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Retraction

Retraction: Individual external dose monitoring of all citizens of Date City by passive dosimeter 5 to 51 months after the Fukushima NPP accident (series): 1. Comparison of individual dose with ambient dose rate monitored by aircraft surveys (2017 J. Radiol. Prot. 37 1)

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Following the Expression of Concern issued on this article on 11 January 2019, IOP Publishing is now retracting this article. On 4 June 2020, IOP Publishing received confirmation from the authors of 2017 J. Radiol. Prot. 37 1 (the first in a series of two research articles) that ethically inappropriate data were used in the study reported in this article. This confirmation follows an investigation into the matter by Date City Citizen's Exposure Data Provision Investigation Committee, which finds that some subjects within the study did not consent to their data being used for research, and it is unclear whether the unconsented data was provided to the author. IOP Publishing believes that the authors were unaware of the ethical problems with this data, which was supplied by a third party. The results of this investigation are available (in Japanese) at https://www.city.fukushima-date.lg.jp/soshiki/3/41833.html (IOP Publishing and the Society for Radiological Protection take no responsibility for the content at this link).

The readers are asked to note that, as part of the article submission process, the authors of the above referenced article confirmed that the research reported in the article adhered to the Ethical Policy of IOP Publishing and the Society for Radiological Protection.

As a member of the Committee on Publication Ethics (COPE), this matter has been investigated by IOP Publishing in accordance with COPE guidelines and it was decided that the article should be retracted. The authors agree with this retraction and have fully complied with all investigations.



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More details are expected to be forthcoming. However, in line with COPE guidelines, we are retracting this article promptly and will update this retraction notice with more information, as necessary and as it is released.

Based on the investigation report it has also been found that there is an error in table 1 of this article. The figure relating to glass badge holders in 2014 3Q is incorrect and should be close to $N = 12\,912$. These data were also provided to the authors by the same third party and the authors were not aware of this mistake in advance of publication of the article.

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Individual external dose monitoring of all citizens of Date City by passive dosimeter 5 to 51 months after the Fukushima NPP accident (series): 1. Comparison of individual dose with ambient dose rate monitored by aircraft surveys

Makoto Miyazaki¹ and Ryugo Hayano

¹ Department of Radiation Health Management, Fukushima Medical University, Fukushima 960-1295, Japan

² Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan

E-mail: m-miya@fmu.ac.jp

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Abstract

Date (da'te) City in Fukushima Prefecture has conducted a population-wide individual dose monitoring program after the Fukushima Daiichi Nuclear Power Plant Accident, which provides a unique and comprehensive data set of the individual doses of citizens. The purpose of this paper, the first in the series, is to establish a method for estimating effective doses based on the available ambient dose rate survey data. We thus examined the relationship between the individual external doses and the corresponding ambient doses assessed from airborne surveys. The results show that the individual doses were about 0.15 times the ambient doses, the coefficient of 0.15 being a factor of 4 smaller than the value employed by the Japanese government, throughout the period of the airborne surveys used. The method obtained in this study could aid in the prediction of individual doses in the early phase of future radiological accidents involving large-scale contamination.

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Keywords: Fukushima Daiichi accident, radiation protection, dose assessment, individual dose, airborne survey, ambient dose, Date City

(Some figures may appear in colour only in the online journal)

1. Introduction

In making decisions regarding appropriate protection policy against radioactive contamination after nuclear accidents (such as the Fukushima Daiichi Nuclear Power Plant: FDNPP accident), obtaining the individual dose distribution is crucial. The ICRP recommends [1, 2] the responsible bodies to characterize the individual dose distribution of the exposed population, and to take appropriate and optimized actions based on the ALARA principle.

The external doses in the first four months of the Great East Japan Earthquake were estimated within the framework of the Basic Survey included the Fukushima Health Management Survey conducted by the Fukushima Prefectural government, based on population movement and activities extracted from the questionnaire distributed to Fukushima residents [3].

After the summer of 2011, many Fukushima municipalities started individual external dose monitoring for members of the public living in existing exposure situations, although such large-scale measurements of the general public have not been considered mandatory in the conventional radiation protection schemes. These municipal dose measurement programs were not initiated nor supervised by the Japanese central government, and thus they were not standardized in terms of the target group, distribution/collection methods, the format of data dissemination, and instructions describing how the dosimeters should be used. The information available to both the residents and administration in the affected areas is therefore rather fragmented. This has made it difficult for citizens to grasp the overall picture of the external exposures even though data have been published by each municipality (e.g. Fukushima City [4]) and by academic sectors [5]. As such, the collected data have not been well utilized for the benefit of the affected communities.

