THE RADIOMETRIC METHOD

Preface

The following emphasises field practice. Such fundamentals as the radioactive decay series are not dealt with here.

1. Principle

The radiometric instrument measures the level of gamma radiation by recording the flashes of light, or ‘scintillations’ that occur when a gamma ray impinges on a special crystal called, a “phosphor”. The brilliance of the flash is proportional to the gamma ray’s energy and each scintillation is detected by a photomultiplier tube that converts the light into a voltage pulse. Since the value of voltage is directly related to the energy, a “spectrum’ of energy levels can be developed and particular elements distinguished.

2. Common Sources of Radiation

Sources can be natural and artificial. The natural gamma radiation that is measured, emanates from many rock types, those containing uranium and potassium being most active including granites, shales and clays, and from radon gas in the atmosphere as a by-product of uranium. Also, cosmic radiation forms a ‘background’ level.

Artificial sources include detecting leakage from reactors and isotopes used as tracers. The latter have generally much higher energy levels than natural sources.

3. Applications

The radiometric method has a number of applications.

1. Obviously it is most applicable to the direct search for uranium.
2. Since many rocks are naturally radioactive to characteristic degrees, the method is suitable to map geology by way of distinguishing different rock types. Indeed the method works more on the chemical response than the physical properties of the rock. In this way different rock types and different phases may be distinguishable when they are not visually.
3. Since gamma rays cannot penetrate more than ~½ metre of rock, the natural response from rocks is however, limited to this order of depth. The method is therefore able to map only the very near surface. In this way, it is useful in agriculture in mapping different soil types.
4. It can detect faults that act as conduits for radiation in the form of radon gas to escape to the surface.
5. Another important application of the method is its ability to determine the actual concentration of the radioactive elements and so ‘assay’ quantitatively rocks or drill-core, in situ, if necessary. This can be quicker than having assays done in a geochemical laboratory and may be sufficient. See section 8.
6. The progress of radioactive tracers used to define rate of flow of liquids can be monitored using radiometric instruments.
7. Contamination in soil from leakage from nuclear reactors.
8. The presence of radioactive radon gas can be a precursor to earthquakes.

4. Instrumentation

The phosphor crystal and the photomultiplier tube (PMT) constitute the 'sensor' and another 'console' contains the high voltage power supply for the PMT and electronics to register the voltage and display the 'count rate'. The whole sequence of one count lasts only a few microseconds. Time intervals for the accumulation of readings to obtain good statistics (See section 5) can be pre-set.

The display is commonly digital with LCDs or dials in older units. An audible output is also often provided. The crystal is commonly sodium iodide (Na I) that is 'doped' with Thallium to improve its response.

One type of instrument is a Scintillometer, which measures the maximum count rate at specified energy levels. The highest energy level provides the 'total count'.

A more advanced instrument is a Spectrometer, which incorporates a pulse-height analyser to measure count rates in specified 'windows' or 'channels' of energy. By choosing appropriate channels, the specific energy levels that characterise elements of interest can be identified. The elements most often measured are Potassium, Uranium and Thorium. A spectrometer that measures these three elements and total count is a 4-channel type. A 256-channel spectrometer records the entire energy spectrum in much more detail but requires a bigger crystal volume to obtain sufficient counts in each channel. At least 8 litres is needed for this and since each litre weighs 4 kg, this 32 kg. crystal requires some form of transport such as a quad-bike or 4WD vehicle.
A hand-portable crystal usually has a volume of (only) 1-2 litres.

5. Statistics

Radioactive decay and in this case, gamma radiation is a random process and measurement over relatively short periods of time will not yield the true value of count rate (usually counts/sec –cps – or counts /min - cpm). It is possible for example, because of the randomness, that no disintegrations occur for a long period of time and then a burst of them happens in a shorter time. Clearly, the count time is too short if it is less than the time during when no rays impinge on the detector. In fact, the probability that a given period will give the true rate decreases as the measurement time decreases.

The statistical 'percentage error', E (%) (See notes on General Aspects of field work for more on errors) can be expressed as;

$$E(\%) = 100/\sqrt{n},$$ where 'n' = the number of counts collected in the time

Thus, for E to be 3% or less, the number of counts has to be 1000 or more. If the number of counts is 100, E = 10%, and for 10 counts, E= 32%, which is generally not good enough.

As the count rate for specific elements, such as Uranium and Thorium, is a lot less than for the Total Count, the period of count time has to be greater in these cases to obtain the same statistical error. To achieve a 3% error for Thorium, the worst case for count rates, can require a sample period of 20-30 minutes. Clearly, some compromise between time taken and accuracy often has to be made.

6. Site Geometry

Theoretically, and hence for calculations of element concentrations (See Section 8), it is assumed that measurements are taken on an infinite plane with uniform properties. In this case, the solid angle from the source to the detector is 2π. In practice, this means a flat, uniform area over a distance of about 5-10 m in all directions. (It depends on the detector height. See section 7).

This requirement does not hold if measurements are taken on the crest of a hill, against a cliff or in a valley. On the hill, the radiation from the surface will be less than for a flat surface as less radiation will reach the detector and against a cliff or in the valley more will be detected.

To maintain consistency of readings care should be taken to keep the surface geometry as constant as possible, or, if this is not possible, some corrections should be applied. In general such corrections can only be approximate. Milsom, Figure 4.3, gives some correction factors for various geometries.

Certainly the existence of varying surface geometry should be recorded in a 'Comments' column along with the reading.

7. Detector Height

The height of the detector above a surface will influence the size of area covered as the solid angle referred to in Section 6 will vary with height. The higher the detector, the more the area measured. This, in turn, interacts with the choice of station interval for maximum coverage. A wider station interval requires a higher position of the detector. It is important for consistency and comparability of readings that the height should not vary on a survey grid. However, raising the height overall may be one way to increase counts if it means encompassing more of a background source.

8. Radiometric Assaying.

As indicated in section 3, the method can be used to derive actual element concentrations. Uranium and Thorium concentrations are expressed in ppm and Potassium as a percentage. It is particularly important that the statistics be adequate for this, that is 3% or less (See section 5). That is, that the number of counts be at least 1000.

In some case this may take too long and a compromise of lesser accuracy accepted.
In one case of measurements on a sample of Serpentinite, less than 300 counts only were obtained after 20 minutes.

The values of concentration are derived by applying "concentration coefficients" to the count readings. These are specific to each instrument and are deduced from measurements made with the instrument on "pads" of known concentration of the 3 elements.

A set of such pads are available through the CSIRO and instrument companies provide a service of checking and if necessary, up-dating the coefficients for a particular instrument. Such pads also provide a constant value for checking the correct performance of an instrument.

9. Background Corrections

The radiometric method is affected by meteorological variations. Principally, the radioactive radon gas that forms a background level can be blown about by wind and it is also influenced by barometric pressure and temperature.

Rain can 'wash' the gas out of the air and so background may be reduced for a time after rainfall. Such events should be "commented' upon.

As radiation is strongly attenuated by water, the radiation from the soil and exposed rock can be greatly suppressed by standing water on the ground. This may be a temporary thing after rain.

As many of these influences cannot be quantified, actual corrections for them can generally not be made. In any case, at least in ground surveying, the influences are minor. The particular conditions at the time of the survey should at least be noted.

10. References

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Milsom....
SEG volume 1 Environmental & Engineering....