Technical Data

Car-Borne Survey Using Ge Semiconductor Detector in the Chugoku Region of Japan

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(Received on March 2, 2012)

(Accepted on July 30, 2012)

We developed a Ge semiconductor detector system that allows real-time mapping of radionuclides using a vehicle. We used this system to conduct a background survey in the Chugoku Region of Japan. ^{214}Bi (U-series) concentration was high in the east and west of Hiroshima Prefecture; ^{208}Tl (Th-series) concentration was high in Oki-island in Shimane Prefecture and in the western part of Hiroshima Prefecture, and ^{40}K was high in the entire area of Hiroshima Prefecture, while the concentrations of all types of radionuclides were low in the plains in the eastern part of Shimane Prefecture. The artificial radionuclide ^{137}Cs was detected in Tottori, Shimane and Yamaguchi Prefectures as well as in the Chugoku Mountains. The results of the survey did not indicate that Shimane Prefecture had been affected by the accident at the Fukushima Daiichi Nuclear Power Plant.

KEY WORDS: car-borne system, Ge semiconductor detector, Chugoku Region, emergency monitoring, nuclear power plant, *in-situ*.

I INTRODUCTION

For emergency monitoring in the event of an accident at a nuclear power plant, surveying using car-borne NaI(Tl) detector (hereinafter, NaI-CBS) is planned for rapid and large-scale measurement of radionuclide concentration. NaI-CBS provides information on the degree of the contamination caused by radionuclides deposited on the land surface within a few tens of meters in the vicinity of the accident zone.

In Japan, research on NaI-CBS technology was advanced by KIMURA¹⁾ and MINATO.²⁾ SUGINO et al.³⁾ indicated the feasibility of using a car-borne measurement system to gain an understanding of the distribution of radionuclides in soil. SAKAMOTO et. al.⁴⁾ developed the NaI-CBS by combining a GPS and a NaI(Tl) high-precision dose rate meter and reported that it was possible to map the contaminated area in the vicinity of Chernobyl.

As seen above, we speculate that the NaI-CBS reflects the condition of the environment even if the measurement data is obtained from on a paved road. Hence, the apparatus is very useful for rapid measurement of the dose rate and is applied widely in emergencies. The obtained data will contribute to the adoption of protection measures such as the evacuation of inhabitants. There is a possibility, however, that when the types of released radionuclides are unknown at the initial stage of an emergency, the spectral analysis by the NaI(Tl) detector may not be able to provide adequate information for

the adoption of protection measures, which will depend on the concentration of each artificial radionuclide.

On the other hand, *in-situ* measurement using a Ge semiconductor detector with good energy resolution does not only make possible dose rate measurement, but also the quantitative determination of the artificial radionuclides deposited on the land surface. *In-situ* measurement using a Ge semiconductor detector will play an important role in predicting the exposure dose in the future, studying decontamination methods, and implementing protection measures such as the limiting the intake of food and drink.

NAGATO et. al.⁵⁾ traveled 8,000 km in Hokkaido with a Ge semiconductor detector installed aboard a vehicle in order to prove the feasibility of using the system, pioneering the use of this system. However, no measurement methods that can be adopted when travelling have yet been established.

Under these circumstances, in order to gain an understanding of the dose rates and the concentrations of artificial radionuclides rapidly during emergency monitoring, we developed a car-borne survey system (hereinafter Ge-CBS) that allows the real-time mapping of radionuclides; in application of the already developed *in-situ* continuous automatic measurement technique⁶⁾ by using a Ge semiconductor detector.

We conducted a Ge-CBS in the five prefectures of Chugoku Region of Japan since September 2009. The surveys helped us to ascertain the usability and the reliability of the system and helped understand the background of the natural and artificial radionuclides. The accident at the Fukushima Daiichi Nuclear Power Plant took place in March 2011, three months after the completion of this survey, releasing radioactive materials into the air and ground over Japan. We investigated the extent and effects of the contamination in Shimane Prefecture.

