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Contribution Ratios of Natural Radionuclides to Ambient Dose Rate in Air After the Fukushima Daiichi Nuclear Power Plant Accident

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Abstract

It is important that the contribution ratio of natural radioactivity to ambient dose rate in air is clarified after the accident at the Fukushima Daiichi Nuclear Power Plant. In this study, ambient dose rates in air were observed at 34 places in eastern Japan and the contribution ratios were clarified. The mean contribution ratio of the natural radionuclides was 71% (range: 0 – 100%). In most places, the natural radionuclides made a larger contribution to the ambient dose rate in air. (80/100 words)

Keywords

Fukushima Daiichi Nuclear Power Plant; Eastern Japan; Ambient dose rate in air; Natural radionuclides; Artificial radionuclides; Mobile survey

Introduction

Large amounts of artificial radionuclides such as ^{131}I, ^{134}Cs and ^{137}Cs were released to the environment in the March 2011 accident at the Fukushima Daiichi Nuclear Power Plant (F1-NPP) of the Tokyo Electric Power Company (TEPCO) [1]. UNSCEAR has estimated that 100-500 PBq of ^{131}I and 6-20 PBq of ^{137}Cs were released from the reactor buildings in March 2011 [2]. These amounts from F1-NPP were about 10% and 20% for ^{131}I and ^{137}Cs, respectively, of those estimated for the Chernobyl accident. While large amounts of the released artificial radionuclides were mainly deposited in areas northeast of F1-NPP such as Futaba Town, Okuma Town, Iidate Village, and Namie Town [3], these radionuclides were diffused and deposited all over eastern Japan depending on the wind direction and precipitation field [4]. Regularly updated ambient dose rates in air obtained from monitoring posts located in each prefecture have been publicized on the website of the Nuclear Regulation Authority since 2011 [5]. The distribution of ambient dose rates in air within 80 km from the F1-NPP has also been publicized by researchers from the Japan Atomic Energy Agency [6].

While many studies about ambient dose rates in air near the F1-NPP (i.e., the Pacific Ocean side of Honshu) have been reported, there are only a few reports, including simulation studies, about the rates on the Sea of Japan side [7, 8] (Fig.1). Additionally, the contribution ratios of artificial radionuclides (^{134}Cs+^{137}Cs) and natural radionuclides (^{40}K, ^{238}U series and ^{232}Th series) to ambient dose rate in air have not been clearly explained. In fact, the ambient dose rate in eastern Japan is not uniform; there are areas on both the Pacific and Sea of Japan sides with higher ambient dose rates depending on the basement geology [9, 10]. In the present study, a car-borne survey and fixed-point observations were carried out on both the Pacific and Sea of Japan sides and the contribution ratios of natural radionuclides were analyzed.

Materials and Methods

Ambient dose rates in air (nGy h^{-1}) were measured during September 10-15, 2014 and November 1-3, 2014 in eastern Japan on both Pacific and Sea of Japan coasts and in the interior (Fig.1). A car-borne survey technique is a common method for fast assessment of dose rate in a large area. The present car-borne survey was carried out using a 3-in × 3-in NaI(Tl) scintillation spectrometer with a global positioning system (EMF Japan Co., Osaka, Japan). Latitude and longitude at each measurement point were measured at the same time as the count rates were recorded. Measurements were performed every 30 s. The survey route mainly selected expressways and major highways such as national routes. The survey route was 3,412 km long. Shielding by the car body was estimated by making measurements inside and outside the car at the 34 numbered locations (Figs. 1a and 1b). Counting time inside and outside the car was set to 2 min. For the outside measurements, a scintillation spectrometer was positioned 1 m above the ground surface. A preliminary experiment was performed and the shielding factor of 1.53 was found from the correlation between count rates inside and outside the car. This factor was used for correction of the measured value so as to better represent the outside count rate. Additionally, the pulse height distributions were obtained outside the car from a total recording period of 10 min at the 34 locations. Obtained data were unfolded using a 22 × 22 response matrix [11] and the ambient dose rates in air were calculated. The dose conversion factor (nGy h^{-1}/cps) was found to be 0.093 by correlation between total count rate and ambient dose rate in air.

