

THE DEVELOPMENT OF THE RADIOACTIVE SNOW GAGE

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INTRODUCTION

Recognizing the need for more basic information upon the physical properties and thermodynamic processes in those snow packs which contribute the major water supplies in the Far West, the Corps of Engineers and the U.S. Weather Bureau cooperated in the establishment of three snow laboratories in the high mountain - heavy snowfall areas of the West in 1945. These laboratories located in California, Oregon and Montana sampled three different climatic regions.

When data from the intensive research program in these laboratories started to flow into the Processing and Analysis Center set up in the South Pacific Division Engineer Office in San Francisco, it became evident that the application of the results of these studies required more precise information on the amount and distribution of the snow cover in the critical watersheds. The inaccessibility of many important watersheds during the winter limits the amount of data which may be obtained from a precipitation gage network or by snow surveys.

In view of the almost insurmountable obstacles to the attainment of satisfactory and frequent information on the available water supplies stored in the mountain snow packs, the writer was urged to try to develop a mechanical or electronic snow stake which would report by radio at frequent intervals the water equivalent of the snow pack in the remote mountain areas.

Recalling the results of some research work which he had undertaken in 1940 at Ohio State University in an effort to adapt spectographic or radioactive tracer procedures to the tracing of stream sediments, it appeared that the newly available by-products of the atomic pile might offer a solution to the telemetering snow stake problem. On a visit to the Ohio Experiment

Station at Wooster in 1947, a former colleague, Dr. J. D. Sayre, an authority and consultant recognized by the Atomic Energy Commission, made available the necessary equipment and radioisotopes for a test of the idea. These preliminary experiments indicated that the emissions from radioactive zinc could be detected quantitatively through more than three feet of water.

Following the development of satisfactory arrangements between the Corps of Engineers, the U.S. Weather Bureau, and the Atomic Energy Commission, the necessary equipment and radioactive materials were obtained during the latter part of the 1947-1948 snow season. Active research and development of the radioactive snow stake was undertaken at the Central Sierra Laboratory near Donner Summit, California. Mr. B. Lyle Hansen, who was Director of that laboratory at the time, not only engaged actively in the research work on this instrument but made many major and important contributions which greatly expedited the development of the gage and lead to some of the basic concepts used in the design of the telemetering system. The radioactive gage and the telemetering system have been discussed in publications by Gerdel, Hansen and Cassidy¹, Doremus^{2, 3}, and Gerdel and Mansfield⁴.

THEORETICAL APPROACH TO THE PROBLEM

The artificial radioactive elements may emit alpha, beta or gamma rays. The gamma rays are about 100 times more penetrating than the beta and 10,000 times more than the alpha rays. Only the gamma rays have sufficient energy to penetrate a deep snow pack.

The intensity of the gamma rays or electromagnetic radiation after passing through a uniformly absorbing media depends upon the thickness of the medium, the intensity of the incident radiation, and the absorption coefficient which is a property of the medium. Under the proper conditions the absorption of monochromatic gamma rays takes place in accordance with the exponential law $I = I_0 e^{-\mu x}$ where I is the intensity measurable through a thickness, x ; μ is the absorption coefficient and I_0 is the intensity of the incident radiation. This absorption coefficient is a constant for any substance regardless of its state of phase. The number of emissions absorbed by a unit of water also would be absorbed by an equal water equivalent unit of snow.

SELECTION OF THE RADIOISOTOPE

A review of the characteristics of the radioisotopes available indicated that Cobalt 60 was the most suitable for the proposed instrument. Its gamma radiation is essentially monochromatic and it has high activity. The 20 Millicurie units in which it is available emit 15×10^8 gamma photons

per second providing a detectable and useable quantity of emissions. Furthermore, its half life of 5.3 years reduces the need for replacement of the radioactive material at the gage site to once in five or six years.

COLLIMATION OF THE EMISSIONS

Some of the first studies indicated that the broad beam of gamma rays emitted from the capsules in which the radioisotope was shipped, when passed through snow, was sufficiently scattered to cause an apparent reduction in the amount of absorption by snow. That is, some of the scattered rays were reflected within the snow pack back toward the detector unit and were measured along with those directly transmitted through the snow. To overcome this defect, a collimator (Fig. 1) was developed to produce a narrow beam of rays; the lead jacket around the inner pipe serving to absorb the rays which would otherwise be scattered.

