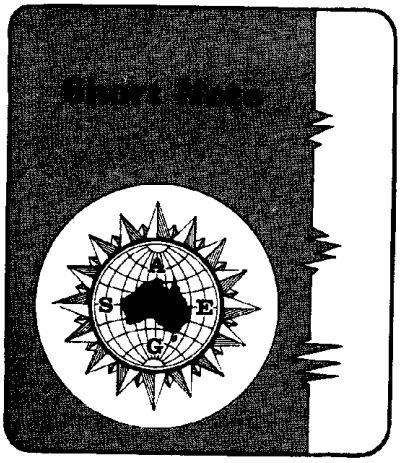

Total Count Gamma Ray Detection and Spectrometry

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This article possibly does not contain any new information. Neither is it a condemnation of gamma ray spectrometry or the use of large radiation crystals. It is intended to examine gamma ray detection comparing total count and spectrometry in several applications.

Figure 1 is a gamma ray spectrum of a sample of pitchblende with sections amplified to emphasise the peaks. Often the same result is obtained by using a linear scale for the energy level and a logrithmic scale for the counts. See Figure 2. Note that all the peaks above an energy level of 184 KeV (0.184 MeV) are due to bismuth 214. This is also the daughter product emitting the 1.76 MeV gamma ray used in field spectrometers today. Most total count scintillometers have a bottom energy detection level of 0.2 or 0.3 MeV. Therefore it suggests that Bismuth 214 is the only daughter product detected by scintillometers and also spectrometers that do not have a very low energy detection capability. This will be elaborated on later.
Turning next to Figure 3. This is the same spectrum as Figure 1 but drawn on double linear scales. Note the real amplitude of the 1.76 MeV "Uranium" peak. This is a very small percentage of the total counts emitted. Tests show it to be 1 to 2 per cent of total count. Hence by using a differential spectrometer on the 1.76 MeV peak we have reduced our detection sensitivity to about 1 per cent of total count. In practical terms a 2 inch by 2 inch crystal (50 x 50 mm) has approximately the same detection capability on total count as a 1000 cubic inch crystal has on the "Uranium" channel. Also both systems detect only Bismuth 214.

Why use spectrometry? If one is seeking uranium in an area where it has been shown that thorium and potassium are relatively minor, then spectrometry has very little application. Also it indicates that on a single channel spectrometer total count is a must for initial exploration. Using a single channel spectrometer on the 1.76 MeV peak reduces the chances of discovery of a weak anomaly by at least a factor of one hundred.

Having given much of the case against spectrometers (at least one more fact will be discussed later), the case for spectrometry will be considered.

For this we look not to the uranium spectrum of Figures 1 and 2 but to the spectra of Thorium and Potassium in Figure 2. Note that the spectrum for K40 cuts out at 1.6 MeV. It can therefore be stated that all gamma rays with an energy of greater than 1.6 MeV are from either thorium or uranium. The reverse is not correct, all energy below 1.6 MeV includes all potassium 40 energy but also it includes large numbers of uranium and thorium gamma rays, including the products of Compton scattering. Looking further the uranium spectrum ceases at approximately 2.4 MeV, so we can state that all energy above this level represents only thorium. Hence thorium can be uniquely indicated by energy above 2.4 MeV. Uranium is in the centre and cannot be uniquely indicated by an integral spectrometer as there are both uranium and thorium peaks in the interval 1.5 MeV to 2.4 MeV. Therefore a differential spectrometer is needed for uranium detection in the presence of thorium. To bring the value of the Thallium 208 "thorium" peak into perspective examine Figure 4. This is the spectrum of thorium drawn on a double linear scale. The Thallium 208 peak at 2.614 MeV is very similar in amplitude to the 1.76 MeV "Uranium" peak of Figure 2, so again it is about one per cent of the crystals detection ability if used in differential spectrometry. A further shortcoming of the choice of Bismuth 214 and Thallium 208 is that they both occur later in the decay chains than Radon and Thoron which, as gasses, can migrate and cause an "out of equilibrium" condition. That is, if the gas or emanation has escaped, Bismuth 214 and Thallium 208 do not represent the amount of uranium present. This problem is less serious for Thorium as Thoron has a half life of 54.4 seconds and so must disintegrate before travelling very far from its point of birth. Likewise the Uranium or thorium can be leached and so Bismuth 214 or Thallium 208 over indicates the amount of uranium or thorium present. Again Uranium 238 is more mobile than Thorium 232 and Uranium assays are more suspect than Thorium. The solution from the foregoing would appear to be to detect a gamma ray coming from U238. This is not feasible with sodium iodide detectors although possible with special solid state detectors such as lithium drifted Germanium. Note the presence of the two U235 peaks. If U235 is present and if the ore is to be useful for fission as it must be, this could be a useful indicator. I am not aware of any field spectrometers using the two U235 peaks.