All the obtained data from the car-borne survey were plotted on distribution maps using generic mapping tools (University of Hawaii, HI, USA). For more detailed analysis, all the obtained pulse height distributions outside the car were analyzed using a response matrix [11] as described above and the separated ambient dose rates from the natural radionuclides (^{40}K, ^{238}U series and ^{232}Th series) and the artificial radionuclides (^{134}Cs and ^{137}Cs).

Results and Discussion

Fig. 2a shows a distribution map of the ambient dose rates in air obtained by the car-borne survey in eastern Japan (*n* = 5,674). Higher ambient dose rates in air were observed in areas west and southwest of the F1-NPP; these data were in agreement with previously reported values [6]. The mean and range of ambient dose rates in air in this survey were 129 nGy h^{-1} and 11-7489 nGy h^{-1}, respectively. On the Sea of Japan side, lower ambient dose rates in air were observed compared to those of the Pacific Ocean side. Especially, the lowest values were observed in Akita Prefecture; the mean and range of absorbed dose rates were 24 nGy h^{-1} and 11 - 59 nGy h^{-1}, respectively.

The distribution maps with enlarged scales of ambient dose rate in air are shown in Figs. 2b and 2c which exhibit the distribution of very high observed dose rates near the F1-NPP. The highest ambient dose rate in air (7489 nGy h^{-1}) was observed in Okuma Town at a location 2.3 km west of the F1-NPP (37.42342 °N, 141.00407 °E in Fig. 2c). This point was located on National Route (NR) 6 that had been in a regulated access zone (NR 6 distance within the zone: 14 km) until September 15, 2014. The mean and range of ambient dose rates in air (*n* = 59; measured on November 1, 2014) at this point were 2812 nGy h^{-1} and 359-7489 nGy h^{-1}, respectively. Here, if a car with the windows closed passed along NR 6 at a speed of 40 km h^{-1}, the effective dose to everyone in the car was calculated as 0.45 μSv. The dose conversion factor used was 0.748 Sv Gy^{-1} [12] for conversion to the effective dose. According to the UNSCEAR [13], the dose conversion factor is defined to be 0.7 Sv Gy^{-1}. However, this factor is available for 0.5 MeV of gamma ray, it cannot use to the energy of gamma ray in the environment (tens of keV – 2.614 MeV). Thus, Moriuch et al. [12] reported factor was used in this study.

