Annex VII of Technical Volume 4
ANALYSIS OF THYROID MEASUREMENTS OF CHILDREN CONDUCTED IN FUKUSHIMA PREFECTURE, 26–30 MARCH 2011

Information was provided on the 1080 thyroid measurements of children aged from 0 y to 15 y from the three settlements Iwake City, Kawamata Town, and Iitate Village. The dates of measurement were from 26–30 March 2011. This dataset contains the following information for each child measured:

- date of measurement;
- age (in years);
- gender;
- settlement;
- result of the measurement of the exposure rate near the thyroid;
- result of background exposure rate measurement;
- net signal which is the difference between the measurement of exposure rate near the thyroid and the background measurement.

General results of the thyroid measurements are presented in Table VII–1.

VII–1. ASSESSMENT OF THE ^{131}I THYROIDAL CONTENT OF THE CHILDREN AT THE TIME OF MEASUREMENT

According to Hosokawa et al. 2013 [VII–1] various teams of Japan's Nuclear Safety Commission (NSC) staff conducted thyroid measurements of children of the three above mentioned settlements on 26-30 March 2011. A team from Hirosaki University measured 272 children at the Kawamata Town Public Citizens' Hall on 29 March, and 299 children at the Iitate Village Office on 30 March. This team used simple scintillation survey meters to conduct measurements of the exposure rate near the thyroid (to account for the gamma-emission of ^{131}I in the thyroid) and against the front part of the shoulder (to account for background exposure rate in the room as well as internal contamination of the body and surface contamination of the clothes and the body).

The Hirosaki University team members searched the premises where the thyroid measurements were conducted for the place where the background exposure rate was the lowest. Team members reported that in Iitate Village the minimum exposure rate was around 0.1 µSv/h. In addition, the team reported that they performed checks of surface contamination of the children before conducting thyroid measurements [VII–1].

Analysis of the thyroid measurements conducted in Kawamata Town on 29 March and in Iitate Village on 30 March showed that the background measurements varied in the range 0.06-0.13 µSv/h at the measurement location in Kawamata Town and in the range 0.09-0.22 µSv/h in Iitate Village. The reason of such variation might be: the presence of surface contamination on the body and clothes and the variation in room background during the day due to contamination introduced by people.

In this analysis, it is assumed that background rate in the room as well as possible internal contamination of the body and surface contamination of the body and clothes contribute equally to the measurement against the thyroid and against the shoulder.

It should be noted that these measurements were undertaken for screening purposes rather than to obtain detailed results for carrying out precise assessments of the doses received.

TABLE VII–1. GENERAL RESULTS OF THE THYROID MEASUREMENTS

Settlement in Fukushima Prefecture	Date of measurement	Number of children	Type of measurement	Results of measurement, μSv/h		
				min	median	max
Iwaki City	26 March	46	Thyroid	0.13	0.18	0.27
			Background	0.12	0.17	0.20
			Net	0	0.01	0.10
	27 March	88	Thyroid	0.13	0.17	0.24
			Background	0.12	0.17	0.21
			Net	-0.01	0.01	0.07
Kawamata Town	28 March	219	Thyroid	0.07	0.10	0.18
			Background	0.07	0.09	0.18
			Net	-0.02	0	0.03
	29 March	272	Thyroid	0.06	0.10	0.17
			Background	0.06	0.09	0.13
			Net	-0.02	0	0.06
	30 March	156	Thyroid	0.07	0.09	0.14
			Background	0.07	0.09	0.13
			Net	-0.01	0	0.04
Iitate Village	30 March	299	Thyroid	0.09	0.12	0.23
			Background	0.09	0.11	0.22
			Net	-0.01	0.01	0.07
Total		1080				

The assessment the ^{131}I thyroid content was conducted by measuring a net exposure rate. This was accomplished by subtracting the result of a measurement with the detector against the shoulder from that with the detector held against the thyroid. During these measurements, it is possible that some children might have had uneven contamination on their clothes or body which could have resulted in the negative values of the net exposure rate for the thyroid as shown in Table VIII–1. This circumstance contributes to the uncertainty of the estimate of the net exposure rate against the thyroid.

The thyroidal ^{131}I content $G(t_m)$ at the time of measurement t_m can be calculated according to the formula:

$$G(t_m) = k_g(ad) \times k_g(j/ad) \times [P_{th}(t_m)-P_b(t_m)] \quad (1)$$

where

$k_g(ad)$ is a calibration coefficient relating the ^{131}I activity in the thyroid of an adult to the indication of the instrument, $kBq/(\mu Sv\ h^{-1})$;
$k_g(j/ad)$ is the ratio of the calibration coefficient relating the ^{131}I activity in the thyroid of a child of age “j” to that of an adult, unitless;
$P_{th}(t_m)$ is the indication of the instrument during the measurement near the thyroid, $\mu Sv\ h^{-1}$;
$P_b(t_m)$ is the “background” measurement due to environmental radiation at the place of measurement, including that from contaminated clothing, and internal and surface contamination of body, and is assumed to be equal to the measurement near the shoulder, $\mu R\ h^{-1}$.

