Dose rate survey inside and outside three public buildings located approximately 40 km northwest of the Fukushima Daiichi Nuclear Power Stations

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We surveyed the reduction of the dose rate inside three public buildings compared to the dose rate outside in Kawamata-machi, Fukushima Prefecture. The three buildings—a wooden construction district meeting place, a steel construction public hall, and a reinforced concrete school building—are located approximately 40 km northwest of TEPCO's Fukushima Daiichi Nuclear Power Stations. The dose rate measurement, performed with a NaI(Tl) scintillation survey meter, was carried out on January 19, 2012. We evaluated the reduction of the dose rate inside the building using the reduction factor, which was determined to be the ratio of the dose rate inside the building to that outside the building. The reduction factors 1 m inside from the window were 0.51–0.56 for the wooden building, 0.34–0.51 for the steel construction building, and 0.27–0.31 for the concrete building. The reduction factors at the center of the room were 0.48 for the wooden building, 0.23–0.34 for the steel construction building, and 0.10–0.16 for the concrete building.

Key Words: *dose estimation, external exposure, dose rate, hotspot*

1. Introduction

The Great East Japan Earthquake that occurred on March 11, 2011, and the ensuing tsunami, caused the accident at TEPCO's Fukushima Daiichi Nuclear Power Station. As a result of that accident, a large amount of radioactive material was released into the environment. Residents living in the contaminated areas have been exposed to high dose rates of radiation. To estimate the external exposure sustained by these residents, it is necessary to measure the dose rate in the place where they reside, and to determine how long they have been living in the contaminated area. So far, environmental radioactivity levels have been investigated using various radiation survey methods, including airborne monitoring surveys, monitoring posts, dust sampling, etc., and the results have been gathered and presented on an official website[1)]. The representative dose rates in the contaminated areas can be obtained from this website. In cases in which the interior contamination is negligible, the dose rate inside the building is lower than the environmental dose rate (i.e., the dose rate outside the building) due to reduction effects such as shielding from outer radiation by materials inside the building. The dose rate inside the building is usually estimated based on an appropriate reduction factor for the dose rate outside the building. This is done because it is difficult to measure the dose rate in an individual building directly. IAEA provides a “shielding factor” to be used as a coefficient to consider the reduction of the interior dose rate versus the exterior dose rate evaluated based on European houses[2]. Kamada *et al.* determined “shielding coefficients” that were designed to correct the external dose rate for inside a car, inside a Japanese wooden house, and inside a concrete building. These shielding coefficients, which were based on measurements taken in Kawamata-machi and Iitate Village in Fukushima Prefecture on May, 2011 after the Fukushima Daiichi Nuclear Power Station accident, are 0.8, 0.4, and 0.1[3]. It is considered, however, that there are not enough experimental results at present to understand the actual radiation situation inside and outside the buildings in Japan.

In this work, we surveyed the reduction of the dose rate inside three types of public buildings compared to outside with the aim of contributing to the dose estimation of the external exposure of residents living in radioactivity-contaminated areas. Several tens of measured dose rates were shown with schematic diagrams of the three buildings. The reduction of the dose rate inside the buildings versus outside was discussed.

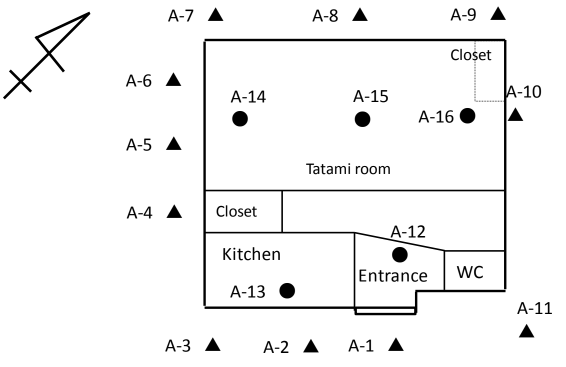

Fig. 1 Schematic diagram of (A) a wooden construction district meeting place. The numbered marks indicate the measuring points.

