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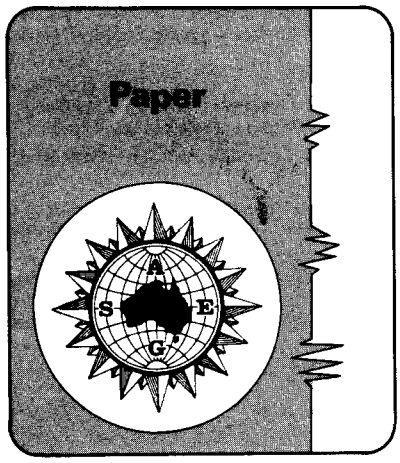

An Australian Facility for the Calibration of Portable Gamma-ray Spectrometers

Bruce L. Dickson

CSIRO Division of Mineral Physics
PO Box 136
North Ryde
NSW 2113
Australia

Leif Løvborg

Risø National Laboratory
Postbox 49
Roskilde
Denmark DK-4000

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Abstract

Five concrete pads containing elevated concentrations of the three radioelements, potassium, uranium and thorium, have been constructed at the CSIRO Institute of Energy and Earth Resources, North Ryde. Analyses of samples taken during construction showed that the pads are homogeneous, and radiation monitoring with a calibrated instrument showed that radioelement concentrations are in agreement with those assigned to similar facilities in Canada, Finland, Sweden and the USA. The North Ryde facility is available to users of gamma-ray spectrometers wishing to calibrate their instruments.

Introduction

The three radioelements, potassium, uranium and thorium, may be determined *in situ* using gamma-ray spectrometry. Accurate determinations require the calibration of spectrometers on specially constructed concrete pads containing enhanced and known radioelement concentrations. The calibration facility described in this paper consists of five pads (2 m diameter, 0.5 m thick) located at the CSIRO Institute of Energy and Earth Resources, North Ryde, NSW. One pad is a blank (B), three pads contain elevated concentrations of potassium (K), uranium (U) and thorium (T) and one pad contains both uranium and thorium (M).

Gamma-ray spectrometry has many applications. For example in mineral exploration, gamma-ray instruments are used in the search for naturally radioactive elements, for geological mapping (particularly for the location of tin and tungsten in granite bodies), in the study of heat flow from the earth and for locating different strata within thick fluvial deposits. In environmental monitoring, gamma-ray readings are used to identify and quantify the concentrations of radioactive elements on the surface around mines, mills and power stations and to examine tailing dumps from mineral processes.

A calibration facility enables gamma-ray spectrometers to be calibrated on sources of known concentrations. In the typical portable spectrometer three energy windows are set to receive radiation from potassium (^{40}K at 1.46 MeV), uranium (^{214}Bi at 1.76 MeV) and thorium (^{208}Tl at 2.61 MeV). However, each window receives radiation from the other radioelements and 'stripping factors' must be determined to enable estimation of the radiation from each radioelement. The calibration pads are used to determine the stripping factors and the window sensitivities from which the concentrations of radioelements are obtained in a field assay. Detectors measuring units of total gamma radiation, e.g. microroentgens per hour, can also be calibrated as the pad concentrations may be converted into such units.

In 1983 the CSIRO Division of Mineral Physics built the pads to enable calibrations of its own detectors and to study aspects of the calibration and long-term stability of such pads. However, the pads are available to others wishing to calibrate their detectors.

Construction of the pads

The pads were constructed with a 2:1 sand:cement mixture using materials chosen for their low radioactivity. Potassium feldspar, monazite sand and pitchblende were used to supply additional quantities of the three radioelements.

Cement preparation and mixing was done at the pad site. The radioactive material required for each pad was distributed equally in the sand. An 8 m^3 concrete mixer was loaded, first with about 75% of the total water needed, then with the sand–ore mix, with cement being interspaced evenly during loading. Water was then added along with concrete retarder to obtain the desired slump which allowed the mixer to be rotated for at least 40 min after the loading procedure to ensure homogeneity of the mix. Finally, about 5 min before pouring, 5 ℓ of superplasticizer was added. Further details of the material selection and construction are given in Dickson (1984).