Analysis of the measurement results against the thyroid $P_{th}(t_m)$ and against the shoulder $P_{th}(t_m)$ showed that they were of a similar magnitude for the vast majority of the measured children. The maximum measured value of net exposure rate $[P_{th}(t_m)-P_b(t_m)]$ was 0.1 µSv/h. This means that the uncertainty in the net measured rate is relatively high due to its being the result of subtracting two values that are close to one another.

O. Kurikhara considered in his analysis of the 1080 thyroid measurements three values of k_g(ad) equal to 26.4, 30.15, and 32 kBq/(µSv h^{-1}). A value of 32 kBq/(µSv h^{-1}) was chosen, although the justification for this choice was not clear. To account for age-dependency, three functions of k_g(j/ad) were considered, as presented in Fig. VII–1. They are: (1) Fukushima (Present), (2) Fukushima (Updated) and (3) Fukushima (Tanaka et al.) [VII–2]. Kurikhara chose the function indicated as 'Fukushima (Updated)', although he indicated that there was a need to conduct a special study to assess age-dependency of the function of k_g(j/ad).

In this analysis, it is noted that the teams from NSC conducted the thyroid measurements with scintillation survey meters made by Aloka TCS-161, TCS-171, and TCS-172, containing detectors of NaI (Tl) with size of 25.4 × 25.4 mm. A similar scintillation survey meter SRP-68-01 containing a detector of NaI (Tl) with a higher size by a factor of about 1.5 was widely used in the thyroid measurements following the Chernobyl accident in 1986 [VII–3]. The factor k_g(j/ad) for the SRP-68-01 survey meter was determined through verified mathematical and experimental studies [VII–4]. Taking account of the similarity of the construction and type of the SRP-68-01 and the survey meters used following the Fukushima accident the same factors for k_g(j/ad) derived for the SRP-68-01 have been applied to the survey meters used for 1080 Japanese children thyroid measurements. At the same time the basic calibration factor for k_g(ad) of 32 kBq/(µSv h^{-1}) as it was used in the original measurements has been adopted. The ratios are plotted in Fig.VII–1.

