



Title	Early Intake of Radiocesium by Residents Living Near the Tepco Fukushima Dai-ichi Nuclear Power Plant After the Accident. Part 2: Relationship Between Internal Dose and Evacuation Behavior in Individuals
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Citation	Health physics. 112(6): 512-525
Issue Date	2017-06
URL	<a href="http://ir.fmu.ac.jp/dspace/handle/123456789/1579">http://ir.fmu.ac.jp/dspace/handle/123456789/1579</a>
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DOI	10.1097/HP.0000000000000657
Text Version	author

1 EARLY INTAKE OF RADIOCESIUM BY RESIDENTS LIVING NEAR THE TEPCO  
2 FUKUSHIMA DAI-ICHI NUCLEAR POWER PLANT AFTER THE ACCIDENT.  
3 PART 2: RELATIONSHIP BETWEEN INTERNAL DOSE AND EVACUATION BEHAVIOR  
4 IN INDIVIDUALS

5  
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25

1 **Abstract**

2 The Tokyo Electric Power Company's Fukushima Dai-ichi Nuclear Power Plant (FDNPP)  
3 accident exposed members of the public to radiation. This study analyses the relation between  
4 personal behavior data obtained from 112 out of 174 subjects who underwent whole-body  
5 measurements by the National Institute of Radiological Sciences (NIRS) during the period from  
6 27 June to 28 July 2011 and their committed effective doses (CEDs) from  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ . The  
7 whereabouts of the 112 persons living in municipalities near the FDNPP (mainly, Namie town)  
8 on several days in March, 2011 are graphed on maps. It was confirmed that most subjects started  
9 evacuation promptly and had left the 20-km-radius of the FDNPP by the end of 12 March. The  
10 individual CEDs were poorly correlated with the person's distances from the FDNPP at any day  
11 in March. Meanwhile, the percentage of persons remaining within the 20-km radius of the  
12 FDNPP was 100% at 16:00 on 12 March and 42.9% at 0:00 on 15 March for those with CEDs  
13  $> 0.1$  mSv, whereas the corresponding values were much lower for those with CEDs  $\leq 0.1$  mSv.  
14 This suggests that the time of evacuation would be one of the crucial factors for the early intake;  
15 however, more personal behavior data are needed to be analyzed to clarify the relevance to the  
16 individual internal dose.

17  
18 **Keywords:** Fukushima Dai-ichi Nuclear Power Plant; personal behavior; committed effective  
19 dose; internal dose

## INTRODUCTION

1  
2 A catastrophic natural disaster triggered by the Great East Japan Earthquake on the Pacific  
3 coast of the main island of Japan on 11 March 2011 with a magnitude of 9.0 killed around  
4 20,000 people (including missing people) (National Police Agency 2016). The main cause of  
5 death was not the earthquake itself, but the massive tsunami generated by the earthquake. The  
6 nuclear reactors at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) run by the Tokyo  
7 Electric Power Company (TEPCO) were automatically shut down at the time of the earthquake;  
8 the ensuing tsunami caused a complete loss of cooling functions of the three reactor cores,  
9 resulting in the release of radionuclides into the environment. This accident has tentatively been  
10 ranked as Level 7, the highest level on the International Nuclear Event Scale (INES), and the  
11 same level as the Chernobyl accident in 1986 (Nuclear Emergency Response Headquarters  
12 2011). According to the recent atmospheric transport and dispersion model (ATDM) analyses  
13 by Katata *et al.* (Katata et al. 2015), the estimated discharge amounts of  $^{131}\text{I}$  and  $^{137}\text{Cs}$  were 151  
14 PBq and 14.5 PBq, respectively. These amounts are much smaller than those in the Chernobyl  
15 accident: 1760 PBq for  $^{131}\text{I}$  and 85 PBq for  $^{137}\text{Cs}$  (UNSCEAR 2000).

16 Much effort has been made to estimate the doses to residents living in the areas radiologically  
17 affected by this accident, in particular, Fukushima Prefecture (Hosoda et al. 2013, Kim et al.  
18 2016, Matsuda et al. 2013, Tsubokura et al. 2015, Nomura et al. 2016, Ishikawa et al. 2016).  
19 However, there have been only a limited number of studies focusing on the early doses to  
20 members of the public. Ishikawa *et al.* reported the estimates of early external doses received  
21 by the Fukushima Prefectural residents for the first four months after the accident based on  
22 time-series ambient dose rate maps and data on the whereabouts of each person (Ishikawa et al.  
23 2015). The arithmetic mean and maximum values of the individual external effective doses  
24 were 0.8 mSv and 25 mSv, and 99.4% of 421,394 Fukushima residents were estimated as having  
25 an effective dose below 3 mSv. On the other hand, the information on which estimations of the  
26 early internal dose can be based has been very scarce. Only about 1,300 human measurements

1 directly related to  $^{131}\text{I}$ , the largest contributor to the early internal dose, were obtained (NIRS  
2 2012, Tokonami et al. 2012, Matsuda et al. 2013, Kamata et al. 2013). Environmental  
3 measurements shortly after the accident are also limited in number, so that it has been difficult  
4 to develop reliable models for internal exposure pathways.

5 The present study analyzed personal behavior data obtained from 112 out of 174 subjects  
6 who underwent whole-body counter (WBC) measurements at the National Institute of  
7 Radiological Sciences (NIRS) from 27 June to 28 July 2011. Details on the results have been  
8 described in the authors' companion paper (Kim et al. 2016). Although these measurements  
9 could detect radiocesium ( $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ ) only, it is hoped that the measurements convey a  
10 clue to understanding the early internal dose to the public, including that from  $^{131}\text{I}$  and the other  
11 short-lived radionuclides. The main purpose of this study was thus to clarify the relationship, if  
12 any, between the individual internal doses from radiocesium and personal behavior data. This  
13 is important from the viewpoint of identifying the behavior patterns that could lead to  
14 significant doses.

## 16 MATERIALS AND METHODS

### 17 Personal behavior data

18 The NIRS performed the WBC measurements on the 174 subjects living near the FDNPP  
19 during the period from 27 June and 28 July 2011. These subjects were selected by Fukushima  
20 Prefectural Government and included 125 adults ( $\geq 18$ -y) and 49 children ( $< 18$ -y) based on the  
21 age at the time of the accident. Ninety of the 174 subjects were residents from Namie town and  
22 the rest were from several municipalities near the FDNPP (**Fig. 1**). Namie town is one of the  
23 areas highly contaminated with radionuclides and has been designated as the difficult-to-return  
24 zone (where the annual external dose is predicted to be higher than 50 mSv) since April, 2011  
25 (Ministry of Economy, Trade and Industry 2012).

26 In this study, the personal behavior data obtained from 112 out of the 174 subjects were

1 analyzed together with their internal doses that were already evaluated in the authors' previous  
2 study (Kim et al. 2016). The composition of the 112 persons by the municipality and gender/age  
3 are displayed in **Fig. 2**. The numbers of adults and children were 78 and 34, respectively. The  
4 personal behavior data were generated from answer sheets of a self-administered questionnaire  
5 on the person's whereabouts in chronological order during the first four months after the  
6 accident, and they were stored in electric files. This questionnaire has been used in the Basic  
7 Survey to estimate individual external doses, one of the core components of the Fukushima  
8 Health Management Survey (Ishikawa et al. 2015, Yasumura et al. 2012). The personal behavior  
9 data were the same as those used in the Basic Survey and consisted of the whereabouts (the  
10 place name and its latitude and longitude), the time spent indoors/outdoors or moving, and the  
11 type of the building where the person stayed (e.g., a wooden house, a concrete building)  
12 although only the whereabouts data were analyzed in this study. These data are provided hourly  
13 until 25 March and daily (representative places to stay or commute) during the period from 26  
14 March to 11 July 2011. The use of the personal behavior data in this study was approved by the  
15 ethics review committees of the NIRS and Fukushima Medical University. For the persons  
16 whose personal behavior data were unavailable, the exposure scenario obtained from a brief  
17 interview by the NIRS staff members at the time of the WBC measurements was used as a  
18 reference.

19

## 20 **Internal dose calculation**

21 The internal dose calculation of the 174 subjects has been described in the authors'  
22 companion paper (Kim et al. 2016). Briefly speaking, the internal dose from  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$   
23 was calculated based on the  $^{134}\text{Cs}$  body content determined by the WBC measurements. The  
24 reason for not using the  $^{137}\text{Cs}$  body content was that the detection rate of  $^{137}\text{Cs}$  was much lower  
25 than that of  $^{134}\text{Cs}$ . Minimum Detectable Activity (MDA) values for  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  were  
26 evaluated to be 320 Bq and 570 Bq, respectively. One reason why  $^{137}\text{Cs}$  was higher than  $^{134}\text{Cs}$

1 in terms of the MDA value was the difference in the key peak in identifying each radionuclide.  
2 In detail, the key peak for  $^{137}\text{Cs}$  (662 keV: 85.1%) overlapped with the other peaks from  $^{134}\text{Cs}$   
3 (605 keV: 97.6%, 569 keV: 15.4%), whereas the key peak for  $^{134}\text{Cs}$  (796 keV: 85.5%, 802 keV:  
4 8.7%) did not. Instead, the  $^{137}\text{Cs}$  body content was determined by multiplying the  $^{134}\text{Cs}$  body  
5 content by the factor (1.1) obtained from measurement results of the subjects from whom both  
6 radionuclides were detected. These results demonstrated that the body contents of  $^{134}\text{Cs}$  and  
7  $^{137}\text{Cs}$  were correlated well with each other. The age-dependent committed dose per unit intake  
8 (DPUI) values and whole-body retention rates were taken from the database published by the  
9 International Commission on Radiological Protection (ICRP) (ICRP 2012) and a software  
10 package, MONDAL, developed by the NIRS (Ishigure et al. 2004), respectively. Regarding the  
11 intake scenario, acute inhalation of Type F compounds with 1  $\mu\text{m}$  in activity median  
12 aerodynamic diameter (AMAD) on 12 March, 2011 was assumed (Kim et al. 2016). From the  
13 results of the previous study, the 90th percentile of the individual internal doses to the subjects  
14 was about 0.1 mSv in committed effective dose (CED) for both the adults and the children.

