Chapter 7
Development of a Carborne Survey System, KURAMA

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Abstract A carborne survey system named KURAMA (Kyoto University RAdiation MApping system) has been developed for the establishment of air dose rate maps in Fukushima and the surrounding area as a response to the nuclear accident at the TEPCO Fukushima Daiichi Nuclear Power Plant. KURAMA is a γ-ray survey system with Global Positioning System (GPS) and up-to-date network technologies developed for the primary use of carborne surveys. The monitoring data tagged by GPS location data are shared with remote servers over the cloud network, then processed by servers for a real-time plot on Google Earth and other various purposes. Based on the success of KURAMA, KURAMA-II, an improved version of KURAMA with better handling and ruggedness, was developed for autonomous operation in public vehicles. About 200 KURAMA-II systems now serve for continuous monitoring in living areas by local buses as well as the periodic monitoring in Eastern Japan by the Japanese government. The outline and present status of KURAMA and KURAMA-II are introduced.

Keywords γ-Ray • Air dose rate • Carborne survey • Fukushima Daiichi Nuclear Power Plant • Mapping • Radiometry

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7.1 Introduction

The magnitude 9 earthquake in Eastern Japan on 11 March 2011 and the following massive tsunami caused a serious nuclear disaster at the Fukushima Daiichi nuclear power plant, which Japan had never experienced before. Huge amounts of radioactive isotopes were released in Fukushima and the surrounding prefectures.

In such nuclear disasters, air dose rate maps are quite important to take measures to handle the incident, such as assessing the radiological dose to the public, making plans for minimizing public exposure, or establishing procedures for environmental reclamation. The carborne γ-ray survey technique is known to be an effective method to make air dose rate maps [1]. In this technique, continuous radiation measurement with location data throughout the subject area is performed by one or more monitoring cars equipped with radiation detectors. Unfortunately, the existing monitoring system did not work well in the disaster. Such monitoring cars tend to be multifunctional; thus, it is too expensive to own multiple monitoring cars in a prefecture. Fukushima was such a case, and worse, both the only monitoring car and the data center were contaminated by radioactive materials released by the hydrogen explosions of the nuclear power plant. Monitoring cars owned by other prefectures were then collected, but these monitoring cars were too heavy to drive on the roads in Fukushima, which were heavily damaged by the earthquake. Thus, daily measurements of the air dose rate in the whole area of Fukushima were eventually performed by humans. The measuring personnel drove around more than 50 fixed points in Fukushima Prefecture twice a day by sedan cars, and they measured the air dose rate of each point by portable survey meters. Airborne γ-ray surveys were performed by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) and the United States Department of Energy, but difficulties in arrangements for the aircraft and their flight schedules prevented immediate and frequent surveys in the areas of interest.

KURAMA and its successor KURAMA-II were developed to overcome such difficulties in radiation surveys and to establish air dose rate maps during the present incident. KURAMA and KURAMA-II were designed based on consumer products, enabling much in-vehicle apparatus to be prepared within a short period. KURAMA/KURAMA-II realize high flexibility in the configuration of data-processing hubs or monitoring cars with the help of cloud technology. In the present chapter, an outline of KURAMA/KURAMA-II as well as their applications are presented.

7.2 KURAMA

KURAMA [2] is a γ-ray survey system with Global Positioning System (GPS) and up-to-date network technologies developed for the primary use of carborne surveys. The system outline of KURAMA is shown in Fig. 7.1.

