

A PROGRESS REPORT ON  
RADIOACTIVE SNOW GAGE USE

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Introduction

For many years there has been a need for more complete information on snow accumulation and its water content for the prediction of flood and power potential from the snow melt. This has been especially true in remote and large drainage basins. In the future this type of information may become necessary in many other areas as greater demands are placed on our water resources.

To meet the need for better measuring facilities, Dr. Gerdel started the development of a radioactive method of measuring snow water content in 1947 (1).

This paper will briefly discuss the radiation principles which serve as a basis for this method of measurement as well as the early development by Dr. Gerdel. Further reported developments in the literature will also be discussed considering characteristics of results, possible costs, and an assessment of the possible radiation hazard. An evaluation will be made concerning possible application to eastern conditions. Some future investigation possibilities will also be mentioned.

Radiation Principles

When material is exposed to neutron bombardment isotopes of the material are formed. The amount of isotope depends on the neutron energy and flux, the length of exposure time and the cross-section of the material. The resulting isotopes are unstable and tend to decay to a more stable form. In the process of decay Alpha ( $\alpha$ ) and Beta ( $\beta$ ) particles are emitted along with gamma ( $\gamma$ ) photons.

Alpha ( $\alpha$ ) particles are high-energy particles consisting of 2 protons and 2 neutrons giving them a 2+ electric charge. These particles produce dense ionization in material and thus dissipate their energy quickly, resulting in a short path of penetration. They have ten times the ionization effect of  $\beta$  particles.

Beta ( $\beta$ ) particles are more penetrating than  $\alpha$  with less ionization. They have a mass and electric charge about equal to the magnitude of an electron. However, their charge may be either plus or minus.

FIG. 1

THEORETICAL  $\gamma$  ABSORPTION  
IN  
 $H_2O, Fe, + Al$   
FOR  
1.33 MEV  $\gamma$  SOURCE  
(HIGHER ENERGY LEVEL FOR  $Co-60$ )

