Applied Radiation and Isotopes 110 (2016) 100–108

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Efficiency calibration and minimum detectable activity concentration of a real-time UAV airborne sensor system with two gamma spectrometers

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HIGHLIGHTS

- A small-sized UAV airborne sensor system was developed.
- Three radioactive models were chosen to simulate the Fukushima accident.
- Both the air and ground radiation were considered in the models.
- The efficiency calculations and MDAC values were given.
- The sensor system is able to monitor in serious nuclear accidents.

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form
2 December 2015
Accepted 5 January 2016
Available online 6 January 2016

Keywords:
Efficiency calibration
Minimum detectable activity concentration
Monte Carlo simulation
Nuclear accident

ABSTRACT

A small-sized UAV (NH-UAV) airborne system with two gamma spectrometers ($LaBr_3$ detector and HPGe detector) was developed to monitor activity concentration in serious nuclear accidents, such as the Fukushima nuclear accident. The efficiency calibration and determination of minimum detectable activity concentration (MDAC) of the specific system were studied by MC simulations at different flight altitudes, different horizontal distances from the detection position to the source term center and different source term sizes. Both air and ground radiation were considered in the models. The results obtained may provide instructive suggestions for in-situ radioactivity measurements of NH-UAV.

1. Introduction

As a mobile device, the unmanned aerial vehicle (UAV) aviation radiation monitoring system is able to provide timely and effective radioactive information, which is vital to facilitate nuclear-emergency measures. In recent years, Finland, USA, and other countries have started related studies and development (Arvela et al., 1990; Zafrir et al., 1993; Kurvinen et al., 2005; Okuyama et al., 2005; Pöllänen et al., 2009; Macfarlane et al., 2014; Sanada et al., 2014; Okuyama et al., 2014; Sanada and Torii, 2015). However, radiation monitoring in serious nuclear accidents is a demanding task. Therefore, it is necessary to carry out relevant research and development.

In the study, a small-sized UAV (NH-UAV) airborne sensor system with two gamma spectrometers ($LaBr_3$ detector and HPGe detector) was developed at Interdisciplinary InnoCentre for Nuclear Technology (IINT) in order to realize the air radiation monitoring under serious accidents, such as the Fukushima Nuclear Accident.

For a newly developed detection system, two significant indicators should be determined: detection efficiency and minimum detectable activity concentration (MDAC) (Bagatelas et al., 2010; Casanovas et al., 2012a; Eleftheriou et al., 2013; Gong et al., 2014). The former indicator can be used to calculate the activity concentration, which is a key factor to assess nuclear accident levels. The latter one indicates the minimum activity concentration that a detection system is able to detect reliably under a specific confidence degree and also represents the measurement capability of the detection system. Additionally, it is a priori evaluation to

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http://dx.doi.org/10.1016/j.apradiso.2016.01.008
0969-8043/

qualify the suitability of the monitoring system in a given application (Casanovas et al., 2014; Zhang et al., 2015; Androulakaki et al., 2015; Kirkpatrick et al., 2015). In recent years, various calculation studies of MDAC (or MDA) have been conducted to evaluate the measurement sensitivity of monitoring detection systems or compare the detection performance of detectors, and almost all the radiation sources of these detector systems are point sources, surface sources or extended sources (such as Marinelli beakers) (Keyser and Hagenauer, 2008; Adekola et al., 2015; Bento et al., 2010; Perez-Andujar and Pibida, 2004; Barnes et al., 2009; Hau et al., 2013). However, in contrast to conventional detection on land, the radioactivity measurement of NH-UAV in air under major nuclear accidents is a type of volumetric source detection and then has the different definition and calculation method on the background and detection efficiency, for the background of the HPGe detector is volumetric source and the detection efficiency of the $LaBr_3$ detector is volumetric efficiency. Hence, the detection environment may vary with monitoring arrangement, thus making the related calculation works more difficult.

It is time-saving and labor-saving if the appropriate monitoring position (including flight altitude and horizontal distance from the detection position to the source term center) of this specific device can be provided before radioactivity measurement. Moreover, in the case of radiation leakage, the size of the source term is another important influencing factor of the detection sensitivity of the system. Therefore, it is meaningful to study the air efficiency and MDAC in multiple surveillance arrangements to offer a priori directive data and suggestions for the applications. In this study, the Fukushima Nuclear Accident was considered as the background. With Monte Carlo (MC) method, the efficiency calibration and MDAC calculation of NH-UAV airborne sensor system were conducted at different flight altitudes, different horizontal distances from the detection position to source term center, and different source term sizes. Additionally, both cases of radiation in the air and on the ground were taken into account in order to make calculation models more precise.