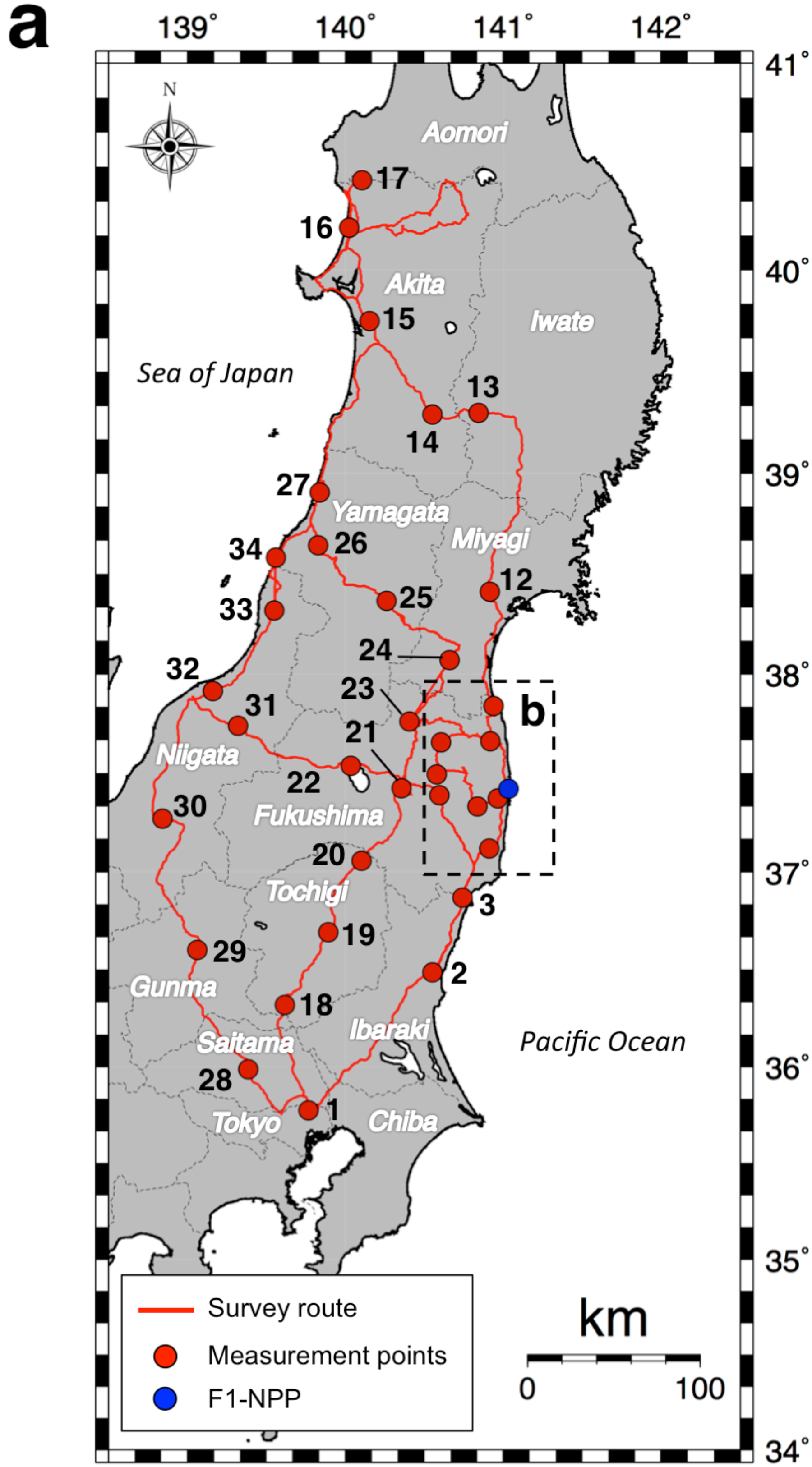
According to the Team in Charge of Assisting the Lives of Disaster Victims, Government of Japan [14], the mean and range of ambient dose rates in air on this same NR 6 obtained with a NaI(Tl) survey meter between July 2 and August 12, 2014 were 4679 nGy h^{-1} and 414 - 19652 nGy h^{-1}, respectively. The effective dose to a person traveling this route by car at a speed of 40 km h^{-1} was estimated from the concentration of radioactivity collected on a dust sampler [14] and was 0.79 μSv for the shielding factor of 1.53 obtained in this preliminary study. A decontamination project has been carried out at Tomioka and Okuma Towns since June 2013 [15]. The present discrepancy in values (0.45 μSv vs. 0.79 μSv) could be attributed to the success of this decontamination project.