15

## 16 **Data analyses**

17 Mann-Whitney's  $U$  test was performed to confirm differences between two groups using  
18 SPSS software package 22. (IBM-Japan Co., Japan). A  $p$ -value below 0.05 was considered  
19 significant. The distances of the subjects from the FDNPP were calculated using Hubeny's  
20 simplified formula (Ubukawa et al. 2014); the latitude and longitude of the FDNPP were set at  
21 37.421071 and 141.032755, respectively. The whereabouts of the 112 persons were also  
22 graphed on maps using Google My Maps (Google).

23

24

## **RESULTS**

### 25 **Individual internal dose**

26 The CEDs of the 112 persons were not significantly different from those of the other 62

1 persons whose personal behavior data were not obtained ( $p=0.618$ ). **Fig. 3** shows the CED  
2 distributions of the 78 adults (Panel A) and the 34 children (Panel B) included in the study. The  
3 78 adults consisted of 34 males and 44 females. The lowest CED bars included persons in whom  
4  $^{134}\text{Cs}$  was not detected (ND); their CEDs were regarded as zero in that case. As shown in the  
5 figure, the CED distributions of the adults and the children are similar to each other ( $p=0.363$ ).  
6 The 90th percentile CED values were also similar to each other: 0.10 mSv for the adults and  
7 0.11 mSv for the children. However, this result indicates the possibility of overestimations of  
8 the internal doses to the children as described in the authors' previous paper. In short, the CED  
9 should be higher in the adults than the children, taking into account the fact that the DPUIs are  
10 relatively comparable among the different age groups (5 y,  $3.6 \times 10^{-9}$  Sv Bq $^{-1}$ ; 10 y,  $3.7 \times 10^{-9}$   
11 Sv Bq $^{-1}$ ; 15 y,  $4.4 \times 10^{-9}$  Sv Bq $^{-1}$ ; Adult,  $4.6 \times 10^{-9}$  Sv Bq $^{-1}$  for inhalation of Type F compounds  
12 of  $^{134}\text{Cs}$ ), and the intake is likely to be larger in adults than children. On the other hand, the  
13 difference in the CED between the adult males and the adult females was found to be significant  
14 ( $p<0.001$ ). **Table 1** summarizes gender,  $^{134}\text{Cs}$  content, CED and the exposure scenario for 30 of  
15 the 125 adult subjects in order of decreasing the CED. The exposure scenarios were obtained  
16 from the interview by the NIRS staff members. All of those ranked in the top ten CEDs were  
17 male. The highest CED (0.63 mSv) was found in a 69-y-old male from Futaba town. According  
18 to his scenario, he saw hydrogen explosion at the Reactor 1 building on March 12 and received  
19 decontamination. His personal behavior data was, however, unavailable. The male with the  
20 second highest CED (0.24 mSv) was supposedly a cattle farmer. He stayed at his pasture until  
21 March 17 to feed his cows.

22

### 23 **Displacement of the persons after the accident**

24 **Figs. 4** and **5** show the whereabouts of the 78 adults and the 34 children on the map of  
25 Fukushima Prefecture at 0:00 on 12, 13, 15, 20 and 25 March (not displaying the persons who  
26 evacuated outside the prefecture). The symbols in these figures denote the groups categorized



1 by the level of CED as follows: Group 1 ( $CED > 0.1$  mSv), Group 2 ( $0.05$  mSv  $< CED \leq 0.1$   
2 mSv), Group 3 ( $0$  mSv  $< CED \leq 0.05$  mSv), and Group 4 ( $0$  mSv) for the adults; Group 1 ( $CED$   
3  $> 0.1$  mSv), Group 2 ( $0$  mSv  $< CED \leq 0.1$  mSv), and Group 3 ( $0$  mSv) for the children. The  
4 persons whose  $^{134}\text{Cs}$  contents were ND were regarded to have zero CED as described earlier.  
5 As shown in the figures, almost all persons had evacuated from the area within a 30-km radius  
6 of the FDNPP as of 20 March. **Fig. 6** shows the representative evacuation scenarios for residents  
7 of Namie town. This scenario was considered as one of the 18 representative evacuation  
8 scenarios for municipalities located near the FDNPP (Akahane et al. 2013) and consists of the  
9 following two passages: (1) Namie town office (departure at 12:00) to Tsushima district (the  
10 northwest part of the town) on 12 March (arrival at 15:00) and (2) Tsushima district (departure  
11 at 10:00) to Adachi gymnasium in Nihonmatsu city (arrival at 14:00) on 16 March. As shown  
12 in **Figs. 4** and **5**, the displacement of persons living in the coastal areas of Namie town generally  
13 agreed with the representative evacuation scenario; however, the actual evacuations had a wide  
14 variety of destinations as time proceeded. It was also confirmed that a significant number of the  
15 study subjects evacuated outside Fukushima Prefecture after the accident.

16 **Fig. 7** shows the time-trend of the numbers of persons staying the following distances from  
17 the FDNPP:  $\leq 5$  km, 5–10 km, 10–20 km, 20–30 km and  $> 30$  km. The distance of the person  
18 during a displacement was calculated as the average of the distances from the departure and  
19 destination places. The Japanese Government issued evacuation orders for residents within the  
20 3-km radius at 21:23 on 11 March, within the 10-km radius at 5:44 and within the 20-km radius  
21 at 18:25 on 12 March, and also issued an indoor evacuation order for residents in the 20- to 30-  
22 km radius at 11:01 on 15 March (Nuclear Emergency Response Headquarters 2011). Our results  
23 show that most of the persons living near the FDNPP had left the 20-km radius before the third  
24 evacuation order.

25

26 **Factors influencing the internal dose**



1 residents of Futaba town, Okuma town and Tomioka town started evacuation in the morning  
2 on March 12 shortly after evacuation orders by each municipality. Such was the case with those  
3 living within the 10-km radius in Namie town. On the other hand, evacuation was delayed in  
4 Iitate village and Kawamata village, which were designated as deliberate evacuation areas  
5 (where the annual cumulative external dose is expected to be higher than 20 mSv) in April,  
6 2011.

7 The displacements of the residents of these municipalities were confirmed in this study. As  
8 seen in **Figs. 4** and **5**, most of the subjects who lived in the coastal areas of Namie town  
9 evacuated to the northwest part of the town by the end of 12 March, and stayed there for a  
10 couple of days. As mentioned earlier, this displacement is similar to one evacuation scenario  
11 for Namie town's residents although the time of evacuation was slightly different. The route of  
12 this scenario is overlapped by the highest contamination area (**Fig. 11**), which is supposed to  
13 give relatively high internal doses to evacuees from Namie town. This was also suggested by  
14 the internal dose estimation obtained by coupling the 18 evacuation scenarios with the ATDM  
15 simulations based on WSPEEDI-II (Worldwide version of System for Prediction of  
16 Environmental Emergency Dose Information version 2) (Kim et al. 2016). The latest ATDM  
17 analyses also predicted that the above area was generated by wet deposition of radionuclides  
18 during the period from late 15 March to early 16 March (Nuclear Emergency Response  
19 Headquarters 2011). Thereby, from the viewpoint of intake via inhalation, it is of great  
20 importance to identify the whereabouts of persons on these days and on 12 March, when a  
21 hydrogen explosion occurred at the Reactor 1 building (15:36). This may be true as  
22 demonstrated by the result of **Table 2**, which suggests that the whereabouts on 12 and 15 March  
23 are a key factor for the resulting internal dose. Of particular concern is intake on 12 March,  
24 when most residents living near the FDNPP were undergoing evacuation. Intake on 12 March  
25 is also important because the internal doses from short-lived radionuclides other than  $^{131}\text{I}$  are  
26 expected to have been relatively high (Shinkarev et al. 2015). It is noted that all the adults

1 categorized into Group 1 remained within a 20-km radius of the FDNPP as of the end of 12  
2 March.

3 Regarding the children analyzed, there was no relationship between the CEDs and personal  
4 behaviors. This can be caused by overestimations of the internal doses to the children as  
5 described earlier. Actual intake is likely to continue intermittently for a certain period of time  
6 depending on the individual exposure environment, although ingestion would be minimized  
7 because of the Japanese government's prompt restrictions on distribution and consumption of  
8 food and drink items contaminated with radionuclides (Hamada et al. 2012). Accordingly, the  
9 assumed intake scenario (namely, acute inhalation on 12 March) could result in significant  
10 overestimations, especially for younger children whose whole-body retention rates are much  
11 lower. It is supposed that the times of inhalation could be estimated by superimposing the  
12 personal behavior data on the radionuclide air concentration maps generated by ATDM  
13 simulations at the same time. This issue will be addressed in the next study.

14 Limitations of the personal behavior data should be mentioned. These data have been  
15 produced based on answers to the self-administered questionnaire. Accordingly, the accuracy  
16 of the data depends on the answerer's memory. Late answerers may have forgotten or confused  
17 details after the accident. In this regard, the personal behavior data used in this study generally  
18 fit with the exposure scenarios obtained at relatively early times after the accident although the  
19 exact time of each person's evacuation was mostly missing from the exposure scenarios. This  
20 may indicate that the data were reasonably accurate for most of the persons analyzed. There are  
21 also other limitations on the personal behavior data. For instance, the whereabouts of a person  
22 during the periods recorded as his or her moving are unknown in the data, which could introduce  
23 a large error for those who moved far from the place of departure over time. The building type,  
24 which is needed for external dose estimation (Akahane et al. 2013), is also difficult to use in  
25 the internal dose estimation because the dose reduction factor for shelter from inhalation cannot  
26 be determined only by building type. This factor is also affected by the duration of plume

1 exposure (United States Environmental Protection Agency 2012).

2 In conclusion, the present study demonstrated that the personal behavior data were  
3 potentially useful for the estimation of the early internal doses to Fukushima residents. As  
4 demonstrated, the time of evacuation would be one of the crucial factors for estimations of the  
5 early intake by residents living near the FDNPP. In other words, this result may suggest that  
6 the dominant pathway of intake was inhalation during exposure to radioactive plumes. However,  
7 it is still necessary to analyze more personal behavior data of the persons who were directly  
8 measured in order to obtain more concrete results. Finally, it is noted that the exposure scenarios  
9 of the persons examined were informative for understanding their exposure situations. It seems  
10 that adult persons with relatively high internal doses have fairly plausible reasons such as direct  
11 contamination, witnessing the explosion, outdoor occupations, etc.

