Title	Representativeness of individual external doses estimated for one quarter of residents in the Fukushima Prefecture after the nuclear disaster: the Fukushima Health Management Survey
Author(s)	Ishikawa, Tetsuo; Takahashi, Hideto; Yasumura, Seiji; Ohtsuru, Akira; Sakai, Akira; Ohira, Tetsuya; Sakata, Ritsu; Ozasa, Kotaro; Akahane, Keiichi; Yonai, Shunsuke; Kurihara, Osamu; Kamiya, Kenji; Abe, Masafumi
Citation	Journal of radiological protection. 37(3): 584-605
Issue Date	2017-09-25
URL	http://ir.fmu.ac.jp/dspace/handle/123456789/1577
Rights	© 2017 IOP Publishing Ltd. This is the Accepted Manuscript version of an article accepted for publication in "Journal of radiological protection". IOP Publishing Ltd is not responsible for any errors or omissions in this version of the manuscript or any version derived from it. The Version of Record is available online at https://doi.org/10.1088/1361-6498/aa6649.
DOI	10.1088/1361-6498/aa6649
Text Version	author

Representativeness of individual external doses estimated for one quarter of residents in the Fukushima Prefecture after the nuclear disaster: The Fukushima Health Management Survey

Tetsuo Ishikawa[1)], Hideto Takahashi[1)], Seiji Yasumura[1)], Akira Ohtsuru[1)], Akira Sakai[1)], Tetsuya Ohira[1)], Ritsu Sakata[2)], Kotaro Ozasa[2)], Keiichi Akahane[3)], Shunsuke Yonai[3)], Osamu Kurihara[3)], Kenji Kamiya[1,4)] and Masafumi Abe[1), a]

[1]Radiation Medical Science Center for the Fukushima Health Management Survey, Fukushima Medical University, Hikarigaoka 1, Fukushima City, 960-1295 Japan

[2]Radiation Effects Research Foundation, 5-2 Hijiyama Park, Minami-ku, Hiroshima City, 732-0815 Japan

[3]National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba City, 263-8555 Japan

[4]Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima City, 734-8551 Japan

Keywords: nuclear disaster, external dose, response rate, representativeness, equivalence test

[a] Present address: Fukushima Prefectural Hospital Bureau, 8-2 Nakamachi, Fukushima City, 960-8043 Japan

Abstract

After the Fukushima Dai-ichi Nuclear Power Plant accident, the Fukushima Health Management Survey (FHMS) was launched. The Basic Survey, a component of FHMS, is a questionnaire used to survey residents across the Fukushima Prefecture about their behavior in the first 4 months after the accident. The questionnaire findings are used to determine individual external doses by linking behavior data to a computer program with daily gamma ray dose rate maps, drawn after the accident. Through June 30, 2015, the response rate was only 27.2% (558,550 population), indicating that the findings might not be generalizable because of poor representativeness of the population. The objective of this study was to clarify if the data from the FHMS Basic Survey were representative of the entire population, by conducting a new survey to compare the external doses between non-respondents and respondents in the previous survey.

A total of 5350 subjects were randomly selected from 7 local regions of Fukushima Prefecture. An interview survey was conducted with the non-respondents to the FHMS Basic Survey. A total of 990 responses were obtained from the previous non-responders by interview survey. For the regions Kempoku, Kenchu, Kennan, Aizu, Minami-Aizu, Soso, and Iwaki, differences in mean effective dose (95% confidence interval) in mSv between the non-responders and previous responders were 0.12 (0.01-0.23), -0.09 (-0.21-0.03), -0.06 (-0.18-0.07), 0.05 (-0.04-0.14), 0.01 (-0.01-0.02), 0.09 (0.01-0.17), 0.09 (0.00-0.17), respectively. The differences fall neither within the interval (-∞, -0.25) nor within the interval (0.25, ∞). These findings imply that mean effective doses between the previous and new respondents were not different, with a significantly indifferent region of 0.25 mSv according to equivalence tests. The present study indicates that the dose distribution obtained from about one-quarter of Fukushima residents represents the dose distribution for the entire Fukushima Prefecture.

1. Introduction

Following the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident, the Fukushima Prefectural Government and Fukushima Medical University initiated the Fukushima Health Management Survey (FHMS) [1]. Ideally, health risks due to the accident should have been determined based on exposure assessments via all pathways (external—cloud shine and ground shine; and internal—inhalation and ingestion). However, in the early post-accident stage, external doses were expected to be effectively higher than internal doses, mainly due to the presence of short-lived radionuclides in addition to cesium. Therefore, the external dose during this period is considered to be of a higher relevance. Then, as a component of FHMS, the Basic Survey was launched to estimate individual external doses for the first 4 months after the accident, targeting all residents of Fukushima Prefecture (approximately 2.05 million) [2]. Since personal dosimeters were not generally available in the time period immediately after the accident, the following approach was used to estimate the 4 month external doses: (1) collecting information on personal behaviors including moves, daily time budget (indoors or outdoors), and dwelling types, using self-administered questionnaires, (2) estimating daily ambient gamma ray dose rate for each division (2×2 km mesh) of Fukushima Prefecture, and (3) superimposing digitized records of moves and activities on the daily gamma ray dose rate maps by a computer program [3].

Regarding the first step, the self-administered questionnaire was prepared in order to collect information from residents on their domicile, places visited, length of time spent indoors and outdoors, and travelling time, during the period from March 11, 2011 to July 11, 2011. Questionnaires were mailed to the original target population beginning in June 2011 and ending in October 2011. It was intended that all registered residents in Fukushima Prefecture at the time of the accident receive a questionnaire. Respondents were requested to return the questionnaire by mail upon completion. Details of the administration and collection of the questionnaire are described in a prior publication [2].

The overall response rate to the original population for the FHMS Basic Survey was 27.2% (558,550/2,055,520) as of June 30, 2015 [4]. Regional variations in the response rates were observed: 20.2%, 21.1%, 22.3%, 24.1%, 25.1%, 29.9%, and 45.7% in Minami-Aizu, Aizu, Kennan, Kenchu, Iwaki, Kempoku, and Soso, respectively. The location of the 7 regions is shown in figure 1. The Minami-Aizu region had the lowest response rate and the respondents, on average, were determined to have the lowest individual dose level. The highest response rate was in the Soso region, where higher individual doses were observed. In the Soso region, Namie Town had the highest response rate (60.6%).