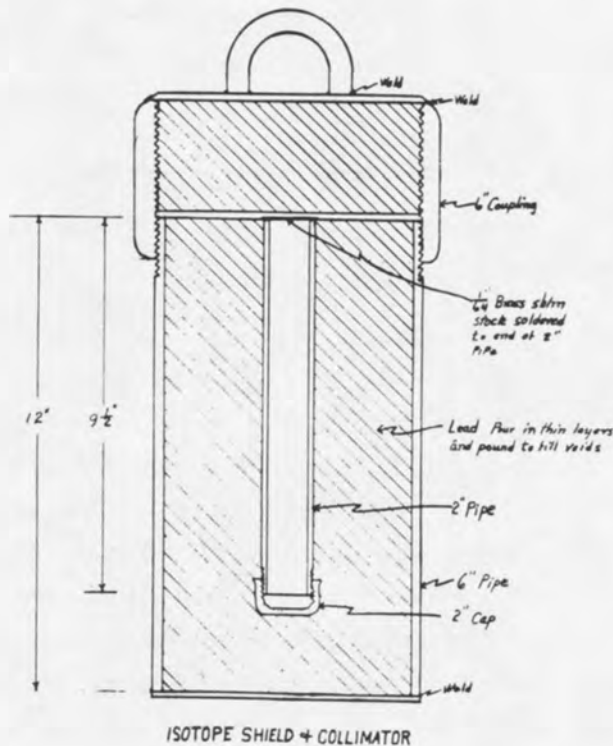


Fig. 1

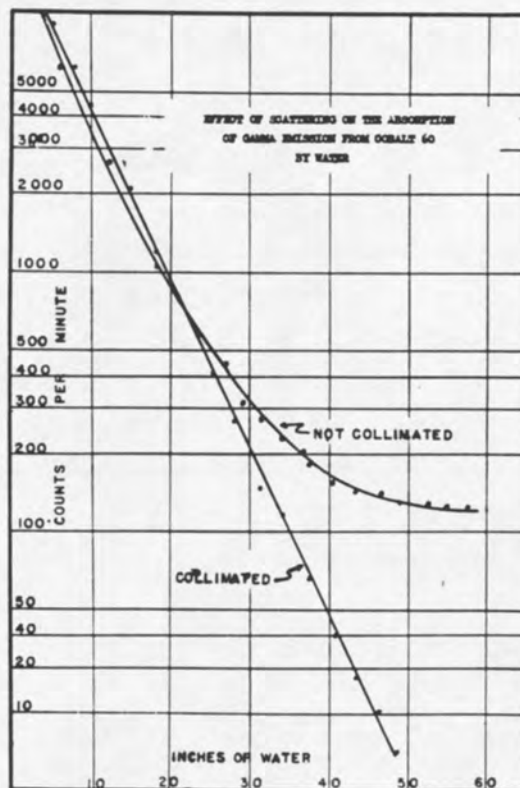
The Isotope Shield and Collimator. Two units of the radioisotope in the original sealed capsules as received from the Atomic Energy Commission are placed at the bottom of the 2" pipe. The lead filled cap is used during transportation and installation of the collimator.

The marked improvement produced by the collimator is indicated by the graph (Fig. 2) on which are plotted the measured emissions from collimated and non-collimated gamma rays thru unit thicknesses of water.

The resultant calibration curve is the type used for converting the detectable emissions into water equivalent values for the snow pack.

Fig. 2

The absorption of collimated and non-collimated gamma emissions by water.



SELECTION OF THE DETECTOR

From the several types of detectors which may be used for measurement of the quantity of photons emitted by a radioactive material, the Geiger-Mueller tube was selected because of its simplicity and long life. The gas in the self quenching type of tube used is ionized by a passing gamma ray and becomes conductive for a millisecond or two. This creates a pulse when the proper electric potential is applied, which may be recorded on a scaler or transmitted by radio as a modulation of a carrier wave and recorded at a counter at a central station which may be located in a water master or stream forecasters office. At present these tubes are less than 1 percent efficient. That is, almost 100 rays pass through the tube for each pulse produced. Any improvement in the efficiency will produce a corresponding increase in both the quality of the data and the maximum quantity of water equivalent snow that can be measured. At present satisfactory measurements cannot be made on snow packs having a water equivalent of more than 52 inches.

