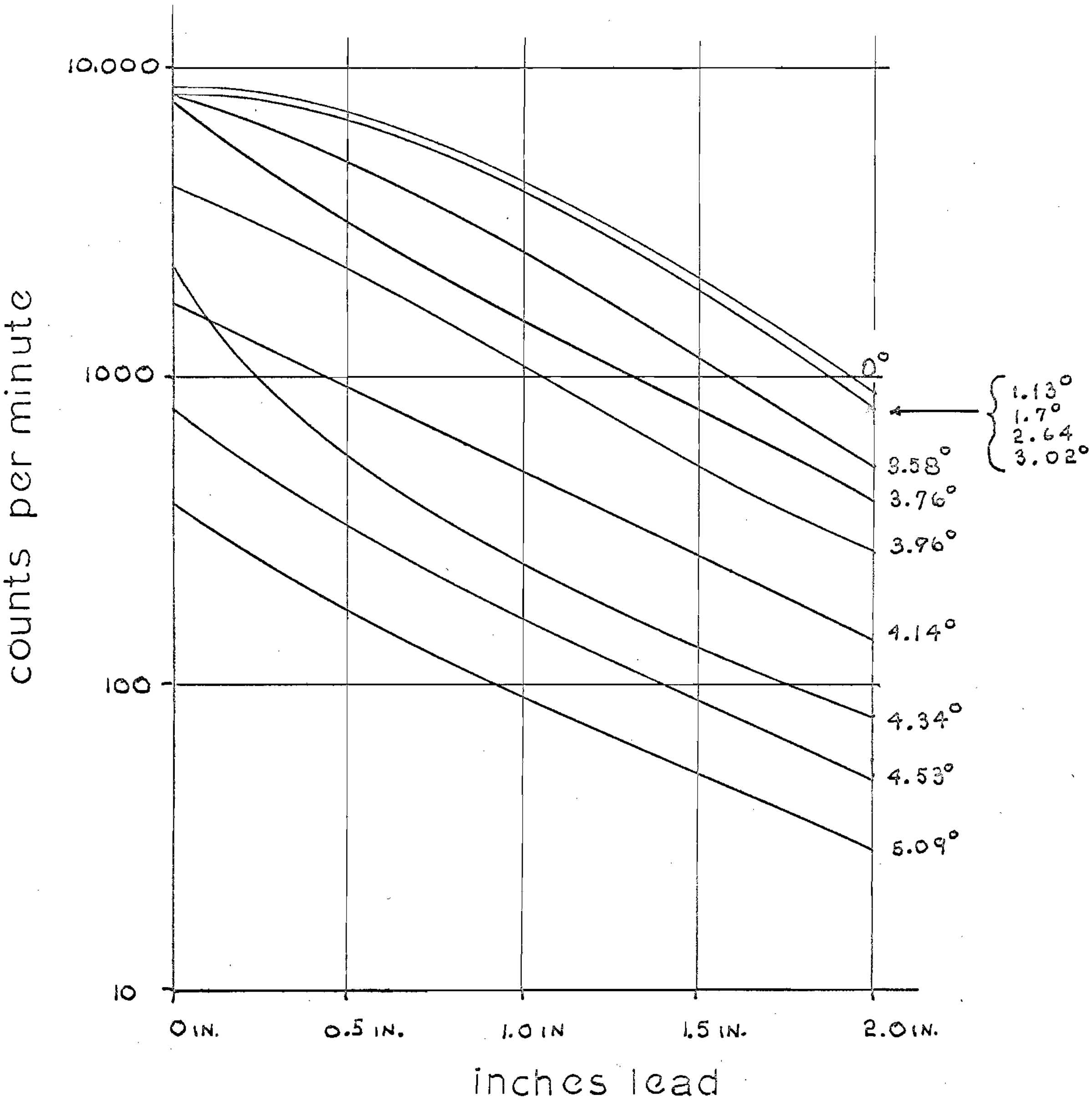


FIGURE 21

collimator alignment vs. system calibration

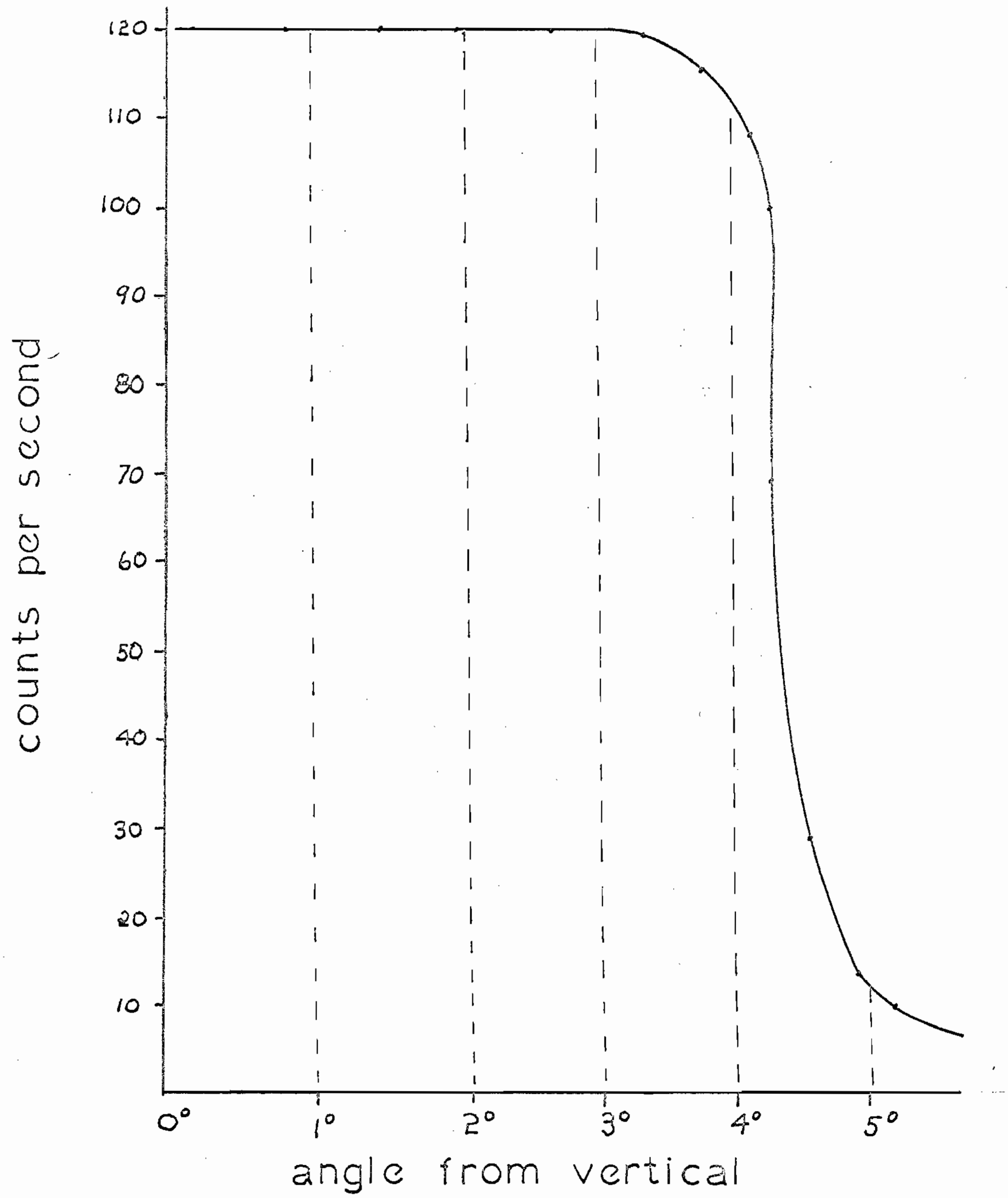


FIGURE 22

count rate vs collimator position

was placed in the field under actual operating conditions. The main problem was to obtain information of the actual snow pack water content. If this information were available, the data from the Improved G-M System could then be compared with the actual water content and system accuracies checked. The snow tubes are a recognized standard, but the accuracy has been shown to be only ± 20%. Therefore it was necessary to obtain a better method of obtaining snow pack water content levels. The scintillation snow gage has evolved into a fairly accurate system. The accuracy has been proven by rather extensive laboratory and field testing.