Date City is located about 50–60 km northwest of FDNPP. Unlike Iitate Village, which is adjacent to Date City and from which the entire population was ordered to evacuate in April 2011 (called the 'deliberate evacuation area' [6]), no evacuation order was issued to Date residents, except for a limited number (128) of households for which the Japanese Government estimated that the exposure to the residents would exceed 20 mSv within the first year after the accident (called the 'specific spots recommended for evacuation' [6]). Among the municipalities in which all the residents continue to live after the FDNPP accident, Date City has the largest gradient of contamination levels within the city borders.

In Date City, residents voluntarily started and actively participated in radiation protection measures immediately after the accident, e.g. ambient dose measurements and school decontamination. The city office also endorsed and supported those activities from early on [7]. The Mayor of Date City ordered the launch of a project to monitor the individual doses of residents, as well as the ambient dose rate throughout the city, with an emphasis on gathering information which could be used to prioritize decontamination based on the contamination levels.

For the measurement of individual external doses, Date City distributed individual dosimeters (radio-photoluminescence (RPL) glass dosimeters: Glass Badge) to kindergarten-, elementary- and junior high school-children in August 2011. The target group was subsequently enlarged as the production capacity of the supplier increased, and the measurements are still ongoing.

It is very notable that Date City distributed the glass badges to all citizens ($\sim 65\,000$ in all) for one year, from July 2012 to June 2013 [8], foreseeing that the actual dose data would

become required when communicating to the citizens. The results published by Date City were further analyzed by the IAEA [9]. No other external dose measurement program of comparable scale has been done in Fukushima, making Date City's data the most comprehensive set of actual measurements of individual doses carried out after the FDNPP accident.

In addition to the external doses, Date City also started to measure the internal doses of citizens in October 2011, which still continue. The decontamination of public facilities and roads was started in the fall of 2011, and that of residences was started in the fall of 2012 (to be discussed further in the following section). In March 2014, Date City announced the completion of its decontamination program.

The present authors made use of the large-scale individual dose monitoring data provided by Date City covering the period from 5 to 51 months after the FDNPP accident, analyzed the relationship of the individual doses to the results of airborne surveys conducted by the Japanese Government [10], the effect of decontamination on the individual doses, and the relationship between the external and internal doses. These results will be published in a series of three papers.

The purpose of this paper, the first in the series, is to establish a method for estimating individual external doses based on the available ambient dose rate survey data, such as the airborne surveys.

Ethics statement

Date City mayor's office entrusted the data to the authors, one of whom (MM) is a Date municipal government advisor. The geocoded household addresses of the glass-badge monitoring participants were pseudo-anonymized by rounding both longitude and latitude coordinates to 1/100 degrees prior to data analyses. This study was approved by the ethics committee of the Fukushima Medical University (approval No. 2603).

2. Materials and methods

2.1. The terrain and radioactive contamination situation of date city

Date City is located about 50–60 km northwest of FDNPP. Adjacent to Date City, the prefectural capital Fukushima City lies to the southwest, Kawamata Town lies to the south, and litate Village lies to the southeast. The total area is about 265 square kilometers, of which agricultural land comprises about 27%, forest about 38%. Date City is endowed with a rich natural environment and fertile arable land. The population in 2010 (prior to the disaster) was about 67 000, and the number of households was about 20 000, most of which were unevenly distributed in the flat land towards the northwest of the city. The population density is low in the eastern and southern parts, which is mountainous, being a part of the Abukuma–kochi highland. About 5400 households (26%) engage in agriculture, of which 900 are full time farmers. Their revenues come mostly from fruit production [12]. This, together with the large fraction of agricultural land area, means that agriculture is an essential part of life in Date City.

Radioactive materials released by the FDNPP accident were unevenly deposited in the northwesterly direction from FDNPP as shown in figure 1. As a result, the contamination levels have a strong gradient from south (high) to north (low) in Date City.

2.2. Zoning based on the difference in the contamination level in date city

In order to assess the distribution of the ambient dose rate throughout the city, in August 2011, Date City generated a map of the ambient dose rate measured at 1 m above the ground by dividing the city into a 1 km grid (500 m in urban areas). Based on this map, Date City



Figure 1. Maps showing the location of Date City and the distribution of ambient dose rates as of November 5, 2011, based on the airborne monitoring surveys conducted from October to November 2011. Adapted from a map published in [11].

made a decontamination plan (1st edition) in October 2011, which stated that decontamination method would be optimized according to the contamination level [13].

