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REGULAR ARTICLE

An assessment of radiation doses at an educational institution 57.8 km away from the Fukushima Daiichi nuclear power plant 1 month after the nuclear accident

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Abstract

Objectives On 11 March 2011, the Great East Japan Earthquake occurred. Due to this earthquake and subsequent tsunami, malfunctions occurred at the Fukushima Daiichi nuclear power plant. Radioactive material even reached the investigated educational institution despite being 57.8 km away from the power station. With the goal of ensuring the safety of our students, we decided to carry out a risk assessment of the premises of this educational institution by measuring radiation doses at certain locations, making it possible to calculate estimated radiation accumulation.

Methods Systematic sampling was carried out at measurement points spaced at regular intervals for a total of 24 indoor and outdoor areas, with 137 measurements at heights of 1 cm and 100 cm above the ground surface. Radiation survey meters were used to measure environmental radiation doses.

Results Radiation dose rates and count rates were higher outdoors than indoors, and higher 1 cm above the ground surface than at 100 cm. Radiation doses 1 cm above the ground surface were higher on grass and moss than on asphalt and soil. The estimated radiation exposure for a student spending an average of 11 h on site at this educational institution was 9.80 μSv.

Conclusions Environmental radiation doses at our educational institution 57.8 km away from the Fukushima Daiichi nuclear power plant 1 month after the accident were lower than the national regulation dose for schools (3.8 μSv/h) at most points. Differences in radiation doses depending on outdoor surface properties are important to note for risk reduction.

Keywords Environmental radiation measurements · Fukushima Daiichi nuclear power plant accident · Systematic sampling · Radiation · Risk assessment

Introduction

Health effects due to radiation exposure after the accident at Fukushima Daiichi nuclear power plant, Okuma Town, Futaba County, Fukushima Prefecture are currently causing concern. There are many reports of the health effects from radiation exposure. The Chernobyl nuclear power plant disaster saw an increase in thyroid cancer in children of every age in the Czech Republic [1], and areas with high radiation pollution in Finland showed many premature births [2]. Even at low radiation doses, previous studies have reported carcinogenic and genetic risks that increase with increasing radiation exposure [3, 4]. Therefore, we need to pay attention even to low radiation exposure.

On 11 March 2011, at 2:46 p.m., the 9.0 magnitude Great East Japan Earthquake, with maximum seismic intensity of 7 at Kurihara City, Miyagi Prefecture, occurred in the Pacific Ocean off the coast of Sanriku, Japan.

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The impact of the earthquake and tsunami resulted in damage to the electrical supply and loss of nuclear reactor cooling functions at the Fukushima Daiichi nuclear power plant. The following day, March 12, a hydrogen explosion occurred at the no. 1 building of Fukushima Daiichi nuclear power plant, followed by a hydrogen explosion at the no. 3 building on March 14. The pressure valve of the nuclear reactor containment vessel at building no. 2 was opened on March 13 [5]. This string of events resulted in the release of iodine-131 (I-131), cesium-134 (Cs-134), and cesium-137 (Cs-137) [6] among other radioactive material from the Fukushima Daiichi nuclear power plant. According to the radioactive material atmospheric dispersion simulation by France's Institute for Nuclear Safety and Radiation Protection (IRSN), from 12:00 p.m. on March 15 until about midnight of March 16, the skies over Fukushima City at any one time measured airborne cesium at a level from 10 to 100 Bq/m^3 [7]. The first increase in radiation dose in Fukushima City, located 60 km from the Fukushima Daiichi nuclear power plant, occurred around 3:00 p.m. on March 15 [8]. According to Mattsson et al., 99% of radioactive material is due to fallout deposited on the Earth's surface with rain [9], so this increase can be attributed to the rain that started to fall around 3:00 p.m. [10]. After Fukushima City recorded its highest dose rate at 24.24 μSv/h on March 15 at 6:40 p.m., a month of decay had passed, and the dose rate on April 15 was 1.60 μSv/h [8].

During this radiation disaster, it is urgent to ensure the safety of students on the premises of educational institutions. Environmental radiation measurements at our educational institution must be carried out for the safety of our students. Radiation doses in rainwater, drinking water, and grass have been reported at an educational institution after the Chernobyl nuclear power plant accident [11], but studies focusing on radiation in the air have not been found. Environmental measurements were reported during the Chernobyl nuclear plant accident [12, 13]; however, there was only one measurement point at each measurement site. To ensure the safety of the students at our educational institution and gain more detailed understanding of the exact points of contamination, it seems more meaningful to implement environmental radiation measurements designed in accordance with systematic sampling with several measurement points at each site [14, 15].