Therefore, because the scintillation system has the required accuracy for checking the G-M system during actual field testing, it was decided to operate both gages at the same site. The same support tower was used for both gages and its configuration can be seen in Figure 23.

The combined systems were then placed into operation at the University of Idaho experimental test site. The results from operating the improved G-M system are shown in Figure 24. These data correlated well with snow tube readings taken at the G-M installation until maximum snow pack water content occurred at the peak of the snow season. The data then separated considerably with the G-M system data showing a faster snow pack melting rate during the snow pack melting period. The cause of this difference was later traced to an actual faster melting rate under the collimator; therefore, the gage was accurate. The reason for this occurring was believed to be caused by one of two problems: (a) the large mass of the G-M lead collimator resulted in a heat source after sunset; and, therefore, the snow pack directly under the collimator continued melting while the rest of the snow pack melting had stopped; and/or (b) the

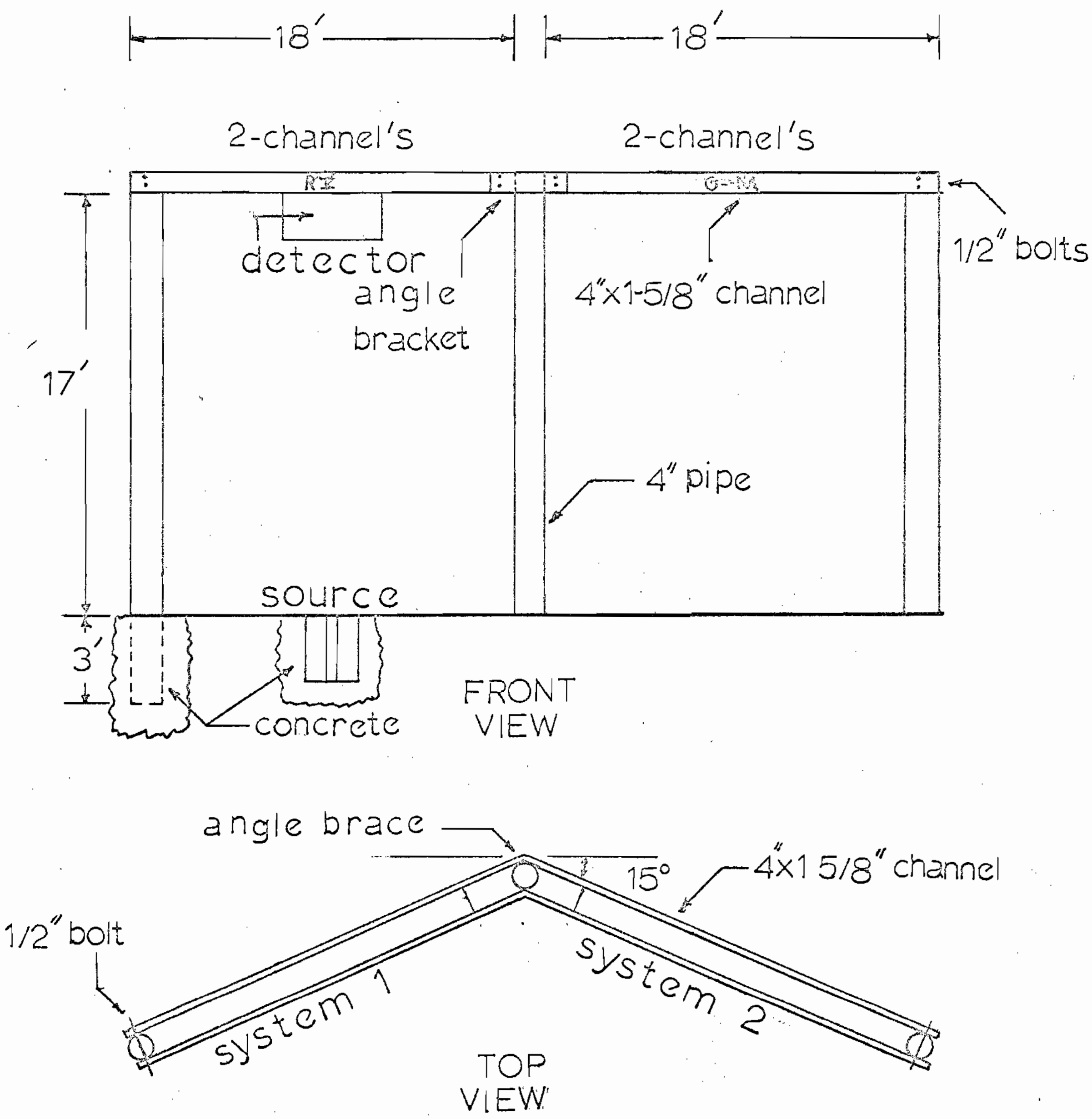
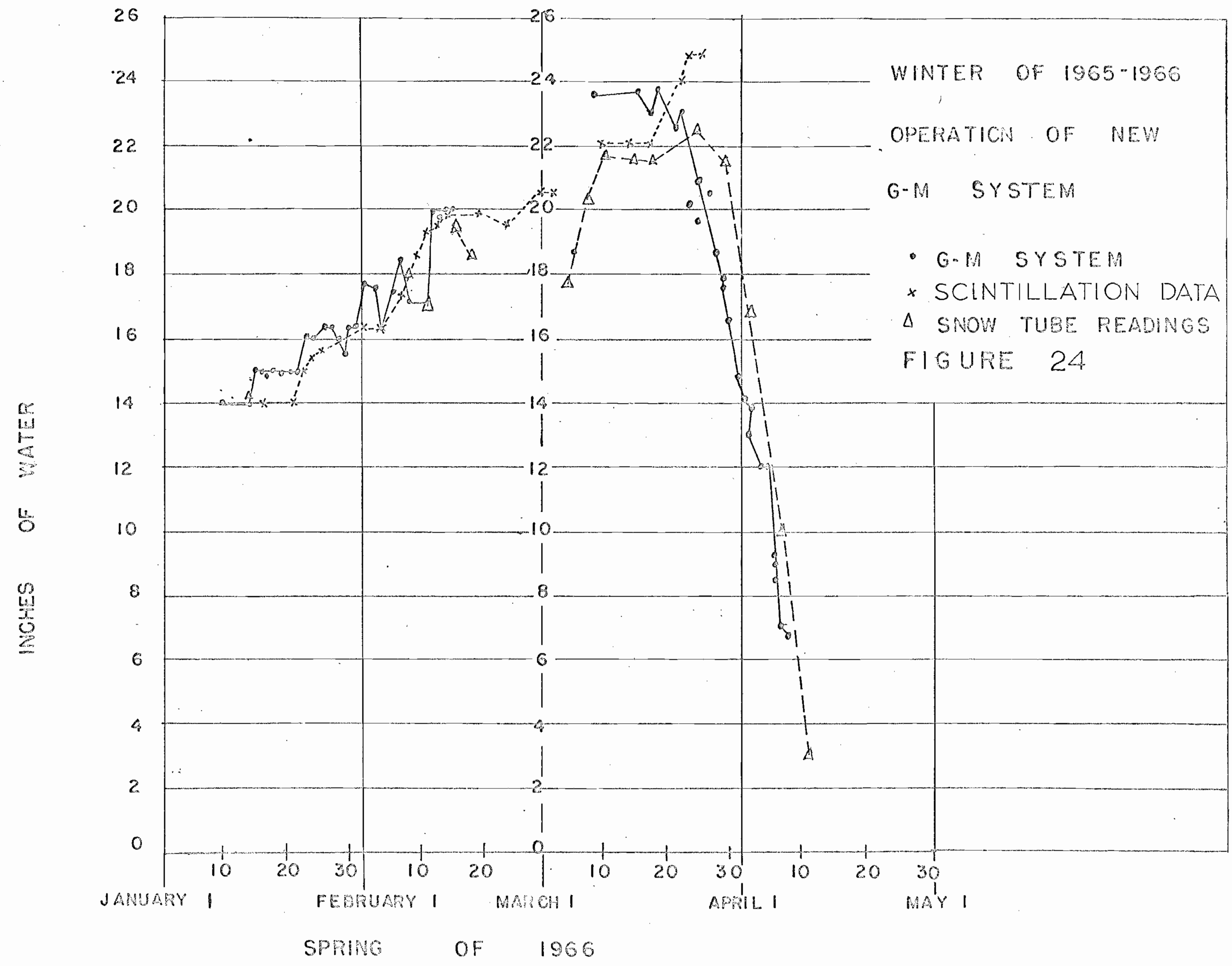


FIGURE 23

support tower



WINTER OF 1965-1966
OPERATION OF NEW
G-M SYSTEM
• G-M SYSTEM
x SCINTILLATION DATA
Δ SNOW TUBE READINGS
INCHES OF WATER
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10
20
30
JANUARY 1
FEBRUARY 1
MARCH 1
APRIL 1
MAY 1
SPRING OF 1966

FIGURE 24

shape and silver color of the collimator reflected and focused the sun's rays resulting in greater heat being absorbed at that point, resulting in greater melting.

