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REMOTE SENSING OF SOIL WATER CONTENT: NATURAL TERRESTRIAL RADIATION ATTENUATION TECHNIQUE

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ABSTRACT

All rocks and soils are radioactive and emit gamma radiation. Since water is an effective absorber of gamma rays, the gamma flux of a soil will be attenuated in relation to soil water content. The paper evaluates the natural gamma flux technique based on a study conducted during the summer of 1985. Gamma measurements were made over four sites and a pond on twelve dates. One site was a sandy soil while the other three were replicates of a silt loam soil. In addition, mean areal gamma measurements were taken over an 800 meter strip of the silt loam soil. A background experiment was also conducted.

The appeal of a remote technique to determine soil water content would be to obtain a relatively inexpensive, non-destructive measurement. Applications include situations where repeated measurements would be required such as tillage, drainage, and crop production research, and irrigation scheduling. The experimental results indicated that the thorium and stripped potassium gamma energy windows could be used effectively to infer soil water content.

INTRODUCTION

Soil water content is one of the most important parameters for crop production and tillage operations. The current techniques for determining soil water content such as the neutron probe, tensiometer, resistance blocks, and gravimetric sampling are all relatively difficult or time consuming measurements. In addition, the above methods are point measurements that involve some degree of disturbance or destruction. Applications for a remote sensing method would be in situations where repeated measurements of soil water content were required such as in tillage, drainage, or crop production research and irrigation scheduling. The purpose of this study was to examine the usefulness and limitations of using the change in natural gamma radiation flux to remotely sense soil water content.

All rocks and soils are radioactive and emit gamma radiation. Since water is an effective absorber of gamma rays, the gamma flux of a soil will be attenuated in relation to a surface snow layer. In the 1960's, researchers in the Soviet Union (Zotimov, 1965, and Kogan et al., 1965) developed procedures to use this concept to remotely determine snow depth. Additional research was conducted in the United States and Canada in the 1970's (Grasty et al., 1974). Aerial snow surveys using the natural gamma attenuation technique have been operational in the Soviet Union since the late 1960's and in the United States since the late 1970's (Peck, 1978). Zotimov (1971) recognized the potential of this technique to determine soil water content since the surface gamma flux is also a function of soil water content. Additional research has been conducted in the United States using aerial gamma measurement to determine soil water content (Feimster and Fritzsche, 1975, and Carroll, 1981). A Canadian study (Loijens, 1980) used a portable four channel gamma spectrometer to make ground based measurements of soil moisture.

THEORY

The three major sources of radioactivity in rocks and soils are uranium, thorium, and potassium-40. Uranium and thorium decay into lead through a complex series of unstable daughter products. Potassium-40 decays directly by beta(+) decay into argon or beta(-) decay into calcium. Since the alpha and beta decay particles are not very penetrating, from a remote sensing standpoint only the very penetrating electromagnetic gamma products of decay are important. The concentration of nuclides in a soil is a function of the parent material. According to Zotimov (1968), the top 30 cm of the soil accounts for 95 percent of the surface gamma flux.

For any location, the parent nuclide source strength can be considered constant due to the very long half lives involved. As a general theoretical position, the ratios of parent and daughter nuclides are in equilibrium. However, one of the daughters of the uranium decay series is radon gas which has a half life of approximately 4 days and is subject to considerable movement.

Radioactive decay involves discrete and characteristic emissions. All radioactive nuclei follow the radioactive decay law which states that the probability that an unstable nucleus decays is the same at any instant. Thus for a large population of unstable nuclei, the process of decay is probabilistic, closely following a Poison distribution, and therefore subject to inherent statistical fluctuation. The gamma energies of interest from soils range from around 0.4 to 3.0 mega electron volts (MeV). A typical natural gamma spectrum and the regions of interest are shown on Figure 1.