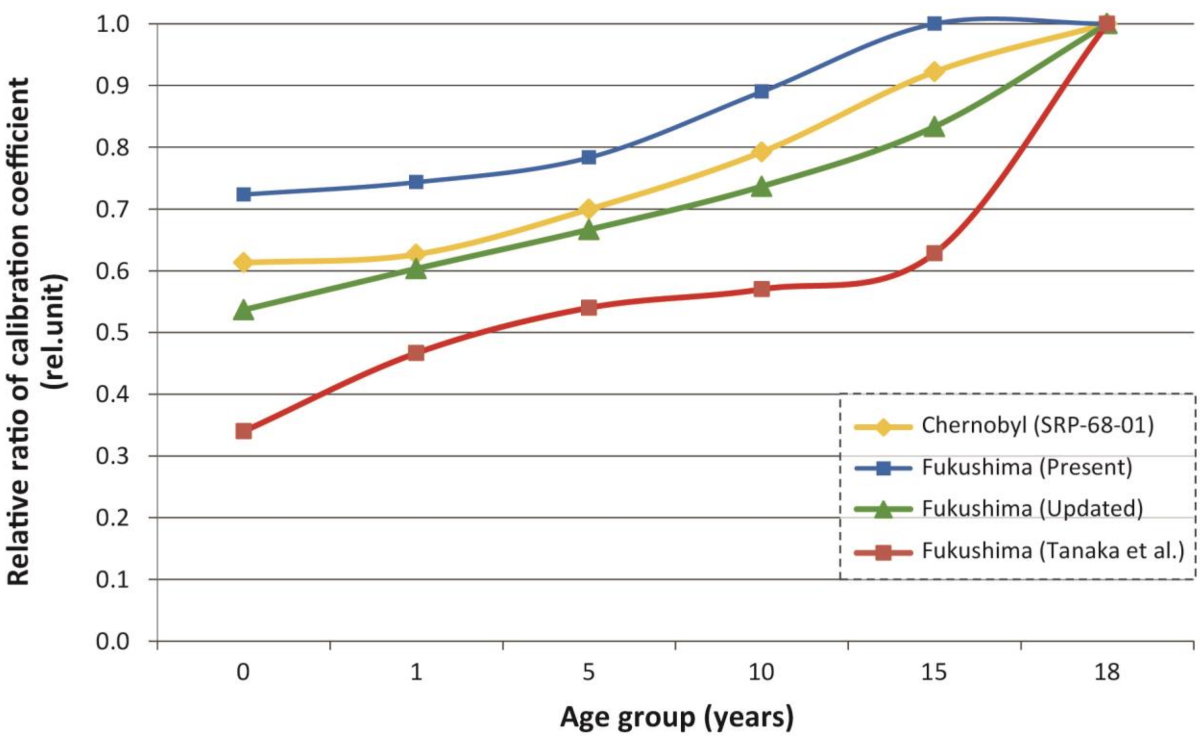


FIG. VII–1.Comparison of the ratio of the calibration coefficient relating the ^{131}I activity in the thyroid of a child of age "j" to that of an adult, kg(j/ad), for various functions.

The estimates of the ^{131}I thyroidal content at the time of measurement were carried out for each subject on the basis of eqn.(1) and values of parameters of $k_g(ad)$ and $k_g(j/ad)$.

In addition, the theoretical estimates of age-dependency of ^{131}I thyroidal content assuming (1) only inhalation intake on 15 March 2011 and (2) only ingestion intake with the same consumption rate for children of any age were also conducted. Those calculations were based on the following equation to derive ^{131}I thyroidal content at time (t) assuming time-dependent consumption rate:

$$G(t_m) = \int_0^t p(\tau) \times e^{-\lambda_{th,j}(t-\tau)} d\tau \qquad (2)$$

where

$p(\tau)$ is time-dependent consumption rate of a subject considered, kBq d^{-1};
$\lambda_{th,j}$ is effective clearance rate of ^{131}I from thyroid of a child of age (j), d^{-1}.

In case of only inhalation intake occurred on 15 March 2011 $p(\tau)$ is considered to be a delta-function which is not equal to zero only on 15 March. Then, the ^{131}I thyroidal content at time (t) assuming only inhalation intake on 15 March 2011, can be written as follows:

$$G(t_m) = C_0 \times f_0 \times \nu_j \times \exp(-\lambda_{th,j} \times t) \qquad (3)$$

where

C_0 is time-integrated concentration of ^{131}I in air, $kBq/(m^3\ d^{-1})$;
f_0 is fraction of inhaled ^{131}I that is retained in the lungs, assumed to be independent on age, dimensionless;
ν_j is breathing rate of a child of age (j), $m^3\ d^{-1}$.

In case of only ingestion intake taking into account that there was no personal interviewing of children during the thyroid measuring procedure, it is assumed that children consumed contaminated food from 15 March 2011 to the date of measurement with the same constant rate regardless of age (j). Then, the ^{131}I thyroidal content at time (t) assuming only ingestion intake since 15 March 2011, can be written as follows:

$$G(t_m) = (R_0/\lambda_{th,j}) \times [1-\exp(-\lambda_{th,j} \times t)] \qquad (4)$$

where

R0 is a consumption rate assumed to be constant for any age (j) and time, kBq/d.

Results of the ratios of the estimates of the ^{131}I thyroidal content derived from direct thyroid measurements and theoretically calculated on the basis of assumption of (1) inhalation only intake and (2) ingestion only intake in the form of normalization ratio of the ^{131}I thyroidal content of group of older children is presented in Table VII–2. Taking account of small number of children of each age (j), it was decided to distribute all children over four age groups (0–3) y, (4–7) y, (8–11) y and (12-15) y with merging four ages in each age group. For a substantial number of children, the estimated net exposure rate was assigned a value of zero, for each of four merging age groups the 75^{th} percentile values were used in the corresponding calculations.

The ratios given in Table VII–2. These data are also presented graphically in Section 4.2.2 (Fig. 4.2-20) for Iwaki City, Fig. VII–2 for Kawamata Town and Fig.VII–3 for Iitate Village.

TABLE VII–2. ESTIMATED RATIOS OF THE ^{131}I THYROIDAL CONTENT DERIVED FROM DIRECT THYROID MEASUREMENTS AND THEORETICALLY CALCULATED ON THE BASIS OF ASSUMPTION OF (1) INHALATION ONLY INTAKE AND (2) INGESTION ONLY INTAKE IN THE FORM OF THE NORMALIZATION RATIO OF THE ^{131}I THYROIDAL CONTENT OF GROUP OF OLDER CHILDREN.

