ATTACHMENT A-23

POWER CALCULATIONS FOR EPIDEMIOLOGICAL DETECTION OF HEALTH EFFECTS FROM THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER STATION

UNSCEAR 2020/2021 Report, Annex B, Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station: implications of information published since the UNSCEAR 2013 Report

Contents

In this attachment, the Committee has assessed whether various possible radiation risks may be discernible in the more highly exposed or more susceptible segments of the Fukushima population from epidemiological studies. Statistical power calculations have been performed for this purpose and judgements reached on the discernibility, above the background rates, of several of the more radiosensitive cancers and ages at exposure (e.g., thyroid, breast, leukaemia, all solid cancers), both among the general public and workers. A comprehensive description is provided of the methodology adopted and of the important underlying assumptions, many of which were deliberately chosen so as not to underestimate the likelihood of discernibility.

Notes

Contents

I. PRELIMINARY CONSIDERATIONS

1. The basic question addressed by the Committee in this attachment is whether various possible radiation risks from the Fukushima nuclear accident will likely be discernible in the more highly exposed or more susceptible segments of the Fukushima Prefecture population or among the Fukushima Daiichi Nuclear Power Station (FDNPS) emergency workers. Statistical power calculations have been performed for this purpose, and judgements reached on the discernibility, above the background rates, of several of the more radiosensitive cancers and ages at exposure (e.g., thyroid, breast, leukaemia, all solid cancers, etc.), both among the general public and workers. The rationale, assumptions, data and methodologies for the determinations of risk are also provided regarding the risk assessment.

2. A preliminary assessment of statistical power was made in conjunction with the UNSCEAR 2013 Report [UNSCEAR, 2014], and published subsequently [UNSCEAR, 2016]. The Committee determined that an update was needed because the estimated doses to the public have been revised, based on the availability of more, and more reliable, data. In addition, estimated baseline cancer risks have undergone a modest amount of change since the UNSCEAR 2013 Report, and new data have become available to update estimates of radiation risk for various cancer endpoints. Several topics to set the stage for the assessment of the ability to detect possible radiation risks in Fukushima Prefecture are described.

A. Selection of health outcomes for study

3. The main health risk of concern from exposure at low radiation doses is the induction of cancer. In particular, leukaemia, female breast cancer and thyroid cancer are malignancies that are known to clearly show excesses in incidence following exposure to ionizing radiation, particularly when exposure occurs at a young age. Statistical power to detect these cancer risks has therefore been assessed.

4. In addition, all solid cancers were selected for analysis to reflect the fact that radiation exposure causes cancer in many organs/tissues of the body and, together with leukaemia, provides information on overall cancer risk, which is widely used in radiation risk assessment and radiation protection. Assessing risk for all solid cancers also provides a more statistically stable risk estimate because larger numbers of cases are available, which can be useful when assessing small risks at low doses [Walsh et al., 2014]. The rates of “all solid cancers” exclude nonmelanoma skin cancers because these forms of skin cancer are reported only irregularly and incompletely to cancer registries. Thyroid cancer was analysed separately, but was excluded from all solid cancers analyses, given that the doses to the thyroid tended to be larger than, and only partially correlated with, doses to other organs/tissues, because the radionuclides released from FDNPS included radioisotopes of iodine for which the thyroid gland has enhanced uptake compared to other organs/tissues. Although female breast cancer also was analysed separately, it was included in all solid cancer analyses, because the doses to the breast from the radionuclide releases are similar to those to other organs/tissues, and female breast cancer is considered a major contributor to “all solid cancers” radiation risk. This attachment refers simply to “all solid cancers” with the implicit understanding that thyroid cancer and nonmelanoma skin cancers are excluded. Analyses of haematopoietic malignancies other than leukaemia were not conducted because little evidence is available supporting an association with radiation exposure at low doses.

B. Statistical approach to assess discernibility of risk

5. In estimating cancer risks, a linear no-threshold dose response was assumed without an attenuating factor for low doses and low dose rates (dose and dose-rate effectiveness factor (DDREF)). The shape of the dose-response model, as applicable to risks at very low doses and low dose rates, is uncertain, although epidemiological data developed in the last decade from cohorts with low doses or doses received in a protracted or fractionated manner, have tended to point toward risks that are roughly commensurate with a linear no-threshold model [Hauptmann et al., 2020; NCRP, 2018]. A linear model without incorporation of a DDREF may perhaps be conservative in estimating radiation risks at low doses or low dose rates (i.e., it may overestimate) [Averbeck, 2009], but it nevertheless can be viewed as a prudent model.

6. It was assumed that a radiation effect would be discernible if the power of a statistical test to detect a difference between a disease rate in the exposed population and the corresponding rate in the unexposed general population (assuming a one-sided significance level of $p = 0.05$) is at least 80%, which is a conventional assumption. The statistical power estimation assumed the following ideal conditions:

- The baseline risk was known (approximated by averaging the age- and sex-specific rates for particular cancers from several essentially unexposed prefectures in Japan to apply to the corresponding population in Fukushima), and that these comparison cancer registries had complete cancer ascertainment and accurate diagnoses;
- Health effects in the exposed population could be detected without any loss in follow-up, misdiagnosis or under-ascertainment of cancer diagnosis; and
- Statistical power was modelled deterministically, assuming a linear no-threshold model that did not account for uncertainty in the risk estimates, except that risk also was assessed for the 95th percentile upper bounds on the average doses. Given that the ideal criteria above cannot be fully met, the actual statistical power to detect excess risks is likely to be somewhat less than calculations assuming those ideal conditions would indicate.

7. For the analyses of age- and sex-specific populations, higher dose subgroups were selected for analysis in addition to the total groups, because a higher dose often will tend to achieve greater statistical power than the entire dose range. The mean dose of the selected group was used to estimate radiation-attributable risk. Because of inevitable uncertainties in the doses, the statistical power assessments were also made using 95th percentile upper bounds on the estimated mean doses, where the upper bounds were derived from the distributions of doses by the Committee using Monte Carlo methods (see attachment A-12).

8. An attempt was made to guard against reliance on one particular data set or resulting model of risk in order to provide representative coverage of risk estimates and the associated statistical power. This conservative strategy was to avoid reliance on a single model that may have underestimated risk. Therefore, when several sets of risk estimates from major relevant studies are available, results are presented for each.

9. The statistical power analyses are limited to residents of Fukushima Prefecture, where exposures were generally larger than in other prefectures. Because there is very limited and inadequate information available on doses to individuals, the analyses were performed using mean doses or 95th percentile upper bound on estimated mean doses for municipalities or groups of evacuees. Dose estimates were developed by the Committee for the 50 non-evacuated municipalities in Fukushima Prefecture and separately for 40 groups of evacuees who followed one or another evacuation pattern (i.e., start and duration of evacuation, route and final

destination). (For simplification, this attachment uses just "evacuated municipalities" or "evacuees" to refer to the groups evacuated from evacuation-ordered, -planned and -prepared areas.) The estimated doses to relevant organs/tissues were employed for the analyses. For three of the non-evacuated municipalities, a subset of people had been evacuated or relocated, and those individuals were subtracted from the non-evacuated population in those municipalities.

C. Statistical power calculations

10. Statistical power can be defined as "the probability that a test of significance will detect a deviation from the null hypothesis, should such a deviation exist" [Walmsley and Brown, 2017], or, in simpler terms, power is the probability that a test of significance will detect an effect if one is present. In these analyses, statistical power is a function of the sample size, the background rate of a particular disease, and the magnitude of the effect, which is related to the dose [Gilbert et al., 2020].

11. The statistical power calculations were implemented using the G*Power program, version 3.1.9.6 [HHU, WEB, 2020], which has been documented by Faul et al. [Faul et al., 2009; Faul et al., 2007]. The statistical power calculations were performed using the choice to compute statistical power, given "alpha, sample size and effect size" for Poisson regression. A variety of scenarios was examined to determine the impact of calculating approximate person-years of observation versus simply number of persons. With the small estimated excess relative risks (ERRs) involved in this report, because of the relatively low doses, identical results to at least the third or fourth decimal place were found using either numbers of persons and cumulative risks, or person-years and cancer rates per year, so for simplicity, numbers of persons and cumulative risks were used in all analyses. This is similar to what was done in the statistical power calculations used for the UNSCEAR 2013 Report [UNSCEAR, 2016]; it was noted that using either Poisson or binomial distributions gave similar results.

12. The calculations used estimates of cumulative baseline risks (CBRs), absent radiation exposure, and cumulative excess risk (CERs) to calculate cumulative fractional risks (CFRs), given a dose estimate and employing a linear model, and to estimate notional numbers of radiation-related cases in the selected population groups. Municipality-average doses estimated for the population of Fukushima Prefecture were generally low. Because radiation risks are uncertain in the low-dose region, the cases "attributable to radiation" calculated here are largely notional (having been inferred using models) and are used only to assess whether a radiation impact on health would likely be discernible or not. An attempt was made to make the assessment somewhat conservative (i.e., using assumptions and values that would tend to increase the estimated statistical power) so that statistical power would not be underestimated. But, as in any statistical power assessment, the results are valid only if the underlying assumptions and values used are appropriate.

D. Statistical measures of health risks in this UNSCEAR report

13. The indicators of health risk used in this UNSCEAR report are defined as follows (adapted from [UNSCEAR, 2020]):

- *Lifetime baseline risk (LBR) and CBR*: CBR is the cumulative baseline risk of a specific disease (incidence or mortality) occurring up to a given age in the absence of the particular exposure under consideration [Walsh et al., 2014]; the LBR is the CBR to age 90. The CBRs and LBRs were calculated as the number of cases in selected

populations, given their respective sex, size of the population group, and age at the time of the FDNPS accident;

- *Lifetime excess risk (LER) and CER*: CER specifies the cumulative risk of a specific disease (incidence or mortality) occurring up to a given age, attributable to a given dose; excess is understood in comparison to a population group not exposed to radiation; the LER is the CER to age 90. The CERs and LERs were calculated, for the selected populations, using the estimated doses and particular risk models;
- *Lifetime fractional risk (LFR) and CFR*: CFR reflects the relative increase represented by the CER in relation to the CBR given by the ratio CER/CBR; the LFR is the ratio LER/LBR to age 90. The CFRs and LFRs reflected the proportional increases compared to baseline rates that were associated with given doses and risk models in the selected populations, i.e., the ratio of a respective CER to CBR, or LER to LBR; and
- *ERR and relative risk (RR)*: RR is the relative risk at some defined dose, and ERR is the excess relative risk at that dose (ERR = RR – 1). When only ERRs, and not LFRs, were reported for models in relevant publications, the simplifying assumption was made in this attachment that the LFRs are approximately equivalent to the ERRs per unit dose times the relevant estimated dose expressed as a fraction of the unit dose.

E. Selection of age- and sex-specific groups to study

14. The 2010 census data [Statistics Bureau of Japan, 2011] were used as an approximation to the numbers of males and females of various ages in each municipality of Fukushima Prefecture as of March 2011 (table A-23.1).

15. For a number of common types of cancer, the best documented and most widespread susceptibility factor for cancer is a young age at exposure, as documented in [UNSCEAR, 2013]. The plan therefore was to analyse groups who were young at the time of their initial FDNPS exposure, with a particular emphasis upon the early childhood group who are likely to be the most susceptible to cancer induction by radiation. Specifically, statistical power was calculated based on the mean doses and numbers of individuals in each municipality or evacuation group who were:

- 1-year-old infants, which used aggregated ages of in utero to age 5 years (all assumed to be age 1 for calculation purposes);
- 10-year-old children, aggregated ages 6–19 years (calculated as if age 10 years); and
- 20-year-old adults, aggregated ages 20–35 years (calculated as if age 20 years at exposure).

Attention focused particularly on the 1-year-old group, because evidence indicates that young children are the most susceptible to radiation risks. A similar strategy was used to analyse statistical power for the UNSCEAR 2013 Report [UNSCEAR, 2016]. Attachments A-13 to A-19 provide dose estimates for exposure at ages 1, 10 and 20 years, respectively, which have been used for the statistical power analyses.

16. Children who were in utero at the time of the FDNPS accident are considered as part of the “age 1 year” group. Fujimori et al. [Fujimori et al., 2014] reported there were nearly 16,000 children in Fukushima Prefecture who were in utero at the time of the accident. With only a slight inaccuracy, the background cancer rates and radiation-related excess risks for the in utero group are assumed to be comparable to that of the 1-year-old group [Preston et al., 2008], although a set of statistical power analyses of leukaemia and thyroid cancer in the in utero group was also performed separately.

17. Females tend to have greater radiation-related risks for solid cancers than males, although the opposite is true for leukaemia. Therefore, analyses were performed separately for females and males. In addition, statistical power was examined for males and females combined, since the larger combined numbers of individuals may tend to increase the statistical power. Analyses were also performed using only the municipalities with cumulative lifetime effective doses >5 mSv, because such analyses sometimes yielded greater statistical power than analyses including municipalities with all dose levels.

18. In addition, statistical power was assessed for the detectability of risks to emergency workers at FDNPS, insofar as the information on worker doses was available.

Table A-23.1. Numbers of Fukushima Prefecture residents in the statistical power analyses, based on summation of municipality age- and sex-specific data from the 2010 Japan census [Statistics Bureau of Japan, 2011] or estimated from total numbers in evacuated municipalities

Group	*Age 1 year*	*Age 10 years*	*Age 20 years*
Non-evacuated plus evacuated municipalities with mean lifetime effective dose >5 mSv			
Male [a]	34 524	77 603	103 120
Female	32 740	77 543	99 870
Total	67 264	155 146	202 990
All non-evacuated municipalities			
Male	55 597	135 044	163 132
Female	52 912	128 436	156 628
Total	108 509	263 480	319 760
Evacuated municipalities [b]			
Male	3 873	8 088	9 847
Female	3 693	7 708	9 385
Total	7 566	15 796	19 232

[a] Municipalities in which 1-year-olds were estimated to have a mean cumulative lifetime effective dose of >5 mSv.
[b] Estimated as the approximate proportion of total evacuees who were in the given age ranges according to the proportions by age and sex in Fukushima Prefecture from the 2010 census data [Statistics Bureau of Japan, 2011].

F. Selected dose groups

19. All the dose values used in this attachment were based on arithmetic rather than logarithmic calculations. The assumption is made that the estimated mean dose to residents of a given age in each municipality is representative of the doses to those residents. Clearly there would be variation among individual residents in their exposure levels in addition to uncertainties in average municipality doses, but insufficient information was available to perform any analysis at the individual level. Therefore, municipality mean doses weighted by numbers of individuals within each non-evacuated or evacuated municipality were used to derive overall mean doses for defined age groups. These mean doses and the 95th percentile upper bounds on the mean doses were used for statistical power analyses.

20. Mean first-year doses and doses at the 95th percentile upper bound on the mean were calculated by the Committee for each non-evacuated municipality for effective dose and for the absorbed dose to the red bone marrow (RBM), breast, thyroid gland and colon. Similarly, mean and upper bound on mean doses were calculated for groups of evacuees who followed different evacuation patterns. The 95th percentiles on mean dose estimates were obtained by the

Committee using Monte Carlo sampling of the dose distributions for municipalities and evacuation scenarios.

21. Yearly increments in effective dose out to 80 years of age ("lifetime dose") after the accident were estimated for those initially exposed at ages 1, 10 or 20 years (table A-23.2). Since fractional increments in dose at age 80 years after the accident were estimated to be very small (0.1% to 0.4% of the initial dose), the dose to 80 years will be considered the "lifetime dose". Ratios of the first-year RBM, colon and breast doses to the first-year effective dose were then applied to the 80-year effective dose to derive estimates of lifetime doses for those organs/tissues, based on the ratios found for 1-year-olds. The ratios of organ/tissue doses to the effective dose ranged from 93% for RBM to 99% for the colon. Lifetime doses to the RBM, colon and breast after the first year were then estimated in proportion to the lifetime effective dose which had been modelled (see attachment A-19).

22. A subset of municipalities with higher average doses was also chosen for statistical power analysis. For analyses of leukaemia, breast cancer and all solid cancers, the subset was defined as those municipalities with average lifetime cumulative effective doses greater than 5 mSv for 1-year-olds. Nineteen of the 50 non-evacuated municipalities and seven evacuated municipalities were in this subset.

23. Doses to the thyroid were notably higher than other doses for some municipalities due to internal exposures from short-lived radioactive iodine isotopes, because the thyroid gland has a highly enhanced uptake of iodine compared to other organs. The geographic pattern of thyroid doses was only partially concordant with that for doses to other organs; for example, lists of municipalities with the five highest average effective doses and five highest thyroid doses had only one municipality common to both lists.

24. Because of the limited concordance of thyroid cancer doses to doses for other organs, a separate higher-dose subset was defined for selected analyses as municipalities with first-year thyroid doses greater than 5 mGy in the respective age group in both evacuated and non-evacuated municipalities.

Table A-23.2. Estimated lifetime cumulative mean doses (mGy) and 95th percentile upper bounds of mean doses for selected organs/tissues in selected dose groups

	Age 1 year [a,b]	*Age 10 years* [a]	*Age 20 years* [a]
Evacuated and non-evacuated municipalities, subset with >5 mSv lifetime effective dose [c]			
Red bone marrow			
Mean dose	12.5	11.7	9.6
95% upper bound on mean dose	19.9	18.6	14.4
Breast			
Mean dose	13.7	11.4	10.3
95% upper bound on mean dose	21.5	17.5	15.7
Colon			
Mean dose	13.9	12.5	9.8
95% upper bound on mean dose	21.8	19.5	15.0
Thyroid gland [d]			
Mean dose	15.9	19.9	17.0
95% upper bound on mean dose	32.0	41.6	33.4

	Age 1 year [a,b]	*Age 10 years* [a]	*Age 20 years* [a]
Non-evacuated municipalities: all doses			
Red bone marrow			
Mean dose	8.9	7.7	6.9
95% upper bound on mean dose	14.4	12.2	10.6
Breast			
Mean dose	9.8	8.0	7.7
95% upper bound on mean dose	15.0	12.2	11.8
Colon			
Mean dose	9.6	8.5	7.1
95% upper bound on mean dose	15.0	12.9	10.6
Thyroid gland			
Mean dose	12.7	11.3	9.4
95% upper bound on mean dose	25.4	22.4	17.6
Evacuated and non-evacuated municipalities: all doses			
Thyroid gland			
Mean dose	12.5	11.1	9.3
95% upper bound on mean dose	24.8	22.3	17.5
Evacuated municipalities only			
Thyroid gland			
Mean dose	10.7	8.3	6.4
95% upper bound on mean dose	25.8	20.5	15.7
Evacuee subset with >5 mGy mean dose in first year			
Mean dose [d]	12.0	10.9	11.4
95% upper bound on mean dose	29.4	30.8	30.0

[a] Age 1 year includes individuals of ages from in utero to 5 years; age 10 years includes ages 6 to 19 years; age 20 years includes ages 20−35 years. All mean and upper bound doses were calculated on a municipal population-weighted basis.
[b] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.
[c] Municipalities in which the lifetime mean effective dose was >5 mSv for those at age 1 year.
[d] For the thyroid gland the higher-dose subsets were the non-evacuated and evacuated municipalities for which the first-year thyroid dose was greater than 5 mGy among those of the respective ages.

II. LIFETIME RISKS TO THE POPULATION FROM THE FUKUSHIMA DAIICHI NUCLEAR POWER STATION RADIATION EXPOSURE

A. Calculation of lifetime baseline risk estimates for study groups

25. The definition used here of the LBR of the incidence of a selected cancer was the cumulative incidence of that cancer up to age 90 years [WHO, 2013]. Using representative Japanese cancer rates [IARC, 2017] from the starting ages, and lifetable methods, the Committee estimated the LBR of leukaemia, breast cancer, thyroid cancer and all solid cancers as first primary malignancies, by adjusting their cumulative rates for rates of prior mortality [Vital Statistics of Japan, 2019] and prior malignancies, i.e., for cancer-free survival, similar to the method used in the statistical power assessment in the UNSCEAR 2013 Report [UNSCEAR, 2016]. The lifetables were based on the latest International Agency for Research on Cancer (IARC) publication of age- and sex-specific cancer rates [IARC, 2017], averaged across the rates

from four long-standing, good quality Japanese prefecture cancer registries (namely, Fukui, Miyagi, Nagasaki and Yamagata prefectures). More details are given in section I of the appendix.