Ambient dose rates in air obtained from all radionuclides, natural radionuclides and artificial radionuclides at 34 locations are shown in Table 1. The mean dose rates from all, natural and artificial radionuclides were 93 nGy h^{-1}, 35 nGy h^{-1} and 57 nGy h^{-1}, respectively. The mean of the contribution ratio of natural radionuclides was 71%. While higher dose rates in air were observed at #9 (i.e., near the F1-NPP), #32 and #33 (i.e., Sea of Japan side) compared to the mean dose rate in Japan (51 nGy h^{-1}) [9], the contribution ratios of natural radionuclides were significantly different. Most ambient dose rates in air observed on the Sea of Japan side are influenced by natural radionuclides and they vary with the basement geology. Abe et al. [9] observed higher dose rates in air in the northern area of Niigata Prefecture (94.0 – 130.6 nGy h^{-1}) before the accident, and their results showed the same tendency as the presently obtained results. These areas have mainly granite formations. The statistical dose rate of this kind of granite has been reported to be 79 ± 25 nGy h^{-1} (n = 143) and higher compared to other rocks such as basalt (20 ± 12 nGy h^{-1}: n = 49) [10]. Additionally, higher dose rates in air from natural radionuclides were also observed near the F1-NPP (#6, #8, #20 and #21) and Sea of Japan side (#26, #27, #31 and #34) for the same reason as given above. The geological map of granite in eastern Japan is shown in Fig. 3 [16], and the obtained higher dose rates in air from natural radionuclides were correlated with that distribution. From the results of this study, it was possible to deduce that when the ambient dose rates in air before the accident were assumed as the ambient dose rates in air from natural radionuclides as shown in Table 1, the ambient dose rates in air after the accident had not changed on the Sea of Japan side. On the contrary, ambient dose rates had increased 0.3 (#21) to 29.2 (#6) times near the F1-NPP.

Table 1 Ambient dose rates in air and contribution ratios of natural radionuclides in eastern Japan in fall 2014

#*	Shielding factor	Ambient dose rate in air ($nGy\ h^{-1}$)			Contribution ratio of natural radionuclides (%)	#*	Shielding factor	Ambient dose rate in air ($nGy\ h^{-1}$)			Contribution ratio of natural radionuclides (%)
		All	Artificial radio-nuclides	Natural radio-nuclides				All	Artificial radio-nuclides	Natural radio-nuclides	
1	1.52	31	0	31	99	18	1.37	43	7	35	83
2	1.37	42	6	36	85	19	1.45	65	35	30	46
3	1.65	82	47	35	43	20	1.54	80	31	50	62
4	1.41	91	63	28	30	21	1.45	69	15	54	78
5	1.64	88	53	35	40	22	1.52	46	4	42	91
6	1.60	1421	1374	47	3	23	1.39	88	64	24	28
7	1.78	58	22	36	63	24	1.54	28	12	16	57
8	1.32	100	50	49	50	25	1.51	38	16	22	59
9	1.46	67	41	26	38	26	1.48	51	2	49	96
10	1.36	90	63	27	30	27	1.43	47	0	47	99
11	1.32	31	13	18	58	28	1.59	37	5	32	87
12	1.54	21	8	13	62	29	1.63	32	2	30	92
13	1.19	21	5	17	79	30	1.55	31	1	30	96
14	1.42	28	2	26	92	31	1.73	51	1	50	97
15	1.07	23	2	21	90	32	1.66	72	0	72	100
16	1.43	28	3	25	88	33	1.40	74	0	74	99
17	1.49	27	3	24	89	34	1.47	50	2	48	96

