Development of a Car-borne γ-ray Survey System, KURAMA

M. Tanigaki, R. Okumura, K. Takamiya, N. Sato, H. Yoshino, H. Yamana

Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan

Abstract

A compact radiometric survey system, named KURAMA (Kyoto University RAdiation MApping system), has been developed as a response to the nuclear disaster of Fukushima Daiichi nuclear power plant. KURAMA is based on GPS (Global Positioning System) and network technology, and intended for the realtime data accumulation of multiple mobile monitoring stations, such as monitoring cars. KURAMA now serves for the car-borne surveys in Fukushima and surrounding prefectures by the Japanese government and local authorities. An outline of KURAMA and discussions on car-borne γ-ray surveys using KURAMA are introduced.

Keywords: radiometry, mapping, γ-ray, car-borne survey, air dose rate, Fukushima Daiichi nuclear power plant

1. Introduction

The magnitude-9 earthquake in east Japan and the following massive tsunami caused the serious nuclear disaster of Fukushima Daiichi nuclear power plant, which Japan had never experienced before. Huge amounts of radioactive isotopes were released in Fukushima and the surrounding prefectures. The heavily contaminated region stretched to the north west region of the Fukushima Daiichi nuclear power plant. Released radioactive isotopes also reached up to the Tokyo metropolitan area, and a considerable amount of deposition occurred in the area.

In such nuclear disasters, air dose rate maps are quite important to help take measures to deal with the incident, such as assessing the radiological dose to the public, making plans for minimizing exposure to the public, or establishing procedures for environmental reclamation. Air dose rate maps should be frequently renewed to both understand and deal with ongoing situations in the environment. The car-borne γ-ray survey technique is known to be an effective method to make air dose-rate maps. In Japan, monitoring schemes, including car-borne γ-ray surveys, have been prepared for any prefectures where nuclear power plants are constructed. In such monitoring schemes, one or two monitoring cars equipped with large-volume γ-ray detectors, neutron detectors and Ge detectors are owned by each prefectural government for immediate car-borne γ-ray surveys and other monitoring activities in incidents. Off-site centers, which are the hubs of data collection, analysis and distribution regarding nuclear incidents, are placed, and the data obtained by monitoring posts and monitoring cars are to be collected for producing and distributing air dose rate maps.

Unfortunately, the scheme didn't work well in the present incident. The destruction of the infrastructures by the earthquake and the radioactive materials released from the Fukushima Daiichi nuclear power plant terminated all activities at the off-site center just after the incident. The only one monitoring car owned by Fukushima prefecture was unoperatable due to the radioactive contamination. Air-borne 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 the arrangement of airplanes and their flight schedules prevented immediate and frequent surveys in the areas of interest. Then daily measurements of the air dose rate in the whole area of Fukushima were eventually performed by humans.

KURAMA was developed to overcome such difficulties in radiation surveys and for establishing air dose-rate maps during the present incident. KURAMA is designed based on consumer products, enabling a lot of in-vehicle apparatus to be prepared within a short period. KURAMA realizes high flexibility in the configuration of a data-processing hub or monitoring cars with the help of cloud technology. In the present paper, an outline of KURAMA as well as discussions regarding car-borne surveys performed by KURAMA is presented.

2. Outline of System

A typical configuration of KURAMA is shown in Fig. 1. Any measurement systems that are operated under severe accidents like the present case are required to obtain durability and flexibility to the failures in the components or the changes in measurement conditions. KURAMA is intended for the use in a common passenger car and the system is simply configured with the commercial-based components for the easy procurement even in the severe circumstances. On the other hand, existing car-borne monitoring systems are based on the specially produced equipment for use with cars especially remodeled for radiation monitoring, therefore, it is quite hard to maintain the function if either one of the components becomes broken. KURAMA is cloud-based system, therefore, KURAMA doesn't require fixed data hubs and explicit network assignments of in-vehicle units to the servers, which are required in the existing car-borne monitoring systems. With these features, KURAMA can maintain the operation by simply replacing the components or reconfiguring data hubs connected to the cloud regardless of the failures of components caused by the disasters or accidents, while the existing measurement systems should halt their operations.