12

13

## CONCLUSION

14 Personal behavior data obtained from 112 of 174 subjects who underwent whole-body  
15 measurements by the NIRS during the period from 27 June to 28 July 2011 were analyzed in  
16 the present study. In addition, the whereabouts of the 112 persons were graphed on a map of  
17 Fukushima Prefecture. As a result, it was confirmed that most of the persons started evacuation  
18 promptly and had left the 20-km radius of the Fukushima Daiichi Nuclear Power Plant (FDNPP)  
19 by the end of 12 March in accordance with evacuation orders by the Japanese government and  
20 local municipal authorities. The representative evacuation scenario for residents of Namie town,  
21 which was expected to yield the high internal dose, was also identified. The individual  
22 committed effective doses (CEDs) from  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  were poorly correlated with the  
23 person's distance from the FDNPP on several days in March. Meanwhile, among the adults  
24 analyzed, the time of evacuation for persons with relatively high CEDs tended to be delayed  
25 compared to that for the others. However, it is still necessary to analyze more personal behavior  
26 data to clarify the relevance to the individual internal dose for estimating the early internal dose

1 mainly due to <sup>131</sup>I.

2

3

#### 4 *Acknowledgements*

5 We wish to express thanks to all members of the research center of radiation emergency  
6 medicine of the NIRS in fiscal year 2011 for their assistance. We also thank Mr. Masanori Yuuki  
7 of Tokyo Nuclear Service Co., Ltd. for his assistance.

8 This study was conducted as part of the comprehensive study on the dose estimation of  
9 residents in the Fukushima Daiichi Nuclear Power Plant accident funded by the Ministry of the  
10 Environment, Japan (2014-2016) and also as a collaborative study between the NIRS and  
11 Fukushima Medical University.

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## Footnotes

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†† Present application: Nuclear Technology Safety Center

## List of Figure captions

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**Fig. 1** Geometrical locations of Fukushima Prefecture and municipalities located near the FDNPP. The gray-colored area (the right of the figure) indicates the municipalities where the 174 subjects lived at the time of the accident.

**Fig. 2** Compositions of the 112 persons by the municipality (left) and gender/age group (right). The values displayed in the figure are the numbers of the persons. In the right circle, M and F denote male and female, respectively. 5y, 10y, 15y and Adult denote the age groups defined in the ICRP Publication 71.

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**Fig. 11** Deposition density map of the total of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  by airborne monitoring (corrected as of 28 August, 2011).

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2 **Table lists**

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4 **Table 1** Summary of the information on the 30 adults in descending order according to the CED.

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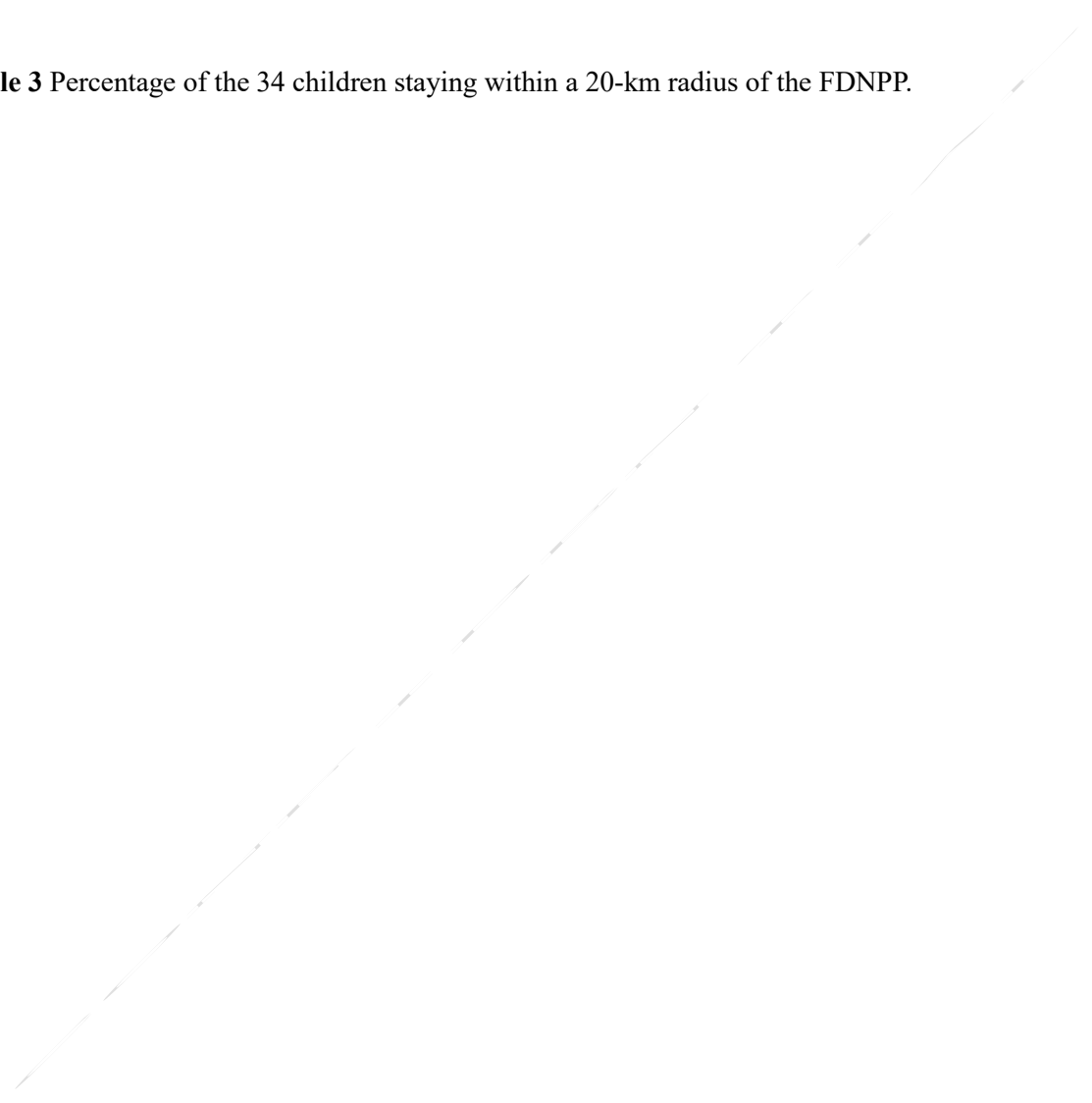
6 **Table 2** Percentage of the 78 adults staying within a 20-km radius of the FDNPP.

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8 **Table 3** Percentage of the 34 children staying within a 20-km radius of the FDNPP.

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**Table 1** Summary of the information on the 30 adults in descending order according to the CED (1/2).

Rank	Gender <sup>†</sup>	Data*	<sup>134</sup> Cs (Bq)	CED (mSv)	Exposure scenario obtained from an interview by the NIRS staff members at the time of the WBC measurements
1	M	N	7.15 x 10 <sup>3</sup>	0.63	He saw the hydrogen explosion outdoors on 12 March and evacuated to Futaba high school. He moved to Nihonmatsu city on 13 March. He reported that he received decontamination.
2	M	N	2.81 x 10 <sup>3</sup>	0.24	He was working in his pasture on 12 March and continued to stay in the area until 17 March to feed his cows. He temporarily evacuated to Tokyo from 17 March to 23 March, and then moved to Nihonmatsu city on 24 March. He visited his pasture once a week thereafter.
3	M	Y	2.70 x 10 <sup>3</sup>	0.22	He evacuated to a hall on March 12 and then evacuated to a gymnasium in Kawamata town.
4	M	Y	2.54 x 10 <sup>3</sup>	0.21	He stayed at his house until 15 March, and then evacuated to Nihonmatsu city.
5	M	N	2.40 x 10 <sup>3</sup>	0.20	He continued to stay in litate village and spent most of his time outdoors. He let his family evacuate.
6	M	N	2.00 x 10 <sup>3</sup>	0.17	He spent most of his time indoors at his house from 12 March to 15 March. He evacuated to Tsushima district (the central area of Namie town) on March 15 and then to Nihonmatsu elementary school on 17 March.
7	M	N	1.70 x 10 <sup>3</sup>	0.15	He stayed at the city hall and evacuated to Kawamata town at 17:00 on 12 March. He stayed there until 29 March. He was in charge of the rescue of people remaining in Futaba town.
8	M	N	1.69 x 10 <sup>3</sup>	0.15	He evacuated by car after the hydrogen explosion on 12 March. His car ran out of fuel at Tsushima district. He hitchhiked to Kawamata town and stayed there for three days. Afterwards, he moved to Date city and then to Fukushima city.
9	M	N	1.78 x 10 <sup>3</sup>	0.15	He was a local government officer. He was in charge of operating a shelter starting 12 March, and was also engaged in persuading reluctant residents to evacuate during March.
10	M	Y	1.67 x 10 <sup>3</sup>	0.14	He continued to work at Tsushima branch office until the end of March.
11	F	Y	1.52 x 10 <sup>3</sup>	0.12	She spent most of her time outdoors until she reached a shelter. She was concerned that she had waited for food outdoors for about two hours on 12 March.
12	F	Y	1.33 x 10 <sup>3</sup>	0.11	She evacuated to Tsushima district from her house on 12 March. She moved to Kawamata town at 6:00 on 13 March and then to Koriyama city on 15 March. She stayed in Nihonmatsu city from 25 March onward.
13	M	Y	1.40 x 10 <sup>3</sup>	0.11	He stayed in Namie town until 17 March. He took a daily walk as usual.
14	F	Y	1.21 x 10 <sup>3</sup>	0.11	She worked outdoors at the playing field of Futaba high school until 20:30 on 12 March to assist with the transport of people requiring care by helicopter. Afterwards, she stayed in Kawamata town and then moved to Nasushiobara city (Tochigi Prefecture).
15	F	Y	1.23 x 10 <sup>3</sup>	0.10	She evacuated to a shelter. She was concerned about her evacuation to Kawamata town.

