United Nations Scientific Committee on the Effects of Atomic Radiation

ATTACHMENT 1

POWER CALCULATIONS FOR EPIDEMIOLOGICAL STUDIES THAT UNDERPIN THE COMMENTARY ON HEALTH IMPLICATIONS IN THE 2013 FUKUSHIMA REPORT

Developments since the 2013 UNSCEAR Report on the levels and effects of radiation exposure due to the nuclear accident following the great east-Japan earthquake and tsunami

A 2015 white paper to guide the Scientific Committee's future programme of work

Notes

Contents

1. In this attachment, the Committee documents the data, assumptions, methodology and argument used to underpin its commentary on health implications for the public and workers that was published in the 2013 report on levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, the UNSCEAR 2013 Fukushima report (appendix E in [UNSCEAR, 2014]).

I. GENERAL ASSUMPTIONS AND CALCULATION METHOD

2. *Assumption 1.* The Committee assumed a linear dose response, and used estimates of lifetime attributable risks per unit dose, to estimate notional numbers of radiation-related cases in the most exposed population groups. District averages of doses estimated for the population of Fukushima Prefecture were low. In the low dose region, radiation risks are uncertain. Thus the “radiation-related cases” calculated here are nothing but notional and serve only to assess

whether a radiation impact on health would likely be discernible or not. This assessment is valid only under the condition of the assumptions made.

3. *Assumption 2*. It was assumed, without further in-depth analysis, that a radiation effect would not become discernible if the power from a statistical test to detect a difference between a disease rate in the exposed subpopulation and the corresponding rate in the general population (assuming a significance level of 0.05) is less than 80%. This statistical test was applied here assuming the following ideal conditions:

- The baseline risk was known (rates of disease for Japan for the age/gender subpopulation);
- Health effects in the subpopulation could be detected without any loss in follow-up;
- Cancer registries were complete.

The study design was a cross section (screening study); incidence could be estimated for the time period between the first and the last screening.

4. The number of cancer cases in each group could be considered as a Poisson-distributed number or the sum of binomial-distributed values. The test statistic could be considered based on the exact test for two Poisson-distributed values (see [Breslow and Day, 1987]), the Chi-Squared test using approximation of normal distributions (see e.g. [UNSCEAR, 2000, Vol. II]). For the purpose of this attachment, the t-test was used as an approximation to compare proportions in two independent groups [Program G*Power]. Using either exact Poisson distributions or an approximation with binomial distributions give similar results for the area of interest, say statistical power in the order of 50–90%. Calculations were compared with the “exact Fisher Test”, the exact Poisson test for group data and with the normal distribution approximation. For very small P and medium sample size, the different methods and approximation methods yielded slightly different results, but this was less relevant compared to the other uncertainties and did not influence the conclusions about discernibility.

II. ALL SOLID CANCER

5. The Committee addressed whether an increased incidence of all solid cancers combined was expected to be discernible in paragraph E28 of [UNSCEAR, 2014].

A. Input

6. Tables 1 and 2 present relevant information derived from the Committee’s estimates of effective doses to people (both evacuated and not evacuated) from Fukushima Prefecture (attachment C-14 of [UNSCEAR, 2014]). Table 1 presents estimates for the numbers of people in Fukushima Prefecture who received doses in the uppermost interval for the average effective dose in the first year after the accident. For those not evacuated, the estimates considered were those for people in districts of Fukushima Prefecture with doses in the uppermost dose interval. For those evacuated, the estimates were for those people who followed evacuation scenarios that led to doses in the uppermost interval. Table 2 shows the upper values of average effective dose in the first year and cumulative effective dose to 80 years of age in districts of Fukushima Prefecture that were not evacuated. Table 3 presents estimated lifetime baseline and notional radiation-associated risk of all solid cancers (excluding thyroid cancers due to the excess thyroid dose over colon dose) for population groups in the regions with the highest deposition, taken from [WHO, 2013].