2.1. In-vehicle Part

The role of this in-vehicle part is to measure air dose rates by tagging them with location data obtained by GPS, and to transmit the data to remote servers for realtime monitoring and analysis. An in-vehicle part of KURAMA consists of a radiation detector, an interface box named "MAKUNOUCHI", a GPS unit, a PC, and a mobile wi-fi router (Fig. 2).

The air dose rate is measured by a conventional NaI scintillation survey meter, which is able to measure the absorption dose rate or radiation equivalence rate. The survey meters used in KURAMA are TCS-161/TCS-171 series[1], manufactured by Hitachi ALOKA medical. For measurements in areas of higher radiation (typically more than 30 μSv/h), ICS-331[2] from Hitachi ALOKA medical is used. Both types of detectors have a capability to output the readout of radiation equivalence rate as DC voltage.

The output from the survey meter is processed in "MAKUNOUCHI", in which a DC amplifier for gain adjustment, and an AD converter for connecting to a PC are implemented.

The GPS receiver used in in-vehicle part is a conventional GPS module supporting the NMEA0183 protocol[3]. Usually, a USB dongle-type module is used for the convenience of handling.

The PC is the center of data processing in the vehicle, and governs the measurement sequence. The software for such data processing is developed as a LabVIEW VI. The dose rate in between $\pm$1.5 sec at the acquisition timing of the location data from GPS is averaged, then tagged with this location data as the air dose rate for the location. This averaged air dose rate along with those measured times and other information, such as the type of connected survey meter and calibration parameters, are stored as a text file on the hard disk in this PC. Another role of PC is to serve as a man-machine interface, such as the input for the parameters for calibration and displaying an immediate plot of the radiation intensity on a map.

2.2. Data Transmission

The data are simultaneously shared by remote servers over the internet. The connection of a monitoring vehicle to the internet is established over a mobile wireless network, usually a 3G mobile data network. In the present KURAMA, Dropbox [4] is used for data sharing. Dropbox is a file hosting service based on the cloud computing technology for users to store and share files and folders with others across the internet by using a differential file synchronization scheme. Additionally, Dropbox automatically manages the synchronization process by dealing with the network connection status. These features are suitable for the data transmission using mobile networks, where unstable network connections are expected.

2.3. Servers and Clients

Servers are responsible for data processing, such as the conversion of measured data for display on the appropriate map and making backups of data files. A conventional PC in which Apache, PHP and Dropbox are installed is used as a server. Upon requests by Google Earth [5] in client PCs, the PHP script dynamically generates a KML file from the data file shared with an in-vehicle PC by Dropbox. Usually, the differential data after the last request from Google Earth is sent by using the <Update> feature in KML for reducing the traffic and improving the response of Google Earth. The backup procedure is periodically performed by one of the servers running Mac OS X, by using the Time Machine feature implemented in the OS.

A client is a PC that displays the measurement data. At present, Google Earth is installed in a client for monitoring the up-to-date status of measurements (Fig. 3). The URL of the php script on a server, the repetition rate of data request, and links to the archived data or some other related data are written in a KML file, named "kurama_index.kml", on a server. A simple file, named "kurama.kml", which only contains the link to "kurama_index.kml" on a server, is given to each client. Each time a client requests data by following the link in "kurama.kml", the request is guaranteed to be processed properly based on the latest configuration of the server side as written in "kurama_index.kml" (Fig. 4). In some cases, both the server and the client features are installed in a same PC for the on-site monitoring, such as monitoring the measurement status in a monitoring car.

3. Operation of KURAMA

KURAMA is already serving for several measurement projects for establishing radiation dose maps by Fukushima prefectural government or by MEXT. An outline of a typical operation of KURAMA is described along with some results of field test for establishing measurement procedures.