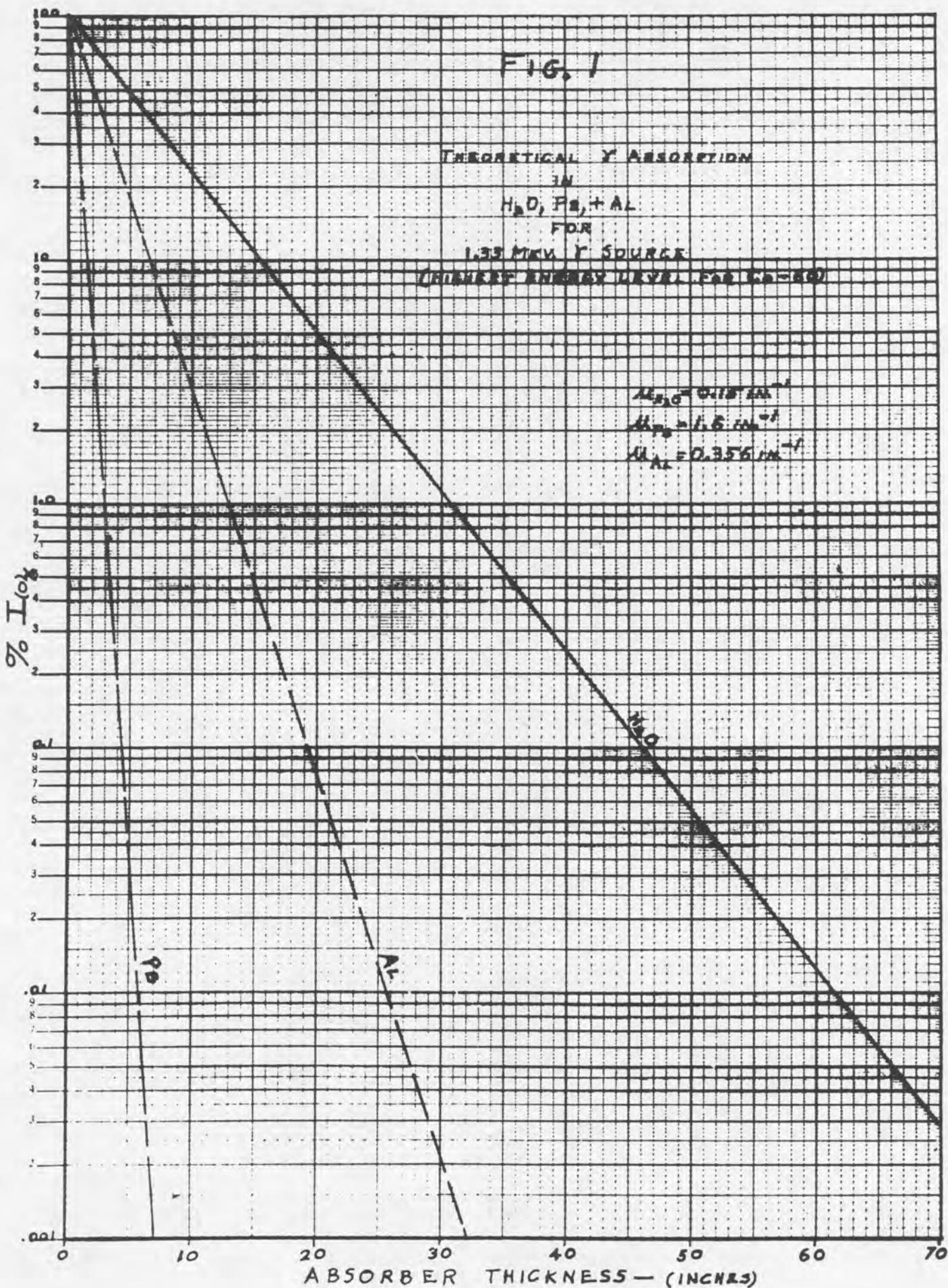
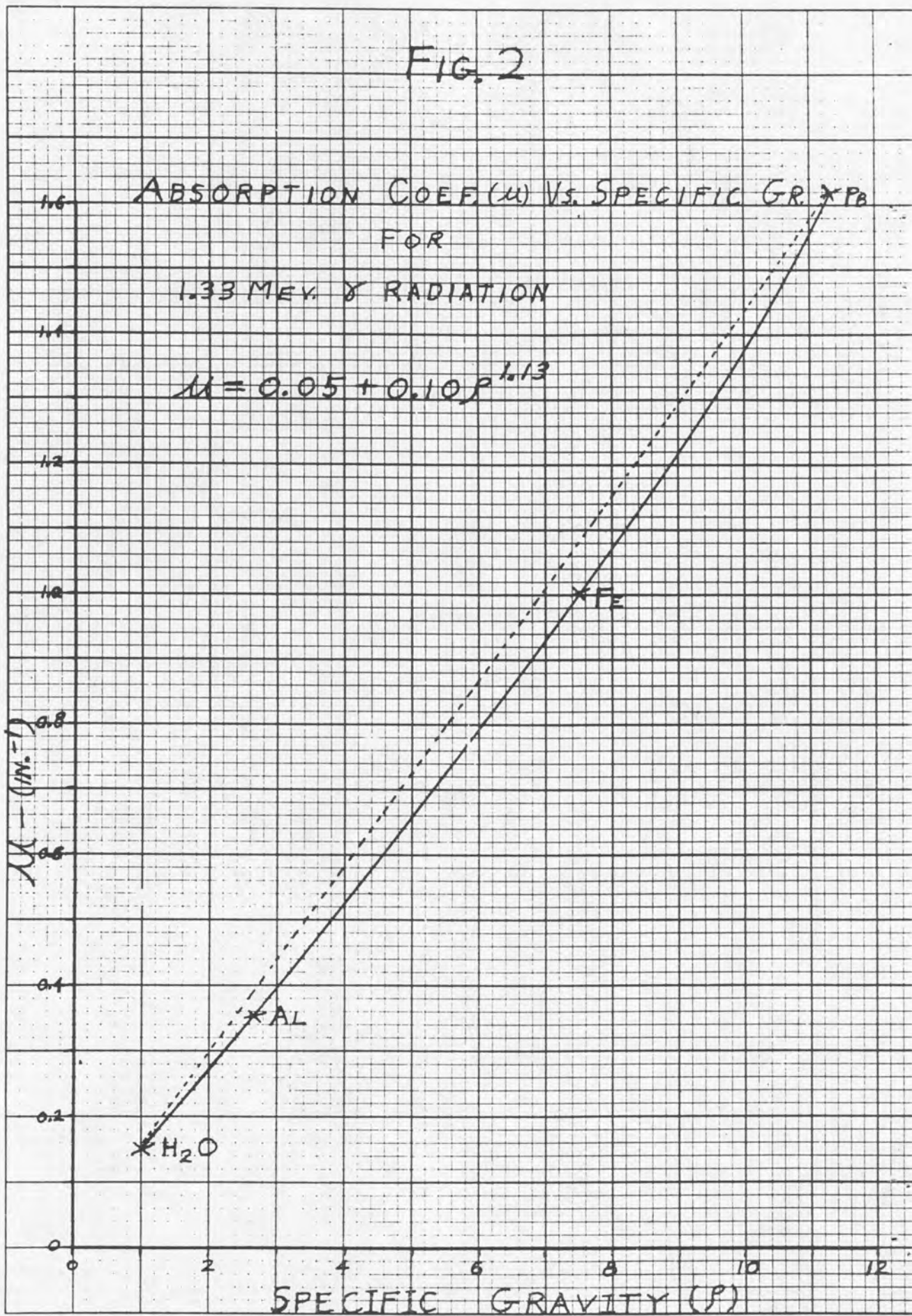


FIG. 2





Gamma ( $\gamma$ ) radiation consists of high-energy "photons" which originate in the atomic nuclei. This radiation is much more penetrating, with much less ionization effect, than either  $\alpha$  or  $\beta$ . If  $\alpha$  penetration is taken as one (1) unit of distance,  $\beta$  will penetrate 100 units, and  $\gamma$  will penetrate 10,000 units (1). This penetration characteristic served as the basis for selecting a  $\gamma$  source for snow pack measurement.