THE COSMIC RAY PROBLEM

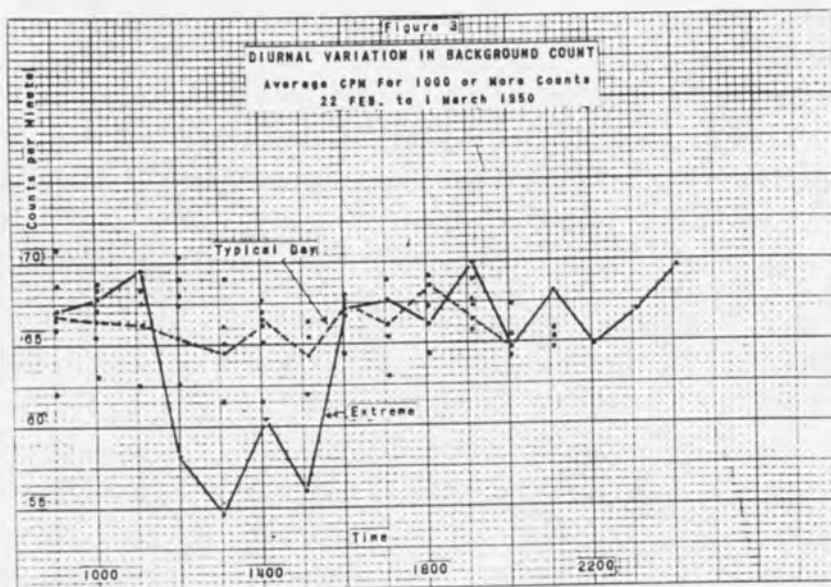
Part of the pulses from the radioactive snow gage will consist of cosmic rays of very high energy which pass through the atmosphere and penetrated a quarter of a mile of rock or several thousand feet of water.

The Geiger tube detects the cosmic background as the average of many "showers" or particles. There is a continuous fluctuation from minute to minute in the number of cosmic ray particles which pass through and activate a Geiger tube. The cosmic ray background must be determined and subtracted from the total count before the thickness of the substance being measured by a radioactive gage can be computed. Measurement precision is limited by the fluctuation in background count. It is not possible to shield the Geiger tube from the cosmic ray background when gamma emissions from a radioisotope are being measured. Cosmic ray energy is at least 30,000 times the energy of Cobalt 60 and possibly 100 times the maximum radioactive energy producible in a laboratory. A lead shield five inches thick would reduce the cosmic background by less than 12 percent and would not appreciably suppress the shower effect or variation in background. The independent but simultaneous measurement of background during the period when the radio-cobalt emissions are measured would reduce counting errors to a minimum. This procedure is not applicable to field radio telemetering snow gages at present.

The summarized data, obtained by studies on the variation in cosmic ray background counts which were made at the Central Sierra Snow Laboratory at an elevation of 7,000 feet in the Sierra Nevada from February 22 to March 5, 1950, are shown in Figures 3 and 4.

Fig. 3

Typical and Extreme
Diurnal Variations
in Background Count.



