GAMMA-TRANSMISSION PROFILING RADIOISOTOPE SNOW DENSITY AND DEPTH GAGE

By

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The 56 years since Dr. Church's 1/ invention of the Mt. Rose Snow Sampler have seen a continuous effort to develop a better method of measuring the water content and density of snowpacks. These efforts have led to refinements in cutting tips, stainless steel and aluminum tubes; new scales for the Mt. Rose Samplers; the development of the pressure pillow; and development of isotope snow gages of various types.

The advent of radioactive isotopes stimulated much research seeking methods of measuring snow by nuclear means. Beginning with the pilot study of Gerdel, et al 2/ in 1950, an average of four or five papers on the use of sealed isotope sources in measuring snow water content have been published each year. The gages have been of two types. The classical isotope snow gage has been patterned after Gerdel's original model. It consists of an isotope source usually suspended above the snow with the detection system normally located under the snow for temperature stability of the electronic system. Isotope sources usually consisted of 30 to 80 millicuries of Colbalt 60. One such model is the snow gage of the U. S. Army Corps of Engineers. It is described by Robinson 3/ as a lead-shielded collimator, containing 80 mc. of Cobalt 60 that is buried in the ground. A scintillation detector is mounted on an H-frame structure 15 feet above the collimator. The detector consists of a sodium iodide (NaI) crystal and a photomultiplier tube. The system will measure snow water content up to a maximum snow depth of 50 inches water equivalent. Beyond this the system "saturates".

Within its limits this system operates well, although temperature variation of the detector causes variations in count rate. This system and all those of the same type yield only one figure--the amount of water between source and detector. The gages measure water content within 1 to 5 percent of actual water present, but they have several disadvantages. All use a large source--from 30 to 80 millicuries of gamma radiation. In mountain areas subject to heavy recreation pressure, they are a safety hazard. The single-point gage must have an above-ground framework which may be warped by heavy snow loads. Metal expansion and contraction of the superstructure from changing temperatures can throw off the calibration. The maximum depth of water equivalent detected by the gages is slightly more than 50 inches. Thus, they cannot be used in deep snowpacks.

Portable Scatter Gages

Danfors, Fleetwood and Schytt 4/ used a portable neutron soil moisture gage to measure density variations in a glacier. A single probe containing a 5 mc. source of Cesium-137 and a Geiger-Mueller tube detector was dropped into an access tube in the snow or the glacier. Outgoing neutrons collided with hydrogen in the ice, snow, or water and were slowed and reflected back to the probe where the "slow" neutrons were detected. These scattered neutrons returned to the detector from a spherical area around the probe. In this gage system, the size of this zone of influence depends upon the density of the mass of ice--the greater the density the smaller the zone of influence. Since the detector receives scattered impulses from an area of from 8 to 16 inches above and below the detector it cannot be used to accurately locate thin zones of density differing from the average snow or ice density within the zone of influence.

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Gay 5/ reported some success in measuring snow density with the neutron single-access tube gages previously used to measure soil moisture and soil density. Experiencing the same problems as Danfors, et al, 4/ he found high count loss at the soil-snow and air-snow interfaces because of energy loss to the soil or the air.

We have successfully used neutron and gamma scatter gages to measure total water content of a snowpack to within 2 percent of actual density. 6/ Three calibration curves for depths of 3, 6 and 12 inches and greater depths were necessary owing to the large spherical zone of influence around each probe and subsequent loss of energy at the snow-air interface. Total snowpack water content from each probe was compared to water content obtained by the Mt. Rose Sampler for an entire season. The estimate of snow water content of snowpacks obtained with the Mt. Rose Sampler was about 5 percent greater at the higher water contents than the estimate obtained by use of the gamma scatter gage, and 1.6 percent greater than that obtained by use of the neutron scatter gage.

The soil moisture and soil density scatter gages are more versatile than the single point Gerdel type gages since they may be used to obtain internal snow structure data in 6 to 12 inch vertical increments. Because of their large vertical zone of influence they require multiple calibration if used closer than 12 inches to an air-snow interface. Measurement taken by these systems is time consuming. One count at each depth requires 1 minute. Counts should be taken at each vertical 6-inch level.