<sup>†</sup> M, Male; F, Female; \* Personal behavior data

**Table 1** Continued (2/2).

Rank	Gender <sup>†</sup>	Data*	<sup>134</sup> Cs (Bq)	CED (mSv)	Exposure scenario obtained from an interview by the NIRS staff members at the time of the WBC measurements
16	M	Y	9.82 x 10 <sup>2</sup>	0.10	His nursing-care facility became a shelter on 12 March. He evacuated to Iwaki city with people requiring care for two days.
17	M	Y	1.04 x 10 <sup>3</sup>	0.09	He worked outdoors to assist with the transport of people requiring care on 12 March. He evacuated indoors when the hydrogen explosion occurred and then evacuated at 16:20 by bus. He underwent decontamination on 13 March. He moved to Saitama Prefecture on 19 March.
18	M	Y	1.12 x 10 <sup>3</sup>	0.09	He is a driver. He worked until 12 March.
19	M	N	1.02 x 10 <sup>3</sup>	0.09	He worked outdoors to help transport people requiring care by helicopter when the hydrogen explosion occurred on 12 March. He noticed the falling dust at that time. He stayed overnight at the gymnasium of Futaba high school and moved to Nihonmatsu city on 13 March by helicopter. He received decontamination and then evacuated to Koriyama city.
20	M	Y	9.10 x 10 <sup>2</sup>	0.09	He commuted to his office on foot or by bicycle from 12 to 15 March. He evacuated to Iwaki city on 15 March and then moved to Chiba city on the same day.
21	M	Y	1.04 x 10 <sup>3</sup>	0.09	He remained in Iitate village. He was in charge of voluntary work preparing food outdoors for several hours from 12 to 15 March.
22	M	N	8.67 x 10 <sup>2</sup>	0.08	He was in charge of operations outdoors on 11 March and supporting evacuees at noon on 12 March. He heard the sound of the explosion when he was working near the seashore in Tomioka town. He evacuated to Kawauchi village at 16:00 and then moved to Koriyama city on 16 March.
23	F	Y	7.42 x 10 <sup>2</sup>	0.07	She evacuated to Iwaki city from 20:00 on 12 March to 8:00 on 13 March. She then stayed at her house in Hirono town. She remained sheltered indoors as requested.
24	M	Y	8.34 x 10 <sup>2</sup>	0.07	He stayed in Tsushima district until 17 March. He stayed in Koriyama city from 17 to 20 March, then Tsushima district from 20 to 27 March, and Aizuwakamatsu city (the central part of Fukushima Prefecture) from 27 to 30 March.
25	M	N	7.30 x 10 <sup>2</sup>	0.07	He stayed at his house until 19 March. He then moved to Koriyama city and stayed there for the next two weeks. In April, he returned to his house and continued his ordinary activities.
26	M	Y	7.11 x 10 <sup>2</sup>	0.07	He stayed at his house until 14 March. He evacuated to Fukushima city at night on 14 March. He returned to his house a few days later because of his backache. He again returned to Fukushima city as requested.
27	M	Y	8.41 x 10 <sup>2</sup>	0.07	He worked as usual until 14 March (mostly, outdoors) and evacuated on 15 March.
28	M	Y	7.94 x 10 <sup>2</sup>	0.06	He evacuated to his relative's house on 15 March. He stayed indoors until then.
29	M	N	6.61 x 10 <sup>2</sup>	0.06	He evacuated to Tokyo at noon on 12 March. He returned to his house once a week a few weeks later.
30	M	Y	7.52 x 10 <sup>2</sup>	0.06	He evacuated to Tsushima district on 12 March. He was concerned with high ambient dose levels in this area.

<sup>†</sup> M, Male; F, Female; \* Personal behavior data

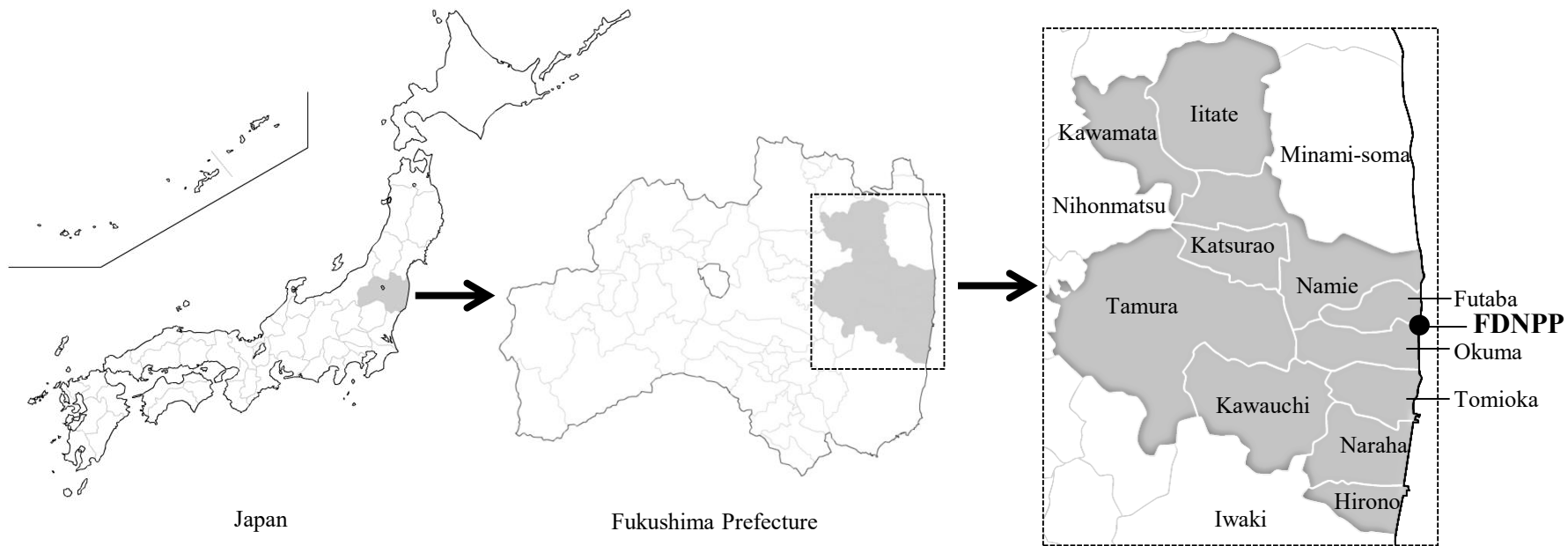
**Table 2** Percentage of the 78 adults staying within a 20-km radius of the FDNPP.

	Number of subjects	12:00 on 12 March	16:00 on 12 March	0:00 on 13 March	0:00 on 15 March	0:00 on 20 March	0:00 on 25 March
Group 1	7	100.0%	100.0%	42.9%	42.9%	14.3%	14.3%
Group 2	15	20.0%	13.3%	6.7%	0.0%	0.0%	0.0%
Group 3	20	30.0%	20.0%	0.0%	0.0%	0.0%	0.0%
Group 4	36	27.8%	13.9%	8.3%	0.0%	0.0%	0.0%



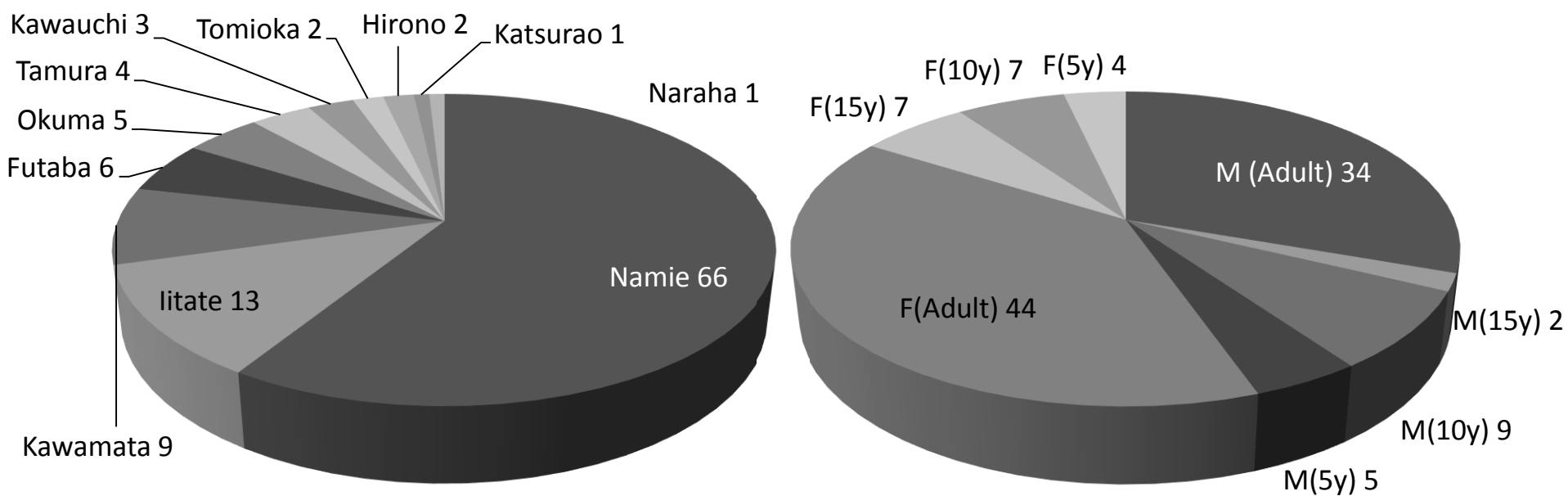
**Table 3** Percentage of the 34 children staying within a 20-km radius of the FDNPP.