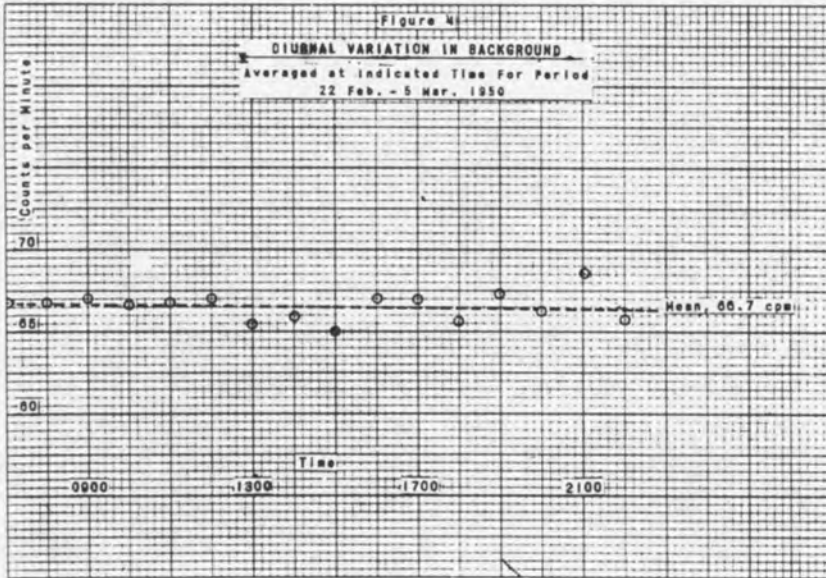


Fig. 4

Average Diurnal Variation in Background Counts. Each Point is the Average for 1000 Counts at the indicated Time for Twelve Successive Days.

The extreme variation in counts which occurred on February 23 as shown in Figure 3 is an example of the effect of intensive magnetic storms or auroral activity. The dotted line is an example of the extent of fluctuation for a more typical day. It has been observed that extreme variation in background counts is associated with poor radio reception.

It is apparent from Figure 4 that fluctuations in the cosmic background are suppressed when counts for several days are averaged. This would be expected from the random nature of the phenomena. During periods when extreme variations occur as shown in Figure 3, it is not possible to measure small changes in water thickness to as high a degree of accuracy. Fortunately, extreme fluctuations in background counts do not appear to be sufficiently frequent to prevent the attainment of a highly satisfactory record of the daily changes in the water equivalent of a snow pack.

CORRECTION FOR DECAY OF GAMMA EMITTER

Radioactive materials decay at a fixed rate. This rate is usually expressed in terms of the half-life which may vary from a portion of a second for some radioactive elements to thousands of years for others. For a given thickness of material through which the emissions pass, less counts will be recorded for each day following the initial measurement. The reduction in counts is a function of the half-life of the radioisotope and a count correction may be applied to assure the highest degree of precision in measurement.

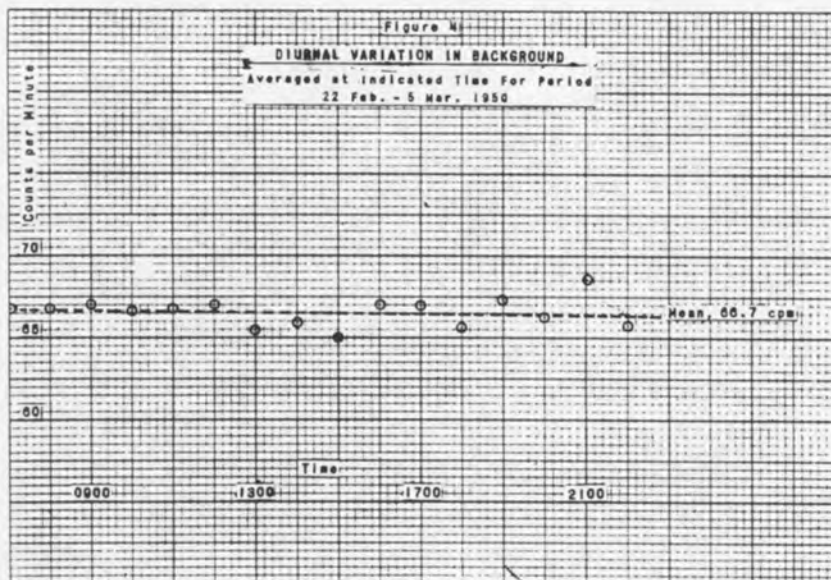


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The correction may be applied in the form of a standard decay equation for Cobalt 60, or a curve may be computed and plotted, Fig. 5) from which the appropriate correction factor can be determined.