GAMMA RADIATION DETECTION AND MEASUREMENT

Since gamma rays are invisible to normal human senses, a detector must be used to convert the radiation to a measurable form. The most suitable detector for our study was a thallium activated sodium iodide (NaI) detector. A gamma photon interacts with the NaI crystal causing scintillation emissions of photons in the visible portion of the spectrum. The detector is formed by optically coupling the crystal to

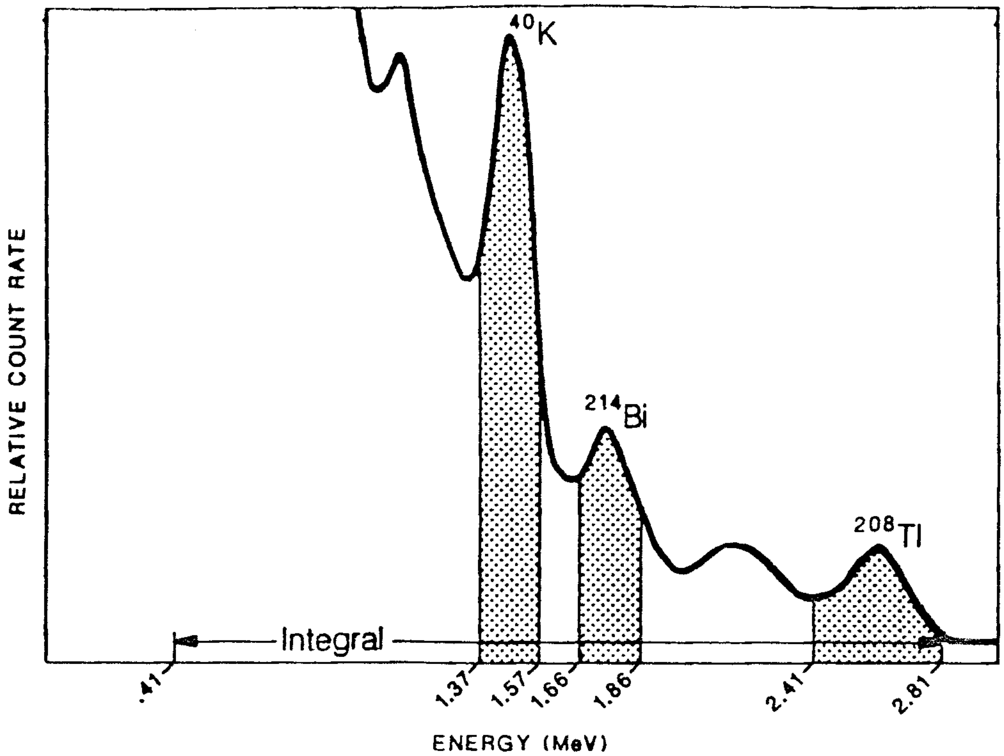

Figure 1. Natural gamma spectrum and windows.

a photomultiplier (PM) tube, which produces a corresponding electrical output. Although the linearity of PM tubes is very good, the energy resolution is limited by the statistical fluctuation inherent to the PM amplification process. For the gamma energies of interest, the initial interactions with the crystal would be single or multiple Compton scattering followed by photo electric absorption. Since these interactions occur in less than a nano-second, a gamma photon would be seen as a single burst of energy. The finite size of a crystal means that there is a chance that a scattered photon will escape, resulting in a continuum of energies recorded below a full energy peak.

FIELD EXPERIMENT

There are two distinct methods of evaluating the gamma flux of the soil. The simplest is the integral window method which simply counts the gamma photon without regard to photon energy. The integral window was the method employed by Loijens (1980). There are two apparent advantages to using the integral window. First, measuring equipment can be relatively simple, and second, high count rates are possible, thus requiring shorter measurement times and providing more favorable counting statistics. However, there are some questions generated by the literature concerning the reliability of the integral window method. These questions were examined over the course of the study.