Thus, we ascertained environmental radiation doses using a well-designed systematic sampling method at our educational institution. Measuring radiation doses makes it possible to assess the estimated radiation accumulation on the premises of our educational institution and contributes to ensuring the safety of our students with regard to radiation effects.

Methods

Measurement location

This study took place at Fukushima Medical University (37°41′N, 140°28′E), 57.8 km west-northwest of the Fukushima Daiichi nuclear power plant (37°25′N, 141°02′E) (Fig. 1).

Measurement date and conditions

Measurements were conducted on Monday 11 April 2011, 1 month after the Great East Japan Earthquake. Measurements began at 9:30 a.m. and ended at 2:45 p.m.. The weather was cloudy, with outside temperature of 15.5°C, 53% humidity, and northerly wind at 1 m/s.

Measurement sites

Measurement sites were assumed spots of student activity, with all of the following 24 areas selected. Indoors, we targeted the entrance hall, the cafeteria (with glass on one side), and a total of 14 lecture rooms and laboratories from the first to the fifth floor. Outdoors, we selected the track field, baseball field, tennis courts, parking lots 1, 2, and 3, the inner courtyard, and roads on the premises of our educational institution. The different surface properties of each location are presented in Table 2. To determine the average dose of radiation in the air at these measurement sites, more than 5 systematic sampling points were selected at each measurement site [16]. Sites that were unable to have more than 5 points, due to size, were assigned a number of points arbitrarily. A total of 137 measurement points were set. The shape of the outside measurement sites was taken into consideration, and we measured 57 points at

Fig. 1 Map of Fukushima Medical University relative to the Fukushima Daiichi nuclear power plant

systematic sampling intervals of about 1 point every 1000 m^2. Indoors, we measured 80 points, with 5 points in a room (4 points 1 m × 1 m from the four corners and 1 point in the center of the room). We confirmed in advance from campus blueprints that the rooms were all of equal size (200 m^2). We measured radiation doses facing both the windows and the interior when measuring points near windows. Indoor measurements were carried out with windows closed.

All sites were measured at a height of 100 cm above the ground surface. The environmental radiation dose at each point was measured with instruments held horizontally to the ground. We added measurement points 1 cm above the ground surface at sites where students may get close to the ground or dust may get stirred up. Sites with additional 1 cm measurements were the entrance hall indoors, and the track field, baseball field, tennis courts, and inner courtyard outdoors. The environmental radiation dose at each point 1 cm above the ground surface was measured with instruments held pointing vertically toward the ground, taking care to avoid contact with the surface of the ground.

In addition to the above-mentioned measurement points, we arbitrarily measured around drains (moss), places where rainwater collects, and gutters. These were measured with 1 point, 1 cm above the ground.

Measuring equipment

Radiation dose rate was measured using a NaI scintillation survey meter (TCS-171 and TCS-172; Aloka, Tokyo). Count rate was measured using a Geiger–Müller (GM) survey meter TGS-136 (Aloka, Tokyo). The NaI scintillation survey meter mainly measures γ-rays, whereas the GM survey meter measures β-rays and γ-rays. Units of μSv/h were used for radiation dose rate and cpm for count rate.

Measurement system

Measurements were carried out by the Environmental Measurement Team from Fukushima Medical University's School of Medicine's Department of Hygiene and Preventive Medicine and Department of Cellular and Integrative Physiology. The team was divided into 3 groups. Each measurement group basically consisted of 3 people: one person to measure using the NaI scintillation survey meter, one person to measure using the GM survey meter, and one person to keep records. In order to prevent errors due to contamination by the people measuring and the measuring devices when outdoors, they were accompanied by another person in charge of exchanging contaminated objects and maintaining cleanliness. Each group included one environmental measurement expert to give advice on accurate measurement. The environmental radiation measurements by both NaI scintillation survey meter and GM survey meter were started simultaneously. Radiation dose rate was recorded when stable with the NaI scintillation survey meter. Count rate was recorded after 1 min of measurement by the GM survey meter.