If a hydrologist is to predict accurately streamflow from snowmelt, or storm flow from rain-on-snow events, he should know the internal density structure of the snow and its depth and depth changes as they occur. No system has previously existed for measuring internal structure of a snowpack in small increments except through destructive sampling. This, of course, prevents later sampling of the same site.

Profiling Gamma-Transmission System

The California Cooperative Snow Research Project has developed a system with which one may profile a snowpack, measuring snow density in 1/2-inch vertical increments. The system may be used as a portable tool or may be placed in a permanent site. The output may be read directly, recorded on an analog chart, or it may be telemetered to a distant location. We expect to have the system completed this year to form a remotely operated, telemetered high elevation "snow sentinel" which can operate in any depth of snow. It can also be used to determine soil moisture.

The system is designed for measuring the mass per unit volume of horizontal layers of material, 1/2 inch thick laying between parallel vertical access tubes. The source of radiation is 5 millicuries of Cesium-137 sealed in the end of a source-holder rod. In use it is raised and lowered in the 3/4-inch diameter access tube sunk into the snowpack. The detector probe is lowered in the 1-9/10 inch diameter access tube. The detector consists of a 1/2-inch thick by 1 1/2-inch diameter sodium iodide crystal, photomultiplier tube, preamplifier, and cable. The two probes are positioned at the same elevation in their respective access tubes. They are raised and lowered as a unit, and kept parallel and equidistant from one another at all times.

In operation the probes are positioned in the access tubes, which are sunk parallel to one another into the snowpack. Gamma photons pulse from the radioactive source in all directions. Those pulses which reach the crystal detector-photomultiplier create an impulse, the amplitude of which is proportional to the electromotive force of the gamma photons received by the detector. The impulses move by cable from the detector to a pulse height analyzer which discriminates against low energy scattered photons. Only non-scattered photons which have traveled in a straight line from radioactive source to the detector without collision are counted. The number of these photons received is proportional to the density of the volume of the material being studied. The unscattered pulses are received by a ratemeter whose output is fed through an amplifier to an analog chart recorder. For precise counting and calibration, a scaler is substituted for the ratemeter, amplifier, and chart recorder. In this case impulses are counted for definite time intervals.

The complete system is highly portable (figures 1 & 2). In its most simple form, without the chart recorder, it weighs about 30 pounds, is portable, self-contained and of modular construction. This packaged circuitry can be substituted in the field in the event of equipment breakdown. The equipment is reasonably waterproof and operates over a temperature range of -23°C. to 60°C. The scaler has a built-in ratemeter for scanning of the Cesium-137 spectrum in setting the pulse height analyzer. The system operates from 110 volts A. C., or from the included rechargeable batteries.

The system was calibrated by inserting known quantities of snow between the source and detector and determining the count rate. It was checked by determining count rate for natural snowpacks into which the access tubes had been placed. Snow was then removed from each counting layer and weighed for density determination.

The calibration data (counts per minute) was transformed into natural logarithms and a regression solved for the data. This followed the relationship: Snow Density = 8.0 - 0.64 (log counts). The associated mean is 0.512, standard deviation from the mean is 0.298, the standard error of the regression is 0.012 and the coefficient of variation (R^2) is 0.998. The gamma transmission scintillation snow gage can be used to measure snow density to within ± 1.2 percent of actual snow density. Only one calibration curve is needed since one may measure snow within 1/2-inch of an interface. (figure 3)

The system was tested for its ability to detect density changes within a snowpack. A natural snowpack was excavated and repacked with known snow densities. One-minute counts were made at intervals of 1-inch, except when approaching or leaving a zone of density change. At such points counts were made in 1/2-inch intervals. The gage measured densities, and the gravimetrically determined densities were within 1 to 2 percent of one another. (figure 4)

The system was tested as a constantly moving profiling snow gage. A snowpack having a natural profile with included lenses of materials having varying densities was profiled by three methods. First, a point-by-point survey of the profile was made by taking counts at 1-inch intervals. Second, the source and detector were simultaneously lowered through the snowpack at a speed of 10 seconds per inch. Third, they were lowered at a speed of 5 seconds per inch (figure 5). Repeat runs at the same speed resulted in curves of almost exactly the same magnitude in every sector of the curves, although the source and detector were lowered by hand and timed with a stopwatch (figure 6). The 5-second-per-inch profile rate resulted in a curve more accurate than even the point-by-point survey. At this rate of movement a 10-foot-deep snowpack can be profiled in 10 minutes. And it can be profiled as often as needed.