The principle involved in the measurement of the water content is that as radiation passes through a material some of the radiation energy is absorbed by interaction in various ways. The total absorption takes place according to the equation

$$I(x) = I(o)_x e^{-\mu x}$$

$I(o)_x$  is the intensity without absorber,

$I(x)$  is the intensity after passing through the absorber,  $\mu$  is the coefficient of absorption (in<sup>-1</sup> or cm<sup>-1</sup>),  $X$  is the thickness of the absorber (in or cm) and  $e = 2.72$ . This equation may be expressed in the

form  $X = \frac{\ln I(o)_x / I(x)}{\mu}$  from which the thickness  $X$  may be calculated

based on the measurement of  $I(x)$  and  $I(o)_x$ . This relationship may also be expressed in terms of the unit basis of  $I(o)_x$  (i.e. %  $I(o)_x$ ), % of  $I(o)_x = 100/e^{\mu x}$ . This is graphically shown in Figure 1 for Pb, Al, and H<sub>2</sub>O subjected to  $\gamma$  radiation from Co - 60. The coefficient of absorption ( $\mu$ ) will vary with the type and energy of radiation as well as the density of the material. Figure 1 will therefore apply only to 1.33 mev  $\gamma$  radiation. In this curve (Fig. 1) it is shown that 1% of  $I(o)_x$  will be the result of passing through about 31 in. of water, 13 in. of aluminum, and 3 in. of lead. Thus a unit thickness of lead is about ten times as effective in reducing this radiation as H<sub>2</sub>O, and aluminum is about two and a half times as effective.

The variation of  $\mu$  with specific gravity ( $\rho$ ) for 1.33 mev.  $\gamma$  radiation is shown in Figure 2. These values are for S.G. ( $\rho$ ) larger than one (1) and standard temperature and pressure conditions. This shows that  $\mu$  increases almost as a straight line function of S.G. However, the empirical equation

$$\mu = .05 - .10\rho^{1.13} \quad (\mu = \text{in.}^{-1})$$

more accurately defines the coefficient as a function of S.G.

Another radiation phenomenon fundamental to the radiation gage consideration, and similar to absorption, is the decay of radioactive sources. The general decay relationship is expressed as  $I(t) = I(o)_t e^{-\lambda t}$ .

The only difference from the absorption equation is the decay constant/unit of time ( $\lambda$ ) and time ( $t$ ). Figure 3 shows the decay relationship for a material having two isotopes decaying with respect to time. An important expression is shown on this curve,  $T_{1/2}$  or half-life of the isotope. This is the time ( $t$ ) required for the radiation level to reduce to one-half its original intensity,  $I(o)_t/2$ . This condition may be expressed as % of  $I(o)_t$  as follows:

$$50 = 100/e^{\lambda t}$$

solving for  $t$  we obtain

$$t = \ln 2/\lambda = T_{1/2}$$

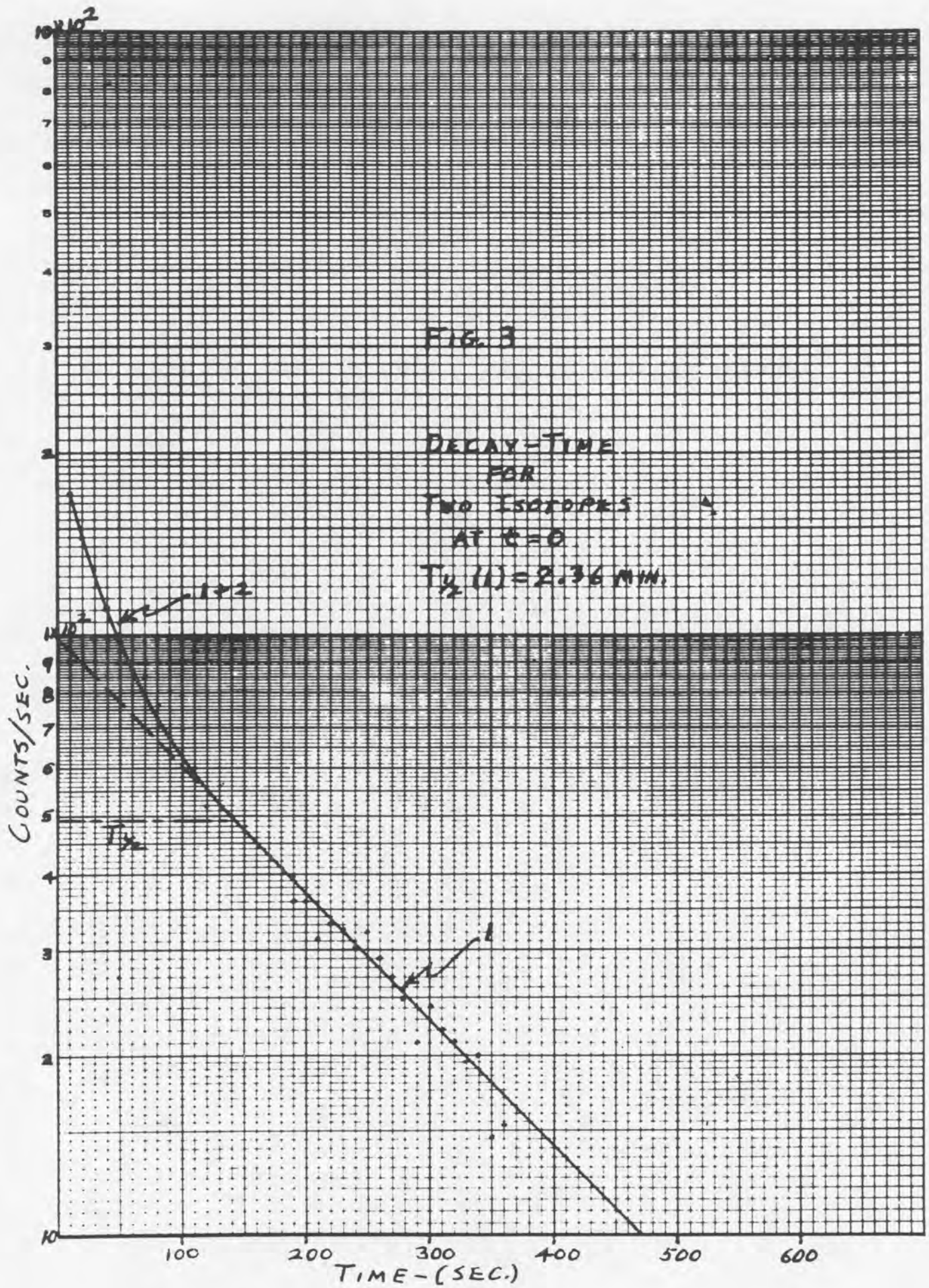
For  $C_{60}$  the half life is about 5.3 years with a decay constant ( $\lambda$ ) of 0.131 years or .000358 days.