Another approach is to use alpha or beta. Alpha detectors are not over robust and unfortunately geophysicists and geologists are. Beta detectors have strong possibilities and beta geiger counters were popular in the 1950 period. Uranium 238 and Thorium 232 do not emit beta but the early daughter products do, so they are more likely to be correct than gamma detectors. It is not the intention to

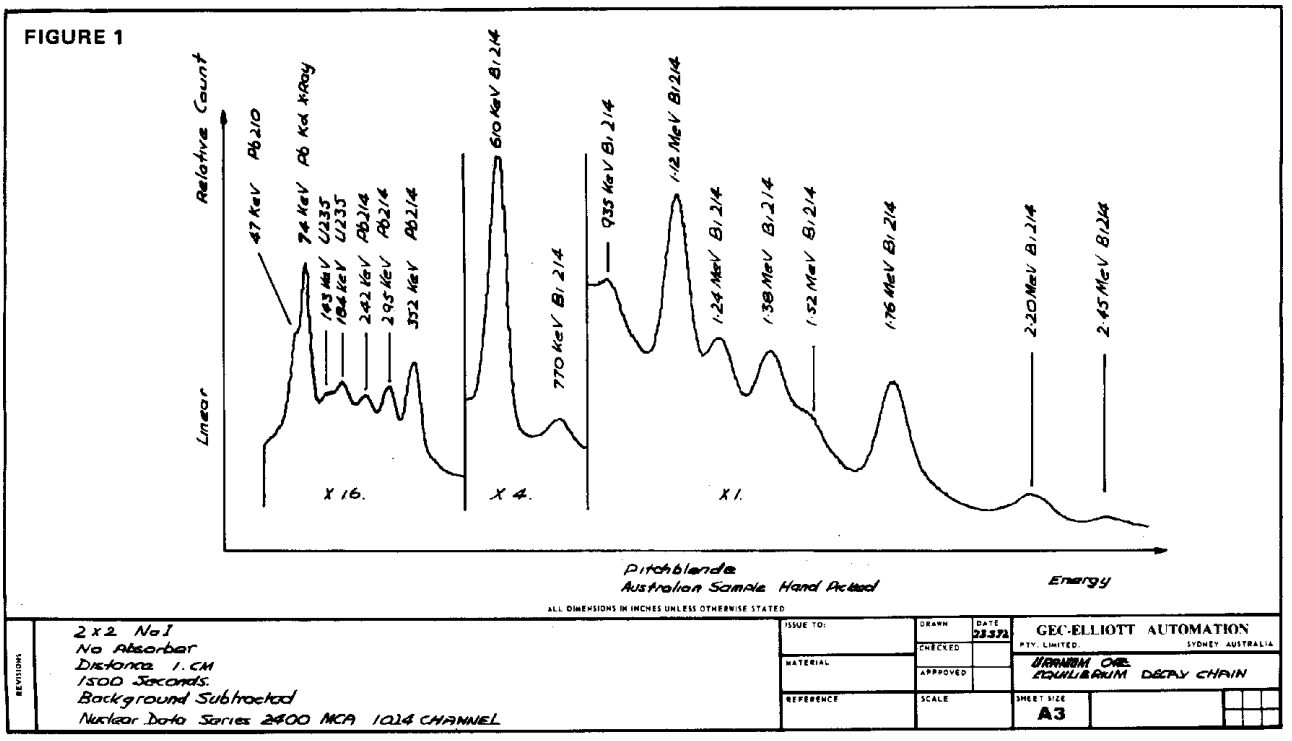
deal with beta detection in this talk, sufficient to bring attention to the work carried out by Eichholz *et al.* on assaying by simultaneous gamma and beta count and the later work on this by Daly & Urquart of the BMR. The author used this method for many years with a proven accuracy of ±10%. This method also gives an indication of equilibrium condition and thorium content. Attention must also be drawn to the work of Mero on use of the lower energy daughters of Uranium.