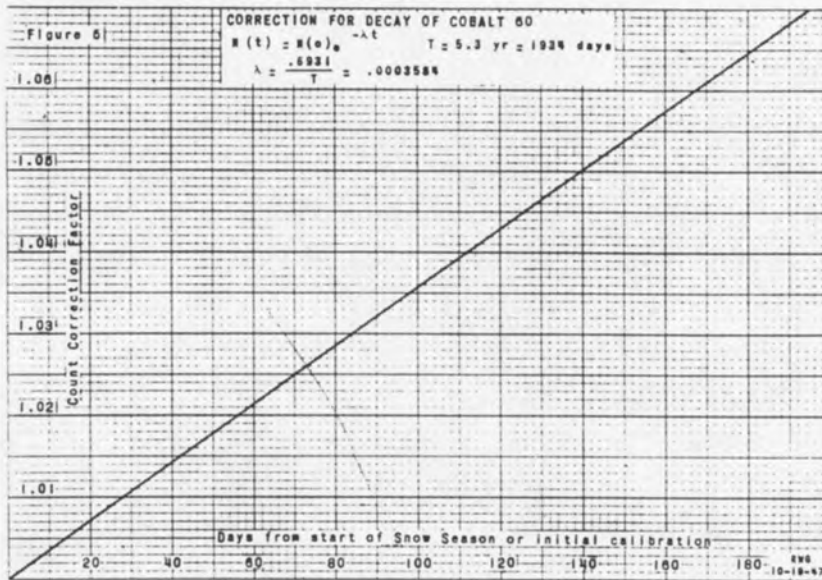
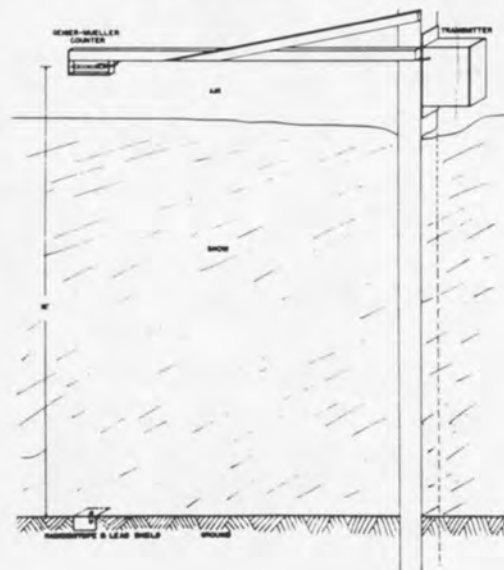


Fig. 5
Correction for the
Decay of Cobalt 60.

THE FIELD STATIONS

After almost a year of preliminary research and instrument development in which major emphasis was given to overcoming or compensating for the many limitations which appeared to be inherent in the method, the first field stations (Fig.6) were constructed in the Castle Creek watershed of the Yuba River near Donner Summit, California. One of these was operated over a transmission line to the Central Sierra Snow Laboratory headquarters and the other was briefly operated on a radio communications circuit at 2650 KC.

Fig. 6
Schematic Diagram of
a field Station.



The radio telemetering station was operated primarily to demonstrate that the G-M tube pulses could be transmitted and recorded at a central receiving station. No effort was made to obtain a sequence of data representative of the water equivalent of the snowpack.

The station operated over the wired circuit was in continuous operation for the major portion of the 1949-1950 snow season. A comparison of the records (Fig. 7) obtained from three different methods of measuring the water equivalent of the snow pack indicated that the radioactive snow gage was a practical possibility.

