# EVALUATION OF THE ISOTOPIC SNOW MEASUREMENT GAGE

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## INTRODUCTION

Recent flooding in the Western United States has magnified the importance of obtaining accurate, reliable snow data. Wise water resource management requires an accurate prediction of runoff to maintain sufficient water in the reservoirs for irrigation while discarding excess water early in the season to prevent flooding. New techniques are being developed using satellite imagery and computer models to analyze entire watersheds, but on-the-ground sensors are still required for calibration and real-time data acquisition.

Two principle methods used for monitoring snow water equivalent of snowpacks are weighing and density gaging. Snow is weighed using butyl rubber or stainless steel snow pillows as sensors. Isotopic gages monitor the snow by measuring density. Although isotopic snow gages have been in use since the early 1960s, this year marks the tenth anniversary of their use to measure remote snowpacks on an operational basis in Montana.

The purpose of this paper is to review the status of the isotopic gage in monitoring snow. It will 1) evaluate the Montana experience over the last ten years, 2) present the principles of isotopic density monitoring, 3) discuss advantages and problems associated with their use, 4) present advances in isotopic measuring technique that could make it more attractive for use in snow measurement, and 5) suggest the future for isotopic gages for water measurement.

## EXPERIENCE USING ISOTOPIC GAGES

One of the early isotopic snow gages to be used operationally at a remote field location was installed during the 1974-75 snow year at Noisy Basin near Bigfork, Montana (USDA, 1975). A Remote Isotopic Profiling Gage (RPG), developed primarily by J.L. Smith and D.W. Willen (Kattelmann, R.C., 1983), and built by Idaho Industrial Instruments, Inc. of Boise, Idaho, was used to monitor snow density as a function of its depth. Figure 1 shows an example of a density profile plotted for the Noisy Basin site for March 2, 1975. The total snow depth is 106 inches. The density ranges from about five percent (new snow) at the surface to about 43 percent at the bottom of the pack. Measurements were made at one-inch intervals. The snow water equivalent was computed using an algorithm that multiplied the average density by the total depth. That was, in effect, a density integration of the snowpack using many density readings. A telephone line connected the profiling gage to a ranger station where data were stored on tape for later re-transmission to the Soil Conservation Service (SCS) in Bozeman, Montana.

Several problems had to be overcome during the first few years of operation. The harsh environmental conditions caused failures in cable connections and in the RPG drive motor. Failures of the telephone link were common. The standard used for snow water equivalent determination and for density calibration of the RPG was a portable snow profiling gage which utilized the radiation backscatter principle to obtain density measurements. Once the RPG was calibrtated to the portable gage, reliable data could be obtained. Licensing difficulties centered around the unattended use of the 10 mci. Cesuim$^{137}$ sources at remote sites. The problem was resolved by requiring that sites be fenced, that precautionary warning signs be displayed, that sources be leak tested annually, and that the isotopic sources be removed from the gage and stored at a secure location during the summer months. Because of cost considerations and complexity of

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operation, this type of gage has limited application and is considered primarily a research tool.

The second generation Remote Isotopic Snow Gage (RSG) is a self-calibrating gage with no moving parts designed and built by R.G. Morrison (1974). Elimination of the drive motor improved reliability in harsh environments and the self-calibration feature has improved the accuracy.

The RSG was initially installed during the 1975-76 snow year in nine Western states. Rather than integrate a density profile to determine snow water equivalent, successive zones of snow are simultaneously sampled to determine the total amount of water. Early data demonstrated the ability of the RSG to accurately and reliably monitor snowpack. Figure 2 shows data collected at the Trinity, Idaho site during 1976. When corrected for inherent overmeasure (Western Snow Conference Metrication Committee, 1983), the manual samples taken with the Federal sampler agree quite closely with the corresponding RSG readings.

Operational problems with the early use of RSG systems involved mainly data storage and retrieval. Data was stored using an on-site thermal printer. The printer consumed a lot of power and was not very reliable, particularly in extremely cold weather. In Montana, these problems were solved by interfacing the isotopic gages directly into the SCS snow telemetry (SNOTEL) system.