3.1. Installation of KURAMA

The installation of an in-vehicle part of KURAMA is simple, i.e., just placing a set of in-vehicle components in a conventional car. Electric power is supplied from the car battery in a car via an AC inverter. The components are usually placed in the back seat. In a measurement with KURAMA, the position of the probe part of the survey meter is carefully chosen so as to maintain the measurement condition as identical as possible. In most cases, the probe part is attached to the grab rail inside a car on the right-side rear door, of which the height is about 1.3 m for most of sedan-type cars in Japan. Note that because vehicles drive on the left side in Japan, the probe is set approximately 1.3 m above the center of the road in this configuration. The directivity of the probe is set towards the backward part of the car so that radiation from the road in the backward direction of the car is detected.

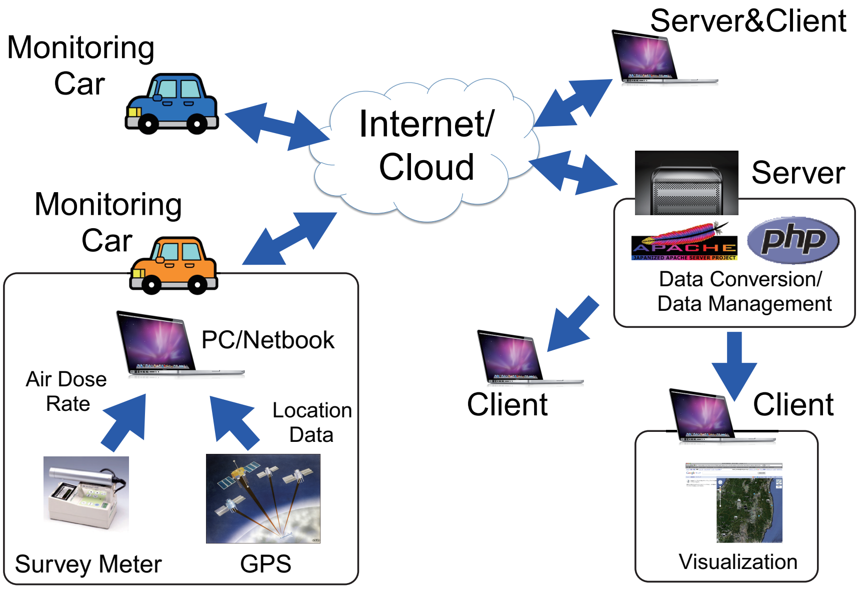

Figure 1: KURAMA system. Monitoring cars and servers are connected over the internet by cloud technology. Therefore, no special implementation or configuration of the communications is required, except for a conventional internet connection.

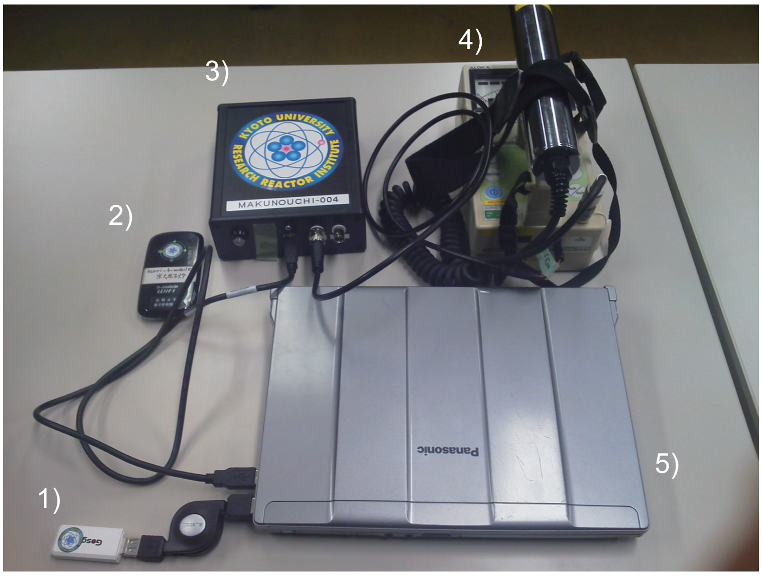

Figure 2: The in-vehicle part is compactly composed of mostly commercial components. 1) GPS unit, 2) 3G mobile wi-fi router, 3) MAKUNOUCHI, 4) NaI survey meter, 5) PC.