*Measurement point locations (#) are shown in Fig. 1.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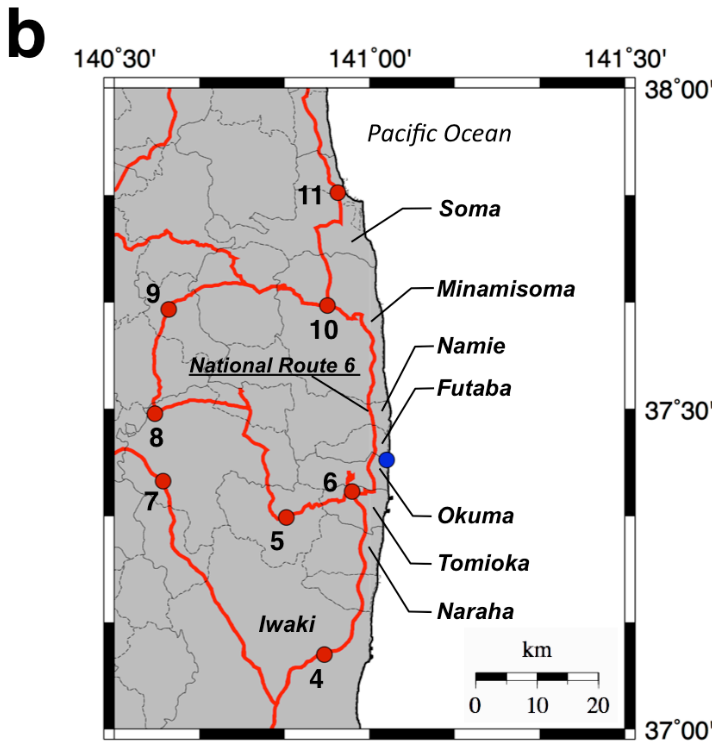
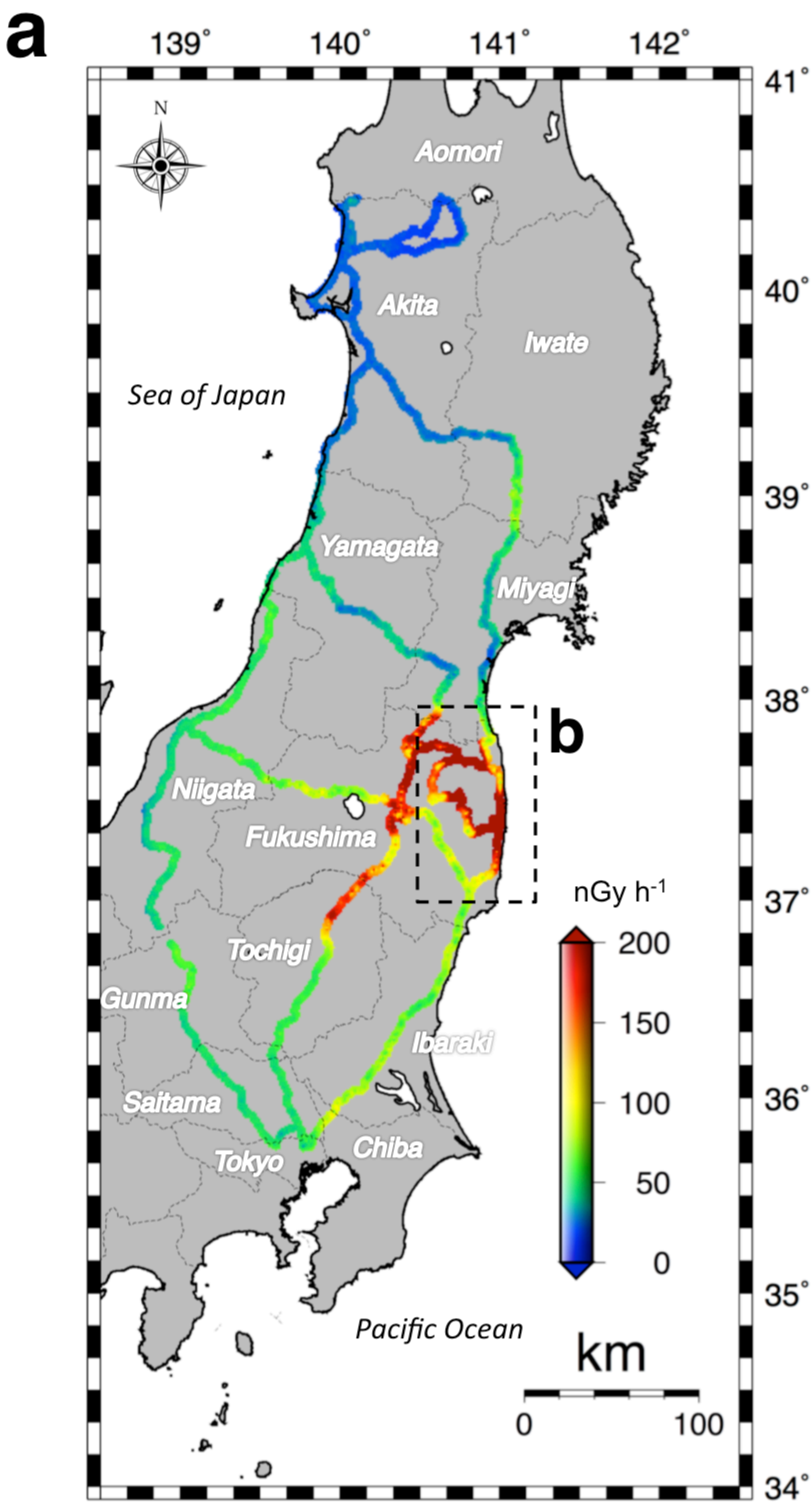