Since the response rate was relatively low, especially in areas with low individual dose level, there was the possibility that the survey results were not representative of the entire Fukushima population because of selection bias. This would mean that the level of external exposure may be different between respondents and non-respondents. The UNSCEAR 2013 Report [5] stated that one of the key priorities for scientific research is to better characterize the distribution of doses to the public expressing variability between individuals. If it can be determined that the FHMS Basic Survey results are representative of the broader population, the survey findings can be used to better understand the distribution of external effective doses for the first 4 months following the nuclear accident.

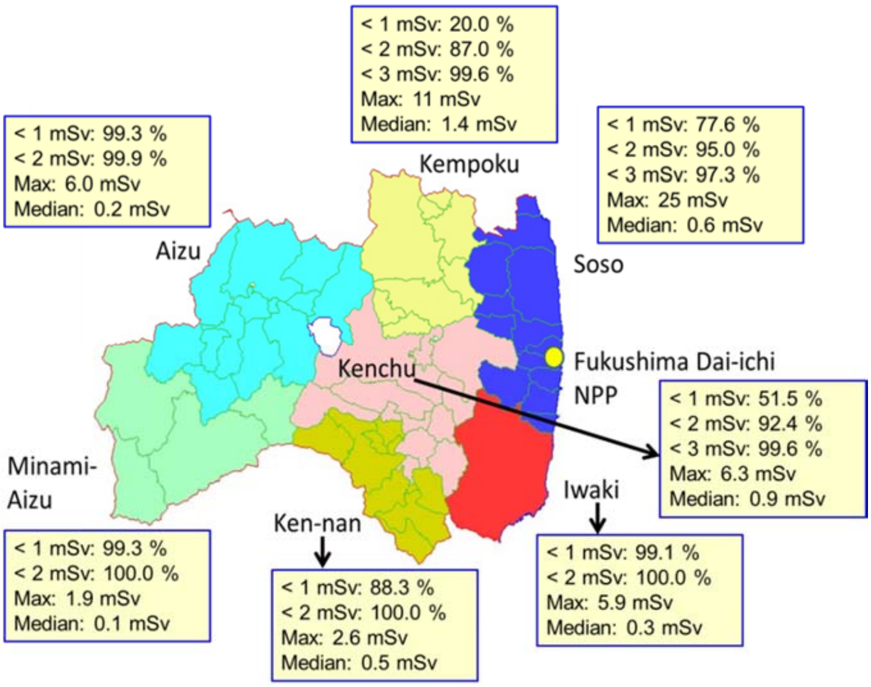

Figure 1. Location of seven regions of Fukushima Prefecture and their individual external dose levels.

Representativeness of survey findings can generally be determined by the response rate. It is recommended that in order for survey findings to be considered generalizable they should have a response rate of at least 80% [6, 7]. Previous efforts have been made to increase the response rate for the FHMS Basic Survey. For example, a simplified version of the questionnaire was developed in November 2013. The simplified questionnaire does not require respondents to fill in details of their behavior. Another effort implemented was to temporarily arrange sites where trained staff provided respondents with support in filling out the questionnaires. Regardless of these efforts, increasing the response rate to approximately 80% or more was not possible, in part because people are unable to accurately recall their behavior for the first 4 months after the accident over time. The response rate, therefore, has remained at the same level even recently. Alternatively, it is possible to demonstrate representativeness of the FHMS Basic Survey results by conducting a new survey to clarify the equivalence in the external dose between previous respondents and non-respondents [8]. An interview survey for those who did not respond to the FHMS Basic Survey was administered. Responses were obtained and individual doses were estimated using the same method as that for previous respondents. Thereafter, the difference in mean effective dose between the previous respondents and the new responders was investigated using the equivalence test method [9-11]. As described above, the individual doses dealt with in the present study indicate effective doses due to external radiation for the first four months only.

2. Materials and methods

2.1 *Basic scheme to evaluate representativeness of the FHMS Basic Survey*

A basic schema for the present study is illustrated in figure 2.

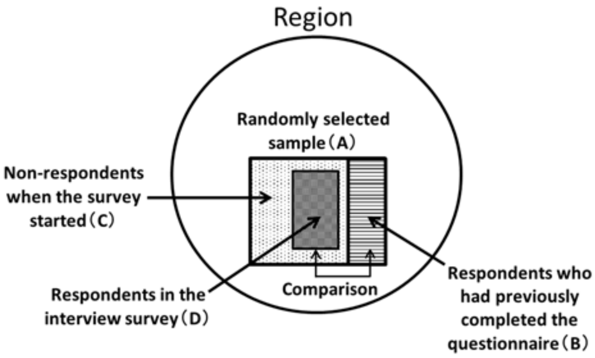

Figure 2. Methods for sampling and comparing respondents.

As the first step, a sample was randomly selected from each of the 7 regions (group A in figure 2) by a stratified two-stage sampling method. The samples can be considered representative of the population for each region, because they were selected randomly. Group A consisted of groups B and C. Members of group B already responded to the FHMS Basic Survey and those in group C did not so. Second, the interview survey was conducted for the non-respondents (group C) to ask them to complete the questionnaire. Third, a comparison by region was made between the effective dose of the respondents in the interview survey (group D) and that of group B members. In order to evaluate if the doses for the groups B and D were equivalent for each region, an equivalence test method was applied for the doses of the 2 population groups, as described in the next section.

Here, the dose distribution is different between regions, depending on several factors, such as the distance and direction from the FDNPP (figure 1), and evacuation status. For example, since most of the population of Soso were evacuated, their median dose was lower than that for Kempoku (non-evacuated area), which was more distant from the FDNPP. Among the non-evacuated areas, Kempoku has the largest median dose due to the radioactive plume deposited in the north-west direction of the FDNPP [2].

