NUCLEAR TECHNIQUES APPLIED TO HYDROLOGY 1/ 604-76

By

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Introduction

Since the early 1950's the application of radiation principles to hydraulic measurements has been considered by resource management. While nuclear weapon and reactor scientists were using water as an absorbing shield or attenuator around intense radioactive sources, a few hydrologists recognized that this approach might well solve problems associated with measurements of water equivalent in the snowfields, and water content in the subsurface soil.

A little over a decade ago, Dr. James Smith[3], had assimilated enough data to recognize the potential of nuclear applications to snow hydrology and began a comprehensive evaluation program at the Central Sierra Snow Laboratory (CSSL).

By 1970 it had been demonstrated that the applications were not only practical and highly accurate, but that they were on the threshold of being reliable and cost effective.

With any practical measurement system there are disadvantages. With nuclear applications the major disadvantage appears to by psychological, since the nuclear age we are passing through carries with it the stigma of war and destruction. Richard Wilson[4] recently presented some thought provoking testimony regarding the use of nuclear power vs. alternative energy sources before the California Assembly. Regarding nuclear radiation releases:

1. Coal burning releases particulate nuclear radiation at a rate greater than any nuclear power plant.
2. Geothermal power plants release radon gas making the turbine room more radioactive than the turbine room in a nuclear plant.
3. There have been NO nuclear accidents in power stations which have caused a public health hazard.
4. From experience we can say that 40,000 to 70,000 people will die in car accidents this year.

While the use of isotopes in hydrology has no correlation to weapons or power reactors in a technical sense, the spin off is there as a psychological barrier, and the most difficult part of selling the practical application of these devices has been the relative RISK vs. BENEFIT achieved.

Radiation Safety

Much publicity has been generated regarding the harmful effect to biosystems from radiation releases by nuclear systems. What is being reported here refers to PARTICULATE radiation which is dispersed over the landscape by wind or water and which can find its way directly into the biosystem where it can and does have harmful effects.

In hydrology we are using electromagnetic signals (Figure 1) from encapsulated radioactive sources where the particulate radiation is trapped and has an infinitely small chance of ever entering the biosystems. Because there is a possibility of the small sources used in hydrology being misplaced or mishandled, certain regulatory constraints are imposed and routine checks are required to determine the integrity of encapsulated sources. This seems to be a small penalty to pay for the information produced by these devices.

Since we are all aware that nuclear radiation is present naturally in the earths crust, and constantly arriving from outer space, it is best to compare the radiation present in the general course of living to that presented at specific hydrologic stations currently utilizing radioactive isotopes.

1/ Presented at the Western Snow Conference, April 20-22, 1976, Calgary, Alberta

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Independent analysts have studied the source geometries being used in the field and have made the following comparisons:

1. If a camper pitched a tent between the two structural members of the gage and occupied the area for a week-end, his excess exposure would be approximately that experienced in living in a brick house as opposed to a wood house for a year; or the excess exposure experienced in jet travel at 35,000 feet flying from Seattle, Washington to New York City three times.[5]

2. "To reach a harmful dose of radiation from the RSG Series of snow gages, ridiculously long exposure times are necessary."[6]

It is not implied that there is absolutely nothing harmful about the use of radioactive sources in hydrology. Precautions are required to assure that the device is secure from inadvertent or accidental handling of exposed source material, and that theft or vandalism is discouraged. However if one is to compare the relative hazard to that of gaining access to a particular site by helicopter, snow mobile, skiis, or by foot, then the isotope usage is many orders of magnitude less hazardous.

Pilot Projects

As mentioned earlier, CSSL had demonstrated the potential value of nuclear snow gages by 1970. With this excellent source of information, we set out to demonstrate that practical working tools could be designed and built commercially and would perform in the hostile environments of the ever changing snow field.

The first two units built by our Company were installed in 1972. One was installed at the National Weather Service's Blue Canyon Observatory near Donner Summit in California. The installation had experienced some cable flooding problems the first year, but has been performing satisfactorily since.

The other unit was installed at the Trinity Site in Idaho on the Boise River Drainage. This particular sale was by no means an easy one. As you are aware, an inherent quality of snow surveyors is skepticism, sales resistance, independence of thought and action, and above all, experience in a unique environment. One other common denominator; they were all recruited from Missouri. The milestone for the 1972-73 snow season was not that there was successful performance with the Trinity Gage, but that Jack Wilson[7] tried it. (Fig. 2)

The Trinity Gage demonstrated several first approaches toward a viable system to predict the quantity of river runoff. The system was totally remote, on demand telemetry, and reporting water equivalent in a snowpack from multiple layers.

