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Factors influencing in situ gamma-ray measurements

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Introduction
In situ passive gamma-ray sensors are very well suitable for mapping physical soil properties. In order to make a qualitative sound soil map, high quality input parameters for calibration are required. This paper will focus on the factors that affect the output of in situ passive gamma-ray sensors, the primary source, soil, not taken into account.

Factors
The gamma-ray spectrum contains information of naturally occurring nuclides 40K, 238U and 232Th and man-made nuclides like 137Cs, as well as the total count rate. Factors that influence the concentration of these nuclides and the count rate can be classified in 3 categories. These are sensor design, environmental conditions and operational circumstances.

Sensor design
The main elements of an in situ gamma-ray sensor that influence the outcome and quality of the output are the crystal and the spectrum analysis method. Material and size of the crystal determine the energy resolution. Though widely used, NaI crystals are not the most efficient capturer of gamma radiation. Alternatives are BGO and CsI. BGO has a low peak resolution, which prohibits use in cases where man-made nuclides are subject of interest. The material is expensive and prone to temperature instability. CsI is robust compared to NaI and BGO. The density of CsI is higher than NaI, yielding better efficiency, especially for smaller crystal sizes. More volume results in higher energy efficiency.

The reduction of the measured spectral information into concentration of radionuclides is mostly done using the Windows analysis method. In Windows, the activities of the nuclides are found by summing the intensities of the spectrum found in a certain interval surrounding a peak. A major flaw of the Windows method is the limited amount of spectral information that is incorporated into the analysis. Another weakness is the inherent use of ‘stripping factors’ to account for contributions of radiation from nuclide A into the peak of nuclide B. This can be overcome using Full Spectrum Analysis (FSA). This method incorporates virtually all data present in the measured gamma spectrum. In FSA, a Chi-squared algorithm is used to fit a set of “Standard Spectra” to the measured spectrum. The uncertainty in the FSA method is at least a factor 2 lower compared to the Windows method.

Environmental conditions
Environmental conditions can influence the signal output and therefore the quality. In general, the density of the medium through which gamma-radiation travels determines the interaction of the radiation with matter and thus affects the sensor readings. Excluding soil as being the source; water is the most important external factor in this respect. The amount of water in soil will affect the signal. In general, energy loss occurs as water content in soil increases. As a result, the nuclide concentrations will be lower. Monte Carlo simulations show a difference of 16% in nuclide concentration for completely dry and fully saturated sandy soils. Another water related issue is rainfall. With rain radon gas, a product of 238U, will precipitate. This causes spectral noise effects. Snow and fog have the same effect to a minor degree. Another aspect is the openness of soil. From experience we know that the concentration of 40K differs if soil is tilled. Finally, on earth there is always radioactive noise present from the galaxy. The “Standard Spectra” used in the FSA method can take noise and geometric effects into account.

Operational circumstances

During a survey an operator should be aware of the effects of driving speed and measurement height. In general, a larger crystal has better energy efficiency and is therefore more suitable for high speed. E.g. a 70 x 150 mm CsI crystal provides qualitative satisfactory output for soil mapping up to 10 km/hr. Sample locations, however, are best measured during a longer period (3 to 5 minutes). The measurement height affects the measurement resolution; the lower the sensor, the smaller the measured area. In addition, Monte Carlo simulations show that the mass of the survey vehicle has to be taken into account. A large tractor e.g. can lead to spectral shape disruptions of 5 to 10%.

Conclusion

Several factors can effect the measured concentrations of radioactive nuclides. Potential users should take mentioned factors into account in respect to their needs when building and applying gamma-ray sensors. For purposes of soil mapping the use of FSA method is preferred, as it incorporates several disturbing factors. This allows the user to create a consistent dataset which will lead to a better understanding of the relation between nuclide concentrations and physical soil properties.