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Measurement of air dose rates over a wide area around the Fukushima Dai-ichi Nuclear Power Plant through a series of car-borne surveys

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A B S T R A C T

A series of car-borne surveys using the Kyoto University RAdiation MApping (KURAMA) and KURAMA-II survey systems has been conducted over a wide area in eastern Japan since June 2011 to evaluate the distribution of air dose rates around the Fukushima Dai-ichi Nuclear Power Plant and to evaluate the time-dependent trend of decrease in air dose rates. An automated data processing system for the KURAMA-II system was established, which enabled rapid analysis of large amounts of data obtained using about 100 KURAMA-II units. The initial data used for evaluating the migration status of radioactive cesium were obtained in the first survey, followed by other car-borne surveys conducted over more extensive and wider measurement ranges. By comparing the measured air dose rates obtained in each survey (until December 2012), the decreasing trend of air dose rates measured through car-borne surveys was found to be more pronounced than those expected on the basis of the physical decay of radioactive cesium and of the air dose rates measured using NaI (Tl) survey meters in the areas surrounding the roadways. In addition, it was found that the extent of decrease in air dose rates depended on land use, wherein it decreased faster for land used as building sites than for forested areas.

1. Introduction

Mobile survey system using vehicles equipped with GPS navigation and gamma-ray spectrometers (*i.e.*, car-borne survey) consists of an instrumentation with crystal packs smaller than those used for airborne survey systems (Sanada et al., 2013). Such a system is useful for evaluating the air dose rate distribution over a wide area for a given time and cost. After the Chernobyl NPP accident, car-borne surveys were conducted in and around the Chernobyl area (Arvela et al., 1990; Sakamoto and Tsutsumi, 1999).

The Kyoto University RAdiation MApping System (KURAMA; Tanigaki et al., 2013) is a small car-borne gamma-ray survey system connected to a mobile personal computer (PC), which has been designed to facilitate car-borne surveys. This system has been succeeded by the KURAMA-II system, which is a simplified (all-in-one) car-borne survey system that uses a built-in computer. These systems are very useful for constructing air dose rate maps over short periods of time without using specially equipped vehicles.

Mapping projects have been conducted after the accident in the Fukushima Dai-ichi Nuclear Power Plant (NPP) (Saito, 2014). Many kinds of measurements have been performed in the projects to make detailed maps in order to predict the distribution of radioactive materials in the future. The KURAMA and KURAMA-II car-borne survey systems were employed in the mapping projects to construct air dose rate maps over a wide range of eastern Japan. The mapping projects consisted of three series of investigations up until the 2012 fiscal year, and the corresponding car-borne surveys were conducted across five time periods as a part of these mapping projects, which are as follows.

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The first mapping project, "Establishment of the Base for Taking Measures for Environmental Impact of Radioactive Substances – Study on Distribution of Radioactive Substances"[1] was conducted from June to November 2011. In this project, the first car-borne survey was conducted to obtain the initial data for evaluating the migration status of radioactive materials released by the Fukushima Dai-ichi NPP accident. This survey was conducted by Japan Atomic Energy Agency (JAEA). The second mapping project, "Investigation and Study of the Secondary Distribution of Radioactive Substances due to the Accident at the Fukushima Daiichi Nuclear Power Plant"[2] was conducted from November 2011 to March 2012. In this project, the second and third car-borne surveys were conducted to determine the distribution of air dose rates over a wide area of eastern Japan. The second survey was again conducted by JAEA, whereas the third survey was conducted by local governments in 10 prefectures in cooperation with JAEA (during data processing). The third mapping project, "Establishment of Technique for Identifying Long-term Impact of Radioactive Substances due to the Accident at the Fukushima Dai-ichi Nuclear Power Plant"[3] was conducted from June 2012 to March 2013. In this project, the fourth and fifth car-borne surveys were conducted to investigate in detail the distribution of radioactive cesium in the environment and to contribute to the creation of a model that would delineate the changing trends of air dose rates. In these surveys, JAEA performed measurements on main arterial roads, whereas the local governments performed detailed measurements on the roads including minor ones.

The purpose of this study is to evaluate the distribution of air dose rates around the Fukushima Dai-ichi NPP over the region of eastern Japan exhibiting certain contamination levels and to determine the trend of decrease in air dose rates up until December 2012.

The details of the measurement systems and methods used for evaluating the air dose rates in this study are described in Section 2. The measurement results are discussed in Section 3. Finally, the results are summarized in Section 4.