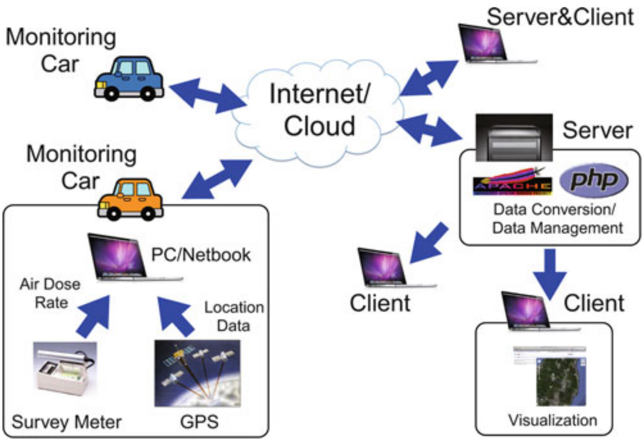

Fig. 7.1 KURAMA system. Monitoring cars and servers are connected over the Internet by cloud technology

An in-vehicle unit of KURAMA consists of a conventional NaI scintillation survey meter with an appropriate energy compensation, an interface box for the analog voltage output of the detector to a USB port of a PC, a GPS unit, a laptop PC, and a mobile Wi-Fi router (Fig. 7.2). Its simple and compact configuration allows users to set up an in-vehicle unit in a common automobile. The software of the in-vehicle part is developed with LabVIEW. The radiation data, collected every 3 s, are tagged by the respective location data obtained by the GPS and stored in a csv file. The csv files updated by respective monitoring cars are simultaneously shared with remote servers by Dropbox over a 3G network, differing from other typical carborne survey systems in which special telemetry systems or storage media are used for data collection. With this feature, anyone can set up their own "Data Center" anywhere so long as a conventional Internet connection and a PC with Dropbox are available. This kind of flexibility should be required in the disasters such as the present situation because the carborne system owned by Fukushima Prefecture was eventually halted as a result of the shutdown of the data center by the disaster.

Once the radiation data in csv format are shared with remote servers, the data file is processed or analyzed by servers in various ways, including the real-time display on Google Earth in client PCs (Fig. 7.3).

KURAMA has served for monitoring activities in Fukushima and surrounding prefectures employed by the Fukushima prefectural government and the Ministry of Education, Culture, Sports, Science and Technology in Japan (MEXT). The team of Fukushima prefectural government makes precise radiation maps of major cities in Fukushima Prefecture mainly for "Hot Spots" search [3], whereas MEXT performed carborne surveys in eastern Japan [4], including the Tokyo metropolitan area (Fig. 7.4).

Fig. 7.2 The in-vehicle part is compactly composed of mostly commercial components: (*1*) GPS unit, (*2*) 3G mobile Wi-Fi router, (*3*) MAKUNOUCHI, (*4*) NaI survey meter, (*5*) PC

Fig. 7.3 Data are simultaneously plotted on Google Earth. The color of each dot represents the air dose rate at the respective point