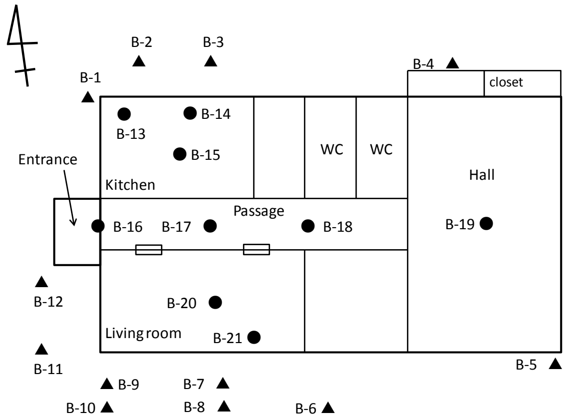

Fig. 2 Schematic diagram of (B) a steel construction public hall. The numbered marks indicate the measuring points.

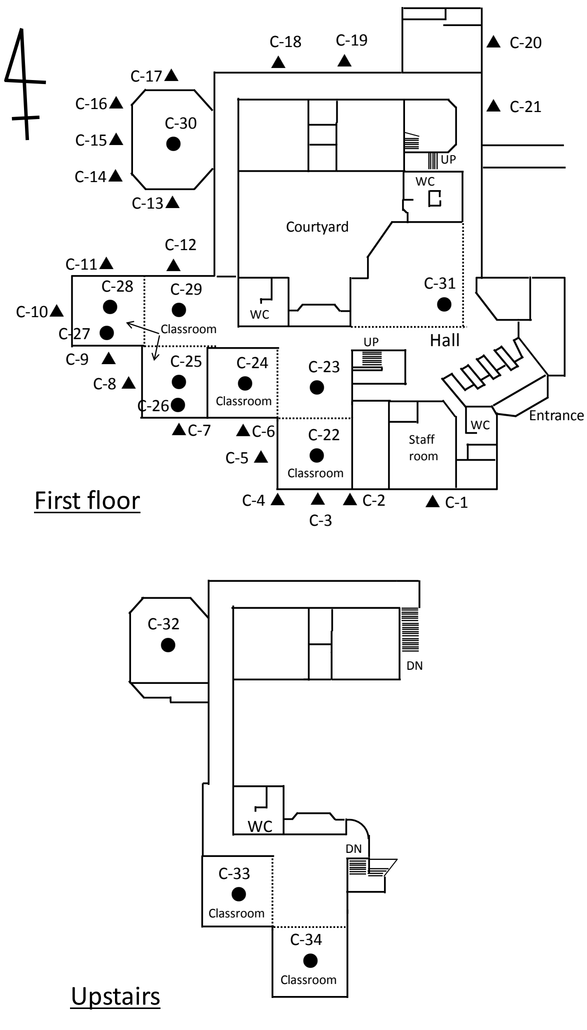

Fig. 3 Schematic diagram of (C) a reinforced concrete school building. The upper part of the figure shows the first floor and the lower part shows upstairs. The numbered marks indicate the measuring points.

2. Materials and methods

Our measurements were carried out in three public buildings, which are all located approximately 40 km northwest of the Fukushima Daiichi Nuclear Power Stations, in Kawamata-machi, Fukushima Prefecture on January 19, 2012, approximately ten months after the Fukushima Daiichi Nuclear Power Stations accident. We selected the three buildings mainly on the building structure and scale. The three buildings were (A) a wooden construction district meeting place, (B) a steel construction public hall, and (C) a reinforced concrete school building. In this work, buildings (A)–(C) are regarded as a representative small, middle, and large scale building where residents stay in other than a house, respectively. Schematic diagrams of buildings (A)–(C) are shown in Figs. 1–3, respectively. The black triangles and black circles in Figs. 1–3 indicate the measuring points with approximate position relations. Buildings (A)–(C) are surrounded by fields and woods. Building (A) is a Japanese-style one-story house with a tatami room, a lavatory and a kitchen. The neighboring places of building (A) are a ground area with weeds and the front of the entrance, which is paved with asphalt. Building (B) is a relatively mid-sized one-story building with a hall, a large living room covered with tatami, a large kitchen, and so on. The north and east sides face upward slopes of the ground in the border with woods and a road. There are planted trees in front of the large living room. The front of the entrance hall is unpaved ground. Building (C) is a unique two-story building built on a slightly elevated hill. There is also a gymnasium, a playground, and a kindergarten within the wide site of building (C). The classrooms have large glass windows on the south side facing the playground.