The system's ability to detect water movement either from snowmelt or from a rain-on-snow event was determined by placing the source and detector at a common depth in a snowpack and spraying water onto the snow surface. The resulting variation of density with time was plotted. The system detected the wetting front when it reached the source detector horizon. The density increased in response to the new water in the pack and remained constant until cessation of water application. The pack then drained to a lower density. The system accurately recorded the pack performance.

Most isotope snow gages have used Geiger-Mueller detectors to avoid temperature-caused problems. The scintillation detector is temperature sensitive. As the temperature of the detector increases, so does the count. This change will cause the pulse height analyzer to shift off the photopeak or other setting.

If the gamma transmission system is used in one place, temperature changes cause little difficulty because the detector remains in the snow at all times and subject to only small temperature changes. These can be controlled by occasional setting of the "window" in the pulse height analyzer.

If the system is to be used in many places in a day, temperature changes pose a problem. In such a case the detector will heat up while out of the snow and cool off inside the pack. The problem can be handled in two ways. The detector can be cased in an insulated jacket, or it can be carried from location to location in an insulated carrying case. Normal electronic drifting of pulse height analyzer circuits also nesessitates resetting the "window" several times each day. The most logical solution to electronic drift and to count change due to temperature effects on the detector consists of using a "peak stabilized pulse height analyzer". This is a new electronic development. The gage is currently made to operate on 110 volts A. C. only. We have ordered a gage tailored to operate at low temperatures and from a 12 volt D. C. source. With this peak-stabilized pulse height analyzer we will eliminate count shifts due to electronic or temperature causes. We have also used a Geiger-Mueller tube detector. With this unit we can profile a snowpack in 1-inch vertical increments. Its sensitivity is far less than that of the scintillation detector.

Since the earliest tests using gamma isotopes to measure snow density, there have been recurrent observations that errors in calibration and measurement might have been caused by different attenuation properties of snow, ice, and free water. It does not seem reasonable to assume that a "hard" gamma would be materially affected by changing water into ice. It appears more likely that erroneous observations have resulted from electronic drift caused by using laboratory equipment under field conditions.

To measure the effect of crystal structure upon gamma attenuation we exposed water, snow, and ice samples from the same source to Cesium-137 gamma radiation in a constant geometry setup. A scintillation detector on the opposite side of the sample detected the gamma photons. The output was received by a multi-channel analyzer and the cesium spectrum was printed out. Counts were integrated under the full width of the peak and a count per minute obtained. Mass cross section of the samples was plotted as a function of counts per minute and a curve fitted to the data. The curves for snow and for ice were compared to that obtained when water alone was used. The mass attenuation coefficient was equal to the slope of the curve, thus a difference in attenuation would be indicated by a difference in the slope of the two curves. When the mass cross section versus counts per minute were plotted into the slope of the regression lines for snow, ice, and water, we found that the samples were not significantly different beyond the 1-percent level from one another (figure 7). Thus, for all practical purposes, the attenuation for water is constant in both the solid and liquid states.

Melt of snow around access tubes becomes a problem if melt progresses to the point where it affects the estimate of snow density between the access tubes. The closer the spacing of the tubes the more critical the melt becomes.

Experiments with use of expanded polystyrene as insulation around the aluminum access tubes showed that heat transfer along the tube could be minimized and resultant snowmelt around the tube reduced to acceptable levels. The most suitable tubing would consist of an aluminum tube for strength surrounded by 1 to 1-1/2 inches of white insulation. Further, we have found that suncupping can be practically eliminated by spraying the snow surface with the evaporation suppressant, hexadecanol.

