Dose rate estimation for northern Miyagi prefecture area in the early stage of the Fukushima Accident

Satoru ENDO*, Tsuyoshi KAJIMOTO, Kiyoshi SHIZUMA

Graduate School of Engineering, Hiroshima University,
1-4-1 Kagamiyama, Higashi-Hiroshima 739-8527, JAPAN
*endos@hiroshima-u.ac.jp

Due to the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident, the Tohoku and northern Kanto areas were widely contaminated. Many soil contamination surveys around the Fukushima Prefecture and southern Miyagi Prefecture areas have been reported. However, there are few reports for the northern Miyagi Prefecture area. A moss sample was taken from Tome City on the 1st May 2011 and measured with a Ge detector. Radioactive nuclides of ^{129m,129}Te, ^{131}I, ^{134,136,137}Cs, ^{110m}Ag, and ^{140}La were clearly identified in the moss sample. The identified radionuclides are the same as those from the FDNPP accident. In order to estimate the radiation dose rate in the northern Miyagi Prefecture area, soil sampling of 30 cm cores was performed at nine locations (Tome City, Kurihara City, Osaki City, Daiwa Town, Sanbongi Town, and Sendai City) on the 19th August 2011. Radioactive concentrations in the soil samples were measured and obtained using a Ge detector. The minimum and maximum concentrations of the sum of the ^{134}Cs and ^{137}Cs radionuclides in the soil were found to be 2.76 and 35.2 kBq/m^2 for the Michino-eki in Sanbongi Town and the Izunuma Lake in Kurihara City, respectively. The radiation dose rate in the early stage of the FDNPP accident in the northern Miyagi prefecture has been estimated using radionuclide concentrations in moss and soil samples. The maximum dose rate at the sampling locations was estimated to be 1.8 μSv/h near the Izunuma Lake in Kurihara City on the 15th March 2011. The cumulative dose for one year from the 15th March 2011 was estimated to be 1.73 -1.81 mSv by the fallout (1.2 mSv) and the natural background (0.53-0.61mSv).

Key Words: *Fukushima, dose, soil contamination, Miyagi*

1. Introduction

The nuclear accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP) was a consequence of the massive earthquake and associated tsunami that struck the Tohoku and north Kanto regions of Japan on the 11th March 2011. Due to the FDNPP accident, large amounts of radionuclides were released, and wide areas in Tohoku and northern Kanto were contaminated. A contamination map and radiation dose map was established using airborne surveys and radionuclide measurements of soil in August 2011, and later updated in November 2011 by the Ministry of Education, Culture, Sports, Science and Technology (MEXT)[1]. It was shown that highly contaminated areas were located in the northwest direction, in particular Fukushima City, Iitate Village, and Namie Town; medium contaminated areas ranged from the middle of the Fukushima Prefecture (called

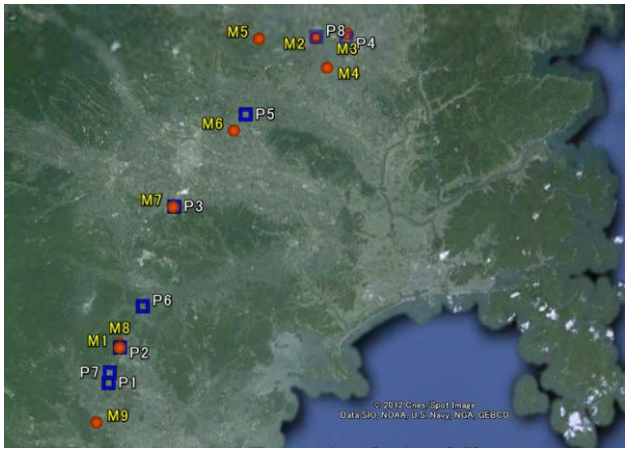

Figure 1. Sampling locations. Blue sqares: 1st May 2011 (P1-P8), Orange circles: 19-20th August 2011 (M1-M9), respectively.

Table 1. Dose rate monitoring by Aloka PD-101.