In the Date City decontamination implementation plan (2nd edition) published in August 2012, a zoning scheme was introduced [14]. Date City used the ambient dose map of August 2011 and the formula used by the Japanese government (see [15], and equation (2)), to classify the households where the annual external dose was estimated to exceed 20 mSv y⁻¹ as A, less than 5 mSv y⁻¹ as C, and the rest as B. In terms of the ambient dose rate, these corresponded to: zone A (\gtrsim 3.5 μ Sv h⁻¹), zone B (1 μ Sv h⁻¹ \sim 3.5 μ Sv h⁻¹) and zone C (<1 μ Sv h⁻¹). The three zones in Date City are shown in figure 2³. The decontamination was to be carried out in this prioritized order. The numbers of households in each zone in August 2012 were as follows:

zone A \sim 2500 households, zone B \sim 3700 households, zone C \sim 15 600 households.

2.3. Individual dose monitoring of residents using glass badges

The individual dose monitoring of residents in Date City was carried out using glass badges usually used for radiation workers; their use by residents living in contaminated areas was not foreseen before the FDNPP accident.

³Note that this map, made available to the authors by Date City is for the measurement carried out in March 2012, so that the dose rates are lower than in August 2011.



Figure 2. The ambient dose rate map of Date City measured in March 2012, together with the zoning according to the dose rate (as measured in August 2011): zone A (>3.5 μ Sv h⁻¹), zone B (1 μ Sv h⁻¹ \sim 3.5 μ Sv h⁻¹) and zone C (<1 μ Sv h⁻¹). Adapted from a map published in [7].

Glass badges are calibrated against personal dose equivalent Hp(10) on a polymethyl methacrylate (PMMA) slab phantom in the anterior-posterior (AP) geometry [16]. However, residents living in contaminated areas receive radiation close to the rotational irradiation geometry, as the radioactive cesium released in the FDNPP accident now exists almost uniformly in the environment. Even in this case, it has been shown that a dosimeter worn on the body trunk gives good approximation of the effective dose [17].

The glass badge is sensitive to natural background radiation (terrestrial γ -rays and cosmic rays). In order to evaluate the additional dose due to the radioactive cesium released by the accident, it is necessary to subtract the background contribution. In generating the glass badge readout report for Fukushima Prefecture residents, the glass-badge supplier, Chiyoda Technol, subtracts a value equivalent to 0.54 mSy y⁻¹ as the background, measured at Oarai Town, Ibaraki Prefecture (130 km south of FDNPP), where the contamination due to the FDNPP accident was low [18]. Date City then mails the results to each monitoring survey participant.

2.4. Monitoring survey participants and measuring periods

The first external contamination measurement survey in Date was conducted for one month in August 2011, and targeted pregnant women and children aged 15 or under. In all subsequent measurement surveys, the measurement period was three months (one quarter, hereafter denoted Q). In particular, the measurement survey conducted from Q2 2012 (Japanese fiscal year, i.e. July–September 2012) through Q1 2013 targeted all citizens, \sim 65 000 in all, of which 81% (52783) received and returned the badge every 3 months for one year. After that, all children up to the age of 18, all pregnant women, and all persons living in zone A continued to participate in the measurements, while the number of participants living in zone B and C has been gradually reduced; in these zones, glass badges are distributed based on random sampling of the population, and also to residents who request one, instead of targeting the entire population.

Table 1 shows the timeline of the glass-badge measurements through Q1 2015, the change of subjects, age distribution, and the total number of participants upon which the present analysis is based.

2.5. Method for comparing individual doses and ambient doses

The Japanese government has been continuously monitoring the accident-affected areas using aircraft equipped with radiation monitors flown at a typical altitude of 300 m [19]. The counting rates are converted to $\dot{H}^*(10)$ at 1 m above the ground, and the results are published as average values within a 250 m × 250 m grid. Tables listing $\dot{H}^*(10)$ at each longitude–latitude coordinate of the grid have been disseminated and are available on the internet [20].

The airborne survey data were then compared with the glass-badge-derived individual doses. As shown in table 1, six airborne surveys (4th through 9th) match the glass-badge measurement periods. We used these six pairs of data in our analysis.

For each period and for each participant, we used the GIS information, the longitude– latitude coordinates of the residence of the participant provided by the Date City office, to look up the $\dot{H}^{*}(10)$ of the nearest grid point, which we hereafter denote the *grid dose rate*, in the corresponding airborne survey database.