The second method is gamma spectroscopy in which photon energies as well as count rates are recorded. Spectroscopy allows for the photon emissions to be related to specific physical processes. As a result, more procedures are available to account for unwanted spectral contributions. In our study, the full gamma spectra were recorded using a Canberra Series 10 portable multi-channel analyzer (MCA) and transferred to cassette tapes for future analysis. The system schematic is shown in Figure 2.

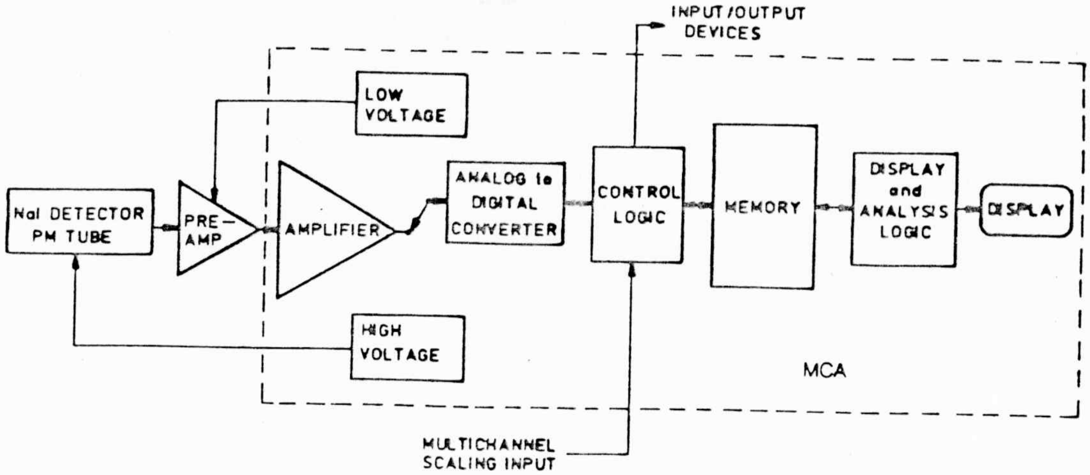

Figure 2. Instrumentation schematic.

The research site was a 1200 meter strip with an east-west orientation. The west 800 meters of the strip had been mapped as a Brookston silt loam. The east 400 meters contained a variety of soils, one of which was a Morocco loamy sand, and a pond. The soil types extended well beyond the borders of the strip. Three experimental sites spaced nearly equally apart were selected in the Brookston silt loam. A fourth site on the Morocoo loamy sand was established in the east end of the strip.

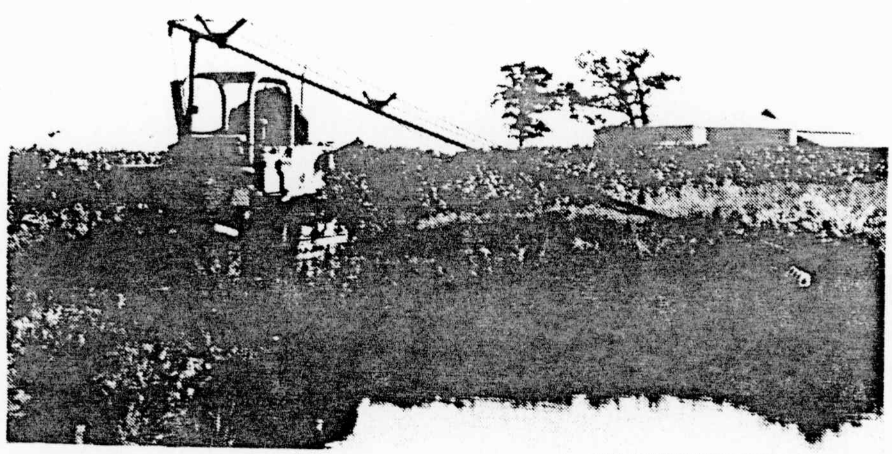

Figure 3. Background gamma readings over pond.