Settlement	Type of data	Normalized ratios of ^{131}I thyroidal content at the time of thyroid measurement			
		0-3 y	4-7 y	8-11 y	12-15 y
Iwaki City	measurements	0.53	0.62	0.67	1.0
	assumed inhalation intake	0.26	0.48	0.76	1.0
	assumed ingestion intake	0.90	0.96	1.00	1.0
Kawamato Town	measurements	0.35	0.80	0.86	1.0
	assumed inhalation intake	0.25	0.47	0.76	1.0
	assumed ingestion intake	0.89	0.95	0.99	1.0
Iitate Village	measurements	0.38	0.83	0.89	1.0
	assumed inhalation intake	0.25	0.47	0.76	1.0
	assumed ingestion intake	0.84	0.92	0.99	1.0

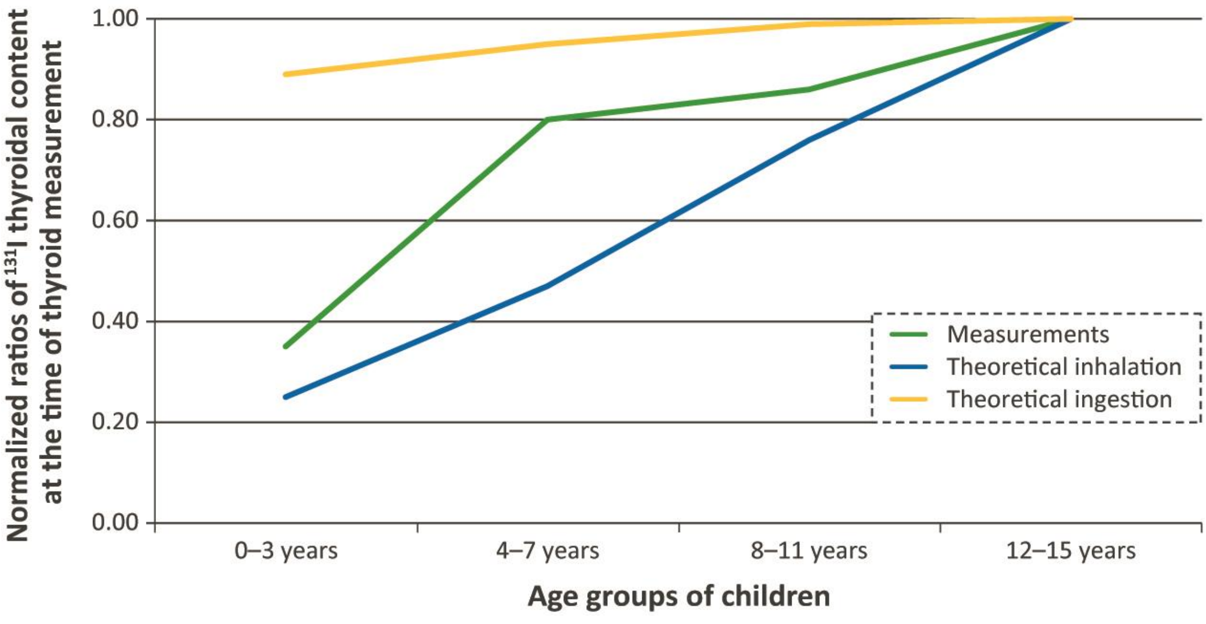


FIG. VII–2. Ratios of the estimates of the ^{131}I thyroidal content derived from direct thyroid measurements and theoretically calculated on the basis of assumption of (1) only inhalation intake and (2) only ingestion intake in the form of normalization to the ^{131}I thyroidal content of group of older children for Kawamata Town.