ID	Location	Dose rate (μSv/h)
P1	Izumi, Sendai City	0.1
P2	Daiwa Town	0.12
P3	Sanbongi Town	0.097
P4	Sanuma, Tome City	0.11
P5	Tajiri, Osaki City	0.11
P6	Tomiya Town	0.083
P7	Izumi Park Town, Sendai City	0.074
P8	Hyoro Mt., Tome City	0.15
—	Natural background	0.06-0.07

"Nakadori") to the Tochigi and Gunma Prefectures; and a "hot area" (slightly higher contamination) was also identified, ranging from northern Miyagi to the southern Iwate Prefecture. There are many studies of the Fukushima Prefecture and the northern Kanto area, however, few studies have so far been reported for the northern Miyagi area. In this report, radionuclide concentrations of moss samples collected on the 1st May 2011, and soil sample collected on the 19th August 2011, were obtained and discussed with respect to the cumulative dose estimation for residents.

2. Materials and methods

(2.1) Moss Sampling

The dose rate in air on the 1st May 2011 was measured by a pocket chamber (Aloka PDM-101) at eight locations (P1: Izumi, Sendai City; P2: Daiwa Town; P3: Michino-eki Sanbongi Town; P4: Sanuma, Tome City; P5: Tajiri, Osaki City; P6: Tomiya Town; P7, Izumi Park Town Sendai City; and P8: Hyoro Mountain (Mt.), Tome City), as marked by blue squares in Fig. 2. The dose rate

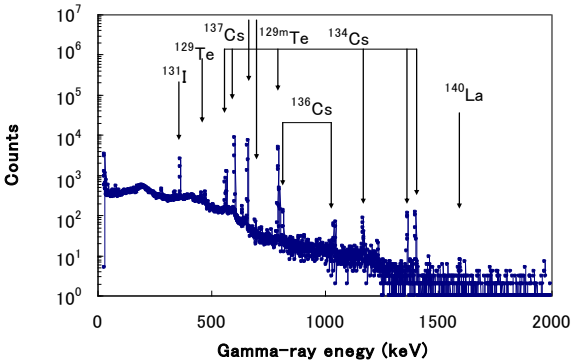

Figure 2. The measured gamma-ray spectrum of moss sample taken at Hyoro Mt., Tome City. The radionuclides of ^{129,129m}Te, ^{131}I, ^{134,136,137}Cs and ^{140}La are clearly identfied and also ^{132}Te and ^{132}I appeared likely to be present in the spectrum, but were accompanied with large errors.

was obtained by measuring the time required for readings of the Aloka PDM-101 to change by 0.01μSv; the typical measuring time was 8-10 min. The measured values were 0.06-0.15 μSv/h, as listed in Table 1. These values are slightly higher than the natural background level[2], especially the dose rate at Hyoro Mt., Tome City, which had the highest values of the eight locations (0.15 μSv/h).

A moss plant sample was then taken from the Hyoro Mt., which is located at northern Miyagi Prefecture. In order to check the contamination at Sendai City, Japanese mugwort-leaves were also collected at Izumi, Sendai City. The moss sample was used for measurement of radioactivity concentration with a Ge detector (GMX-30200-P, ORTEC) and the radioactivity profile images for the moss and the Japanese mugwort-leaves were carried out for one and 72 hours respectively, using imaging plates (BAS-2000, Fuji Film Co. Ltd.).

(2.2) Soil sampling

Radioactive nuclides of ^{129m,129}Te, ^{131}I, ^{134,136,137}Cs, ^{110m}Ag, and ^{140}La were clearly identified in the moss sample; small levels of ^{132}Te and ^{132}I also appeared likely, although this was accompanied by large errors. These radionuclides were the same as those of the contamination around the Fukushima Prefecture, therefore, soil samples were taken on the 19-20th August 2011 at nine locations in the northern area of the Miyagi Prefecture (M1: Daiwa Town; M2: Hyoro Mt., Tome City; M3: Sanuma, Tome City; M4: Minamikata, Tome City; M5: Izunuma Lake (Lk.), Kurihara City; M6: Tajiri, Osaki City; M7: Michino-eki, Sanbongi Town; M8:

Daiwa, Town; M9: Yoshinari, Sendai City). At each soil sampling point, the dose rate was measured by a scintillation survey (Aloka ICS-161). Sampling locations are marked by orange circles in Fig. 1. Soil cores were sampled from open space of soil grand using a steel pipe (30 cm length, 4.4 cm diameter). The sampled soil core was transfered into polyethylene bags for carrying back to Hiroshima University. Each sample was dried at 120 degrees in an oven overnight. The dried samples were sieved through a 2 mm mesh to remove pebbles and large organic content. Each soil sample (40 g), was placed into a polystyrene U9 container (3 cm height, 4.8 cm diameter) after homogenization in the polyethylene bags. Gamma rays from the soil sample were measured by a low background Ge-detector (GMX-30200-P; Ortec). The inventory (kBq/m^2) was calculated from the product of the measured radioactivity concentration (Bq/g) and the sample mass (g), divided by the sampling area (15.2 cm^2). The inventory was used for the external dose estimation in section 3.4.