Table 1. Assumed numbers of non-evacuated persons in districts of Fukushima Prefecture in the uppermost interval of the average first-year effective dose and of evacuated persons following evacuation scenarios with doses in the uppermost interval of average first-year effective dose (based on attachment C-14 to [UNSCEAR, 2014])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Interval of effective dose (mSv)*	*Assumed population with doses in dose interval*
Non-evacuated adults	4 to 5	252 642
Non-evacuated children	5 to 6	36 715
Non-evacuated infants	7 to 8	14 513
Evacuated adults	9 to 10	1 109

Table 2. Upper values of average first-year and cumulative (up to age 80 years) effective dose to people in non-evacuated districts of Fukushima Prefecture (table C14 in [UNSCEAR, 2014])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*First-year effective dose (mSv)*	*80-years effective dose (mSv)*
Non-evacuated adults	4.3	11
Non-evacuated children	5.9	16
Non-evacuated infants	7.5	18

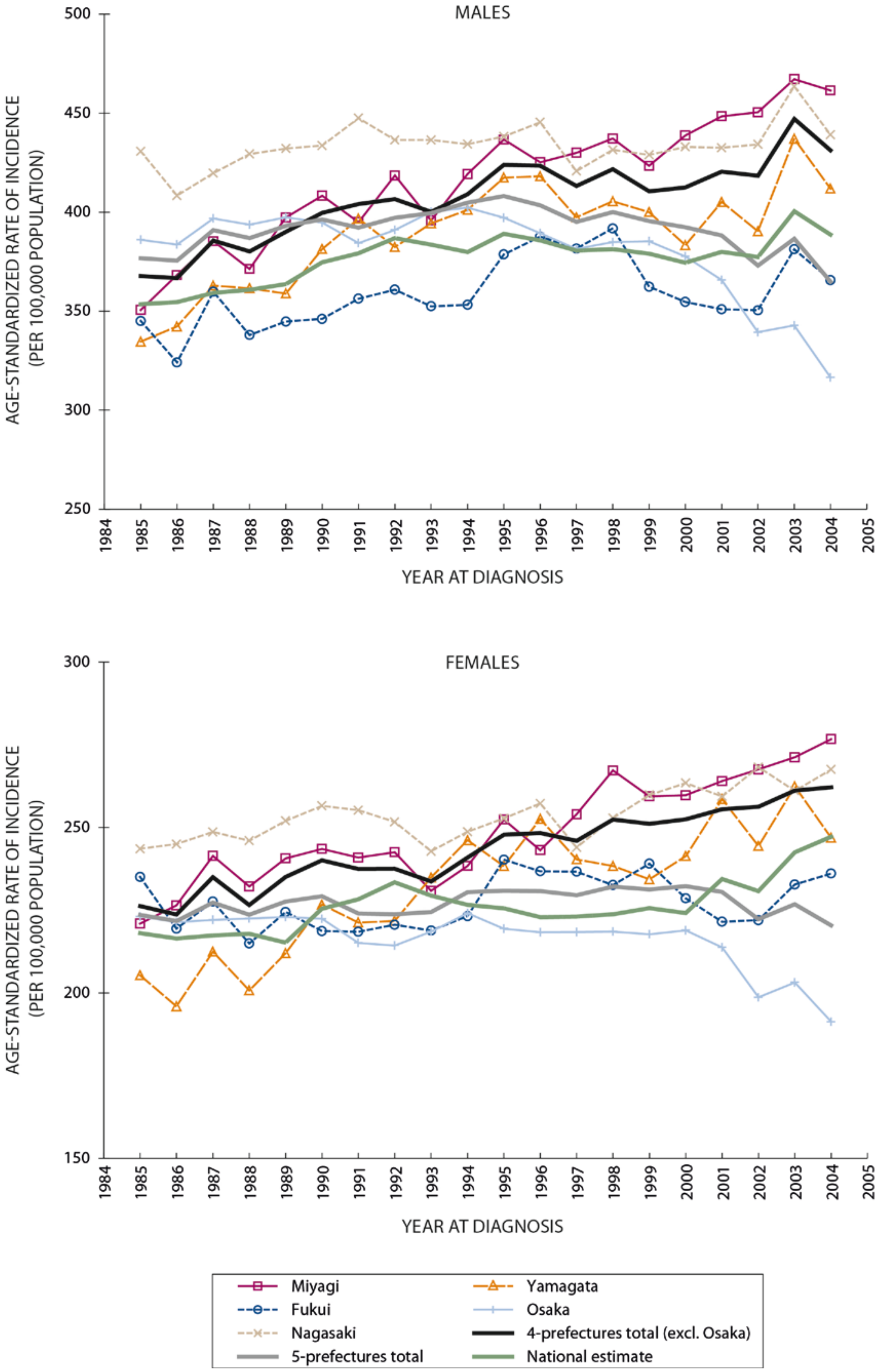
Table 3. Estimated lifetime baseline and radiation-associated risk of all solid cancer (excluding thyroid cancers due to excess of thyroid dose over colon dose) for population groups living for four months in the regions with the highest deposition density and subsequently in the western least contaminated region of Fukushima Prefecture (tables 34, 35 and 36 in [WHO, 2013])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Lifetime colon dose (mGy)*	*Baseline risk*	*Radiation-associated risk estimate*
Women	23	29.07×10^{-2}	0.59×10^{-2}
Men	23	40.74×10^{-2}	0.39×10^{-2}
Girls	26	29.09×10^{-2}	0.86×10^{-2}
Boys	26	40.71×10^{-2}	0.57×10^{-2}
Female infants	27	29.04×10^{-2}	1.11×10^{-2}
Male infants	27	40.60×10^{-2}	0.73×10^{-2}