According to the results of the FHMS Basic Survey thus far, there was not a large difference in the dose distribution between municipalities within each region, except for the Soso region. In Iitate Village of the Soso region, doses were distributed from <1 mSv to larger than 15 mSv, whereas doses were less than 2 mSv for all respondents from Sinchi Town of Soso region. This variation in the Soso region was considered in determining the size of the sample (group A in figure 2) randomly selected.

The size of the samples that should be selected from each region depended on the range of individual dose levels. The sample size necessary for the equivalence test can be calculated statistically as described in the next section. Generally, similar to the Soso region, where the residents experienced a wide range of exposure levels as shown in figure 1, more samples corresponding to group A in figure 2 were selected than other regions.

The study protocols of the FHMS Basic Survey and the interview survey were reviewed and approved by the Ethics Review Committee of Fukushima Medical University. The study was conducted in accordance with approved guidelines.

2.2 *Design of equivalence test between respondents and non-respondents in dose distribution*

To show no-difference between groups, an equivalence test, rather than t-test, is essential [12]. In this study, the equivalence test was designed to compare the dose level between the 2 groups (groups B and D shown in figure 2) [13]. The equivalence test consisted of 2 one-sided tests, one is $H0{:}\Delta>\delta_0$, $H1{:}\Delta<\delta_0$, and the other is $H0{:}\Delta<-\delta_0$, $H1{:}\Delta>-\delta_0$, with 2.5% significance level, respectively, where Δ is the population mean difference between groups, and pre-determined margin δ_0 is called the indifference margin (equivalence margin). It is equivalent if a 95% interval of population mean difference is included neither $(-\infty,-\delta)$ nor (δ,∞). In the present study, the pre-determined margin was set as (−0.25 to 0.25) mSv, considering the uncertainty of effective doses described below. In this case, if any of the 95% confidence interval of the difference was neither within the interval $(-\infty, -0.25)$ nor $(0.25, \infty)$, effective doses for the 2 groups can be regarded as equal.

It is well known that effective doses cannot be measured directly and estimations are uncertain. The external dose estimation in the FHMS Basic Survey also has some uncertainties described elsewhere [3, 4]. It is difficult to quantify the uncertainty precisely, but the estimated external dose values were considered to have only one significant digit. Therefore, 0.25 mSv is small compared with the uncertainty of the effective dose.

Once the equivalence margin is determined, the sample size necessary for conducting the equivalence test with a certain significance level [14] between the 2 groups for each region can be estimated from statistical parameters, and the standard deviation for individual doses obtained in the FHMS Basic Survey thus far (equations (1) and (2)). The standard deviation for individual doses for each region is shown in table 1. The response rate, arithmetic mean, and standard deviation of individual doses were calculated based on responses before the interview survey was planned (as of Oct 31, 2014).

For indifference region Δ=0.25 (mSv), and in the region i, and estimated standard deviation of the external dose σ_i (mSv), we calculated sample size N_D per region i as

$$N_D = 2\left(\frac{Z_{0.025}+Z_{0.05}}{\Delta/\sigma_i}\right)^2 \quad (1)$$

with significance level 0.05, and power 0.80, with the upper percentile q of normal distribution, Z_q.

After calculating N_D, number of subjects that should be included in the interview survey can be calculated. Considering the expected number of people who had previously responded, the number of people that should be randomly selected (N_A ($N_{A'}$), corresponding to group A in figure 2, can be estimated. On the basis of these calculations, the sample size randomly selected for each region was determined.

Table 1. Number of people that should be randomly selected from each region and parameters used for its calculation.

Item No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Region	Response rate for the Basic Survey as of Oct. 31, 2014*	Expected response rate in interview survey	Arithmetic mean of individual doses#	Standard deviation of individual doses#	Equivalence margin	Nubmer of responses necessary in interview survey (group D in figure 2)	Number of target subjects for the interview survey +expected number of people who had already responded (group A in figure 2)	Number of people randomly selected (round number of N_A)
	p_{i1} (%)	p_{i2} (%)	m (mSv)	σ_i (mSv)	Δ (mSv)	N_D	N_A	$N_{A'}$
Kempoku	29.8	20.0	1.37	0.53	0.25	94	672	700
Kenchu	23.7	20.0	1.00	0.65	0.25	142	930	950
Kennan	21.9	20.0	0.56	0.31	0.25	32	207	250
Aizu	20.9	20.0	0.24	0.14	0.25	7	42	100
Minami Aizu	20.0	20.0	0.12	0.13	0.25	6	35	100
Soso	45.4	20.0	0.75	1.01	0.25	343	3,138	3,150
Iwaki	25.0	20.0	0.32	0.18	0.25	11	73	100
Total						634	5,097	5,350

*As of Oct 31, 2014. Responses from radiation workers are included
#As of Oct 31, 2014. Doses for radiation workers are excluded

As a result of calculation with equation (1), the number of responses necessary for the equivalence test with an equivalence margin of 0.25 mSv was 634 across the entire prefecture (group D in figure 2). However, it is difficult to obtain responses from all target subjects (group C in figure 2). It is expected that some subjects will not participate in responding to the survey. In order to estimate the number of subjects who should be included in the interview survey, expected response rate for the interview survey should also be estimated. Considering the above process, the sample size N_A can be calculated by equation (2).

For response rate of the FHMS Basic Survey p_{i1}, and expected response rate in this survey p_{i2}, the sample size N_A per region i was calculated as

$$N_A = N_D / p_{i2}(1 - p_{i1}) \qquad (2)$$

Here, expected response rate (p_{i2}) was assumed to be 20%.

As shown in figure 2, the subjects for the interview survey were selected by excluding respondents from a randomly selected group for each region. Considering the expected number of people who already responded among the randomly selected people, the number of people that should be randomly selected was calculated to be 5,097 by using equation (2) (table 1 (7), N_A). Rounding up the small number of subjects, the randomly selected people was finally determined to be 5,350 for the entire prefecture (table 1 (8), $N_{A'}$).