In figure 3, we present the geographical locations of the participants and their grid dose rates for each of the six measurement periods, in separate panels. The grid dose rates are color coded, and the area of each circle is drawn proportionally to the number of participants within each the grid cell.

Since *background radiation has been subtracted* from the glass badge data, we subtracted 0.04 μ Sv h⁻¹ from the airborne H^{*}(10) data in our analyses to compensate. This value (0.04) was used by the Japanese government in the published formula which related the ambient dose rate to the effective dose [15].

3. Results

Figure 4 shows the box-and-whisker plots of the individual dose rates versus grid dose rates for six periods. The left-hand column from top shows the 4th, 5th, and 6th airborne monitoring, the right hand column from top shows the 7th, 8th, and 9th airborne monitoring (also see table 1). The abscissa is the grid dose rate in increments of $0.1 \ \mu\text{Sv} \ h^{-1}$. The box-and-whiskers represent distributions of the individual dose rates (derived from the three-month accumulated doses) of the subjects, whose grid dose rates were within the bin. The boxes cover 25th percentile to 75th percentile of the distribution, and the whiskers cover the 1st percentile to 99th percentile of the distribution. The dots represent outliers. Below each box-and-whisker plot, a histogram of population versus grid dose rate is shown.

The reduction of grid dose rates from the 4th monitoring to the 9th monitoring is already evident in figure 3. Correspondingly, the distributions of the number of subjects versus gird dose rates shown in figure 4 is steadily shifted to the left (i.e. to lower dose rates).

Japanese Fiscal Year	Quarter/ Month(s)	Participants	Airborne Monitoring	Age distribution of the glass-badge monitoring participants
Japanese Fiscal Year 2011 2012 2013	Aug	1.Pregnant women, 2.Kindargarten 3.Elementary 4.Junior High		2011 Sep - Nov 1000 000 000 000 000 000 000 0
	Sep-Nov	1.Ages 0∼15 2.Pregnant	4 th (November)	200
	Dec-Feb	women 3.the specific spots		1200 2012 1Q 1000 N = 9304
2012	Q1 (Apr-Jun)	recommended for evacuation	5 th (June)	200 L
	Q2 (Jul-Sep)	All citizens		2012 30
	Q3 (Oct-Dec)		6 th (November)	1000 N = 59056
	Q4 (Jan-Mar)			400 200
2013	Q1			1200 2013 2Q
	Q2	1.Ages 0∼15 2.Pregnant	7 th (September)	800 N = 24278
	Q3	women 3.Zone A&B 4.Zone C	8 th (November)	
	Q4	random sampling +		2013 3Q 1000 N = 24162
2014	Q1	applicant		800 600 400
	Q2	1.Ages 0~15 2.Pregnant		
	Q3	women 3.Zone A&B 4.Zone C	9 th (November)	1200 2014 3Q 1000 N = 21080
	Q4	random sampling +		600 400
2015	Q1	applicant		0 0 20 40 60 80 100 Age

Table 1. Timeline of the glass-badge measurement surveys in Date City from 5 to 51months after the FDNPP accident.

The mean coefficient $\langle c \rangle$, the average ratio of the individual dose rate to the grid dose rate was

$$\frac{\text{individual dose rate}}{\text{grid dose rate}} \right\rangle = 0.15 \pm 0.03, \tag{1}$$

where $\langle \rangle$ denotes the average over all data in the six periods excluding the outliers. This coefficient was used to draw the pink shaded band in each panel of figure 4. Note that the Japanese



Figure 3. Geographical locations of the survey participants and their grid dose rates for each of the six measurement periods. The left-hand column (a)–(c) shows the 4th, 5th and 6th airborne monitoring, the right-hand column (d)–(f) shows the 7th, 8th and 9th airborne monitoring. The grid dose rates are color coded ($0-4 \ \mu \text{Sv} \ h^{-1}$), and the area of each circle is drawn proportionally to the number of participants within the grid. In the period corresponding to the 6th airborne monitoring, glass badges were distributed to all citizens, so that (c) indicates the overall population distribution within the city.



Figure 4. Box-and-whisker plots of the individual dose rates versus grid dose rates for the six periods. The left-hand column (a)–(c) shows the data corresponding to the 4th, 5th and 6th airborne survey periods, and the right-hand column (d)–(f) shows those corresponding to the 7th, 8th and 9th periods.