B. Calculation of lifetime excess risk and lifetime fractional risk estimates

26. For estimation of LERs and LFRs, which were needed for calculating statistical power, doses were estimated for each applicable organ/tissue and each Fukushima municipality or evacuated locality, as detailed in attachments A-13 to A-19. Estimated RBM doses were used to assess leukaemia risk, colon doses for the risk of all solid cancer, and breast and thyroid doses for those respective organs/tissues. Weighted mean doses, with weighting by the number of persons of selected sex and ages in each municipality, and 95th percentile upper bounds on the means were then used to calculate the aggregated mean dose and its 95% upper bound.

27. For the population affected by the FDNPS accident, a LER is an estimate of the excess number of cancer cases of a selected type, given the size of the exposed population being analysed and the estimated average dose. The LERs are scaled linearly according to dose, which is based on the assumption that, for cancer endpoints, the lifetime risks for doses less than a few hundred mGy or received at a low dose rate are essentially proportional to organ/tissue doses [Walsh et al., 2014].

28. The LERs and LFRs used in the statistical power attachment [UNSCEAR, 2016] to the UNSCEAR 2013 Report [UNSCEAR, 2014] were calculated with respect to radiation dose based on the assumptions that the minimum latency period was 2 years for leukaemia, 3 years for thyroid cancer, and 5 years for breast cancer and all solid cancer, and starting with LFRs in the WHO Fukushima report [Walsh et al., 2014; WHO, 2013]. These LFRs served as preliminary CER estimates, which were adjusted for this report by applying ratios of new estimates of ERRs derived from recent published reports to the formerly used estimates. These are reported as one of the models used to assess risks in this attachment. The description of the calculation of LFRs is given for the various risk models applied to each type of malignancy in the relevant sections below. In developing models, the simplifying assumption was made in this attachment that when LFRs are not available in relevant publications, ERRs can be substituted for them, which may be approximately true for low doses. A comparison of the LERs used for the UNSCEAR 2013 Report [UNSCEAR, 2016] with those provided by selected models in the present report is given in table A-23.3, and the sources of the LERs given in the table are described in the table footnotes. More details concerning the calculation of LERs are provided in section II of the appendix.

Table A-23.3. Cumulative lifetime baseline risk (LBR) to age 90 years and lifetime excess risk of the incidence of selected malignancies as absolute per cent increases in risk for an absorbed dose of 100 mGy to relevant organs, as estimated in the UNSCEAR 2013 Report [UNSCEAR, 2016] and in this assessment

Starting age (years)	*Male*			*Female*		
	Baseline risk, this assessment (LBR (%))	*UNSCEAR 2013 Report (LER (%))*	*This assessment (LER (%))*	*Baseline risk, this assessment (LBR (%))*	*UNSCEAR 2013 Report (LER (%))*	*This assessment (LER (%))*
All solid cancer (except thyroid cancer)[a]						
1	42.8	2.30	2.37	29.9	3.50	3.86
10	42.8	1.85	1.91	29.9	2.75	3.03
20	42.7	1.40	1.44	29.8	2.10	2.37

Starting age (years)	*Male*			*Female*		
	Baseline risk, this assessment (LBR (%))	*UNSCEAR 2013 Report (LER (%))*	*This assessment (LER (%))*	*Baseline risk, this assessment (LBR (%))*	*UNSCEAR 2013 Report (LER (%))*	*This assessment (LER (%))*
Leukaemia [b]						
1	0.63	0.11	0.55	0.47	0.08	0.50
10	0.57	0.07	0.36	0.42	0.05	0.34
20	0.55	0.06	0.06	0.40	0.04	0.04
Female breast cancer [c]						
1				6.09	1.00	1.41
10				6.09	0.66	0.94
20				6.09	0.42	0.59
Thyroid cancer [d]						
1	0.37	0.10	0.16	1.15	0.43	0.60
10	0.37	0.073	0.089	1.15	0.28	0.35
20	0.37	0.039	0.048	1.14	0.15	0.19

[a] Based on absorbed colon dose. Calculated by comparing the linear ERR coefficients of Grant et al. [Grant et al., 2017] to those of Preston et al. [Preston et al., 2007], both based on the Japanese Life Span Study (LSS). A comparison of the newer Grant coefficients to the older Preston coefficients that had been used in the UNSCEAR 2013 Report [UNSCEAR, 2014] gave ratios of 1.10 for females and 1.03 for males.
[b] Based on absorbed dose to the RBM [Berrington de Gonzaléz et al., 2016; Hsu et al., 2013; UNSCEAR, 2020]. Information concerning additional models used to assess LFRs and LERs is given in the text (paragraph 32).
[c] Based on absorbed breast dose. A ratio of 1.29 was found for the newer LSS risk estimate [Brenner et al., 2018] compared to the former one [Preston et al., 2007] used in the UNSCEAR 2013 Report.
[d] Based on absorbed thyroid dose. The statistical power assessment for the UNSCEAR 2013 Report [UNSCEAR, 2016] provided the 2013 LER for age 1, and Walsh et al. [Walsh et al., 2014] provided the LERs for ages 10 and 20. The LERs for the current assessment derive from a recent UNSCEAR report [UNSCEAR, 2020] and are based on the newest LSS thyroid cancer data [Furukawa et al., 2013]. Information concerning additional models used to assess LFRs and LERs is given in the text (paragraph 38).

C. Lifetime leukaemia risk

29. Leukaemia is often considered a sentinel malignancy after radiation exposure because of the high relative risk per unit dose compared to most other forms of malignancy, particularly at young ages at exposure. However, it is an uncommon malignancy compared to many other forms of cancer, which limits the statistical power to detect excess risks after low-dose exposure.

30. The LBRs for sex and age groups were calculated by lifetable methods similar to those in the statistical power attachment to the UNSCEAR 2013 Report [UNSCEAR, 2014], but using updated age-sex specific leukaemia rates from three long-standing prefecture cancer registries in Japan (Fukui, Miyagi and Yamagata prefectures) [IARC, 2017] with adjustment for cancer-free survival, as described in section I of the appendix. The LBRs for the present leukaemia calculations had values similar to those of the UNSCEAR 2013 Report, for instance with respective values for males of: 0.62% and 0.60% for ages 1–90, 0.57% and 0.58% for ages 10–90, and 0.53% and 0.57% for ages 20–90 years.

31. The LER and LFR estimates are based on estimates of the first year absorbed dose to the RBM in attachment A-15 plus continued lifetime dose proportionate to the lifetime effective dose (attachment A-19). It should be noted that linear risk estimates were used for leukaemia, even though the LSS leukaemia data [Hsu et al., 2013] have shown a linear-quadratic curve with upward curvature. At low doses or low dose rates, however, the dose response is considered approximately linear [Walsh et al., 2014].

32. Four models were applied to estimate the excess risk of leukaemia from radiation exposures due to the FDNPS accident:

(a) First, the LERs and LFRs for sex and age groups in the UNSCEAR 2013 Report were based on a report by Walsh et al. [Walsh et al., 2014] which provided standardized results from the WHO Fukushima report [WHO, 2013]. The risk estimates here are based on the updated rather than the original LBRs;

(b) Second, the recent UNSCEAR report [UNSCEAR, 2020] derived CFR estimates for exposure at ages 1 and 10 years with observation to age 40 years of 3.0 at 100 mGy, which was based on a study of children in the United Kingdom of Great Britain and Northern Ireland with radiation exposure from CT examination [Berrington de Gonzaléz et al., 2016]. The model included both leukaemia proper and myelodysplastic syndromes, of which the latter had a much higher risk coefficient [Berrington de Gonzaléz et al., 2016; Pearce et al., 2012]. The study yielded LFR estimates of 3.0 at 100 mGy for ages 1–40 and 3.1 for ages 10–40 years;

(c) Third, the LFR estimates from the LSS study [Hsu et al., 2013; UNSCEAR, 2020] were 2.15 for ages 1–40 and 0.85 for ages 10–40 years;

(d) Fourth, a recent analysis of data from nine pooled studies of childhood external radiation exposures with RBM doses ≤100 mGy was reported [Little et al., 2018]. It yielded an ERR estimate of 0.84 at 100 mGy for all leukaemia except the chronic lymphocytic type, which was employed as a LFR estimate. This risk estimate from the pooled analysis included the leukaemia results from the United Kingdom study of computerized tomography (CT) examinations, but without the myelodysplastic syndrome cases.

33. Because the UNSCEAR and pooled-study risk estimates were primarily limited to young ages of observation, from ages 41 to 90 the estimated LFR coefficients from the WHO report of lifetime risk were applied [Walsh et al., 2014; WHO, 2013]. When suitable LFRs for cumulative lifetime incidence of leukaemia were not available for adult exposures, as in the case of the United Kingdom CT study [UNSCEAR, 2020], the ratio of 1.25 was derived from [UNSCEAR, 2020], based on the recent INWORKS worker study ERR for leukaemia mortality [Leuraud et al., 2015] compared to the LSS leukaemia ERR for adults [Kaiser and Walsh, 2013]. The ratio was applied to the WHO-based risk coefficient to derive a LFR for age 20 at exposure, with the results shown for age 20 for this assessment model in table A-23.4. None of the models found a difference in the LFRs by sex, so the same LFR model was applied for both sexes. The LFRs at a 100 mGy RBM dose for these models, as applied to the Fukushima Prefecture population, are shown in table A-23.4, and these LFRs were applied in performing statistical power calculations of lifetime leukaemia risk.

34. Each model, with results shown in table A-23.5, has strengths and disadvantages. The WHO 2013 Fukushima model, derived from older LSS data, provides a baseline for comparison of newer models. The LSS model [Hsu et al., 2013; UNSCEAR, 2020] is based on a Japanese population similar to the Fukushima population and had well-characterized whole-body doses, but the duration of the single exposure was very brief and many exposures were much higher than exposures in the Fukushima population. The pooled study of low-dose childhood exposures [Little et al., 2018] was estimated from relatively low total doses (<100 mGy), but based primarily on one or a few brief exposures, many of which were partial-body exposures. The UNSCEAR model [UNSCEAR, 2020], based on the study of United Kingdom children with CT examinations [Berrington de Gonzaléz et al., 2016], had small, fractionated exposures and a good quality follow-up. However, the LFR included both leukaemia and myelodysplastic syndromes, and the latter appeared to upwardly bias the risk estimates. In particular, this report showed the highest risk estimate per 100 mGy of 3.3 (95% CI: 0.4, 11.4) [Berrington de Gonzaléz et al.,

2016] compared to other models, but the previous report of the United Kingdom CT study with virtually the same data found that the risk was about 45% smaller if the myelodysplastic syndrome cases were not included [Pearce et al., 2012]. In addition, a recent Netherlands study of leukaemia after childhood CT exposures reported ERRs per 100 mGy of 0.21 (95% CI: −0.12, 2.40) for leukaemia and 0.04 (95% CI: −0.12, 1.61) for combined leukaemia and myelodysplastic syndromes [Meulepas et al., 2019], which were appreciably numerically lower than the value from the United Kingdom CT study used in the UNSCEAR analysis [Berrington de Gonzaléz et al., 2016; UNSCEAR, 2020].

Table A-23.4. Lifetime fractional risks of leukaemia attributable to radiation at a red bone marrow radiation dose of 100 mGy according to various models

Age (year) and sex	*WHO model, LFR (%)*[a]	*This assessment model, LFR (%)*[b]	LSS model, LFR (%)[c]	*Pooled study model, LFR (%)*[d]
Age 1–Male	18.5	87.0	66.3	34.4
Age10–Male	11.5	62.5	24.1	23.9
Age 20–Male [a]	10.0	12.5	10.6	
Age 1–Female	17.5	106	79.4	38.3
Age 10–Female	11.0	79.6	28.0	27.8
Age 20–Female [a]	9.5	11.9	7.0	

[a] [UNSCEAR, 2016; Walsh et al., 2014; WHO, 2013]. These LFRs were also used for the attained ages of 41–90 years with all models.
[b] [Berrington de Gonzaléz et al., 2016; UNSCEAR, 2020]. Modelling was performed only for ages 1 and 10 years. The basis for the age 20 LFR is given in paragraph 32.
[c] [Hsu et al., 2013; UNSCEAR, 2020].
[d] [Little et al., 2018]. The model was based primarily on childhood and adolescent exposures, so it was not applied for age 20.

35. Table A-23.5 shows the statistical power estimates at 100 mGy using LFRs derived from the models mentioned above. LFRs based on the estimated municipality doses are shown for males and females for combined evacuated and non-evacuated municipalities in table A-23.A2 in section II of the appendix. To summarize the results, the estimates of risk based on the mean doses, considered the best estimates of risk, generally did not achieve the 80% statistical power criterion for detectability of risk. The 95th percentile upper bounds on the mean dose from the Monte Carlo dose calculations sometimes achieved 80% statistical power with the UNSCEAR model of risk [UNSCEAR, 2020], but not with the other three models. Even though the LFRs for leukaemia are relatively high compared to almost all solid cancers, there is little indication of potential detectability of excess risk owing to the low doses and the low background incidence of leukaemia in the population. For instance, in the subgroup from in utero to five years old at the time of the FDNPS accident, who are expected to be the most sensitive group for leukaemia, about 10–50 excess incident cases of leukaemia during their lifetime may be inferred from the estimated dose levels to the red bone marrow, depending on the model used, while the baseline number (in the absence of radiation exposure from the FDNPS accident) is about 640 cases with a 95% coverage interval of 590 to 690. Furthermore, this range does not include possible variations in background rates among geographic localities, changes in rates over calendar time, etc. Even 50 potential excess cases would probably not be discernible among 640 expected cases, given the estimated range of uncertainty in the baseline risk. In addition, the previous discussion in paragraph 34 of this attachment suggests that the expected excess leukaemia cases may be fewer than the highest calculated number of 50 derived from the United Kingdom CT report [Berrington de Gonzaléz et al., 2016].

36. In summary, because of the low estimated doses to the children and young adult populations, excess cases of leukaemia attributable to radiation exposure are generally not discernible, although a few findings using the UNSCEAR model [UNSCEAR, 2020] suggest the possibility of discernible risk (statistical power estimates >0.70 for mean doses) among those of ages 1 or 10 at the time of the accident, as well as when using upper bound dose estimates.

Table A-23.5. Leukaemia, lifetime excess incidence attributable to radiation exposure: statistical power for mean and 95th percentile upper bound on mean lifetime doses by sex and age at the time of the Fukushima Daiichi Nuclear Power Station accident for all residents of evacuated and non-evacuated municipalities and for those with >5 mSv cumulative lifetime effective dose. Statistical power is shown for various models of risk

Group – sex and age (years)	*Statistical power using WHO risk estimates* [a]		*Statistical power using UNSCEAR 2020 risk estimates* [b]		*Statistical power using LSS risk estimates* [c]		*Statistical power using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Evacuated and non-evacuated municipalities with cumulative lifetime effective dose > 5 mSv								
Male								
1	0.10	0.13	0.45	0.77	0.31	0.59	0.15	0.26
10	0.09	0.12	0.44	0.75	0.14	0.22	0.14	0.23
20	0.07	0.09	0.09	0.11	0.08	0.10	0.09	0.12
Female								
1	0.08	0.11	0.46	0.78	0.31	0.59	0.14	0.24
10	0.09	0.12	0.66	0.94	0.19	0.32	0.18	0.32
20	0.07	0.08	0.08	0.10	0.07	0.07	0.07	0.08
Both sexes								
1	0.11	0.17	0.71	0.96	0.50	0.85	0.21	0.39
10	0.10	0.14	0.72	0.96	0.24	0.43	0.21	0.37
20	0.08	0.11	0.10	0.14	0.08	0.11	0.10	0.14
All evacuated and non-evacuated municipalities								
Male								
1	0.09	0.12	0.39	0.71	0.27	0.53	0.14	0.23
10	0.10	0.13	0.57	0.88	0.13	0.20	0.17	0.30
20	0.07	0.09	0.08	0.10	0.08	0.09	0.09	0.11
Female								
1	0.08	0.10	0.41	0.72	0.28	0.53	0.13	0.21
10	0.07	0.09	0.39	0.69	0.12	0.19	0.12	0.19
20	0.07	0.08	0.07	0.09	0.06	0.07	0.07	0.08
Both sexes								
1	0.10	0.15	0.63	0.94	0.44	0.79	0.19	0.34
10	0.10	0.15	0.74	0.97	0.18	0.30	0.22	0.39
20	0.08	0.11	0.09	0.13	0.08	0.10	0.09	0.13

Group – sex and age (years)	*Statistical power using WHO risk estimates* [a]		*Statistical power using UNSCEAR 2020 risk estimates* [b]		*Statistical power using LSS risk estimates* [c]		*Statistical power using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
All non-evacuated municipalities only								
Male								
1	0.09	0.12	0.40	0.72	0.28	0.53	0.14	0.23
10	0.10	0.14	0.57	0.89	0.13	0.20	0.17	0.30
20	0.07	0.09	0.08	0.10	0.08	0.10	0.09	0.11
Female								
1	0.08	0.11	0.41	0.73	0.28	0.53	0.13	0.21
10	0.07	0.09	0.40	0.70	0.13	0.19	0.12	0.19
20	0.07	0.08	0.07	0.09	0.06	0.07	0.07	0.08
Both sexes								
1	0.10	0.15	0.64	0.94	0.45	0.79	0.19	0.35
10	0.11	0.15	0.75	0.97	0.18	0.43	0.22	0.39
20	0.08	0.10	0.09	0.12	0.08	0.10	0.09	0.13

[a] [Walsh et al., 2014; WHO, 2013].
[b] [UNSCEAR, 2020].
[c] [Hsu et al., 2013].
[d] [Little et al., 2018].
[e] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.

D. Lifetime thyroid cancer risk (without a thyroid screening programme)

37. A later section on the Fukushima Health Management Survey (FHMS) screening programme (see paragraphs 63–71 of this attachment) discusses statistical power in the context of thyroid cancer screening. In the absence of a screening programme, the LBRs were derived from age- and sex-specific thyroid cancer rates from four long-standing prefecture cancer registries in Japan (Fukui, Miyagi, Nagasaki and Yamagata prefectures) [IARC, 2017] using lifetable methods with adjustment for cancer-free survival. The LBRs for thyroid cancer incidence, absent systematic screening, were low, at about 1.2% for females and 0.4% for males. The LERs and LFRs for sex and age groups in the UNSCEAR 2013 Report [UNSCEAR, 2014] were based on a report by Walsh et al. [Walsh et al., 2014], which provided standardized results from the WHO Fukushima report [WHO, 2013].

38. For the present report, the LFRs were calculated with four models (see table A-23.6):

(a) First, the LFR coefficients from the WHO report were applied [Walsh et al., 2014; WHO, 2013], as they had been for the UNSCEAR 2013 Report [UNSCEAR, 2016];

(b) Second, the ERR coefficients of the latest report on thyroid cancer risk in the Japan LSS [Furukawa et al., 2013] were used. The study provided ERR coefficients for exposure at age 10 and 20 with follow-up through age 60. The LFRs for ages 1, 10 and 20 years at 100 mGy of exposure were 19.6%, 12.8% and 2.7%, respectively; it was assumed these risk coefficients were pertinent until age 90;

(c) The third estimators were based on approximate averages of linear dose responses for the Chernobyl thyroid screening studies in Ukraine [Brenner et al., 2011] and Belarus

[Zablotska et al., 2011] for ages 1 and 10 years at exposure. The LFRs at 100 mGy were estimated as 58% for age 1 and 18% for age 10 years at exposure;

(d) Fourth, the ERR coefficient from a pooled analysis of nine studies of thyroid cancer risk in those exposed as young people to doses up to 100 mGy was applied for ages 1 and 10 at exposure [Lubin et al., 2017]. The ERR coefficient was 86% at 100 mGy for their combined ages 1 and 10 years at exposure. Since the pooled study data were primarily for exposures below 20 years of age, the average of the ERRs of thyroid cancer in the United Kingdom [Haylock et al., 2018] and South Korean [Lee et al., 2019] national studies of radiation workers was instead shown in the pooled study columns for the 20-year-old groups. The average ERR was approximately 9.2% at 100 mGy.

Since the risk estimates for the Chernobyl and pooled-analysis models were based primarily on observed risk at younger ages, the LFR estimate from the WHO report was applied for ages 41 to 90. When LFRs were not already available, the LFR estimates were based on ERR coefficients rather than excess absolute risk (EAR coefficients because ERR coefficients tend to be less sensitive to screening frequency and often vary less with attained age [UNSCEAR, 2020]. Analyses in the several reports did not indicate that risk coefficients differed significantly by sex, so identical ones were used for males and females.