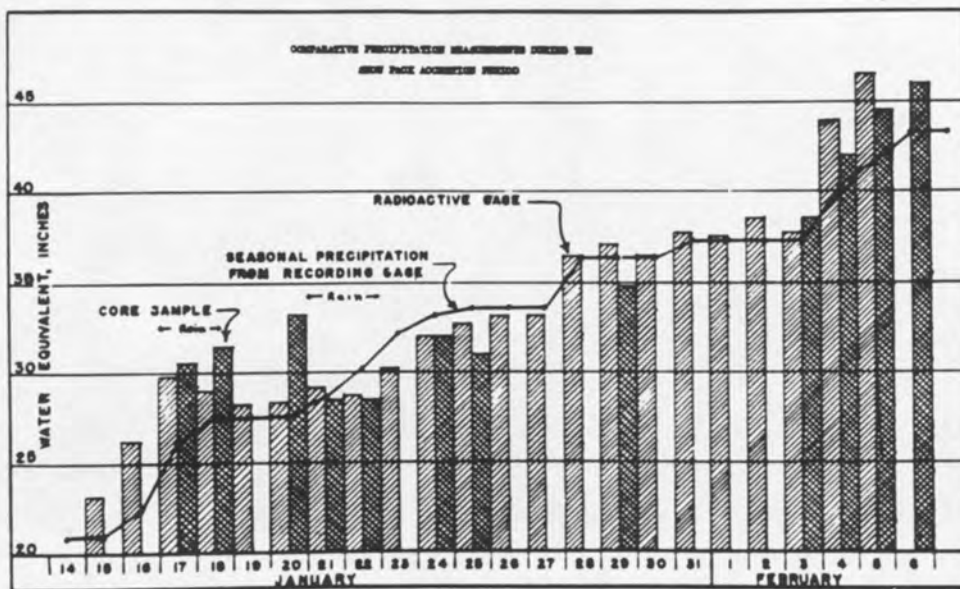


Fig. 7

Comparison of Record from the Radioactive Snow Gage, a Precipitation Gage and a Snow Core Sample, at the Central Sierra Snow Laboratory Headquarters Meteorological Station.

For the 1950-1951 season, field stations (Fig. 8) were constructed as permanent installations. A standard 18-foot Hubbard Truss Arm, such as used for supporting street lights, was mounted on a pole so that the outer end of the arm was 15 feet above the ground.

Fig. 8

Pole and Hubbard Truss
Arm for supporting the
Geiger Tube.



The collimator containing two units of Cobalt 60 was set in a concrete platform flush with the ground surface (Fig. 9) and immediately beneath the Geiger tube housed in a waterproof case suspended on the outer end of the arm. The construction of this case with the thin window permitting passage of the gamma rays and housing a preamplifier in addition to the G-M tube will be described by Mr. Doremus of Motorola, Incorporated in the following paper. The concrete platform (Fig. 10) was used to eliminate any tilting of the collimator when the soil became saturated by snow melt water. Before pouring the concrete, the outer case was greased to permit removal for replacement of the radioisotope.



Fig. 9

Centering the Collimator
beneath the Geiger Tube.



Fig. 10

Permanent Installation of
the Collimator in a con-
crete Platform.

Included in the housing at the end of the truss arm is a small disc of radioactive strontium-90 which emits such weak beta rays that they may be absorbed in a movable metal shield between the strontium-90 and the and the Geiger tube. The disc of radioactive strontium has been calibrated in terms of counts per minute on the G-M tube at that particular station. For brief but fixed intervals of time during each active period of operation the absorption shield between the beta standard and the Geiger tube is automatically lifted and a count which included the Beta emissions, the cosmic background and the emissions from the Cobalt 60 are recorded. When the combined Cobalt and cosmic emissions are subtracted from the total for all three emissions, any appreciable difference from the known value for the beta standard indicates some difficulty with the instrument. A marked difference is usually indicative of a defective G-M tube. These tubes, normally may be expected to last for several snow seasons but a certain number of failures may occur each year when a large number of such stations are operated.

Having demonstrated that the radioactive snow gage was a realistic possibility, several electronic engineering organizations were invited by the Corps of Engineers to submit bids on the development and production of a suitable radio telemetering system. Motorola, Incorporated of Chicago was given the contract and, after almost a year of work, installed two field stations, a relay or repeater station and central receiving and data recording station in the High Sierra in January 1950. Except for minor failures associated primarily with the programming clock, exceptionally satisfactory results have been obtained. Development at the field level has been continued by Motorola and the two stations are in operation for the 1951-52 season.

Mr. Doremus of Motorola will discuss his organization's work in the development and design of a reliable radio telemetering system which can operate unattended in the high mountains and at low temperatures for as long as 9 or 10 months.

ACKNOWLEDGEMENTS

The project for development of an automatic instrument for measuring and telemetering of snow stored water was a Civil Works Investigation of the Corps of Engineers. Development of procedures permitting use of radioisotopes for this purpose was undertaken by the Cooperative Snow Investigations program which is operated jointly by the Corps of Engineers, Department of the Army and the Weather Bureau, Department of Commerce. The major portion of research on this project was conducted in the Central Sierra Snow Laboratory, one of three laboratories operated by the Cooperative Snow Investigations. The author was at that time Technical Supervisor of the Cooperative Snow Investigations.

The Cobalt 60 used in these investigations was procured by the Corps of Engineers, on allocation from the Isotopes Division, U.S. Atomic Energy Commission. The Strontium 90 was obtained by the Corps of Engineers from the United States Radium Corporation on allocation from the Isotopes Division, U. S. Atomic Energy Commission.

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