Statistics

Mean, standard deviation (SD), maximum, and minimum values were calculated for indoor and outdoor measurement sites for each measurement area. To compare measurements taken at heights of 1 cm and 100 cm above the ground surface, we used the Mann–Whitney U test. To compare lecture room and laboratory floor heights, we used one-way analysis of variance. Comparison of surface properties used the Tukey–Kramer test after one-way analysis of variance. All tests were two-sided with significance level of 1%. SPSS version 17.0 statistical software (SPSS Japan Inc., Tokyo) was used.

Results

Results of measurements 100 cm above the surface in lecture rooms and laboratories are presented in Table 1. The mean radiation dose rate ranged from 0.07 to 0.16 μSv/h, and the mean count rate ranged from 64 to 92 cpm. No significant difference was observed in radiation dose rate and count rate by floor. The mean radiation dose rate and mean count rate at 100 cm above the surface in the entrance hall were 0.34 μSv/h and 194 cpm, respectively, slightly higher than other indoor location means. In the cafeteria, the mean radiation dose rate and mean count rate were 0.14 μSv/h and 102 cpm, respectively, with a maximum radiation dose difference of fourfold on the window side (facing the window 0.40 μSv/h, facing inside 0.10 μSv/h).

Results of measurements at 100 cm above the surface outside are presented in Table 2. The mean radiation dose rate ranged from 1.01 to 2.95 μSv/h, and the mean count rate ranged from 731 to 1603 cpm. No radiation doses at 100 cm above the surface exceeded the suggested national regulation dose for schools (April 19, 2011 Indoor and Outdoor School Radiation Doses, 3.80 μSv/h) [17].

Mean comparisons of radiation dose rates and count rates measured at 1 cm and 100 cm above the surface are shown in Fig. 2. Comparing radiation doses measured at 1 and 100 cm above the surface, significant differences were found in radiation dose rate at the track field, baseball field, and tennis courts. In addition, significant differences in count rate were found at the track field, baseball field, tennis courts, and inner courtyard. Mean outdoor radiation dose rates measured at 1 cm above the surface were

Table 1 Results of radiation measurements at 100 cm above the ground surface in lecture rooms and laboratories at our educational institution in Fukushima

Measured sites	Radiation dose rate (μSv/h)				Count rate (cpm)			
	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD
1st Floor								
1-A ($n = 5$)	0.10	0.07	0.08	0.01	99	53	79	18
1-B ($n = 5$)	0.08	0.06	0.07	0.01	74	60	64	6
1-C ($n = 5$)	0.24	0.13	0.16	0.05	93	70	79	9
2nd Floor								
2-A ($n = 5$)	0.14	0.07	0.10	0.03	104	84	92	8
2-B ($n = 5$)	0.11	0.06	0.09	0.02	100	79	89	8
2-C ($n = 5$)	0.11	0.07	0.09	0.02	89	69	79	8
2-D ($n = 5$)	0.12	0.08	0.10	0.01	80	60	71	8
2-E ($n = 5$)	0.14	0.08	0.11	0.02	91	60	79	12
3rd Floor								
3-A ($n = 5$)	0.12	0.06	0.08	0.03	93	52	73	17
3-B ($n = 5$)	0.14	0.09	0.11	0.02	97	79	87	8
3-C ($n = 5$)	0.15	0.10	0.12	0.02	95	66	80	11
4th Floor								
4-A ($n = 5$)	0.10	0.05	0.07	0.02	88	69	78	9
4-B ($n = 5$)	0.12	0.09	0.10	0.01	86	62	74	10
5th Floor								
5-A ($n = 5$)	0.10	0.05	0.07	0.02	86	67	75	7
Mean ± SD	0.10 ± 0.03				79 ± 12			
p value*	$p = 0.185$				$p = 0.236$			

* p Values for comparison of means by floor height calculated by one-way analysis of variance test

Table 2 Results of outdoor radiation measurements at 100 cm above the ground surface at our educational institution in Fukushima

Measurement site	Surface properties	Radiation dose rate (μSv/h)				Count rate (cpm)			
		Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD
Track field ($n = 12$)	Grass, soil	3.18	2.72	2.95	0.16	1864	1392	1603	158
Baseball field ($n = 10$)	Grass, soil	2.70	1.72	2.25	0.32	1609	953	1320	221
Tennis courts ($n = 7$)	Artificial turf	2.39	2.05	2.21	0.15	1230	1093	1179	49
Inner courtyard ($n = 5$)	Grass, asphalt	2.85	1.32	1.84	0.59	1295	830	956	194
Parking lot 1 ($n = 7$)	Asphalt	1.53	1.07	1.36	0.15	1105	728	941	116
Parking lot 2 ($n = 10$)	Asphalt	1.72	0.88	1.32	0.23	1109	720	925	112
Parking lot 3 ($n = 3$)	Asphalt	1.15	0.82	1.01	0.17	857	556	731	157
Road ($n = 3$)	Asphalt	1.77	1.42	1.57	0.18	1045	742	906	153
Mean ± SD		1.98 ± 0.69				1162 ± 317			

1.4 times higher than those measured at 100 cm above the surface. The overall mean count rate measured at 1 cm above the surface was 4 times higher than that measured at 100 cm above the surface.