39. The advantages of the LSS risk estimates is that they are based on the Japanese population and have a long follow-up time. The Chernobyl studies have the advantage of being based on exposures at relatively low dose rates and include internal exposures, as was the case in Fukushima. The pooled study has the advantage of having a large number of thyroid cancers and being based on low-dose data, while the WHO analysis serves as a comparative baseline for the newer risk estimates and has the advantage that it directly estimates lifetime risk.

40. The thyroid gland received larger internal exposures than did other organs or tissues from short-lived radioisotopes of iodine in the first few weeks after the FDNPS accident. Dose estimation was implemented by adding together the first-year total absorbed thyroid doses from internal and external exposure and the continuing doses for the lifetime, as estimated in attachments A-14 and A-18. The average lifetime doses and 95th percentile upper bound lifetime doses for the thyroid gland are given in table A-23.2.

Table A-23.6. Lifetime fractional risks (LFRs) of thyroid cancer (without systematic population screening) attributable to radiation at a thyroid radiation dose of 100 mGy according to various models

*Age (*year*)*	*WHO model, LFR (%)*[a]	*LSS model, LFR (%)*[b]	*Chernobyl model, LFR (%)*[c]	*Pooled study model, LFR (%)*[d]
Age 1–Male	34.0	19.6	37.7	42.0
Age10–Male	19.5	12.8	19.3	29.7
Age 20–Male	9.20	2.7		9.20
Age 1–Female	42.0	19.6	45.2	50.9
Age 10–Female	24.5	12.8	23.2	37.0
Age 20–Female [a]	9.20	2.7		9.20

[a] [Walsh et al., 2014; WHO, 2013]. These LFRs were also used for the attained ages of 41–90 years with the Chernobyl and pooled-study models.
[b] [Furukawa et al., 2013].
[c] [Brenner et al., 2011; Zablotska et al., 2011]. Because the model was based primarily on childhood and adolescent exposures, it was not applied for age 20.
[d] [Lubin et al., 2017]. Because the model was based primarily on childhood and adolescent exposures, a coefficient representing the average ERR derived from two large occupational studies of adult exposures [Haylock et al., 2018; Lee et al., 2019] was used for age 20.

41. Table A-23.7 shows estimated statistical power for the various models of radiation risk for thyroid cancer. The LFRs for thyroid cancer are generally greater than for other cancer sites, owing to the extra dose contributed by the first-year internal exposure to radioiodides and the relatively high LFRs per unit dose. The statistical power results suggest that excess thyroid cancer risk is most likely not detectable, as shown by the results for mean doses. There is also a suggestion that it might be detectable among females of ages in utero to five years if doses were to correspond to the 95% upper bound estimates. However, for this subgroup about 650 incident thyroid cancers (with a 95% confidence interval of approximately 600–700 cancers) would be observed in Fukushima Prefecture over the lifetime in the absence of radiation or systematic population screening for thyroid cancer, and about 16–50 additional cancers might theoretically be attributable to radiation exposure, depending on the risk model used. A statistical power analysis showed that an excess of 50 cases or less would be undetectable among the much larger baseline number of thyroid cancers. Moreover, the LBRs of diagnosed thyroid cancer vary markedly by geographic area; the age-aggregated rates across the four prefectures used to estimate average background rates varied by over 60% for both males and females, and variation would likely be greater for smaller geographic units such as municipalities. Such variations would introduce statistical "noise" much larger than the radiation-associated difference that is being evaluated, so the ability to discern a meaningful increase in thyroid cancer is thought to be unlikely. (See paragraph 46 of this attachment for further discussion of the detectability of risks.)

Table A-23.7. Thyroid cancer (without systematic screening) lifetime incidence: statistical power for mean and 95th percentile upper bound on mean lifetime doses by sex and age at the time of the Fukushima Daiichi Nuclear Power Station accident for all residents of evacuated and non-evacuated municipalities and for those with >5 mGy first-year thyroid dose

Group – sex and age (years)	*Statistical power using WHO risk estimates* [a]		*Statistical power using LSS risk estimates* [b]		*Statistical power using Chernobyl risk estimates* [c]		*Statistical power using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with first year thyroid dose >5 mGy								
Male								
1	0.16	0.35	0.10	0.18	0.18	0.50	0.20	0.46
10	0.12	0.25	0.09	0.16	0.12	0.25	0.18	0.43
20	0.07	0.11	0.06	0.06			0.07	0.11
Female								
1	0.39	0.85	0.16	0.36	0.43	0.89	0.50	0.94
10	0.27	0.68	0.13	0.30	0.25	0.63	0.45	0.93
20	0.10	0.17	0.06	0.08			0.10	0.11
Both sexes								
1	0.41	0.88	0.18	0.44	0.49	0.94	0.57	0.97
10	0.38	0.70	0.15	0.36	0.26	0.71	0.52	0.96
20	0.11	0.20	0.06	0.08			0.11	0.14
All municipalities								
Male								
1	0.15	0.33	0.10	0.17	0.17	0.38	0.10	0.43
10	0.12	0.25	0.09	0.16	0.12	0.25	0.19	0.43
20	0.08	0.11	0.06	0.06			0.08	0.11

Group – sex and age (years)	*Statistical power using WHO risk estimates* [a]		*Statistical power using LSS risk estimates* [b]		*Statistical power using Chernobyl risk estimates* [c]		*Statistical power using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Female								
1	0.37	0.82	0.15	0.33	0.40	0.86	0.47	0.92
10	0.28	0.68	0.14	0.30	0.26	0.64	0.48	0.93
20	0.10	0.17	0.06	0.07			0.10	0.11
Both sexes								
1	0.39	0.85	0.18	0.41	0.46	0.92	0.54	0.96
10	0.29	0.71	0.16	0.36	0.30	0.71	0.54	0.96
20	0.11	0.20	0.06	0.08			0.11	0.14
Non-evacuated municipalities only: all doses								
Male								
1	0.15	0.32	0.10	0.17	0.17	0.37	0.19	0.43
10	0.12	0.25	0.09	0.16	0.12	0.24	0.18	0.42
20	0.07	0.11	0.06	0.07			0.08	0.11
Female								
1	0.35	0.81	0.15	0.33	0.40	0.86	0.46	0.92
10	0.28	0.68	0.14	0.29	0.26	0.62	0.47	0.92
20	0.10	0.17	0.06	0.07			0.10	0.11
Both sexes								
1	0.38	0.84	0.17	0.40	0.46	0.91	0.53	0.96
10	0.29	0.69	0.16	0.35	0.29	0.70	0.53	0.95
20	0.11	0.20	0.06	0.08			0.11	0.14

[a] [Walsh et al., 2014; WHO, 2013].
[b] [Furukawa et al., 2013].
[c] [Brenner et al., 2011; Zablotska et al., 2011].
[d] [Lubin et al., 2017]. For age 20 the statistical power estimates are based on the average of thyroid cancer risk estimates from the United Kingdom and South Korean national worker studies [Haylock et al., 2018; Lee et al., 2019].
[e] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.

E. Lifetime female breast cancer risk

42. The background incidence of breast cancer is fairly high in females, with LBRs of about 6.1%, as estimated by a lifetable method based on age-specific incidence data from four Japan prefectures, with adjustment for cancer-free survival. The LBRs for the 1, 10 and 20-year-old age groups were virtually identical because few breast cancers occur before age 25. The lifetime risk attributable to radiation was based on absorbed breast dose (see table A-23.2). The UNSCEAR 2013 Report [UNSCEAR, 2014] and WHO report [Walsh et al., 2014; WHO, 2013] had used a risk coefficient based on the Preston et al. [Preston et al., 2007] analysis of breast cancer risk in the LSS. It is used here with updated lifetime LBR incidences. A recent report [Brenner et al., 2018] updated the LSS risk estimate and found an average 29% increase in breast cancer risk per 100 mGy compared to the earlier study [Preston et al., 2007], and the factor 1.29 was used to generate the LFRs for the Brenner et al. model. The statistical power for lifetime breast cancer risk is shown in table A-23.8 for both models. Based on the statistical power results,

it is not expected that an excess of breast cancer would be detectable, even at the 95th percentile upper bound on the mean dose after early childhood exposure.

Table A-23.8. Female breast cancer lifetime incidence: statistical power for mean and upper bound doses by age at the time of the Fukushima Daiichi Nuclear Power Station accident for residents of all non-evacuated and evacuated municipalities, and for those with >5 mSv cumulative lifetime effective dose

Group – age at first exposure (years)	*LSS risk model* [a]			*UNSCEAR 2013 risk model* [b]	
	Mean cumulative organ dose [c]		*95%ile upper bound on mean dose*	*Mean cumulative organ dose*	*95%ile upper bound on mean dose*
	LFR (%)	*Statistical power*	*Statistical power*	*Statistical power*	*Statistical power*
Municipalities with lifetime effective dose >5 mSv					
1	3.2	0.40	0.70	0.29	0.52
10	1.8	0.33	0.58	0.24	0.42
20	1.0	0.20	0.34	0.15	0.24
All municipalities					
1	2.1	0.33	0.60	0.24	0.43
10	1.2	0.29	0.50	0.21	0.36
20	0.7	0.18	0.29	0.14	0.21

[a] [Brenner et al., 2018].
[b] [UNSCEAR, 2014; Walsh et al., 2014; WHO, 2013].
[c] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.

F. Lifetime risk of all solid cancer (excluding thyroid cancer and nonmelanoma skin cancer)

43. The LBRs for all solid cancer, excluding thyroid cancer and nonmelanoma skin cancer, were based on the age- and sex-specific rates of the aforementioned four prefecture cancer registries. Nonmelanoma skin cancer is conventionally excluded from lifetable calculations because it is reported inconsistently to cancer registries and it usually confers little health detriment. Thyroid cancer was excluded because the geographic pattern and magnitude of doses to the thyroid from the FDNPS accident differed substantially from those to other organs and tissues. The LBRs are based on lifetable calculations of cumulative rates from the aforementioned four unexposed prefectures, with adjustment for cancer-free survival ([UNSCEAR, 2014] as shown in the appendix, table A-23.A1). The LFR for all solid cancer in the Committee's previous statistical power assessment [UNSCEAR, 2016] was based on an incidence analysis of the Japanese LSS study [Preston et al., 2007], which has recently been updated with further follow-up of the LSS cohort [Grant et al., 2017]. The sex-specific ratios of the newer linear risk coefficients [Grant et al., 2017] to the previous ones were applied for evaluating all solid cancer risk. The ratios were 1.10 for females and 1.03 for males. The estimated mean doses to the colon, as shown in table A-23.2, were applied in estimating the LFRs.

44. The LBRs indicated that without radiation exposure about 29% of females and 42% of males would develop a solid cancer during their lifetime. These LBRs were virtually identical for the 1, 10 and 20-year-old age groups, because nearly all solid cancers occur after 25 years of age. The LFRs (LERs as a percentage of the LBRs) and the estimated statistical power to detect those LFRs are shown in table A-23.9.

Table A-23.9. All solid cancer (except thyroid cancer and nonmelanoma skin cancer) lifetime incidence: statistical power for mean and upper bound doses by sex and age at the time of the Fukushima Daiichi Nuclear Power Station accident for residents of all non-evacuated municipalities, for non-evacuated municipalities plus evacuated municipalities, and for the subset of municipalities with >5 mSv cumulative lifetime effective dose [Grant et al., 2017]

Group – sex and age (years)	*Non-evacuated municipalities*			*Non-evacuated plus evacuated municipalities*	
	Mean colon dose [a]		*95%ile upper bound on mean dose*	*Mean colon dose*	*95%ile upper bound on mean dose*
	LFR (%)	*Statistical power*	*Statistical power*	*Statistical power*	*Statistical power*
Municipalities with lifetime effective dose >5 mSv					
Male					
1	0.8	0.24	0.43	0.24	0.43
10	0.5	0.26	0.46	0.26	0.47
20	0.3	0.17	0.27	0.17	0.28
Female					
1	1.8	0.55	0.86	0.54	0.87
10	1.2	0.59	0.88	0.80	0.99
20	0.7	0.36	0.62	0.37	0.64
Both sexes					
1	1.2	0.58	0.89	0.57	0.89
10	0.8	0.62	0.91	0.80	0.99
20	0.5	0.38	0.65	0.39	0.67
All municipalities					
Male					
1	0.5	0.20	0.36	0.20	0.35
10	0.4	0.23	0.40	0.23	0.41
20	0.2	0.16	0.24	0.15	0.25
Female					
1	1.2	0.46	0.78	0.46	0.77
10	0.9	0.52	0.82	0.51	0.84
20	0.5	0.32	0.55	0.32	0.56
Both sexes					
1	0.8	0.49	0.81	0.48	0.80
10	0.6	0.55	0.85	0.54	0.87
20	0.3	0.34	0.59	0.34	0.59

[a] Based on cumulative mean colon doses and 95th percentile upper bounds on the means, summed to age 80 years.

45. For the best estimate of municipality doses (mean doses), the statistical power results indicated that a radiation-related risk of all solid cancer (excluding thyroid cancer and nonmelanoma skin cancer) was generally unlikely to be discernible, as shown in the columns for mean doses in table A-23.9. A potential exception to this occurred for females initially exposed at age 10, with a related value for both sexes: statistical power achieved the 80% criterion for the mean dose, indicating that one might potentially see a radiation-associated excess in this subpopulation (but see caveats in the next paragraph). Furthermore, if the mean doses were

actually at the 95% upper bounds (upper bound columns), the estimates indicated it may be possible to detect risks for females and both sexes combined.

46. There are several reservations to the finding of high statistical power for risk estimates of all solid cancer:

(a) First, because there is a high baseline risk and large numbers of individuals, even a very small relative risk – in this case relative risks of 1.005 to 1.018 – can show substantial statistical power. But these potentially "statistically significant" expected relative risks of under 1.02 would not be very meaningful, and genuine risks versus subtle confounding effects would be difficult to discern;

(b) Second, a key assumption in the present calculation of statistical power is that both the LBRs and the LERs are known precisely and accurately (without bias), so that there is no inherent uncertainty in those estimates. That is undoubtedly not the case. For instance, total cancer baseline incidence rates differ appreciably in different Japanese prefectures [UNSCEAR, 2014], with differences of 5–15% that far exceed the magnitude of the radiation-associated risk. Baseline incidence rates (LBRs) in smaller geographic units, such as municipalities, would be expected to have even larger variability due to the statistical instability associated with smaller numbers, plus the influence of sociodemographic confounding factors that produce variability in LBRs;

(c) Third, the LERs also have inherent uncertainty – for example, uncertainties in the coefficients and the dose-response model used. If the variability in rates and the uncertainties in the excess risk coefficient and modelling parameters could be factored into the estimation, the statistical power values probably would be materially smaller and excess risk would not be expected to be discernible because any signal of radiation risk would be masked by the additional background "noise";

(d) Fourth, while the upper 95% confidence bound on the mean is a possible value, it is not nearly as likely as some value nearer the mean [Poole, 1987]. (This can be visualized by thinking of a Gaussian, "bell shaped", curve. A narrow vertical slice near the 95th percentile encompasses much less area under the curve than a vertical slice of equal width near the mean, where the size of the area relates approximately to the likelihood that it contains the true value.) Because of the background variability in rates and other reasons listed above, it is expected that an excess risk of all solid cancer is not very likely to be discernible.

III. LEUKAEMIA AND THYROID CANCER RISKS TO AGES 30 OR 40 YEARS

47. Exposure of children shows the highest radiation relative risks for leukaemia and thyroid cancer [UNSCEAR, 2013], and these cancers have the highest ERR expression of those risks in the first decades after exposure [Furukawa et al., 2013; Hsu et al., 2013]. Therefore, analyses were conducted of whether cumulative excess risks of leukaemia or thyroid cancer are likely to be seen up to 30 or 40 years of age for those at 1 or 10 years of age at the time of the FDNPS accident.

A. Leukaemia risk to ages 30 or 40 years after childhood exposure

48. The CBR estimates to ages 30 or 40 years for those at age 1 or 10 years at exposure in Fukushima Prefecture were calculated with lifetable methods, using rates of leukaemia by sex and 5-year age intervals derived from four prefecture cancer registries in Japan (Fukui, Miyagi, Nagasaki and Yamagata Prefectures)and adjusted for malignancy-free survival.

49. The CER and CFR values for leukaemia up to age 30 or 40 years after exposure at ages 1 or 10 years were estimated based on three models:

(a) First, the recent UNSCEAR report [UNSCEAR, 2020] provided values to derive CFR estimates for exposure to 100 mGy at age 1 year and observation to ages 30 or 40 as 2.9 and 3.0, respectively, for their preferred model, which was based on a study of leukaemia and myelodysplastic syndromes among children in the United Kingdom with radiation exposure from CT examinations [Berrington de Gonzaléz et al., 2016]. For age 10 at exposure, the CFR estimates to ages 30 or 40 were 3.0 and 3.1, respectively, at 100 mGy;

(b) The second model consisted of LFR estimates at 100 mGy from the LSS study [Hsu et al., 2013; UNSCEAR, 2020], which were 2.75 for ages 1–30, 2.15 for ages 1–40, 1.15 for ages 10–30 and 0.85 for ages 10–40 years at 100 mGy;

(c) Third, a recent analysis of data from nine pooled studies of childhood external radiation exposures with RBM doses ≤100 mGy [Little et al., 2018] yielded an ERR estimate of 0.84 at 100 mGy, which was employed as a LFR estimate.

50. Calculations were based on dose to the RBM. The estimated RBM mean doses and 95% upper bounds were calculated for the appropriate age intervals by adding to the first-year RBM dose the subsequent cumulative effective doses, adjusted for the ratio of RBM dose to effective dose, from the second year to age 28 or 30 years to allow for a two-year latency period between dose and associated leukaemia risk.

51. CFR values for estimating leukaemia risk up to ages 30 or 40 for the various risk models are given in section II of the appendix. The statistical power results are shown in table A-23.10 for each of the risk models. The model based on CT examinations in the United Kingdom indicated discernible risk, especially in the subsets of those exposed at 1 or 10 years of age with >5 mSv mean lifetime dose. The LSS also had a suggestion of discernible risk (statistical power ≥0.70) for age 1 at exposure. However, there was generally little indication of detectable risk at the mean doses for the models based on the LSS cohort or pooled studies, though there were results suggesting discernible risk at the 95th percentile upper bound dose.

52. The greatest statistical power was for those initially exposed at age 1 (that is, in utero to five years) and observed up to 40 years of age. Including both sexes for this scenario, and depending on the risk model applied, about 10–40 cases may be attributable to radiation exposure compared to about 160 LBR baseline cases in the absence of radiation exposure from the FDNPS accident, with an estimated range of uncertainty in the baseline estimate of about 50 cases. Of note, the discussion of suggested upward bias (see paragraph 34 of this attachment) in the United Kingdom CT study [Berrington de Gonzaléz et al., 2016] that produced the highest risk estimates [UNSCEAR, 2020] among the models for lifetime leukaemia risk is also directly applicable to the 30 or 40 year risk estimates here. It suggests the calculated excess of 40 cases may also be upwardly biased.