2. Measurement systems and methods

2.1. Detector and measurement method

The first and second car-borne surveys were conducted (until December 2011) using the KURAMA system developed by Kyoto University. The KURAMA system obtains the ambient dose equivalent rate $H^*_{(10)}$. In this paper, the obtained value is represented as the "air dose rate." The KURAMA system shown in Fig. 1 provides for the simultaneous output of position coordinate data using GPS and air dose rates from the analog output of a NaI (Tl) survey meter (TCS-161, Hitachi Aloka Medical, Mitaka) connected to a mobile PC. An ionization-chamber-type survey meter was used in addition to the NaI (Tl) survey meter mainly inside a 20 km radius from the Fukushima Dai-ichi NPP where measured air dose rates were greater than 30 μSv/h. The KURAMA system was installed in a vehicle with the detection section of the meter set indoors at the top of the rear seat such that the survey meter was arranged to align with the near center of the roadway. The air dose rates were automatically measured using the survey meter, and the output was sent every 5 s to the PC through an interface box (for the first survey, the output was calculated every 10 s) along with the position coordinate information recorded by GPS. Fig. 2 shows the measurement scheme of the air dose rates conducted using the KURAMA system. The acquired data were transferred to a "gateway server" from the PC via a mobile line. The measurement data transmitted to the gateway server were stored in a "dropbox" using cloud computing. The data stored in the drop box were processed and stored in "data conversion servers" for visualizing using Google Earth (Google Inc.), and the measured values were displayed by superimposing them on the images obtained using Google Earth installed on a PC in order to check the measurement status in nearly real time. The data being sent to the data conversion servers were also processed to correct or delete outliers after daily measurements.

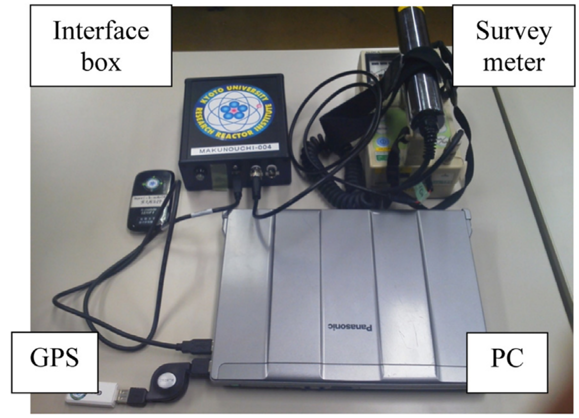

Fig. 1. The KURAMA system.

The second version of the KURAMA system, KURAMA-II, was also developed by Kyoto University. It was a simplified survey system that can be operated even by users with no technical knowledge of radiation measurements (e.g., to set up the survey meter). As shown in Fig. 3, a thallium-activated cesium iodide (CsI (Tl)) scintillation detector, which has performance similar to the NaI (Tl) scintillation survey meter of the KURAMA system, a data transmission substrate set, and a data processing unit (a built-in computer) were installed in a tool box 35 cm (length) × 15 cm (side) × 17 cm (height). The crystal size of the CsI (Tl) scintillation detector (C12137, Hamamatsu Photonics, Hamamatsu) was 13 mm × 13 mm × 20 mm. Optical signals from the scintillator were amplified using a multi-pixel photon counter, and it was possible to measure photons in the range of 30–2000 keV. The

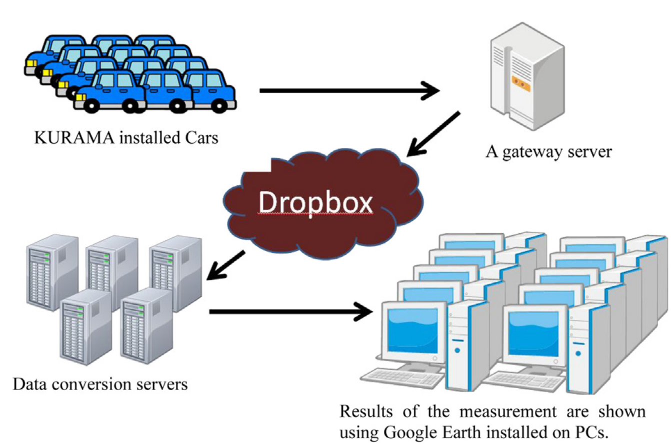

Fig. 2. Data processing scheme used by the KURAMA and KURAMA-II systems.

[1] The report is available at http://radioactivity.nsr.go.jp/ja/contents/6000/5235/view.html (in Japanese).
[2] The report is available at http://fukushima.jaea.go.jp/initiatives/cat03/entry02.html (in Japanese).
[3] The report is available at http://fukushima.jaea.go.jp/initiatives/cat03/entry05.html (in Japanese).