	Number of subjects	12:00 on 12 March	16:00 on 12 March	0:00 on 13 March	0:00 on 15 March	0:00 on 20 March	0:00 on 25 March
Group 1	5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Group 2	7	57.1%	42.9%	0.0%	0.0%	0.0%	0.0%
Group 3	22	13.6%	4.5%	4.5%	0.0%	0.0%	0.0%

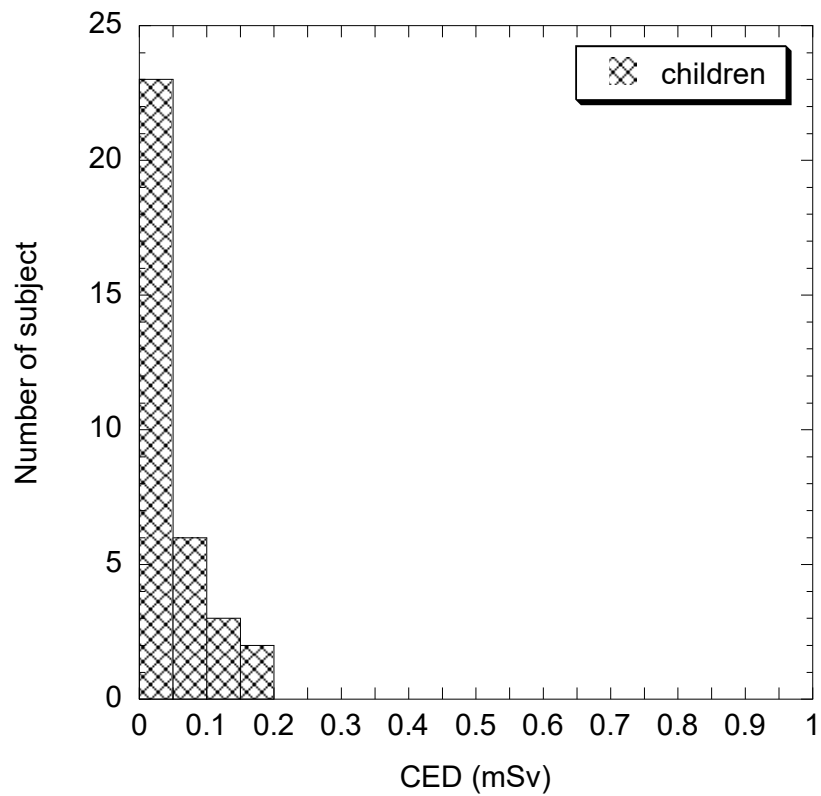
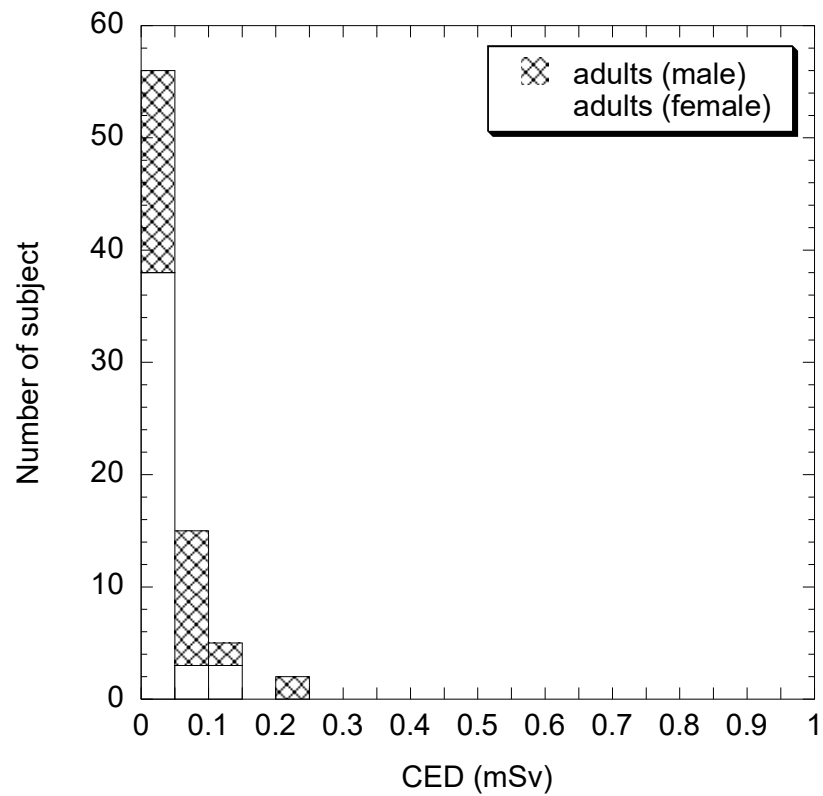


**Fig. 1** Geometrical locations of Fukushima Prefecture and municipalities located near the FDNPP. The gray-colored area (the right of the figure) indicates the municipalities where the 174 subjects lived at the time of the accident.

Figure 2

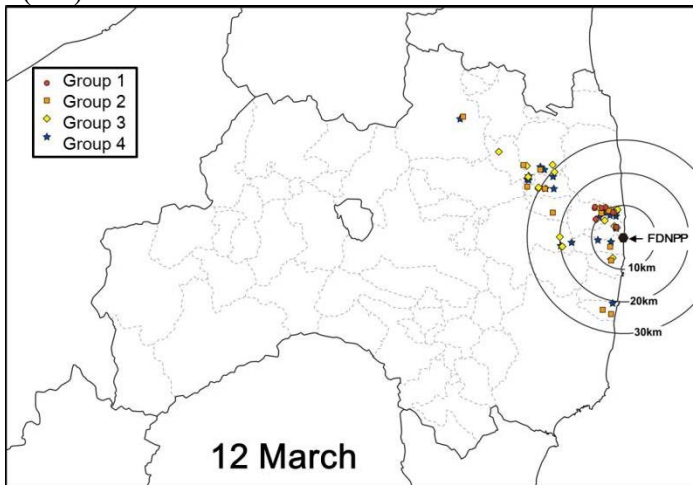


**Fig. 2** Compositions of the 112 persons by the municipality (left) and gender/age group (right). The values displayed in the figure are the numbers of the persons. In the right circle, M and F denote male and female, respectively. 5y, 10y, 15y and Adult denote the age groups defined in the ICRP Publication 71.

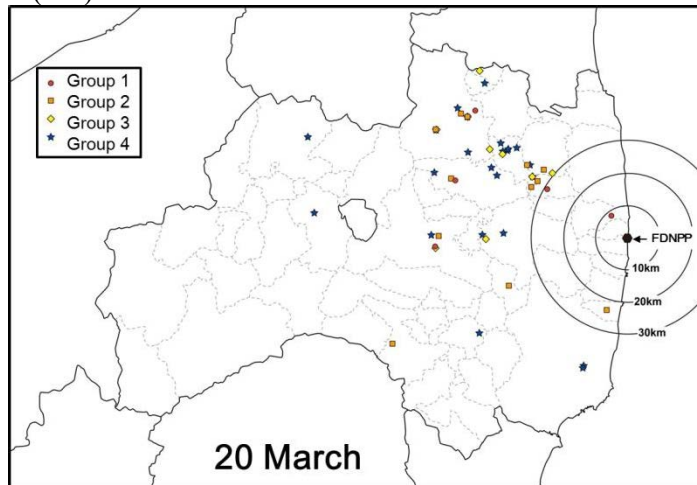


**Fig. 3** CED distributions of the 78 adults (left) and the 34 children (right).

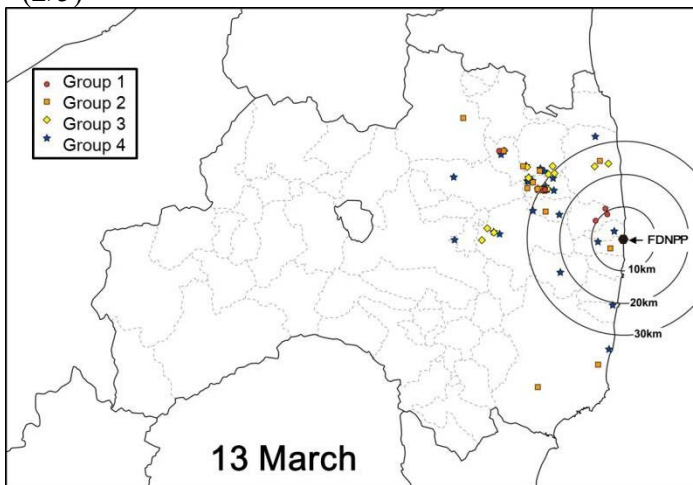
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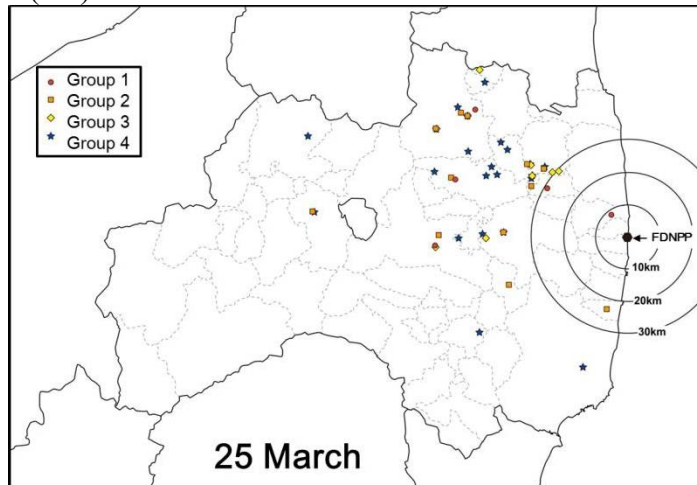
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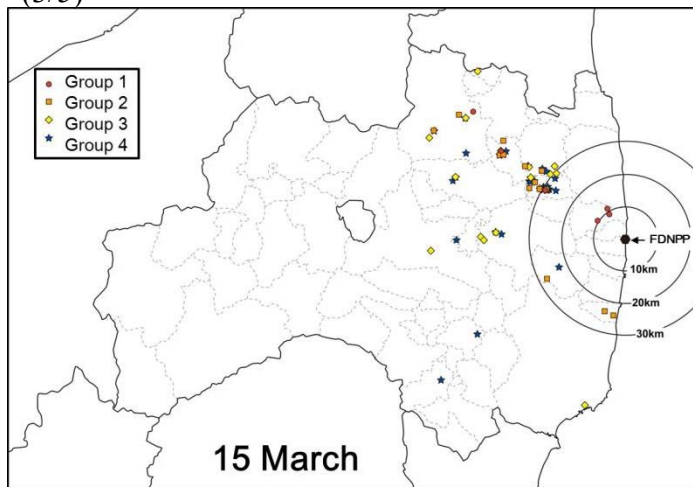
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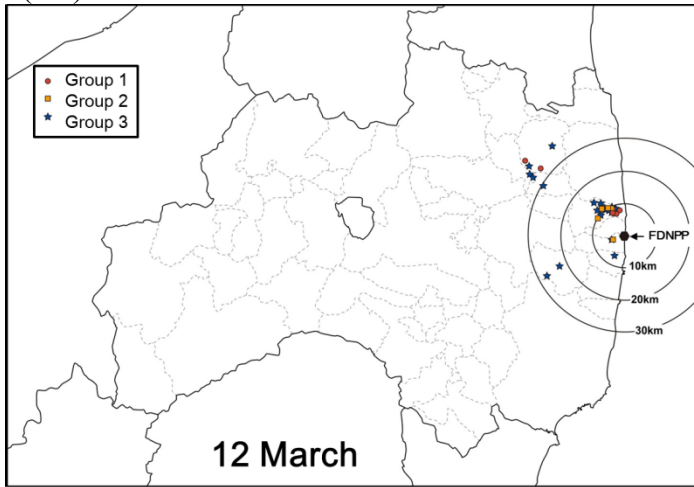