Having considered the results of complete spectra of Uranium and Thorium taken with Sodium Iodide detectors, consideration is now given to the properties of Sodium Iodide. Sodium iodide scintillometers first made their appearance in the 1950's and a patent (of doubtful value) was awarded in the U.S. on 4th June 1954. Airborne crystals of 30mm x 30mm were used and the author first used a 5 inch diameter by 2 inch thick crystal in 1956 and this crystal is still in use by the S.A. Dept. of Mines & Energy. Crystals have grown and 3000 cubic inches is now available (in DC3) and 1000 cubic inches is commonplace. Figure 5 is a plot of absorption of gamma rays against crystal thickness for various energy gamma rays. A thickness of one inch stops 90% of 0.2 MeV rays while 6 inches is necessary to stop the 2.62 Thorium rays. Figure 6 presents the same information in a different manner. Both indicate the high efficiency of detectors at lower energies. Considering the 1.76 MeV Uranium peak, 80% absorption is obtained with a thickness of 4 inches (10cms) and 90% by a 5.5 inch (14cms) thickness, an increase of 10% in efficiency for a thickness increase of 40%. This suggests that it is not economic to use a thickness greater than 4 inches to detect the 1.76 MeV peak of uranium. Hence most crystals in use at present have a thickness of 4 inches. Statistics have not so far been mentioned and this is a further reason for the large crystals for spectrometry. A count of 16 counts in the 1.76 MeV channel has a standard deviation of 4 counts, that is, the count can vary from 12 to 20 counts for the same sample of uranium, ±25% in the grade estimate. Because of the low counts in the "uranium" and likewise in the total count channel for very small outcrops, the validity of an anomaly is brought into question. One company has a combination of an inboard and a towed crystal so that both detectors progressively cross the area. If the anomaly is not present on the record of both detectors then it could be statistical.

To summarize so far. It is recommended that all radiometric surveys whether ground or airborne, should have a total count channel with the bottom of the energy acceptance range as low as possible with consideration of noise and cosmic rays. For identification of the parent element with field spectrometers 1.76 MeV and 2.62 MeV have been chosen and these require large crystal volume for accuracy and even so are inefficient detectors of the elements. Gamma spectrometry does not overcome the problem of equilibrium using sodium iodide crystals. This has the side effect of making it necessary to use other than gamma detection information in the selection and rejection of 1.76 MeV uranium anomalies. A one inch thick crystal is 90% efficient on 0.2 MeV and 30% efficient on 2.62 MeV.