(2)

government employs the following standard behavioral scenario in evaluating the additional effective dose based on the ambient dose rate [15]: a person spends 8 hours outdoors without any shielding, and stays 16 h in a wooden house where the dose rate is 40% of that of outside [21], with the natural background dose rate of 0.04 μ Sv h⁻¹. In this scenario, the conversion factor for obtaining the additional effective dose from ambient dose rate excluding the background dose rate is 0.6, i.e.

individual dose rate (μ Svh⁻¹) = 0.04 + 0.6 × ambient dose rate

The thick blue line in each panel of figure 4 corresponds to this scenario. As shown, the blue line (the government estimate based on its standard behavioral scenario) lies well above the pink band, which is based on actual measurements.

The coefficient *c* has a distribution as shown in figure 5, in which a cumulative probability distribution of *c* is plotted using a log-normal grid. As shown, 50-percentile is c = 0.15, 90-percentile is c = 0.31 and 99-percentile is c = 0.56. The percentage of the participants whose *c* coefficient exceeded the Japanese-government value of 0.6 was 0.7%.

4. Discussion

Date City has been monitoring the individual doses of its citizens since five months after the Fukushima-Daiichi Nuclear Power Plant Accident. As a result, the accumulated individual monitoring data compiled by Date City is the most comprehensive record of the temporal and locational changes in individual doses of residents living in areas affected by the accident. This detailed archive of dose information meets the recommendations of the ICRP: 'In a situation of long-term contamination, it is essential to establish a radiation monitoring system allowing follow-up of the radiological situation and the implementation of adequate protection strategies [2]'. The authors analyzed the data upon the request of Date City so that crucial lessons applicable to the post-accident situation can be derived, particularly regarding existing exposure situations, and to help understand what will be needed in the event of future radiological disasters.

The present study showed that the individual dose rate is proportional to the ambient dose rate with a coefficient $c = 0.15 \pm 0.03$. The coefficient obtained in this study is smaller than the government-adopted value of 0.6 by a factor of ~0.25. Naito *et al* [22], who targeted a small group of some 100 people, found a coefficient of ~0.2, also smaller than the government value. These results show that coarse-grained airborne data can be a useful estimator for predicting the individual doses of residents living in contaminated areas.

In our (and Naito *et al*'s) work, we both used the actually measured $H^*(10)$ (airborne monitoring) and Hp(10) (individual dose monitoring) data to empirically deduce the coefficient *c*. On the other hand, the Japanese government in 2011 constructed a model to estimate the effective dose from $H^*(10)$, which, in retrospect, overestimates the personal dose by a factor of $3 \sim 5$.

After large-scale radioactive contamination events such as the FDNPP accident, it should be expected that the response capacity of local governments will be overstretched. In the case of Fukushima, local governments concentrated their efforts on preparing and distributing the equipment to residents, and it was not possible to ensure the proper use of the personal dosimeters by everyone, as is regularly done for radiation workers. As a result, the data collected by Date City does not include information about whether or not each participant actually lived at the address registered at the city office, or whether they routinely wore the glass badge as requested. Therefore, strictly speaking, the values measured by the glass-badges are not necessarily equal to the individual doses of every participant. This is a limitation of the



Figure 5. A log-normal plot of the cumulative probability distribution of the c coefficient.

present study. However, we believe the differences in actual dosimeter use patterns among the participants do not greatly affect the present results, as discussed below.

Nomura *et al* [23] analyzed the results of the glass badge measurements conducted continuously for school children in Minamisoma City, and reported that there is no statistically significant difference in the personal doses between the group who reported in the questionnaire that they wore the badge properly, versus the group who said they did not.

In the study of Naito *et al* [22], participants were given strict instructions regarding the usage of the dosimeter, which were duly observed, and they each carried a GPS receiver together with the electronic dosimeter which recorded hourly doses. The hourly dose was compared with the ambient dose rate estimated by combining the GPS information and the airborne monitoring database. The coefficient deduced from this well-controlled academic research targeting a small number of participants is extremely close to that derived in the current study, based on a municipality-driven long-term monitoring program involving tens of thousands of residents.

5. Conclusions

We have shown that the personal doses measured using glass badges in Date city are proportional to the ambient dose rates at the residences of the participants estimated from aircraft monitoring. As a result, the authors conclude that it is possible to predict the external exposure dose received by each individual based on the aircraft monitoring data. The conversion factor derived in the present study, should help greatly in estimating the individual external exposure doses in real life in the contaminated areas affected by the FDNPP accident. The method obtained in this study could aid in the prediction or in the estimation of the external doses of residents in the early phase of future radiation accidents involving large-scale contamination.

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