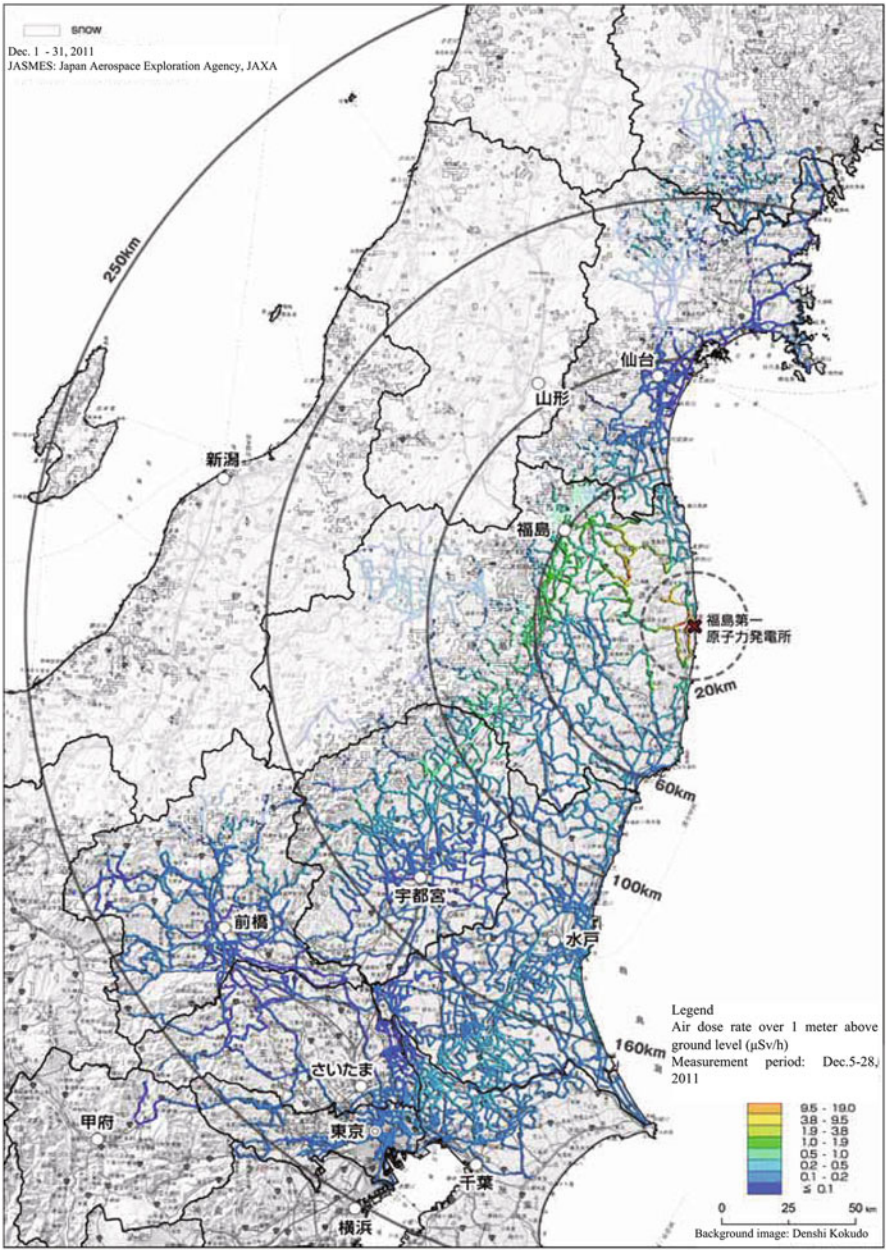

Fig. 7.4 Air dose rate mapped by KURAMA in December 2011 [4]. MEXT performed the first and second carborne surveys in East Japan by KURAMA in June and December 2011, respectively

7.3 KURAMA-II

Long-term (several decades) and detailed surveillance of radiation are required in residential areas that are exposed to the radioactive materials. Such monitoring can be realized if moving vehicles in residential areas such as buses, delivery vans, or bicycles for mail delivery have KURAMA onboard. KURAMA-II is designed for such purposes.

KURAMA-II is based on the architecture of KURAMA, but the in-vehicle part is totally redesigned (Fig. 7.5). The platform is based on CompactRIO series of National Instruments to obtain better durability, stability, and compactness. The radiation detection part replaces the conventional NaI survey meter with a Hamamatsu C12137 detector [5], a CsI detector characterized as its compactness, high efficiency, direct ADC output, and USB bus power operation. The direct ADC output enables obtaining γ-ray energy spectra during the operation. The mobile network and GPS functions are handled by a Gxxx 3G series module for CompactRIO by SEA [6].

The software for KURAMA-II is basically the same code as that of the original KURAMA, thanks to the good compatibility of LabVIEW over various platforms. Additional developments are employed in several components such as device control software for the newly introduced C12137 detector and Gxxx 3G module, the startup and initialization sequences for autonomous operation, and the file transfer protocol.