Figure 3 shows the radiation dose rate and count rate for different surface properties at 1 cm above the ground. With regards to radiation doses, grass > soil > artificial turf > asphalt. For count rate, grass > soil ≈ artificial turf ≈ asphalt. Compared with other surface properties, asphalt had a significantly lower radiation dose rate and grass had a significantly higher count rate.

Arbitrary measurement sites around drains (moss), places where rainwater collects, and gutters had radiation dose rates at over 30 (the upper limit of the measuring instrument was 30 μSv/h), 6.90, and 5.67 μSv/h, respectively. Count rates were 50900, 22200, and 8960 cpm, respectively.

We attempted to calculate the cumulative radiation dose per day by simulating a student day on the premises of our educational institution. As an example of one day in the life of a student on the premises of our educational institution, we considered a typical schedule as: park the car in parking

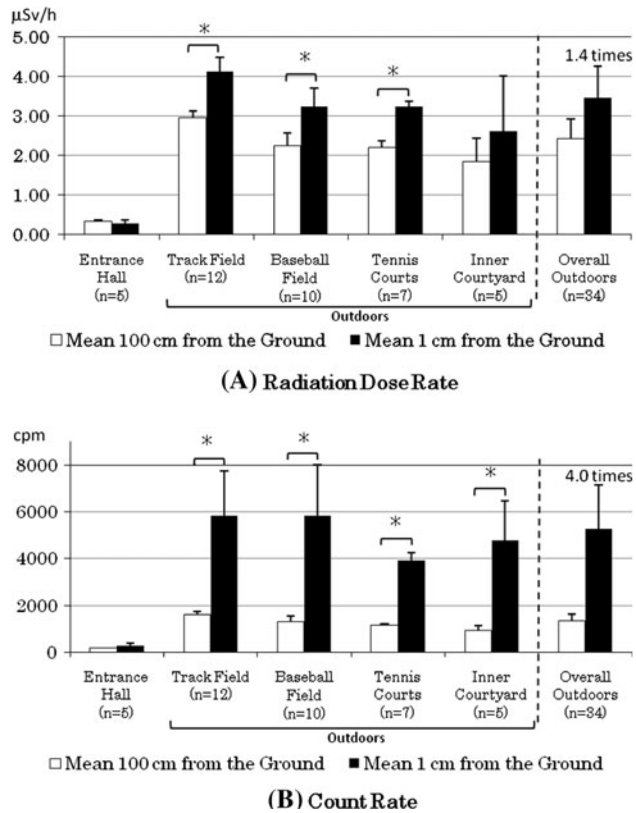

Fig. 2 Comparison of mean radiation dose rates and count rates measured at 1 cm and 100 cm above the ground surface, by area. Mean ± standard deviation are indicated; $^{*}p < 0.01$ compared with mean measurement at 100 cm above the ground by Mann–Whitney *U* test