The foregoing dealt with airborne and ground spectrometry. Borehole logging has additional restrictions. The CSIRO have carried out very worthwhile work with probes of diameters of 4 inches containing crystals of 2 inches diameter, however most exploratory holes are at best NX and more often AX with a diameter of 1.7/8 inches. This restricts probes to a diameter of around 1½" (38mm) and a crystal diameter of 1 inch (25mm) and for mechanical reasons (19mm). At the diameter of a 1" crystal we have maximum stopping efficiency dropping away at the diameter thicknesses. This is satisfactory for total count but has an efficiency of only 30% for 1.76 and 2.62 MeV. Look again at Figure 2 and remember this was taken with a sodium iodide detector. Borehole spectrometry should therefore be taken

FIGURE 1



some probes of this diameter have crystals of ¾ inch with large diameter crystals at low speed or small crystals stationery for several seconds. Even for total count 2 metres per minute is now standard. No amount of equipment at the top of the hole can compensate for deficiency in the detector in the hole. Lastly as a final warning on borehole logging speed, even with everything else perfect, a chart recorder takes up to a second to traverse across the chart.

References

EICHHOLZ, G. C. *et al.* The Determination of Uranium & Thorium in ores. *Can. J. Phys.* 31, 613-628.

DALY, URQUHART and GIBSON. Assaying of Radioactive Rocks & Ores. *Bulletin No. 31* Bureau of Mineral Resources 1956.

MERO, J. L., 1960. Uses of the Gamma Ray Spectrometer. *Geophysics* Vol. 25 No. 5, 1054-1076.