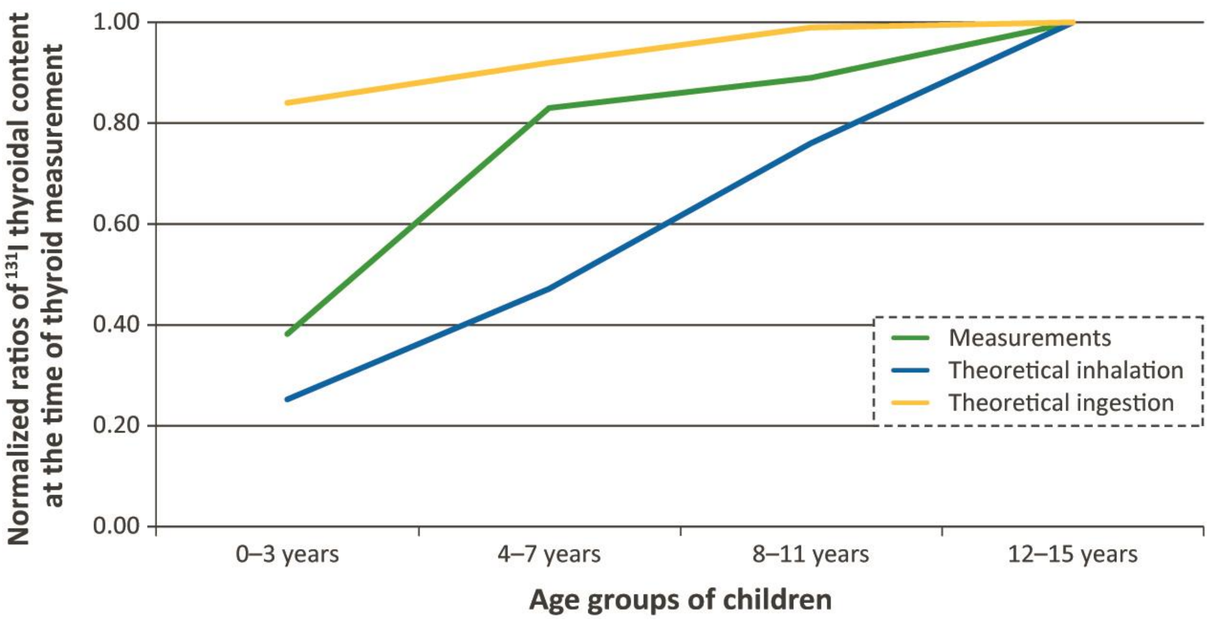


FIG. VII–3. Ratios of the estimates of the ^{131}I thyroidal content derived from direct thyroid measurements and theoretically calculated on the basis of assumption of (1) only inhalation intake and (2) only ingestion intake in the form of normalization to the ^{131}I thyroidal content of group of older children for Iitate Village.

It can be seen from Fig. 4.2–20 and Figs VII–2 and VII–3 that the normalized ratios of the ^{131}I thyroidal content at the time of measurement in the three settlements are closer to those calculated using an assumption of inhalation intake rather than ingestion intake. In the case of the Chernobyl accident, the corresponding ratios derived from direct thyroid measurements were strongly consistent with ingestion intake of cows' milk locally produced and the normalized ratios for younger groups of children were usually observed to be greater than 1.0. At the same time the ratios indicated in Fig. 4.2–20 and Figs VII–2 and VII–3 derived from direct thyroid measurements indicate that some ingestion intake might have occurred. However, these figures suggest that inhalation was likely to have been the dominant exposure pathway.

VII–2. ASSESSMENT OF THYROID DOSE FROM INCORPORATED ^{131}I

The formula of thyroid dose calculation (D) due to internal exposure from β-γ-rays of ^{131}I can be written as follows, for persons with thyroid measurements [VII–3]:

$$D = N \times (E_e/m) \times G(t_m) \times F(t_m) \qquad (5)$$

where:

N is the number of seconds in a day (= 86 400 s/d)
E_e/m is the quotient of the average energy of β-γ radiation absorbed in the thyroid per radioactive decay of ^{131}I, in Joules, and of the mass of the thyroid, in kg; the numerical values of E_e/m are based on data proposed in ICRP Publication 56 (ICRP 1990) [VII–5]. The values of E_e/m are in the range from 1.6×10^{-12} J/kg per radioactive decay of ^{131}I for the adult to 1.9×10^{-11} J/kg per radioactive decay of ^{131}I for the newborn;
$F(t_m)$ is the function describing the retention of ^{131}I in the human thyroid, d.

It is assumed that the inhalation occurred on 15 March 2011 was the main pathway for the children measured on 26–30 March 2011. Then, the function $F(t_m)$ describing the retention of ^{131}I intake by the thyroid can be written as:

$$F(t_m) = \exp(\lambda_{th,j} \times t_m) / \lambda_{th,j} \quad (6)$$

where:

t_m is the time elapsed from the inhalation intake occurred on 15 March 2011 to the date of the thyroid measurement, d.

An estimate of the term of $(E_e/(m \times \lambda_{th,j})$ can be derived from the following relationship

$$E_e/(m \times \lambda_{th,j}) = F_{ing} / f_1 \quad (7)$$

where:

F_{ing} is the age-dependent dose factor for ingestion intake of ^{131}I given in ICRP Publication 56 [VII–5]; and
f_1 is the thyroidal uptake of ^{131}I in case of ingestion intake; dimensionless.

Log-normal distributions of individual thyroid dose estimates for children derived from direct thyroid measurements assuming inhalation intake are presented for the three settlements in Figs VII–4 to VII-6.

The distributions of individual doses presented in Figs VII–4 to VII–6 reflect the fact that a zero value was assigned to a substantial proportion of individual thyroid dose estimates (for Iwaki City 41%; for Kawamata Town 68%, and for Iitate Village 34%), for which the net exposure rate of the thyroid was equal to zero or was a negative value (see Table VII–1)[1]. This means that, for a substantial proportion of the measurements, the ^{131}I thyroidal content was very low or less than or equal to the limit of detection of ^{131}I in the thyroid. Typically, the limit of detection is determined by the characteristics of the survey meters used, the background exposure rate in the room, internal activity in the body (other than ^{131}I in the thyroid) and surface contamination of clothes and the body. For those measurements where ^{131}I thyroidal activity exceeded the detection level, the results show a good approximation to a straight line on the normal probability scale versus log scale axis for Iwaki City (Fig.VII–4) and Kawamata Town (Fig.VII–5). However, as shown in Fig.VII–6, this is not the case for Iitate Village, where a better fit to a log-normal distribution would be obtained by the use of two lines. A possible explanation for this is that the cumulative distribution of individual thyroid dose estimates for the children in Iitate Village might reflect the exposure of two groups of children who were subject to different radiological conditions, for example from two different areas of Iitate Village with different levels of deposited activity and corresponding differences in the integrated concentrations of ^{131}I in air. Such situations may occur following non-uniform deposition. The possible reasons from deviations from a lognormal distribution are explored further in Section 4.2.1.8 and Box 4.2–1.