Figure 3: Typical screen shot of a client PC. Measured data are displayed as colored dots. The position and color of a dot represent the position and the air dose rate at the measurement point. Detailed information (date, time, latitude, longitude, air dose rate, etc.) is displayed by clicking the respective dot.

3.2. Calibration and Shielding Effect of the Car Body

The values to be determined by car-borne measurements are the air dose rate of 1 m above the ground surface at respective points. Therefore, the shielding effect by the car body and the correction to the height of the probe should be determined. The center of a flat ground without any objects of at least 10 m radius and covered with asphalt or concrete is chosen as the calibration point for establishing the shielding factor. Firstly, the air dose rate at 1 m height at the calibration point is measured by a calibrated NaI survey meter, and then a monitoring car with the NaI survey meter installed is placed at the calibration point for the measurement of the same air dose rate by the probe inside the monitoring car (Fig. 5).

The shielding factors were measured at several points of different air dose rates in the Fukushima area, and the relation was able to be expressed as a linear function with a slope of 1.3 and a small negative y-intercept on the order of $10^{-1}\mu$Sv/h (Fig. 6). This small y-intercept can be understood as an effect of contamination of the measurement cars, or the differences in the distributions between the terrestrial isotopes and the artificial isotopes that are released in the present incident. The shielding factors were measured for typical sedan car models including TOYOTA Prius and TOYOTA Comfort. No significant differences were found as long as the car type is a sedan. In general, shielding factors varies depending on the car types, e.g. 1.4, 2.2 and 1.6 for station wagon, small-size and mid-size community bus, respectively. A detailed evaluation on the shielding effect including the simulation calculation is now in progress. In the actual drawing of radiation maps, the negative y-intercept is neglected in the correction of the shielding effect to guarantee the prudence of the evaluated air dose rate.

3.3. Measurement

Typically, a designated area is surveyed by several monitoring cars at a time. The car models used in the car-borne measurement with KURAMA were mainly TOYOTA Prius and TOYOTA Comfort, which are one of the most typical sedan cars in Japan. Each monitoring car with three staffs, i.e., a driver, a navigator, and an operator of KURAMA, runs at a speed of 20 ~ 60 km for about 8 hours per day. The sampling period of the air dose rate was set to be 3 to 10 seconds; thus, around 3000 to 10000 points for every 10 to 150 m were measured for each monitoring car per day. The precision of GPS detection was within an error of 5 to 10 meters. Dropbox daemon successfully managed the intermittent connection of mobile network, and updates of data file were resumed once the monitoring car came back into the coverage area.

4. Results

KURAMA has served for the several measurement projects to establish maps of environmental radioactivity levels conducted by MEXT, the prefectural government of Fukushima and municipalities in eastern Japan. Fukushima prefectural government now uses KURAMA for precise surveys in residential areas to find possible hot spots, which are to be authorized for evacuations after additional precise surveys. MEXT conducted car-borne surveys twice, one in June 2011 for Fukushima prefecture and the surrounding area (Fig. 7), and the other in December 2011 for a wider region in Eastern Japan (Fig. 8). Some of the results have already been released to the public from the prefectural government of Fukushima[6] and from MEXT[7][8].

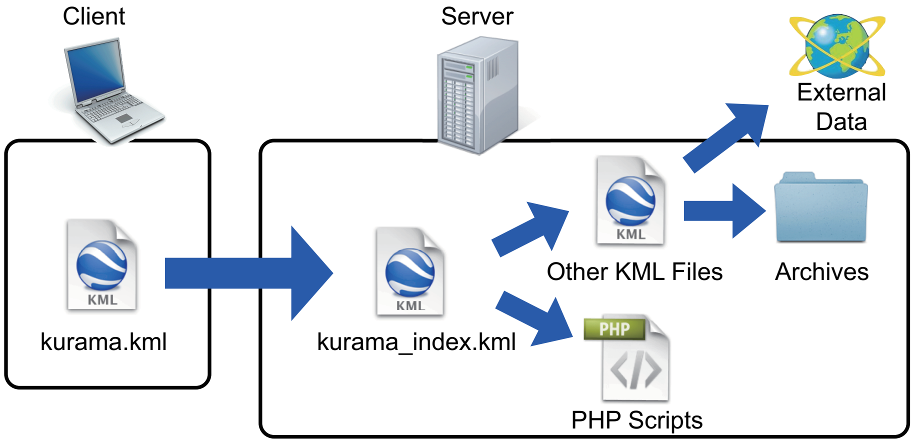

Figure 4: Flow of the request from a client. Each time a client makes a request to the link in "kurama.kml", the request is redirected to scripts or files, as described in "kurama_index.kml" on the server.