Table A-23.10. Leukaemia: statistical power to detect excess malignancies up to age 30 or 40 years after childhood radiation exposure in both evacuated and non-evacuated municipalities, using estimated doses, linear excess relative risk models of estimated cumulative excess leukaemia risk from the three models [Hsu et al., 2013; Little et al., 2018; UNSCEAR, 2020] and cumulated age/sex-specific baseline risk of leukaemia from four Japan prefectures [UNSCEAR, 2020]

Group – sex (M, F, or B for both) and age (years)	*Statistical power using UNSCEAR 2020 risk estimates* [a]		*Statistical power using LSS risk estimates* [b]		*Statistical power using pooled-analysis risk estimate* [c]	
	Mean tissue dose [d]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with cumulative lifetime effective dose >5 mSv						
M, ages 1–30[e]	0.55	0.86	0.52	0.83	0.14	0.22
F, ages 1–30	0.48	0.79	0.45	0.75	0.13	0.20
B, ages 1–30	0.77	0.98	0.73	0.97	0.19	0.32
M, ages 1–40	0.70	0.95	0.48	0.80	0.16	0.27
F, ages 1–40	0.63	0.92	0.43	0.74	0.15	0.25
B, ages 1–40	0.90	0.99	0.70	0.96	0.23	0.41
M, ages 10–30	0.57	0.87	0.18	0.31	0.14	0.21
F, ages 10–30	0.49	0.79	0.16	0.27	0.12	0.19
B, ages 10–30	0.79	0.98	0.26	0.46	0.18	0.31
M, ages 10 –40	0.81	0.98	0.18	0.31	0.18	0.31
F, ages 10–40	0.75	0.97	0.17	0.28	0.17	0.28
B, ages 10–40	0.96	0.99	0.26	0.47	0.26	0.47
All municipalities						
M, ages 1–30	0.51	0.82	0.47	0.79	0.13	0.20
F, ages 1–30	0.44	0.75	0.41	0.72	0.12	0.18
B, ages 1–30	0.72	0.97	0.68	0.95	0.17	0.29
M, ages 1–40	0.65	0.94	0.44	0.76	0.15	0.25
F, ages 1–40	0.59	0.90	0.39	0.69	0.14	0.23
B, ages 1–40	0.87	0.99	0.65	0.94	0.21	0.37
M, ages 10–30	0.49	0.80	0.16	0.26	0.12	0.18
F, ages 10–30	0.42	0.71	0.14	0.23	0.11	0.16
B, ages 10–30	0.70	0.95	0.22	0.38	0.16	0.26
M, ages 10–40	0.72	0.96	0.16	0.26	0.16	0.26
F, ages 10–40	0.66	0.93	0.15	0.24	0.15	0.24
B, ages 10–40	0.92	0.99	0.22	0.40	0.22	0.39

[a] [UNSCEAR, 2020].
[b] [Hsu et al., 2013; UNSCEAR, 2020].
[c] [Little et al., 2018].
[d] Using RBM cumulative mean doses or 95th percentile upper bound on the means summed to ages 28 (for risk to age 30) or 38 (for risk to age 40)
[e] Age at initial exposure through age of final observation. Risk was calculated assuming a two-year lag of the doses to account for the minimum latency period.

B. Statistical power to detect thyroid cancer risk (in the absence of a screening programme) to ages 30 or 40 years after childhood exposure

53. The CBR estimates to ages 30 or 40 years for those in Fukushima Prefecture at age 1 or 10 years at exposure were calculated using sex- and age-specific rates of thyroid cancer from the cancer registries of four essentially unexposed prefectures, parallel to the approach used for leukaemia.

54. Three models were used in estimating CFRs for thyroid cancer up to ages 30 or 40 years:

(a) First, thyroid cancer CER estimates of radiation risk after exposure at ages 1 or 10 years were adapted from a recent UNSCEAR report [UNSCEAR, 2020], based on LFR estimates of radiation risk at ages 30 or 40 from the Japanese atomic bombing survivors LSS [Furukawa et al., 2013; Jacob et al., 2014];

(b) Second, CFRs were also calculated based on studies of thyroid cancer after exposure to radioactive iodine isotopes from the Chernobyl accident. Approximate averages of the ERR reports from the Ukraine [Brenner et al., 2011] and Belarus [Zablotska et al., 2011] were used for the CFRs, namely, ERR estimates of 0.58 and 0.18 at 100 mGy for ages 1 and 10 years at exposure, respectively. Estimates based on EAR vary highly because of screening effects, stable iodine intake levels, different baseline rates etc., so only ERR modelling was used in deriving the CFR estimates;

(c) Third, a pooled study of thyroid cancer in nine cohorts with childhood external radiation absorbed thyroid doses under 200 mGy was recently reported by Lubin et al. [Lubin et al., 2017]. An ERR estimate of 0.86 per 100 mGy for the subset of the Lubin et al. study with absorbed radiation doses up to 100 mGy was used as the CFR estimate.

55. The modelled ERRs did not differ in a consistent manner by sex or age at exposure [UNSCEAR, 2020]. More details of methods and coefficients for calculating the CERs and CFRs are provided in section IV of the appendix. The evacuees tended to have relatively high thyroid doses but are only a small fraction of the prefecture population, so the results of the statistical power analyses are shown in table A-23.11 for the combined non-evacuated and evacuated municipalities.

56. The complementary strengths of the models of thyroid cancer risk can be briefly stated. The UNSCEAR [UNSCEAR, 2020] risk coefficients from the LSS study have the advantage of being based on the Japanese population, with well-characterized doses and substantial numbers of tumours. The average intake of stable iodine in the diet and other lifestyle characteristics are therefore likely to be similar to the population affected by the FDNPS accident. The CFRs were also explicitly calculated for the relevant ages [UNSCEAR, 2020]. The Chernobyl thyroid cancer risk coefficients are based primarily on protracted ^{131}I exposures over weeks to months, as are the Fukushima data, rather than one brief exposure as for the LSS. The thyroid doses were reasonably well characterized, being based primarily on measurements of radioiodine in the thyroid shortly after the accident in the Ukraine [Likhtarov et al., 2014] or other detailed models in Belarus. In the Chernobyl studies the thyroid cancer detection was more systematic than in the LSS because it was based on screening programmes. The pooled study of Lubin et al. [Lubin et al., 2017] has the advantage of being based on a large number of thyroid cancers, because it incorporated data from nine different studies with a thyroid dose range of 100 mGy and below, but some studies may have had surveillance bias that increased the risk estimates and most of the studies included brief exposures.

57. Table A-23.11 indicates that the magnitude of excess risks was fairly similar for the three models of radiation-related thyroid cancer, as shown by the similar evidence regarding statistical power. For all the models, however, statistical power was inadequate to consider the excess risk of thyroid cancer at young ages (in the absence of a systematic screening programme) to be detectable. This owes a large part to the fact that thyroid cancer rarely presents clinically at young ages.

Table A-23.11. Thyroid cancer (without systematic screening): statistical power to detect excess cancer by age 30 or 40 years after childhood radiation exposure in the combined evacuated and non-evacuated municipalities, using models of thyroid cancer risk based on the Japanese Life Span Study [UNSCEAR, 2020], the Chernobyl studies in the Ukraine [Brenner et al., 2011] and Belarus [Zablotska et al., 2011], or a study of nine pooled data sets [Lubin et al., 2017]

Group – sex (M, F, or B for both) and age (years)	*CFR (%)*[a]	*Japanese LSS risk estimates*		*Chernobyl risk estimates*		*Pooled study risk estimate*	
		Mean tissue dose[b]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with first year absorbed thyroid dose >5 mGy							
M, ages 1–30[c]	13.9	0.10	0.19	0.08	0.12	0.10	0.17
F, ages 1–30	13.9	0.17	0.40	0.12	0.23	0.16	0.36
B, ages 1–30	13.9	0.20	0.48	0.13	0.26	0.19	0.43
M, ages 1–40	10.7	0.12	0.23	0.10	0.19	0.14	0.29
F, ages 1–40	10.7	0.24	0.57	0.20	0.46	0.31	0.71
B, ages 1–40	10.7	0.28	0.65	0.22	0.53	0.36	0.79
M, ages 10–40	6.3	0.09	0.15	0.07	0.09	0.17	0.40
F, ages 10–40	6.3	0.14	0.33	0.09	0.16	0.40	0.88
B, ages 10–40	6.3	0.16	0.38	0.10	0.18	0.47	0.93
All municipalities							
M, ages 1–30	10.9	0.10	0.18	0.08	0.12	0.10	0.16
F, ages 1–30	10.9	0.17	0.38	0.11	0.21	0.16	0.34
B, ages 1–30	10.9	0.20	0.45	0.13	0.25	0.18	0.40
M, ages 1–40	8.4	0.12	0.22	0.10	0.18	0.14	0.28
F, ages 1–40	8.4	0.22	0.54	0.19	0.46	0.29	0.68
B, ages 1–40	8.4	0.26	0.62	0.21	0.50	0.34	0.76
M, ages 10–40	3.5	0.09	0.15	0.07	0.09	0.18	0.42
F, ages 10–40	3.5	0.15	0.33	0.09	0.16	0.43	0.90
B, ages 10–40	3.5	0.16	0.38	0.10	0.18	0.50	0.95

[a] CFR values are given for the Japanese LSS risk estimates.
[b] Using thyroid cumulative mean doses or 95th percentile upper bound on the means summed to ages 27 (for risk to age 30) or 37 (for risk to age 40).
[c] Ages shown are age at exposure to final age at observation. Excess risk was calculated assuming a three-year minimum latency period. Data for ages 10–30 are not reported because the numbers of cases were small during the 20-year period.

IV. IN UTERO EXPOSURE AND CANCER RISK

58. The embryonic and fetal stages of development are believed to be sensitive to cancer induction by radiation exposure [Wakeford, 2013; Wakeford and Little, 2003]. This is seen most clearly for childhood leukaemia, though in utero exposure may also raise risk for childhood solid tumours as well. Wakeford [Wakeford, 2013] estimated the ERR of childhood leukaemia from in utero exposure as 5.1 (95% CI: 2.8, 7.6) per 100 mGy based on a number of studies of medical radiation exposure. This risk estimate is statistically compatible with that derived for young children in the LSS exposed during the atomic bombings of Japan. Studies of Japanese atomic bombing survivors exposed in utero have found an increased risk of cancer in adulthood, and this increased risk is at about the same level as the risk experienced by survivors exposed in childhood [Preston et al., 2008].

59. For the analyses of statistical power among those exposed in utero in non-evacuated municipalities, the in utero mean doses were 0.2 mGy (95% upper bound on the mean of 0.7 mGy) for RBM, and 4.3 mGy (95% upper bound on mean of 12.5 mGy) for the thyroid gland. The RBM doses were averaged over all 40 weeks of pregnancy, while the thyroid doses were averaged over weeks 10–40, the period for which there is thyroid functional activity. About 16,000 children received in utero FDNPS exposures in Fukushima Prefecture [Fujimori et al., 2014].

60. To estimate statistical power for childhood leukaemia the baseline rates from four unexposed prefectures were averaged and cumulated for ages 0–19 years and the risk coefficient by Wakeford [Wakeford, 2013] was applied. The results using either the mean cumulative RBM dose or the 95% upper bound on the mean dose all yielded statistical power <10% for leukaemia in children. When the 95% upper bound on the risk coefficient of Wakeford was applied to the upper bound on the mean dose, the statistical power was still <15%.

61. Statistical power results for thyroid cancer for the in utero group were obtained for up to age 30 years and to age 40 years, using the CFRs of the various models (see paragraph 38 of this attachment) for age 1 year for both the cumulative mean dose and 95% upper bound on the mean. In no case did the statistical power exceed 10%.

62. Statistical power analyses of the in utero cohort were also conducted for breast cancer and all solid cancers up to ages 30 and 40 years. The detection of excess incidence of female breast cancer was modelled from the recent LSS report [Brenner et al., 2018], using ERR coefficients appropriate for exposure at age 0 and attained ages of 30 or 40. For both the female in utero subgroup with effective doses over 5 mSv and for the entire female in utero group, the statistical power was less than 10% for either attained age 30 or 40, even at the 95% upper bound of mean dose. For the incidence of all solid cancers, risk coefficients were derived from the recent LSS paper on Japanese atomic bombing survivors [Grant et al., 2017], using ERR coefficients appropriate for exposure at age 0 years and attained ages of 30 or 40 years from their model. The results for in utero males, females and both sexes combined showed statistical power under 10% for both the estimated mean dose and the 95% upper bound on the mean. The low statistical power for the in utero group results from the combination of relatively low doses, a small sample size (under 16,000 in the analysis), and low frequencies of cancer below ages 30 or 40.

V. THYROID CANCERS DIAGNOSED IN THE FUKUSHIMA HEALTH MANAGEMENT SURVEY EXAMINATION PROGRAMME

63. The purpose of these analyses is to estimate whether excess thyroid cancer is likely to be discernible in the FHMS cohort of those with ultrasound examinations who were exposed at about age 1 year or age 10 years, and screened and observed out to the ages of 30 or 40 years. Given that the rates of thyroid cancer detected by the FHMS ultrasound thyroid screening programme are much higher than those observed in the general Japanese population of comparable age, very few of whom have had ultrasound screening, a strategy had to be developed to estimate expected thyroid cancer rates to ages 30 or 40 years for the FHMS. In doing this, the assumption was made that the thyroid cancer incidences observed in the FHMS screenings represent the baseline rates for the analysis of statistical power. This is potentially a conservative assumption, because it would result in greater statistical power for a given assumed ERR than if lower baseline rates were used, due to factoring out an assumed radiation component from the existing rates. Based on other studies, the minimum latency period for radiation induction of thyroid cancer is about three to four years.

A. Cumulative baseline risk estimation

64. Because the FHMS thyroid ultrasound examinations have found uniquely high frequencies of suspected/confirmed thyroid cancer, an ad hoc methodology was employed to estimate rates from existing FHMS data and to project them into the future up to age 30 or 40 years. The steps in this process are described in section V of the appendix.

65. The approach to estimate the CBR of cancer to age 30 or 40 years was to use the annual rates of thyroid cancers derived from the second and third rounds of screening for various age groups as indicated in reference [FHMS, 2016; FHMS, 2017; FHMS, 2020] out to age 20 years, after which the rates were projected forward to age 30 or 40 years by assuming that the annual rates with continued screening would increase in proportion to the corresponding age-related baseline rates of thyroid cancer (without screening or radiation exposure) in the Japanese population.

66. A number of assumptions had to be made to model risk in the FHMS. Approximations had to be made of the number of participants who were initially exposed in the age range from in utero to age 5 years, and the number whose first-year thyroid doses were >5 mGy, since relevant data were not available. The subsequent second and third screening examinations were considered to represent incident cancers, which are the primary basis of the calculations. Specifically, the numbers of FHMS examinees and thyroid cancers by age and sex were obtained from the second and third examinations up to age 20 years, and age-specific annual rates of "suspected or confirmed" thyroid cancers detected by fine needle aspiration biopsy in the FHMS examination program were estimated from those data.

B. Cumulative excess risk and cumulative fractional risk estimation

67. Thyroid doses have been estimated for a subset of FHMS participants but are generally not available. Therefore, the mean doses, including both external and internal radioiodine doses, and upper bounds on the means for municipalities and evacuated locations for the 1-year-old group were used to estimate thyroid doses and to estimate the proportion who had received over 5 mGy. A minimum latency period of 3 years was assumed in calculating radiation risks.

68. The recent UNSCEAR report [UNSCEAR, 2020] has estimated CBR and CFR risks for thyroid cancer after exposure beginning at age 1 or 10 years, basing the CBRs on a Ukrainian population. However, because the background rates in FHMS with ultrasound screening differ from those in the Ukraine, the CBR values from the UNSCEAR report could not be used directly for this assessment. Therefore, only the CFRs (the ratios of the CERs to the corresponding CBRs) in that report, which were based on the most recent LSS thyroid cancer ERR estimates [Furukawa et al., 2013], were used; the ratios were applied to the baseline cumulative thyroid cancer rates derived as described above. Because the risk coefficients did not vary significantly by sex, they were applied to both sexes to estimate CER risks. The LSS-based CFRs for a dose of 100 mGy and up to age 30 were 0.94 for exposure at age 1 and 0.42 at age 10 years; the CFRs for up to age 40 were 0.70 and 0.34, respectively, for a 100 mGy dose.

69. Approximate averages from the Chernobyl studies [Brenner et al., 2011; Zablotska et al., 2011] of the ERR coefficients for those of ages 0 to about 4 years, and those of older childhood ages, were applied to the age 1 year and age 10 years data, respectively. These averaged ERR coefficients, applied as CFRs, were 0.58 at 100 mGy at age 1 year and 0.18 at age 10 years. An estimate was also employed from the study by Lubin et al. [Lubin et al., 2017], which pooled low-dose data from nine different studies of thyroid cancer after external irradiation before about age 20. The ERR of 0.86 at 100 mGy, based on the dose-response slope at doses up to 100 mGy, was used to calculate the CER and CFR. The ERR did not differ consistently by sex or age at exposure in that study. Further details of modelling the CBR, CER and CFR estimates are provided in section V of the appendix.

70. For those who were of ages 18 years or older at the time of screening, participation rates for the second and third rounds of FHMS thyroid screening were only 25.7% and 16.4%, respectively. Therefore, the conservative assumption was made that after 20 years of age, 30% of the FHMS cohort would have baseline thyroid cancer rates corresponding to receiving screening at the FHMS-designated ages up to ages 30 or 40 years, while the remaining 70% would have baseline thyroid cancer rates corresponding to the rates elsewhere in Japan, where there is almost no population ultrasound screening of young adults. With the estimates from the existing data to age 20 years and the assumptions about future incident thyroid cancers, the CBRs up to age 30 for those exposed at age 1 were about 0.32% for females and 0.27% for males; the respective values to age 40 were about 0.53% for females and 0.48% for males. Results of the statistical power analysis are shown in table A-23.12. The results indicate that, at the Committee's best estimates of doses (mean dose), a risk of excess thyroid cancer is not expected to be detectable using any of the models of thyroid cancer risk, although there is one weak exception (statistical power >0.70) for combined sexes at ages 10–40. The few 95th percentile upper bound statistical power results that suggest possible detectability should be treated circumspectly because of geographic variability in thyroid cancer rates (see paragraph 41), other unaccounted for factors that increase uncertainties (see paragraph 46), and because several conservative assumptions were made.

Table A-23.12. Thyroid cancer, Fukushima Health Management Survey: statistical power to detect excess cancer by age 30 or 40 years after childhood radiation exposure, using models of thyroid cancer risk based on the Japanese atomic bombing survivor Life Span Study [UNSCEAR, 2020], the Chernobyl studies in the Ukraine [Brenner et al., 2011] and Belarus [Zablotska et al., 2011], or study of nine pooled data sets [Lubin et al., 2017]

Group – sex (M, F, or B for both) and age (years)	*Japanese LSS risk estimates*		*Chernobyl risk estimates*		*Pooled study risk estimate*	
	Mean tissue dose [a]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with first year absorbed thyroid dose >5 mGy						
M, ages 1–30[b]	0.20	0.46	0.13	0.25	0.18	0.41
F, ages 1–30	0.21	0.50	0.13	0.28	0.19	0.45
B, ages 1–30	0.31	0.73	0.18	0.42	0.28	0.67
M, ages 10–30	0.17	0.41	0.09	0.16	0.38	0.87
F, ages 10–30	0.19	0.47	0.09	0.17	0.44	0.92
B, ages 10–30	0.26	0.68	0.11	0.24	0.64	0.99
M, ages 1– 40	0.21	0.48	0.13	0.26	0.19	0.43
F, ages 1–40	0.22	0.52	0.14	0.29	0.20	0.47
B, ages 1–40	0.33	0.75	0.19	0.44	0.30	0.69
M, ages 10–40	0.18	0.43	0.09	0.16	0.41	0.89
F, ages 10–40	0.20	0.50	0.10	0.18	0.47	0.94
B, ages 10–40	0.28	0.71	0.12	0.25	0.68	0.99
All municipalities						
M, ages 1–30	0.19	0.44	0.12	0.24	0.17	0.39
F, ages 1–30	0.20	0.47	0.13	0.26	0.19	0.42
B, ages 1–30	0.30	0.70	0.17	0.40	0.27	0.64
M, ages 10–30	0.17	0.42	0.09	0.16	0.41	0.88
F, ages 10–30	0.20	0.48	0.10	0.17	0.47	0.93
B, ages 10–30	0.28	0.69	0.12	0.24	0.69	0.99
M, ages 1–40	0.20	0.45	0.13	0.25	0.18	0.41
F, ages 1–40	0.21	0.49	0.13	0.27	0.19	0.44
B, ages 1–40	0.32	0.72	0.18	0.41	0.28	0.66
M, ages 10–40	0.19	0.44	0.09	0.16	0.45	0.91
F, ages 10–40	0.21	0.51	0.10	0.18	0.51	0.95
B, ages 10–40	0.30	0.72	0.12	0.25	0.73	0.99

[a] Using thyroid cumulative mean doses or 95th percentile upper bound on the means summed to ages 27 (for risk to age 30) or 37 (for risk to age 40).
[b] Ages shown are age at exposure to final age at observation.

71. Table A-23.13 addresses the impacts of the FHMS screening programme upon estimates of potential thyroid cancer attributable to radiation. It compares the cumulative background (CBRs) and excess (CERs) thyroid cancer with and without the FHMS thyroid screening programme for up to ages 30 or 40. The table indicates that the estimated thyroid cancer CBRs up to ages 30 or 40 were roughly 2–9 times greater for the FHMS than if there were no systematic ultrasound screening, and the numbers of excess suspected or confirmed thyroid cancers would increase proportionately.