Fig. 1 Location of the Fukushima Daiichi Nuclear Power Plant, the survey route for measuring ambient dose rate in air, and the 34 points for the fixed-measurement observations.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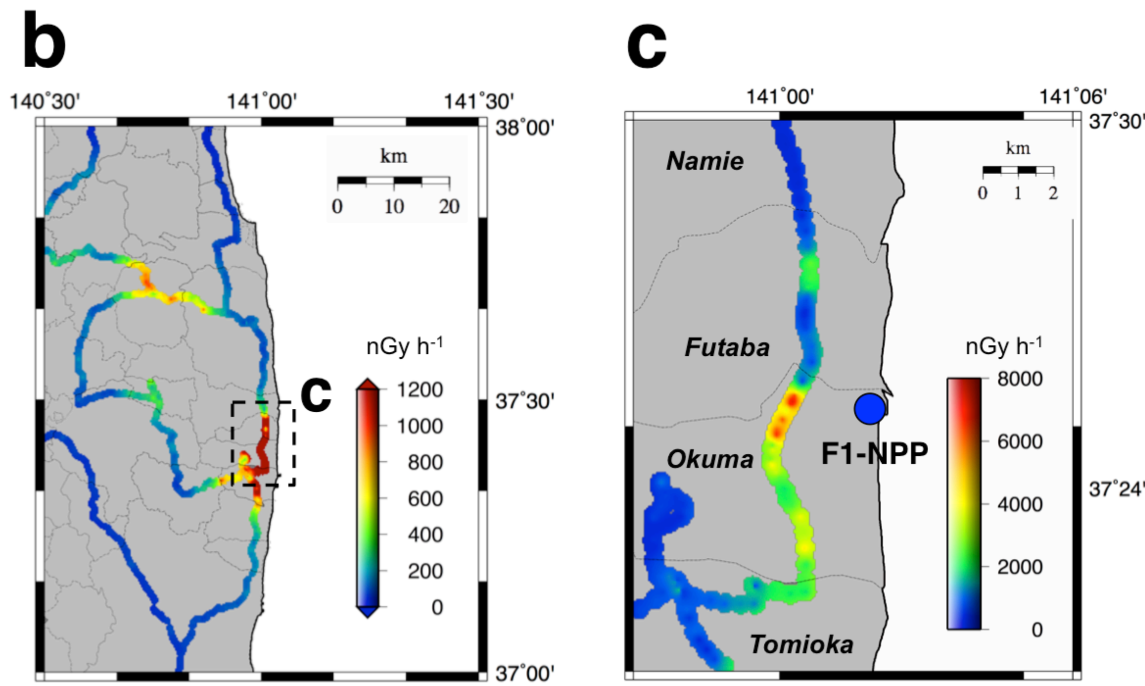

Fig. 2 The distribution maps of ambient dose rate in air in eastern Japan in fall 2014 with different magnifications and scale ranges (a, b and c).