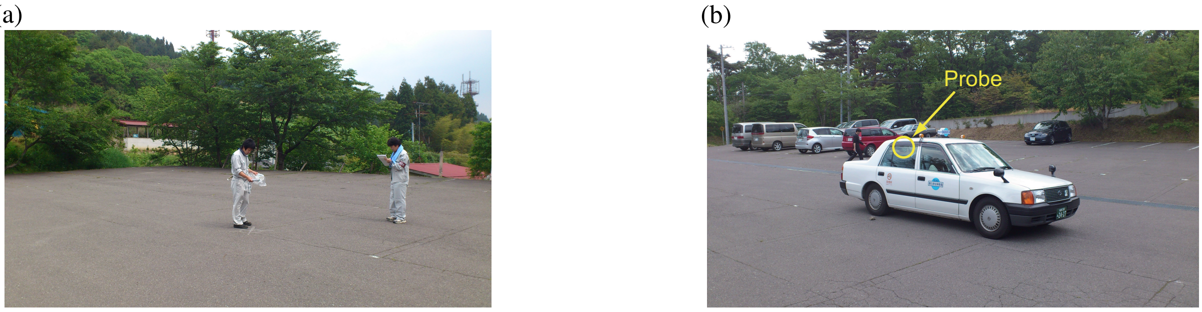

Figure 5: The determination of the shielding factor of a monitoring car. The center of a flat ground without any objects at least 10 m radius and covered with asphalt or concrete is chosen as the calibration point. (a) The air dose rate at 1 m height of the calibration point is measured. (b) The monitoring car with the survey meter attached is then placed at the calibration point, and the air dose rate is measured by the attached survey meter.

5. Discussion

The results by KURAMA are compared with those by other methods to evaluate the validity of the measurement by KURAMA.

In April 2011, Fukushima prefectural government measured the air dose rate of 1 m above the ground surface for the school grounds of about 1600 schools in Fukushima prefecture[9]. The measurement points of KURAMA in June 2011 within the distance of 50 m, 100 m, and 200 m from these measurement points by Fukushima prefectural government were selected, then these air dose rates were compared with those of corresponding points by Fukushima prefectural government (Fig. 9). Clear positive correlations (Pearson's r > 0.8) were observed for all cases. Some points are clearly deviated to give higher air dose rate for KURAMA, and those are considered as the effect of localized contaminations of street trees or buildings along the road where the monitoring cars ran. The present result suggests the gradation of air dose rate in Fukushima is not that sharp, which is consistent with the fact that the mean-free paths of γ-rays from ^{137}Cs and ^{134}Cs in the air become about 100 m.

A comparison with the result from the air-borne survey was reported by MEXT[10]. The result shows a good agreement overall (Fig. 10). The air dose rate by the air-borne survey is about 0.9 times those by KURAMA in average, with rather wide distribution of ±0.3. This can be understood as the result of the altitude correction in the airborne survey in Fukushima, where 70 % of its area is occupied by mountainous region. The altitude used in the correction is usually the averaged one for the visual field of the detector, which turns out to be the under- or over-correction to the radiation from the valley and hill parts in mountainous region.

More detailed discussions are available from MEXT[10][11], and other reports will soon be available from MEXT and other related institutes.