[1] Negative values were treated as zero values of net exposure.

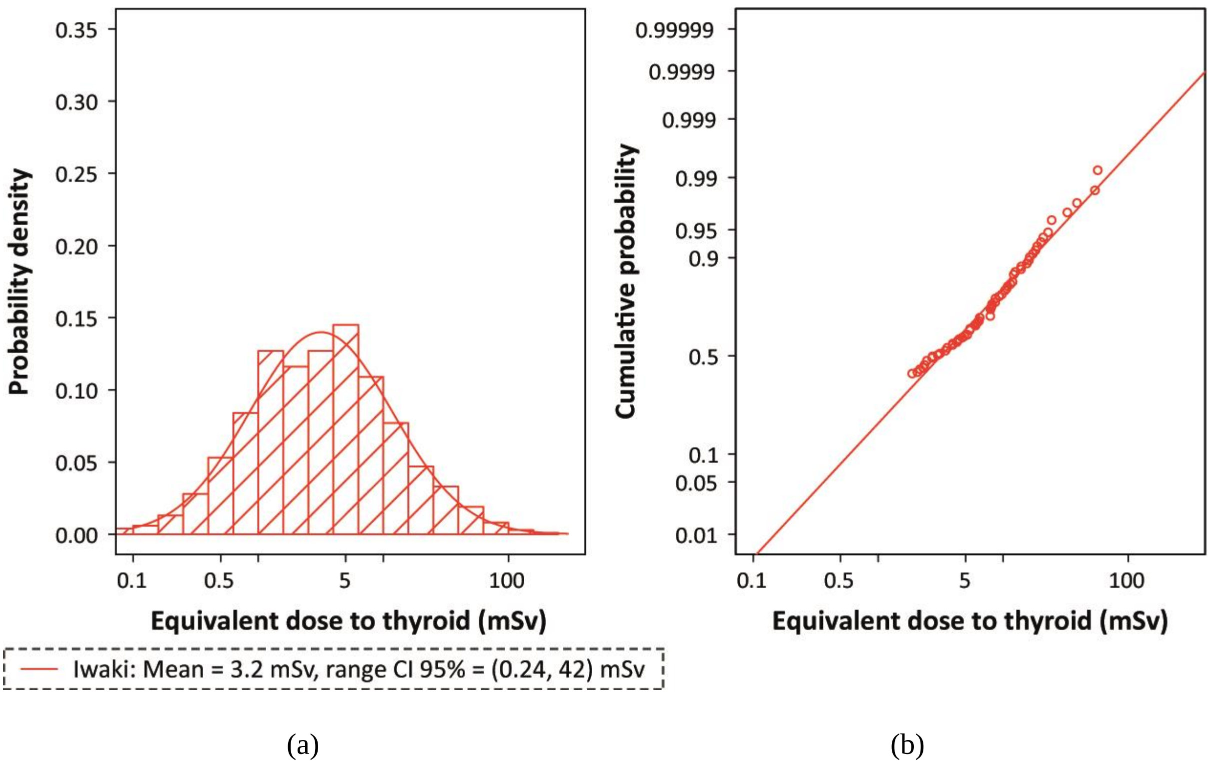


FIG. VII–4. (a) The normalized idealized probability density function and (b) the cumulative probability distribution of equivalent dose to the thyroid estimated for children of Iwaki City derived from direct thyroid measurements and assuming inhalation intake.