In order to suspend the detector over the pond and crop canopy, a boom and work station were built and mounted on a crawler tractor. Most of the gamma spectrum measurements were recorded over a 10 minute period in order to provide reasonably high count rates. The first reading on each date that an experiment was conducted was taken with the boom in the full down position over the pond as shown in Figure 3. The second reading was taken in a continuous mode over the 800 meter silt loam strip with the detector supported at a height of 6 meters. Three 10 minute readings were then taken at each of the 4 sites. Concurrent with the gamma measurements, soil samples were taken at each site at 0-10, 0-20 and 0-30 cm depths. The soil samples were weighed immediately after collection and oven dried at 105 degrees Celsius for a minimum of 48 hours. The instrumentation was also mounted on an ultralight aircraft as shown in Figure 4 to evaluate the feasibility of this method of data collection. The field equipment and instrumentation are shown in Figures 5 and 6.

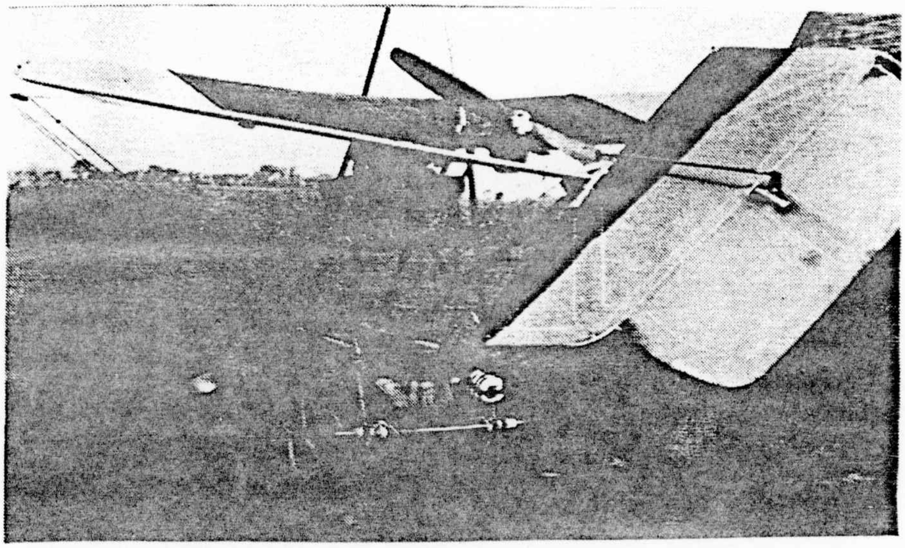

Figure 4. Instrumentation mounted on an ultralight.

ANALYSIS AND RESULTS

A gamma spectrum recorded over soil will include the signal from non-soil sources. These include secondary cosmic rays, intrinsic radioactivity from the experimental equipment, and airborne sources. For the purposes of our study, cosmic and equipment contributions could be considered constant. The primary airborne source is radon gas whose concentration is variable. Since the thorium window energies are higher, radon has no effect. The radon contribution was removed from the potassium window by a calibrated stripping function using the uranium window. For the integral window, background including radon was determined by a reading over water. This was also the method used by Joijens (1980).

In order to examine the reliability of the background measurements, an ancillary experiment was conducted. Continuous background readings were recorded on 4 dates. A sample is given in Figure 7. The experiment indicated that the background variation was sufficient to mask any useful information that could be obtained from the integral window.