Spacing studies showed that access tubes can be separated 24 inches and still retain good counting statistics while 5 millicurie Cesium-137 source is being used.

The snow gage is being operated during the winter season January to June 1966 in a semi-permanent location at the Central Sierra Snow Laboratory at Donner Pass in the Central Sierra of California (figures 8 & 9). The source and detector probes are raised and lowered by an overhead pulley system powered by a reversible electric motor. Profiling speed is 5 seconds per inch. The time constant for both ratemeter and chart recorder is set at 5 seconds. The output from the ratemeter is plotted directly on to an analog chart. Accuracy of the measurements is within 2 percent of actual density.

An overhead suspended pulley system for raising and lowering the source and detector should be used only at locations where an operator is stationed. It is not recommended for operational field use. The detector source cannot be raised or lowered during heavy winds. It can be operated during rains, provided a "sock" is fastened over the access tubes to keep water out of the tubes.

Specifications are currently being completed for fabrication of a remotely operating, telemetered snow gage. This gage will consist of access tubes capped at their tops to prevent entry of water. The tubes will be filled with a dry inert gas to prevent condensation. The probes will be raised and lowered from below the soil surface. The electronic equipment will be housed in an insulated, waterproof box. Electricity to operate the system can be supplied by a propane-fed, bottled-gas thermo-electric generator or from line voltage if it is close at hand. In remote locations the heat from the generator will be used to keep the electronics at an optimum temperature.

The detector in the remotely operating unit will be a sodium iodide crystal scintillation unit. The signal will be fed to a peak-stabilized pulse height analyzer, a ratemeter, a digital voltmeter, and a Bell telephone data phone set. The data may be telemetered over a phone line or by radio. High-speed transmission may be obtained by adding a tape recorder to the package.

At the receiving office the incoming signal will pulse through a data phone set into either a computer or a printout unit.

Estimated costs for an entire field station are estimated at $10,000. The cost of the office receiving unit can be as low as $2,000.

As a manual, portable gage the unit need only consist of source and detector, pulse height analyzer, ratemeter, and a chart recorder with a built-in amplifier. The high voltage supply in the ratemeter supplies power to the detector. A 12-volt D. C. battery supplies power to the pulse height analyzer and the amplifier. The source detector can be raised and lowered by hand or by use of a small mechanical lifter. Use of such equipment would require visiting the scene at each measurement period. The complete unit will cost about $5,000.

The scintillation transmission gage should form the core of any snow research program. In snow hydrology, in glacier research, and in avalanche research, the system should find extensive use. Here for the first time is an instrument with which one may survey repeatedly the same profile in a snowpack and determine density to as small vertical increments as is desired. Profiles under different covers and on various aspects may be repeatedly surveyed and their performance related to causative stimuli. Snowmelt may be studied and the movement of water within a pack may be traced.

In operational snow hydrology--snow surveying--the gage can be a valuable addition to the surveyor's bag of tools. With the gage operating as a "snow sentinel" in headwater locations actual water content, snow depth, and density changes within the pack can be determined as often as desired. Relations between melt at a central location and other cover--aspect conditions nearby may be determined and melt for large areas predicted from performance of the snow at the gage site. Expressed mathematically this data can be programmed for a computer. Then by feeding in day-to-day melt from the "snow sentinel" one may predict actual melt and subsequent streamflow. By relating current internal pack structure to predicted weather, short-range melt forecasting should be possible.

Current flood warning systems depend upon stream gages to warn of rising streams. Perhaps one of the greatest uses to which the snow gage could be put would be that of a "snow sentinel" during rain-on-snow storms. In a rain-on-snow situation, the density of the various horizons within a snowpack may be determined throughout the storm from a rain gage. The snowpack may be profiled at intervals throughout the storm. From each profile run one may determine the snowpack depth, density of each layer, and total water content of the pack. From a knowledge of the incremental rainfall amounts, and the amount stored in the snowpack, one can determine how much of the incoming rain is being stored in the pack and how much is being released to the soil or as overland flow.

