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# Calibration of a 5x5 NaI(Tl) for Prompt In-Situ Gamma-ray Spectrometry System

## Umerjanje 5x5 NaI(Tl) detektorja za in-situ sistem spektrometrije gama

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### Abstract in English

It is important to determine the presence of different radionuclides in the environment at all times in order to control and assess the risk level they pose to the environment. Laboratory and in-situ gamma-ray spectrometry can be used for detecting, monitoring, and assessing levels of radioactivity and radiation dose rates in the environment due to both natural and artificial sources. In this study, the greatest challenge in the calibration of detectors for in-situ gamma spectrometry has been solved. Calibration factors that can be used to convert the net count rates of collected spectrum's photopeak using a portable gamma-ray spectrometer, to quantitative specific activities have been derived. Calibration pads were simulated using standard materials RGU, RGK, and RGTh from International Atomic Energy Agency (IAEA). Region of interest (ROI) were carefully determined around these photopeaks in order to obtain count rates due to each radionuclide under its reference peak. The conversion factors obtained are reliable.

**Keywords:** Gamma ray spectrometry, NaI(Tl) detector, window analysis method, calibration factor

### Abstract in Slovene

Določevanje prisotnosti različnih radionuklidov v okolju je pomembno z vidika nadziranja in ocenjevanja stopnje tveganja, ki ga predstavljajo za okolje. Laboratorijska in in-situ spektrometrija gama se lahko uporablja za odkrivanje, spremljanje in ocenjevanje ravni radioaktivnosti in stopnje sevanja v okolju, ki jih predstavljajo naravni in umetni viri. Največji izziv te raziskave je bilo umerjanje detektorja za in-situ spektrometrijo gama. Izpeljani so bili kalibracijski faktorji, ki jih je mogoče uporabiti za pretvorbo neto števila zbranih vrhov (photopeak) spektra z uporabo prenosnega spektrometra gama. Kalibracijske plošče so bile simulirane z uporabo standardnih materialov RGU, RGK in RGTh iz Mednarodne agencije za atomsko energijo (IAEA). Območja zanimanja so bila skrbno določena okoli teh vrhov (photopeak) z namenom pridobiti stopnje štetja za vsak radionuklid pod referenčnim vrhom. Dobljeni pretvorbeni faktorji so zanesljivi.

**Ključne besede:** spektrometrija gama, NaI(Tl) detektor, metoda analize okna, kalibracijski faktor

## Introduction

Gamma ray spectroscopy system provides practical way to characterise dispersed radionuclides in or on the soil to ascertain possible changes in the environmental radioactivity. The gamma ray spectrometers generally used are made up of sodium iodide NaI(Tl) scintillation detectors or hyper pure Germanium (HPGe) detectors attached to multichannel analysers [1]. NaI(Tl) scintillation detectors are preferable because of their relatively high

efficiency and cheap maintenance but have the disadvantage of a poorer resolution [2].

Both laboratory and in-situ gamma spectroscopy are often used for detection, monitoring, and assessing levels of radioactivity and radiation dose rates in the environment due to both natural and artificial sources. Laboratory gamma spectroscopy systems have a more straightforward method of calibration while the calibration of an in-situ gamma spectroscopy system is a more rigorous process. In-situ gamma spectrometry has been used by many researchers including [3–6].

This study however seeks to derive empirical calibration factors that can be used to convert the net count rates of collected spectrum's photopeak, obtained using a portable gamma-ray spectrometer, to quantitative specific activities. This work therefore is aimed at solving the greatest challenge involved in the calibration of detectors for in-situ gamma spectrometry [7].

## Materials and methods

The gamma-ray spectrometer used in this study is portable 5 × 5 NaI(Tl) scintillation detector which has a gain that is sensitive to change in temperature and magnetic fields in its immediate surroundings. It consists of combined Amplifier-Voltage supply, an ORTEC Multipurpose Analyser (MCA), and a Multichannel Buffer (MCB), which performs data acquisition and analysis. It also consists of a digiBase, which is a 14-pin photomultiplier tube base for the gamma-ray spectroscopy applications with a NaI(Tl) scintillation detector. It combines a miniaturised preamplifier and detector high voltage, 0 V to +1,200 V bias, with a powerful digital multichannel analyser and special features for fine time-resolution measurements. It is supplied with MAESTRO-32 MCA Emulation Software, which contains all that is necessary to control and to adjust the acquisition parameters, acquire the data, and save the spectra [8]. The digiBASE also incorporates a gain stabiliser to significantly diminish the sensitivity of the detector [9]. It works by monitoring the centroid of a designated peak in the energy spectrum; the fine gain is automatically and continuously adjusted to maintain the centroid of the peak at its desired position.

