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Fast in situ gamma spectroscopy using hand-held spectrometer with NaI probe

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ABSTRACT

In this work a hand-held spectrometer InSpector 1000 with NaI (Tl) 2″ x 2″ detector has been adapted to fast in situ gamma-ray spectroscopy. Two specially designed mounting stands with shielding have been built, allowing conducting measurements in different geometries. Three particular geometries (NW, IS50, IS00) have been chosen for efficiency calibration and further study. The first one (NW) is intended for small environmental samples (volume ca 140 cm^3) collected on site. IS50 geometry is a typical in situ geometry meant for radioactivity measurements in soil with detector pointed towards the ground. In this geometry the probe is shielded and mounted 50 cm above the soil surface. The new proposed geometry IS00 is designed in the way that the detector is inserted directly into the soil in order to increase the counting efficiency. The methods of efficiency calibration involved using calibration standards (in NW geometry) and the results obtained in previous in situ measurements with InSpector 2000 portable spectrometer with HPGe detector and ISOCS™ Shield Systems, which is routinely used in environmental measurements.

NW geometry turned out to be useful for natural radioisotopes concentrations (K-40, U-238 and Th-232), which significantly exceed typical values of those concentrations observed in Poland. Both IS50 and IS00 geometries are applicative for quick (2 h long measurement) evaluation of typical concentrations of K, U and Th in soils. The newly proposed geometry IS00 is superior as it showed lower detection limits and uncertainties as well as its handling was far easier than of IS50. Authors have proven that hand-held spectrometer InSpector 1000, together with mounting stands and shielding, can be successfully used for fast in situ gamma-spectroscopy. Its relatively small weight and good mobility are additional assets. Moreover, detailed procedures for measurements in each geometry have been developed to conduct such analyses properly.

1. Introduction

In situ gamma spectroscopy is a widely used quantitative study which allows to determine the concentrations of gamma-radioactive isotopes in different materials rapidly, utilizing gamma radiation spectra acquired on site. Exploiting this technique avoids the necessity of collecting representative samples of analyzed substance, transporting them to laboratory and further processing before the actual measurement, which definitely saves time and makes the whole procedure much easier and convenient. Moreover, it might be even impossible to collect the sample in some cases, due to various factors. This would happen when the studied material is too radioactive or its size is too big. These are the instances where using in situ spectroscopy is a must.

HPGe or large scintillation (mainly NaI crystal) detectors, often with some heavy lead shielding, separate multichannel analyzer with electronics (ADC converter, amplifier etc.) and additional equipment such as PC to display the results online or different types of stands to mount the detector properly, are the most commonly used gamma spectroscopy systems in terms of various in situ studies (Lettner et al., 1996). These include radioactivity measurements in soils (Al-Masri and Doubal, 2013; Baeza et al., 2016), air (Kock and Samuelsson, 2011; Moonjun et al., 2017) and many other media (Klusoň, 2010). Usually such advanced setups work fine and give satisfyingly good results, but in some specific cases (like hardly accessible areas, for example) they appear to be too clunky and their usage becomes highly inconvenient because of their very limited mobility.

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Therefore, the idea of adapting hand-held gamma spectrometer with 2″ x 2” NaI detector to in situ measurements has been proposed at Laboratory of Radiometric Expertise, Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland (later referred to as LER IFJ PAN). The compactness of this device and its small weight, both allowing it to be easily used by one person, were the main assets that made it an obvious alternative for more robust systems in case of in situ gamma spectroscopy.

The aim of the study was to adapt mobile hand-held spectrometer with NaI probe to in situ measurements (mainly soil measurements) and evaluate its practical utility in this field of gamma spectroscopy. Two specially designed mounting stands have been built in order to have the possibility of conducting measurements in various geometries. Efficiency calibrations for several chosen geometries have been performed and their correctness verified by making comparison measurements using the spectrometer with HPGe detector which had been used at LER IFJ PAN for such surveys routinely before. Furthermore, accurate procedures for carrying out in situ examinations with hand-held spectrometer, which ensure obtaining repeatable and reliable results, have been developed.

2. Material and methods

2.1. Spectrometers

The main device used in the study was hand-held gamma spectrometer InSpector 1000 Digital Hand-Held MCA with IPROS-2 Stabilized 2″ x 2” NaI probe with integrated preamplifier and programmable HVPS (Canberra) (from now on the whole spectrometer with the probe is referred to as InSp1000). Some of its most important technical specifications are as follows: multichannel analyzer (MCA) with 4096 channels; energy range from 25 keV to 3 MeV; data storage: more than 256 spectra; size: 190 × 165 × 64 mm; mass (with the probe): under 2.4 kg; operating temperature: −10 °C to +55 °C; display: color LCD and touch panel; operating time − approx. 12 h (with fully charged battery).