Table A-23.13. Thyroid cancer without systematic screening or with Fukushima Health Management Survey screening: estimates of cumulative baseline risks and cumulative excess risks, given the cumulative fractional risks for the Japanese Life Span Study [Furukawa et al., 2013; UNSCEAR, 2020]

Group	*CBR* [a]	*Japanese LSS risk estimates*	
		CER [a]	*CFR (%)*
Females, all doses			
N/S, ages 1–30[b]	8.0	0.82	10.3
FHMS, ages 1–30[b]	32.1	3.3	10.3
N/S, ages 1–40	21.9	1.8	8.4
FHMS, ages 1–40	53.0	4.4	8.4
N/S, ages 10–30	7.9	0.37	4.6
FHMS, ages 10–30	33.4	1.5	4.6
N/S, ages 10–40	21.9	0.90	4.1
FHMS, ages 10–40	54.3	2.2	4.1
Males, all doses			
N/S, ages 1–30[a]	2.2	0.22	10.3
FHMS, ages 1–30	27.1	2.8	10.3
N/S, ages 1–40	5.2	0.43	8.4
FHMS, ages 1–40	48.0	4.0	8.4
N/S, ages 10–30	2.2	0.10	4.6
FHMS, ages 10–30	26.5	1.2	4.6
N/S, ages 10–40	5.2	0.21	4.1
FHMS, ages 10–40	47.4	1.9	4.1

[a] The calculation of CBR is per 10,000 males or females. The cumulative excess risks shown are per 10,000 individuals, given mean cumulative absorbed thyroid doses of about 11 mGy for age 30 and 12 mGy for age 40 (with a dose lag of three years to account for the minimum latency period).
[b] "N/S" stands for "not screened" CBRs and corresponding CFRs (see paragraphs 53–55 of this attachment). "FHMS" indicates CBRs modelled from the FHMS data and extended to ages 30 or 40 years, as described in the text (paragraphs 63–70 of this attachment). Ages shown are age at exposure to final age at observation.

VI. STATISTICAL POWER TO DETECT EXCESS RISKS AMONG WORKERS

72. The discernibility of an excess of all solid cancer (except thyroid cancer and nonmelanoma skin cancer) was assessed among the identified 21,776 male emergency workers after the FDNPS accident [Kitamura et al., 2018]. The estimated average effective dose was low (about 12.5 mSv in the first year after the accident), but statistical power calculations were also performed using a hypothetical 30 mSv upper bound on the average effective dose. To calculate an LBR, the assumption was made that all the workers were 20 years old at the time of exposure, which would yield a larger LBR and LER than exposure at older ages. The calculation of LBRs followed the description in section I of the appendix.

73. As in the general population, the LER was estimated by applying the adjusted LFR coefficient for 20-year-old males as shown in table A-23.9. The resulting statistical power estimates for both the mean dose and hypothetical upper bound dose shown in table A-23.14 indicate no discernible risk of solid cancer. A dose-response statistical power analysis conducted by a Japanese oversight committee confirmed the findings reported here: the expected 60-year incidence of all solid cancer among the potential worker cohort of about 19,000 achieved less

than 40% statistical power with a dose-response analysis based on the LSS dose-response coefficient [JNIOSH, 2020].

74. Shimura et al. [Shimura et al., 2015] identified a subset of 174 FDNPS emergency workers who had received an effective dose of greater than 100 mSv. Similar statistical power calculations were performed for this subset, using the stated mean effective dose of approximately 140 mSv. Because the assessment of the contribution of internal doses was limited, a hypothetical upper bound effective dose was taken to be 250 mSv, as shown in table A-23.14. The statistical power to detect an excess risk in this subset of higher dose workers is very low, owing primarily to the small number of such workers.

75. The risk of excess thyroid cancer among adult worker populations is somewhat uncertain. A variety of studies, including ones with 167,000, 94,000 and 90,000 radiation workers have not found a statistically significant excess risk of thyroid cancer incidence [Haylock et al., 2018; Hunter et al., 2013; Kitahara et al., 2018; Lee et al., 2019]. On the other hand, a case-control study of Chernobyl clean-up workers with an estimated mean thyroid dose of 62 mGy reported a significant excess risk, though possible surveillance bias could not be ruled out [Kesminiene et al., 2012].

76. A subset of 1,757 FDNPS emergency workers was identified who had estimated thyroid doses of >100 mGy. The mean dose in this subset was estimated to be about 370 mGy, with an upper bound on mean dose of about 1 Gy. Using the thyroid cancer LBR and LER estimates for those 20 years old at exposure, the statistical power for detecting an excess risk in this subset was assessed. The results of the statistical power analysis, shown in table A-23.14, indicate that an excess risk would not be expected to be discernible for either the subset of workers with estimated thyroid doses of >100 mGy or for all FDNPS emergency workers, although the discernibility of risks with long-term thyroid screenings could not be estimated.

Table A-23.14. Statistical power to detect excess cancer risks among Fukushima Daiichi Nuclear Power Station emergency workers

All emergency workers (N = 21 135) *Assuming all organs/tissues received a uniform first-year dose to give a mean effective dose of 12.5 mSv; also, assuming a 30 mSv upper bound dose (no doses from subsequent years were added)*	*Statistical power at mean dose*	*Statistical power at assumed upper bound dose*
All solid cancers	0.09	0.17
Leukaemia	0.10	0.21
Thyroid cancer [a,b]	0.06	0.06
Workers with >100 mSv (N = 174), mean ~140 mSv, and an assumed 250 mSv upper bound dose (no doses from subsequent years were added)		
All solid cancer	0.09	0.13
Leukaemia	0.09	0.13
Thyroid cancer [a,b]	0.06	0.07
Workers with thyroid doses >100 mGy (N = 1 757), estimated mean thyroid dose 370 mGy, assumed upper bound dose 1 Gy [a]	0.18	0.53

[a] Under the assumption of no special thyroid screening.
[b] Assuming only a uniform whole-body dose.

VII. OVERALL INTERPRETATION AND DISCUSSION

77. The goal of the statistical power calculations was to determine if radiation risks for several of the most radiosensitive cancers and ages at exposure would likely be discernible above the background rates of those diseases, given the number of relevant individuals and average doses in Fukushima Prefecture. Potential risks to FDNPS emergency workers were also examined.

78. Statistical power analyses were conducted using municipality-average doses and 95% upper bounds on the average doses. Risks were projected using a linear no-threshold model. The approach intentionally built some conservatism into the risk estimation, so as not to underestimate risk. The results generally do not point toward an expectation of discernible risks, given the estimated doses to the population, although there appeared to be some possibility of detecting an excess leukaemia risk in the group who were of ages in utero to five years at the time of the FDNPS accident. Parallel calculations at the 95% upper bound of doses, even though such doses are less likely, have also supported the notion that risks would not be discernible for the most part. As pointed out, especially in paragraph 46 of this attachment, there are reasons to view the several suggestions of potentially detectable elevated risks at the upper bound doses as probably unrealistic in view of the intrinsic variability in cancer rates among localities.

79. Several conservative assumptions were made in estimating statistical power (i.e., assumptions that would tend to overestimate statistical power). The often considerable uncertainties in the lifetime baseline risks (for example, for thyroid cancer) were not accounted for, and such uncertainties would tend to diminish statistical power. Modelling of the Japanese atomic bombing survivor LSS indicates that for a variety of cancer endpoints, the ERR estimate of risk decreases with increasing attained age [Preston et al., 2007]. The modelling of lifetime excess risk here, however, assumed the ERR was constant at all attained ages, which would tend to overestimate risk at the older ages when the models were based primarily on data for younger ages. It was assumed that malignancies in the exposed population could be detected without any under-ascertainment or misdiagnosis. For the analysis of the risk of excess thyroid cancer in the FHMS cohort, a continuing participation rate higher than that actually observed was used to project future risk, and a constant rather than declining rate of thyroid cancer detection was projected although the observed detection rate was declining with successive screenings. These, and other somewhat conservative assumptions, were incorporated to help guard against underestimating the statistical power to detect risks.

80. On the other hand, several limitations of the results of the statistical power analyses should be kept in mind. Ad hoc methods were used to update and adjust the excess rates (LERs, CERs) without conducting a full reassessment with the sophisticated methods that are sometimes employed but require more detailed modelling and more information to implement (e.g., [Little et al., 2010; UNSCEAR, 2008]). However, most of the adjustments and risk coefficients were rather small, so it is not believed that validity was seriously compromised. Perhaps the greatest limitation is that insufficient information was available to model statistical power for dose-response analyses based on individuals. The only statistical power analysis available based on an individual dose distribution was of FDNPS emergency workers; it confirmed the present findings of low statistical power to detect radiation risk for all solid cancer among the workers [JNIOSH, 2020]. The calculation of statistical power assumed that both LBRs and LERs were known precisely and accurately (without bias), and realistic uncertainties in those estimates could not be taken into account. Furthermore, the power analyses did not incorporate uncertainties in the forms of the models or of the risk-coefficients employed, though they did evaluate dose uncertainties. When calculated LFRs were not available in the original sources, the statistical power analyses were based on simple ERR models rather than EAR models, because EAR

coefficients were not always available and EAR models are difficult to generalize across populations, ages and variations in the prevalence of disease screening.

81. The statistical power analyses have implications for potential epidemiological studies of Fukushima risks from ionizing radiation after the FNDPS accident. Epidemiological study designs are likely to include only a fraction of the population of a given age range affected by the FDNPS accident. This implies that the statistical power would probably be less than for the prefecture-wide analyses reported here. Although a dose-response analysis for individuals would likely increase the statistical power if the doses were well estimated, for Fukushima Prefecture residents there are substantial uncertainties in reconstructing individual doses that would restrict the statistical power.

VIII. CONCLUSIONS

82. Analyses were conducted of lifetime risks for particularly radiosensitive malignancies: leukaemia, thyroid cancer and female breast cancer, as well as all solid cancers (excluding thyroid cancer and nonmelanoma skin cancer). For the best estimates of organ/tissue doses, radiation-related risks for these malignancies are not expected to be discernible. For risks at young ages – up to ages 30 or 40 years – the risk of thyroid cancer (without a systematic thyroid screening programme) was not likely to be detectable based on the best estimates (means) of organ/tissue doses, although there was mixed evidence regarding possible discernibility of leukaemia risk after exposure in early childhood. Projections of the FHMS ultrasound thyroid screening programme up to ages 30 or 40 years did not indicate discernible risks using any of three different risk models. Taking dose uncertainties into account, there were a few indications that at the 95% upper bound on the average doses a few risks might be detectable in the future, but those are thought to be unlikely in that, among other things, the variation in background cancer rates will be greater than has been assumed in this assessment. All in all, there was no indication that large excesses of cancer would be expected, and no clear indication that the estimated numerically small excesses would likely be discernible.

APPENDIX

I. CALCULATION OF LIFETIME BASELINE RISKS

A1. The statistical power attachment [UNSCEAR, 2016] to the UNSCEAR 2013 Report [UNSCEAR, 2014] contained information from formal calculations of LBRs for most of the cancer endpoints being considered here by age at initial exposure and sex [Walsh et al., 2014; WHO, 2013]. Given that the baseline cancer rates used in the UNSCEAR 2013 Report are now somewhat outdated, this assessment updated the previous LBR estimates using newer baseline cancer incidence rates [IARC, 2017].

A2. Specifically, in the 2013 statistical power calculations [UNSCEAR, 2016], the LBRs were based on the average of cancer incidence rates for 2000–2004 in four prefectures (Fukui, Miyagi, Nagasaki and Yamagata) that had reasonably good, long-term prefecture-wide cancer registries [IARC, 2013; Katanoda et al., 2012]. The most recent update of IARC cancer incidence rates for 2008–2012 [IARC, 2017] in the four Japanese prefectures was used for the present calculations. The age- and sex-specific rates for leukaemia, thyroid cancer, breast cancer (females only) and all solid cancer (less nonmelanoma skin cancer and thyroid cancer) were obtained from the IARC tabulations for the prefectures. However, in the case of leukaemia, Nagasaki Prefecture was excluded in calculating the average rates, because it appeared that at older ages the rates were substantially elevated above those of the other prefectures, perhaps because of the radiation exposure by the atomic bombings of Nagasaki, or because of the high prevalence in Nagasaki of adult T-cell leukaemia which is related to HTLV-1 viral exposure [Tajima et al., 1990]. The age-sex specific leukaemia rates were applied to the numbers of persons then at risk of an incident first-primary cancer which were derived after accounting for prior cumulative rates of mortality [Vital Statistics of Japan, 2019] and cancer diagnosis (designated as "cancer-free survival").

A3. These LBRs, shown in table A-23.A1, were then applied to Fukushima Prefecture subgroups by determining the numbers of individuals in the various subgroups defined by sex, age and municipality from the 2010 Japan census data [Statistics Bureau of Japan, 2011]. Additional individuals who were in utero at the time of the FDNPS accident were added to the census numbers and included in the calculations. Table A-23.A1 compares the cumulative lifetime baseline risks from the UNSCEAR 2013 Report and the present report.

Table A-23.A1. Cumulative lifetime baseline risk (to age 90 years) estimates of selected malignancies, for the UNSCEAR 2013 Report [UNSCEAR, 2014] and this UNSCEAR report

Starting age (years)	*Male*		*Female*	
	UNSCEAR 2013 Report (LBR (%))	*This assessment (LBR (%))*	*UNSCEAR 2013 Report (LBR (%))*	*This assessment (LBR (%))*
All solid cancer (except thyroid cancer and nonmelanoma skin cancer)[a]				
1	40.6	42.8	29.0	29.9
10	40.7	42.8	29.1	29.9
20	40.7	42.7	29.1	29.8
Leukaemia				
1	0.60	0.63	0.43	0.47
10	0.58	0.57	0.41	0.42
20	0.57	0.55	0.40	0.40

Starting age (years)	*Male*		*Female*	
	UNSCEAR 2013 Report (LBR (%))	*This assessment (LBR (%))*	*UNSCEAR 2013 Report (LBR (%))*	*This assessment (LBR (%))*
Breast cancer				
1			5.5	6.1
10			5.5	6.1
20			5.6	6.1
Thyroid cancer [a]				
1	0.21	0.37	0.77	1.15
10	0.21	0.37	0.77	1.15
20	0.21	0.37	0.76	1.14

[a] Thyroid cancer is treated separately in what follows because doses to the thyroid gland in some geographic areas were substantially greater than doses to other organs. The 2013 LBR thyroid cancer estimates were based on Walsh et al. [Walsh et al., 2014].

II. CALCULATION OF LIFETIME EXCESS RISKS AND LIFETIME FRACTIONAL RISKS

A4. It would theoretically be inappropriate to apply the final cumulative dose to all person-years at risk, as that would imply that the dose received at some late age could affect risk at an earlier time. However, in this study most of the dose was received at early ages; for example, for those exposed at age 1 year, over 70% of the dose was received by 10 years after initial exposure, 95% by 40 years and about 99% by 60 years. For thyroid cancer, a large percentage of the lifetime thyroid dose was received in the first year. Using the calculated lifetime dose (to age 80 years) therefore has virtually no impact on the risk assessment.

A5. Estimated LERs and LFRs for the radiation-related incidence of all solid cancer, breast cancer, leukaemia and thyroid cancer by sex for those of ages 1, 10 or 20 years at the time of the FDNPS accident were developed based on recent risk estimates. For breast cancer and all solid cancer (except nonmelanoma skin cancer and thyroid cancer), the calculation started with the respective age/sex-specific LERs from the WHO Fukushima report [WHO, 2013] which they termed “lifetime attributable risks” (LARs). These were provided in dose-standardized form by Walsh et al. [Walsh et al., 2014]. The applicable estimated doses were to the colon for all solid cancer and the female breast, RBM (leukaemia) and thyroid gland. An LFR is simply the ratio of the LER to its corresponding LBR. For all solid cancer the LERs and LFRs were updated by using the ratio of the newest ERR coefficients for all solid cancer from Grant et al. [Grant et al., 2017] to the ERRs previously used from Preston et al. [Preston et al., 2007]. The ratio of those coefficients was 1.10 for females and 1.03 for males. For female breast cancer the ratio of the age-specific ERR coefficients derived from the recent report of Brenner et al. [Brenner et al., 2018] to the coefficients of the earlier Preston et al. report [Preston et al., 2007] were applied to update the LERs and LFRs. The estimated ratio was 1.29.

A6. The application of the LFRs to the study subgroups defined by sex and age (ages 1, 10, 20 years) entailed several steps:

(a) Calculation of organ/tissue doses for municipalities by age groups. For each municipality in Fukushima Prefecture, the numbers of individuals for each sex/age subgroup were determined from the 2010 Japan census data [Statistics Bureau of Japan, 2011], or they were derived from [Fujimori et al., 2014] for those exposed in utero. The person-weighted mean lifetime doses for prefecture residents for the colon (for all solid cancer), RBM (for leukaemia), breast and thyroid gland were estimated by the Committee. Similarly, the

95th percentile upper bound estimates of the mean doses were calculated by the Committee by Monte Carlo sampling. Lifetime doses were calculated separately for evacuated and non-evacuated municipalities. Because cumulative doses out to age 80 were estimated by the Committee only for effective dose and absorbed dose to the thyroid, ratios of first-year organ/tissue dose to first-year effective dose were used to estimate lifetime doses for the other organs/tissues of interest, e.g., mean lifetime RBM dose for an age group in a given municipality (and similarly for the 95th percentile upper bound). For example, for leukaemia this was carried out by summing the year-one RBM dose, and the second year to age 80 cumulative dose times the year-one ratio of the RBM dose to effective dose. This was performed for ages 1, 10 and 20 years for each municipality, where typical yearly effective doses to age 80, given a particular year-one dose, were as estimated by the Committee ($RBM_{Av\text{-}Y1}$ / $Eff\text{-}dose_{Av\text{-}Y1}$) = average ratio of RBM dose to effective dose in year one, based on average doses across municipalities;

(b) Derivation of the mean and 95th percentile upper bound of the mean doses for the subset of municipalities that had estimated lifetime effective doses of >5 mSv at age 1. The estimated mean lifetime doses (estimated cumulative dose over 80 years) and estimated 95th percentile upper bound on the mean lifetime doses were derived in a similar way. If a fraction of individuals was evacuated from a municipality (which notably occurred in three municipalities), only the non-evacuated subset was used. The applicable numbers of individuals for the subgroups defined by sex and age at exposure were estimated from the census data [Statistics Bureau of Japan, 2011];

(c) Another subset included the evacuees, who experienced different patterns of evacuation (40 scenarios in all), and the person-weighted mean doses for relevant organs/tissues were similarly obtained for that subset. The numbers of individuals in the subgroups defined by sex and age at exposure were again estimated. The first-year doses, which took into account both evacuation and destination sites and calendar times, were converted to approximate cumulative lifetime doses for individual cancer sites, using the simplifying assumption that their destination site was their residence for the remaining lifetime;

(d) The LFRs and LERs per 1 mGy were then multiplied by the estimated lifetime mean dose for the subsets of people in various age, sex and dose groups. Strictly speaking, the LFRs and LERs are not precisely linearly related to dose, but at doses below a few hundred mGy a linear dose transform is a good approximation [Walsh et al., 2014]. The LFR (ratio of the LER to the respective LBR) can be used to calculate statistical power;

(e) For the subgroups selected, the estimated LFRs and LERs were also calculated using the 95th percentile upper bounds on the respective mean dose estimates. The 95th percentile upper bounds of the first-year mean doses for the relevant organs were derived for each municipality in Fukushima Prefecture by Monte Carlo sampling as part of the dosimetry evaluation (see attachments A-13 to A-19).

A7. Table A-23.A2 provides a selection of the LFRs that were used to calculate hypothetical lifetime risks of leukaemia attributable to radiation according to various models. A description of the models is given in paragraph 32 of this attachment. Similarly, table A-23.A3 provides a selection of the LFRs that were used to calculate estimated lifetime risks of thyroid cancer (without population screening) according to the designated models, as described in paragraph 38 of this attachment.