Table 2 Radionuclide concentrations of moss samples taken from Hyoro Mt., Tome City, and Minami-Soma City [3]. The concentration were decay corrected to the 15th March 2011.

Nuclide	Radioactivity concentration (Bq/g)			
	Hyoro Mt.		Minami-Soma	
^{129m}Te	1.69	±0.43	12.2	±0.5
^{129}Te	0.76	±0.30	7.6	±0.3
^{131}I	42.1	±0.9	93.1	±0.3
^{132}Te	66.2	±164	67.2	±0.9
^{132}I	48.8	±139	56.2	±1.2
^{134}Cs	4.24	±0.03	8.7	±0.04
^{136}Cs	0.64	±0.10	1.7	±0.04
^{137}Cs	4.45	±0.04	9.4	±0.04
^{110m}Ag	0.009	±0.007	—	—
^{140}La	0.15	±0.06	—	—

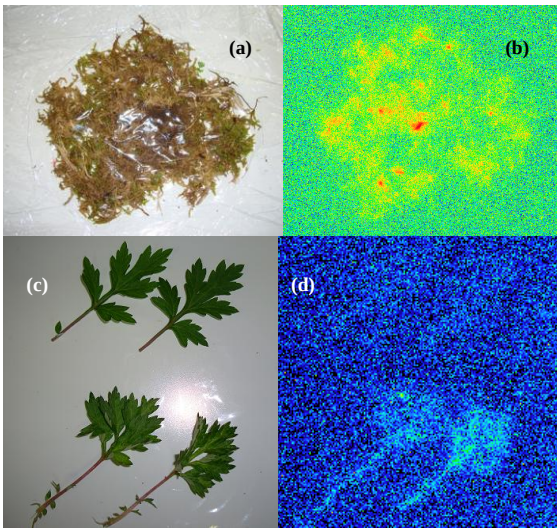

Figure 3. (a) Photograph and (b) radioactivity profile of the moss sample. (c) Photograph and (d) radioactivity profile of the Japanese mugwort-leaf samples. The upper two leaves were taken from Higashi-Hiroshima City, the lower two leaves were taken from Izumi, Sendai City, respectively.

(2.3) Estimation of exposure

The time dependence of the air dose rate can be calculated from the deposition density (kBq/m^2) in the soil [3]. To calculate the dose rate in air at 1 m above ground level, a conversion factor for each radionuclide's deposition density [4] was used. In order to estimate the initial deposition, the inventory of ^{134}Cs and ^{137}Cs, which is the sum of the total radioactivity in a soil core divided by the sampling area of 15.2 cm^2, was used, and a decay correction was applied for the 15th March 2011 when the main deposition occurred in the Fukushima Prefecture [3].

The dose rate in air was estimated using the obtained radioactivity concentration. First, the initial dose rate in air was calculated by:

$$D^0_i = K_i A_i \quad (1),$$

where D^0_i, is the dose rate in air (μGy/h), K_i is the conversion factor (μGy/h)/(kBq/m^2), and A_i is the initial concentration (kBq/m^2) of ith radionuclide (i=^{129}Te, ^{129m}Te, ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{136}Cs, and ^{137}Cs). The conversion factors used were the values given by Beck[4]. The time dependence was obtained by:

$$D_i(t) = D_i^0 (1/2)^{t/T_i} \quad (2),$$

$$D_{tot}(t) = \sum_i D_i(t) \quad (3)$$

where T_i is a physical half-life for the ith radionuclide (i=^{129}Te, ^{129m}Te, ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{136}Cs, and ^{137}Cs), and D_{tot} (μGy/h) is the total dose rate in air.

Table 3 Measured dose rate D_M (μSv/h) by Aloka ICS-161 and the obtained inventory (kBq/m^2).