For the file transfer protocol, a simple file transfer protocol based on RESTful was developed because Dropbox does not support VxWorks, the operating system

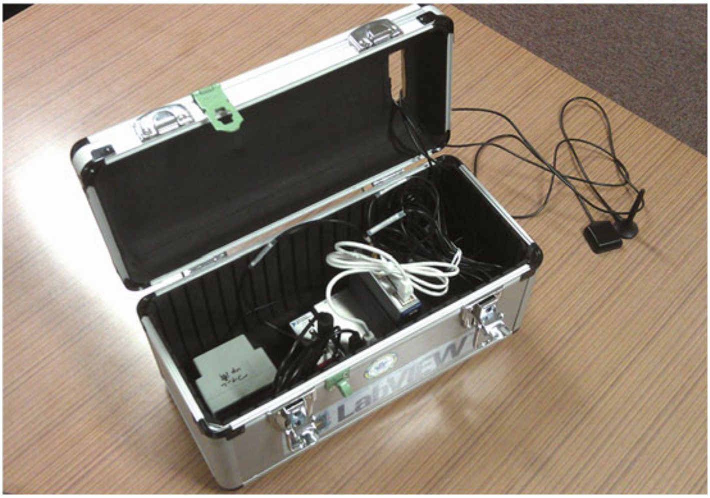

Fig. 7.5 In-vehicle unit of KURAMA-II. A CsI detector and a CompactRIO are compactly placed in a tool box 34.5×17.5×19.5 cm in size

Fig. 7.6 KURAMA-II during field test on a city bus

of CompactRIO. In this protocol, a chunk of data as a time-stamped file in csv format is produced for every three measuring points. The size of a chunk is typically about 400 bytes. Then, every chunk is transferred to a remote "gateway server" by the POST method. The gateway server combines received chunks to the data file, which is shared by remote servers using Dropbox as did the original KURAMA.

Even though the present transfer protocol works well, the existence of the "gateway server" can be a bottleneck in this data collection scheme. National Instruments is now developing a cloud service named "Technical Data Cloud" [7], which natively supports CompactRIO. This service can be one of the alternatives of Dropbox for KURAMA-II.

A field test on a city bus has been carried out since December 2011 in collaboration with Fukushima Kotsu, one of the largest bus operators in Fukushima Prefecture (Fig. 7.6). City buses are suitable for continuous monitoring purposes because of their fixed routes in the center of residential areas, and their routine operations. Up to now, this field test has been basically successful. The present file transfer protocol successfully manages data transmission under the actual mobile network. Several minor problems in hardware and software were found and fixed during this test, and stable operation has continued for more than a year.

7.4 Current Status and Future Prospects

Based on the success in the field test on city buses in Fukushima City, the region of this field test has been extended to other major cities in Fukushima Prefecture since January 2013, i.e., Koriyama City, Iwaki City and Aizuwakamatsu City. Five KURAMA-II in-vehicle units are deployed for this test, and the results are