The measurement of decay or absorption or any other radiation phenomena must be determined by some type of counting system. Such systems include all counts received by the instrument. Some of the counts are the result of environmental radiation and must be separated from the total to give an accurate indication of the system under study. This background correction is very important when the total count is very low, in the order of 200 cpm or less. This can be obtained by making readings without any known source near the instrument. Normal ranges of background counts in the laboratory, using G- M counters, have been observed to be from 40 - 65 cpm. This is subject to considerable variation depending on location.

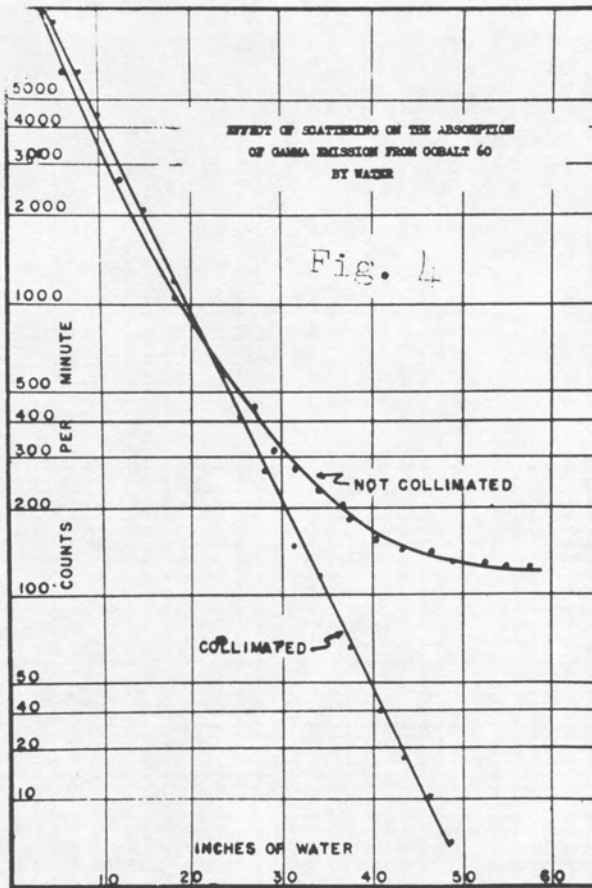
The preceding discussion presents the theoretical concepts necessary to understand the radioactive measuring gage. These concepts served as the basis for Dr. Gerdel's development of the gage in 1947-48, for the Corps of Engineers, Central Sierra Laboratory, near Donner Summit, California. Briefly, this development consisted of the selection of a radiation source, counting system and feasibility studies. (1)

Cobalt-60 was selected as the radiation source because it primarily emits  $\gamma$  radiation with only two energy levels, 1.17 and 1.33 mev.; it has a high level of activity and is readily available. Also the half-life is fairly long, 5.3 years. Thus the decay correction would be small for any one snow season and source replacement would not be too frequent (1). The error would amount to about 0.4" of water equivalent at the end of 150 days if no corrections are considered.