Possible solutions of the two above problems are: (a) change the painted color of the collimator, (b) increase the tower height, which decreases the effect of the heat source on the snow pack, (c) decrease the total mass of the collimator.

Except for the problem mentioned, the Improved G-M System agreed very closely with the data from the scintillation system during the winter season. Thus the original idea of a Geiger-Muller snow gage has been realized successfully.

CONCLUSION

The purpose of this study was to design a low cost replacement for the scintillation snow gage. A complete system redesign was performed around the idea of using the G-M tube due to its advantage of low cost and simplicity.

The collimators used by the study system were too large for practical use. The author has made a preliminary study on reducing collimator size and feels that if the lead thickness is reduced to $1\frac{1}{2}$" when building the G-M tube collimator the accuracy of the system will not be affected. The total weight of the system will be around 400 lbs, or 200 lbs per section. This would be more practical and easier to handle. The calculations made were purely theoretical and the smaller size could only be verified by actual field testing.

The system that evolved from this study was tested and shown to be the equivalent of the scintillation snow gage in overall accuracy. Therefore it could be projected that the G-M snow gage might become accepted as the generally used field gage due to its balance of cost, accuracy, resolution, reliability, and simplicity.

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APPENDIX A

APPENDIX A

GEIGER-MULLER COUNTER TUBE THEORY

The Geiger-Muller (G-M) counter tube has been the most widely used detector of nuclear radiation for many years. The great utility of the G-M tube is a result of several of its characteristics. Some of the more important of these are high sensitivity, large size of the output signal, and reasonable cost.

The characteristics of the G-M tube will be analyzed with regard to tube application as a detector in a radioisotope snow gage. With this information available the type of Geiger-Muller counter tube for the snow gage can then be selected.

I. ENCLOSED GAS VOLUME DETECTOR

There are three basic types of enclosed gas volume detectors: (1) ionization chamber, (2) proportional counter, and (3) Geiger-Muller counter. The difference between the three types of radiation detectors is based on the production of ionization in a gas and the separation and collection of the ions by means of an electrostatic field.

For the application under consideration, the Geiger-Muller tube is the most sensitive of the three types in counting lightly ionizing particles such as gamma-radiation which is the type of radiation employed in the radioisotope snow gage.

The G-M tube detector is shown in Figure A-1. The Geiger-Muller tube in this configuration takes advantage of the extreme gas amplification that can be obtained when high accelerating voltages are applied to the electrodes. At the correct high voltage, when a molecule is ionized, an electron avalanche occurs spreading the charge throughout the entire tube giving a single pulse out of the G-M tube for each gamma-photon causing ionization within the G-M tube.

II. PLATEAU CHARACTERISTICS OF THE GEIGER-MULLER TUBE

When the high voltage potential is located at the Geiger region, the number of ions produced in each avalanche is independent of the magnitude of the primary ionization caused by the gamma-ray. If the high voltage is slowly increased, eventually the number of positive ions reaching the cathode from a given ion sheath will be sufficiently large to cause finite production of secondary electrons which cause spurious discharges of the tube by traveling to the anode.

As shown in Figure A-2, over the region of anode voltage between V_t, the Geiger threshold, and that giving appreciable occurrence of spurious discharges, each ionization event in the sensitive volume of the counter gives rise to a single avalanche, and for constant radiation flux a counting-rate vs. voltage plateau is obtained.[9] In practical cases the plateaus are found to have a finite slope due to the variation of sensitive volume as the high voltage varies.

This plateau region is of particular interest in constructing a high voltage power supply. If the value of voltage is selected such that it is at the center of the plateau region, any variation in high voltage will cause less change in the G-M tube output count-rate under constant radiation flux conditions.

III. SELF-QUENCHED GEIGER-MULLER TUBES

In G-M tubes containing pure gases, the positive ions during

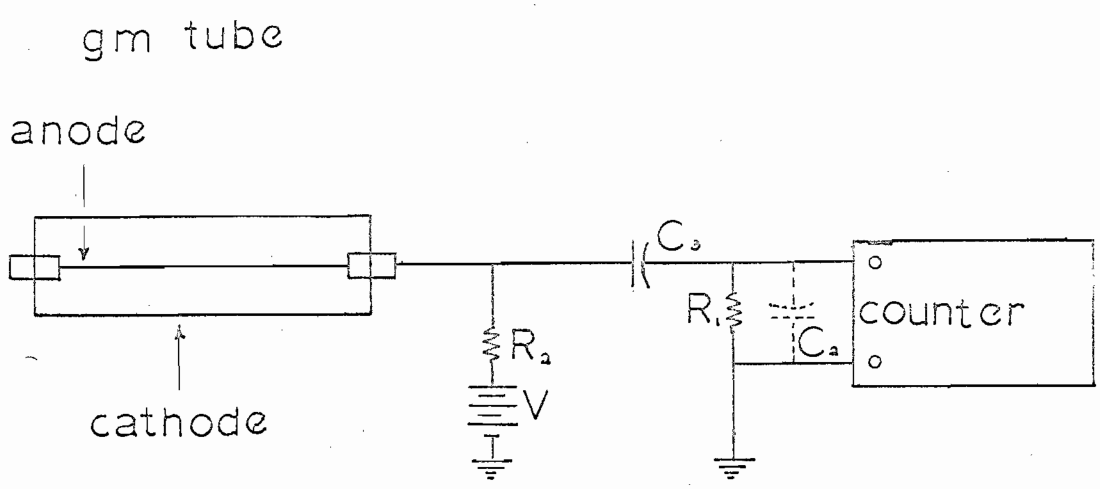

FIGURE A-1
geiger-muller detector

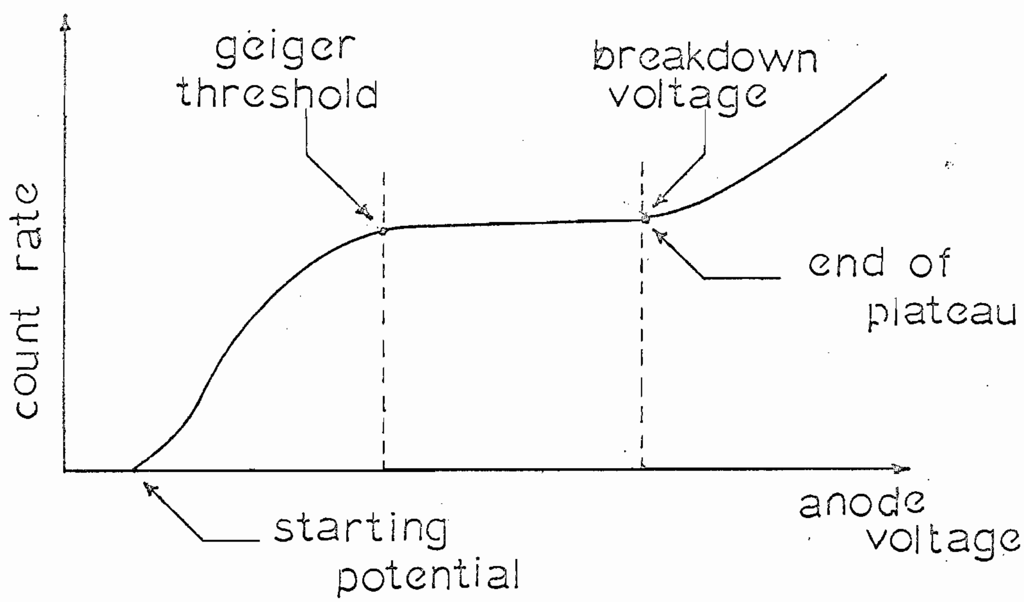

FIGURE A-2
geiger plateau

avalanche migrate all the way to the cathode before neutralization. During the neutralization process photon energy in the ultraviolet region is usually released. This photon has sufficient energy to create another discharge unless provision is made to prevent, or quench, it.

