Journal of Environmental Radioactivity 178-179 (2017) 177–185

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Environmental gamma radiation analysis for Ulsan city with the highest nuclear power plant density in Korea

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ARTICLE INFO

Article history:
Received 21 March 2017
Received in revised form
17 August 2017
Accepted 18 August 2017

Keywords:
Environmental radiation
Site monitoring
Radiation distribution contour
Nuclide recognition
Dose assessment
Simultaneous visualization

ABSTRACT

This study presents a real-time measurement-based rapid radiation distribution visualization system for radionuclide recognition, which can quickly scan a contaminated environment. The system combines a portable detector with a digital map and a program for quick data treatment. Radiation information at the measurement location is transferred between a detector and a laptop. It includes environmental and artificial components, specific radionuclides, and total radionuclides. After scanning the area, the radiation distributions are comprehensively displayed in 2D and 3D maps corresponding to the measured area, all in a few tens of seconds. The proposed method was verified using the standard ^{137}Cs and ^{60}Co sources. The gamma radiation distribution of the areas measured in Ulsan city, which included non-destructive testing and radioisotope treatment facilities, hospitals, transportation spots, and residential and commercial areas, showed that Ulsan city has maintained safe levels of radiation. The system performed well. In addition, it was found that this system could detect unexpected hot spots quickly in affected environments.

1. Introduction

Environmental radiation monitoring (ERM) has been implemented for technical and social reasons, such as to estimate radiation exposure to the public, determine public nuclear reliability, and determine nuclear emergencies (Cember, 1969; Richard and Shultis, 1999). Radiation monitoring systems based on fixed monitoring stations can predict and evaluate the impact of nuclear accidents (Urso et al., 2012). However, after the Fukushima nuclear accident, radiation and non-radiation factors including natural disasters, have been considered among the factors that seriously affect the living environment (Yang, 2014). Therefore, there has been increasing demand for rapid real-time radioactivity measurements, including non-destructive testing, to advance a comprehensive understanding of the radiation level distribution in cases when radioactivity is released into the environment from unexpected radiation accidents in nuclear power plants (NPPs) (Jiao et al., 2008). In particular, during emergencies, a rapid assessment of radiation level distributions can be achieved prior to exactly measured dose rates, even when measurements are uncertain (Galmarini et al., 2008). Recently, the decision to decommission the Kori nuclear power plant (NPP) unit-1, which was made in June 2015, necessitated a rapid on-site environmental radiation monitoring technology for the environmental restoration at the large decontaminating and decommissioning (D&D) site (Franklin and Fernandes, 2013; Mazeika et al., 2016). In addition, rapid radiation distribution monitoring is increasingly desired for emergency monitoring of artificial nuclides including radioactive cesium (^{137}Cs) and radioactive cobalt (^{60}Co), which are among the fission products from nuclear reactions involving neutrons (Buehling et al., 1988; Peters, 1988; Ware and Fern, 1988).

A rapid radiation level distribution monitoring technology has been developed by combining radiation technology and intelligence technology to obtain actual measurements using a radiation detector and GPS-based contour mapping program (Kim et al., 2007; Kim et al., 2008; Klusoň, 2010). This method has enabled comprehensive understanding of radiation level distributions in the measured area via 2D or 3D radiation contours on a corresponding map. However, the method is limited in that it shows only the total radiation level including environmental and artificial radioactivities, and cannot distinguish between radionuclides; therefore, the method does not provide the radiation dose

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http://dx.doi.org/10.1016/j.jenvrad.2017.08.015

estimation required to protect public safety based on the amounts each radionuclide resulting from nuclear reactions. The dose estimations for both external and internal exposures, which require knowledge of the types of released radionuclides, are essential for the management of D&D sites, emergencies, and accidents, in addition to the normal operation of NPPs (Szegvary et al., 2007). Therefore, a portable detection system capable of nuclide recognition is needed to determine on-site environmental radiation level distributions. Prompt analysis and display of the type of radioactivity produced should follow as soon as the measurement is finished in the given area. On the other hand, the measured data should be shared between the site and the main office for effective environmental radiation control and management, which simultaneously displays the measured radiation level distribution at both places (Park et al., 2006).

Safecast (Brown et al., 2016) and KURAMA (Tanigaki et al., 2013) technologies can be used to determine the environmental dose rate distribution. Safecast is a dosimeter-based system, while KURAMA is a NaI detector-based monitoring system. Although the two technologies can be used to identify geographic information-based radiation dose distributions, the proposed technology can, in addition, confirm information about nuclear species.