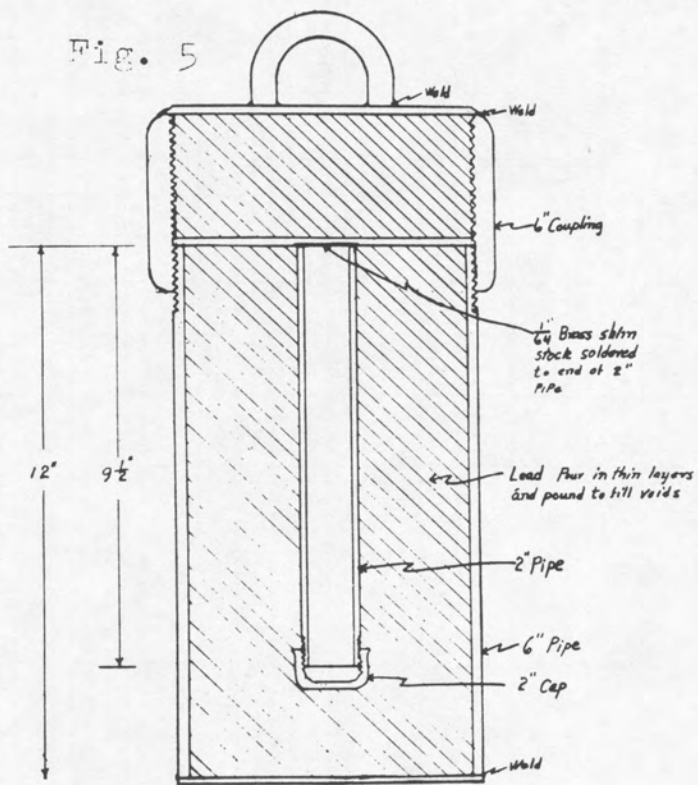
The first experiments were made with a point source. The resulting count rates plotted against water depth deviated considerably from the expected straight line on semi-log paper. It was found that collimation produced more satisfactory results. A comparison of collimated and non-collimated radiation absorption is shown in Fig. 4. The collimator is shown in Fig. 5 (1).







Courtesy Dr. R. W. Gerdel (1)



Courtesy Dr. R. W. Gerdel (1)

Several counting methods were considered and the G. - M. Counter was selected. This selection was based on the consideration that G. - M. systems are simple, rather durable, and it would be practical for depths up to about 50 in. of water.

Background correction studies were also made. It was found that the background, cosmic and local causes, varied from hour to hour with a mean of about 67 cpm. and a range of about 55-70 cpm. (1). These values agree well with observed laboratory observations in the eastern part of the country.

During the 1949-50 snow season further studies were carried out on actual snow pack measurement using a wired circuit radioactive snow gage, precipitation gage and snow core sampling. The results (Jan. and Feb. 1950) showed the feasibility of using such equipment under actual conditions (1). A schematic sketch of the typical installation is shown in Fig. 6. The radioactive gage results varied up to 15% from the core sample results. Telemetering possibilities were also investigated during this time. In addition, it was also deemed desirable to have a weak Strontium - 90 source near the counting tube to provide a means of determining instrument trouble.

In 1950-51 further studies were carried on using new G-M tubes (1 - A type). This tube appeared to be more sensitive giving background counts of 165 cpm. as compared to previously reported values of about 66 cpm.

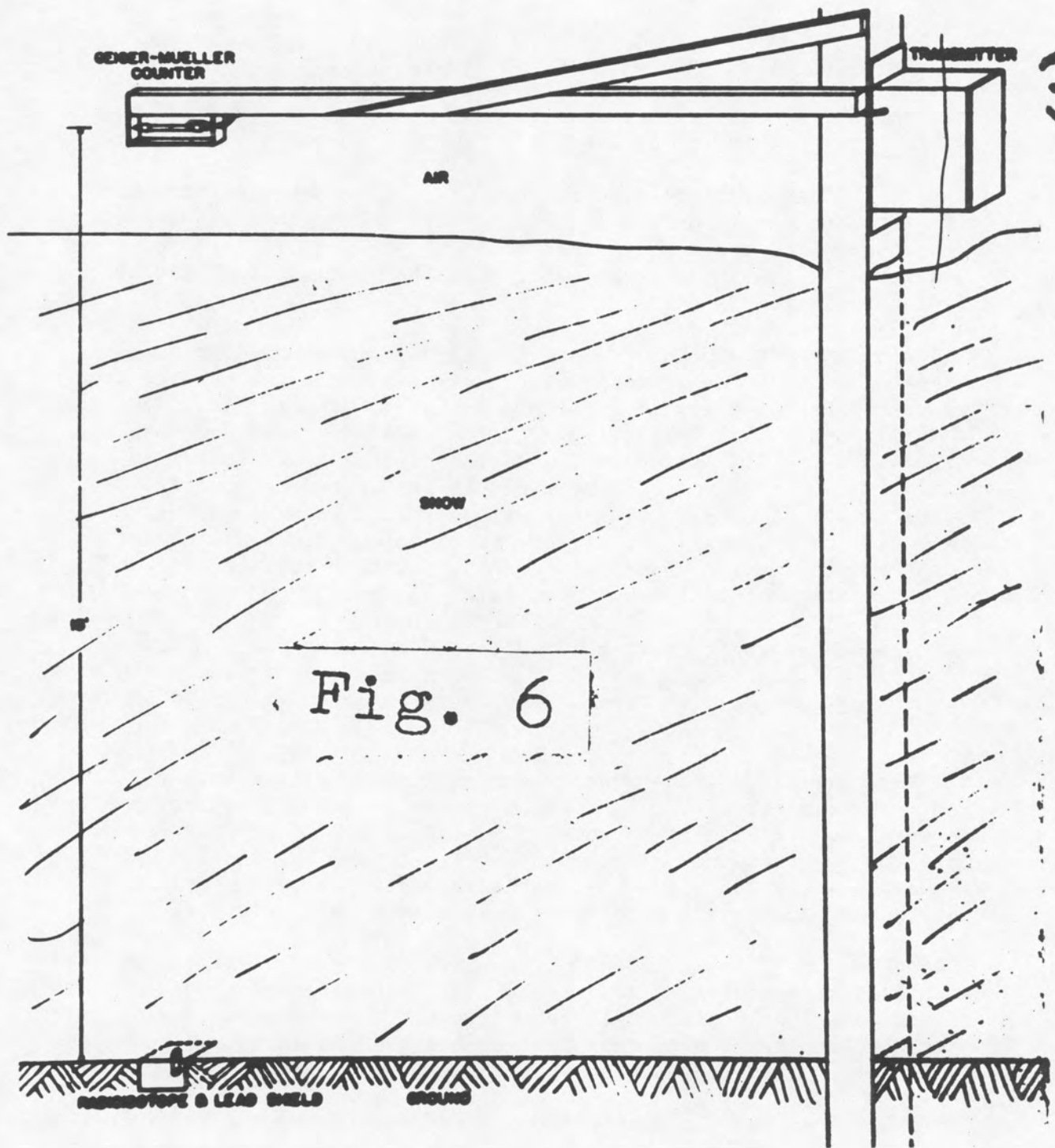
The snow water content measurements during this time were still made using wired circuits. The mean % variation from snow tube measurements were about  $\pm 7\%$  with a range from  $-17\%$  to  $+12\%$ . There appeared to be more low readings than high. Radio telemetering was installed during this season, early 1951, and some mechanical difficulties were reported. However, the telemetering system was concluded to be practical.