2.3 *Random sampling of subjects*

One of the most common random sampling methods is stratified two-stage sampling [15]. The first step of the two-stage cluster sampling was done in the following way: considering the feasibility of sampling from each of the 7 regions, zip-codes were used as keys to select the cluster samples. The target population of the FHMS Basic Survey comprises the population who lived in Fukushima Prefecture at the time of the Great East Japan Earthquake. They are registered in a database at Fukushima Medical University, together with information on their present address. On average, an area with a single zip-code includes 516 persons registered for the FHMS Basic Survey.

It is possible to select a group of persons who have addresses within the same zip-code from the database. For every zip-code used in Fukushima Prefecture, the number of persons registered as subjects of the FHMS Basic Survey was calculated for the area corresponding to each zip-code. In this process, the address (zip-code) at the time of the earthquake was used.

If the calculated number of registered people for a zip-code area was between 350 and 700, it was regarded as an area with a suitable number of people, because the average number was 516 as described above. If the number of people was larger than 700, the area was divided into 2 or more areas in order that each divided area had a population of 350 to 700. In contrast, if the number of registered people in an area with a single zip-code was lower than 350, 2 or more areas were merged to have a population between 350 and 700. When selecting the areas for each of the 7 regions, a systematic sampling (equivalent interval) method [16] was used. This procedure is demonstrated in figure 3.

In the second stage, 50 persons were randomly selected from each area with an adjusted population between 350 and 700. As an example, in the Kempoku region, the total number of persons that should be selected was 700, according to table 1 (N_A). Second, 14 areas should be selected as part of first-stage sampling, using the method shown in figure 3. In the second-stage sampling, age distribution was also considered. According to available data on age distribution in Fukushima Prefecture before the accident, age group populations of 0-19 years, 20-59 years and ≥60 years were 377,825, 987,882, and 663,357, respectively [17]. The ratio was almost 2:5:3. Dividing 50 according to this ratio, 10 persons were selected for ages <20 years, 25 persons for ages 20-59 years, and 15 persons for ages ≥60 years.

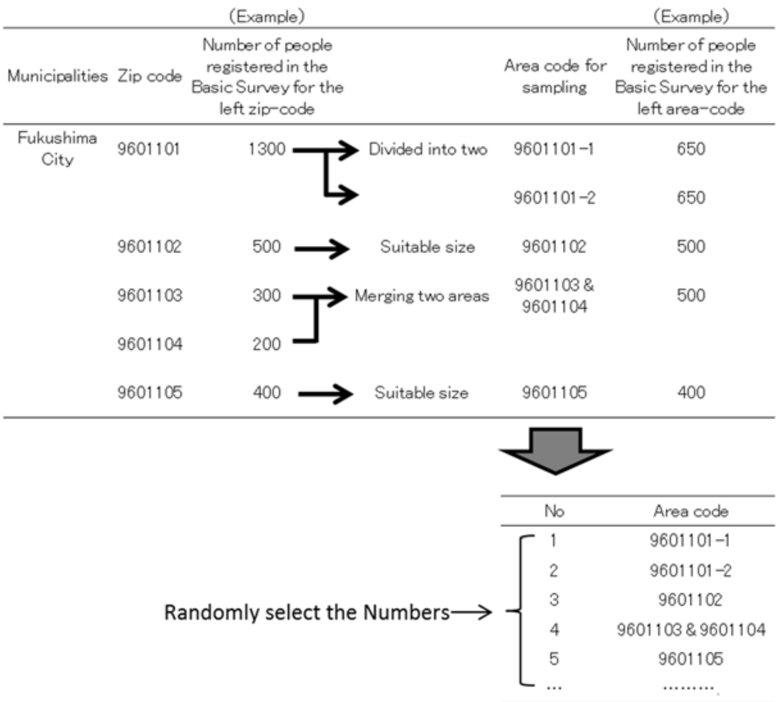

Figure 3. Random sampling procedures for cluster samples.

Table 2. The number and location of areas where subjects for interview survey were selected.

Region	Municipalities	No of areas selected	Basic Survey population
Kempoku	Fukushima City	8	295,645
	Nihonmatsu City	2	60,857
	Date City	2	67,577
	Motomiya City	1	31,762
	Kawamata Town	1	15,885
	Other three municipalities	0	32,316
	Total	14	504,042

Region	Municipalities	No of areas selected	Basic Survey population
Kenchu	Koriyama City	12	339,719
	Sukagawa City	2	80,163
	Tamura City	2	41,723
	Tenei Village	1	6,470
	Hirata Village	1	7,053
	Miharu Town	1	18,993
	Other six municipalities	0	63,116
	Total	19	557,237

Region	Municipalities	No of areas selected	Basic Survey population
Soso	Soma City	12	37,371
	Minami-soma City	23	70,013
	Hirono Town	2	5,165
	Naraha Town	3	7,963
	Tomioka Town	5	15,751
	Kawauchi Village	1	2,996
	Okuma Town	3	11,473
	Futaba Town	3	7,051
	Namie Town	6	21,335
	Katsurao Village	1	1,541
	Shinchi Town	2	8,357
	Iitate Village	2	6,588
	Total	63	195,604

Region	Municipalities	No of areas selected	Basic Survey population
Kennan	Sirakawa City	3	65,428
	Izumizaki Village	1	6,931
	Tanakura Town	1	15,384
	Other six municipalieies	0	64,482
	Total	5	152,225

Region	Municipalities	No of areas selected	Basic Survey population
Aizu	Aizu-wakamatsu City	1	127,815
	Aizu-misato Town	1	23,411
	Other eleven municipalities	0	115,977
	Total	2	267,203

Region	Municipalities	No of areas selected	Basic Survey population
Iwaki	Iwaki City	2	348,226
	Total	2	348,226

Region	Municipalities	No of areas selected	Basic Survey population
Minami-Aizu	Tadami Town	1	5,030
	Minami-aizu Town	1	18,495
	Other two municipalities	0	7,264
	Total	2	30,789

As a result, the number and location of selected areas are shown in table 2. As expected, the areas that tended to be selected were from municipalities with larger populations. For example, in the Kempoku region, 14 areas were selected, and 8 among the 14 areas were from Fukushima City, which has the largest population in the Kempoku region. In the Soso region, 63 areas needed to be selected. Approximately one-third of the areas were selected from Minami-Soma City, which has the biggest population the Soso region, and one area was selected from Katsurao Village, which has the smallest population. For the Soso region, areas were selected from all municipalities.