This multiple discharge may be prevented by an external circuit which lowers the potential across the tube below the Geiger threshold whenever an electron avalanche occurs. This prevents the tube from discharging again because of photon energy released during neutralization of the positive ions.

Another method of quenching employs the self-quenched tube[10] which contains a small percentage of a quenching gas in addition to the major constituent of the filling gas. There are two types of self-quenched tubes in use, namely, the organic-quenched and the halogen-quenched tubes.

The purpose of the quenching agent is to collect and neutralize the positive ions before they reach the cathode. The organic-quenched tube uses ethyl alcohol or ethyl formate and works acceptably except that the agent is consumed during the neutralization process resulting in a life limit of about 3×10^8 counts.[9]

In the halogen-quenched G-M tube[11] a small quantity of halogen gas, such as bromine or chlorine, is added to the filling gas. The quenching action is similar to the organic tubes with one exception, the quenching gas is not consumed; therefore, the life of the tube is almost unlimited.

The halogen-quenched tubes are characterized by one drawback, their plateaus are shorter, with larger slopes, as compared to other types of tubes.

IV. DEAD-TIME PROBLEMS WITH GEIGER-MULLER TUBES

Since the G-M tube's operation is based on gas ionization, the G-M tube will have an inherent dead-time that has to be considered. The dead-time of the G-M tube, t_d, can be explained as the time taken by the moving ion sheath to reach a radial distance x from the wire at which the field in the vicinity of the wire returns to its threshold values.[12] The value t_d is therefore determined by the design of the G-M tube and varies considerably between tube types designed for various applications.

During this period after discharge, the electric field in the G-M tube is below normal due to the positive ion sheath. Any radiation causing additional ionization are modified accordingly as shown in Figure A-3.

The dead-time of the circuit sets a lower limit on the time interval between the arrival of nuclear particles. This time interval will be anywhere from t_d to $t_d + t_r$ depending on the sensitivity of the output circuit.

There is a method where a correction factor can be employed to find out how many pulses are lost during the dead-time of the tube, using Equation (A-1).

$$I_o = \frac{I}{1-I\tau} \qquad \text{(A-1)}$$

where

I_o = actual radiation flux level

I = radiation flux level detected

τ = dead-time of the G-M tube

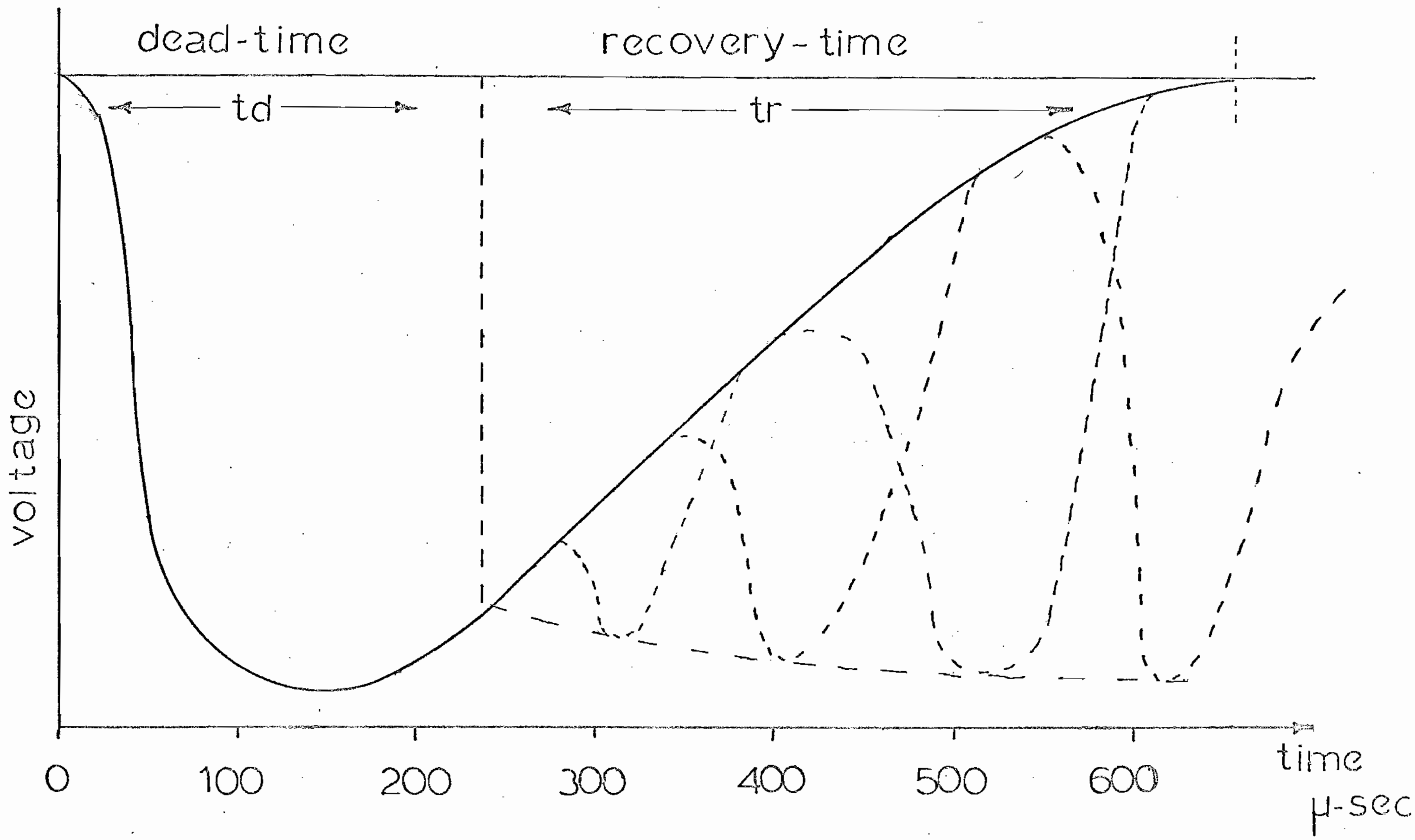

FIGURE A-3
GM dead-time effects

But this turns out to be only an approximation. At high counting rates there are a large number of ion sheaths in various stages of migration and each avalanche is of lower intensity because of the depressed anode. The charge q per unit length is also reduced causing the dead-time of the circuit to also go down.[13] Therefore, an accurate correction factor for lost counts at high count-rates is rendered quite difficult as the intensity of the radiation flux varies as in the case of the radiation snow gage.

V. SELECTION OF A GEIGER-MULLER TUBE FOR USE IN A RADIOISOTOPE SNOW GAGE

When selecting a G-M tube from what is available on the market the following things were taken into consideration.

<u>Cost</u>: The main purpose of this study was to develop a system that was more economical than the present scintillation system. Therefore, the lowest possible cost was required.

<u>Reliability</u>: The snow gage must operate for 10 months unattended. As was indicated in the previous section on G-M tubes, it was determined that a self-quenched tube using halogen gas has almost an unlimited life. Therefore, a halogen-quenched G-M tube should be employed.

<u>Dead-time</u>: The dead-time of the G-M tube should be as low as possible to allow high source strengths and decreased error at low snow pack water content levels.

<u>Temperature</u>: The G-M tube's operation should be unaffected by temperatures ranging from -30°C to +30°C.

