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Development and calibration of a real-time airborne radioactivity monitor using direct gamma-ray spectrometry with two scintillation detectors

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HIGHLIGHTS

- A real-time airborne radioactivity monitor was developed.
- The monitor is formed using two scintillation detectors for gamma-ray spectrometry.
- The detectors are shielded with Pb. One detector is pointing up and the other down.
- The monitors were calibrated using experimental data and Monte Carlo simulations.
- The efficiency calculations and MDAC values are given.

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ABSTRACT

The implementation of in-situ gamma-ray spectrometry in an automatic real-time environmental radiation surveillance network can help to identify and characterize abnormal radioactivity increases quickly. For this reason, a Real-time Airborne Radioactivity Monitor using direct gamma-ray spectrometry with two scintillation detectors (RARM-D2) was developed. The two scintillation detectors in the RARM-D2 are strategically shielded with Pb to permit the separate measurement of the airborne isotopes with respect to the deposited isotopes.In this paper, we describe the main aspects of the development and calibration of the RARM-D2 when using NaI(Tl) or $LaBr_3$(Ce) detectors. The calibration of the monitor was performed experimentally with the exception of the efficiency curve, which was set using Monte Carlo (MC) simulations with the EGS5 code system. Prior to setting the efficiency curve, the effect of the radioactive source term size on the efficiency calculations was studied for the gamma-rays from ^{137}Cs. Finally, to study the measurement capabilities of the RARM-D2, the minimum detectable activity concentrations for ^{131}I and ^{137}Cs were calculated for typical spectra at different integration times.

1. Introduction

The Euratom Treaty requires each Member State to establish the necessary facilities to carry out real-time monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards (2000/473/Euratom, 2000). Following these requirements, there is an automatic real-time surveillance network in Catalonia (ES-E, Spain-East) that is essentially composed of two types of monitors (Casanovas et al., 2011): aerosol and Geiger monitors. The aerosol monitors provide artificial alpha and beta, radon and gamma (due mainly to the iodine isotopes) activity concentrations. The Geiger monitors provide the ambient dose equivalent rate.

In a previous study (Casanovas et al., 2011), it was identified that the use of in-situ real-time gamma-ray spectrometry would help to identify and characterize abnormal radioactivity increases quickly. In this sense, the isotope identification can distinguish between artificial and natural radioactivity increments, and the quantification can establish alert levels based on the limits provided by legislation.

Thus, three different types of radiation monitors using either NaI(Tl) or $LaBr_3$(Ce) scintillation detectors have been developed recently and implemented into the Catalan surveillance network: a water monitor (Casanovas et al., 2013), an aerosol monitor using a particulate filter (Casanovas et al., 2012c, 2014) and the monitor presented in this study.

Environmental monitoring with real-time gamma-ray spectrometry using scintillation detectors has become fairly common,

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especially when the measurements are performed directly in the environment (i.e., without needing to concentrate the isotopes in a fiber or charcoal filter). For this purpose, either NaI(Tl) (Aage et al., 2003; Zhang et al., 2013) or $LaBr_3$(Ce) detectors (Toivonen et al., 2008; Mattila et al., 2010) have been used.

However, when measuring directly in the environment, the characterization of the radiation source term in a nuclear release is a demanding task. In particular, it is difficult to know if the contributions to the measured spectra are from a radioactive cloud or from a deposition on the ground.

For this reason, a Real-time Airborne Radioactivity Monitor using Direct gamma-ray spectrometry with two scintillation detectors (RARM-D2) was developed. The RARM-D2 enables the discrimination between the isotopes contained in a radioactive cloud from those deposited or emerging from the ground, which enables a good primary characterization of the radioactivity source term in a nuclear release.

In this work, we describe the main aspects of the development and calibration of the RARM-D2, either using NaI(Tl) or $LaBr_3$(Ce) detectors, with particular emphasis being placed on the efficiency calibration. In addition, several typical spectra are shown, and the measurement capabilities of this monitor were studied for ^{131}I and ^{137}Cs with different integration times and for both detector types.

2. Materials and methods

2.1. Description of the RARM-D2

A general scheme of the developed monitor (Casanovas et al., 2012b) is shown in Fig. 1. The RARM-D2 is formed using two scintillation detectors, one pointing up (1) and the other pointing down (2), which are shielded with Pb (3). This geometrical disposition together with the shielding permits the discrimination between the isotopes contained in a radioactive cloud from those deposited or emerging from the ground, which can be of interest after a nuclear accident to characterize the radiation source term.