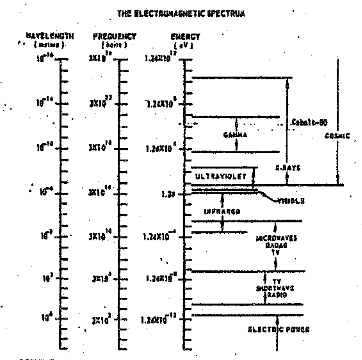
By the 1974-75 season, the inevitable Murphies problems had been solved, and the system has not failed to respond to interrogation since. In April, 1975 (Figure 3) the information was used operationally by the Bureau of Reclamation to adjust reservoir levels in the Boise River Drainage area. During the current 1975-76 runoff, the information is being used to confirm model accuracy in programs developed by the users. (Figure 4)

To further compliment CSSL's work on nuclear gaging, our Company designed and built three profiling gages. These gages are performing their second season of operation and the data are being utilized to better understand the structural properties of snow. The installations are in Montana, Colorado, and Switzerland. The INSTAAR[8] data will be the subject of another paper on this program.

To provide a simple and reliable tool for Prairie Hydrology, a third approach has been implemented. This gage utilizes naturally found radioactive materials. The source is placed on the ground surface in a preferred geometry with the detector placed in a single upright pole. (Figure 5) This system is not recommended for applications where the snow field exceeds 150 cm in depth or where the snow water equivalent exceeds 50 mm.

Counting the Clicks

From a data acquisition standpoint, nuclear systems present a distinct advantage. The basic information is all digital and the attenuation factors are exponential. What this



Type of Radiation	Wavelength Range* (meters)	Frequency Range (hertz)	Energy Range (eV)
Electric Power	∞ - 3×10^6	0 - 10^2	0 - 4.1×10^{-13}
Radio Waves	3×10^6 - 3×10^{-4}	10^2 - 10^{12}	4.1×10^{-13} - 4.1×10^{-3}
Infrared	3×10^{-4} - 7.6×10^{-7}	10^{12} - 4×10^{14}	4.1×10^{-3} - 1.6
Visible	7.6×10^{-7} - 3.8×10^{-7}	4×10^{14} - 7.9×10^{14}	1.6 - 3.3
Ultraviolet	3.8×10^{-7} - 3×10^{-9}	7.9×10^{14} - 10^{17}	3.3 - 410
X Rays	1.2×10^{-7} - 4.1×10^{-12}	2.5×10^{15} - 7.3×10^{19}	10 - 3×10^{5}
Gamma Rays	1.5×10^{-10} - 1.2×10^{-15}	2×10^{18} - 2.5×10^{23}	8×10^{3} - 10^{9}
Cosmic Rays	1.2×10^{-7} - ---	2.5×10^{15} - ---	10 - ---

*Ranges are approximate; no exact end points exist.