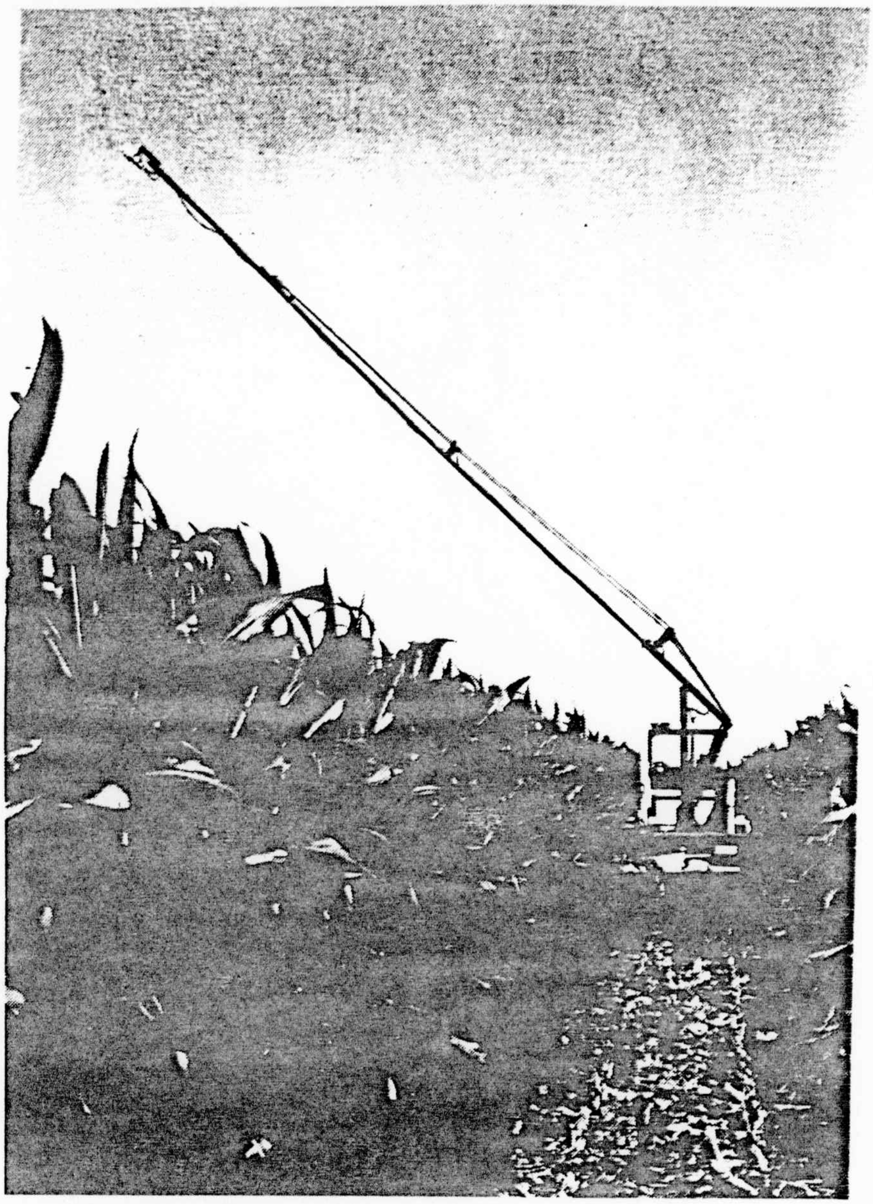

Figure 5. Boom over corn.