7. Cancer registries in Miyagi, Yamagata, Fukui and Nagasaki prefectures were considered to be relatively complete since 1985 [Katanoda et al., 2012]. The age standardized annual cancer incidence in 2000 to 2004 in Miyagi and Nagasaki was about 450 cases per 100,000 males, and in Fukui and Yamagata about 380 cases per 100,000 males (figure I). Correspondingly, the annual incidence was about 270 cases per 100,000 females in Miyagi and Nagasaki prefectures, and about 230 cases per 100,000 females in Fukui prefecture.

Figure I. Age standardized annual cancer incidence in five prefectures of Japan [Katanoda et al., 2012]



B. Assumptions

8. *Assumption 3*. The 80-year cumulative effective dose to people in the district with the highest average dose, E_{80} (table 2), may be applied to the population, P_{upper}, in the uppermost dose interval of the dose distribution calculated in attachment C-14 to [UNSCEAR, 2014]. Calculations were performed for females and males separately. In both cases P_{upper} was assumed to be 50% of the value for the total population in table 1.

9. *Assumption 4*. Notional numbers of lifetime radiation-associated cases of all solid cancer (excluding thyroid cancers due to excess of thyroid dose over colon dose) may be estimated by a linear dose response with a radiation-associated risk per unit dose, R_{sc} (derived from table 3):

$$N_{\text{sc,attr}} = P_{\text{upper}}\, E_{80}\, R_{\text{sc}}$$

10. *Assumption 5*. An upper estimate of the lifetime dose of the evacuees for the scenario with the highest first-year dose may be obtained by adding the difference of the lifetime dose and the first-year dose in the district with the highest first-year dose. According to tables 1 and 2, the upper estimate for the lifetime effective dose of adult evacuees would be 16 mSv.

11. *Assumption 6*. The upper estimate of the lifetime dose of adult evacuees for the scenario with the highest first-year dose may be combined with the radiation-associated risk per unit dose for non-evacuated persons to obtain an estimate of the number of notional radiation-associated cases.

C. Results

Table 4. Estimated numbers of baseline and notional radiation-associated cases of solid cancer in the most exposed populations groups as defined in table 1, excess relative risks, and power to detect the increased risk comparing the estimate to the baseline risk for Japan (one-sided test)

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities. Note that calculations are based on radiation-associated risks per unit dose for the scenario of relocated people (table 3), which are slightly higher than those for non-evacuated people and slightly lower than those for evacuated people

Population group	$N_{sc,base}$	$N_{sc,attr}$	*ERR*	*Power*
Non-evacuated women	36 722	351	0.010	73%
Non-evacuated men	51 463	232	0.005	43%
Non-evacuated girls	5 340	96	0.018	53%
Non-evacuated boys	7 473	64	0.009	–*
Non-evacuated female infants	2 107	54	0.025	<50%
Non-evacuated male infants	2 946	35	0.012	–*
Evacuated women	161	2.2	0.014	–*
Evacuated men	226	1.6	0.007	–*

* *<30%.*

12. If non-evacuated women and men were to be studied together, then the power would amount to 82%. The power would be even greater, if all eight population groups would be studied together. However, considering the large differences of cancer incidence rates in the different prefectures of Japan (figure I) an excess relative risk of 1% is not expected to be discernible, if a control group with the same baseline incidence as in the exposed group is not defined. Moreover, defining a control group of similar size, with similar age and sex structure

and with the same baseline risk seems almost impossible taking into account the large variation in incidence rates in Japan. Breaking down the population of Fukushima Prefecture into exposed and non-exposed subpopulations would already reduce the power to less than 80%.