FIGURE 1

Pg 50 Radiological Health Handbook, U S Department of Health and Welfare

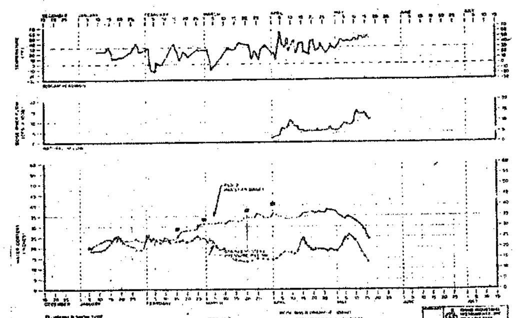


FIGURE 4

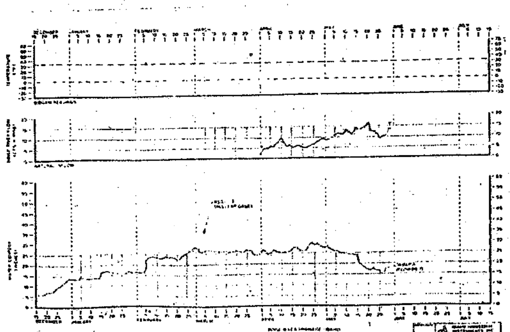


FIGURE 2

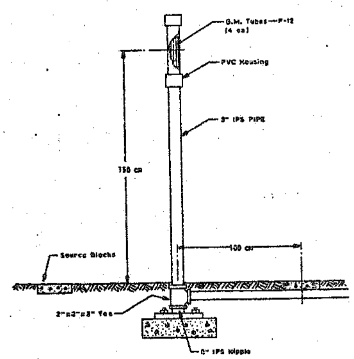


FIGURE 5

LSG-1 ELEVATION VIEW

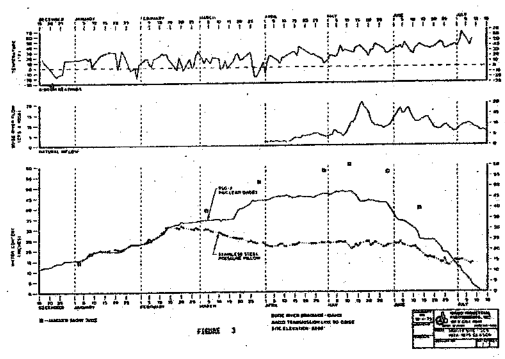


FIGURE 3

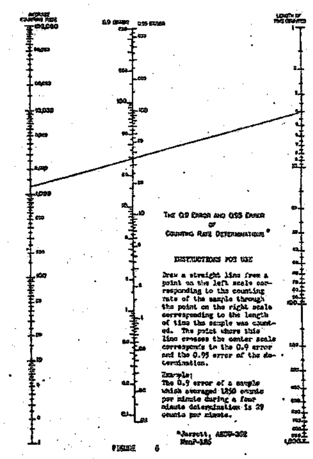


FIGURE 6

does from a measurement standpoint is to eliminate the inevitable temperature coefficients in analog systems and to establish a standard curve that can be used for all systems.

Everyone is familiar with the audio output of Geiger Counters since they have gained notoriety in almost every doomsday movie or television program expounding the hazard of nuclear systems. For hydrology measurements, we have only to count the clicks. The more moisture between the source and detector, the fewer the clicks.

Another pronounced advantage of nuclear measurements is the ability to select the accuracy range by merely extending the click counting. The more clicks you start with, the more accurate will be the measurement. (Figures 6 & 7, Statistical Counting Error)

The decision on required accuracy must be determined from the available power supply since to count longer, obviously one must consume more energy. On the systems operating in the field, it has been felt that a 1% measurement was adequate for most applications. This 1% number comes from establishing a preset scaler count to 60,000 events. This system is measuring the output of a nuclear source through a known and unchanging media. For gages using Cobalt as the source, this is accomplished in the reference column where the measurement zone is in air. (Figure 8, Zig Zag Reference) This preset scaler controls all measurement zones. When the scaler reaches the selected value, i.e. 60,000 events, all other measurement scalers are shut down. Since the source is gradually decreasing in output, each measurement takes slightly longer to obtain. If the initial time to achieve the 60,000 counts with cobalt takes three minutes, the same 60,000 counts will take six minutes in 5.2 years.

For the natural radiation (LSG) series of gages, the source decay is quite long (4.51×10^9 years) and no decay correction need be applied. In these systems the count period is controlled by specific time. For a 150 cm gage one can register approximately 30,000 events in 30 minutes, or 60,000 events in 60 minutes. If one wished to count for a day, the statistics would be based on approximately 1.5 million pulses. This would produce a very accurate measurement.

System Deficiencies

As was mentioned before, radiation is present everywhere. As the site elevation increases, background radiation also increases. This is because there is less air, thus less attenuation between the particular site and the major source of radiation, outer space. Different areas also have varied amounts of naturally found radiation sources present in the earths crust. The major contributors are uranium, thorium and potassium. There are, however, approximately forty isotopes which spontaneously emit electromagnetic signals ranging from the very light Helium-3 to the very heavy Uranium-238.

Since the objective from a safety standpoint is to have available no more radiation than is necessary to achieve a specific accuracy, it is prudent to minimize the isotopic inventory, while at the same time maintain the desired accuracy. This creates a situation where one must override the background contribution from a statistical counting standpoint, however must recognize that gallactic interference or site natural interference may have to be accounted for. For this reason we prefer to make the final adjustments to the system at the particular site.