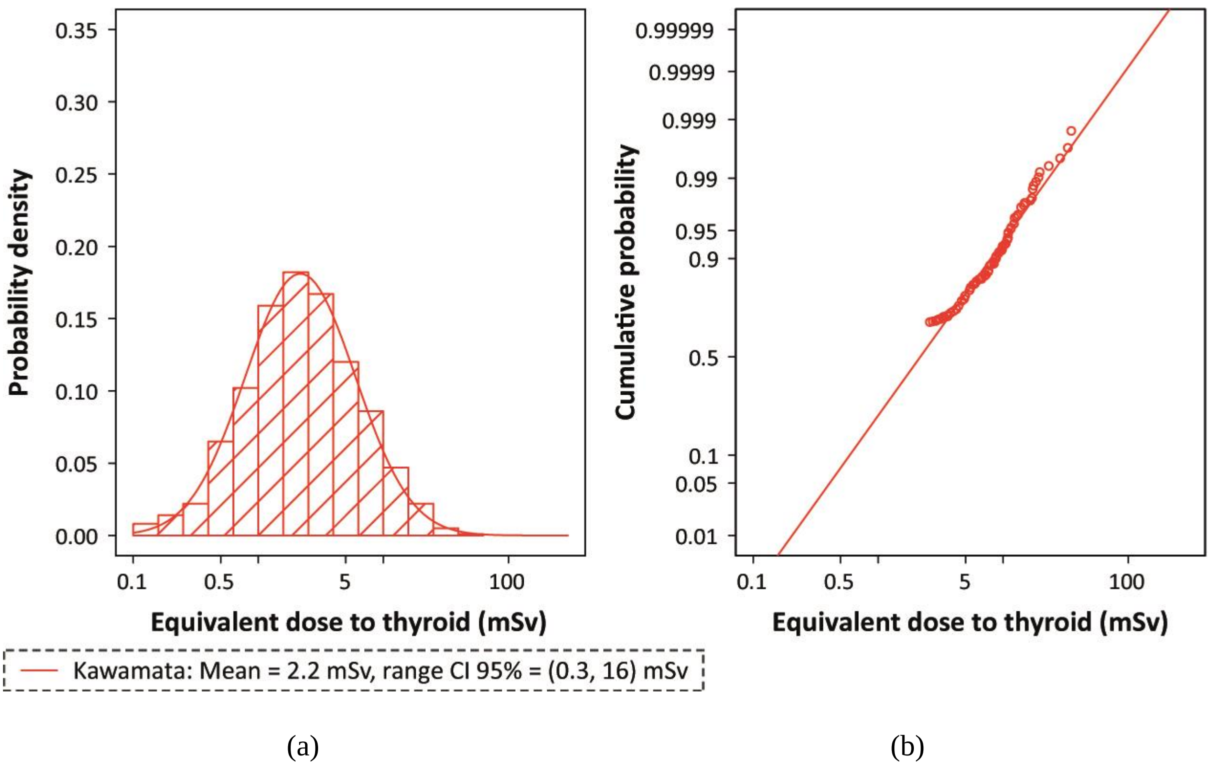
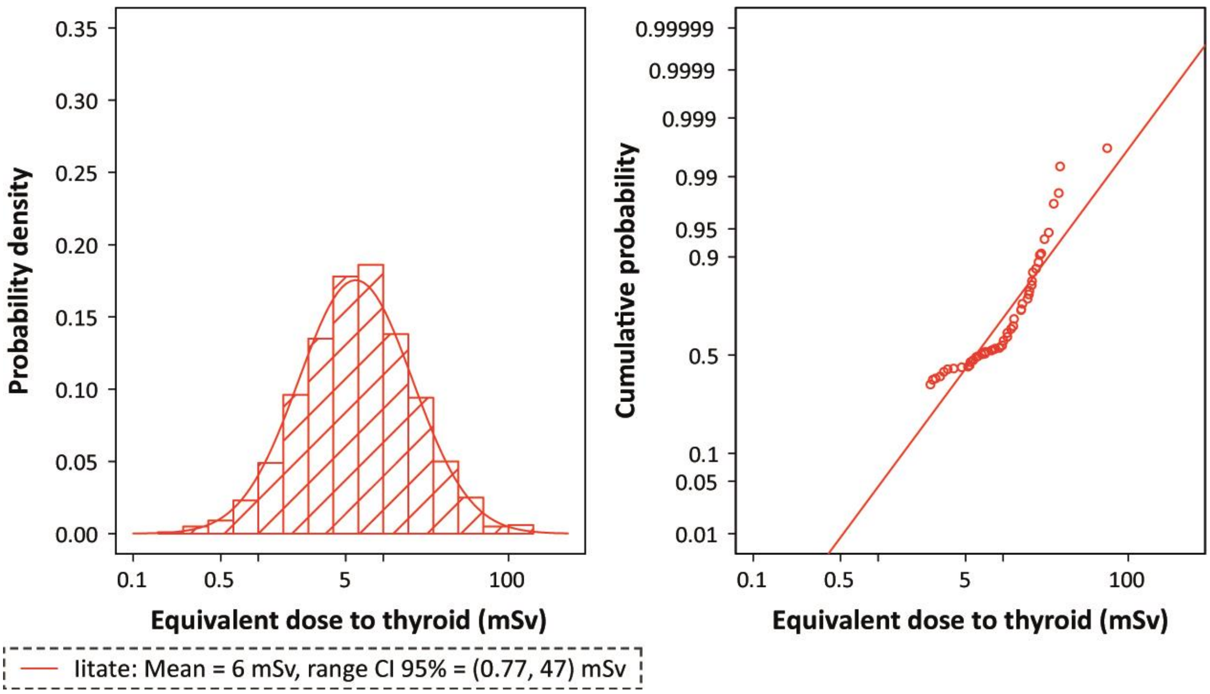


FIG. VII–5. (a) The normalized idealized probability density function and (b) the cumulative probability distribution of equivalent dose to the thyroid estimated for children of Kawamata Town derived from direct thyroid measurements and assuming inhalation intake.