Because of the problems encountered with operating and maintaining the RSG system and difficulties in their licensing, most states except those serviced by the Montana and Utah Data Collection Offices, have abondoned the use of isotopic gaging for more conventional weighing methods. Montana has been able to solve the early problems associated with the RSG system and, therefore, has benefitted from continual snow data from isotopic monitors. Figure 3 shows recent data from Lick Creek, Montana site obtained from RSG gages currently in use.

## PRINCIPLES OF ISOTOPIC DENSITY MEASUREMENT

Isotopic density gaging uses a well-known principle of physics, gamma attenuation. A small radioactive source, emitting gamma rays, is embedded in a lead collimator which has a small hole angled toward a detector. The purpose of the collimator is to reduce the intensity of the gamma radiation in every direction except toward the detector. As a beam of gamma radiation passes through a substance on its way to the detector it decreases in intensity or is attenuated, due to absorbtion of energy within the substance. The amount of attenuation is a function of density and follows an exact pattern for all substances including water, soil and air. The gamma intensity received at the detector is portrayed as a number of counts over a given time interval. The fewer counts detected, the more dense the attenuating substance.

The RPG used three vertical tubes forming an equilateral triangle. One vertical tube was used for support. A second tube contained the gamma source. The third tube held the detector. A lift motor moved the source and the detector simultaneously, keeping them in the same horizontal plane. Readings could be taken at approximately 2.5-, 5.0-, or 10.0-centimeter intervals. The number of counts per minute received at the detector for a given interval was recorded. The source and detector were then moved up an increment by the lift motor and another reading was taken. The density of the snow for each interval was determined using a calibration curve of counts vs. density. Total snow depth was determined when counting indicated readings being taken in air. Average density and total snow water equivalent could then be readily calculated.

The RSG consists of two vertical tubes 100 centimeters apart (see Figure 4). The RSG has fixed sources that direct the gamma radiation through the snowpack at an angle toward fixed detectors in the opposite tube. This forms a zig-zag pattern between the tubes and effectively divides the area between them into zones. Each zone has one detector and a single source can be used for two adjacent zones. Since the geometry is fixed and the readings represent the average density for a given zone, the water equivalent is determined directly for each zone. The total water equivalent is the sum of all of the zones.

The main advantage of the RSG type of gage is that it has no moving parts, thus increasing its reliability. Once it is properly calibrated, calculations are simple and water equivalent is determined directly. An added feature of the RSG is its ability to self-calibrate. The location of an additional reference detector in the top of one of the vertical tubes allows a nominal count for air to be obtained. Changes in this reference count due to source decay or interference from external radioactive interference are used to adjust to count period. Some RSG systems have been modified to include a zone of soil moisture monitoring which can be used in conjunction with snow measurement to predict runoff.

## PROS AND CONS IN ISOTOPIC MONITORING

There are three reasons the use of isotopic snow gages should be considered. The first is accuracy and precision. Accuracy is based on the total number of counts detected during the reading. Therefore a reading can be made more accurate by using a bigger source or by extending the count time. Precision is determined by the standard deviation given an infinite number of counts. Isotopic gages can provide a precision of 1 1/2 percent of full scale readings (Smith, J.L., 1969).

A second reason to consider isotopic gages is component reliability. The RSG has no moving parts, which eliminates the major element in this type of sensor failure. The use of CMOS circuitry, decreasing power consumption, has decreased maintenance requirements.

Third, governmental restrictions placed on the use of remotely located isotopic gages can be beneficial. The "CAUTION RADIOACTIVE MATERIALS" signs tend to be a deterrent to vandalism and the fences around each isotopic site keep grazing livestock and wild animals from damaging or destroying sensors.

Most of the problems associated with isotopic sensing were solved during their early years of use. There are, however, some persistent problems to be dealt with before isotopic monitoring can reach its full potential.

The detector used in isotopic gages is a Geiger-Muller (GM) tube. The GM tubes had a high failure rate in the early years of remote site use. The past few years have seen an improvement in GM tube construction, with an associated decrease in failure rate. Part of the problem stemmed from the GM tube requirement of a bias voltage of 900 volts at the detector. Buried cables from the high voltage power supply leading to the detector were particularly prone to corrosion and had to be replaced. It is now possible to replace the original GM tubes with detectors using a low voltage bias, or to replace the original GM tube circuitry and completely eliminate the high voltage cables.