In the 1951-52 snow season further development studies were carried on with radiotelemetering. Many mechanical troubles were reported, such as battery problems, moisture in cables, etc. Also the snow during this time reached depths greater than 15 feet and thus could not be measured. When the snow melted many of the structures were damaged.

From 1952 on there have been continued studies and efforts to use the radiation type of gage. The report of the studies indicates that the wired systems produce very reliable results and the radio telemetering systems still have a fairly large number of mechanical troubles. These latter troubles can undoubtedly be rectified with experience.

From this preliminary research and development, commercial radio-telemetering systems have been developed. One available system which has been produced uses the more sensitive scintillation counting method (4).





(1)   
 L. P. ...   
 M. ...   
 D. ...   
 T. ...   
 T. ...   
 T. ...

Schematic Field Station

Equivalent Water Depth

Accuracy

|             |            |
|-------------|------------|
| 0 - 5 in.   | + 0.25 in. |
| 5 - 25 in.  | + 0.50 in. |
| 25 - 50 in. | + 5%       |

It would appear that these reported accuracy values are based on the standard deviation of radiation counting,  $\sigma = \sqrt{N + 1}$ . Background effects are reportedly eliminated by pulse-count shaping and pulse-height discrimination which reduces count results to those produced by 1.17 - 1.33 mev.  $\gamma$  energy levels.

Foreign Development

It has been reported that in the Soviet area the concept of this type of snow gage has also been developed (5). The reports indicate that a portable gage has been produced using Co - 60 with resulting accuracies of 3 - 5 per cent for snow depths of 9.85 feet (3 meters). It is questionable whether such a portable system would have any advantage over conventional snow tube methods.

Radiation Hazard

There is always some hazard in handling any radioactive materials. If the radiation effects and characteristics are understood, the danger can be kept to a minimum.

The radiation exposure which could be received at gage sites would be most severe in the "beam". This "beam" hazard could be computed by a point source analysis (3). For 40 mc, Co - 60, the dose relationship would be as follows:

| <u>Distance from Source</u><br>(ft.) | <u>Dose Rate</u><br>(r/hr.) |
|--------------------------------------|-----------------------------|
| 1                                    | 0.6                         |
| 15                                   | 0.00268                     |

At one foot the maximum daily exposure would be obtained in about ten minutes. These results are about one-half to one-fourth the values reported in the Corps of Engineers' Report CWI - 170 (2). The collimated beam effect may account for this difference.

If two (2) inches of lead are placed around the source (comparable to the Co - 60 in the Collimator and neglecting the steel) the radiation dose rate would be about 0.8 r/hr. at the outside edge. Maximum daily exposure would then be obtained in about 7 mins. Figure 9 shows the time-distance relationship for a 0.1r dose.