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II MEASUREMENT METHOD

1. Measurement system

We conducted a background survey in the Chugoku Region from September 2009 through December 2010; surveying was done only when there was no rain on an investigation day as well as the previous day. We also investigated the extent and effects of the contamination resulting from the accident at the Fukushima Daiichi Nuclear Power Plant; this investigation was carried out between June and August 2011, and only in Shimane Prefecture.

The Chugoku Region has an area of 31,900 km². We traveled 26,200 km and conducted measurement at 5,740 points. The measurement system was carried in the vehicle (Toyota Alphard well-cab), fixing a Ge semiconductor detector (P type HP-Ge with a relative efficiency of 87% and an energy resolution of 2.3 keV), a NaI(Tl) detector (3 inches ϕ sphere), multichannel analyzer (MCA), and data processing equipment to a portable cart. (Fig. 1).

We obtained photon data when the car was in motion, during the survey. Position information was acquired by GPS at the start and end of a measurement, and the middle point was made into the measurement representative position. We made it a rule to carry out a 5 min measurement using both the Ge and NaI(Tl) detectors. This was minimum interval required to detect U-series, Th-series, and ⁴⁰K. We obtained the photon data of the range from 50 keV to 4 MeV by Ge measurements and the photon data of the range from 50 keV to 3 MeV by NaI measurements.

The respective real-time spectra for both detectors were displayed on the computer monitor located at the front passenger seat; we simultaneously performed real-time analysis of the Ge measurement data using the *in-situ* Ge measurement method⁷⁾ in accordance with ICRU53.⁸⁾ We calculated the dose rate and concentration of the U-series, Th-series, ⁴⁰K and artificial radionuclides based on the assumptions that (1) the ground is an infinite flat plane; (2) natural radionuclides are

evenly distributed in soil; and (3) artificial radionuclides are distributed on land surface. After calculating the dose rate and concentration of radionuclides, we verified the measurement location and results by displaying measurement data in a map immediately.

The measurement data of NaI(Tl) detector was analyzed by using the G(E) function and then stored to serve as a complementary data to Ge analysis. We traveled at speeds of 30–50 kmh⁻¹ and recorded nearly all the route on memory card as a video image. We also established a local area network (LAN) using a data communication card and virtual private network (VPN) between the computer aboard the vehicle and that of the research center to allow remote control and sharing of information.

2. Data correction

With regard to the directional characteristics, the Ge-crystal, which is vertically long with dimensions of $\phi = 79.7$ mm and $L = 92.1$ mm, is almost flat at gamma rays energies from 100 keV to 2 MeV. In order to observe the directional characteristics of the shield of the vehicle, ¹³⁷Cs (386 kBq) and ⁶⁰Co (221 kBq) were irradiated from the outside of the vehicle towards the Ge detector inside the vehicle. The results are shown in Fig. 2.

Thus, the shielding effect by the vehicle is so large that the energy of a gamma ray is small. Since there are many structural objects on the chassis of a vehicle, the detection rate just under the vehicle decreases enormously.

The Ge detector was placed at a height of 130 cm, and the NaI(Tl) detector was placed at a height of 160 cm above the ground surface inside the vehicle. In order to correct the spectrum measured by the Ge detector, we compared the spectrum measured at a height of 1m above the ground on a wide plane surface and the spectrum measured inside the vehicle on the same spot, and obtained the correction coefficient about shielding of the vehicle and height of measurement for every energy. Subsequently, we analyzed the spectrum rectified using the correction coefficient. We did not

Fig. 1 State of the installation of the Ge semiconductor aboard the vehicle.

Fig. 2 Shielding effects by angle in the vehicle. Relative value when gamma ray counting rates in the setting condition where there are no vehicle is set to 100.

analyze any data obtained while traveling in a tunnel for more than 1 min.

The detection lower limit values of Ge-CBS in a 5 min measurement were about 2 nGyh^{-1} , 4 nGyh^{-1} , 0.5 nGyh^{-1} and 0.05 nGyh^{-1} for the U-series, Th-series, ^{40}K and ^{137}Cs respectively.