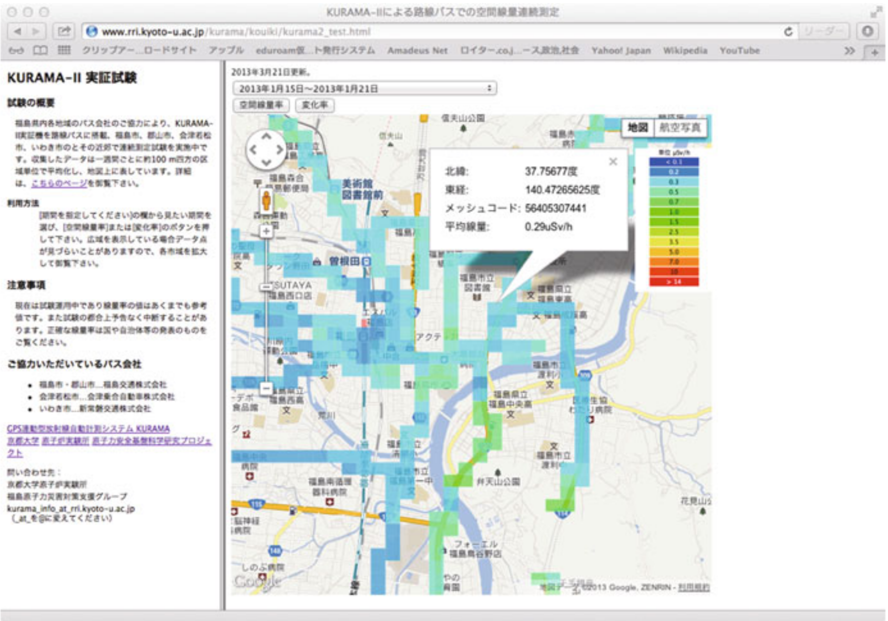

Fig. 7.7 Results of field tests on city buses are released to the public on a weekly basis. Averaged data are shown in every one-eighth grid square defined by the Statistics Bureau of the Ministry of Public Management, Home Affairs, Posts and Telecommunications

summarized and released to the public from the website [8] on a weekly basis (Fig. 7.7). In Fukushima City, around 30 additional KURAMA-II units will soon be deployed for minute mapping as well as the follow-up survey of distribution of air dose rate over the course of time.

The autonomous operation feature of KURAMA-II enables extended measurements of air dose rate with less effort. MEXT conducted a carborne survey for a month in March 2012 in which 100 KURAMA-II were leased to municipalities in eastern Japan [9]. KURAMA-II were placed in sedan cars of municipalities and the cars were driven around by ordinary staff members of the municipalities who did not have special training in radiation measurement. The survey was successful and proved the performance and scalability of the KURAMA-II system. Now this survey is conducted periodically by MEXT and the nuclear regulatory agency (NSR), which is the successor of the radiation monitoring of the present incident (Fig. 7.8).

CompactRIO is designed for applications in harsh environments and limited space. Therefore, KURAMA-II can be used for other than carborne surveys (Fig. 7.9). For example, KURAMA-II is loaded on a motorcycle: this is intended not only for attachment to motorcycles used for mail delivery, but also for monitoring in regions where conventional cars cannot be driven, such as the narrow paths between rice fields or those through forests. Also, KURAMA-II with a DGPS unit is about to be used for precise mapping by walking in rice fields, orchards, parks, and playgrounds in Fukushima Prefecture.