<u>Size</u>: The tubes should be as small as possible for best volumetric efficiency when the collimators are designed for the gage.

Keeping in mind the above requirements, an Amperex 76NB3 G-M tube was selected after careful evaluation of what was currently available on the market. The performance data for the G-M tube selected are given in Appendix B.

APPENDIX B

APPENDIX B

SPECIFICATIONS FOR GEIGER-MULLER TUBE

Manufacturer: Amperex

Model: 76NB3

Description:

The 76NB3 is an inexpensive, rugged gamma counter for survey, demonstration, or monitoring applications. The infinite-life, halogen filling gives this tube an unusual electrical ruggedness to match its mechanical strength.

The absence of flanges or external glass structures enables these tubes to be bundled in multiple arrangements with good volumetric efficiency.

General Data:

Operating temperature range - -55° to $+75^{\circ}$C

Gas filling - Neon plus halogen admixture

Cathode material - stainless steel (28% chromium, 72% iron)

Effective cathode dimensions - 5-13/16" long x 0.605" I.D. x .009" wall

Performance data:

Operating voltage	900 volts D. C.
Plateau length	in excess of 125 volts
Slope of plateau	less than 15% per 100 volts
Starting voltage (0.3 volt pulses)	825 volts maximum
Capacity at terminals	1.5 mmf

Radical sensitivity (approx)	80%
Dead-time (approx)	100 microseconds
Maximum counting-rate	1700 counts per second
Background (shielded with 2" lead and 1/8" aluminum)	50 counts per minute
Roentgen energy dependence (unfiltered)	= 30%
Life expectance in counts	unlimited by use

APPENDIX C

APPENDIX C

GAMMA-RAY SHIELDING

The G-M tube itself is not capable of electronic energy discrimination; therefore, when designing a G-M snow gage system it is necessary to collimate (shield) the system against the unwanted radiation energy levels. To properly design the necessary collimators it is necessary to understand shielding theory and what radiation energy levels affect the accuracy of the system.

The reason for shielding against certain radiation energy levels can best be explained by looking at a Cobalt-60 energy spectrum following attenuation by snow and water, Figure C-1.

This figure shows that there is a difference between the two spectral plots when comparing snow and water. If a G-M tube were used to detect this spectral plot, its error between snow and water would be proportional to the area difference between the two plots. It can be seen that the Cobalt-60 photopeak region, which represents the principal energies of photons, 1.1 mev and 1.3 mev, emerging from the radioactive source, is the most desirable portion of the spectral plot. In this region, the plots are identical for snow and water. Since the G-M tube is not capable of energy discrimination, the same result must be obtained through the use of lead shielding.

Before it is possible to design the necessary collimators for the G-M system, it must be known what radiation energy levels are to be collimated, or shielded, against. In Chapter II it was theorized that because of the source's energy levels of 1.1 mev and 1.3 mev, attenuation

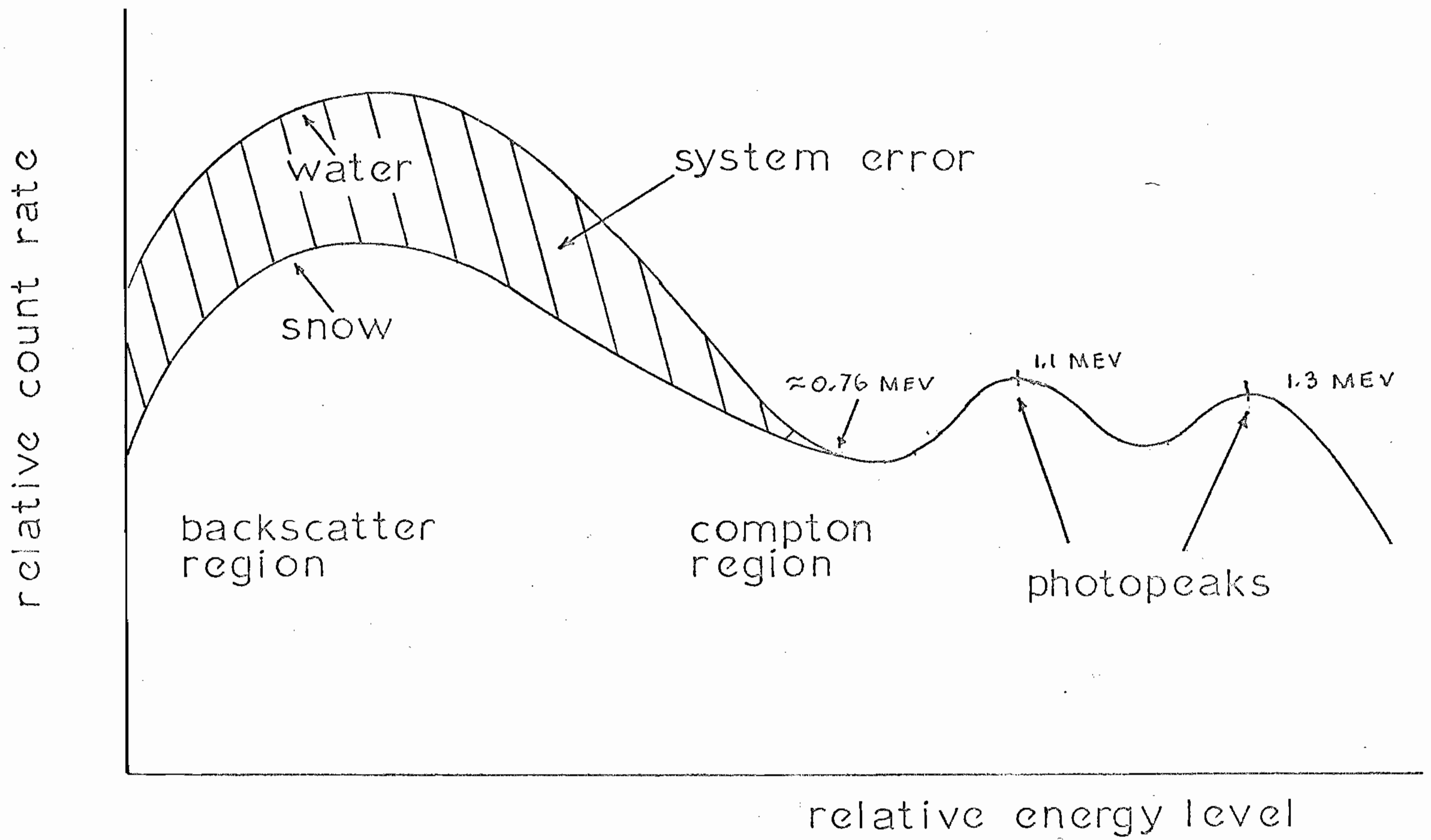

FIGURE C-1

cobalt 60 spectra following attenuation by snow and water by the snow pack is due to the Compton effect.

Table 2 shows the fraction of the initial photon energy that is retained after Compton scattering.[14]

Table 2

Fraction of Photon Incident Energy Retained After Compton Scattering

Initial Proton Energy (mev)	Fraction Retained by Photon
0.1	0.861
0.4	0.690
0.8	0.592
1.0	0.560
1.5	0.505
2.0	0.469

This table shows that a 1.0 mev photon retains 0.560 mev of its photon energy after Compton scatter, while a 1.50 mev photon retains 0.7575 mev. Since the principal photopeak energies for Cobalt-60 are 1.1 mev and 1.3 mev, the Compton energy levels, x, retained by the photons emerging from the radioactive source after collision must be between the two values 0.560 and 0.7575 mev.

Looking again at Figure C-1 it can be seen that the two spectral plots for snow and water began to separate around 0.74 mev. This indicates that the radiation energy level affecting the G-M system is due to Compton scattering. It can now be stated that:

(1) Photon attenuation due to the snow pack, as previously

theorized and experimentally shown, is due to Compton scattering.

(2) It is not necessary to shield against energy levels greater than 0.74 mev because they do not affect the accuracy of the system.

When designing the collimators for the G-M system, the nomogram shown in Figure C-2 can be used. This nomogram takes into account the effect of build up, the scattering of degraded radiation from all points of the absorber. The accuracy over most of the range is better than 10% and, at extreme positions, is 25%.