Moreover, we corrected the dose rate measured by the NaI(Tl) detector based on the fact that a dose rate is reduced by 30% inside the vehicle. That dose rate data were also used to verify whether the dose rate obtained by the Ge detector was adequate.

III RESULTS AND DISCUSSION

1. Geometrical conditions of a measurement object

Prior to the investigation of NaI-CBS and Ge-CBS, we conducted *in-situ* measurements at various points where the geometrical conditions were different both inside and outside of the vehicle in order to study the effect of the geometrical configuration around the vehicle on the measurement. **Fig. 3** shows the ratio of the dose rate at the following locations:

- In the center of a wide plane surface with a radius of 15 m.
- At 1 m off from the valley side edge on a mountainside 7 m-wide road with a cliff angle of 60° .
- In the center of a 15 m-wide road with the both road sides cut at an angle of 60° .
- In the center of an 80 m-long, 7 m-wide, 7 m-high tunnel.

The dose rate ratio by the NaI(Tl) detector on a plane surface (geometry A) is 0.70, and is shielded 30% by a vehicle. The shielding rate decreased with an increase in the solid angle; a shielding rate of 22% was achieved at 4π inside the tunnel.

A comparison of the dose rate measured by the Ge detector and that by the NaI(Tl) detector showed that the dose rate measured outside of the vehicle by the Ge detector was slightly lower than that recorded by the NaI(Tl) detector in every case. This is due to the fact that the Ge detector cannot measure the influential cosmic-ray components that contribute by less than 3 MeV as a Compton component. The dose rates measured inside of the vehicle by the Ge detector was lower by 17% to 20% than those by the NaI(Tl) detector except inside of the tunnel. This owes to the fact that the measurement of the Ge detector is based on the dose rate obtained from the

Fig. 3 Differences of the dose rate by the geometric form at the time of the measurement.

peak counts and does not reflect the increase of the Compton component with the decrease of the peak counts due to the shielding.

The dose rates measured by the Ge detector and NaI(Tl) detector agreed only in the measurement conducted inside the tunnel. This is because of the fact that the gamma rays incident from the direction of 4π is calculated assuming their origin from an infinite plane.

The fluctuations in dose rate of the both detectors while travelling are as shown in **Fig. 4**. In this way there are cases that the difference of the dose rate between the 2 detectors widely differ because the geometry and incident energies change incessantly. It would be ideal to correct the dose rate instantly according to the geometry. Because of the obvious difficulty involved, however, we conducted the analysis by applying the correction coefficient of every energy obtained from a wide plane surface.

2. A background survey in the Chugoku Region

Figure 5 shows the results of all the dose rates of the Ge-CBS in Chugoku Region in computational mesh by $3'$ both in latitude and longitude (from east to west: 4,530 m; from south to north: 5,550 m). There are a number of areas with a high dose rate spread across Hiroshima Prefecture; in particular, the areas ranging from the west of Hiroshima Prefecture to Masuda City, Shimane Prefecture, and the area north of Fukuyama City had dose rates over 60 nGyh^{-1} . These high dose rate areas coincided with the granite area in the Sanyo Region, and the dose rates nearly agreed with the data for the eastern part of Hiroshima Prefecture, where URABE et al⁹⁾ had conducted a survey.

In the meantime, the dose rate in the east-central part of Shimane Prefecture and Shimane peninsula was 40 nGyh^{-1} or less. These areas overlap with the green tuff area created during the formation of the Japan Sea. When we compared the resultant whole map to the dose rate map of the Japanese Archipelago prepared by MINATO,¹⁰⁾ no considerable difference was observed between the maps.

Fig. 4 Comparison in dose rate between the Ge detector and NaI(Tl) detector while travelling from the plains to the mountain areas in the eastern part of Shimane prefecture.

Fig. 5 Distribution of the total dose rate measured by the Ge-CBS in Chugoku Region. (3' computational mesh both in latitude and longitude) 2009/9–2010/12.

In the Ge-CBS (5 min measurement) conducted in Chugoku Region, ^{214}Bi (609 keV), ^{208}Tl (583 keV, 2,615 keV), and ^{40}K (1,461 keV)—all of which are natural nuclides—were detected all the time.