If the access tubes extend into the soil, the same system can be used to measure soil moisture and the water balance extended to take into account the water loss to the soil.

As the snowpack begins to melt it becomes more shallow. This depth decrease can be measured with each profile run.

If rainfall ceases during a storm and snow begins to fall, this change will be reflected in the pack performance by water draining from the pack. The loss of water causes a reduction of the abnormally high densities experienced with free water in the pack. Further, the depth of the snowpack begins to increase as new snow falls.

The scintillation detector, gamma transmission system is relatively cheap, may be used as a portable gage or adapted for remote, telemetered operation. It is a precise electronic tool which has been adapted in every respect to conditions such as are encountered in snow surveying. The tool is accurate and safe. For the first time snow hydrologists have a tool with which they may minutely examine the internal structure of a snowpack as often as desired.

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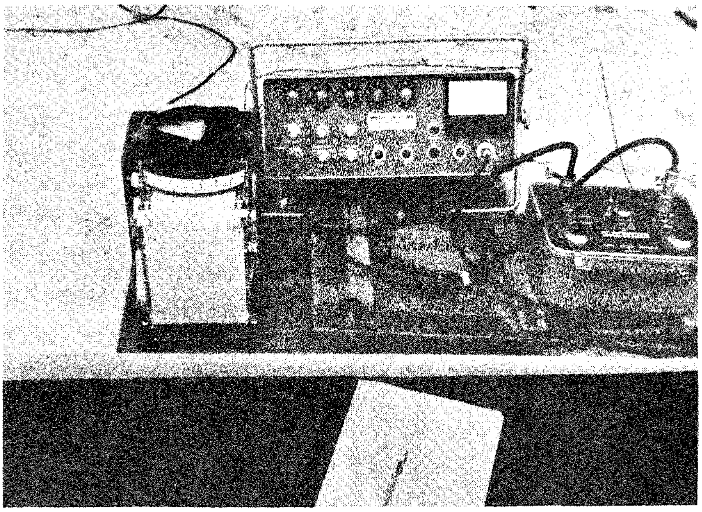

Figure 2. From right to left: pulse height analyzer, scaler-ratemeter and analog chart recorder.

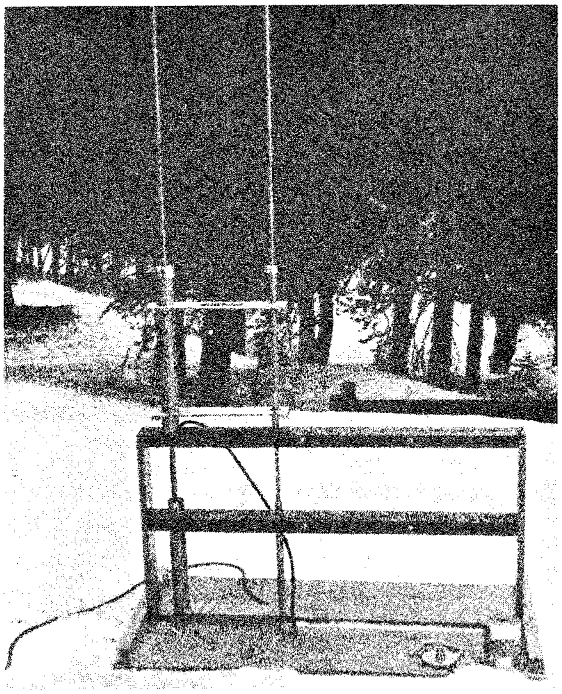

Figure 1. Twin tubes in aligment jig with detector probe in left tube and source in right tube.