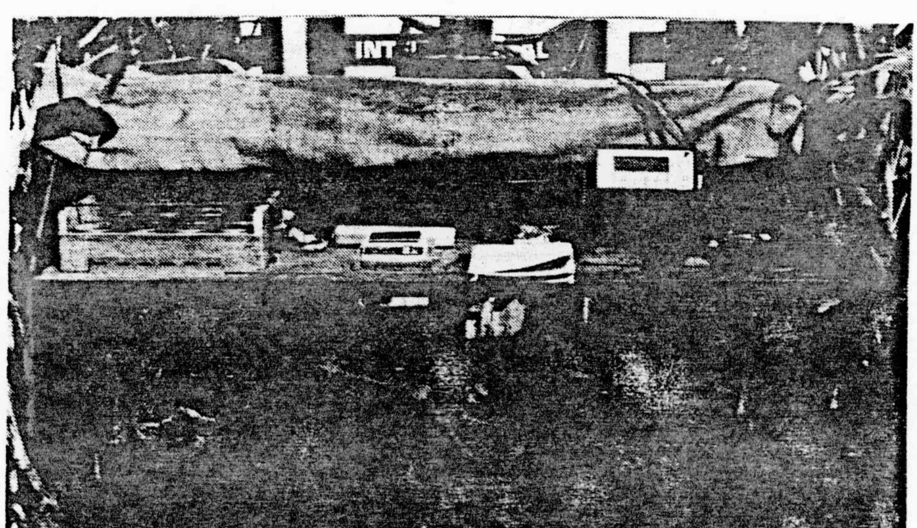

Figure 6. Field instrumentation.

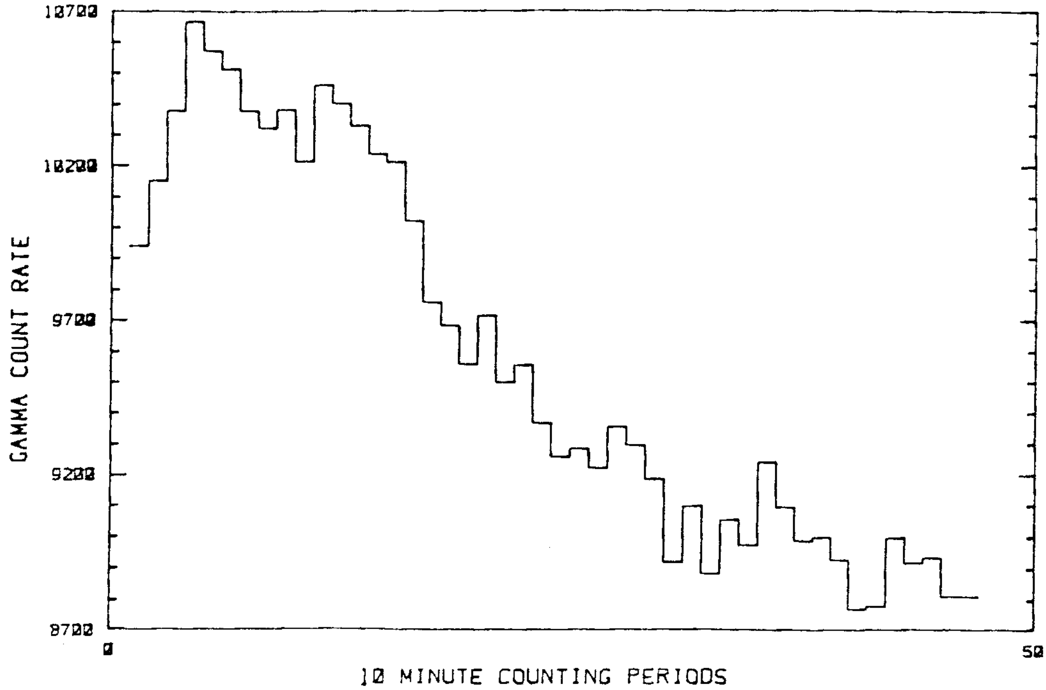

Figure 7. Gamma background readings.

Results from the thorium window and versions of the potassium window are given in Table 1 with an example shown in Figure 8. Indicator variables were introduced into the regression analysis to partially account for water content differences due to soil profile changes. The use of profile indicators was particularly important for the sandy soil site. The theoretical estimated standard error values (RMS) were calculated from the counting statistics. The RMS values for the thorium and continuous strip potassium windows were very close to the theoretical values. The other results contain a higher error contribution from the gravimetric sampling and site anomalies. Gamma measurements can be made from an ultralight and would be useful for soil water content determination if flying height is measured and controlled.