ID	Location	D_M	Inventory (kBq/m^2)		
			^{134}Cs	^{137}Cs	Cs sum
M1	Daiwa	0.075	2.59 ±0.12	2.87 ±0.11	5.46 ±0.16
M2	Hyoro Mt.	0.095	9.00 ±0.21	11.0 ±0.19	20.0 ±0.29
M3	Sanuma	0.08	7.43 ±0.33	8.61 ±0.30	16.0 ±0.44
M4	Minamikata	0.065	2.41 ±0.23	3.02 ±0.21	5.43 ±0.31
M5	Izunuma Lk.	0.10	16.7 ±0.47	18.5 ±0.42	35.2 ±0.63
M6	Tajiri	0.09	9.17 ±0.39	10.8 ±0.35	19.9 ±0.52
M7	Sanbongi	0.08	1.34 ±0.13	1.42 ±0.11	2.76 ±0.17
M8	Daiwa	0.08	3.87 ±0.18	3.74 ±0.16	7.61 ±0.24
M9	Yoshinari	0.07	2.74 ±0.18	3.00 ±0.16	5.75 ±0.24

Table 4 Estimated dose rate in air for the initial fallout and on the 19th August 2011, and the measured dose rate on the 19th August 2011.

	Dose rate in air (μSv/h)*		Dose rate in air (μSv/h)	
	Calculated		Measured	
	Initial		19 Aug 2011	
	Fallout	Fallout	Total**	ICS-161
Daiwa Town	0.28	0.013	0.073	0.075
Hyoro Mt., Tome City	1.1	0.047	0.107	0.095
Sanuma, Tome City	0.78	0.038	0.098	0.08
Minamikata, Tome City	0.29	0.013	0.073	0.065
Izunuma Lk, Kurihara City	1.8	0.084	0.144	0.10
Tajiri, Osaki City	1.0	0.047	0.107	0.09
Michino-eki, Sanbongi Town	0.14	0.007	0.067	0.08
Daiwa Town	0.36	0.019	0.079	0.08
Yoshinari, Sendai City	0.30	0.014	0.074	0.07

*The unit of the calculated dose rate in μSv/h is assumed to be the same as μGy/h.
**The total is the dose rate including the natural background (assumed to be 0.06 μSv/h).

3. Results and discussions

(3.1) Moss sample

The measured gamma-ray spectrum of the moss sample is shown in Fig. 2. The ^{129,129m}Te, ^{131}I, ^{134,136,137}Cs, and ^{140}La radionuclides are clearly identified, and ^{132}Te and ^{132}I also appear likely (although accompanied by large errors). These radionuclides were the same as those found at Minami-Soma, Fukushima Prefecture, also shown in Table 2. From these results it can be concluded that the radioactive contamination originated from the FDNPP accident.

(3.2) Radioactivity profiles by imaging plate technique

The radioactivity profiles observed by the imaging plate technique, and the corresponding photographs for the moss and Japanese mugwort-leaves, are shown in Fig. 3 (a)-(d). Fig. 3 shows the photograph (a), and radioactivity profile (b), of the moss sample exposed for one hour, and the photograph (c), and radioactivity profile (d), of the Japanese mugwort-leaf samples exposed for 72 hours. The upper two leaves in Fig. 3 (d) were taken from Higashi-Hiroshima City, whereas the lower two leaves were taken from Izumi, Sendai City. These images clearly show that radioactive nuclides were attached to the moss sample, and also, that the Japanese mugwort-leaves from Izumi, Sendai City were less contaminated (by a factor of 1/200 from the exposed time) than the moss from the Hyoro Mt., Tome City. However, it is certain that radionuclides did fall in Sendai City.