The calibration of portable gamma ray spectrometers for the use of natural radioactivity measurements is done most times by the use of standard spectra that are obtained using at least three concrete pads enriched in K, U, and Th, and another that is pad free of radioactivity is used to represent the background [10, 11]. These pads are usually at least 2 $m^2$ in area and 0.5 m thick [12]. The design of an ideal pad enriched with one radionuclide inside and a perfect homogeneous distribution of the radioisotopes in its volume tend to be expensive and nearly unrealistic; hence, a simpler customised and applicable procedure was adopted. There are two calibration steps used to determine the performance of the detector. First is the energy calibration, which is the procedure that made it possible to interpret the acquired spectrum as a function of the energy associated with the events of decay. This is a function of the concentration of radioactive elements present in the system under analysis. The second stage in the calibration process was the determination of the factors that related the count rate under a photopeak to soil radioactivity concentration ($BqKg^{-1}$) of the radionuclide and dose rate in air.

### *Energy calibration*

Energy calibration of the detector was performed by weighing the standard materials, RGU, RGK, and RGTh, from the International Atomic Energy Agency (IAEA) in petri dishes. Total masses of 144.00 g, 183.90 g, and 130.02 g of RGU, RGK, and RGTh, respectively, were used. The standard materials in the petri dishes were arranged to depict the inhomogeneous distribution of the radionuclide in the environment. The detector was placed directly above the arrangement at a height of 140 mm. This was allowed because as much as possible only the natural radioactivity, as a result of the low gamma emitting radionuclides present in the soil, was intended to be captured. The Window Analysis Method (WAM) was applied as spectrum analysis method. In this method, only the region of interest of the spectrum is considered [10]. The assessment of the concentration of Potassium was therefore done by studying the single peak emitted

by $^{40}K$ at the energy of 1,460 keV, Uranium, $^{238}U$ was at the energy of 1,765 keV from $^{214}Bi$, while Thorium, $^{232}Th$, was through the gamma rays of $^{208}Tl$ with energy equal to 2,614 keV. After a preset time of 300 s [13], a spectrum was captured, and the channels of the various photopeaks corresponding to the gamma energies were identified. Figure 1 shows the spectrum as captured during the experiment. The photopeaks of interest were 295 keV, 1,120 keV, and 1,765 keV. The calibration procedure continued with the selection of the calibration option of the software and inserting the gamma energies of each of the peaks of interest against their channel numbers. A relation of the gamma energy versus the channel number was thus established by the software. The regions of interest (ROI) were carefully determined around these photopeaks in order to obtain count rates due to each radionuclide under its reference peak. These count rates were converted to soil activity concentration of the radionuclides using the conversion factors.

### *Efficiency calibration*

The pulse height distribution that was obtained earlier from the detector and MCA only informs us about the distribution of energy depositions in the active volume of the detector. In order to do a radionuclide-specific quantification of the activity, efficiency calibration linking the number of recorded counts in the detector to the ground deposition activity level is required [14]. According to [15], the number of counts per second, $N_f$, obtained under a photopeak due to a particular gamma energy, $E$, is related to the soil radioactivity concentration, $A$ of the radionuclide producing the peak by Equation 1 [16].

$$\frac{N_f}{A} = \frac{N_f}{N_o}\frac{N_o}{\varnothing}\frac{\varnothing}{A} \quad (1)$$

In Equation 1, $\frac{N_f}{A}$ is the photopeak count rate at the gamma energy per unit activity concentration of the radionuclide in the soil ( $\frac{cps}{Bqkg^{-1}}$ ), $\frac{N_f}{N_o}$ is the angular correction factor, which accounts for the nonuniformity of the detector response to gamma rays incident at varying angles, $\frac{N_o}{\varnothing}$ is the on-axis response of the detector (normal to detector face) given in the count rate per uncollided