6. Future Prospects

As the situation of Fukushima Daiichi nuclear power plant stabilizes, the monitoring activities should move to constant activities while intending the recovery of daily life in both Fukushima and the surrounding area to confirm the safety of the people living there, and to prevent from any unexpected compilations of radioactive isotopes in the living areas. These kinds of activities should last for tens of years; therefore, the efforts and costs for these kinds of activities should be minimized. A more comprehensive monitoring scheme based on KURAMA is planned. A large number of new versions of KURAMA, which are characterized by their autonomous operation and their small integrated body, are to be installed in vehicles that are operated as regular services in residential region, such as buses on regular routes,

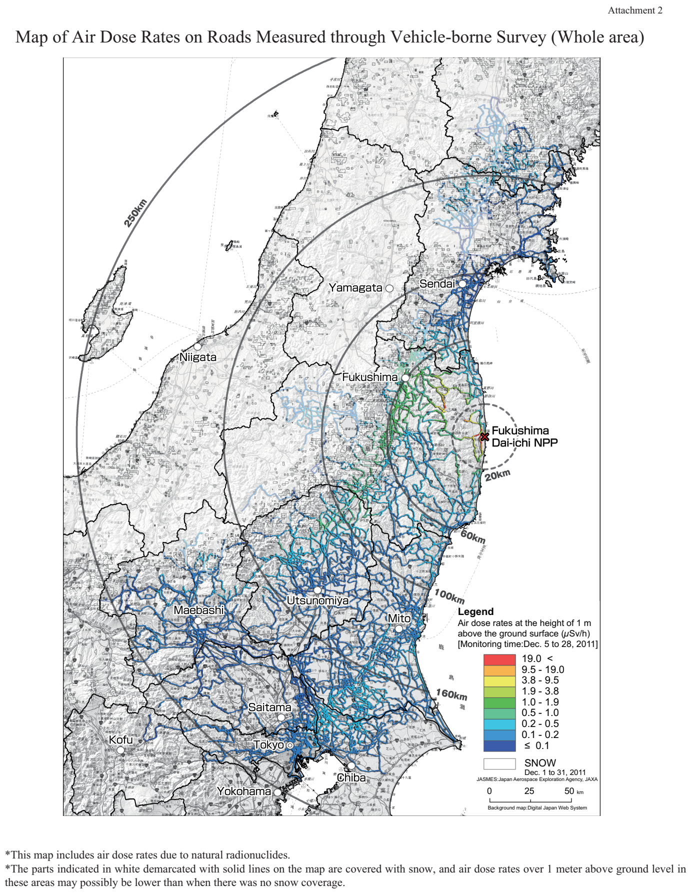

Figure 6: Typical result of the shielding factor of a sedan car body determined during the measurement project organized by MEXT in June, 2011. Air dose rates inside a measurement car were measured at the points of various air dose rates, and a simple linear function is found to be sufficient for the overall range of the air dose rate expected in Fukushima.

motor cycles for postal services, and delivery vans for convenience stores. We have succeeded in the large-scale operation of new versions of KURAMA, namely KURAMA-II. One hundred monitoring cars with KURAMA-II were simultaneously operated in the East Japan area for one month in March 2012. KURAMA-II will be introduced in a following paper[12].