Future Systems

The computer industry has revolutionized the electronics world. Every month some new innovation changes the systems design philosophy. Three years ago the state of the art was TTL logic with MIL SPEC components down to 40°C available. Two years ago CMOS logic was available offering higher noise immunity and a drop in power consumption by a factor of one hundred. On the horizon are economically attractive miniprocessor chips which will integrate several hundred standard chips into an assembly the size of a cigarette package. With any commercial product, the market determines the cost effectiveness of the approach. While snow hydrology does not present a sizeable market for miniprocessor applications, it may be that future units will be adaptable to these techniques without the $20,000 first unit cost.

The largest single deficit in the current remote hydrology system is the reliability and performance of the power supply under widely changing temperature extremes.

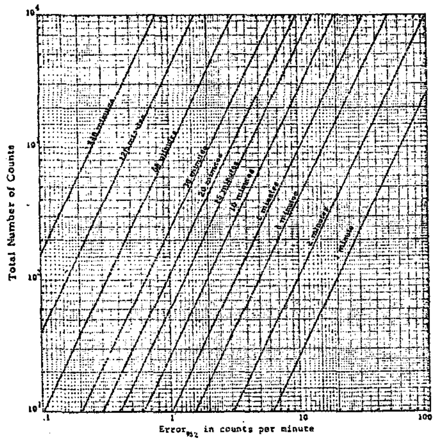
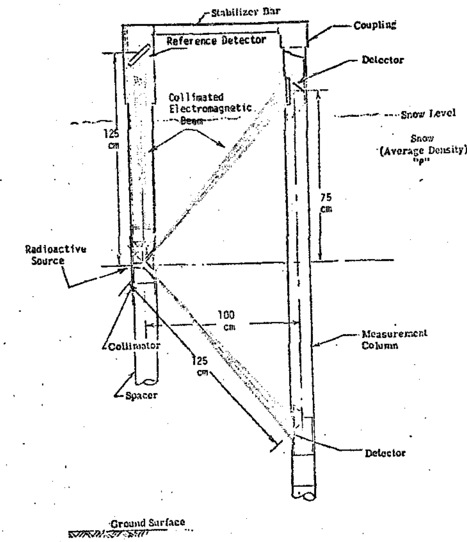


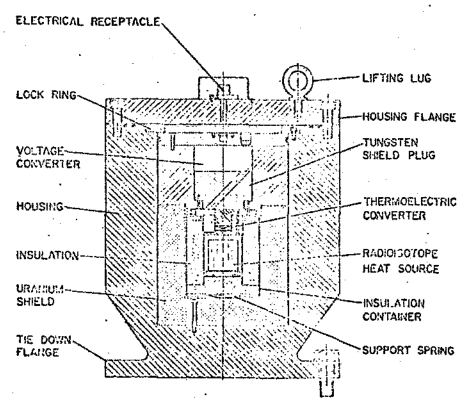
FIGURE 7



ZIG-ZAG REFERENCE GEOMETRY

DETAIL OF UPPER SOURCE COLLIMATOR PIPE ARRAY AND DETECTOR RELATIONSHIP

FIGURE 8



ONE WATT RADIOISOTOPE THERMOELECTRIC GENERATOR

Gulf General Atomic Model

FIGURE 9

Present systems use modest battery packs with solar cell rechargers. The systems now in use can sustain themselves annually provided they can receive an average of five hours of sunlight a week. This becomes difficult in the more northern regions where storms tend to blanket the solar cell and the daylight hours are limited during the dark winter months. An inherent weakness of the solar cell is the lifetime of the light sensitive circuit. Their output diminishes if any moisture finds its way into the sensitive diodes.

A very real solution to this problem would be the adaptation of nuclear waste products to thermoelectric generators. A one-half watt continuous electrical output system coupled with a battery could sustain a station for thirty years at an estimated cost of 6% of the present cost. A bonus from this approach is the thermal output of the isotope. For every watt of electrical output, approximately ten watts of thermal heat is available to maintain constant temperatures in critical areas of the system. (Figure 9)

Conclusions

The increasing importance of accurate, reliable, and timely snowfield data has been amplified by the energy crisis. Hydrologic science has become the most important program in todays long list of priorities. Tomorrows shortages in energy can become secondary problems if we do not manage our water resources wisely.

This paper has attempted to give a glimpse of where we have been, where we are, and where we can be by utilization of very fundamental nuclear measurement techniques. It is hoped that a clearer understanding of the principles, a reduced fear of the limited hazard, and an insight into the potential benefits have been presented.

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