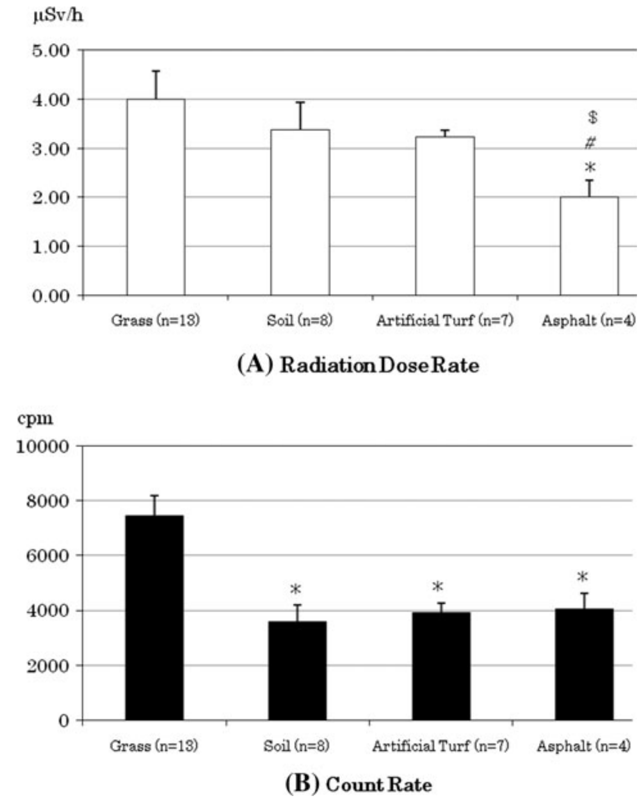

Fig. 3 Comparison of mean radiation dose rates and count rates measured at 1 cm above the ground surface, by surface property. Means ± standard deviation are indicated; $^{*}p < 0.01$ compared with grass; $^{\#}p < 0.01$ compared with soil; $^{\$}p < 0.01$ compared with artificial turf by one-way analysis of variance following Tukey–Kramer post hoc test

lot 3 (10 min), first period class in 1-A (8:40–10:10 a.m.), second period class in 2-B (10:20–11:50 a.m.), lunch in the cafeteria for 1 h, third period lab in 4-A (1:00–2:30 p.m.), fourth period lab in 4-A (2:40–4:10 p.m.), track team practice after class on the track field for 3 h, and return to the car in parking lot 3 (10 min). Using this example, we calculated the accumulated radiation dose for about 11 h on campus as 1.01 µSv/h × 1/6 h + 0.08 µSv/h × 1.5 h + 0.09 µSv/h × 1.5 h + 0.14 µSv/h × 1 h + 0.07 µSv/h × 3 h + 2.95 µSv/h × 3 h + 1.01 µSv/h × 1/6 h = 9.80 µSv. To calculate the annual radiation exposure for this simulation on the premises of our educational institution, we used 9.80 µSv × 365 days = 3.58 mSv/year. In addition, if we suppose the student is living in a wooden house when off campus, we can calculate annual radiation exposure as 1.60 µSv/h (Fukushima city's radiation dose on April 15) × 0.4 (reduction rate for a wooden house when radioactive materials attach to the surface) [18] × 13 h × 365 days = 3.04 mSv/year. Thus, the dose of radiation exposure for 1 year for a student is estimated to be 6.62 mSv.

Discussion

Environmental radiation measurements designed using a systematic sampling method at our educational institution 1 month after the Fukushima Daiichi nuclear power plant accident showed radiation dose rates and count rates lower indoors than outdoors. Outdoor measurements at the same site indicated higher radiation dose rates and count rates at 1 cm above the ground surface compared with those at 100 cm. In addition, there were higher radiation doses at 1 cm above the surface of grass and moss than above asphalt and soil surfaces. These measurement results allowed us to calculate an estimate of the cumulative daily dose of radiation on the premises of our educational institution.

Radiation dose rates and count rates were lower indoors than outdoors. Because background radiation doses indoors before the accident (from 0.04 to 0.07 µSv/h) show little change when compared with radiation dose rates after the accident, we thought that indoor dose rates before and after the accident would show small changes due to environmental effects. The International Atomic Energy Agency

(IAEA) has reported lower radiation indoors than outdoors, although indoor radiation rates depend on building materials [18]. The penetrating power of radiation is different depending on the radiation type. β-Rays can be blocked by thin metal such as aluminum, and γ-rays can be blocked by lead, iron, and concrete [19]. So, an interior surrounded by concrete with a high shielding effect would have a low dose of radiation. Indoors, however, entrances with people frequently coming and going or areas near windows show high doses of radiation, which suggests that care must be taken not to spend a long time in these locations. It is important to stay inside as much as possible unless you have something to do outdoors, in order to reduce radiation exposure. Moreover, because there was no significant difference in radiation dose rates and count rates depending on floor, we believe there are few differences in radiation effect by floor when in a building surrounded by concrete.