The dose rates inside and outside the buildings were

Table 1 The measured dose rates in buildings (A)–(C).

Measuring point shown in Figs. 1-2			Dose rate [μSv h^{-1}]
Inside / Outside the building	No.	Notes	
Outside	A-1		1.6
	A-2		1.8
	A-3		2.2
	A-4		1.6
	A-5		1.6
	A-6		1.6
	A-7		1.5
	A-8		1.5
	A-9		1.7
	A-10	near wall	1.4
	A-11		1.7
Inside	A-12		0.67
	A-13	1 m from the window	1.0
	A-14	1 m from the window	0.81
	A-15	center of the room	0.77
	A-16		0.78
Outside	B-1	near wall	2.4
	B-2		2.8
	B-3		3.2
	B-4	near wall	4.1
	B-5	near wall	1.7
	B-6		3.3
	B-7		1.7
	B-8		3.2
	B-9		1.5
	B-10		2.1
	B-11		1.4
	B-12		1.4
Inside	B-13	1 m from the window	1.2
	B-14	1 m from the window	1.1
	B-15	center of the room	0.74
	B-16		0.85
	B-17		0.48
	B-18		0.40
	B-19	center of the room	0.53
	B-20	center of the room	0.57
	B-21	1 m from the window	0.86

Measuring point shown in Fig. 3			Dose rate [μSv h^{-1}]
Inside / Outside the building	No.	Notes	
Outside	C-1		3.8
	C-2		2.5
	C-3		2.7
	C-4		2.0
	C-5		2.2
	C-6		2.0
	C-7		2.5
	C-8		2.1
	C-9		2.0
	C-10		1.4
	C-11		1.5
	C-12		2.1
	C-13		1.3
	C-14		1.6
	C-15		1.4
	C-16		1.7
	C-17		1.4
	C-18		1.9
	C-19		1.7
	C-20		1.5
	C-21		3.4
Inside	C-22	center of the room	0.33
	C-23		0.23
	C-24	center of the room	0.21
	C-25	center of the room	0.25
	C-26	1 m from the window	0.68
	C-27	1 m from the window	0.62
	C-28	center of the room	0.28
	C-29		0.25
	C-30	center of the room	0.23
	C-31		0.18
	C-32	center of the room	0.18
	C-33	center of the room	0.19
	C-34	center of the room	0.24

measured using NaI(Tl) scintillation survey meters (TCS-171 and TCS-172, Hitachi Aloka Medical, Ltd., Tokyo, Japan). The probes of the NaI(Tl) survey meters were set to an altitude of 1 m from the floor inside the buildings and 1 m from the ground outside the buildings. The points 1 m inside from the glass window and at the center of the room for the living room and the kitchen where a person would stay in relatively for a long time were mainly selected as the measuring points inside the building. Outside the building, we performed the dose rate measurements along building circumference at suitable distance to the scale of the building. When we found the spot of a particularly high dose rate, we surveyed the source point. Actually, in order to acquire reference data, we measured the dose rates at a number of measuring points that are not shown in Figs. 1–3.