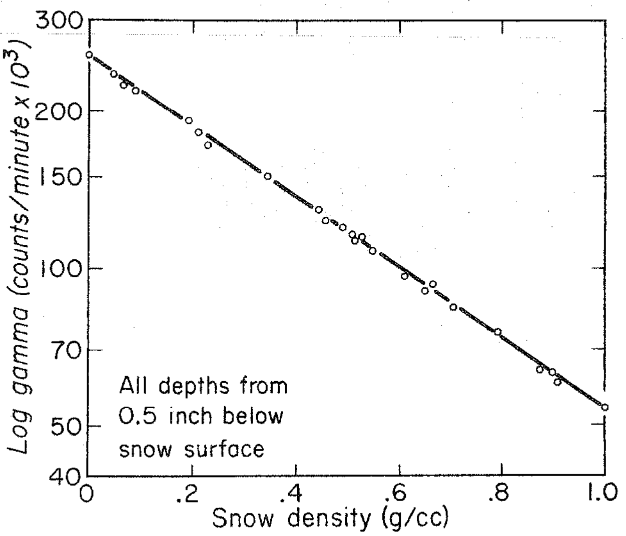

Figure 3. Calibration curves for the two probe gamma-transmission system counts vs. snow density.

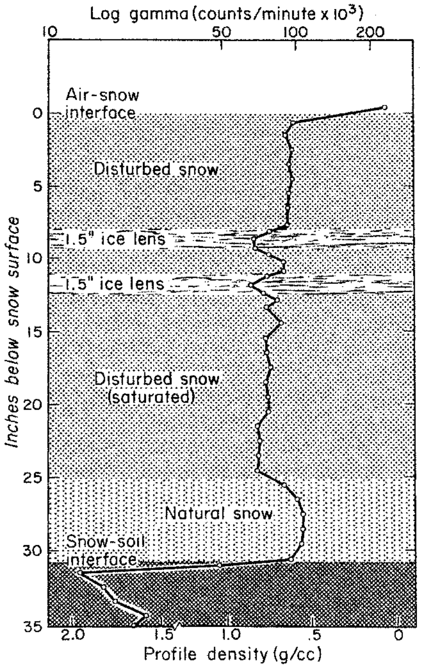

Figure 4. Relationship between counts per minute and density throughout an air-snow-soil profile, April, 1965.

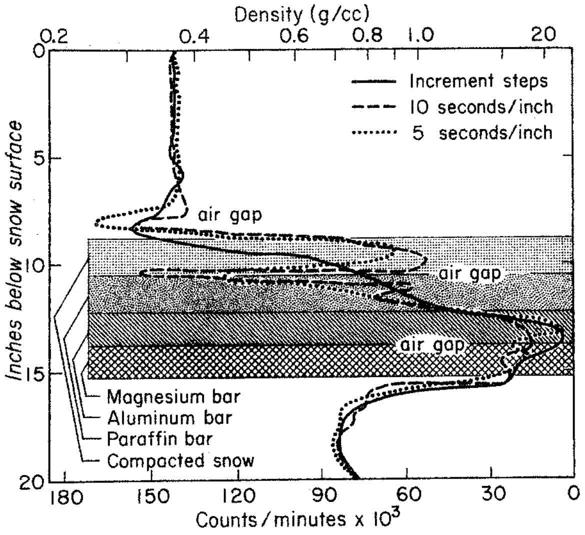

Figure 5. Incremental scaler vs. ratemeter scanning of an artificial profile using gamma transmission.

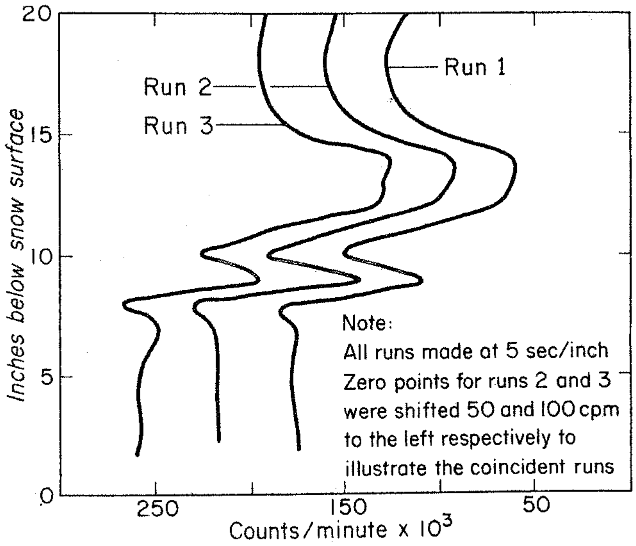

Figure 6. Scanning repeatability of three consecutive runs made through the same natural snow profile.