7. Acknowledgement

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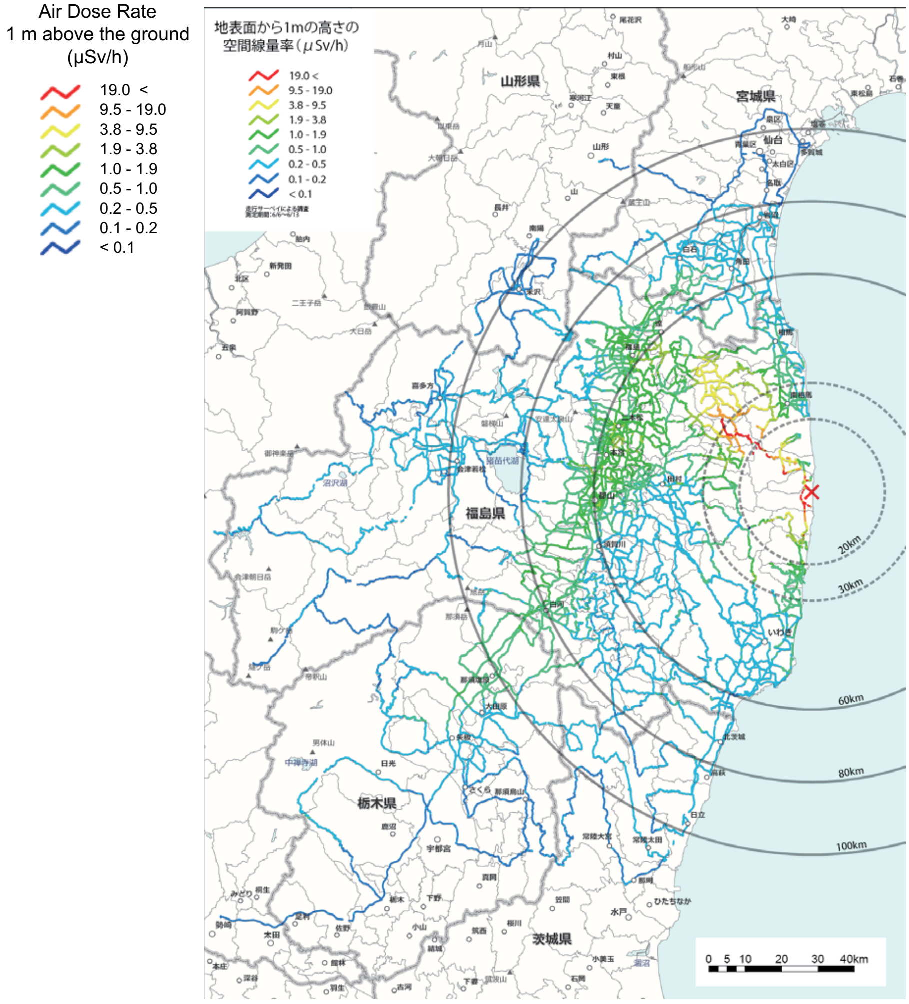

Figure 7: Radiation map drawn based on the result of the car-borne survey with KURAMA by MEXT in June, 2011[10].

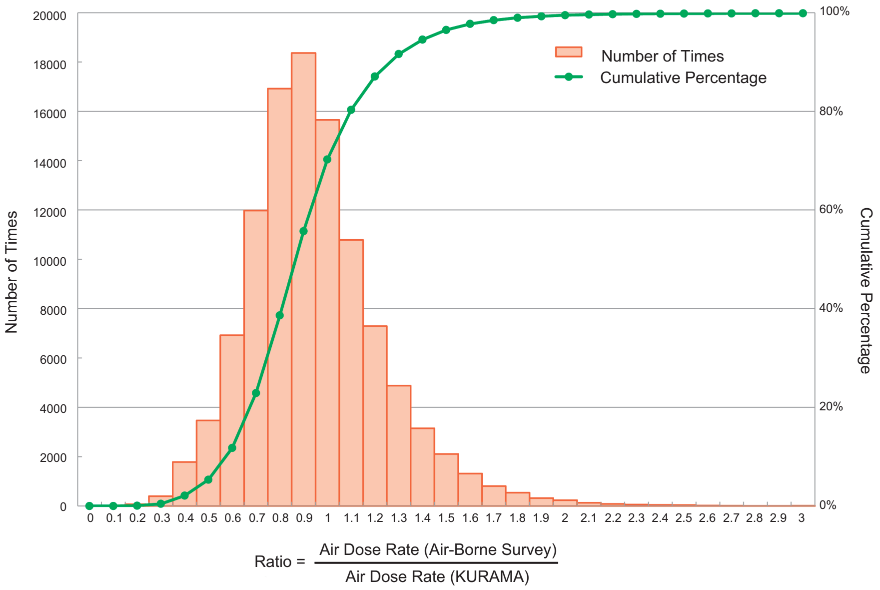

Figure 8: Radiation map drawn based on the result of the car-borne survey with KURAMA by MEXT in Dec. 2011[11]. The parts indicated in white demarcated with solid lines on the map were covered with snow during the investigation period. The air dose rates in these areas may have been affected by the snow coverage.