The study presented in this paper focused on a method of detecting radiation level distributions with one click of a mouse, immediately after measurements are taken, and simultaneously visualizing detected and measured nuclides with dose assessment. The method enables information to be shared between the site and the main office in the event of a nuclear accident. The proposed rapid nuclide-recognizing portable system is developed by integrating the hardware of a commercial detector and the software of a MATLAB-based contour mapping program that displays radiation levels on a GPS (Global Positioning System)-connected digital map.

2. Methods

The proposed system combines the hardware of a gamma spectrometry detector for the radiation dose measurement along with the software of the radiation data-mapping program. The portable gamma radiation detector of the scintillation type was designed and fabricated for on-site radiation measurements of various radionuclides. The contour-mapping program, implemented with MATLAB software, enables the 2D or 3D display of radiation level distributions with one click of a mouse immediately after the corresponding area is scanned by the portable gamma radiation detector. The simultaneous display at both the on-site laptop and the main office desktop is implemented by data transmission using the CDMA (code division multiple access) method.

2.1. Gamma radiation detector

The main features of the detector used for on-site environmental radiation measurement, which has a cylindrical shape selected for its compactness. Real-time gamma counts can be obtained at dose rates of 0.01130 μSv/h, in an energy range from 80 keV to 3 MeV, with a resolution of 7.5% for the 662 -keV peak of ^{137}Cs. The detector is capable of real-time identification of background and artificial radionuclides, and it can be carried in a backpack because of the scintillator's small size, packaged compactly with the MCA (multichannel analyzer), preamp, and electronics so that the detector has a diameter of 90 mm and a length of 530 mm. The detector can operate in high voltage conditions of up to 1 kV (at 1 mA); it is also waterproofed with a plastic resin cladding, and can operate in temperatures from −25 to 50 °C. The system has a 7.2 V/6.6 A lithium ion battery that can operate for up to 5 h, and it communicates via a Bluetooth module with a GPS and RS-232 interface that generates GPS coordinate-based radiation dose rates.

The performance of the detector was tested by comparing the relative difference between the measured and calculated activity. The measured activity is the deduced value from the experiment on the relationship between the dose rate and the count rate. The standard source was directly attached to the surface of the detector and the dose rate was measured. The measured activity can be obtained from the relationship between the dose rate and the count rate, while the activity was calculated using the decay equation with time interval between the manufacturing and the experiment date. The relative difference is defined as the ratio of the difference between the calculated and the measured radioactivity to the measured activity. Experimental uncertainty can occur through the measuring process, such as activity, counting, distance, and dose rate. The standard source was used and the distance between the source and the detector was fixed as zero. Therefore, the effect of the distance on the uncertainty can be negligible. The experimental uncertainty includes factors such as counting error, dose rate, and interpolation of the result of the relationship between the dose rate and the count rate.

2.2. Data communication

Spectrum analysis to identify the detected radionuclides is essential to determine radiation level distributions and dose rates. In the proposed system, spectra are transferred by the RS-232 serial communication method. The input commands “NAI” and “RP2” are used to obtain the detected spectrum, and the meaning and information of the output message of these commands are provided in Table 1.

2.2.1. “NAI” command

The “NAI” command obtains real-time data on the latitude, longitude, and environmental dose rate; for example, the input “:NAID8; ” imports the designated data to the MATLAB program for radiation distribution contour mapping based on geographic information.

2.2.2. “RP2” command

The “RP2” command obtains the detected spectrum data in real time; for example, the input “:RP20000000054; ” produces a response composed of the relevant event value per channel over the detection time. The size of each event value is 4 bytes. The data are saved in order of the Most Significant Bit (MSB) to Least Significant Bit (LSB). The length of data is fixed at 1024 bytes. The numerical values of radioactivity for each radionuclide are obtained by analyzing the spectrum data on the counted number per channel.

2.3. Spectrum analysis

Spectrum analysis is needed to identify each nuclide. Therefore, the Mariscotti method is applied to define the peak of each nuclide from the spectrum data, where this study targeted the radionuclides of ^{137}Cs and ^{60}Co (Mariscotti, 1967). These radionuclides were obtained from standard sources.

Based on data communication with the detector and spectrum analysis, the following data was obtained and used as variables in the contour mapping program: “Latitude,” “Longitude,” “Dose Rate of Environmental,” “Activity of ^{137}Cs,” “Activity of ^{60}Co,” “Activity of Artificial Nuclides,” and “Total Dose Rate.”