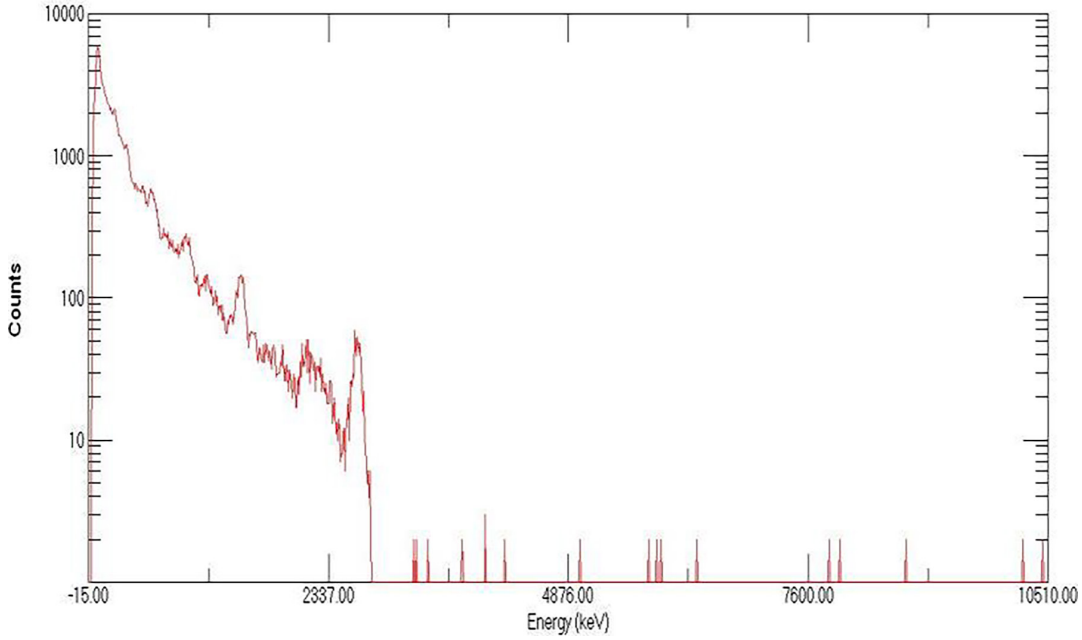



**Figure 1:** *Spectrum obtained during calibration showing gamma lines of the primordial radionuclides.*

flux of parallel gamma rays ($\frac{cps}{\gamma m^{-2}s^{-1}}$), $\frac{\varnothing}{A}$ represents the total uncollided flux per unit source activity concentration ($\frac{\gamma m^{-2}s^{-1}}{Bqkg^{-1}}$), and $\varnothing$ is the gamma r y unscattered flux on the detector ($\gamma m^{-2}s^{-1}$).

***Determination of calibration factors***

The factor $\frac{N_o}{\varnothing}$ represents the response of the detector to photons at normal incidence. Its value was determined by placing the uranium standard material (RGU-1) obtained from the International Atomic Energy Agency (IAEA) at a distance of 140 mm from the detector face. After a preset counting time of 300 s, a spectrum was obtained. Figure 1 is the spectrum showing the response of the detector to the associated radionuclide with the photopeaks of interest, with 1,460 kev for $^{40}$K, 1,764 kev for $^{226}$Ra, and 2,615 kev for $^{232}$Th. A region of interest was carefully marked around the photopeaks so that the count rate, $N_o$, was obtained. The flux $\varnothing$ was determined by using Equation 2 [16].

$$\varnothing = \frac{A \times \gamma}{4\pi R^2} \qquad (2)$$

Here γ is the gamma yield at a particular gamma energy, *R* is source to detector distance (m), and A is radiation source activity ($Bqkg^{-1}$).

$\frac{N_f}{N_o}$ was determined from count rate under photopeaks obtained by moving the standard source from $0^0$–$50^0$ in steps of $10^0$. If $\frac{N_f(E,\theta)}{N_o}$ is the ratio of the detector response to gamma ray of energy *E*, at angle, θ, with respect to the response at θ= $0^0$, then $\frac{N_f}{N_o}$ can be determined using Equation 3 [15].

$$\frac{N_f}{N_o} = \frac{1}{\varnothing}\int_0^{\pi/2} \varnothing(\theta)\frac{N_f(E,\theta)}{N_o}d\theta \qquad (3)$$

The determination of $\frac{N_f}{N_o}$ can be achieved by numerically integrating Equation 3 (Jibiri and Farai, 2005). The integration was performed in this work by using the experimental values of $\frac{N_f(E,\theta)}{N_o}$ and the value of $\varnothing$. By substituting the values of $\frac{N_o}{\varnothing}$, $\frac{N_f}{N_o}$, and $\frac{\varnothing}{A}$ in Equation 1, the desired conversion factor $\frac{N_f}{A}$ is obtained.

***Determination of in-situ background***

A body free from the presence of any radionuclide was simulated. This was achieved by putting distilled water into a fairly large bathtub to attenuate the natural background gamma rays. The in-situ gamma spectrometer was mounted on the water body, and counting was done for a preset time of 300 s. A spectrum was captured, and the count rate under the photopeaks of $^{40}$K, $^{226}$Ra, and $^{232}$Th were determined by carefully taking the region of interest, ROI, around the photopeaks.

## Results and discussion

Table 1 presents the results of calibration of the detector used in this work for in-situ gamma spectrometry using the window analysis method. The calculated values of the conversion factor, $\frac{N_f}{A}$, obtained here can be used for in-situ gamma-ray spectrometry.

## Conclusion

The in-situ gamma spectrometer has been properly calibrated and can be deployed for radiation detection, measurement, characterisation as well as for emergency response assessments. The calibration procedure developed in this work for the in-situ gamma-ray spectrometer is reliable, cost effective, and realisable. It has equally given reliable conversion factors for the

**Table 1:** *In-situ conversion factors.*

| Radionuclide | $\frac{N_o}{\emptyset}\left(\frac{cps}{\gamma m^{-2}s^{-1}}\right)$ | $\frac{\emptyset}{A}\left(\frac{\gamma m^{-2}s^{-1}}{Bqkg^{-1}}\right)$ | $\frac{N_f}{N_o}$ | $\frac{N_f}{A}\left(\frac{cps}{Bqkg^{-1}}\right)$ |
|---|---|---|---|---|
| $^{40}K$ | 0.013 | 0.433 | 0.895 | 0.005 |
| $^{238}U$ | 0.008 | 0.616 | 1.647 | 0.008 |
| $^{232}Th$ | 0.001 | 1.451 | 1.045 | 0.002 |

5 x 5 NaI(Tl) detector, which can be used for prompt detection of gross contamination in the environment.

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