Table A-23.A2. Leukaemia, lifetime fractional risk (LFR) attributable to radiation exposure: LFRs for mean and 95th percentile upper coverage bound on mean lifetime doses by sex and age at the time of the Fukushima Daiichi Nuclear Power Station accident for all residents of evacuated and non-evacuated municipalities and for those with >5 mSv cumulative lifetime effective dose. LFRs are shown for various models of risk

Group – sex and age (years)	*LFRs (%) using WHO risk estimates* [a]		*LFRs (%) using UNSCEAR 2020 risk estimates* [b]		*LFRs (%) using LSS risk estimates* [c]		*LFRs (%) using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with cumulative effective dose >5 mSv								
Male								
1	2.31	3.74	10.9	17.6	8.29	13.4	4.30	6.96
10	1.32	2.09	7.16	11.4	2.76	4.37	2.74	4.34
20	0.96	1.47	1.20	1.84	1.02	1.56		
Female								
1	2.19	3.54	13.2	21.4	9.92	16.0	4.79	7.75
10	1.26	2.00	9.13	14.5	3.21	5.09	3.18	5.05
20	0.91	1.40	1.14	1.75	0.67	1.03		
All municipalities								
Male								
1	1.64	2.66	7.70	12.5	5.87	9.55	3.05	4.96
10	0.89	1.41	4.82	7.65	1.85	2.94	1.84	2.92
20	0.69	1.06	0.86	1.32	0.73	1.12		
Female								
1	1.55	2.52	9.38	15.3	7.02	11.4	3.39	5.52
10	0.85	1.35	6.14	9.75	2.16	3.43	2.14	3.40
20	0.65	1.00	0.82	1.26	0.48	0.74		

[a] [Walsh et al., 2014; WHO, 2013].
[b] [UNSCEAR, 2020].
[c] [Hsu et al., 2013].
[d] [Little et al., 2018].
[e] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.

Table A-23.A3. Thyroid cancer (without systematic screening), lifetime fractional risk (LFR) attributable to radiation exposure: LFRs for mean and 95th percentile upper coverage bound on the mean lifetime doses by sex and age at the time of the Fukushima Daiichi Nuclear Power Station accident for all residents of evacuated and non-evacuated municipalities and for those with thyroid doses >5 mGy in the first year. LFRs are shown for various models of risk

Group – sex and age (years)	*LFRs (%) using WHO risk estimates* [a]		*LFRs (%) using LSS risk estimates* [b]		*LFRs (%) using Chernobyl risk estimates* [c]		*LFRs (%) using pooled risk estimate* [d]	
	Mean tissue dose [e]	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*	*Mean tissue dose*	*95%ile upper bound on mean dose*
Municipalities with first year absorbed thyroid dose >5 mGy								
Male								
1	5.40	10.9	3.11	6.26	5.99	12.0	6.68	13.4
10	3.88	8.12	2.55	5.33	3.83	8.02	5.91	12.4
20	1.56	3.07	0.46	0.90			1.56	3.07
Female								
1	6.67	13.42	3.11	6.26	7.19	14.5	8.09	16.3
10	4.87	10.2	2.55	5.33	9.65	6.16	7.35	15.4
20	1.56	3.07	0.46	0.90			1.56	1.82
All municipalities								
Male								
1	4.24	8.45	2.44	4.87	4.70	9.37	5.24	10.4
10	2.16	4.34	1.42	2.85	2.14	4.29	3.30	6.62
20	0.85	1.61	0.25	0.47			0.85	1.61
Female								
1	5.24	10.4	2.44	4.87	5.64	11.2	6.35	12.7
10	2.72	5.45	1.42	2.85	2.57	5.76	4.10	8.23
20	085	1.61	0.25	0.47			0.85	1.01

[a] [Walsh et al., 2014; WHO, 2013].
[b] [Furukawa et al., 2013].
[c] [Brenner et al., 2011; Zablotska et al., 2011].
[d] [Lubin et al., 2017].
[e] Based on cumulative mean doses and 95th percentile upper bounds on the means, summed to age 80 years.

III. LEUKAEMIA RISK: CALCULATION OF CUMULATIVE FRACTIONAL RISK FROM AGES 1 OR 10 YEARS TO AGES 30 AND 40 YEARS

A8. The CFRs of the models employed for estimating leukaemia risks from ages 1 or 10 years to 30 and 40 years of age are given in table A-23.A4. The values are scaled to the estimated cumulative doses for all municipalities in Fukushima Prefecture up to 28 or 38 years of age, respectively, to allow for a two-year dose latency period. The same coefficients per 100 mGy were applied for both sexes, as no statistically significant differentials by sex were reported. Cumulative baseline rates are also reported for males and females.

Table A-23.A4. Leukaemia, cumulative fractional risk (CFR) attributable to radiation exposure: CFRs for mean and 95th percentile upper coverage bound on the mean cumulative doses by age at the time of the Fukushima Daiichi Nuclear Power Station accident to ages 30 or 40 years, for all residents of evacuated and non-evacuated municipalities and for municipalities with >5 mSv cumulative effective doses. LFRs are shown for various models of risk

Age initial exposure to final age of observation	*Cumulative baseline risk: male; female (%)*	*CFRs using UNSCEAR 2020 risk estimates* [a]		*CFRs using LSS risk estimates* [b]		*CFRs using pooled-analysis risk estimates* [c]	
		At mean tissue dose (%) [d]	*At 95%ile upper bound on mean dose (%)*	*At mean tissue dose (%)*	*At 95%ile upper bound on mean dose (%)*	*At mean tissue dose (%)*	*At 95%ile upper bound on mean dose (%)*
Municipalities with cumulative effective dose >5 mSv							
1–30	0.113; 0.096	32.2	52.0	30.5	49.3	9.3	15.1
1–40	0.146; 0.129	34.9	56.4	25.0	40.5	9.8	15.8
10–30	0.062; 0.052	28.5	45.1	10.9	17.3	8.0	12.6
10–40	0.095; 0.086	32.1	50.8	8.8	13.9	8.7	13.8
All municipalities							
1–30	0.113; 0.096	23.3	37.9	22.1	36.0	6.7	11.0
1–40	0.146; 0.129	24.1	39.2	17.3	28.1	6.7	11.0
10–30	0.062; 0.052	24.1	39.2	9.2	15.0	6.7	11.0
10–40	0.095; 0.086	24.9	40.5	6.8	11.1	6.7	11.0

[a] [UNSCEAR, 2020].
[b] [Hsu et al., 2013; UNSCEAR, 2020].
[c] [Little et al., 2018].
[d] Using RBM cumulative mean doses or 95th percentile upper bound on the means summed to ages 28 (for risk to age 30) or 38 (for risk to age 40).

IV. THYROID CANCER RISK: CALCULATION OF CUMULATIVE EXCESS RISK AND CUMULATIVE FRACTIONAL RISK TO AGES 30 OR 40 YEARS

A9. Three approaches were used in estimating CERs for thyroid cancer (without systematic thyroid screening) up to ages 30 or 40 years. First, thyroid cancer CER estimates of radiation risk after exposure at ages 1 or 10 years were [UNSCEAR, 2020] based on ERR estimates from the Japanese atomic bombing survivor LSS [Furukawa et al., 2013; Jacob et al., 2014] which were adopted as CFR estimates. The CFR estimates at a thyroid dose of 100 mGy were 0.196, 0.128 and 0.027 at ages 1, 10 and 20 years, respectively.

A10. Second, CFRs were calculated based on two studies of exposure to radioactive iodine isotopes from the Chernobyl accident in the Ukraine [Brenner et al., 2011] and Belarus [Zablotska et al., 2011]. Both studies had individual estimates of dose from ^{131}I based mainly on thyroid measurements made within a few weeks after the accident, with additional modelling of related characteristics [Likhtarov et al., 2014] (but with fewer individual thyroid measurements of radioactive iodine exposure in the Belarus study). In neither study did the ERR estimates differ statistically significantly by sex: female ERRs tended to be larger in the Ukraine study, but male ERRs were nominally larger in the Belarusian study. For those exposed at ages 0–3 or 0–4 years, the ERRs were 0.74 (95% CI: not estimable) and 0.40 (95% CI: 0.10, 1.5) per 100 mGy for the

Ukrainian and Belarusian studies, respectively. At ages 4 or 5 to 11 years, the ERRs were 0.16 (95% CI: 0, 0.85) and 0.20 (95% CI: 0.041, 0.62) per 100 mGy, respectively. For calculating CFR estimates, approximate averages of the ERRs were used as notional coefficients: CFR of 0.58 per 100 mGy for exposure at age 1 year and 0.18 for age 10 years.

A11. Third, CFRs were also calculated based on a recent pooled analysis of nine studies of low-dose childhood external radiation exposure [Lubin et al., 2017]. The ERR coefficient derived from individuals who received thyroid doses up to 100 mGy was used as the CFR: 0.86 at 100 mGy. Since Lubin et al. [Lubin et al., 2017] did not find statistically significant differences in risk coefficients by age at exposure, the same coefficient was applied for those exposed at 1 and 10 years of age.

V. FUKUSHIMA HEALTH MANAGEMENT SURVEY THYROID CANCER RISK: CALCULATIONS BASED ON THE FUKUSHIMA HEALTH MANAGEMENT SURVEY ULTRASOUND THYROID EXAMINATION PROGRAMME

A12. Data were evaluated for the first three rounds of FHMS ultrasound thyroid examinations (hereafter, "screenings") to apply risk coefficients to estimate the likelihood that excess thyroid cancer would be detectable in the FHMS study.

A13. The rates of ascertained thyroid cancers has declined with successive rounds of ultrasound screening, even though usual sporadic thyroid cancer rates increase with age. The decrease probably reflects a "harvesting effect" when there are multiple rounds of screening within a few years: the first "prevalence" screening detects both indolent pre-existing cancers and early incident cancers, and the early detection leads to lower numbers of detected cases at later screenings [Jacob et al., 2014]. Thus, the overall rates of thyroid cancer per year on average for the intervals (from the FDNPS accident to the first screening, then between successive screenings) were estimated to be 2.0, 1.2 and 0.6 per 10,000 persons per year for the first three rounds of screening, respectively. The second and third screenings were considered to represent incident cancers (i.e., newly occurring cancers), which are the primary basis of the calculations.

A14. The analysis was based on the number of screened people at the second round of screening because:

- The first round of screening primarily reflected the prevalence of detectable thyroid cancers before radiation effects would be expressed (the first round of screening began about six months after the FDNPS accident and continued until about four years after the accident), and many of these thyroid cancers would have been present at the time of the accident;
- It was thought unlikely that the number of future screened people would increase beyond the second round number of participants. This was borne out by the decreasing numbers screened in rounds 1, 2 and 3: 300,476, 270,516 and 217,904, respectively. Beginning with round 2, an unknown number of individuals who were exposed in utero (out of a total of about 16,000 in Fukushima Prefecture [Fujimori et al., 2014]) were also screened and were included in the age 1 year numbers used in the calculations. Analyses also added into the baseline rate the age-appropriate rate of thyroid cancer detected at the first screening, which increased the statistical power slightly. Since the first screening occurred within roughly 0.5–4 years after the accident, the first screening thyroid cancer rate was only added in for the 10-year-old cohort, because, in the first screening, no thyroid cancers were diagnosed among those younger than 6 years of age at the accident, so the rate was zero for those considered to be exposed at one year of age.

A15. First, the numbers of screened people in the subcohorts had to be established. As elaborated below, the number of screened people and cancers ascertained, by age and sex, was based on numbers in the second and third rounds of screening.

A16. Certain approximations had to be made to model risk in the FHMS. Because the numbers of screened males and females by age at initial exposure were not available, approximate fractions of the screened FHMS cohort by age and sex were made from the results of the first-round screening, which was conducted soon after the accident. The fraction of total screened people who were tallied as ages 0–5 years at the time of the first round of screening was considered to be the fraction in the age 1 year group, and the remaining proportion, those of ages 6–18 years at first round screening, was considered the fraction in the 10-year-old group. These fractions were applied to the second round of screening to define the age 1 year and age 10 years groups. The proportion of those with first-year doses >5 mGy also was approximated from the corresponding proportion of 1-year-old infants in Fukushima Prefecture who were in municipalities with first-year thyroid doses >5 mGy; this proportion was applied to define >5 mGy groups in the FHMS.

A17. The modelling of thyroid cancer in the FHMS approximated the observed yearly rates of thyroid cancer based on male and female observed cancers by year of age and categorized into the FHMS-reported age-category denominators. Estimates of average intervals of time from the FDNPS accident to first screening, first to second screening, and second to third screening were then applied to derive estimates of annual rates of thyroid cancer. The estimated intervals were 1.95, 2.10 and 2.15 years, respectively.

1. Calculation of cumulative baseline risks

A18. Because the FHMS thyroid ultrasound examinations have found high frequencies of suspected/confirmed thyroid cancer, there is no other existing reference with comparable baseline thyroid cancer rates. Therefore an ad hoc methodology was employed to estimate CBRs of thyroid cancer from existing FHMS data, and then to project CBRs into the future up to ages 30 or 40 years. The approach was to use the actual rates of thyroid cancer found in the rounds of screening for various age groups up to 20 years of age. As described above, the numbers of thyroid cancers by screening age and sex were obtained in rounds 2 and 3 of the FHMS screening, and sex and age-specific annual rates of “suspected or confirmed” thyroid cancers detected by fine-needle aspiration biopsy were estimated up to age 20 years. The rates for various age groups were derived from [FHMS, 2016; FHMS, 2017; FHMS, 2020].

A19. After age 20 years the rates were projected forward to age 30 or 40 years by assuming the annual thyroid cancer rates with screening would increase in proportion to the corresponding age-related baseline rates of thyroid cancer (without both radiation and systematic screening) in the Japanese population. The rates were calculated to increase by about 5.6% per year of age for males and 5.7% for females, based on four tumour registries in unexposed prefectures. However, because the proportion participating in the FHMS screening after about age 18 years fell off sharply in the second and third rounds of screening to 25.7% and 16.4%, respectively, the modelling was made more realistic by taking the participation rate into account. A conservative assumption (that is, overestimating the theoretical number of detected cancers) was made that 30% continued to be examined from age 20 to ages 30 or 40 years, while the remaining 70% would have only baseline thyroid cancer rates for ages 20 to 30, or 20 to 40, corresponding to the rates elsewhere in Japan where there is almost no population ultrasound screening of young adults. This projection is also likely to be conservative, because it ignores the “harvesting” effect of the early detection of thyroid cancers.

A20. The steps to estimate the CBRs are briefly described:

(a) The sex- and age-specific person-weighted average annual rates of thyroid cancer were calculated for the second and third rounds of screening ("incident cancers") based on the numbers of thyroid cancers found in various age categories, as given in FHMS reports. Average intervals between screenings were estimated to convert the risks to average annual rates;

(b) Beginning with the sex- and age-specific numbers of screened people and thyroid cancers observed in the second and third rounds of FHMS screening, annual sex- and age-specific cancer rates were estimated from the screening data to derive the cumulative thyroid cancer risk up to age 20 years. To implement this, lifetable calculations were performed, adjusting for cancer-free survival, i.e., decrementing the population at risk yearly to account for the estimated proportions with prior mortality (based on all-Japan rates) or prior thyroid cancers (from the FHMS data);

(c) After 20 years of age, the annual percentage increase in thyroid cancer rates was calculated (using the averages of rates from four essentially unexposed prefectures – (Fukui, Miyagi, Nagasaki and Yamagata) [IARC, 2017] based on the ratio of the rates at age 35–39 years to the rates at age 20–24 years, separately for males and females. The annual percentage increases were then applied to estimate thyroid cancer rates for ages 21–30 years or 21–40 years. The increments were about 5.6% per year for males and 5.7% for females. Annual proportional increments were applied to the age 20 cumulative screening rates of thyroid cancer for 30% of the cohort, the proportion assumed to continue with screening, and the baseline thyroid cancer rates without screening were applied to the remaining 70%.

A21. Table A-23.A5 shows basic data for the second and third rounds of screening, from which the FHMS CBRs were generated. Information on the first-round screening is presented also, even though first screening results were used only to increment the baseline rate of thyroid cancer at age 10 years (using the rate for ages 11–15 years).

Table A-23.A5. Number of participants, number of cytologically diagnosed suspicious/malignant (S/M) thyroid tumours and annual rates of tumours by sex and age group at screening, for the first through third screenings

	Age at screening (years)[a]				
First screening	0–5	6–10	11–15	16–22	Total
No. males	45 065	47 201	43 351	16 068	151 685
No. S/M thyroid cancers [b]	0	0	11	28	39
Yearly rate [c,d]	0	0	1.3	9.0	1.3
No. females	42 732	44 804	42 769	18 486	148 791
No. S/M thyroid cancers	0	1	19	57	77
Yearly rate	0	0.11	2.3	15.8	2.7
Second screening	2–7	8–12	13–17	18–23	Total
No. males	31 764	43 683	45 526	15 414	136 387
No. S/M thyroid cancers	0	5	9	18	32
Yearly rate	0	0.55	0.94	5.6	1.1
No. females	30 072	41 699	44 017	18 322	134 110
No. S/M thyroid cancers	0	3	22	14	39
Yearly rate	0.34	2.4	3.6	1.4	1.4

	Age at screening (years)[a]				
Third screening	4–9	10–14	15–19	20–24	Total
No. males	32 242	41 662	31 821	4 325	110 050
No. S/M thyroid cancers	0	4	7	2	12
Yearly rate	0	0.45	1.0	2.2	0.50
No. females	30 456	40 004	31 760	5 627	107 847
No. S/M thyroid cancers	0	5	12	1	18
Yearly rate	0	0.58	1.8	0.83	0.77

[a] Ages at the time of screening.
[b] S/M = suspicious or malignant thyroid cancer by cytological determination.
[c] Rates given per 10,000 person-years. Numbers of S/M cancers and participants by age and sex were obtained from [FHMS, 2016; FHMS, 2017; FHMS, 2020].
[d] Yearly rates assumed mean intervals of 1.95 years from the accident to the first screening, 2.1 years from the first to the second screening, and 2.15 years from the second to the third screening.

2. Calculation of cumulative excess risks and cumulative fractional risks

A22. As described in paragraphs 23–24 of this attachment, first-year thyroid doses for non-evacuated and evacuated municipalities were estimated by the Committee, and the temporal course of continuing thyroid doses was also estimated. The cumulative dose estimates out to ages 27 or 37 years (to allow for a three-year latency period to ages 30 or 40 years, respectively) were applied to the risk coefficients for CER estimation.

A23. The recent UNSCEAR report [UNSCEAR, 2020] has estimated CBR and CER risks for thyroid cancer after exposure beginning at age 1 or 10 years, basing the CBRs on the Ukrainian population. However, because the background rates in the FHMS with ultrasound screening differ from those in the Ukraine, the UNSCEAR report could not be used directly for this assessment. Therefore, the CFRs, the ratios of the CERs to the corresponding CBRs, in the UNSCEAR report were used by applying the CFRs to the baseline thyroid cancer rates (CBRs) derived in the FHMS. For those exposed at age 1 year, the CFRs after a thyroid dose of 100 mGy were about 0.79 and 0.68 for follow-up to ages 30 and 40 years, respectively, in the UNSCEAR report [UNSCEAR, 2020]. The corresponding ratios for those exposed at age 10 years were about 0.41 and 0.35 at 100 mGy, respectively. The risk coefficients derived in the report did not vary significantly by sex in the UNSCEAR report analysis, so the same CFRs were applied to both sexes in their estimation of risks.

A24. CFRs were also calculated based on two studies of exposure to ^{131}I and other radioisotopes of iodine from the Chernobyl accident in the Ukraine [Brenner et al., 2011] and Belarus [Zablotska et al., 2011], as described in section IV of this appendix. The notional average risk coefficients from those studies for ages 1 and 10 years were applied to the FHMS baseline risks. The statistical power results are shown in the main text, table A-23.12. In addition, CFRs based on the pooled analysis of nine studies of external irradiation and thyroid cancer risk at doses of 100 mGy or less by Lubin et al. [Lubin et al., 2017] were applied to the calculated CBRs, with statistical power results shown in table A-23.12.

VI. ARITHMETIC MEAN OR AVERAGE DOSES AND UPPER BOUNDS (95TH PERCENTILES) ON THE MEANS FOR MUNICIPALITIES IN FUKUSHIMA PREFECTURE AND FOR EVACUATED GROUPS

A25. This section comprises a number of tables that contain the Committee's estimates of the arithmetic mean doses in the first year and over a lifetime, to those residing in each of the non-evacuated municipalities of Fukushima Prefecture and for those residents evacuated from one or other locations of Fukushima Prefecture. In addition, the tables provide the estimates of upper bounds (95th percentile) on the mean doses.

A26. For the non-evacuated municipalities in Fukushima Prefecture the mean first-year doses and upper bounds are tabulated for effective dose and absorbed dose in the thyroid, breast, colon and RBM for three ages at exposure: adults (table A-23.A6), 10-year-old children (table A-23.A7) and 1-year-old infants (table A-23.A8). In addition, the means and upper bounds on the absorbed dose to thyroid and to the RBM for a fetus in the first year after the accident are tabulated (table A-23.A9). Table A-23.A10 shows the means and upper coverage bounds on the effective dose over a lifetime for adults, 10-year-old children and 1-year-old infants for Fukushima Prefecture (excluding evacuated areas).