2.4 *Interview survey*

Using the stratified two-stage sampling method, a total of 5,350 persons were selected. Although the sampling was based on the address (zip-codes) at the time of the earthquake, most people in evacuation areas moved to another place, including outside Fukushima Prefecture. In the present study, the evacuees living outside Fukushima

Prefecture were excluded from the subjects for the interview survey, because it would not have been cost-effective to include them. In addition, selected persons may have been deceased. Therefore, of the 5,350 persons selected, those who had already responded, died, or moved outside Fukushima Prefecture were excluded. As a result, the final number of subjects for the interview survey was 2,980, as shown in table 3.

Table 3. Subjects for interview survey for each region.

Region	Number of clusters	Number of people	Original sampling			Number of persons excluding died, moved, or already responded			
			0–19y	20–59y	≥60y	0–19y	20–59y	≥60y	Total
Kempoku	14	700	140	350	210	67	268	149	484
Kenchu	19	950	190	475	285	124	375	208	707
Kennan	5	250	50	125	75	26	108	64	198
Aizu	2	100	20	50	30	12	46	22	80
Minami Aizu	2	100	20	50	30	9	46	27	82
Soso	63	3,150	630	1,575	945	265	733	364	1,362
Iwaki	2	100	20	50	30	9	36	22	67
Total	107	5,350	1,070	2,675	1,605	512	1,612	856	2,980

A notice was mailed to the 2,980 subjects requesting their participation, before conducting the interview survey. The notice was sent to their present address, as recorded in the database, however, a portion of subjects had relocated and could not be found. In such cases, the notice was returned by the post office due to an invalid address. After sending out the notice, a total of 335 persons were excluded from the study, including those with invalid addresses (251 persons), those who declined to participate after receiving the notice (70 persons), and those who died or moved outside Fukushima Prefecture (14 persons), as shown in table 4. The proportion of excluded persons did not differ greatly by region. It ranged from 7.1% (Kennan) to 12.6% (Kempoku). Therefore, any participation bias by region resulting from the exclusion appears limited.

Table 4. Types of responses for sending the notice for each region.

Types of responses for sending a notice	Whole Prefecture		Kempoku		Kenchu		Kennan		Aizu		Minami Aizu		Soso		Iwaki	
	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)
Undeliverable due to incomplete address	251	8.4	48	9.9	53	7.5	9	4.5	4	5.0	4	4.9	129	9.5	4	6.0
Declined	70	2.3	10	2.1	16	2.3	5	2.5	3	3.8	3	3.7	30	2.2	3	4.5
Died or moved	14	0.5	3	0.6	8	1.1	0	0.0	0	0.0	0	0.0	2	0.1	1	1.5
Remaining subjects	2645	88.8	423	87.4	630	89.1	184	92.9	73	91.3	75	91.5	1201	88.2	59	88.1
Total	2980	100	484	100	707	100	198	100	80	100	82	100	1362	100	67	100

As a result, 2,645 people remained as participants in the interview survey. Since the number of responses necessary for the interview survey was 634, as shown in table 1, the necessary response rate was calculated to be approximately 24% (634/2,645). This was slightly larger than the expected response rate assumed when the sample size was calculated (20%, table 1). In particular, the Soso region needed the highest response rate, of about 30%, due to many invalid addresses for evacuees determined when notices were returned as undeliverable.

The number of families containing subjects of the interview survey was calculated beforehand. The 2645 subjects belonged to 2345 families, out of which 254 families had multiple subjects for the interview survey. Among them, most of the families had two subject members, but 22 families had three or four subjects. However, the proportion of families with multiple subjects did not differ greatly by region, as shown in table 5. Kenchu region appeared to be the sole exception, which may be because Kenchu region contains a large city (Koriyama City) with the second biggest population in Fukushima Prefecture. On average, it also has more one-person households. This could explain the lower number of families having multiple subjects for the interview survey.

Table 5. Number of families and subjects of the interview survey.

Region	Surveyed subjects	Surveyed families	Families having a single subject	Families having multiple subjects	
				Number	(%)
Kempoku	423	362	305	57	15.7
Kenchu	630	585	546	39	6.7
Kennan	184	160	137	23	14.4
Aizu	73	63	54	9	14.3
Minami Aizu	75	67	59	8	11.9
Soso	1201	1055	921	134	12.7
Iwaki	59	53	47	6	11.3
Total	2645	2345	2069	276	11.8

The presence of a certain number of families having multiple subjects is related to the sampling process. In the present study, we selected 50 persons from each of the areas with populations of 350–700 persons. The population was first divided into three age groups (0–19 y, 20–59 y, and >60 y) and then 10, 25 and 15 persons were randomly selected from each group, in accordance with the average age distribution of the population of Fukushima Prefecture. However, the age distribution differed by area. For example, in areas where the younger population was numerically smaller than the average, the number of families who had children (<20 y) was generally smaller. This means that the families with children tended to have a higher probability of having two subjects.

Due to the random sampling for each age group, a certain number of the subjects were from the same families as other subjects. However, the proportion of families having multiple subjects (average: 11.8%) did not differ greatly by region. This could indicate that the random sampling generated minimal bias by region.

The interview survey was initiated in June 2015. Efforts were made to increase the response rate to the interview survey. When the survey staff visited a person at home, but could not make contact, subsequent visitation would take place, and a form requesting that the subject contact their office would be provided. In the Soso region in particular, 2 or more visits were conducted to ascertain a response, as this region needed the largest response rate.

For responses obtained by the interview survey, individual doses were estimated using the NIRS computer program [3], using the same method as for previous responders. Equivalence testing was conducted for the 2 groups (previous respondents vs. respondents in the interview survey). In addition, dose distribution was compared between the two groups.

3. Results

3.1 *Interview survey*

There were 2,645 subjects contacted for an interview for this survey, and 990 subjects responded. The types of responses in the interview survey by region are shown in table 6.

Table 6. Types of responses in the interview survey by region.