Example. The required thickness of a lead shield that will reduce the dose of a 1.0 mev point source by 2×10^{-8}. A line is drawn from the number 2×10^{-8} at the right through 1.0 mev or the proper gamma-energy scale. Reading on the appropriate side of the slab-thickness scale the answer is found to be 9.67 inches.

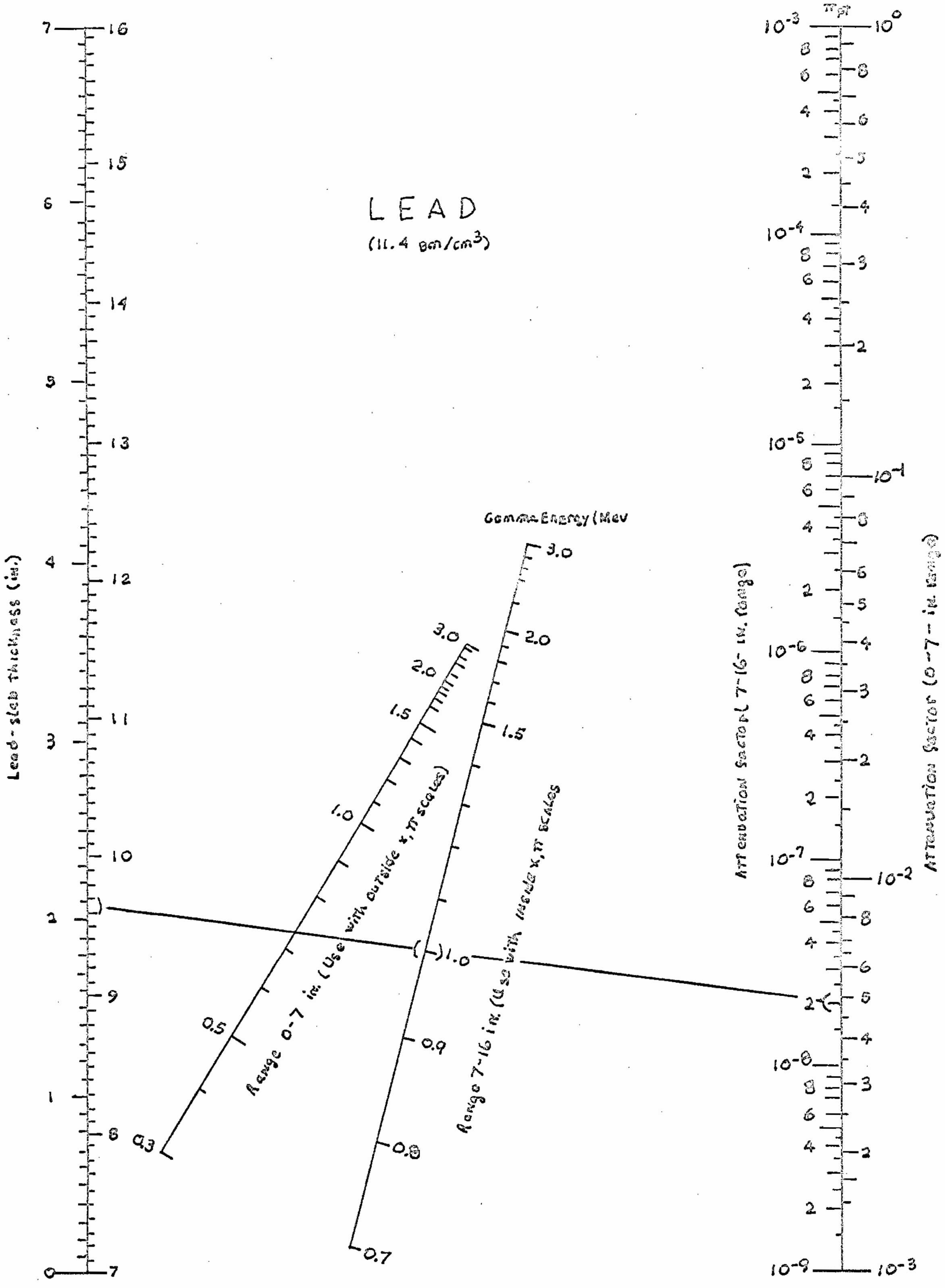

FIGURE C-2
lead nomogram

APPENDIX D

APPENDIX D

STATISTICAL CONSIDERATIONS

The timed counts obtained from the Geiger-Muller system will show fluctuations for a constant amount of water equivalent due to the random nature of the gamma events. At high water equivalent levels, the error introduced by these statistical variations may be the limiting factor of the gage. Statistical theory shows that to minimize these fluctuations, the largest possible sample of data should be obtained. Nomographs are available which show, for any total count obtained, the accuracy that should be attributed to the data with a particular level of confidence. Such a nomograph for radioactive disintegrations is shown in Figure D-1.[17] A confidence level of 0.8 indicates that 8 times out of 10, the data will be within the per cent error intersected by a line drawn from the confidence level figure to the total count number. Two times in ten the count rate may be somewhat more in error than indicated. If a greater level of confidence is desired, then the 0.99 level can be used; however, at low total counts this may give a pessimistic indication of the data. The total count from the Geiger-Muller detector prior to being divided for radio transmission is the value to be used in entering the nomograph. The statistical error expected in the total count is the per cent error referred to in the statistical nomograph. To convert the count rate error to actual error in water equivalent, the chart of Figure D-2 is used. There is not a linear relationship between the count rate error and water equivalent error due to the logarithmic nature of the gamma attenuation by the snow peak.

As an example in the use of the above graphs, suppose the total count 16,384 has been obtained in a time interval of 256 seconds. This corresponds to a count rate of 64 counts per second. From the typical calibration curve of Figure D-3, this count rate corresponds to 23.7 inches of water equivalent. Using the nomograph of Figure D-1, the total count of 16,384 can be expected to be in error by as much as ± 1.3% at the 0.9 level of confidence. This error in count (or count rate) corresponds to ± 0.1 inches of water from Figure D-2. Hence, the water equivalent measured by the system is 23.7 inches and it can be expected that 9 times out of 10 this figure will not be in error by more than ± 0.1 inch from a statistical standpoint.