Figure 6 shows the results of the analysis of the

radionuclides measured by the Ge-CBS in Chugoku Region in a 3' computational mesh. The U-series and Th-series were represented by ^{214}Bi (609 keV) and ^{208}Tl (583 keV), respectively, and ^{40}K and ^{137}Cs were also represented. ^{214}Bi (U-series) was high in the east and west of Hiroshima Prefecture, ^{208}Tl (Th-

Fig. 6 Distribution of the dose rate measured by the Ge-CBS in Chugoku Region. (3' computational mesh both in latitude and longitude) 2009/9–2010/12.

series) was high in the Oki-island of Shimane Prefecture and from the west of Hiroshima Prefecture to the west of Shimane Prefecture, and ^{40}K was high in the entire area of Hiroshima Prefecture.

Although not many nuclide maps that show the location of natural radionuclides are available, data ¹¹⁾ compiled by the National Institute of Advanced Industrial Science and Technology is available. These data represent the analysis of river stones, and the distribution concentration roughly coincides with our analysis except for some differences in uranium and thorium. From those stated above, however measurement on a road has great influence of the base material of a road, a survey using a car-borne system is useful for gaining an understanding of the environmental radiation in the study area (except for cosmic-rays) by the shielding effect of a chassis acting effectively.

The purpose of the present survey was the detection of artificial radionuclides. We could detect ^{137}Cs only in mountainous areas in Tottori, Shimane and Yamaguchi Prefecture, but their detection frequency was low. This coincides with the past *in-situ* Ge measurement results that the dose rate of ^{137}Cs is less than 0.06 nGy h^{-1} in many parts of the plains of Shimane Prefecture,¹²⁾ while that in many mountainous areas is over 0.2 nGy h^{-1} .¹³⁾ This shows that the detection of artificial radionuclides on the south side of the Chugoku Mountains (Sanyo Region) is rare and many radioactive materials blown by the westerly wind were deposited on the north side of the Chugoku Mountains (San-in Region) after nuclear tests etc.

3. Study of the effects of the accident at the Fukushima Daiichi Nuclear Power Plant

On March 11, 2011, the Fukushima Daiichi Nuclear Power Plant located at Okuma-cho, Fukushima Prefecture suffered a meltdown due to the earthquakes and subsequent tsunamis in the aftermath of the East-Japan Great Earthquake. A large amount of radioactive materials was released from the reactors 1, 2, and 3, and much of this material was deposited in eastern Japan.¹⁴⁾ The presence of radioactive materials in atmospheric suspended dust was also confirmed its effect in western Japan.

Because of the possibility of an uneven distribution of high concentration areas, we conducted the Ge-CBS around Shimane Prefecture from June, 2011 to September. We covered the whole Shimane area using a $3'$ computational mesh. We could not confirm the presence of ^{134}Cs that would prove the effect of the accident, however, the presence of ^{137}Cs at a similar level of the background was found. We could also not detect the presence of ^{134}Cs in the analysis of the radionuclides collected from the soil in Shimane Prefecture.

IV CONCLUSION

- 1) We conducted a reliable measurement during a background survey in Chugoku Region, covering the whole area using a $3'$ computational mesh both in latitude and longitude.
- 2) We successfully mapped the natural radionuclides by nuclide, which proved to be reliable.
- 3) We could detect the presence of ^{137}Cs , an artificial

radionuclide, to a low level in 5 min measurements and confirmed its background.

- 4) We could not confirm the effects of the accident at the Fukushima Daiichi Nuclear Power Plant in the present Ge-CBS conducted between June and September 2011 in Shimane Prefecture.

The Ge-CBS allows the understanding of the concentration of artificial radionuclides at normal monitoring levels. Moreover, the Ge-CBS is able to determinate quantity of an artificial radionuclides nuclide with a nuclear accident that the deposition amount on land surface will be possibly several orders of magnitude higher. Therefore, we can conclude that a Ge - CBS is the choice that is convincing in monitoring a wide area quickly at the time of the nuclear disaster.

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