Laboratory analyses

As well as the concentration of radioelements, one of the critical features of a pad is the homogeneity of the distribution of the radioelements. This requires extensive sampling. Approximately 1 kg samples of mix were taken on a regular grid after every 12 cm of mix had been poured. A total of 84 samples were obtained from each pad and stored for 3–6 wk in plastic bags. Each sample was then crushed, air-dried at 110 °C for 18 h and 250 g subsamples were packed into 300 ml metal containers. These containers were stored for 3 wk and analysed by gamma spectrometry in the laboratory using standard procedures (Dickson *et al.* 1982).

As in field gamma-ray spectrometry, the concentrations of potassium, uranium and thorium are determined in the laboratory by measuring the intensity of characteristic gamma-rays within selected energy windows. A matrix inversion technique was used to correct for counts received in these windows from background radiation and from gamma-rays resulting from Compton scattering of higher energy radiation (Stromswold & Kosanke 1978).

The calibration of the laboratory spectrometer for uranium and thorium was based on samples of crushed concrete doped with these elements and assayed by laboratories in Australia, Canada, Denmark, Israel, South Africa and the USA (D. George, pers. comm.). The potassium results were calibrated using potassium sulphate packed to the same density as the crushed concretes. Preliminary results showed that the potassium values were significantly affected by the packing density of the material in the sample cans.

TABLE 1
Summary of laboratory radiometric analyses

Pad	K(%)	eU (p.p.m.)	eTh (p.p.m.)
B	0.19±0.07	0.77±0.63	2.26±1.21
K	4.15±0.11	0.97±0.53	2.62±1.09
U	0.15±0.20	89.5±5.1	2.63±1.46
M	0.15±0.17	38.9±1.6	95.7±2.6
T	0.14±0.16	7.8±1.5	166.2±4.1

Radiometric analyses obtained for the five pads are summarized in Table 1. The standard deviations of the distribution of the 84 results for the concentrations of the major radioelement in each pad are generally less than 6% of the mean. This indicates that a high degree of homogeneity was achieved in the distribution of the added radioelements in the pads. Complete lists of the results are presented in Dickson (1984).

Intercomparison monitoring

A set of *in situ* radioelement concentrations was obtained using a portable spectrometer that had been calibrated on similar but larger pads in Canada, Finland, Sweden and the USA. This monitoring trial was one of a number of similar intercomparisons of newly constructed pads in six countries sponsored by the International Atomic Energy Agency (Lφvborg 1982). As at the other facilities, that in Australia was monitored by recording window counts with a Geometrics GR 410 portable spectrometer using 76 × 76 mm NaI(Tl) scintillation detector. The detector was placed at the centre of each pad and counts were accumulated to give better than 1% standard deviation in each window. Counts were converted to radioelement concentrations relative to the least radioactive (blank) pad. The sensitivity factors were obtained on large pads so that these require correction for the smaller pad dimensions of the Australian facility and the effective 5 cm elevation of the detector probe above the pad surface (Lφvborg 1982). The results obtained are given in Table 2.

Figures 1 and 2 show the monitored uranium and thorium values, respectively, plotted against the laboratory-determined values for crushed, dried material. The *in situ* values include the effect of pore moisture in attenuating the gamma-rays. Thus theoretically the slope of the regression of laboratory assay versus the monitoring assay should be given by $1/(1 + w_f)$ where w_f is the average fractional moisture in the monitored pads. The observed slopes for uranium and thorium are very close to each other and, being slightly greater than unity, are consistent with this moisture assumption.

Derived Ur and dose-rate values

The total content of radioelements in the ground is often measured by portable scintillation detectors that do not discriminate between the contribution of potassium, uranium and thorium. Such detectors are often calibrated in dose-rate units (μR/h) which is not meaningful, since the response of a small crystal to terrestrial gamma radiation is different from that to point sources typically used in these calibrations. In 1976 the International Atomic Energy Agency established a unit of radioelement concentration which is based on the total count response of 1 p.p.m. U in radioactive equilibrium. This unit, known as Ur, is an adequate remedy for expressing scintillometer readings in areas of mixed radioelement content. Since the uranium equivalents of thorium and potassium are reasonably well known (Lφvborg 1984), the *in situ* concentration of the pads may be used to assign Ur values to them relative to the blank pad. The conversion factors used were 1 p.p.m. Th = 0.39 ± 0.02 Ur and 1% K = 1.10 ± 0.20 Ur, and the assigned values are given in Table 2.