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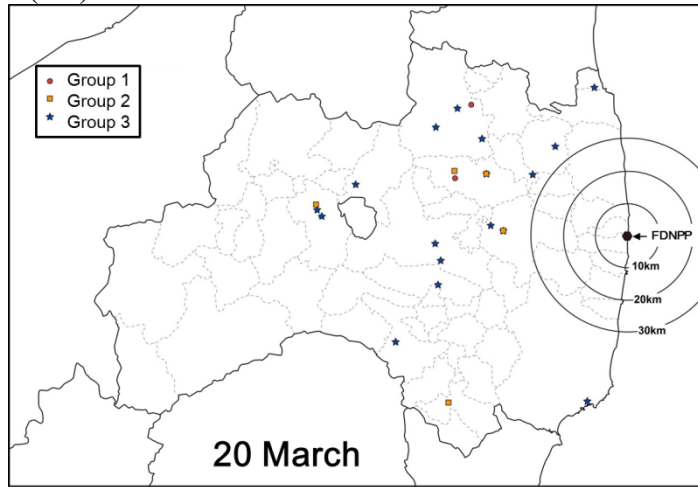


**Fig. 4** Whereabouts of the 78 adults at 0:00 on 12, 13, 15, 20 and 25 March. The persons who evacuated outside Fukushima Prefecture are not displayed. The symbols denote the groups divided by the level of the CED (see the text).

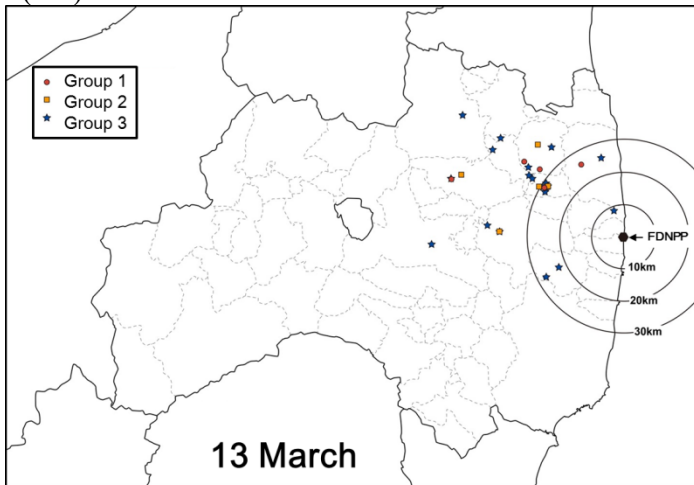
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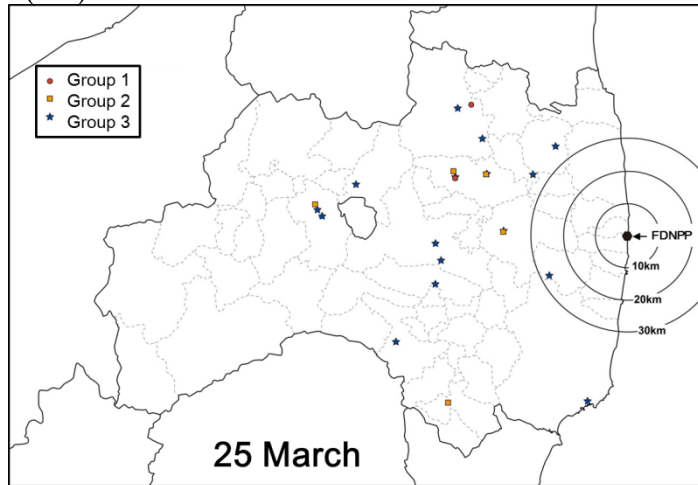
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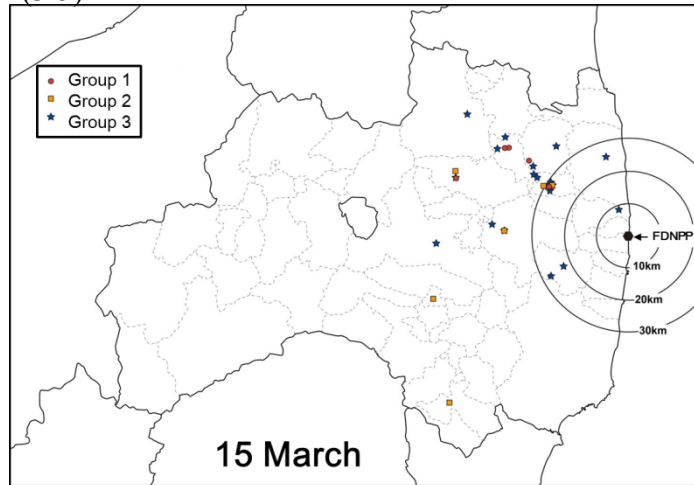
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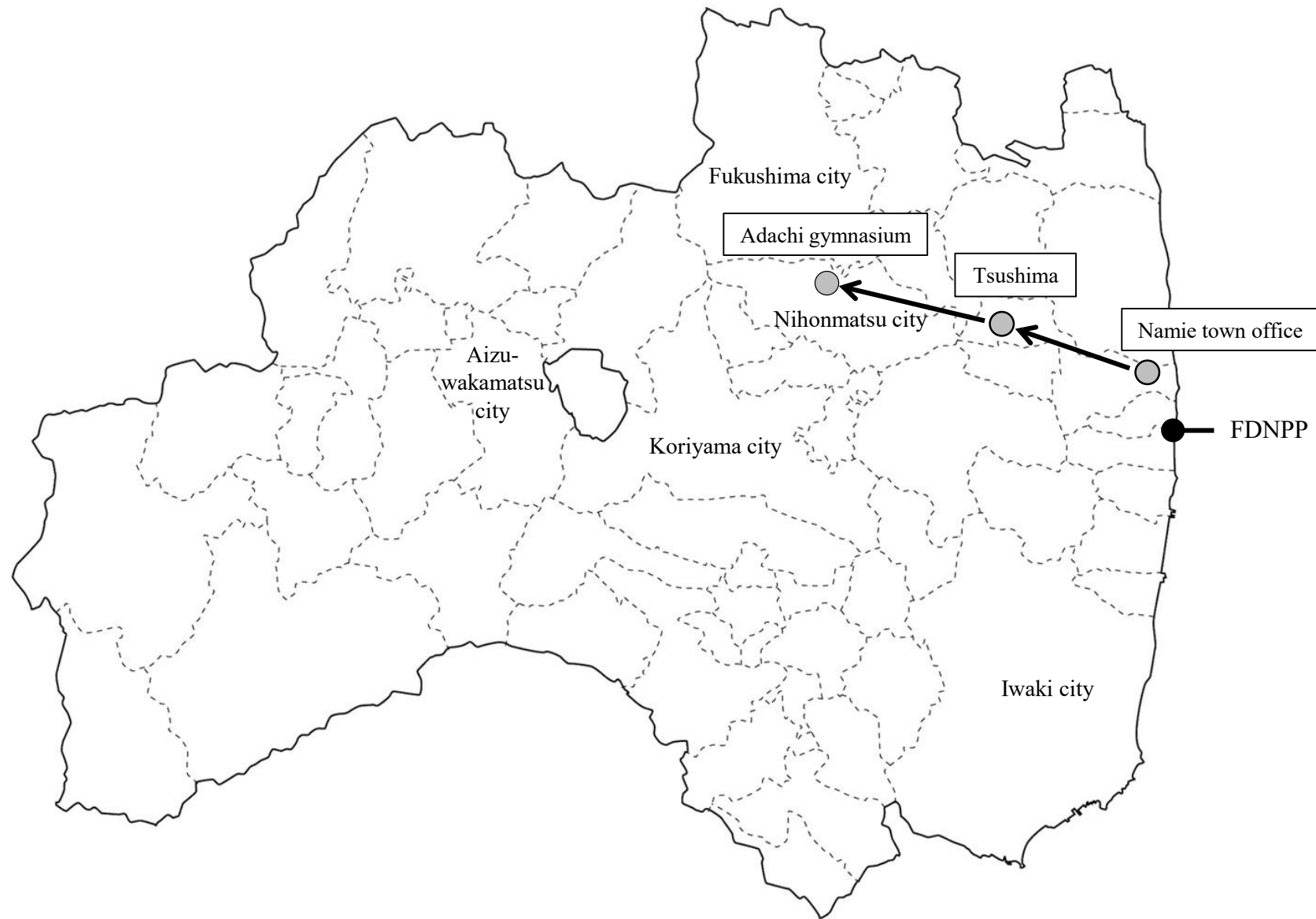
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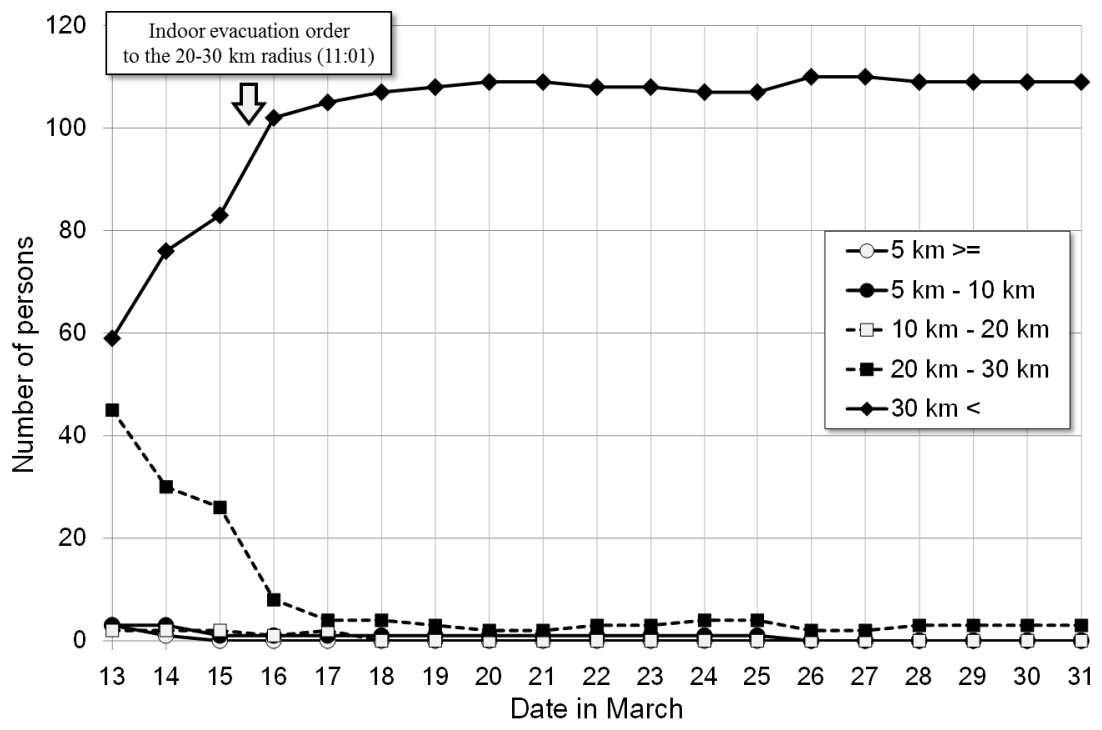
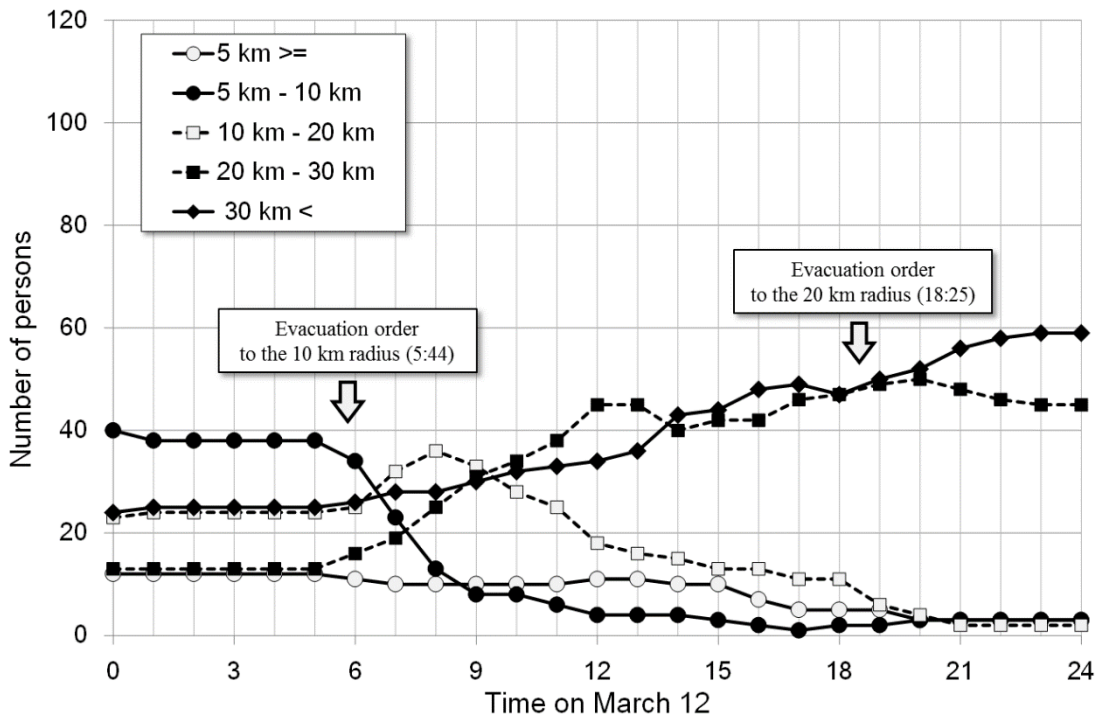
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**Fig. 5** Whereabouts of the 34 children at 0:00 on 12, 13, 15, 20 and 25 March. The persons who evacuated outside Fukushima Prefecture are not displayed. The symbols denote the groups divided by the level of the CEDs (see the text).