Outdoors, there were differences in radiation dose rates and count rates depending on height from the surface, with most measurements at 1 cm above the surface significantly higher than those at 100 cm above the surface. These results match those reported by Ogata, with a tendency for radiation doses near the ground surface to be higher than those in the air [20]. One of the factors for high radiation doses near the surface could be accumulation of radioactive material deposited on the ground. Considering I-131, Cs-134, and Cs-137, with half-life of 8.05 days, 2.06 years, and 30.1 years [21, 22], respectively, cesium will have a larger health impact in the future. Svendsen et al. reported an increase in respiratory diseases after a nuclear power plant accident because dust with high cesium concentrations from the soil can often be inhaled [23]. Wearing a mask is considered to be effective to prevent dust inhalation, and one way to prevent ingestion of radioactive materials is to avoid outdoor eating and drinking. Our results suggest making sure to wash and gargle after returning indoors from outdoors, and not eating with hands that have touched the ground. It is important to implement these easy daily behaviors in order to prevent internal exposure. In addition, I-131, Cs-134, and Cs-137 emit β-rays and γ-rays [24]. It has been suggested that β-rays have a larger impact on the surface of the ground because the radiation range of β-rays is shorter than that of γ-rays [24]. The ratio of radiation dose rates at 1 cm above the ground surface to those at 100 cm was approximately 1.4, and the ratio of count rates at 1 cm above the ground surface to those at 100 cm was approximately 4.0. The radiation dose rates include γ-rays detected by the NaI scintillation survey meter, whereas the count rates include both β-rays and γ-rays detected by the GM survey meter. Considering the difference between the ratio of radiation dose rates and the ratio of count rates, we believe that there were more β-rays close to the surface of the ground. Care must be taken not to increase exposure amounts near the surface of the ground, so it is advisable that outdoor exercise should be carried out indoors.

Comparing surface properties of the ground for measurement at 1 cm above the surface, asphalt had significantly lower radiation dose rates, whereas grass had significantly higher count rates. These results seem to indicate a possible effect that radioactive material is easier to move with rainwater from asphalt, whereas with grass, it accumulates on the plant surface at first and then is difficult to wash away. Soil and artificial turf showed no significant difference in radiation dose rates compared with grass, but count rates were significantly lower compared with grass. These differences may be attributed to radioactive material easily permeating soil and artificial turf, and then depending on the depth of penetration, β-rays being blocked but γ-rays with powerful radiation range getting through into the air. Therefore, it is suggested that the penetration of radioactive material differs depending on the properties of the ground. It has been reported that, in usual times, asphalt has higher natural radiation doses than soil [25]. Our study showed that soil had a higher radiation dose than asphalt. Radioactive material deposited in the soil may be difficult to wash away after a nuclear power plant accident. This suggests that attention must be paid to different ground surface properties.

Arbitrary measurement sites showed radiation doses higher than the national regulation dose. High radioactive material contamination has been reported being found on lake bottoms and areas with pooled water or sediment after the Chernobyl nuclear power plant accident [26]. Our findings matched those previous results. We suggest that attention must be paid to areas with pooled rainwater, moss, and soil deposits.

Assuming a typical student life, an estimated annual radiation dose of 3.58 mSv was calculated. Both the Japanese government and international nuclear power committees, such as the International Commission on Radiological Protection (ICRP) and IAEA, have established a cumulative radiation external exposure dose of 20 mSv/year. Our finding was lower than that national and international regulation dose. If there really is no risk at radiation doses under 20 mSv/year, then this study at our educational institution located 57.8 km from the Fukushima Daiichi nuclear power plant suggests radiation doses at levels having no impact on health for students leading a typical student life on campus.

This study has several limitations. Measurements were taken only once, 1 month after the Fukushima Daiichi nuclear power plant accident. With radiation exposure, it is important to monitor people's long-term accumulation [27], so it is necessary from here on to conduct long-term monitoring of the shifting radiation doses on the premises of our educational institution. It is also important to track changes over time according to the properties of the ground surface. In this study, a simulation of environmental radiation effects on students at our educational institution was possible, but in order to gain more detailed understanding of individual radiation exposure, it is necessary to conduct a study of actual student life using a personal dosimeter.

In this study after the accident at Fukushima Daiichi nuclear power plant, we carried out a risk assessment designed for environmental measurements of radiation doses at our educational institution located 57.8 km from the power plant. Almost all measured doses 1 month after the accident were below the national regulation dose for schools; however, there were some areas of the premises that showed high doses of radiation. It was possible to calculate an estimate of accumulated daily radiation on the premises of our educational institution. Our simulation showed an accumulated radiation dose of 3.58 mSv/year for a typical campus life. Monitoring and surveys are required to ascertain the longitudinal health effects of radiation. Our results will be useful in bringing attention to daily life behavior with regards to radiation exposure and estimating radiation exposure at educational institutions.

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Conflict of interest The authors declare that there is no conflict of interest.

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