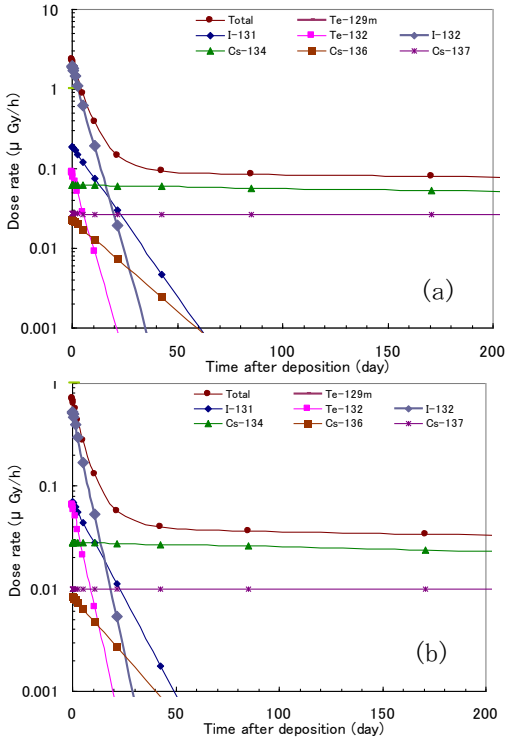

Figure 4. Time variation of the dose rate for (a) Izunuma Lk., Tome City, and (b) Yoshinari, Sendai City. From the time dependence, the dose rates on the 19th August 2011 are estimated as 0.14 μSv/h and 0.074 μSv/h, respectively. ICS-161 measured dose rate values of 0.1 μSv/h and 0.07 μSv/h on 19th August 2011, respectively.

(3.3) Radioactivity concentration in soil

The results of radioactivity concentration measurements (Bq/g) in soil are shown in Table 3. The dose rate measured by an ICS-161 at each sampling point is also listed in Table 3. The inventory of ^{134}Cs and ^{137}Cs ranged between 2.76-35.2 kBq/m^2. These values show similar trends to the radiation map published by MEXT [1].

(3.4) Estimation of external exposure

The external exposure was estimated using Eqs. (1)-(3), where the initial concentrations were taken to be the same as the inventory in Table 3, except for ^{132}Te and ^{132}I. The values for ^{132}Te and ^{132}I were assumed to have the same ratio between ^{137}Cs and ^{132}Te (^{132}I) as for the Minami-Soma data in Table 2[3], because of the large error in the measured concentrations of ^{132}Te (and ^{132}I) in the moss sample from Hyoro Mt.

Examples of the calculated results are shown in Fig. 4 (a) for the Izunuma Lk., Kurihara City, and Fig. 4 (b) for Yoshinari, Sendai City. The dose rate in air in the early stage of deposition was dominated by ^{132}I (half-life = 3.2 days), due to radio-equilibrium with ^{132}Te. After about two weeks, the dose rate in air was dominated by ^{134}Cs (half-life = 2.065 years). The estimated dose rate in air, and the measured values on the 19th August 2011 are listed in Table 4. The initial dose rate soon after deposition was estimated to be nearly 0.3 μSv/h, except for the northern Miyagi areas such as: Hyoro Mt., Tome City; the Izunuma Lk., Kurihara City; and Tajiri, Osaki City. The dose rate at a time after radioactive deposition near the Izunuma Lk. was estimated to peak at 1.8 μSv/h on the 15th March 2011 at the nine sampling locations. A cumulative dose for one year from the Izunuma Lk. sample is estimated to be 1.2 mSv; an increase on the natural background. The natural radiation level ranged between 0.06-0.07 μSv/h[2], corresponding to 0.53-0.61 mSv/y [2]. Therefore, the total cumulative exposure in this area is estimated to be 1.73-1.81 mSv/y for the first year after the incident.

4. Conclusion

In order to estimate the radiation dose rate in the northern Miyagi Prefecture area, soil core samples (depth 30 cm) were taken at nine locations (Tome City, Kurihara City, Osaki City, Daiwa Town, Sanbongi Town, and Sendai City), on the 19th August 2011. Radioactive concentrations in the soil samples were measured using a Ge detector. The minimum and maximum concentrations of the sum of the ^{134}Cs and ^{137}Cs nuclides in the soil were found to be 2.76 and 35.2 kBq/m^2 at Michino-eki in Sanbongi Town, and the Izunuma Lake in Kurihara City, respectively.

The radiation dose rate in the early stage of the FDNPP accident in the northern Miyagi Prefecture was estimated using radionuclide concentrations in moss and soil samples. The dose rate at a time after radioactive deposition near the Izunuma Lake in Kurihara City was estimated to peak at 1.8 μSv/h on the 15th March 2011 in the nine sampling locations. A cumulative dose from radioactive deposition for one year from the 15th March 2011, was estimated to be 1.2 mSv, originating from the maximum radionuclide deposition outdoors. The sum of the estimated cumulative dose by the fallout (1.2 mSv) and the natural background (0.53-0.61 mSv) was determined to be 1.73-1.81 mSv for the first year.

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