III. THYROID CANCER

13. The Committee addressed whether an increased incidence of thyroid cancers was expected to be discernible in paragraph E32 of [UNSCEAR, 2014]. Individuals in a subpopulation of Fukushima Prefecture were being screened for thyroid diseases. Therefore, it would not be appropriate to base power calculations for thyroid cancer on national rates for Japan, but rather on the expected thyroid cancer incidence in the screened population.

A. Input

1. Exploratory analysis

14. Table 5 presents estimates of the baseline and radiation-associated risk of thyroid cancer among persons having been exposed as infants while living for four months in the regions with the highest deposition density and then subsequently in the western least-contaminated region of Fukushima Prefecture, as presented in table 37 of [WHO, 2013]. Table 6 gives an estimate of baseline and radiation-associated risk of thyroid cancer after exposure during infancy to a dose to the thyroid of 100 mGy under the conditions of intensive screening as currently performed in Fukushima Prefecture [Jacob et al., 2014].

Table 5. Baseline and estimated radiation-associated risk of thyroid cancer among persons exposed as infants while living for four months in the regions with the highest deposition density and subsequently in the western least-contaminated region of Fukushima Prefecture, neglecting the effect of screening (table 37 in [WHO, 2013])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Sex	*Lifetime thyroid dose (mGy)*	*Baseline risk without screening*	*Radiation-associated risk estimate*
Female	122	0.77×10^{-2}	0.52×10^{-2}
Male	122	0.21×10^{-2}	0.12×10^{-2}

Table 6. Baseline and estimated radiation-associated risk of thyroid cancer risk among persons exposed as infants with a thyroid dose of 100 mGy considering the effect of screening [Jacob et al., 2014]

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Sex	*Period after exposure (years)*	*Baseline risk with screening*	*Radiation-associated risk estimate*[a]
Female	20	0.089×10^{-2}	$0.12\ (0.007; 0.51) \times 10^{-2}$
Female	50	2.3×10^{-2}	$1.4\ (0.11; 4.6) \times 10^{-2}$
Male	50	0.52×10^{-2}	$0.30\ (0.015; 1.2) \times 10^{-2}$

[a] *Best estimate and 95% confidence interval.*

2. Power calculations

Table 7. Estimated baseline and average radiation-associated increased risk of thyroid cancer among the population screened in Fukushima Prefecture, considering the estimated influence of screening for two time periods after exposure [Jacob et al., 2014]

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Thyroid dose (mGy)	*Period after exposure (years)*	*Baseline risk with screening*	*Radiation-associated risk estimate*[a]
20	20	0.23×10^{-2}	$0.021\ (0.0007;\ 0.081) \times 10^{-2}$
20	50	2.2×10^{-2}	$0.13\ (0.005;\ 0.40) \times 10^{-2}$

[a] *Best estimate and 95% confidence interval.*

Table 8. Infants in areas of Fukushima Prefecture with first-year thyroid doses from external exposure and inhalation that exceeded 10 mGy or were less than 3 mGy (attachment C-16 of [UNSCEAR, 2014])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Thyroid dose (mGy)	*Whole population*	*Screened*[a]	*Girls <3 years*[a]
>10	740 000	111 000	11 000
<3	444 000	66 000	6 600

[a] *Based on assumption 9.*

B. Assumptions

15. *Assumption 7*. Lifetime radiation-associated risk of thyroid cancer may be estimated by a linear dose response with a risk per unit dose, R_{th} (derived from tables 5, 6 and 7).

16. *Assumption 8*:

- The (simple) null hypothesis, H0, that there is no increased risk for exposed persons (that is $P_{exp} = P_{nonexp}$);
- The alternative hypothesis, H1, that there is an increased risk for exposed persons (that is $P_{exp} > P_{nonexp}$, which is a one-sided test);
- Accepted error Type 1 (i.e. probability that H0 is correct and the study concludes it to be wrong) of 5%;
- *t*-test to compare proportions in two independent groups, using the approximation of binomial distribution;
- Study design: cross-section (screening) study, where the incidence can be estimated for the time period between the first and the last screening;
- Software: program G Power [Program G*Power].