Types of responses for interview survey	Whole Prefecture		Kempoku		Kenchu		Kennan		Aizu		Minami Aizu		Soso		Iwaki	
	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)
Responded	990	37.4	177	41.8	227	36.0	71	38.6	34	46.6	49	65.3	407	33.9	25	42.4
Contacted, but no response was received	327	12.4	87	20.6	88	14.0	33	17.9	8	11.0	7	9.3	95	7.9	9	15.3
Could not be contacted	664	25.1	104	24.6	185	29.4	49	26.6	5	6.8	6	8.0	299	24.9	16	27.1
Could not be visited	212	8.0	28	6.6	30	4.8	12	6.5	3	4.1	5	6.7	132	11.0	2	3.4
Declined	452	17.1	27	6.4	100	15.9	19	10.3	23	31.5	8	10.7	268	22.3	7	11.9
Total	2645	100	423	100	630	100	184	100	73	100	75	100	1201	100	59	100

Description of the response types (interview survey):
(1) Contacted, but no response was received

The survey staff handed out questionnaires and asked the participants or their family to cooperate, but did not get their responses

(2) Could not be contacted:
The survey staff visited the participants twice or more and left a notice but could not contact them.

(3) Could not be visited:
The survey staff visited the participants to find out that they had moved to a different place. Two cases were considered; (1) the participants had moved after receiving the notice or (2) the notice was delivered to the address although the participants did not live there (in this case the notice should have been returned to the sender by the post office).

Although the survey staff visited the targeted subjects 2 times or more, especially in the Soso region, response rate was limited because 25% of subjects were absent. In addition, although the notice for the interview survey was not returned for the final 2,645 subjects identified for the interview survey, 8% did not live at the latest address registered in the database. Although there were limitations in reaching the subjects, 37% of subjects responded. As shown in table 6, the proportion of those who declined to participate ranged from 6.4% to 31.5% by region. The proportion did not differ greatly by region, except within the Aizu region (31.5%). In the Aizu region, however, while the minimum required number of responses necessary in the interview survey was 7 (N_D in table 1), the number of responses obtained was 34, which was much larger than required.

The number of families having subjects for the interview survey was also checked against the respondents in the interview survey. Among the respondents, 78 families had multiple subjects. The proportion of families having multiple subjects ranged from 4.1% (Kenchu) to 13.3% (Aizu) among the seven regions (average: 8.6%). This average did not vary largely from the average for all subjects before the interview survey (average proportion: 11.8 %, table 5).

As a result, the number of respondents for each region (table 6) exceeded the numbers necessary for the equivalence test (N_D) as shown in table 1.

From the 990 respondents, excluding 3 participants who lived outside the prefecture during the dose estimation period, 2 who were born after March 11, 2011, and 24 radiation workers, estimated doses of 961 respondents were compared with those of individuals who had previously completed the questionnaire.

3.2 *Equivalence test*

The equivalence test was conducted for individual doses for the 2 groups for each region. A difference in mean effective dose between the respondents in the interview survey and the respondents who had previously completed the questionnaire in each of the 7 regions ranged from -0.09 mSv to +0.12 mSv (table 7).

Table 7. Comparison between respondents who had previously completed the questionnaire and those who participated in the interview survey.

Region	Items	Respondents who had completed the questionnaire	Respondents in the door-to-door survey	Difference and 95% CI in mean effective dose (mSv)
Kenpoku	Mean effective dose (mSv)	1.41	1.53	0.12 (0.01 – 0.23)
	Survey population	168	171	
Kenchu	Mean effective dose (mSv)	1.04	0.95	−0.09 (−0.21 – 0.03)
	Survey population	190	224	
Kennan	Mean effective dose (mSv)	0.73	0.68	−0.06 (−0.18 – 0.07)
	Survey population	41	71	
Aizu	Mean effective dose (mSv)	0.19	0.24	0.05 (−0.04 – 0.14)
	Survey population	11	34	
Minami-Aizu	Mean effective dose (mSv)	0.19	0.19	0.01 (−0.01 – 0.02)
	Survey population	15	49	
Soso	Mean effective dose (mSv)	0.73	0.81	0.09 (0.01 – 0.17)
	Survey population	1,138	388	
Iwaki	Mean effective dose (mSv)	0.32	0.40	0.09 (0.00 – 0.17)
	Survey population	25	24	

For 3 regions (Kempoku, Soso, and Iwaki), the mean effective dose for the respondents in the interview survey was significantly higher than that for respondents who had completed the questionnaire. However, the results showed that any of the 95% CI differences in mean effective doses were neither within the interval (-∞, -0.25) nor within (0.25, ∞). This indicated that the effective doses for the 2 groups were equivalent with 95% confidence (significance level: 5%). Therefore, the dose distribution previously reported for the FHMS Basic Survey was considered to be representative of the entire population of each region.

In addition, a comparison of dose distribution between the 2 groups (respondents who had completed the questionnaire and respondents in the interview survey) for each region is shown in table 8. The distributions were similar to each other. For reference, dose distribution for all respondents before starting the interview survey for each region is also shown in table 8. The “respondents who had completed the questionnaire” in table 8 were selected through the random sampling (group B in figure 2). It can be seen that the dose distribution was similar between “all respondents” and the “respondents who had completed the questionnaire” (respondents selected through the random sampling) for each region, which indicated that the random sampling was reasonable.

Table 8. Comparison of dose distribution between the 2 groups for each region.