3. Results and discussion

The measured dose rates in buildings (A)–(C) are given in Table 1. The measured dose rates outside the buildings were 1.3–3.8 μSv h^{-1}, which are highly elevated values compared to the ordinary natural background dose rate in Japan[4)]. In addition, they did not indicate a uniform distribution for each building. This is because the distribution of the radioactivity that accumulated in the environment, which resulted in the high dose rates in the contaminated areas, was not uniform. It was affected by various factors, including topography, the surface state of the ground, weather, and so on. The maximum dose rates outside the buildings were (A) 3.2 μSv h^{-1}, obtained on piled-up fallen leaves, (B) 4.1 μSv h^{-1}, obtained on raindrops, and (C) 6.4 μSv h^{-1}, obtained on raindrops. These correspond to a rise in dose rate due to so-called hot spots.

We evaluated the reduction of the dose rate inside the buildings using the reduction factor, which was determined to be the ratio of the dose rate inside the building to the dose rate outside the building. The reduction factors 1 m inside from the glass window and at the center of the room for buildings (A)–(C) are given in Table 2. With regard to the measuring point outside the building, a representative point close to the measuring point inside the building was chosen there. The reduction factors 1 m inside from the window were 0.51–0.56 for building (A), 0.34–0.51 for building (B), and 0.27–0.31 for building (C), and the reduction factors at the center of the room were 0.48 for building (A), 0.23–0.34 for building (B), and 0.10–0.16 for building (C). The results show that it is preferable to stay in the place apart from the window to reduce the external exposure if possible. For both 1 m inside from the window and the center of the room, the reduction factor was (C) < (B) < (A). The effect of the shielding with building materials is estimated to be (C) > (B) > (A). The attenuation of radiation by the distance from the window to the center of the room is also estimated to be (C) > (B) > (A). In short, our results for the reduction effect of the dose rate qualitatively agree with the expectations from the structure and the scale of buildings (A)–(C). In ref. 3), Kamada *et al.* determined "shielding coefficients" to correct the external dose rate for inside a Japanese wooden house and inside a concrete building. These coefficients, which were based on measurements taken in Kawamata-machi and Iitate Village, are 0.4 and 0.1. If the difference in significant digit can be ignored, our "reduction factors" at the center of the room agree with their "shielding coefficients" in less than 60%. It is thought that both are actually synonymous.

Table 2 Reduction factors obtained from the present measurements.

Measuring points related to evaluation of the reduction of the dose rate			Reduction factors (the ratio of the dose rate inside the building to the dose rate outside the building)	
Outside the building	1 m inside from the window	Center of the room	1 m inside from the window	Center of the room
A-2	A-13	-	0.56	-
A-5	A-14	A-15	0.51	0.48
B-2	B-13	-	0.43	-
B-3	B-14	B-15	0.34	0.23
B-7	B-21	B-20	0.51	0.34
C-3	-	C-22	-	0.12
C-6	-	C-24	-	0.11
C-7	C-26	C-25	0.27	0.10
C-9	C-27	C-28	0.31	0.14
C-15	-	C-30	-	0.16

4. Summary

We measured the dose rate inside and outside three buildings in Kawamata-machi, Fukushima Prefecture: a wooden construction district meeting place, a steel construction public hall, and a reinforced concrete school building. A NaI(Tl) scintillation survey meter was used for these measurements. We evaluated the reduction factors, which were determined to be the ratio of the dose rate inside the building to the dose rate outside the building. The reduction factors 1 m inside from the window were about one-half or less for the three buildings. The reduction factors at the center of the room were 0.48 for the wooden building, 0.23–0.34 for the steel construction building, and 0.10–0.16 for the reinforced concrete building. Our results almost agree with the previous work performed under similar conditions for the Japanese wooden house and the concrete building.

We think that it is necessary to perform more experimental research on the reduction of the dose rate inside buildings compared to outside to contribute to a more accurate dose estimation of the external exposure of residents living in radioactivity-contaminated areas. This is because there are a great variety of buildings and specific dose rate distribution. In particular, data are short for the building of two or more story structure in the present work.

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