Deep Snow Measurements Suggested Using Cosmic Radiation

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The attenuation of highly penetrating cosmic radiation shows promise as a means of measuring the water equivalent of snow cover. The attenuation of cosmic radiation by water is sufficient to make the method practicable, especially for deep snow. As an example, statistical counting errors in a two-detector setup (using 10 cm by 10 cm NaI(Tl) scintillation detectors, one above the snow and one beneath the snow) would produce a water equivalent measurement accuracy of better than 1% in measuring 100 cm of water with a 24-hour measurement time.

The inventory of water resources in deep snow covers is of critical importance in many areas of the world. The accurate measurement of water equivalent at a site, especially by automated unmanned equipment, is an important factor in effective river forecasting and water resource management. During the last 2 decades, several water equivalent measurement methods capable of automation have been considered. These include (1) pressure sensing devices such as snow pillows [*Beaumont*, 1965; *California Department of Water Resources*, 1969], (2) radionuclear devices measuring attenuation of gamma radiation by snow intervening between an artificial radioactive source and a detector [*U.S. Army Corps of Engineers*, 1955; *Smith et al.*, 1970], (3) radionuclear devices monitoring snow attenuation of gamma radiation from natural radioisotopes in the soil [*Bissell and Peck*, 1973], and (4) radionuclear devices profiling snow density through backscattering of X rays [*Blincow and Dominey*, 1974].

A new method was proposed in 1973 by *Bissell and Peck* [1974] that uses highly penetrating cosmic radiation, inferring the water equivalent of a snow cover by the degree to which it attenuates the cosmic radiation. Counts produced in a NaI(Tl) scintillation detector by gamma rays greater than 3 MeV in energy were suggested, since counts at this energy range are due entirely to cosmic radiation for the application considered. The cosmic ray response of NaI(Tl) detectors is caused primarily by photons generated by cosmic ray interactions with nuclei present in the air, water, and soil or in the detector system itself [*Burson*, 1974].

Consequently, a NaI(Tl) detector was taken to Lake Mead, Nevada, and lowered to various depths to determine if the response to cosmic radiation was sufficiently reduced to provide meaningful measurements of typical deep snow water equivalents. The results given in Figure 1 show that attenuation is sufficient to make the method practicable. The attenuation curve for a detector placed at the water-soil interface would be expected to be only slightly different from that shown in Figure 1.

A typical automated snow measurement site might consist of one detector buried at some shallow depth in the soil and another suspended above the maximum expected depth of snow. The ground detector would provide two types of information: (1) all counts above 3 MeV would be counted, representative of the cosmic radiation flux as attenuated by the overlying snow cover, and (2) all counts below 3 MeV (or those in selected spectral windows) would be counted, representative of gamma flux from radioisotopes in the soil, changes in which are in turn representative of soil moisture changes in the vicinity of the detector. The influence of the buried detector in perturbing the natural soil moisture profile near it would need investigation. The detector suspended above the snow would also provide two types of information: (1) all counts above 3 MeV would be counted, representative of the cosmic radiation flux unattenuated by the snow cover (this value would serve as a 'control' to eliminate slight but critical variations in cosmic radiation due to barometric pressure, season, and time within the solar cycle), and (2) all counts below 3 MeV or those in selected spectral windows would be taken, representative of the natural terrestrial gamma radiation flux as attenuated by the snow cover. Such a setup would provide shallow snow measurements (up to about 50-cm water equivalent) by using the attenuation of terrestrial radiation and deep snow measurements by using cosmic

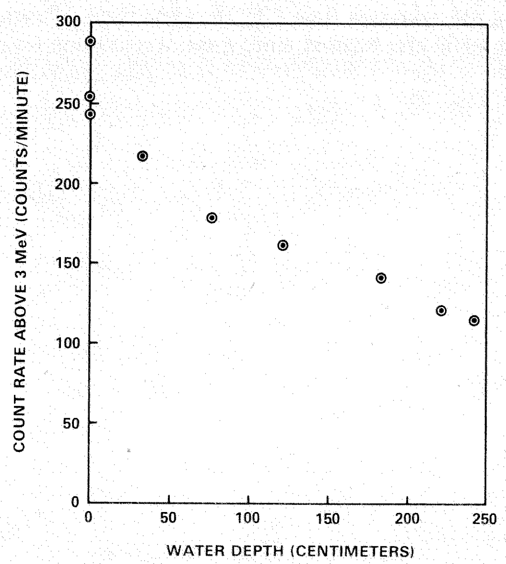

Fig. 1. Counts per minute above 3 MeV in a 10 by 10 cm NaI(Tl) crystal as a function of water depth in Lake Mead.