TABLE 2
Summary of pad monitoring results

Pad	K (%)	eU (p.p.m.)	eTh (p.p.m.)	Ur (p.p.m.)	Exposure (μR/h)
K	3.68±0.04	0.24±0.10	−1.02±0.19	3.9	4.49
U	0.20±0.06	87.4±1.8	−0.86±0.34	87.3	46.4
M	−0.02±0.04	39.1±0.9	88.8±1.3	73.7	41.4
T	−0.12±0.04	9.56±0.45	157.8±2.1	71.0	41.2

Note: The measured values are relative to the background (B) pad, thus a negative result indicates lower K or eTh in that pad than in the B pad.

The pads may also be used to calibrate instruments used in environmental radiation monitoring. The gamma-ray exposure rates due to 1% K, 1 p.p.m. U and 1 p.p.m. Th distributed within a 2 m diameter, 0.5 m thick matrix of (assumed) density 2.19 g cm^{-3} were calculated using a gamma-ray transport code GAMO (Kirkegaard & Lφvborg 1980). The code simulates gamma-ray transport by scattering and absorption

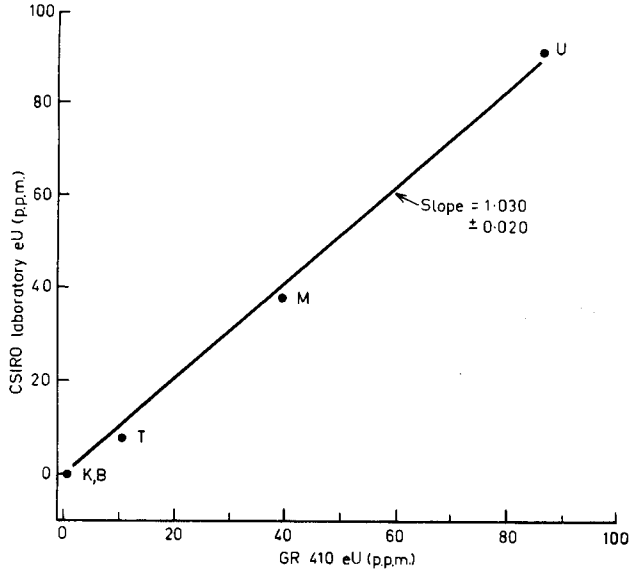

FIGURE 1

Correlation of the independently estimated uranium concentrations of the pads.

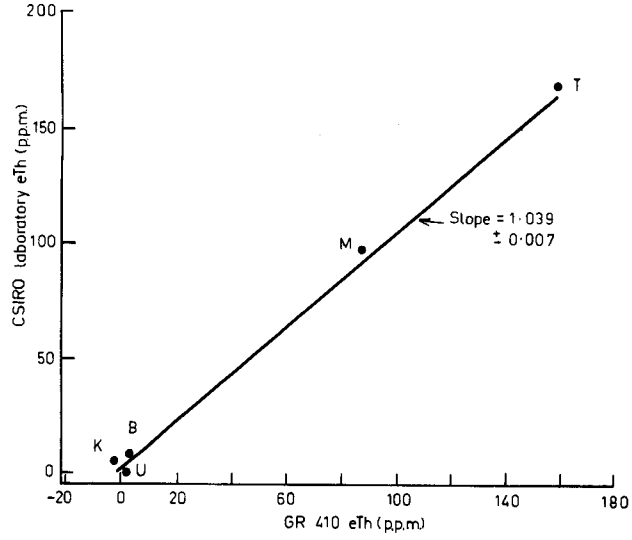

FIGURE 2

Correlation of the independently estimated thorium concentrations of the pads.

using Monte Carlo techniques. The estimated responses were: 1% K = 1.25 μR/h, 1 p.p.m. U = 0.53 μR/h and 1 p.p.m. Th = 0.23 μR/h. These responses were used to convert the *in situ* radioelement concentrations to exposure rates. The values which are relative to the blank pad are given in Table 2. It should be noted that simple field scintillometers with their low thresholds of 50–100 keV underestimate the exposure rate contributions from potassium and thorium (Lovborg *et al.* 1981) and should invariably be calibrated in Ur rather than in μR/h.

Acknowledgments

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