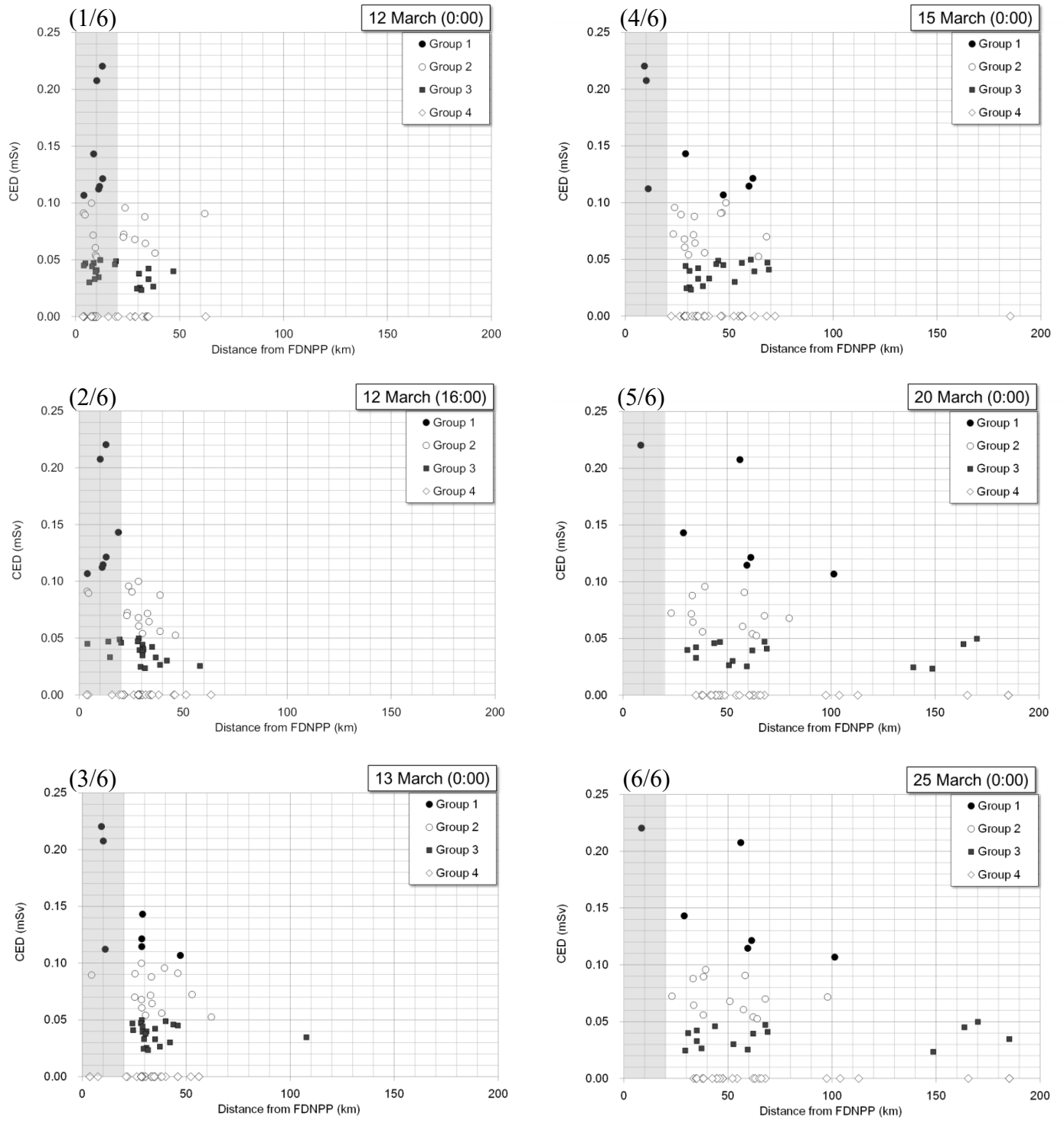


**Fig. 6** Representative evacuation scenarios for residents of Namie town.

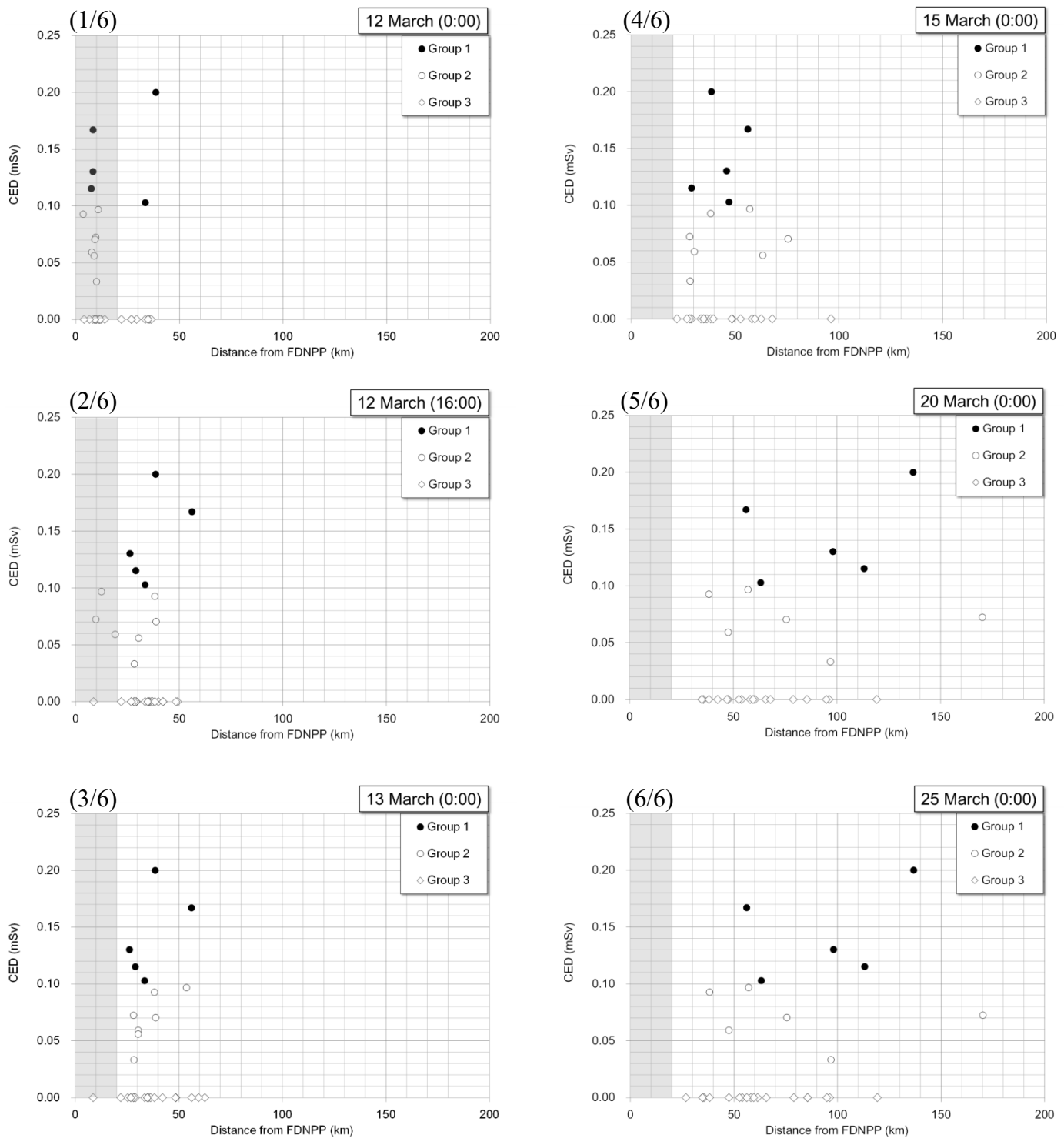


**Fig. 7** Time-trend of the distances between whereabouts of the persons and the FDNPP on 12 March (hourly, the upper panel) and 13-31 March (daily, the lower panel)





**Fig. 8** Relationship between the distances of the 78 adults from the FDNPP and their CEDs for each time and date displayed.