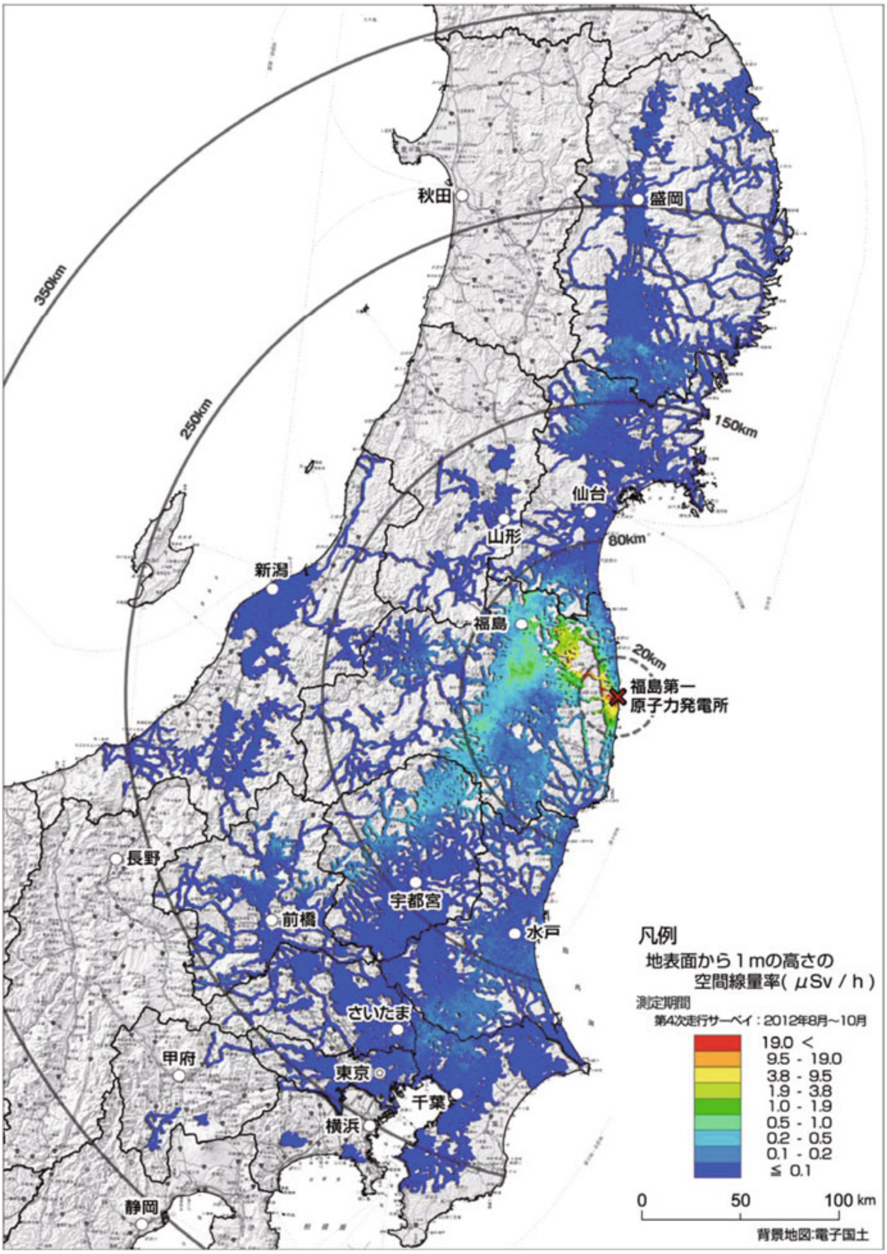

Fig. 7.8 Map of air dose rates on roads measured by KURAMA-II in periodic survey conducted by NSR between August and October 2012 [10]

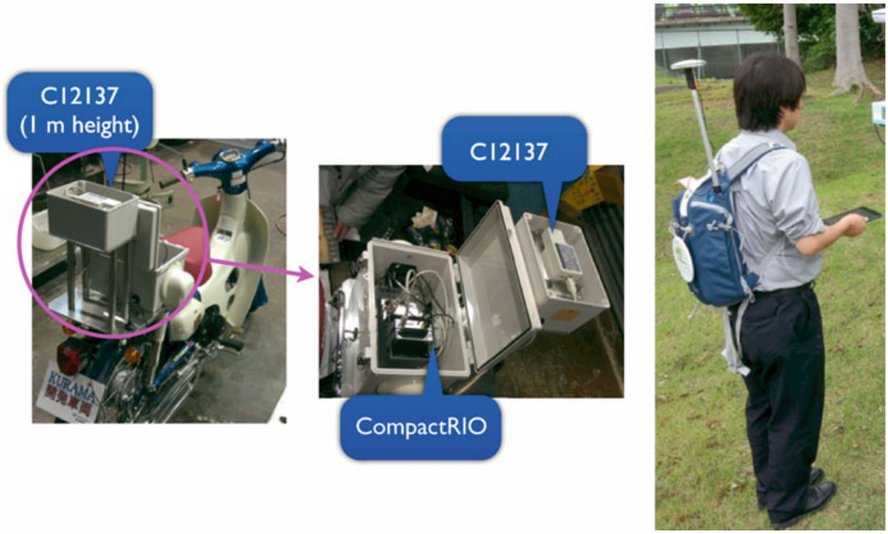

Fig. 7.9 KURAMA-II for bicycle survey (*left and middle*) and walking survey (*right*). All are the basically the same hardware and software configuration with different installations. In the case of the walking survey, the existing GPS part is replaced with DGPS for better precision of positioning the measurements

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