Kennan

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	24,846	88.16	31	75.61	58	81.69
1–2	3,320	11.78	10	24.39	13	18.31
2–3	17	0.06				
Total	28,183	100	41	100	71	100
Maximum (mSv)	2.6		1.4		1.8	
Median (mSv)	0.5		0.7		0.5	

Minami-Aizu

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	4,771	99.29	15	100	49	100
1–2	34	0.71				
Total	4,805	100	15	100	49	100
Maximum (mSv)	1.9		0.2		0.2	
Median (mSv)	0.1		0.2		0.2	

Kenchu

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	56,569	51.28	97	51.05	134	59.82
1–2	45,269	41.04	79	41.58	68	30.36
2–3	8,050	7.30	13	6.84	22	9.82
3–4	417	0.38	1	0.53		
4–5	5	0.00				
5–6	3	0.00				
6–7	1	0.00				
Total	110,314	100	190	100	224	100
Maximum (mSv)	6.3		3		2.7	
Median (mSv)	0.9		0.9		0.7	

Iwaki

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	71,999	99.09	25	100	24	100
1–2	624	0.86				
2–3	30	0.04				
3–4	4	0.01				
4–5	1	0.00				
5–6	1	0.00				
Total	72,659	100	25	100	24	100
Maximum (mSv)	5.9		0.6		0.7	
Median (mSv)	0.3		0.3		0.4	

Kempoku

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	24,789	20.09	25	14.88	20	11.70
1–2	82,689	67.00	118	70.24	119	69.59
2–3	15,397	12.48	25	14.88	31	18.13
3–4	464	0.38			1	0.59
4–5	40	0.03				
5–6	18	0.01				
6–7	10	0.01				
7–8	1	0.00				
8–9	1	0.00				
9–10						
10–11						
11–12	1	0.00				
Total	123,410	100	168	100	171	100
Maximum (mSv)	11		2.9		3.1	
Median (mSv)	1.4		1.3		1.5	

Soso

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	55,298	77.57	874	76.80	287	73.97
1–2	12,402	17.40	227	19.95	88	22.68
2–3	1,650	2.31	18	1.58	7	1.80
3–4	584	0.82	2	0.18		
4–5	449	0.63	6	0.53	4	1.03
5–6	356	0.50	5	0.44	1	0.26
6–7	217	0.30	2	0.18		
7–8	113	0.16	2	0.18	1	0.26
8–9	72	0.10	1	0.09		
9–10	39	0.05				
10–11	35	0.05	1	0.09		
11–12	29	0.04				
12–13	13	0.02				
13–14	12	0.02				
14–15	6	0.01				
>15	14	0.02				
Total	71,289	100	1138	100	388	100
Maximum (mSv)	25		10		7.4	
Median (mSv)	0.5		0.6		0.6	

Aizu

Effective dose (mSv)	All respondents (June 30, 2015)		Respondents who had completed the questionnaire (group B in figure 2)		Respondents in interview survey (group D in figure 2)	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
< 1	43,955	99.27	11	100	33	97.06
1–2	298	0.67			1	2.94
2–3	25	0.06				
3–4	1	0.00				
4–5						
5–6						
6–7	1	0.00				
Total	44,280	100	11	100	34	100
Maximum (mSv)	6		0.3		1.3	
Median (mSv)	0.2		0.2		0.2	

4. Discussion

4.1 *Difference in effective dose between age groups*

The subjects for the interview survey were selected considering age distribution for the population of Fukushima Prefecture before the accident, but the response rate for the survey was actually different between the 3 age groups. Therefore, the dependence of dose on age group was investigated. In the Soso region, from where the largest number of survey subjects were selected, the numbers of responses to the interview survey according to the 3 age groups (<20 years, 20-59 years, ≥60 years) were 64 (16.5%), 173 (44.6%), and 151 (38.9%), respectively. The mean effective doses for the 3 age groups were 0.86±0.48 mSv, 0.79±0.73 mSv, and 0.82±0.69 mSv (mean±SD), respectively. In contrast, numbers of respondents who had previously completed the questionnaire were 250 (22.0%), 521 (45.8%), and 367 (32.2%), which corresponded to mean effective doses of 0.76±0.96 mSv, 0.72±0.80 mSv, and 0.71±0.76 mSv, respectively. No significant difference in the mean effective dose was found between the 3 age groups.

In the Kempoku region, the number of responses to the interview survey according to the 3 age groups (<20 years, 20-59 years, ≥60 years) were 12 (7.0%), 75 (43.9%), and 84 (49.1%), respectively. The mean effective doses for the 3 age groups were 1.45±0.58 mSv, 1.47±0.43 mSv, and 1.60±0.50 mSv (mean±SD), respectively. In contrast, numbers of respondents who had previously completed the questionnaire were 63 (37.5%), 66 (39.3%), and 39 (23.2%), which corresponded to the mean effective doses of 1.42±0.58 mSv, 1.38±0.51 mSv, and 1.43±0.52 mSv. No significant difference in the mean effective dose was found between the 3 age groups. Although the age distribution was different between the respondents in the interview survey and previous respondents (the proportion of young respondents was lower in the interview survey), it would have little effect on the results. Findings were similar for the other 5 regions. Therefore, dependence of the effective dose on the 3 age groups would be small.

4.2 *Representativeness of dose distribution*

Based on the results that doses for the 2 groups (respondents in the interview survey and those who previously completed the questionnaire) were equivalent for each region, a dose distribution for entire prefecture can theoretically be estimated. The dose distribution for non-respondents (those who had not completed the FHMS Basic Survey at the time of starting the interview survey) can be assumed to be similar to that of the respondents (those who already completed the FHMS Basic Survey at the time of starting the interview survey) for each of the 7 regions.

Thus, assuming that responses were collected from all of the original target population (approximately 2.05 million), a dose distribution for the entire prefecture can theoretically be estimated. As no bias was suggested in the response rates by effective dose category from tables 7 and 8, the dose distribution of all residents in Fukushima Prefecture could be estimated as the sum of the dose-specific numbers of subjects in each region, adjusted for overall response rate of the region.

For example, the total number of respondents in the Kempoku region was 123,410 before starting the interview survey, as shown in table 8. That number represented about 24.5% of the total population (504,042) registered in the FHMS Basic Survey (table 2). Assuming that the dose distribution for the respondents could represent that for all residents in the Kempoku region, the dose distribution for the FHMS Basic Survey population was calculated in the following way. For example, the number of people with effective doses less than 1 mSv was calculated by dividing 24,789 (table 8) by 0.245 (response rate), which resulted in 101,245. After the same adjustment was applied to other regions, and summing the figures for each dose band, the rate of all Fukushima residents (about 2.05 million) with doses less than 1 mSv was calculated to be 63.9%, <2 mSv 94.2%, and <3 mSv 99.5%, which were almost the same as the dose distribution for respondents for the FHMS Basic Survey (<1 mSv 62.0%, <2 mSv 93.8%, and <3 mSv 99.3% before starting the interview survey, as of June 30, 2015) [4].