A27. For the evacuated locations, the arithmetic mean and upper bound doses in the first year are tabulated for effective dose and absorbed dose in the thyroid for three ages at exposure: adults (table A-23.A11), 10-year-old children (table A-23.A12) and 1-year-old infants (table A-23.A13).

Table A-23.A6. Mean and upper bound[a] on the effective dose, absorbed dose to thyroid, absorbed dose to breast, absorbed dose to colon and absorbed dose to red bone marrow for adults in the first year after the accident for municipalities in Fukushima Prefecture (excluding evacuated areas)

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Aizubange Machi	0.69	1.1	1.2	2.5	0.75	1.2	0.69	1.1	0.68	1.1
Aizumisato Machi	0.30	0.53	0.82	2.0	0.30	0.50	0.29	0.49	0.28	0.46
Aizuwakamatsu Shi	0.55	0.94	1.1	2.5	0.59	0.94	0.55	0.89	0.53	0.85
Asakawa Machi	0.47	0.76	1.0	2.1	0.49	0.76	0.47	0.72	0.45	0.69
Bandai Machi	0.49	0.81	1.3	2.8	0.51	0.79	0.48	0.75	0.46	0.72
Date Shi	2.6	4.4	6.2	17	2.8	4.4	2.5	4.0	2.5	3.9
Fukushima Shi	3.8	6.2	7.2	15	4.1	6.2	3.7	5.7	3.7	5.6
Furudono Machi	0.43	0.72	1.2	2.5	0.44	0.69	0.43	0.67	0.40	0.63
Hanawa Machi	0.41	0.69	1.2	2.5	0.42	0.64	0.40	0.62	0.38	0.59
Hinoemata Mura	0.079	0.17	0.46	1.3	0.07	0.11	0.07	0.13	0.07	0.12
Hirata Mura	0.40	0.67	1.0	2.1	0.42	0.65	0.40	0.62	0.39	0.60
Inawashiro Machi	0.49	0.88	1.9	5.3	0.48	0.77	0.45	0.73	0.43	0.71
Ishikawa Machi	0.24	0.42	0.73	1.7	0.24	0.38	0.24	0.38	0.22	0.36
Iwaki Shi	0.84	1.5	2.6	7.5	0.87	1.4	0.84	1.3	0.79	1.2
Izumizaki Mura	0.95	1.5	1.5	2.9	1.0	1.6	0.96	1.5	0.94	1.4
Kagamiishi Machi	0.97	1.6	1.5	3.1	1.1	1.7	0.98	1.5	0.95	1.5
Kaneyama Machi	0.084	0.17	0.47	1.2	0.07	0.12	0.08	0.14	0.07	0.12

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Kawamata Machi	1.6	2.7	3.5	9.3	1.7	2.7	1.6	2.5	1.6	2.4
Kitakata Shi	0.41	0.69	0.93	2.0	0.44	0.67	0.41	0.64	0.40	0.62
Kitashiobara Mura	0.89	1.4	1.9	3.9	0.95	1.5	0.88	1.4	0.86	1.3
Koori Machi	3.5	5.6	8.6	20	3.7	5.6	3.4	5.1	3.3	5.0
Koriyama Shi	2.6	4.1	3.5	6.3	2.9	4.4	2.6	4.0	2.6	3.9
Kunimi Machi	1.6	2.6	4.5	11	1.7	2.5	1.5	2.3	1.5	2.2
Miharu Machi	1.4	2.2	2.0	3.7	1.5	2.3	1.4	2.2	1.4	2.1
Minamiaizu Machi	0.12	0.25	0.52	1.4	0.12	0.20	0.12	0.22	0.11	0.20
Minamisoma Shi	2.3	4.0	11	37	2.1	3.2	2.0	3.3	1.9	2.9
Mishima Machi	0.26	0.46	0.67	1.5	0.27	0.43	0.26	0.42	0.25	0.40
Motomiya Shi	2.1	3.4	3.3	6.4	2.3	3.5	2.1	3.2	2.1	3.1
Nakajima Mura	0.48	0.80	1.0	2.1	0.52	0.80	0.49	0.76	0.47	0.73
Nihonmatsu Shi	3.1	5.1	5.6	12	3.4	5.2	3.1	4.7	3.0	4.6
Nishiaizu Machi	0.14	0.27	0.57	1.4	0.13	0.22	0.13	0.23	0.12	0.21
Nishigo Mura	1.5	2.5	2.2	4.1	1.7	2.6	1.6	2.4	1.5	2.4
Ono Machi	0.42	0.74	1.1	2.8	0.45	0.70	0.43	0.69	0.41	0.64
Otama Mura	2.6	4.4	4.6	9.4	2.9	4.6	2.7	4.3	2.7	4.2
Samegawa Mura	0.44	0.74	1.1	2.5	0.45	0.70	0.43	0.68	0.41	0.64
Shimogo Machi	0.23	0.40	0.64	1.5	0.24	0.37	0.23	0.37	0.21	0.34
Shinchi Machi	1.1	2.0	4.3	14	1.1	1.7	1.1	1.7	1.0	1.6
Shirakawa Shi	1.3	2.1	2.0	3.7	1.4	2.2	1.3	2.0	1.3	2.0
Showa Mura	0.25	0.46	0.66	1.6	0.26	0.42	0.25	0.42	0.24	0.39
Soma Shi	1.2	2.2	5.4	19	1.1	1.7	1.1	1.8	1.0	1.6
Sukagawa Shi	1.2	2.0	1.9	3.5	1.4	2.1	1.3	1.9	1.2	1.9
Tadami Machi	0.16	0.29	0.55	1.3	0.16	0.25	0.16	0.26	0.15	0.24
Tamakawa Mura	0.31	0.54	0.81	1.9	0.32	0.50	0.31	0.49	0.29	0.46
Tamura Shi	0.65	1.1	1.4	3.5	0.70	1.1	0.66	1.1	0.64	1.0
Tanagura Machi	0.79	1.3	1.7	3.6	0.84	1.3	0.79	1.2	0.76	1.2
Ten-ei Mura	1.8	3.1	2.6	4.9	2.1	3.3	1.9	3.0	1.9	2.9
Yabuki Machi	0.63	1.0	1.1	2.3	0.69	1.0	0.64	0.98	0.62	0.95
Yamatsuri Machi	0.32	0.55	0.79	1.8	0.33	0.53	0.31	0.51	0.30	0.48
Yanaizu Machi	0.26	0.45	0.71	1.6	0.26	0.41	0.25	0.41	0.24	0.39
Yugawa Mura	0.67	1.1	1.2	2.4	0.73	1.1	0.68	1.0	0.66	1.0

[a] Upper bound is the 95th percentile of the mean dose.

Table A-23.A7. Mean and upper bound on the effective dose, absorbed dose to thyroid, absorbed dose to breast, absorbed dose to colon and absorbed dose to red bone marrow for 10-year-old children in the first year after the accident for municipalities in Fukushima Prefecture (excluding evacuated areas)

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Aizubange Machi	0.84	1.4	2.0	4.3	0.84	1.3	0.86	1.3	0.80	1.2
Aizumisato Machi	0.36	0.66	1.5	3.8	0.34	0.54	0.35	0.57	0.32	0.53
Aizuwakamatsu Shi	0.66	1.1	1.8	4.4	0.66	1.0	0.68	1.1	0.64	1.0
Asakawa Machi	0.56	0.93	1.7	3.9	0.55	0.83	0.57	0.87	0.53	0.80
Bandai Machi	0.60	1.0	2.1	4.8	0.57	0.87	0.59	0.90	0.55	0.84
Date Shi	3.1	5.3	9.2	27	3.1	4.9	3.2	5.0	3.0	4.7
Fukushima Shi	4.5	7.4	10	23	4.6	7.0	4.7	7.1	4.4	6.7
Furudono Machi	0.53	0.90	2.0	4.6	0.49	0.75	0.52	0.80	0.47	0.73
Hanawa Machi	0.50	0.85	2.0	4.6	0.46	0.70	0.49	0.75	0.44	0.68
Hinoemata Mura	0.10	0.22	1.0	2.7	0.07	0.11	0.08	0.13	0.07	0.11
Hirata Mura	0.49	0.83	1.7	3.9	0.47	0.71	0.49	0.75	0.45	0.69
Inawashiro Machi	0.61	1.1	3.2	9.0	0.53	0.84	0.55	0.88	0.51	0.82
Ishikawa Machi	0.30	0.52	1.4	3.3	0.27	0.41	0.28	0.44	0.26	0.40
Iwaki Shi	1.0	1.8	4.2	12	0.97	1.5	1.1	1.6	0.94	1.4
Izumizaki Mura	1.1	1.9	2.2	4.8	1.2	1.8	1.2	1.8	1.1	1.7
Kagamiishi Machi	1.2	1.9	2.3	5.1	1.2	1.8	1.2	1.9	1.1	1.8
Kaneyama Machi	0.11	0.23	1.0	2.7	0.07	0.12	0.08	0.14	0.07	0.12
Kawamata Machi	2.0	3.3	5.2	14	2.0	3.0	2.0	3.1	1.9	2.9
Kitakata Shi	0.50	0.84	1.6	3.6	0.49	0.74	0.50	0.77	0.47	0.71
Kitashiobara Mura	1.1	1.7	2.9	6.2	1.1	1.6	1.1	1.7	1.0	1.6
Koori Machi	4.2	6.8	13	31	4.2	6.2	4.3	6.4	4.0	6.0
Koriyama Shi	3.1	4.9	4.7	8.9	3.2	4.9	3.3	5.0	3.1	4.7
Kunimi Machi	1.9	3.2	6.9	17	1.9	2.8	1.9	2.9	1.8	2.7
Miharu Machi	1.7	2.7	2.9	5.7	1.7	2.6	1.8	2.7	1.7	2.5
Minamiaizu Machi	0.16	0.32	1.1	3.0	0.12	0.20	0.13	0.23	0.12	0.20
Minamisoma Shi	2.8	5.3	17	60	2.3	3.5	2.6	4.0	2.2	3.4
Mishima Machi	0.32	0.56	1.3	3.0	0.30	0.46	0.32	0.49	0.29	0.45
Motomiya Shi	2.5	4.0	4.6	9.5	2.6	3.9	2.6	4.0	2.5	3.7
Nakajima Mura	0.59	0.97	1.7	3.7	0.58	0.88	0.60	0.92	0.55	0.85
Nihonmatsu Shi	3.7	6.0	7.9	18	3.8	5.8	3.9	5.9	3.7	5.5
Nishiaizu Machi	0.17	0.34	1.1	3.0	0.14	0.23	0.15	0.25	0.14	0.22
Nishigo Mura	1.8	3.0	3.1	6.2	1.9	2.9	2.0	3.0	1.8	2.8
Ono Machi	0.51	0.91	1.9	5.0	0.50	0.77	0.52	0.82	0.48	0.74
Otama Mura	3.2	5.3	6.5	14	3.3	5.2	3.4	5.3	3.2	5.0
Samegawa Mura	0.53	0.91	1.9	4.3	0.50	0.77	0.53	0.82	0.49	0.75

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Shimogo Machi	0.28	0.51	1.2	2.9	0.26	0.40	0.27	0.43	0.25	0.39
Shinchi Machi	1.4	2.6	6.9	23	1.2	1.8	1.3	2.1	1.2	1.8
Shirakawa Shi	1.6	2.5	2.8	5.8	1.6	2.4	1.6	2.5	1.5	2.3
Showa Mura	0.30	0.57	1.2	3.3	0.28	0.45	0.30	0.48	0.27	0.44
Soma Shi	1.4	2.9	8.7	32	1.2	1.9	1.4	2.2	1.2	1.8
Sukagawa Shi	1.5	2.4	2.7	5.4	1.5	2.3	1.6	2.4	1.5	2.2
Tadami Machi	0.20	0.37	1.1	2.8	0.17	0.27	0.18	0.29	0.17	0.26
Tamakawa Mura	0.38	0.67	1.5	3.6	0.35	0.54	0.37	0.58	0.34	0.53
Tamura Shi	0.78	1.4	2.3	5.8	0.78	1.2	0.81	1.3	0.75	1.2
Tanagura Machi	0.95	1.6	2.7	6.0	0.94	1.4	0.98	1.5	0.90	1.4
Ten-ei Mura	2.2	3.7	3.6	7.3	2.3	3.7	2.4	3.7	2.2	3.5
Yabuki Machi	0.76	1.2	1.8	4.0	0.77	1.2	0.79	1.2	0.74	1.1
Yamatsuri Machi	0.39	0.68	1.4	3.4	0.36	0.57	0.38	0.60	0.35	0.56
Yanaizu Machi	0.31	0.56	1.3	3.2	0.29	0.45	0.30	0.48	0.28	0.44
Yugawa Mura	0.81	1.3	1.9	4.2	0.82	1.2	0.84	1.3	0.79	1.2

Table A-23.A8. Mean and upper bound on the effective dose, absorbed dose to thyroid, absorbed dose to breast, absorbed dose to colon and absorbed dose to red bone marrow for 1-year-old infants in the first year after the accident for municipalities in Fukushima Prefecture (excluding evacuated areas)

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Aizubange Machi	0.98	1.6	2.3	5.1	0.98	1.5	0.99	1.5	0.91	1.4
Aizumisato Machi	0.42	0.76	1.8	4.5	0.39	0.63	0.40	0.66	0.36	0.58
Aizuwakamatsu Shi	0.78	1.3	2.1	5.2	0.77	1.2	0.79	1.2	0.72	1.1
Asakawa Machi	0.66	1.1	2.1	4.7	0.64	0.97	0.66	1.0	0.59	0.90
Bandai Machi	0.70	1.2	2.5	5.7	0.67	1.0	0.68	1.1	0.62	0.95
Date Shi	3.7	6.2	11	32	3.6	5.7	3.7	5.8	3.4	5.3
Fukushima Shi	5.3	8.7	12	27	5.4	8.3	5.4	8.3	5.0	7.6
Furudono Machi	0.62	1.0	2.4	5.5	0.57	0.88	0.61	0.93	0.53	0.81
Hanawa Machi	0.58	0.99	2.4	5.5	0.54	0.82	0.57	0.87	0.50	0.76
Hinoemata Mura	0.12	0.24	1.2	3.2	0.072	0.12	0.087	0.15	0.068	0.11
Hirata Mura	0.57	0.97	2.1	4.6	0.55	0.83	0.57	0.87	0.51	0.77
Inawashiro Machi	0.70	1.3	3.7	10	0.62	0.98	0.63	1.0	0.57	0.91
Ishikawa Machi	0.34	0.60	1.6	4.0	0.31	0.47	0.33	0.51	0.28	0.44
Iwaki Shi	1.2	2.1	5.1	15	1.1	1.7	1.2	1.9	1.1	1.6
Izumizaki Mura	1.3	2.2	2.7	5.7	1.4	2.1	1.4	2.1	1.3	1.9
Kagamiishi Machi	1.4	2.2	2.7	6.0	1.4	2.2	1.4	2.2	1.3	2.0

Municipality	*Effective dose (mSv)*		*Thyroid dose (mGy)*		*Breast dose (mGy)*		*Colon dose (mGy)*		*RBM dose (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Kaneyama Machi	0.12	0.25	1.2	3.2	0.079	0.13	0.093	0.16	0.074	0.12
Kawamata Machi	2.3	3.8	6.1	16	2.3	3.5	2.3	3.6	2.1	3.2
Kitakata Shi	0.59	0.98	1.9	4.3	0.57	0.86	0.58	0.89	0.53	0.80
Kitashiobara Mura	1.3	2.0	3.3	7.1	1.3	1.9	1.3	1.9	1.2	1.8
Koori Machi	5.0	8.0	15	37	4.9	7.4	4.9	7.4	4.5	6.8
Koriyama Shi	3.6	5.7	5.5	10	3.8	5.8	3.8	5.8	3.5	5.3
Kunimi Machi	2.3	3.7	8.2	20	2.2	3.3	2.2	3.3	2.0	3.0
Miharu Machi	2.0	3.1	3.4	6.7	2.0	3.1	2.1	3.1	1.9	2.8
Minamiaizu Machi	0.18	0.37	1.3	3.6	0.14	0.23	0.15	0.26	0.13	0.21
Minamisoma Shi	3.3	6.2	21	72	2.7	4.1	3.0	4.7	2.5	3.8
Mishima Machi	0.38	0.65	1.5	3.6	0.35	0.53	0.36	0.56	0.32	0.50
Motomiya Shi	2.9	4.7	5.4	11	3.0	4.6	3.0	4.6	2.8	4.3
Nakajima Mura	0.69	1.1	2.0	4.4	0.67	1.0	0.69	1.1	0.62	0.95
Nihonmatsu Shi	4.4	7.1	9.2	21	4.5	6.8	4.5	6.9	4.1	6.3
Nishiaizu Machi	0.20	0.38	1.4	3.6	0.16	0.25	0.17	0.29	0.15	0.24
Nishigo Mura	2.2	3.5	3.6	7.2	2.3	3.5	2.3	3.5	2.1	3.2
Ono Machi	0.60	1.1	2.3	6.1	0.58	0.89	0.61	0.95	0.53	0.83
Otama Mura	3.7	6.2	7.6	16	3.9	6.2	3.9	6.2	3.6	5.7
Samegawa Mura	0.62	1.1	2.3	5.2	0.59	0.90	0.61	0.94	0.54	0.83
Shimogo Machi	0.33	0.58	1.4	3.5	0.30	0.46	0.32	0.50	0.28	0.44
Shinchi Machi	1.6	3.0	8.3	28	1.4	2.1	1.6	2.4	1.3	2.0
Shirakawa Shi	1.8	3.0	3.4	6.9	1.9	2.9	1.9	2.9	1.7	2.6
Showa Mura	0.35	0.66	1.5	4.0	0.33	0.52	0.34	0.56	0.30	0.48
Soma Shi	1.7	3.3	10	39	1.4	2.2	1.6	2.5	1.3	2.0
Sukagawa Shi	1.7	2.8	3.2	6.4	1.8	2.7	1.8	2.8	1.7	2.5
Tadami Machi	0.23	0.43	1.3	3.4	0.19	0.30	0.21	0.33	0.18	0.28
Tamakawa Mura	0.44	0.77	1.7	4.3	0.41	0.63	0.43	0.67	0.38	0.58
Tamura Shi	0.92	1.6	2.8	6.7	0.91	1.4	0.94	1.5	0.85	1.3
Tanagura Machi	1.1	1.9	3.2	7.1	1.1	1.7	1.1	1.7	1.0	1.5
Ten-ei Mura	2.6	4.3	4.2	8.5	2.7	4.3	2.8	4.3	2.5	4.0
Yabuki Machi	0.89	1.4	2.1	4.7	0.90	1.4	0.91	1.4	0.83	1.3
Yamatsuri Machi	0.45	0.79	1.7	4.0	0.42	0.66	0.44	0.70	0.39	0.62
Yanaizu Machi	0.37	0.64	1.6	3.9	0.34	0.52	0.35	0.55	0.31	0.48
Yugawa Mura	0.94	1.6	2.3	5.0	0.96	1.5	0.97	1.5	0.89	1.3

Table A-23.A9. Mean and upper bound on the absorbed dose to thyroid and absorbed dose to red bone marrow for a fetus in the first year after the accident for municipalities in Fukushima Prefecture (excluding evacuated areas)