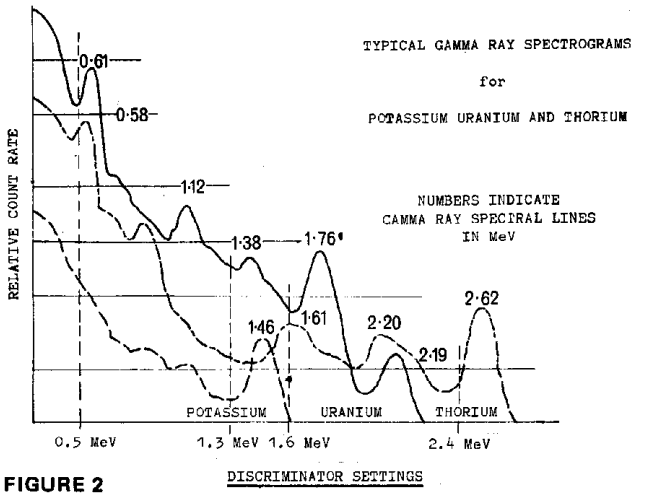


FIGURE 2

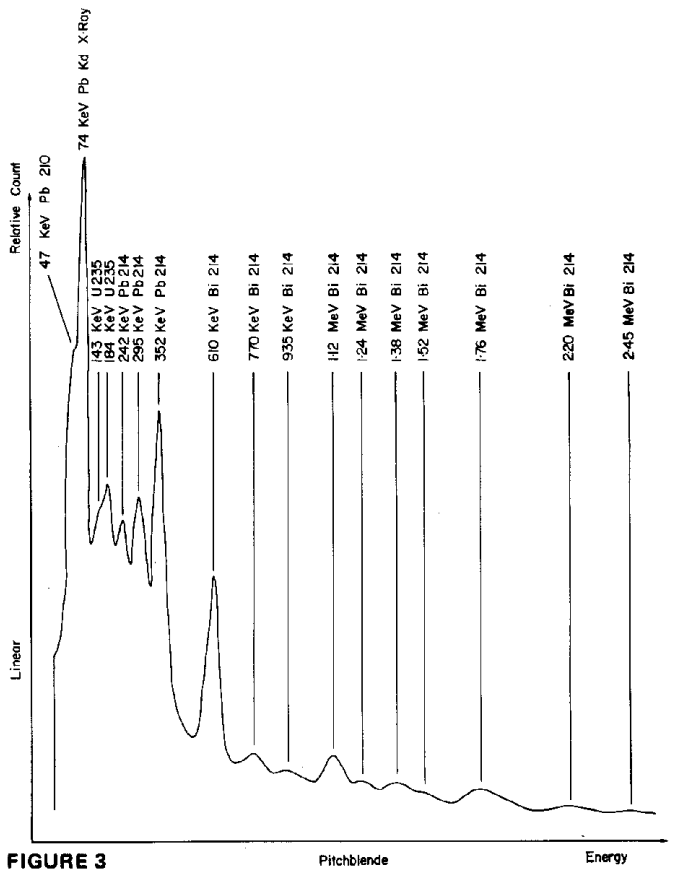


FIGURE 3

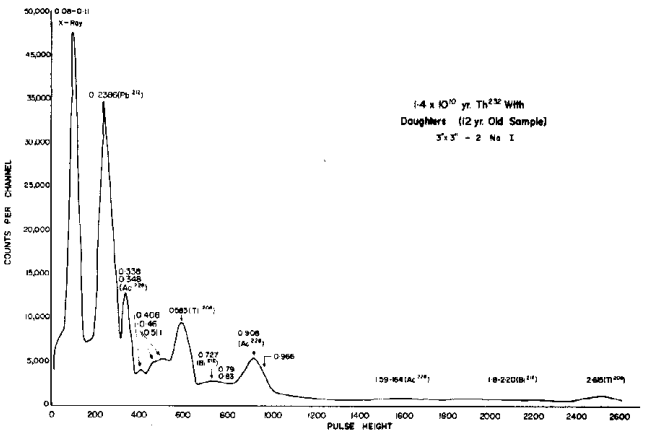


FIGURE 4

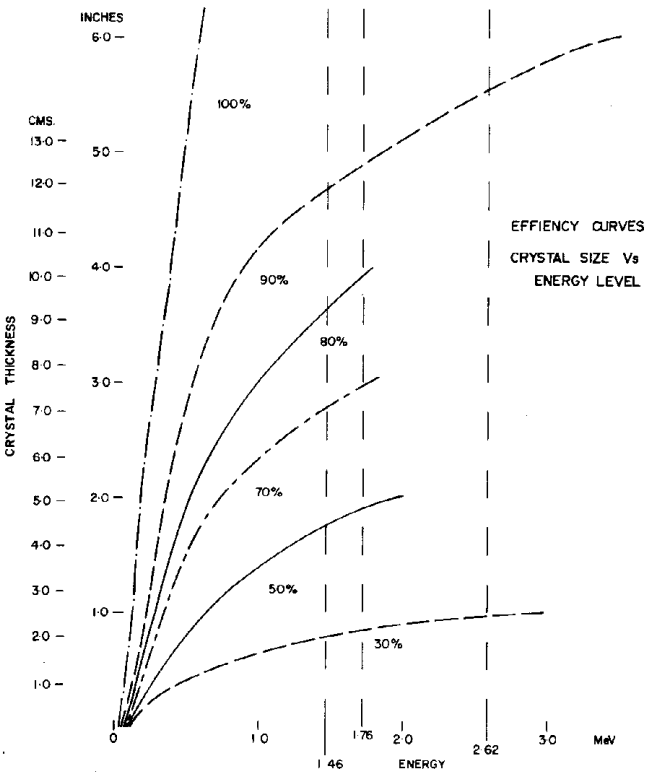


FIGURE 5

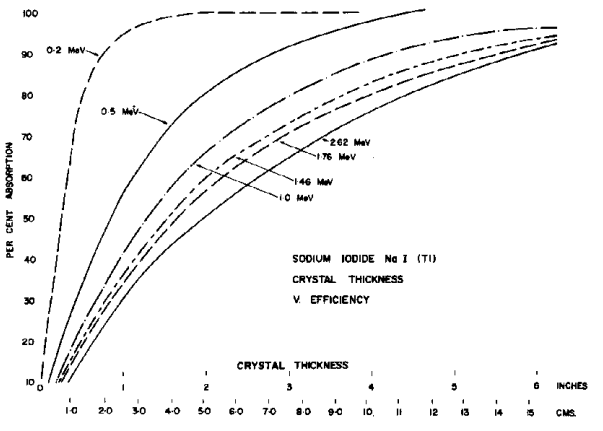


FIGURE 6