17. *Assumption 9*. In a hypothetical epidemiological study, thyroid cancer incidence would be compared between population groups living in districts of Fukushima Prefecture who received first-year thyroid doses as infants from external exposure and inhalation that exceeded 10 mGy or were less than 3 mGy. Based on population statistics in Japan, it was assumed that the screened population constituted 15% of the total population, and that girls younger than 3 years constituted 1.5% of the total population. It was further assumed that the difference

between the average lifetime thyroid dose for the two groups of districts amounted to 10 mGy for the whole of the screened population, and to 20 mGy for females exposed as girls younger than 3 years.

18. *Assumption 10*. The value of the risk per unit dose could be higher than the best estimate used in the power calculations. Thus, additional power calculations were performed assuming values of risks from radiation exposure that were 2.5 times higher than the best estimate. In further calculations it was assumed that the size of the control group was twice that of the main analysis.

C. Results

1. Exploratory analysis

19. Based on calculations in [WHO, 2013], the lifetime relative risk for female infants with the thyroid dose of 50 mGy amounted to $(0.52 \times 50/122 + 0.77) / 0.77 = 1.28$. For male infants with the thyroid dose of 50 mGy, the lifetime relative risk amounts to $(0.12 \times 50/122 + 0.21) / 0.21 = 1.23$.

20. Based on calculations of Jacob et al. [Jacob et al., 2014], the relative risk 50 years after exposure for female infants who received a thyroid dose of 50 mGy amounts to $(1.4 \times 50/100 + 2.3) / 2.3 = 1.30$. For male infants who received a thyroid dose of 50 mGy, the relative risk amounts to $(0.3 \times 50/100 + 0.52) / 0.52 = 1.29$.

2. Power calculations

Table 9. Power of theoretical epidemiological studies of thyroid cancer incidence in Fukushima Prefecture for two time periods after the accident

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population	$D_{high} - D_{low}$ *(mGy)*	*Radiation-associated risk*	*20 years after exposure*	*50 years after exposure*
All screened	10	Best estimate	11%	–*
		2.5 × best estimate	28%	70%
Girls <3 years	20	Best estimate	11%	31%
		2.5 × best estimate	27%	87%
Girls <3 years Non-exposed doubled	20	Best estimate	14%	40%

* *<30%.*

21. On purely statistical grounds, and conditional on the above assumptions being valid, an increased incidence of thyroid cancer due to radiation exposure might theoretically be discernible, if:

- The health of females exposed before the age of 3 years would be followed for the next 50 years;
- Their average thyroid dose were larger than the one in a control group by at least 20 mGy;

- The risk for radiation-induced thyroid cancer were actually a factor of 2.5 higher than the best estimate in Jacob et al. [Jacob et al., 2014];
- All persons could be followed-up for decades.

IV. LEUKAEMIA

22. The Committee addressed whether an increased incidence of leukaemia was expected to be discernible in paragraphs E34 and E35 of [UNSCEAR, 2014].

A. Input

Table 10. Number of non-evacuated persons in districts of Fukushima Prefecture and of evacuated persons for evacuation scenarios who received an average dose to red bone marrow dose greater than 4 mGy in the first year (see assumptions 11 and 12)

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Range of red bone marrow dose (mGy)*	*Size of population with doses in range*
Non-evacuated adults	4 to 5	252 642
Non-evacuated children	4 to 6	77 863
Non-evacuated infants	4 to 8	62 522
Evacuated adults	4 to 10	44 016

Table 11. Average doses to red bone marrow in the first-year and accumulated up to age 80 years of people in non-evacuated districts of Fukushima Prefecture — and of evacuees for evacuation scenarios — who received doses greater than 4 mGy in the first year (see assumptions 12, 13 and 15)

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Red bone marrow dose in the first year (mGy)*	*Red bone marrow dose accumulated to age 80 years (mGy)*
Non-evacuated adults	4.3	11
Non-evacuated children	5.0	14
Non-evacuated infants	5.6	13
Evacuated adults	6.3	13

Table 12. Lifetime baseline and estimates of radiation-associated risk of leukaemia for population groups in regions with highest deposition densities (tables 34, 35 and 36 in [WHO, 2013])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Lifetime red bone marrow dose (mGy)*	*Baseline risk*	*Radiation-associated risk estimate*
Women	22	0.40×10^{-2}	0.009×10^{-2}
Men	22	0.57×10^{-2}	0.015×10^{-2}
Girls	26	0.41×10^{-2}	0.014×10^{-2}
Boys	26	0.58×10^{-2}	0.020×10^{-2}
Female infants	26	0.43×10^{-2}	0.027×10^{-2}
Male infants	26	0.60×10^{-2}	0.040×10^{-2}