Municipality	*Absorbed dose to thyroid of fetus (mGy)*		*Absorbed dose to RBM of fetus (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*
Aizubange Machi	0.89	1.7	0.41	0.67
Aizumisato Machi	0.65	1.4	0.18	0.28
Aizuwakamatsu Shi	0.84	1.6	0.36	0.58
Asakawa Machi	0.78	1.5	0.28	0.46
Bandai Machi	0.97	1.9	0.31	0.50
Date Shi	4.3	10	1.4	2.3
Fukushima Shi	4.8	10	2.1	3.4
Furudono Machi	0.89	1.8	0.25	0.40
Hanawa Machi	0.88	1.8	0.23	0.38
Hinoemata Mura	0.41	1.1	0.047	0.070
Hirata Mura	0.77	1.5	0.24	0.39
Inawashiro Machi	1.4	3.4	0.26	0.42
Ishikawa Machi	0.59	1.3	0.14	0.23
Iwaki Shi	2.0	4.7	0.56	0.91
Izumizaki Mura	1.0	1.8	0.56	0.91
Kagamiishi Machi	1.1	1.9	0.56	0.92
Kaneyama Machi	0.42	1.1	0.051	0.076
Kawamata Machi	0.72	1.4	0.25	0.41
Kitakata Shi	1.3	2.6	0.52	0.85
Kitashiobara Mura	5.9	14	1.9	3.1
Koori Machi	2.2	3.7	1.5	2.4
Koriyama Shi	3.2	7.8	0.87	1.4
Kunimi Machi	1.3	2.3	0.81	1.3
Miharu Machi	0.45	1.1	0.074	0.11
Minamiaizu Machi	7.8	23	1.0	1.7
Minamisoma Shi	0.54	1.2	0.16	0.25
Mishima Machi	2.1	3.9	1.2	1.9
Motomiya Shi	0.74	1.5	0.30	0.48
Nakajima Mura	3.7	7.6	1.7	2.9
Nihonmatsu Shi	0.48	1.2	0.083	0.13
Nishiaizu Machi	1.4	2.4	0.89	1.5
Nishigo Mura	0.85	1.8	0.24	0.39
Ono Machi	3.03	6.0	1.47	2.4
Otama Mura	0.85	1.7	0.26	0.42
Samegawa Mura	0.57	1.2	0.19	0.30
Shimogo Machi	3.1	8.4	0.58	0.94
Shinchi Machi	1.3	2.2	0.75	1.2

Municipality	*Absorbed dose to thyroid of fetus (mGy)*		*Absorbed dose to RBM of fetus (mGy)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*
Shirakawa Shi	0.54	1.2	0.15	0.23
Showa Mura	3.9	11	0.55	0.90
Soma Shi	1.3	2.1	0.72	1.2
Sukagawa Shi	0.48	1.1	0.11	0.17
Tadami Machi	0.64	1.3	0.18	0.29
Tamakawa Mura	1.2	2.4	0.44	0.72
Tamura Shi	1.7	2.8	1.1	1.7
Tanagura Machi	0.82	1.5	0.39	0.63
Ten-ei Mura	0.68	1.4	0.25	0.40
Yabuki Machi	0.57	1.2	0.15	0.24
Yamatsuri Machi	0.88	1.6	0.40	0.64
Yanaizu Machi	0.89	1.7	0.41	0.67
Yugawa Mura	0.65	1.4	0.18	0.28

Table A-23.A10. Mean and upper bound on the effective dose over a lifetime for adults, 10-year-old children and 1-year-old infants for Fukushima Prefecture (excluding evacuated areas)

Municipality	*Effective dose over a lifetime to adults (mSv)*		*Effective dose over a lifetime to 10-year-old children (mSv)*		*Effective dose over a lifetime to 1-year-old infants (mSv)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Aizubange Machi	2.8	4.6	3.2	5.1	3.6	5.8
Aizumisato Machi	1.1	1.9	1.2	2.1	1.4	2.4
Aizuwakamatsu Shi	2.0	3.2	2.2	3.6	2.5	4.1
Asakawa Machi	1.8	2.8	2.0	3.1	2.2	3.5
Bandai Machi	1.7	2.8	1.9	3.1	2.2	3.5
Date Shi	11	18	12	20	14	23
Fukushima Shi	16	26	18	29	21	33
Furudono Machi	1.6	2.6	1.8	2.9	2.1	3.3
Hanawa Machi	1.5	2.4	1.7	2.7	1.9	3.1
Hinoemata Mura	0.24	0.42	0.27	0.48	0.30	0.53
Hirata Mura	1.5	2.4	1.7	2.7	1.9	3.0
Inawashiro Machi	1.9	3.1	2.1	3.5	2.4	3.9
Ishikawa Machi	0.90	1.5	1.0	1.6	1.1	1.8
Iwaki Shi	2.4	3.9	2.7	4.4	3.1	5.0
Izumizaki Mura	4.0	6.3	4.4	7.0	5.0	8.0
Kagamiishi Machi	4.1	6.6	4.5	7.4	5.1	8.4
Kaneyama Machi	0.27	0.47	0.30	0.53	0.34	0.58
Kawamata Machi	6.7	11	7.4	12	8.5	13
Kitakata Shi	1.6	2.5	1.8	2.8	2.0	3.2
Kitashiobara Mura	3.6	5.7	4.0	6.4	4.5	7.2
Koori Machi	15	23	17	26	19	29
Koriyama Shi	11	18	13	20	14	23

Municipality	*Effective dose over a lifetime to adults (mSv)*		*Effective dose over a lifetime to 10-year-old children (mSv)*		*Effective dose over a lifetime to 1-year-old infants (mSv)*	
	Mean	*Upper bound*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Kunimi Machi	6.5	10	7.2	11	8.2	13
Miharu Machi	6.0	9.4	6.6	10	7.6	12
Minamiaizu Machi	0.43	0.76	0.48	0.86	0.54	0.95
Minamisoma Shi	8.3	13	9.4	15	11	17
Mishima Machi	1.0	1.6	1.1	1.8	1.3	2.1
Motomiya Shi	9.1	14	10.1	16	11	18
Nakajima Mura	1.9	3.0	2.1	3.3	2.4	3.8
Nihonmatsu Shi	14	22	15	24	17	27
Nishiaizu Machi	0.49	0.84	0.55	0.94	0.62	1.1
Nishigo Mura	6.8	11	7.5	12	8.5	14
Ono Machi	1.7	2.7	1.9	3.0	2.1	3.4
Otama Mura	12	19	13	22	15	25
Samegawa Mura	1.6	2.6	1.8	2.9	2.1	3.3
Shimogo Machi	0.45	0.75	0.52	0.87	0.59	0.99
Shinchi Machi	4.2	6.8	4.7	7.6	5.4	8.7
Shirakawa Shi	5.4	8.5	6.0	9.5	6.8	11
Showa Mura	1.0	1.6	1.1	1.8	1.2	2.1
Soma Shi	4.3	7.0	4.9	8.0	5.6	9.0
Sukagawa Shi	5.3	8.3	5.9	9.2	6.7	11
Tadami Machi	0.48	0.79	0.54	0.90	0.60	1.0
Tamakawa Mura	1.2	1.9	1.3	2.1	1.5	2.4
Tamura Shi	2.3	3.9	2.8	4.6	3.2	5.4
Tanagura Machi	3.3	5.2	3.6	5.8	4.1	6.5
Ten-ei Mura	8.3	14	9.1	15	10	17
Yabuki Machi	2.5	3.9	2.8	4.4	3.1	5.0
Yamatsuri Machi	0.69	1.2	0.8	1.3	0.91	1.5
Yanaizu Machi	1.0	1.6	1.1	1.8	1.2	2.0
Yugawa Mura	2.8	4.4	3.1	4.9	3.5	5.5

Table A-23.A11. Mean and upper bound on the effective dose in the first year to adults evacuated from localities in Fukushima Prefecture, including doses received before and during the evacuation and at the destination

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Futaba	01(FT1)	Saitama Ken	Saitama Shi	0.36	1.0	1.7	3.8
Futaba	02(FT2)	Ibaraki Ken	Kasama Shi	0.79	2.1	8.3	28
Futaba	03(FT3)	Ibaraki Ken	Yuki Shi	0.59	1.3	4.9	15
Futaba	04(FT4)	Fukushima Ken	Koriyama Shi	2.5	4.3	7.1	19
Futaba	05(FT5)	Tochigi Ken	Sano Shi	0.61	1.0	1.6	2.4

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Kawauchi	06(TM1)	Niigata Ken	Niigata Shi	0.046	0.072	1.1	1.7
Tomioka	07(TM2)	Chiba Ken	Chiba Shi	0.50	1.0	2.3	5.0
Tomioka	08(TM3)	Chiba Ken	Chiba Shi	0.39	0.65	2.0	3.9
Tomioka	09(TM4)	Fukushima Ken	Iwaki Shi	0.78	1.8	5.5	17
Naraha	10(NR1)	Tochigi Ken	Nasushiobara Shi	0.79	1.3	2.1	3.6
Naraha	11(NR2)	Chiba Ken	Chiba Shi	0.47	1.0	3.0	8.0
Naraha	12(NR3)	Fukushima Ken	Iwaki Shi	0.78	1.8	5.4	17
Naraha	13(NR4)	Tochigi Ken	Mooka Shi	0.60	1.0	1.6	2.3
Naraha	14(NR5)	Fukushima Ken	Iwaki Shi	0.66	1.4	3.7	11
Okuma	15(OK1)	Fukushima Ken	Aizuwakamatsu Shi	0.65	1.5	3.4	9.0
Okuma	16(OK2)	Fukushima Ken	Tamura Shi	0.81	1.7	3.3	8.2
Futaba	17(OK3)	Tokyo Ken	Shinjuku Ku	0.33	0.87	2.4	6.6
Tamura	18(OK4)	Fukushima Ken	Tamura Shi	1.2	3.1	2.6	5.5
Odaka	19(OK5)	Tochigi Ken	Nasushiobara Shi	0.95	1.7	3.6	9.1
Namie	20(NM1)	Tokyo Ken	Shinjuku Ku	0.25	0.56	2.5	7.1
Namie	21(NM2)	Fukushima Ken	Soma Shi	1.1	2.3	7.0	22
Namie	22(NM3)	Fukushima Ken	Koriyama Shi	2.3	3.8	3.3	5.4
Tsushima	23(NM4)	Fukushima Ken	Nihonmatsu Shi	3.1	5.6	8.0	21
Namie	24(NM5)	Yamagata Ken	Yonezawa Shi	0.38	1.2	5.9	20
Iitate	25(IT1)	Fukushima Ken	Koriyama Shi	2.6	4.5	9.2	25
Iitate	26(IT2)	Fukushima Ken	Kitashiobara Mura	0.41	0.64	2.0	3.0
Iitate	27(IT3)	Saitama Ken	Saitama Shi	0.37	1.0	3.5	8.6
Iitate	28(IT4)	Fukushima Ken	Iitate Mura	5.5	9.0	9.1	16
Odaka	29(OD1)	Tokyo Ken	Shinjuku Ku	1.2	3.9	15.2	54
Odaka	30(OD2)	Yamagata Ken	Tsuruoka Shi	0.10	0.16	0.8	1.3
Haramachi	31(OD3)	Kanagawa Ken	Yokohama Shi	0.22	0.57	1.4	2.3
Odaka	32(OD4)	Tokyo Ken	Shinjuku Ku	0.73	2.3	11.6	40
Odaka	33(OD5)	Saitama Ken	Saitama Shi	0.52	1.6	6.2	20
Haramachi	34(HK1)	Kanagawa Ken	Yokohama Shi	0.32	0.91	2.9	7.7
Iitate	35(HK2)	Yamagata Ken	Yamagata Shi	0.21	0.44	1.9	3.2
Kashima	36(HK3)	Kanagawa Ken	Yokohama Shi	1.1	2.4	5.9	18
Haramachi	37(HK4)	Fukushima Ken	Soma Shi	1.2	2.7	8.1	25
Hirono Town	38 (NIRS 10)	Fukushima Ken	Ono Shi	0.76	2.0	2.2	5.1
Katsurao Village	39 (NIRS 12)	Fukushima Ken	Fukushima Shi	2.9	4.7	3.6	5.6
Katsurao Village Office	40 (NIRS 14)	Fukushima Ken	Fukushima Shi	3.9	7.3	8.0	21

Table A-23.A12. Mean and upper bound on the effective dose in the first year to 10-year-old children evacuated from localities in Fukushima Prefecture, including doses received before and during the evacuation and at the destination

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Futaba	01(FT1)	Saitama Ken	Saitama Shi	0.44	1.2	3.0	6.3
Futaba	02(FT2)	Ibaraki Ken	Kasama Shi	0.99	2.5	12	38
Futaba	03(FT3)	Ibaraki Ken	Yuki Shi	0.79	1.8	8.3	25
Futaba	04(FT4)	Fukushima Ken	Koriyama Shi	3.006	5.3	11	29
Futaba	05(FT5)	Tochigi Ken	Sano Shi	0.75	1.2	2.8	4.2
Kawauchi	06(TM1)	Niigata Ken	Niigata Shi	0.10	0.16	2.4	3.8
Tomioka	07(TM2)	Chiba Ken	Chiba Shi	0.65	1.3	4.2	8.5
Tomioka	08(TM3)	Chiba Ken	Chiba Shi	0.51	0.84	3.7	6.8
Tomioka	09(TM4)	Fukushima Ken	Iwaki Shi	1.0	2.3	9.4	28
Naraha	10(NR1)	Tochigi Ken	Nasushiobara Shi	0.96	1.6	3.5	6.0
Naraha	11(NR2)	Chiba Ken	Chiba Shi	0.62	1.3	5.2	13
Naraha	12(NR3)	Fukushima Ken	Iwaki Shi	1.0	2.4	9.0	27
Naraha	13(NR4)	Tochigi Ken	Mooka Shi	0.74	1.2	2.8	4.1
Naraha	14(NR5)	Fukushima Ken	Iwaki Shi	0.84	1.8	6.4	17
Okuma	15(OK1)	Fukushima Ken	Aizuwakamatsu Shi	0.80	1.8	5.3	13
Okuma	16(OK2)	Fukushima Ken	Tamura Shi	1.0	2.1	5.4	13
Futaba	17(OK3)	Tokyo Ken	Shinjuku Ku	0.44	1.1	4.3	11
Tamura	18(OK4)	Fukushima Ken	Tamura Shi	1.4	3.5	4.1	8.0
Odaka	19(OK5)	Tochigi Ken	Nasushiobara Shi	1.2	2.2	6.2	15
Namie	20(NM1)	Tokyo Ken	Shinjuku Ku	0.36	0.82	4.6	12
Namie	21(NM2)	Fukushima Ken	Soma Shi	1.4	3.1	12	37
Namie	22(NM3)	Fukushima Ken	Koriyama Shi	2.7	4.4	4.8	7.6
Tsushima	23(NM4)	Fukushima Ken	Nihonmatsu Shi	3.7	6.6	11	29
Namie	24(NM5)	Yamagata Ken	Yonezawa Shi	0.58	1.8	10	33
Iitate	25(IT1)	Fukushima Ken	Koriyama Shi	3.1	5.3	13	32
Iitate	26(IT2)	Fukushima Ken	Kitashiobara Mura	0.54	0.82	3.9	5.9
Iitate	27(IT3)	Saitama Ken	Saitama Shi	0.51	1.3	6.3	15
Iitate	28(IT4)	Fukushima Ken	Iitate Mura	6.5	11	13	24
Odaka	29(OD1)	Tokyo Ken	Shinjuku Ku	1.5	5.0	22	75
Odaka	30(OD2)	Yamagata Ken	Tsuruoka Shi	0.14	0.20	1.6	2.6
Haramachi	31(OD3)	Kanagawa Ken	Yokohama Shi	0.30	0.70	2.8	4.4
Odaka	32(OD4)	Tokyo Ken	Shinjuku Ku	0.96	3.0	17	55
Odaka	33(OD5)	Saitama Ken	Saitama Shi	0.74	2.2	11	34
Haramachi	34(HK1)	Kanagawa Ken	Yokohama Shi	0.44	1.2	5.3	13
Iitate	35(HK2)	Yamagata Ken	Yamagata Shi	0.32	0.59	3.9	6.2
Kashima	36(HK3)	Kanagawa Ken	Yokohama Shi	1.4	3.1	9.9	29
Haramachi	37(HK4)	Fukushima Ken	Soma Shi	1.6	3.6	14	42

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Hirono Town	38 (NIRS 10)	Fukushima Ken	Ono Shi	0.92	2.3	3.7	7.8
Katsurao Village	39 (NIRS 12)	Fukushima Ken	Fukushima Shi	3.5	5.6	4.8	7.2
Katsurao Village Office	40 (NIRS 14)	Fukushima Ken	Fukushima Shi	4.6	8.7	12	31

Table A-23.A13. Mean and upper bound on the effective dose in the first year to 1-year-old infants evacuated from localities in Fukushima Prefecture, including doses received before and during the evacuation and at the destination

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Futaba	01(FT1)	Saitama Ken	Saitama Shi	0.54	1.4	3.9	7.9
Futaba	02(FT2)	Ibaraki Ken	Kasama Shi	1.2	3.1	16	50
Futaba	03(FT3)	Ibaraki Ken	Yuki Shi	0.95	2.2	11	33
Futaba	04(FT4)	Fukushima Ken	Koriyama Shi	3.6	6.5	16	44
Futaba	05(FT5)	Tochigi Ken	Sano Shi	0.91	1.4	3.8	6.1
Kawauchi	06(TM1)	Niigata Ken	Niigata Shi	0.15	0.24	3.6	5.9
Tomioka	07(TM2)	Chiba Ken	Chiba Shi	0.78	1.6	5.7	11
Tomioka	08(TM3)	Chiba Ken	Chiba Shi	0.62	1.0	5.1	9.2
Tomioka	09(TM4)	Fukushima Ken	Iwaki Shi	1.2	2.7	12	34
Naraha	10(NR1)	Tochigi Ken	Nasushiobara Shi	1.2	1.9	4.6	7.9
Naraha	11(NR2)	Chiba Ken	Chiba Shi	0.74	1.5	6.6	16
Naraha	12(NR3)	Fukushima Ken	Iwaki Shi	1.2	2.7	11	34
Naraha	13(NR4)	Tochigi Ken	Mooka Shi	0.89	1.4	3.8	5.8
Naraha	14(NR5)	Fukushima Ken	Iwaki Shi	1.0	2.1	8.1	21
Okuma	15(OK1)	Fukushima Ken	Aizuwakamatsu Shi	0.98	2.1	7.0	17
Okuma	16(OK2)	Fukushima Ken	Tamura Shi	1.2	2.6	7.7	19
Futaba	17(OK3)	Tokyo Ken	Shinjuku Ku	0.53	1.3	5.6	14
Tamura	18(OK4)	Fukushima Ken	Tamura Shi	1.7	4.1	5.4	10
Odaka	19(OK5)	Tochigi Ken	Nasushiobara Shi	1.5	2.6	8.6	21
Namie	20(NM1)	Tokyo Ken	Shinjuku Ku	0.44	1.0	5.9	15
Namie	21(NM2)	Fukushima Ken	Soma Shi	1.7	3.6	15	45
Namie	22(NM3)	Fukushima Ken	Koriyama Shi	3.2	5.3	6.3	10
Tsushima	23(NM4)	Fukushima Ken	Nihonmatsu Shi	4.4	7.7	13	34
Namie	24(NM5)	Yamagata Ken	Yonezawa Shi	0.69	2.1	13	41
Iitate	25(IT1)	Fukushima Ken	Koriyama Shi	3.6	6.3	16	39
Iitate	26(IT2)	Fukushima Ken	Kitashiobara Mura	0.69	1.0	5.7	9.3
Iitate	27(IT3)	Saitama Ken	Saitama Shi	0.64	1.5	8.5	18
Iitate	28(IT4)	Fukushima Ken	Iitate Mura	7.8	13	16	29
Odaka	29(OD1)	Tokyo Ken	Shinjuku Ku	1.9	6.3	30	103
Odaka	30(OD2)	Yamagata Ken	Tsuruoka Shi	0.17	0.25	2.2	3.5

Location	*Scenario*	*Scenario destination*		*Effective dose (mSv)*		*Thyroid dose (mGy)*	
		Prefecture	*Location*	*Mean*	*Upper bound*	*Mean*	*Upper bound*
Haramachi	31(OD3)	Kanagawa Ken	Yokohama Shi	0.39	0.85	4.0	6.6
Odaka	32(OD4)	Tokyo Ken	Shinjuku Ku	1.2	3.8	23	77
Odaka	33(OD5)	Saitama Ken	Saitama Shi	0.93	2.8	15	45
Haramachi	34(HK1)	Kanagawa Ken	Yokohama Shi	0.55	1.5	7.2	17
Iitate	35(HK2)	Yamagata Ken	Yamagata Shi	0.42	0.74	5.7	9.7
Kashima	36(HK3)	Kanagawa Ken	Yokohama Shi	1.6	3.6	12	35
Haramachi	37(HK4)	Fukushima Ken	Soma Shi	2.0	4.5	19	58
Hirono Town	38 (NIRS 10)	Fukushima Ken	Ono Shi	1.1	2.8	4.7	9.8
Katsurao Village	39 (NIRS 12)	Fukushima Ken	Fukushima Shi	4.1	6.6	5.5	8.3
Katsurao Village Office	40 (NIRS 14)	Fukushima Ken	Fukushima Shi	5.4	10	14	37

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