2. Materials and methods

2.1. NH-UAV airborne sensor system

NH-UAV (Fig. 1) is a multi-function airborne sensor system which can identify nuclide types, measure activity concentration, depict radioactive plume outline, and calibrate dose rate. The system consists of two parts: an airborne monitoring module (AMM) with a UAV and a ground control station (GCS) with a laptop-PC, a telescopic antenna mast and some related launching devices. Additionally, NH-UAV is an oil-driven fixed-wing. It can fly fully autonomously but it can be controlled manually, too.

The double detector unit (DDUT) (Fig. 2) is the detection core of NH-UAV consisting of an HPGe (model trans-SPEC-DX-100T) and a $LaBr_3$ (Saint-Gobain) (Cao et al., 2015).

In this picture, B represents the $LaBr_3$ scintillator detector, whose probe is directly exposed to air, monitoring a wide range of radioactivity, including radioactive gases and radioactive aerosols. However, considerable deviations occur because of radioactivity in the distance. C denotes the HPGe detector with wolfram shield, detecting the radioactivity adsorbed on the filter to precisely obtain small-scope nuclide information of radioactive aerosols. However, radioactive gases cannot be detected because of shielding in the device.

To obtain precise nuclide information, the detection data of the HPGe and $LaBr_3$ detectors should be corrected. A certain algorithm is utilized to validate, supply, and optimize the detection data to achieve the precise types and activity concentrations of radioactive nuclides within a small scope.

In general, the process of radioactivity measurement of the HPGe detector consists of three steps. Firstly, the air flow enters from the air inlet (H) and goes out through the air exhaust (F), and then the radioactive aerosols are deposited on the filter membrane (G). Secondly, the filter membrane (with the radioactive aerosols) is transmitted by the motorized roller (E) to the HPGe probe (C) to be detected. Finally, the measured data is first framed with data transmission and then transmitted to the PC on the ground.

2.2. Simulation set up for NH-UAV airborne sensor system

Monte Carlo technique is a powerful tool for simulations of particle transport (Sweezy et al., 2003). In this study, Monte Carlo N-Particle code was performed under different flight altitudes (with source term size $R=1000$ m), different horizontal distances from the detection position to the source term center (with flight altitude H=100 m) and different source term sizes (with flight altitude $H=100$ m). In Fig. 3, H and L are all in the range of 100–900 m, and R is in the range of 100–1000 m. In this study, MCNP code was implemented for two aspects: one was the air efficiency calibration of the HPGe and $LaBr_3$ detectors and the other was the simulation of background spectrum of the HPGe detector. The spherical segment geometry (Fig. 3) was used to simulate the radioactive environment of the air and ground radiation. In radioactive environment, γ photons flew randomly and interacted with the detectors. The accurate specifications (materials, dimensions) of the two detectors are shown in Fig. 4.

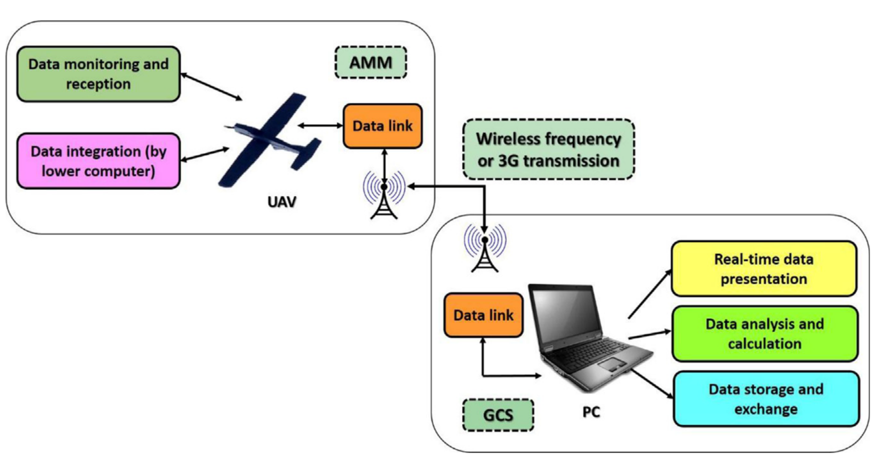

Fig. 1. Simplified sketch of NH-UAV airborne sensor system.