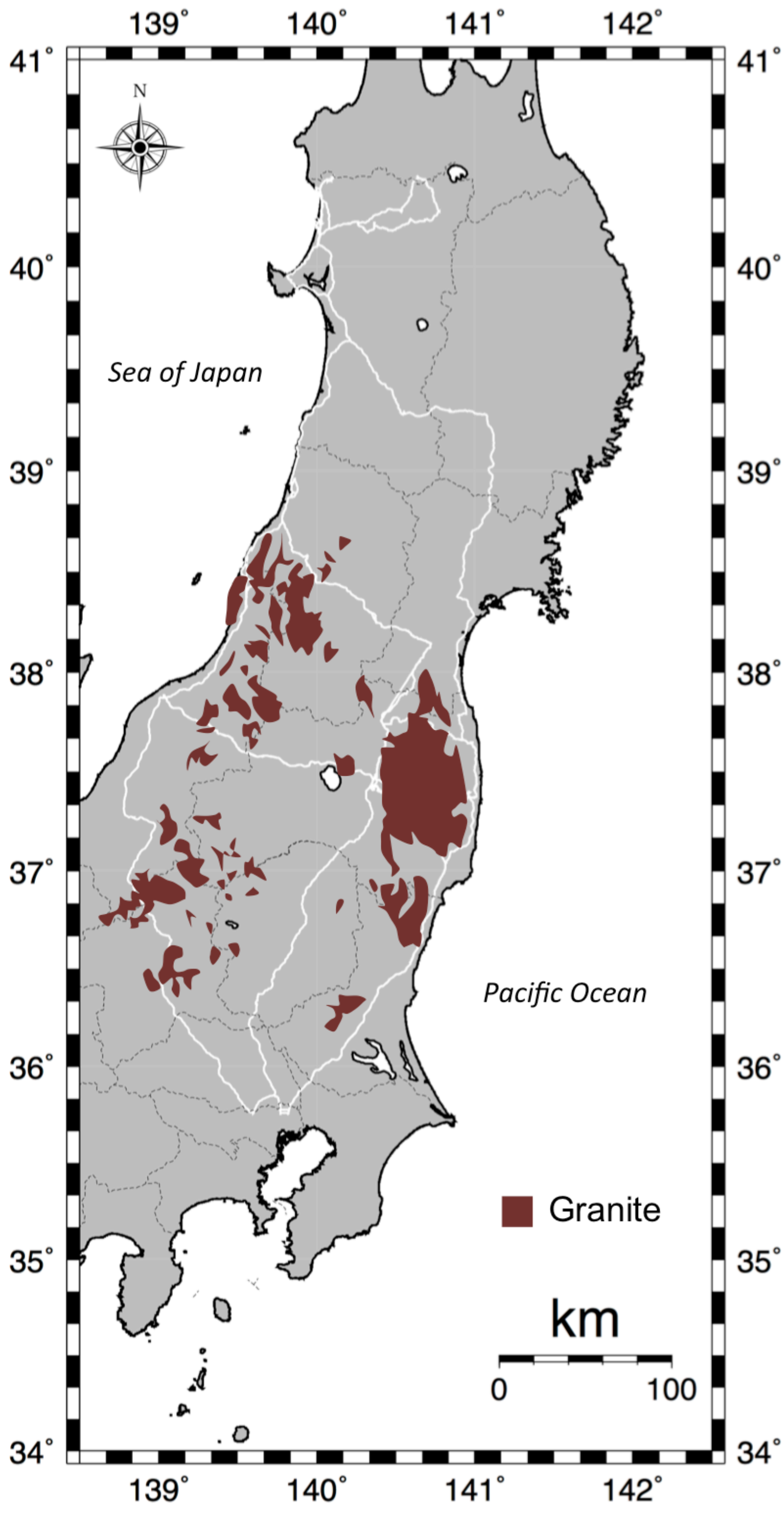

Fig. 3 The geological map showing granite formations in eastern Japan [15].

Conclusions

A 3,412 km car-borne survey in eastern Japan including an area around F1-NPP (i.e., the Pacific Ocean side) and the Sea of Japan side was performed. This survey was quite extensive and considered the underlying geology. While a higher ambient dose rate of 1421 nGy h^{-1} was observed in a southwestern area 8 km from F1-NPP (#6), with the exception of this site, most of the dose rates represented contributions from natural radionuclides. From the results on the Sea of Japan side, it could be concluded that the main contribution to the ambient dose rates was influenced by the natural radionuclides with no evidence of a change in their values that would correlate to the F1-NPP accident.

Acknowledgements

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