It can operate in four different modes: dose, locator, spectroscopy and nuclide identification (NID). The results can be seen on the display online.

The first two modes make InSp1000 a useful dosimetric tool (gamma dose rate, cumulative dose over a certain time measurements and a few other minor features), especially considering the fact that they can be exploited even with the probe disconnected as InSp1000 can utilize its internal Geiger-Müller counter. However, the main assets of InSp1000 are its spectroscopy and NID modes, which take advantage of the NaI probe and integrated multichannel analyzer resulting in the ability of performing routine gamma spectrometry measurements. The spectroscopy mode allows acquiring and analyzing gamma radiation spectra, whereas NID mode displays the results of a spectrum analysis, presenting isotopes that have been found and their activity values with uncertainties.

The device that had been routinely exploited at LER IFJ PAN for in situ surveys is the mobile gamma spectrometer InSpector 2000, Model 1300 (Canberra) with HPGe detector (type XtRa, GX4020 Extended Range, relative efficiency 40%), shield systems (Model ISOXSHLD ISOCS™, 5.5 cm thick lead and 90° collimator) - the whole system is from now on referred to as InSp2000. It was used in this study to partially calibrate and verify the results obtained with InSp1000.

2.2. Geometries

In order to conduct measurements in various geometries, two mounting stands have been built. Three different geometries: NW, IS50 and IS00 have been assigned for further study, i.e. efficiency calibration and verification measurements. Moreover, a special kind of shielding has been designed to provide some background radiation reduction (in case of NW geometry). It is also light and compact enough to be handled by one person conveniently. It is a hollow cylinder made of 4 mm thick lead sheet sealed with PMMA disc (also covered with lead sheet) at its one end. A hole drilled in the disc allows the InSp1000 probe to be inserted into the cylinder.

2.2.1. NW

NW geometry is intended for small samples (approximate volume: 140 cm^3) collected on site. The first of the stands is used in this geometry. A PVC pipe (47 mm in diameter, only a few millimeters more than the diameter of the InSp1000 probe) has been mounted vertically in a wooden base. During the measurement, the probe is located in the pipe and the NaI detector is situated just above it. The detector is surrounded by the shielding, and its open end is closed by a simple lead cover. In addition, tightly fitted acrylic cap is mounted at the top of the detector, so that the analyzed sample is always positioned in the same way relative to the detector. The sample itself is located in a cylindrical plastic container. The whole setup for the NW geometry has been presented in Fig. 1.

2.2.2. IS50

This is a typical in situ geometry meant for radioactivity measurements of soils, rocks and any other types of huge (volume-wise) materials, where a spectrometer can be stood on its surface. The second stand is used in this geometry. It is an aluminum structure with the base of a shape of the letter C, which increases its stability in harsh conditions, and with a special basket that can slide on a horizontal rail. During the measurement the shielding with the probe inside of it are inserted into the basket, so that the detector is pointed towards the ground and it collects the incoming signal from well-defined solid angle. The rail makes it possible to position the basket with the probe at any height between 10 and 70 cm. After several tests the height of 50 cm has been chosen for further study. Knowing the level at which the detector is located above the examined surface, the area of the ground from which the signal will be gathered can be easily calculated. Furthermore, the thickness of the analyzed material, which mostly contributes to the obtained spectrum, as well as its density have to be assumed in order to perform efficiency calibration. The setup for the IS50 geometry has been presented in Fig. 2.

2.2.3. IS00

This is a new, simple, yet very promising type of the geometry in which the probe is inserted directly into the ground in the way that one of the ends of the NaI detector is located at the level of the surface (see Fig. 3.). The probe itself is wrapped in a thin foil in order to protect it from any potential contamination. The volume that effectively contributes to the signal collected by the detector has been assumed to be a cylinder with some arbitrary established radius and height. The reason behind trying out such geometry was its expected increased total efficiency which could be crucial in terms of fast in situ measurements, especially while using such small detector.

2.3. Calibration

In case of in situ gamma spectroscopy, the efficiency calibration is most often the biggest challenge due to the use of nontrivial geometries. In this work three different approaches have been given a try and two of those have been actually implemented in order to get efficiency curves, later used for calculating isotopes

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