The detectors used in this study were two 2″ × 2″ NaI(Tl) and two 2″ × 2″ $LaBr_3$(Ce) scintillation detectors, which made it possible to have one of each pointing up and down, respectively. The NaI(Tl) detectors were Model 905-3 from ORTEC® and the $LaBr_3$(Ce) detectors were BrilLanCe™380 from Saint-Gobain Crystals. All detectors were connected to a multichannel pulse-height analyzer of 2000 channels. The Pb shielding was specifically designed for this monitor and was manufactured by TECNIBUSA Protección Radiológica S.L.

The system integrates a meteorological station (Davis Vantage Pro2 Weather Station, Davis Instruments Corp., California, U.S.A.) that provides the following data: wind speed and direction, temperature, humidity, barometric pressure, rainfall and solar radiation. The integration of a meteorological station can provide valuable information for studying the evolution of the radiation source term, especially in cases of nuclear accidents.

The system is controlled using a specially designed software in the Delphi programming language. The obtained data are transmitted to a main server via an ADSL connection (using the SSL/TLS protocol), the system is remotely controlled using the TCP/IP protocol. However, other redundant means of communication are possible (GSM, radiofrequency, satellite, etc.). From the main server, it is also possible to activate alternative measurement systems (e.g., high flow filters for laboratory analysis) and to send automatic messages (SMS or emails) to a predefined contact list in response to either radiological criteria or different sensor signals.

2.2. Calibration of the RARM-D2

The calibration methodology for NaI(Tl) and $LaBr_3$(Ce) detectors has been described in detail in a previous paper (Casanovas et al., 2012a) and adapted specifically for this monitor. This methodology encompasses energy, resolution and efficiency calibrations.

2.2.1. Energy and resolution calibrations

The energy and resolution calibrations were established using five radioactive point sources (^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co and ^{152}Eu) and complemented with some emissions from natural background isotopes (such as ^{214}Pb, ^{214}Bi, ^{40}K or ^{208}Tl). The detectors were adjusted to cover the energy range from 0 to 3000 keV. The stability of the energy calibration in the systems without automatic gain control was controlled by means of software using the method described in (Casanovas et al., 2012d).

2.2.2. Efficiency calibrations

The efficiency calibration establishes the relationship (for each energy of the gamma-rays) between the number of counts under a peak and the activity (or activity concentration) of a radioactive source. In the RARM-D2, we are interested in measuring volumetric activity (Bq m^{-3}) with the detector pointing up and superficial activity (Bq m^{-2}) with the detector pointing down.

To obtain a complete efficiency curve for each detector and geometrical disposition, efficiency calculations were performed

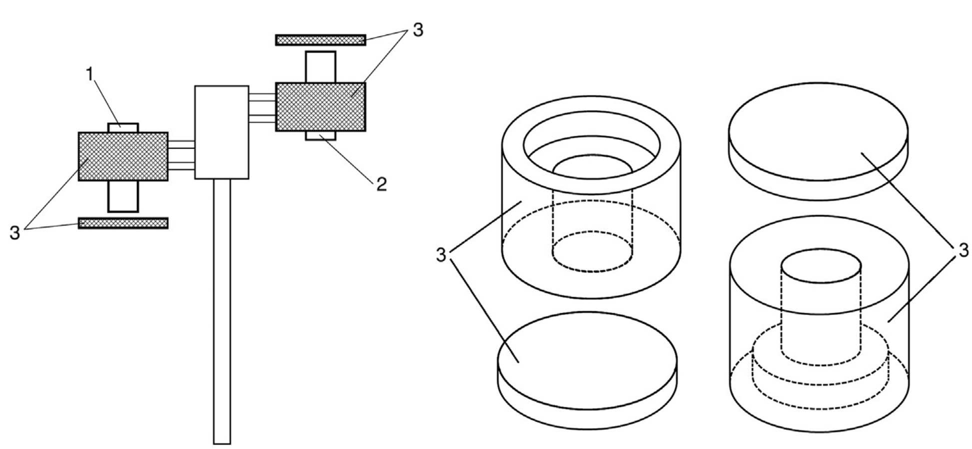

Fig. 1. General scheme of the RARM-D2 (left) and detailed scheme of the Pb shielding (right). The main elements are: detector pointing up (1), detector pointing down (2) and Pb shielding (3).