It should be noted that the present study has the following limitations as a sampling survey. A small number of people with higher doses can be seen in the highly affected population of all respondents for the FHMS Basic Survey (up to 25 mSv in Soso region, table 8). These higher doses were not found in the population for the sampled respondents (maximum: 11 mSv for 1,138 persons), since the proportion of higher doses was very small (only 0.1% for >11 mSv) even for all respondents in Soso region. These higher doses were also not found in respondents in the interview survey. The maximum dose for respondents in the interview survey was 7.4 mSv. This may also be due to the number of respondents in the interview survey (n=388) being of too small a number for the dose to be readily detected.

Another possibility is that the distribution of higher doses was slightly different between the 2 groups (respondents who had previously completed the questionnaire (group B) and respondents in the interview survey (group D)). In the Soso region, for example, for groups B and D, in the 75th percentile, the estimated doses were 0.9 mSv and 1.0 mSv; in the 90th, 1.4 mSv each in the 95th, 1.7 mSv and 1.6 mSv; and in the 99th, 4.9 mSv and 4.1 mSv, respectively. They were similar to each other up to the 97th percentile, but they seemed to differ slightly for the larger percentile values. It is possible that the dose distribution for the higher doses in the interview survey was not exactly the same as that for the previous respondents.

From the data obtained in the present study, it could not be determined if those who received such higher doses were present among non-respondents to the FHMS Basic Survey, partially because the sampling size was designed for conducting the equivalence test, not for detecting possible higher doses within limited sample numbers. It is a limitation of the present study. However, the dose distribution obtained in the FHMS

Basic Survey could be the same as the dose distribution for the entire population, except for a small proportion of the very highly affected population.

5. Conclusion

The objective of this study was to clarify if the results of the FHMS Basic Survey were representative of all Fukushima residents. To achieve this objective, those who did not respond to the FHMS Basic Survey were randomly selected from each of the 7 regions of Fukushima Prefecture. Responses were obtained from the previous non-responders by interview survey. An equivalence test with an equivalence margin of 0.25 mSv was conducted for effective doses between the respondents to the interview survey and previous respondents, for each region. The results showed that differences in mean effective dose (95% Confidence Interval) for the 7 regions fall neither within the interval $(-\infty, -0.25)$ nor within $(0.25, \infty)$. Findings indicated that the 2 groups were equivalent in effective dose. Although the response rate for the FHMS Basic Survey was approximately 27%, the dose distribution obtained thus far could represent the dose distribution for the entire population.

The present study examined effective doses due to external exposure for the first four months only. It should be noted that health risk assessments are based on estimation of effective doses via all pathways (external—cloud shine and ground shine; and internal—inhalation and ingestion).

Acknowledgments

The present study was supported by the national "Health Fund for Children and Adults Affected by the Nuclear Incident." The findings and conclusions of this article are solely the responsibility of the authors and do not represent the official views of the Fukushima Prefecture government. The authors declare no conflict of interest.

References

[1] Yasumura S, Hosoya M, Yamashita S, Kamiya K, Abe M, Akashi M, Kodama K, Ozasa K and for the Fukushima Health Management Survey Group 2012 Study protocol for the Fukushima health management survey *J. Epidemiol.* **22** 375-383

[2] Ishikawa T et al 2015 The Fukushima Health Management Survey: estimation of external doses to residents in Fukushima Prefecture *Sci. Rep.* **5** 12712

[3] Akahane K, Yonai S, Fukuda S, Miyahara N, Yasuda H, Iwaoka K, Matsumoto M, Fukumura A, Akashi M 2012 NIRS external dose estimation system for Fukushima residents after the Fukushima Dai-ichi NPP accident *Sci. Rep.* **3** 1670

[4] Fukushima Radiation and Health, Fukushima Medical University 2015 The Basic Survey. 20th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey, Fukushima. Fukushima: Fukushima Medical University. (Aug 31, 2015) (http://www.fmu.ac.jp/radiationhealth/)

[5] United Nations Scientific Committee on the Effects of Atomic Radiation 2014 UNSCEAR 2013 report Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami. New York: United Nations

[6] Fincham JE 2008 Response rates and responsiveness for surveys, standards, and the Journal *Am. J. Pharm. Educ.* **72**(2) Article 43

[7] Draugalis JR, Coons SJ, Plaza CM 2008 Best practices for survey research reports: a synopsis for authors and reviewers *Am. J. Pharm. Educ.* **72**(1) Article 11

[8] Liu H, Cella D, Gershon R, Shen J, Morales LS, Riley S, Hays RD 2010 Representativeness of the PROMIS internet panel *J. Clin. Epidemiol.* **63**(11) 1169-1178

[9] Schuirmann DL 1981 On hypothesis testing to determine if the mean of a normal distribution is contained in a known interval. *Biometrics* **37** 617.

[10] Robinson AP, Froese RE 2004 Model validation using equivalence tests. *Ecol. Modell.* **176** 349-358

[11] Wellek S 2003 Testing statistical hypotheses of equivalence. New York: CRC press. 284.

[12] Limentani GB, Ringo MC, Ye F, Bergquist ML and MCSorley EO 2005 Beyond the t-test: statistical equivalence testing *Anal. Chem.* **77** 221-226

[13] Blair RC, Cole SR 2002 Two-sided equivalence testing of the difference between two means *J. Mod. Appl. Stat. Methods* **1** 139-142

[14] Zhong B 2009 How to calculate sample size in randomized controlled trial? *J. Thorac. Dis.* **1** 51-54

[15] Sedgwick P 2013 Stratified cluster sampling *BMJ* **347** f7016.

[16] The Pennsylvania State University 2016 Sampling theory and methods: Chapter 8.1 Systematic Sampling. (https://onlinecourses.science.psu.edu/stat506/node/40)

[17] Fukushima Prefecture 2016 Population by age group (5-year-step) (in Japanese). (https://www.pref.fukushima.lg.jp/sec/11045b/15859.html)