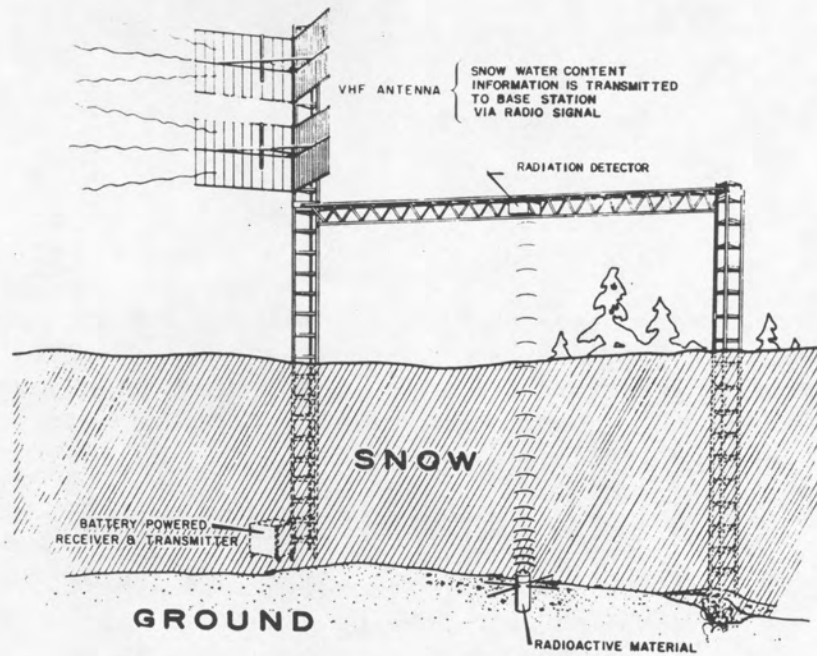


FIGURE 7 TYPICAL GAGE SITE SHOWING TOWER, ANTENNAS AND WATERPROOF EQUIPMENT SHELTER.

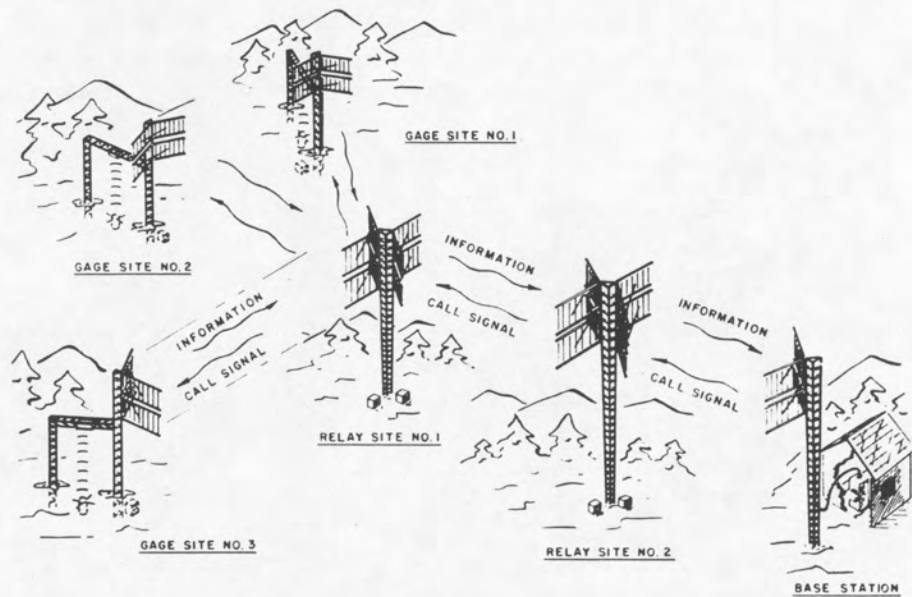


FIGURE 8 INSTALLATION AND TELEMETERING ARRANGEMENT.



It would be possible to work 40 hr./week, 1.7 feet from the source, to give the max. of 0.3r/week or about 6.5 feet to just obtain the max. allowable continuous (24 hrs./day) dose of 5r/yr. These are occupational criteria. For non-occupational, but controlled areas, it is considered desirable to maintain less than 0.5 r/yr. for the general population. Twenty feet from the source would provide the required protection. At actual gage sites these distances would be very safe because the lead collimator would be placed in concrete in the ground and further absorption material would thus be provided. Doubling source strength would of course increase distance requirements if the same amount of lead is used.