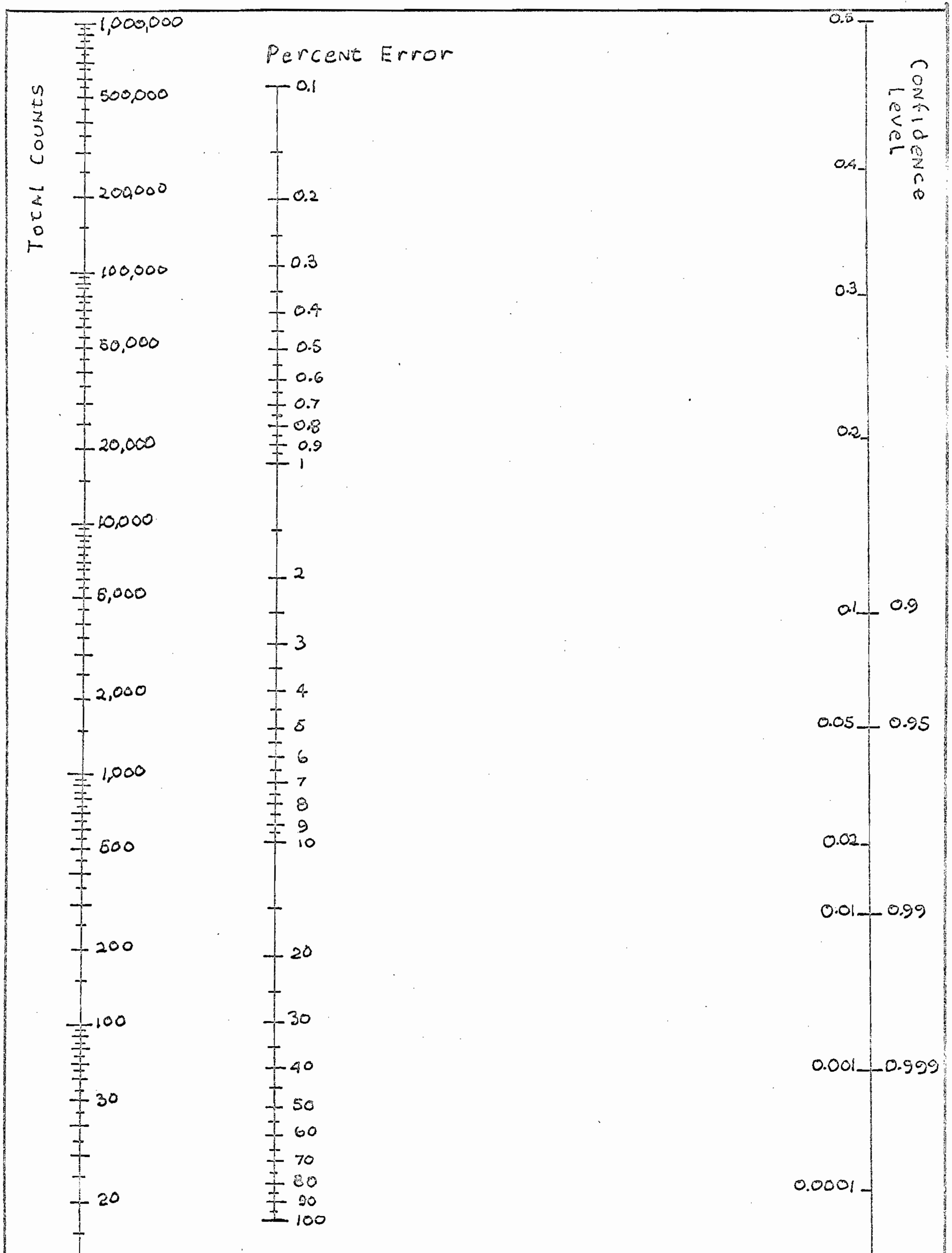

Figure D-1 Statistical Nomograph

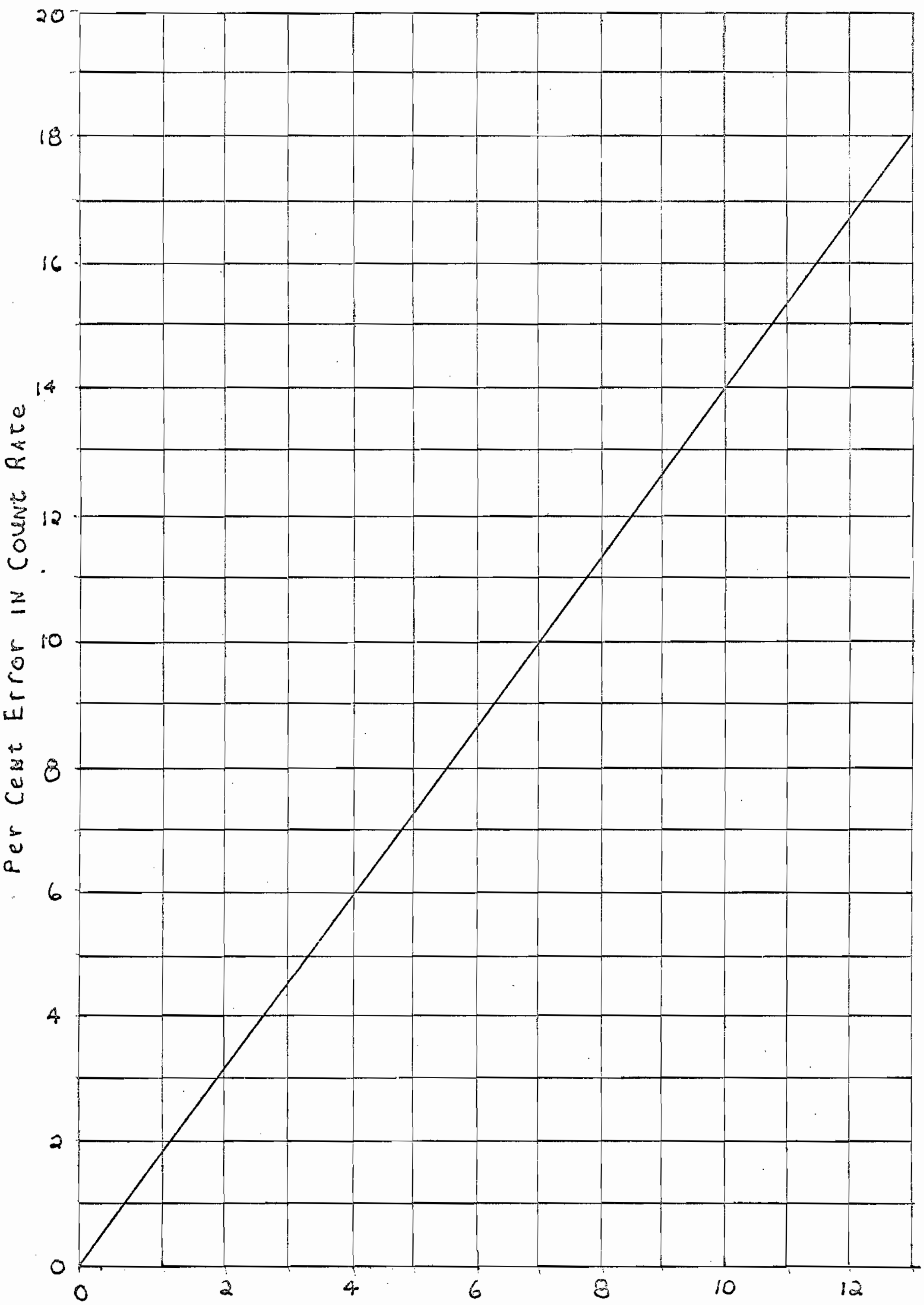

Figure D-2 Relationship between count rate error and water equivalent error

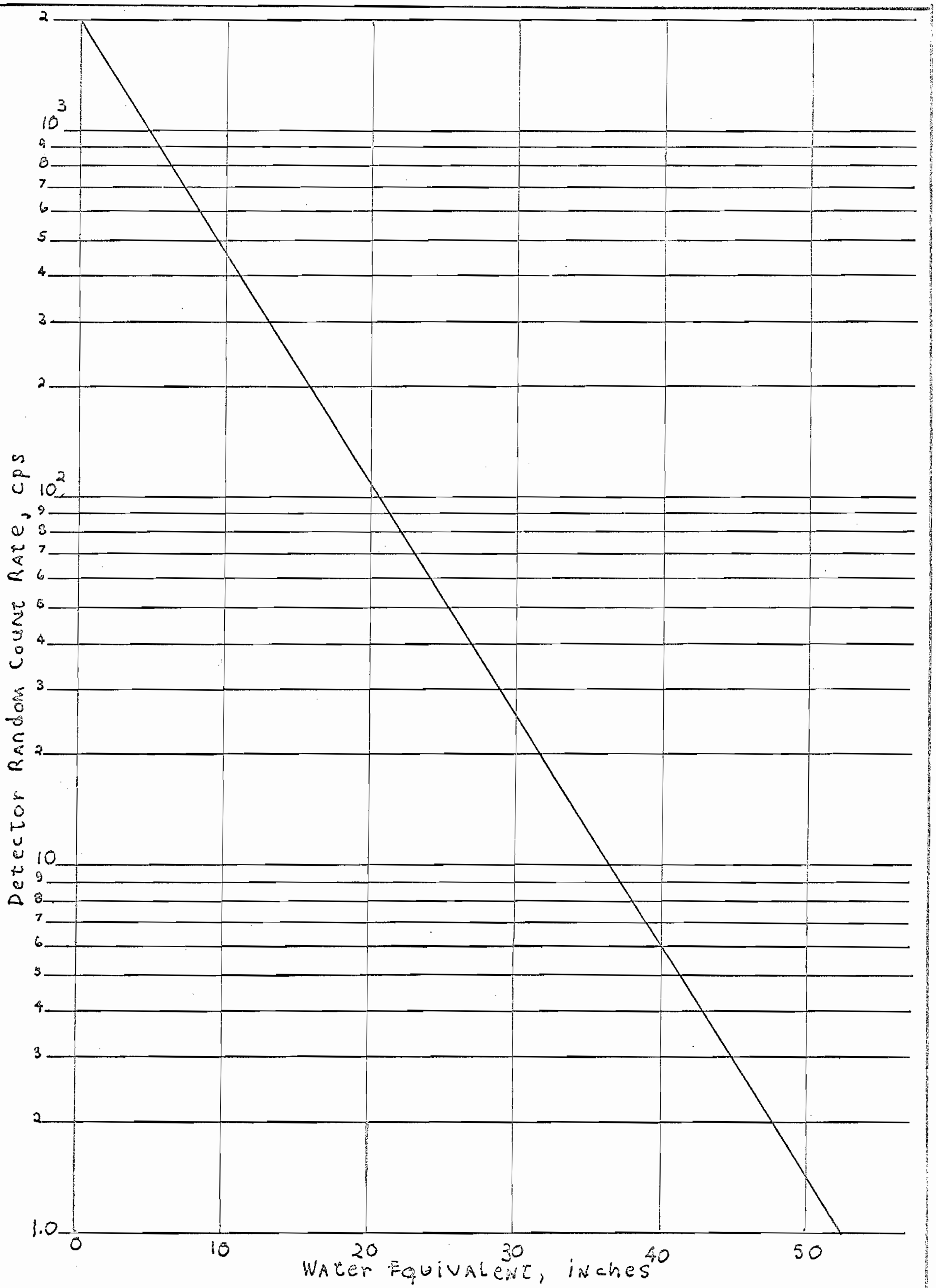

Figure D-3 IMPROVED G-M SNOW GAGE CALIBRATION CURVE

APPENDIX E

APPENDIX E

SPECIFICATIONS FOR DC-DC CONVERTER

Manufacturer: Universal Transistor Products Corp.

Model: UTP-351

Electrical Specifications:

Input voltage:	6.0 VDC
Input current:	60 milliamps
Output voltage:	1440 UDC
Output current:	120 microamps
Ripple:	Less than 1% peak to peak

APPENDIX F

APPENDIX F

TRANSISTOR BINARY

<u>Manufacturer:</u> Engineered Electronics Company

<u>Model:</u> T-102A

<u>Electrical Specifications:</u>

A. Input:

1. Signal frequency range: 0 to 250 kc in T mode (Pin #4)
2. Minimum trigger input amplitude: (Pin #4)

   A Flip Flop will not trigger on any positive-going input pulse of 1.5 volts or less, regardless of rise time

   A Flip Flop will always operate on any positive-going pulse of 6.0 volts or greater, at a rise time up to 1 µsec.
3. Maximum Trigger Input Amplitude: 9 V peak
4. Rise Time: .1 µsec. to 1 µsec.