Late in the melt season, sun cupping around the vertical poles of the isotopic gages causes decreased accuracy of the readings. Because the gage reads air where the snow has melted away from the poles, a reduced snow water equivalent is indicated. One method for reducing this effect in the lowest measurement zone is to locate the first layer source outside of the detector column as is shown in Figure 4.

Because of the geometry of the collimator, there is a small blind layer between its ports where no snow can be detected. The complete snowpack cannot be measured and the water content will be slightly underestimated. Additional sources and detectors in each zone solve the problem but substantially increase the cost.

Another hurdle that must be overcome is the licensing of the radioactive sources used in the gages. At present, sources are licensed through the Nuclear Regulatory Commission as well as by individual state licensing agencies. There is a need for gages with smaller sources that can be generally licensed by the manufacturer. When this is done, purchase as well as control of individual gages will become a much more simple process.

## ADVANCES IN ISOTOPIC MEASUREMENT

Several advances have occurred recently that have improved the desirability of isotopic monitoring. One area is in detector development. Another is in electronic circuitry.

Two recent detector developments have made it possible to improve both performance and reliability of isotopic gages. The first was the development of the low bias, solid state detector. Semi-conductors made of Cadmium Telluride (Cd-Te) are not being used to detect gamma radiation (Whited, R.C., 1979). These detectors have greater sensitivity and appear to be more reliable than GM tubes. They require only 50 to 60 volts, substantially less than their predecessors. Being small (2mm cube) they fit into many applications where size is important. They are presently used in medical instruments and nuclear dosimeters. Replacing the GM tube in a snow gage with a Cd-Te detector will eliminate the need for high voltage cabling and will allow the use of smaller isotopic sources. Smaller source size should make licensing easier. At present, Cd-Te detectors are expensive. Experiments are being conducted which will hopefully bring the costs down and increase their availability.

A recent development from the Los Alamos Scientific Laboratory (LASL) is being incorporated into nuclear snow and soil moisture gages. Although not a detector itself, the LASL contribution is a miniature DC-DC converter which mounts in the GM tube detector assembly, eliminating the need for long, high voltage cables. The converter is inexpensive and is easily installed in existing isotopic gages.

Major advances in on-site microprocessing capability have made it possible to have an inexpensive monitor that will integrate into a fully automated sensing system such as SNOTEL, to provide near real-time data, including maximums, minimums and mean determinations for virtually any remote sensor.

## THE FUTURE OF ISOTOPIC GAGES IN WATER MANAGEMENT

We now have ten years of operational experience using isotopic gages for snowpack monitoring in Montana. We are satisfied with the results we have gotten. Improvements in design and the incorporation of state of the art electronics make present day nuclear gaging devices desirable as well as affordable.

Some of the RSG gages such as the one at Lick Creek, Montana were fitted with one zone for monitoring soil moisture. More recently, multi-zone gages have been developed which can be custom tailored to cropping, irrigation and other water management needs. A relatively inexpensive portable soil moisture gage is now available with the same capabilities. Experiments performed using isotopic sensors to measure soil moisture showed that this method was more accurate and reliable than was tensiometric soil moisture monitoring (Wheeler, P.A., 1983).

We have seen that isotopic moisture monitoring has applications ranging from the mountain watershed to the valley farm. It is not unreasonable to expect that in the near future we will see isotopic sensing expanded to monitor lake and reservoir elevations, river stages, forest burning indexes, controlled sprinkler irrigation scheduling and the regulation of irrigation application rates.

We expect that isotopic sensors will play an increasing role in correlating "ground truth" measurements with global satellite imagery as more disciplines shift their energies to regional and larger scales. These types of efforts are making it possible for us to better predict water availability over larger and larger areas as greater demands are made on this precious resource.