(a) (b)

FIG. VII–6. (a) The normalized idealized probability density function and (b) the cumulative probability distribution of equivalent dose to the thyroid estimated for children of Iitate Village derived from direct thyroid measurements and assuming inhalation intake.

By comparison, Fig. VII–7 presents cumulative distributions of individual thyroid dose estimates for children aged up to 17 y who resided at the time of the Chernobyl accident in settlements in Bragin, Khoiniki, and Narovlya raions (districts) of Gomel Oblast of Belarus [VII–6]. The estimates of geometric mean for two distributions for the Belarusian children up to 17 y following the Chernobyl accident are in the range from 510 mGy to 1300 mGy (absorbed dose to thyroid), while the estimates of geometric mean for three settlements in Fukushima prefecture for the children aged up to 15 y following the Fukushima accident are in the range from 2.2 to 6.6 mSv (equivalent dose to thyroid).

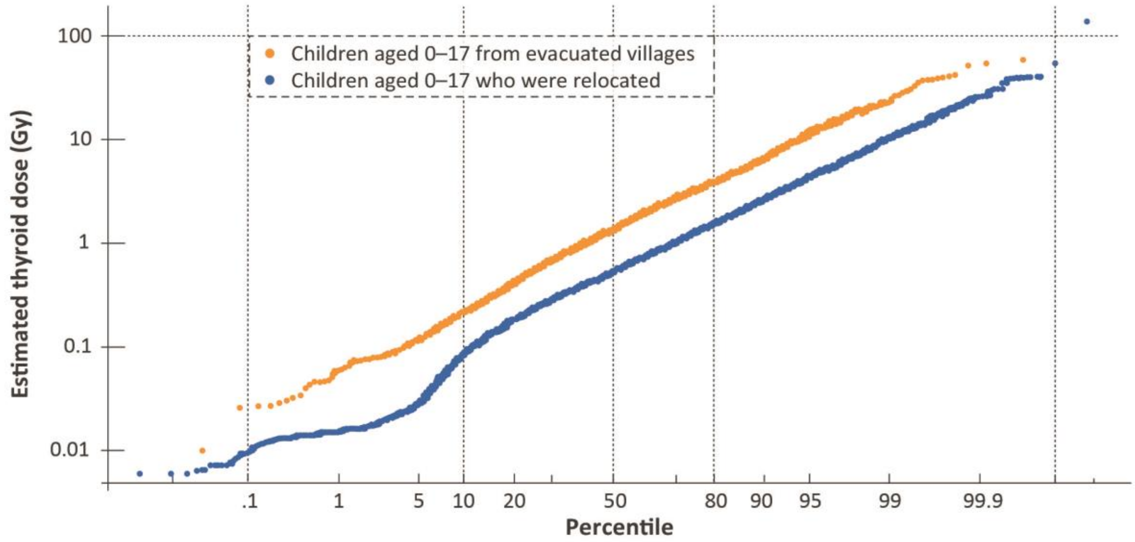


FIG. VII–7. Cumulative distributions of individual thyroid dose estimates for children aged up to 17 y who resided at the time of the Chernobyl accident in settlements in Bragin, Khoiniki, and Narovlya raions (districts) of Gomel Oblast of Belarus [VII–6].[2]

The very different internal exposures to the thyroid for members of the public following these two accidents may be explained by two reasons: (i) the higher contamination level of ^{131}I in areas around the Chernobyl NPP following the accident compared to that arising from the Fukushima Daiichi accident; and (ii) the different dominant pathways for the public in the initial periods of the accidents. Following the Chernobyl accident, intake by ingestion was predominant, and greater than intake by inhalation by a factor of more than 10, while for the Fukushima Daiichi accident, the predominant intake pathway was inhalation, as described above (see also Section 4.2.2). The dominance of inhalation intake over ingestion intake of ^{131}I for the Fukushima Daiichi accident is attributable to the prompt notification and restrictions of foods implemented by the Japanese authorities and the differences in dietary intakes of foods in the areas affected by each accident.

[2] Children from evacuated settlements of those three raions left contaminated areas before 5 May 1986; the other children from non-evacuated settlements (less contaminated) of those raions were relocated, typically by 7 May 1986.

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