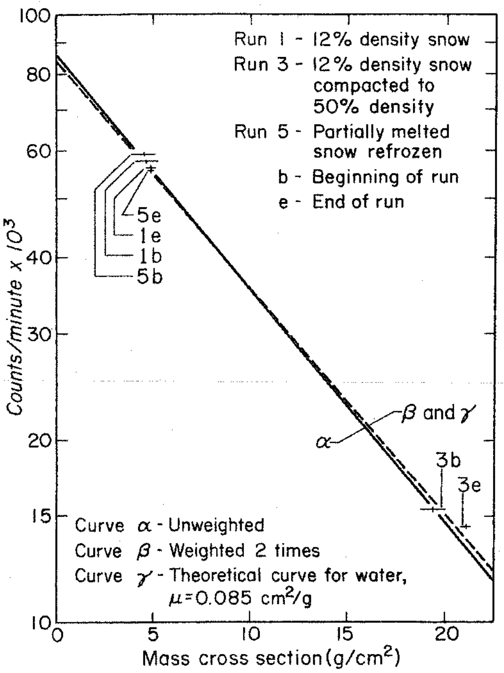

Figure 7. Counts per minute vs. cross section for snow and melt water samples.

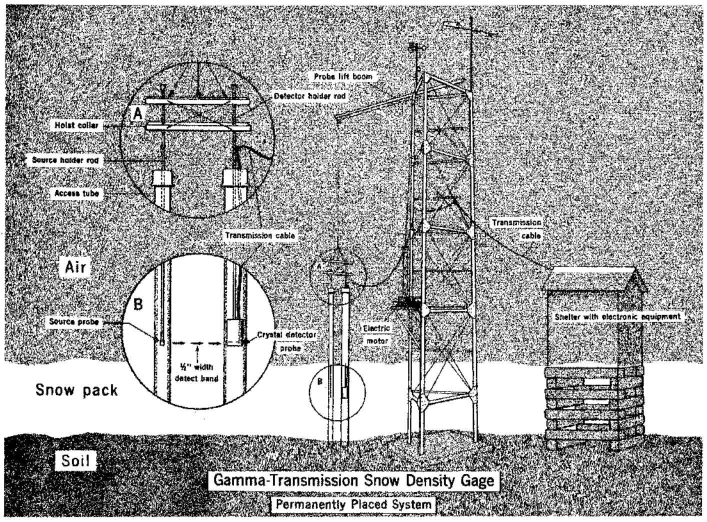

Figure 8. Gamma-transmission snow density gage in a permanent position as used at the Central Sierra Snow Laboratory.

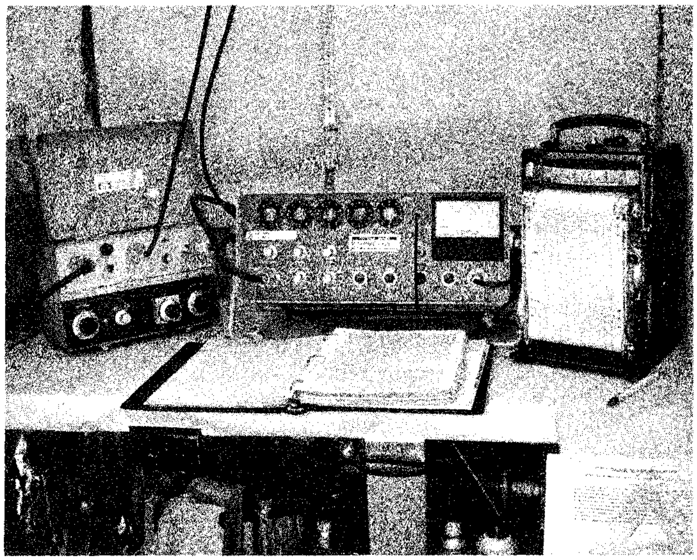

Figure 9. Electronic equipment for use with the snow gage. From left to right, pulse height analyzer, scaler-ratemeter, and chart recorder with amplifier.