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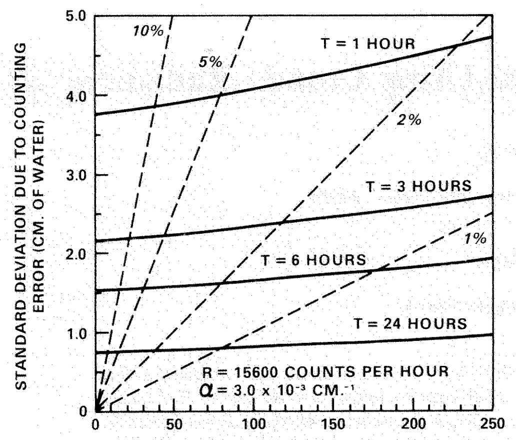

Fig. 2. Calculated standard error in centimeters of water of snow measurement using dual cosmic radiation detectors (one 10 by 10 cm NaI(Tl) scintillation crystal in each).

attenuation. Soil moisture estimates obtained with the ground detector would be a valuable additional product if the temporal variability of radon daughter product contributions is not too great.

For purposes of calculating the accuracy of the tandem cosmic detector setup the attenuation curve of Figure 1 was approximated by an exponential. Under the assumption that counting statistics errors dominated, the standard deviation of the estimated water equivalent was calculated as a function of counting times according to the following equation derived from probability theory:

$$\sigma_w = \frac{1}{\alpha}\left(\frac{1 + e^{\alpha w}}{RT}\right)^{1/2} \tag{1}$$

where w is the water equivalent, α is an attenuation coefficient, R is the counting rate, and T is the collection time. The relation (1) is plotted in Figure 2 for several values of T by using the rates R obtained with the 10 cm by 10 cm NaI(Tl) crystal at Lake Mead. The counting error in measuring 10 cm of water and 100 cm of water would be less than 10% and 1%, respectively, for 24-hour collection times. The effect of increasing the detector size can be inferred roughly from Figure 2 by increasing the collection time T by the same factor. Plastic scintillators could also be used, since spectral resolution would not be important for the cosmic ray component (above 3 MeV). Large plastic scintillators are inexpensive in relation to NaI(Tl).

The error given by (1) must be considered only as a guide, since the actual attenuation curve in Figure 1 is not quite exponential. Further, the error given by (1) must be considered a lower limit, since detector gain errors and attenuation curve parameter evaluation errors will also contribute to actual method error. Automatic gain stabilization would be required for the detectors. Gain stabilization was not utilized in the Lake Mead experiment, a spread in the data at the water surface thus resulting (Figure 1). Some on-site snow tube measurements would be required to 'calibrate' the attenuation curve.

The authors know of no immediate plans for design and fabrication of a prototype cosmic snow measurement detector. We hope that by this forum the cosmic snow measurement method will be brought to the attention of parties interested in its test, evaluation, and potential applications.

REFERENCES

Beaumont, R. T., Mt. Hood pressure pillow snow gage, *J. Appl. Meteorol.*, *4*, 626–631, 1965.

Bissell, V. C., and E. L. Peck, Monitoring snow water equivalent by using natural soil radioactivity, *Water Resour. Res.*, *9*(4), 885–890, 1973.

Bissell, V. C., and E. L. Peck, Measurement of snow at a remote site: Natural radioactivity technique, in *Proceedings of the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources*, U.S. National Academy of Sciences–National Research Council, Washington, D. C., 1974.

Blincow, D. W., and S. C. Dominey, A portable profiling snow gage, in *Proceedings of the 42nd Annual Meeting of the Western Snow Conference*, Western Snow Conference, Spokane, Wash., 1974.

Burson, Z. G., Airborne surveys of terrestrial gamma radiation in environmental research, *IEEE Trans. Nucl. Sci.*, *21*(1), 558–571, 1974.

California Department of Water Resources, Annual progress report on activities at the alpha instrument evaluation site–1969, State of Calif. Resour. Agency, Sacramento, Dec. 1969.

Smith, J. L., H. G. Halverson, and R. A. Jones, The profiling radioactive snow gage, in *Transactions of Isotopic Snow Gage Information Meeting*, pp. 17–47, Idaho Nuclear Energy Commission and USDA Soil Conservation Service, Sun Valley, Idaho, 1970.

U.S. Army Corps of Engineers, Development and test performance of radioisotope-radiotelemetering snow-gage equipment, *Civil Works Investment Proj. CWI-170*, 74 pp. + appendix, S. Pac. Div., San Francisco, Calif., 1955.

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