**Fig. 9** Relationship between the distances of the 34 children from the FDNPP and their CEDs on each time and date displayed.

Figure 10

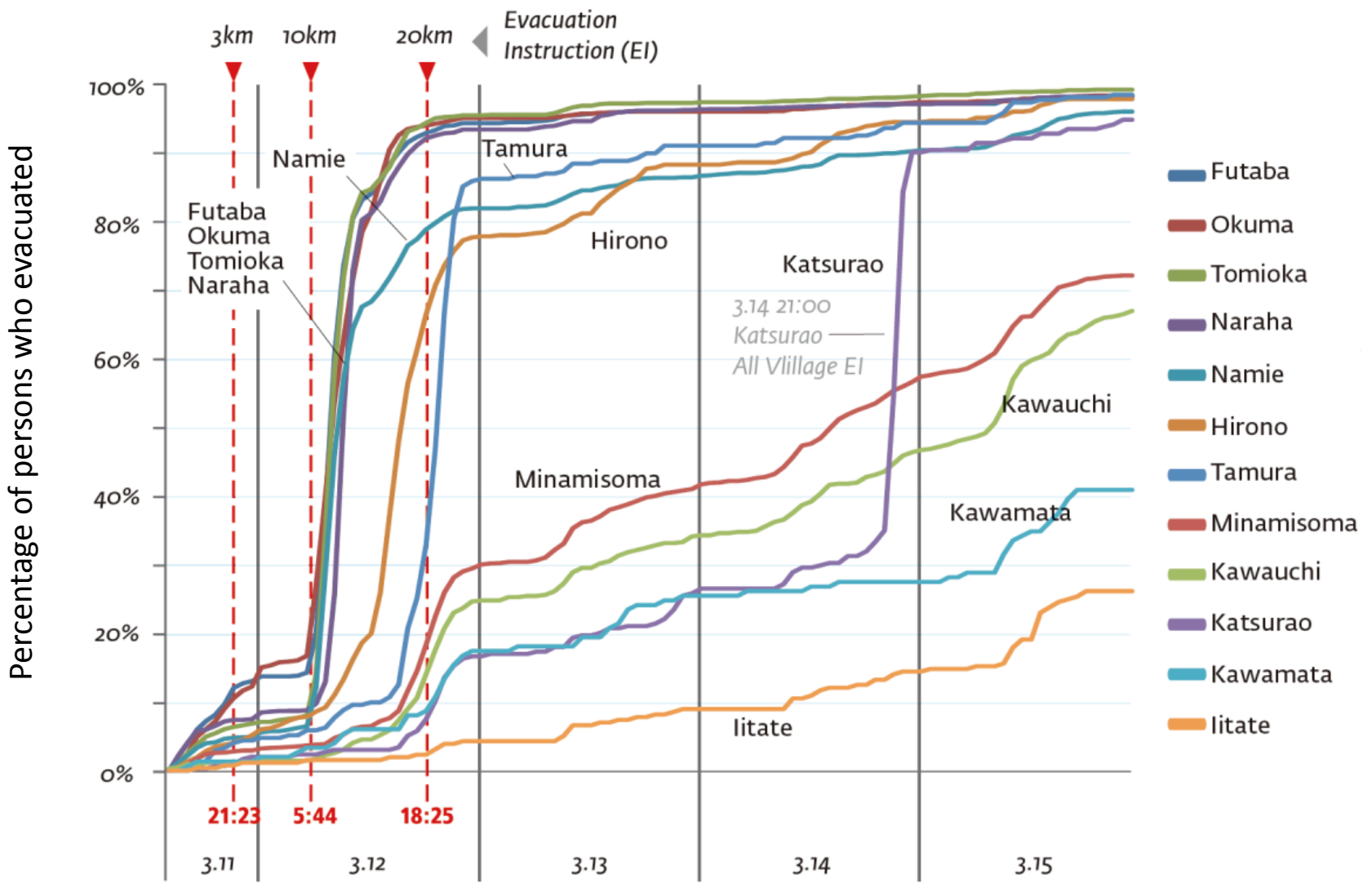


Fig. 10 Time trend of percentages of those who evacuated from each municipality. The original figure is slightly modified.

Figure 11

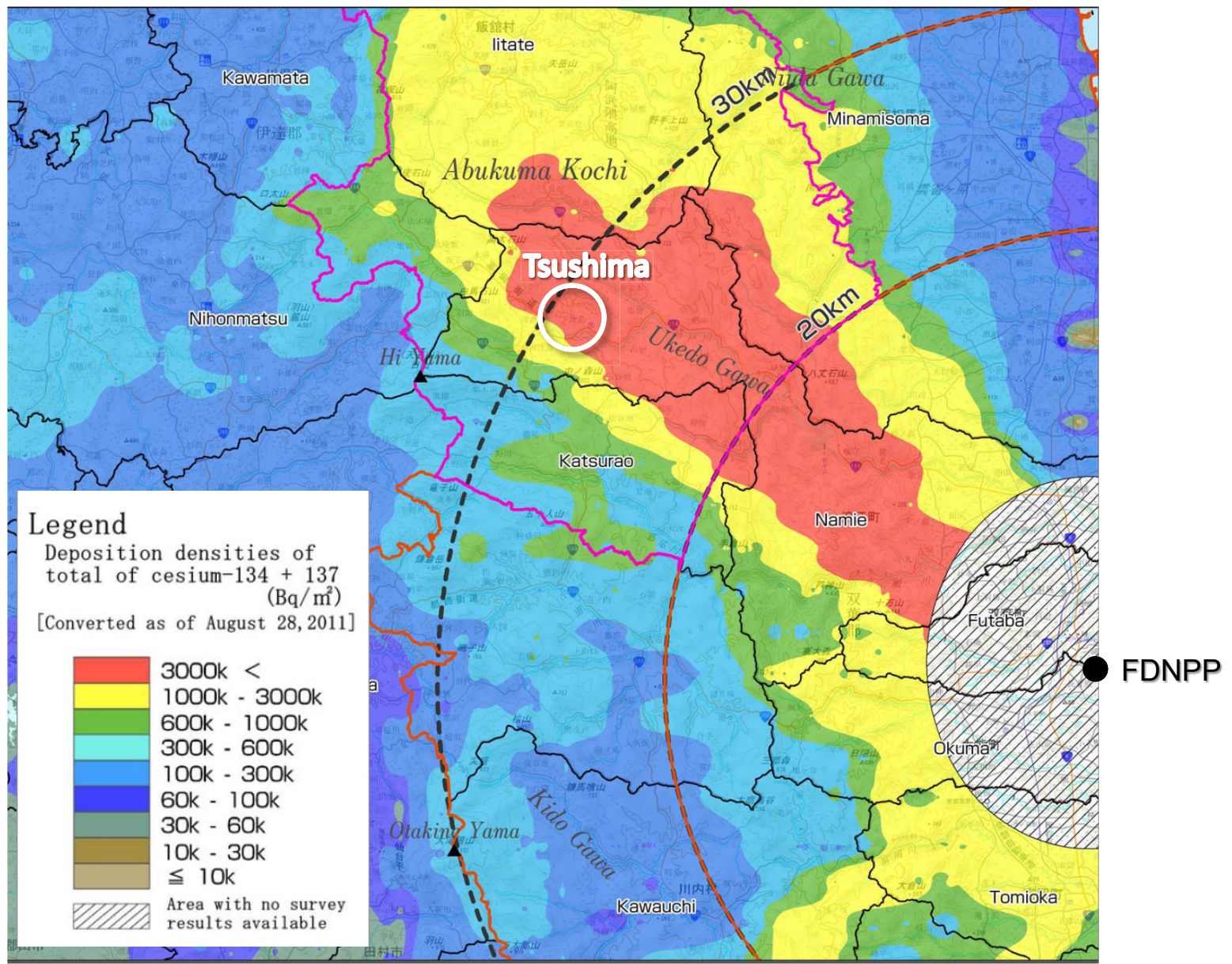


Fig. 11 Deposition density map of the total of <sup>134</sup>Cs and <sup>137</sup>Cs by airborne monitoring (corrected as of 28 August, 2011).