Table 1. Results from thorium and potassium windows

Site(s)	Nuclide	Depth (cm)	Ave. Count	Time (min)	R^2 Simple	R^2 Profile	RMS Data	RMS Theory
Strip	K-40	20	3702	20	.870		1.47	1.87
Silt*	Tl-208	20	3792	90	.833		1.79	1.62
Silt*	K-40	20	17238	90	.752		2.13	0.87
Silt	K-40	10	5795	30	.660	.755	2.60	1.49
Silt	K-40	20	5795	30	.603	.643	2.57	1.49
Silt	K-40	30	5795	30	.551	.590	2.54	1.49
Sand	K-40	20	5620	30	.472	.831	1.75	1.46

* Summed results

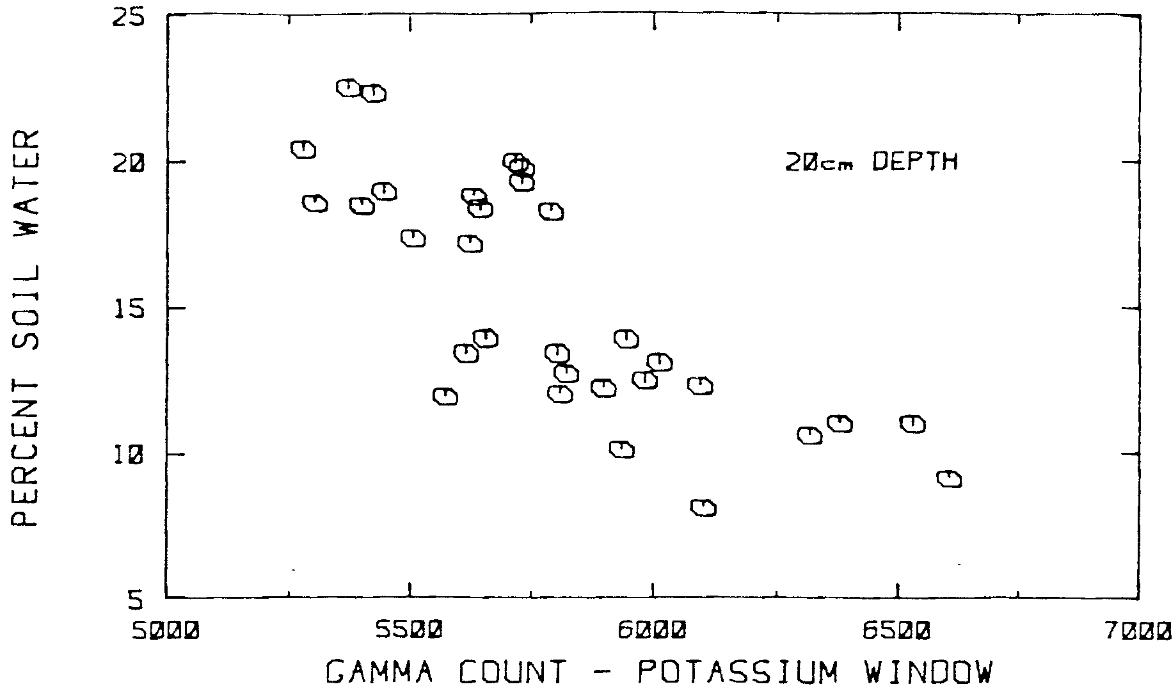

Figure 8. Example of potassium window results.

CONCLUSIONS

On the basis of the study the following conclusions can be made:

1. The thorium window can be used to infer soil water content but long counting times are required.

2. The potassium window can be used to infer soil water content but requires a two-channel analyzer for stripping the uranium contribution.

3. The accuracy of the technique is controlled primarily by counting statistics, and its use is limited by instrumentation expense and counting time requirements.

4. A method of obtaining frequent background readings is required before advantage can be taken of the high count rates and simple instrumentation available with the integral window.

5. Further research is required to establish operational sensor calibrations and base soil radioactivity.

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