5. Input Impedance: 1.8K resistive in series with 500 µµf capacitive maximum (Pin #4)
6. Base Input: (Pins #2 and #3) Minimum pulse amplitude, from -3.5VDC level to -1VDC level
7. Signal Frequency Range, R-3 Mode: 0 to 250 kc (alternate pulses to base inputs, Pin #2 and Pin #3)

B. Output:

1. Type: 2 outputs of opposite polarity; "0" output, (Pin #7); "1" output, (Pin #8)

2. Amplitude: Unloaded 8 V level shift from -11 VDC to -3 VDC nominally

3. Rise Time: 0.2 µs to 1.0 µs, depending on load and input signal

4. Loads: Typical load is a parallel combination of 1 Flip Flop, 1 Emitter Follower plus 50 µµf capacitance to ground. (Capacitive load on one output may deteriorate the rise time at the other output. Rise time can be restored by using emitter follower between flip-flop output and capacitive load.)

   Maximum Resistive Loading: For 1 V level shift, 27K to 12V common (Pin 6); 10K to -12V (Pin #1).

5. Fall Time: Approximately 2.0 µsec.

C. Power Requirements:

1. -12V at 5.0 ma. Pin #1 negative with respect to Pin #6

2. Supply Voltage Tolerance: ± 10% with proportional changes upon input-output characteristics.

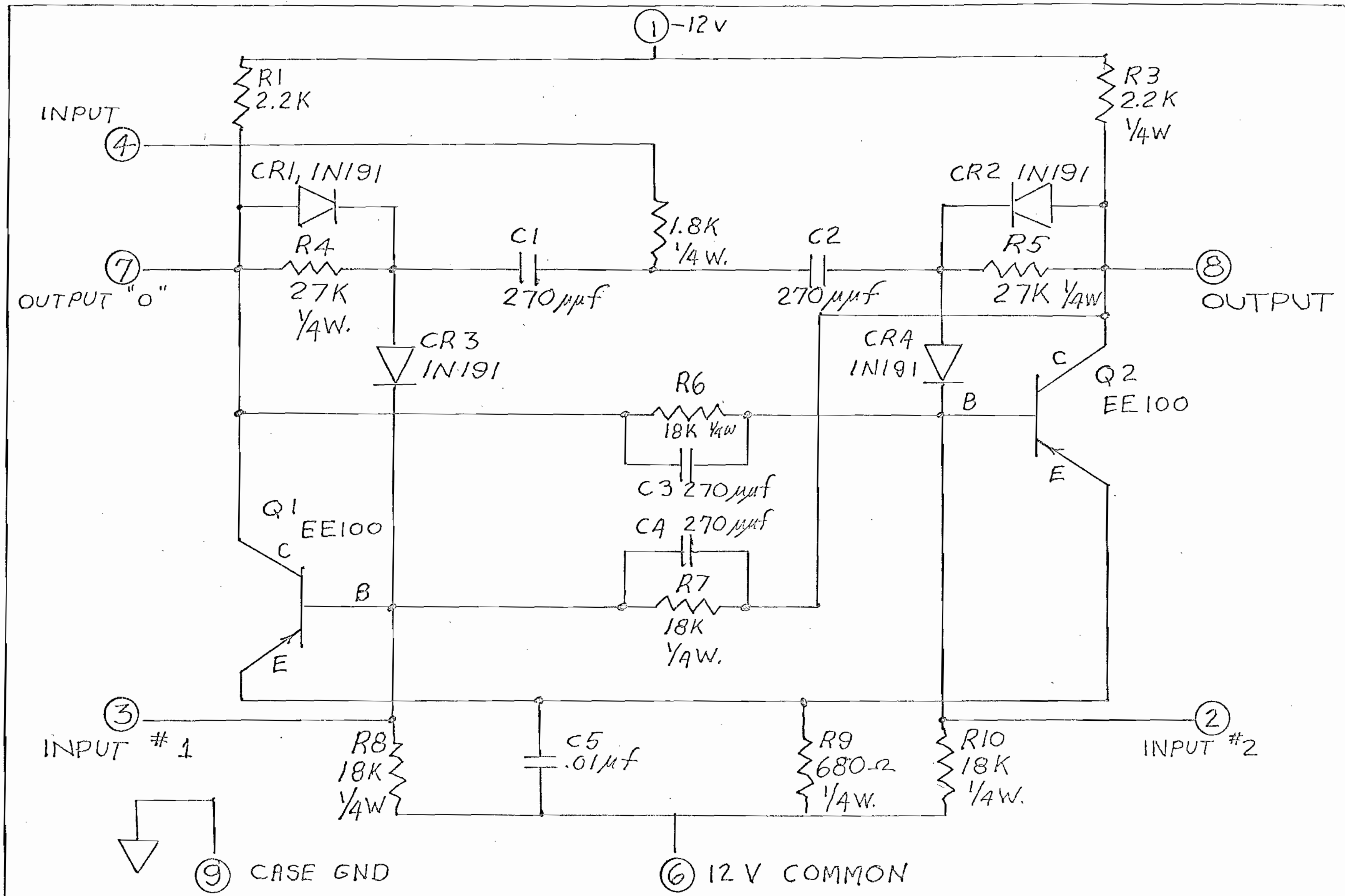

FIGURE F-1
FLIP-FLOP T-102 A