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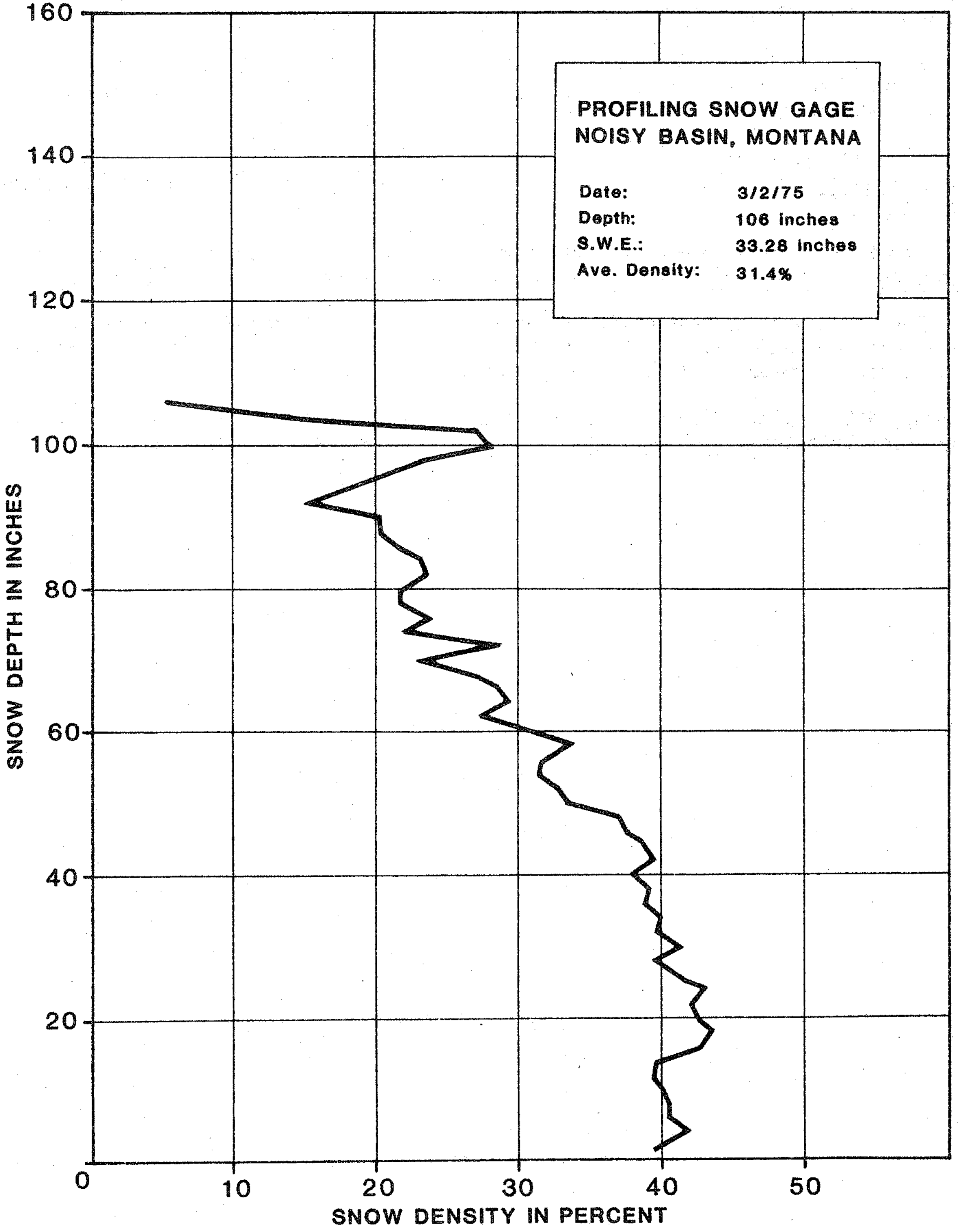
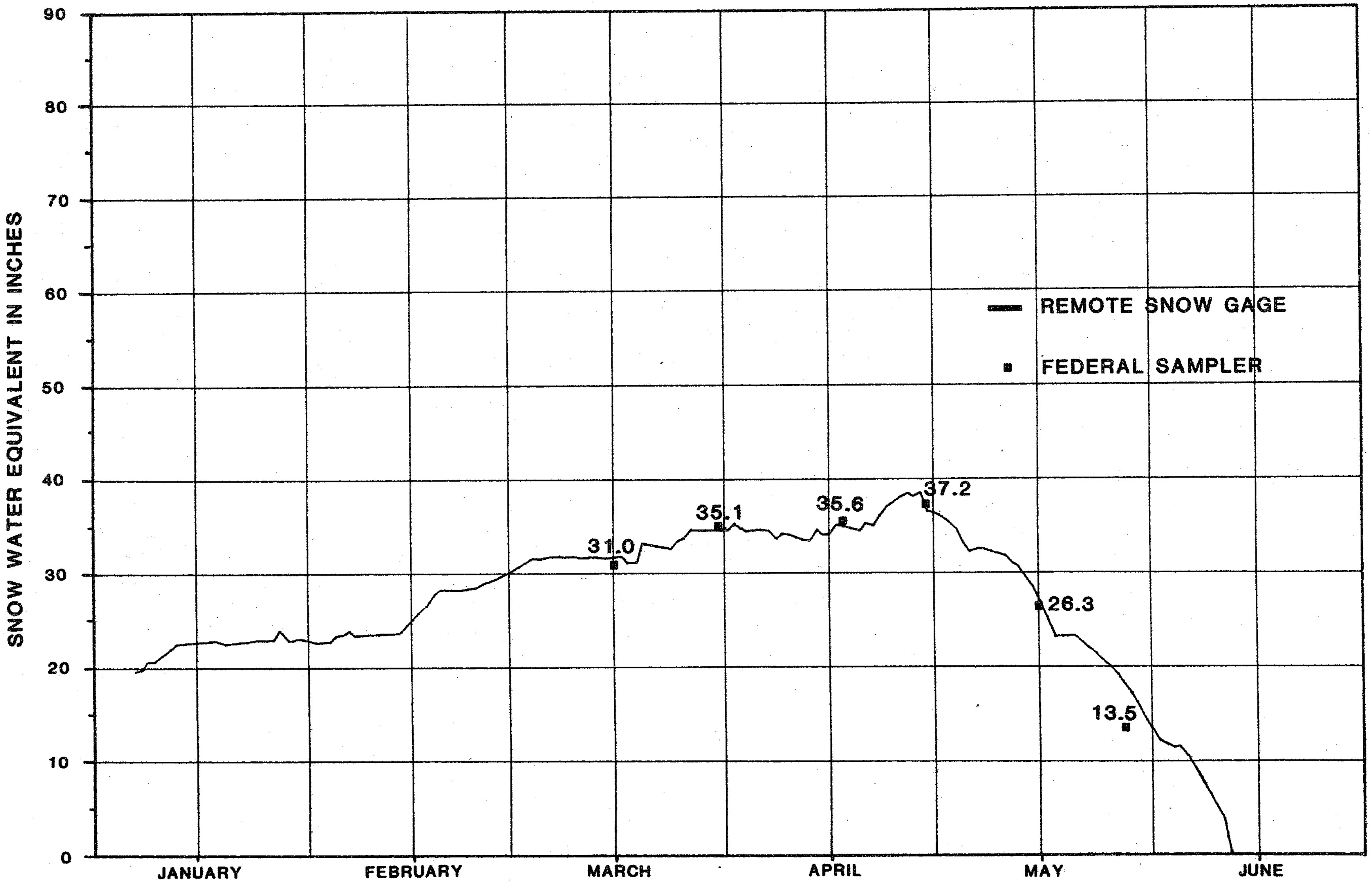