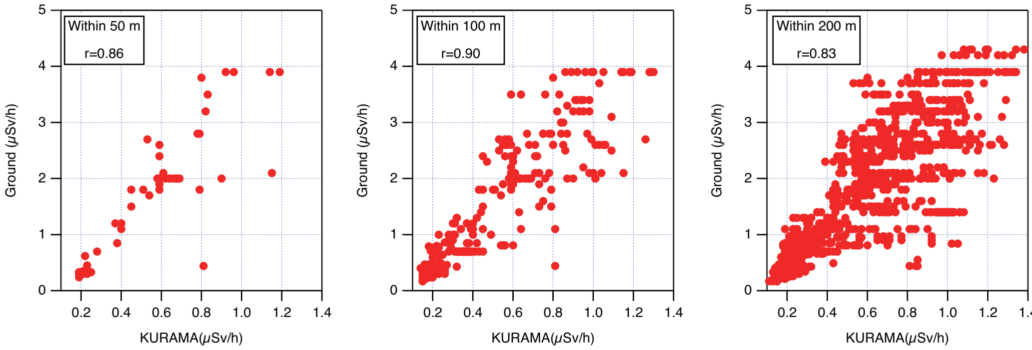

Figure 9: Correlations of air dose rates at school grounds by Fukushima prefectural government in April 2011 and those at surrounding points by KURAMA in June 2011. Typically, a measuring point by Fukushima prefectural government were surrounded by several measurement points by KURAMA.

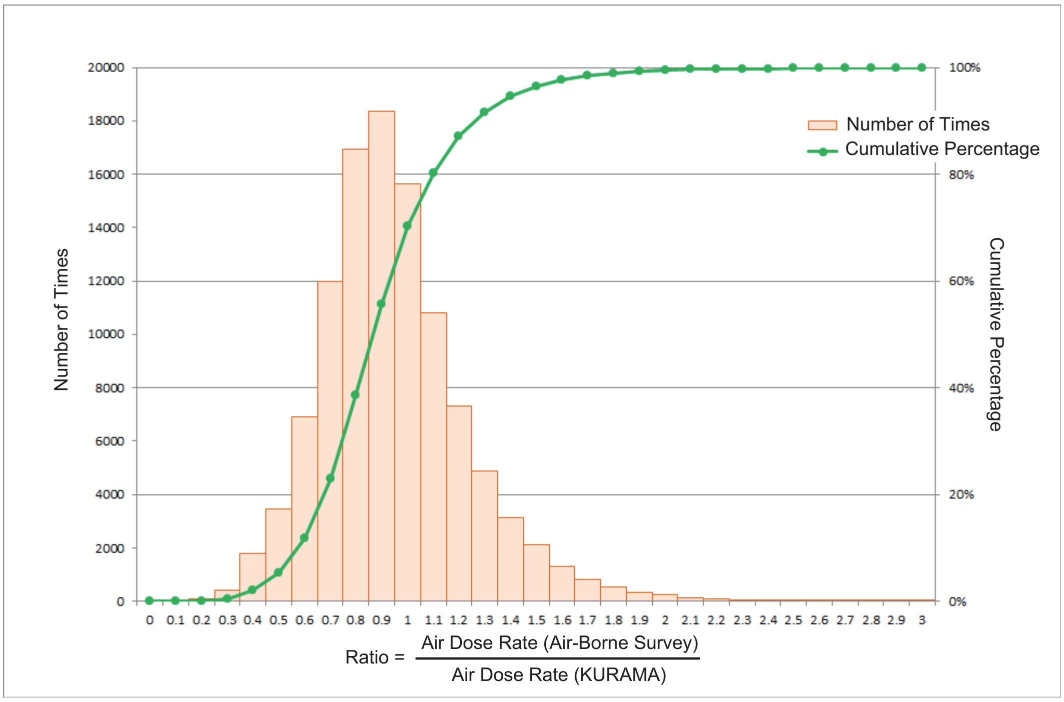

Figure 10: Correlation of air dose rates determined by the air-borne survey by MEXT from May 31 to July 2 and by KURAMA in June 2011[10].

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