### Costs

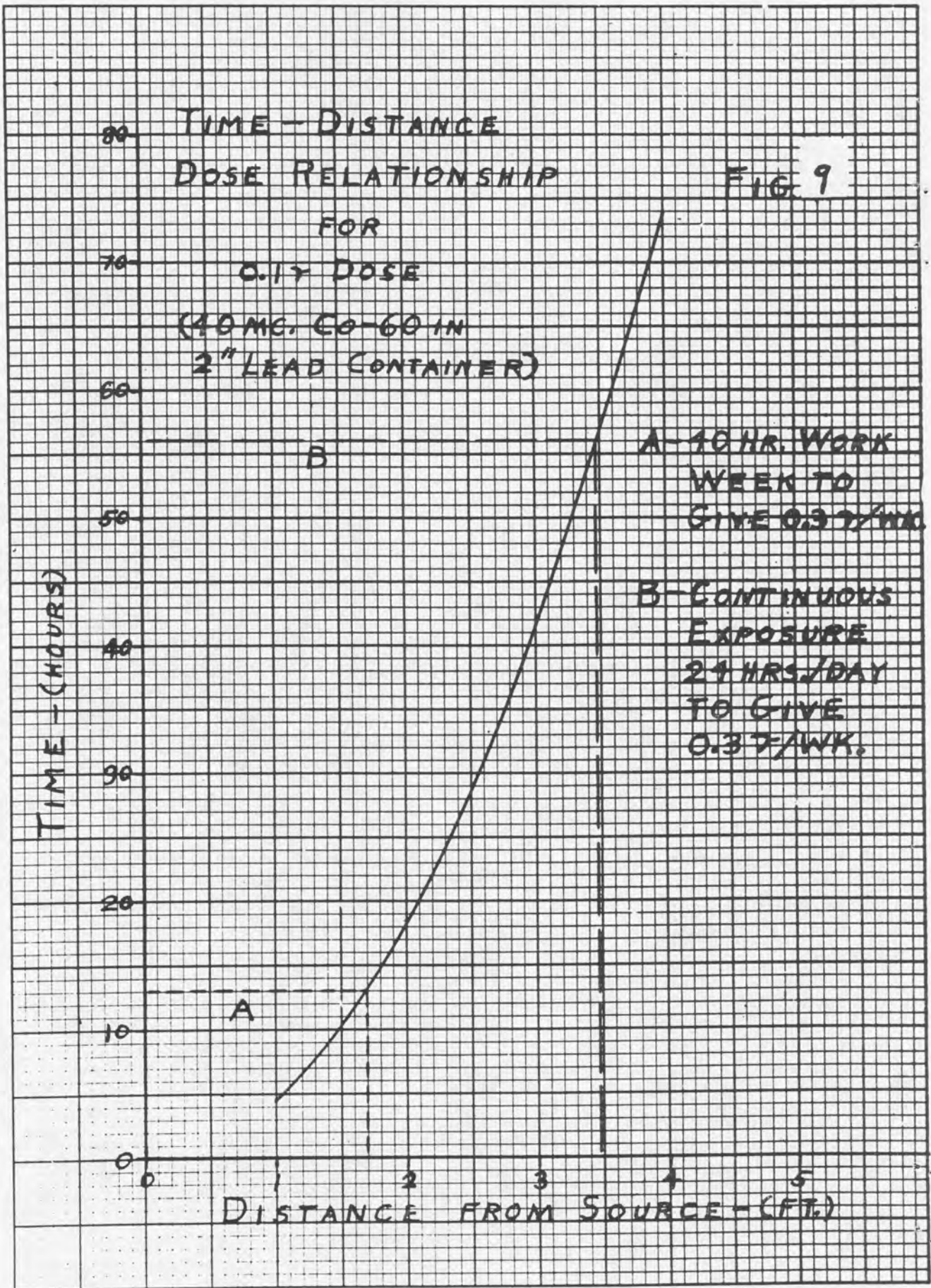
The cost information from the literature is not very easily delineated (2)(4). However, it is estimated that equipment costs for a base station, relay station, and one gage station (radiotelemetering system) would range from \$15,000 to \$28,000. Additional gage stations would appear to cost from \$5,000 to \$8,000 each. Installation would be an added cost.

### Eastern Application

This type of snow measuring equipment could be advantageously applied to the Eastern area where distance or difficult locations prevent the adequate measurement of snow accumulation and its water content. In the small but critical drainage basins where distance and difficult terrain might not be the problem, it would be possible to obtain more complete, detailed and daily information on snow stored water and the melt potential.

In this area of the country we generally have less snow accumulation than in the west. The maximum expected mean snow depth would generally be about five (5) feet with an upper limit of water equivalent of about eighteen (18) inches. This would indicate that it would be possible to use weaker sources and lower counter elevations above the ground. However, it would appear that there would not be much advantage to using weaker sources. The radiation hazard up to 100 mc. would only be moderate, even in this more populated part of the country. Better accuracy could be obtained under our general snow conditions using about the 40 mc. source and possibly lower counter tube elevations. Dead time corrections would have to be considered if counting rates are increased above 20,000 cpm.

The installation and cost of radiation snow gage equipment could be justified in many eastern areas. Such facilities would provide daily snow and ice accumulation data, expressed as inches of water, for the whole snow season. This would provide more accurate and complete flood and power potential predictions for winter and spring runoff.



### Future Possibilities

There appear to be many aspects of this method of measuring stored water in the form of ice and snow which could be investigated to develop further improvements. One possibility would be to use a source with a longer half-life. Al - 26 might hold some promise in the future if cost and material volume could be reduced. This isotope has a very long half-life, mostly one rather high  $\gamma$  radiation energy level, and thus it could meet the gage requirements. It does have fairly high  $\beta$  activity which might produce a considerable amount of secondary  $\gamma$  radiation unless proper absorption is provided.

Another possibility which would increase the time before source replacement is required would be to use larger quantities of Co - 60, such as 200 mc. When new, some of the radiation could be reduced by lead absorbers and as the source decayed the amount of absorber could be reduced. If 200 mc. were used at the beginning, it would have a useful life of about 17 years if 20 mc. is considered to be the lowest tolerable level. The difference in initial cost would be small.

### Summary

1. This method of measuring the water equivalent of snow accumulation gives satisfactory results. The apparent mean variations from the snow tube method are about + 7%.
2. The wired systems would appear to be more dependable than the radiotelemetering systems. Further experience and development may improve this in the future.
3. The radiation hazard is not severe, nor is it difficult or costly to provide adequate protection for sources up to about 100 mc.
4. Equipment costs for radiotelemetering systems would appear to range from \$15,000 - \$28,000 for a one gage installation and \$5,000 - \$8,000 for each additional gage site.
5. More accurate daily water equivalent snow and ice accumulation could be obtained for a drainage basin. Better flood and power predictions could thus be developed on a day-to-day basis.
6. Source replacement time intervals could be increased by using longer half-life material or larger amounts of Co - 60. These possibilities would need further study.



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