PROFILING SNOW GAGE
NOISY BASIN, MONTANA
Date: 3/2/75
Depth: 106 inches
S.W.E.: 33.28 inches
Ave. Density: 31.4%
160
140
120
100
80
60
40
20
0
10
20
30
40
50
SNOW DEPTH IN INCHES
SNOW DENSITY IN PERCENT

FIGURE 1



TRINITY, IDAHO 1976

FIGURE 2

## COMPARISON DATA FROM
## LICK CREEK, MONTANA

### 1983 Water Year-Inches SWE

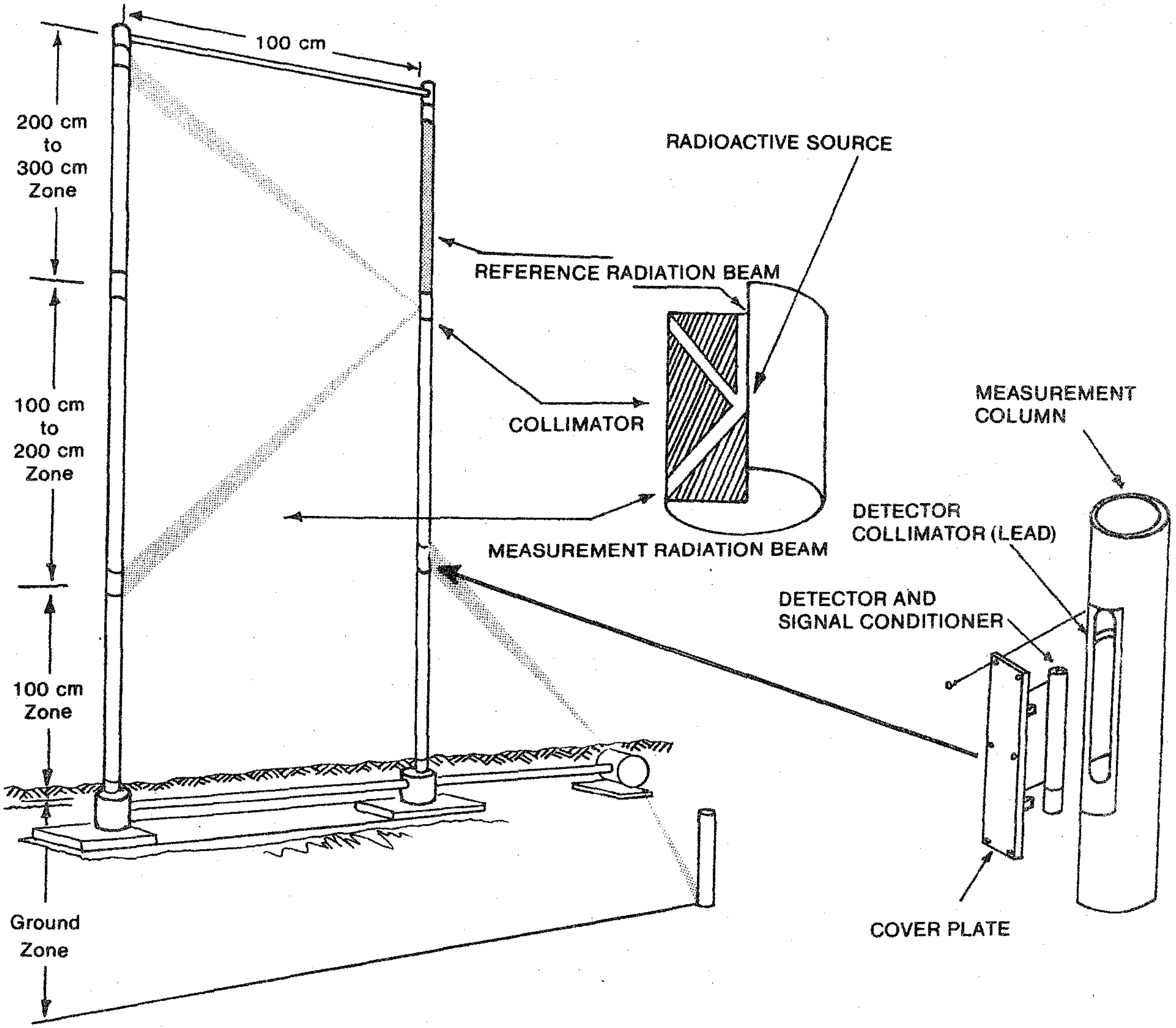
| Date | Corrected Snow Course | Pillow Manometer | RSG Reading |
|---|---|---|---|
| 12-27 | 5.1 | 4.1 | 4.4 |
| 1-26 | 4.8 | 4.2 | 5.4 |
| 2-28 | 6.1 | 5.5 | 6.5 |
| 3-29 | 8.8 | 9.5 | 8.1 |
| 4-28 | 9.0 | 8.4 | 7.7 |
| 5-12 | 8.4 | 7.2 | 4.3* |
| 5-27 | 2.3 | 0.2 | 0.0* |

### 1984 Water Year - Inches SWE

| Date | Corrected Snow Course | Pillow Manometer | RSG Reading |
|---|---|---|---|
| 12-27 | 3.5 | 3.7 | 5.0 |
| 1-26 | 5.6 | 4.3 | 6.6 |
| 2-27 | 8.4 | 6.3 | 6.9 |
| 3-27 | 11.4 | 9.5 | 10.4 |

* Reading not adjusted for loss of SWE due to sun cupping.

FIGURE 3



**RSG - 1A - S SNOW GAGE**

**RSG DETECTOR ASSEMBLY**

Fig. 4