Table 13. Cumulative baseline and estimated radiation-associated risk of childhood leukaemia in regions with highest deposition densities (table 40 in [WHO, 2013])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*15-years red bone marrow dose (mGy)*	*Baseline risk*	*Radiation-associated risk estimate*
Female infants	26	0.03×10^{-2}	0.017×10^{-2}
Male infants	26	0.03×10^{-2}	0.025×10^{-2}

B. Assumptions

23. *Assumption 11*. Leukaemia is a relatively rare disease. The number of leukaemia cases among non-evacuated children and infants, and among evacuated adults in the uppermost dose intervals will be small. Thus, larger population groups of size $P_{>4\mathrm{mGy}}$, defined by red bone marrow doses exceeding 4 mGy, are considered here.

24. *Assumption 12*. Numerical values of effective dose (in millisieverts) may be used to approximate the absorbed dose to red bone marrow (in milligrays). Calculations are performed for females and males separately. In both cases $P_{>4\mathrm{mGy}}$ is assumed to be 50% of the value for the total population in table 10.

25. *Assumption 13*. Lifetime red bone marrow doses may be estimated from first-year red bone marrow doses by multiplication with the ratio of lifetime effective doses and first-year effective doses as derived from table 2.

26. *Assumption 14*. Notional numbers of radiation-associated cases of leukaemia during lifetime and of childhood leukaemia may be estimated by a linear dose response with a radiation-associated risk per unit dose, R_{lk} (derived from tables 12 and 13):

$$\text{For lifetime:} \quad N_{lk,attr} = P_{>4mGy} \, D_{80} \, R_{lk}$$

$$\text{For childhood:} \quad N_{lk,attr} = P_{>4mGy} \, D_{15} \, R_{lk}$$

27. *Assumption 15*. An upper estimate of the lifetime dose to evacuees for the scenario with the highest first-year dose may be obtained by adding the difference of the lifetime dose and the first-year dose in the district to the highest first-year dose.

C. Results

Table 14. Estimated numbers of baseline and notional radiation-associated cases of leukaemia during lifetime of the most exposed population groups as defined in table 10

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities. Note that calculations are based on radiation-associated risks per unit dose for the scenario of relocated people (table 13), which are slightly higher than those for non-evacuated people and slightly lower than those for evacuated people

Population group	$N_{lk,base}$	$N_{lk,attr}$	*ERR*	*Power*
Non-evacuated women	505	5.6	0.011	–*
Non-evacuated men	720	9.3	0.013	–*
Non-evacuated girls	160	2.9	0.018	–*
Non-evacuated boys	226	4.1	0.018	–*
Non-evacuated female infants	134	4.2	0.031	–*
Non-evacuated male infants	188	6.2	0.033	–*
Evacuated women	88	1.1	0.013	–*
Evacuated men	125	1.9	0.015	–*

** <30%.*

Table 15. Estimated numbers of baseline and notional radiation-associated cases of childhood leukaemia in the most exposed populations groups as defined in table 10

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	$N_{lk,base}$	$N_{lk,attr}$	*ERR*	*Power*
Non-evacuated female infants	9.4	2.7	0.28	–*
Non-evacuated male infants	9.4	3.9	0.42	–*

** <30%.*

V. BREAST CANCER

28. The Committee addressed whether an increased incidence of breast cancer was expected to be discernible in paragraph E36 of [UNSCEAR, 2014].

A. Input

Table 16. Number of non-evacuated females in districts of Fukushima Prefecture — and of evacuated females — with average breast dose greater than 4 mGy in the first year(see assumptions 16 and 17)

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Range of breast dose (mGy)*	*Population in range*
Non-evacuated adults	4 to 5	126 321
Non-evacuated children	4 to 6	38 932
Non-evacuated infants	4 to 8	31 261
Evacuated adults	4 to 10	22 008

Table 17. Average first-year and cumulative breast dose up to age 80 years in non-evacuated districts of Fukushima Prefecture and in evacuation scenarios exceeding first-year doses of 4 mGy (see assumptions 17, 18 and 20)

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group	*Breast dose in the first year (mGy)*	*Breast dose accumulated to age 80 (mGy)*
Non-evacuated adults	4.3	11
Non-evacuated children	5.0	14
Non-evacuated infants	5.6	13
Evacuated adults	6.3	13

Table 18. Lifetime baseline and radiation-associated risk of breast cancer for females in regions with highest deposition densities (tables 34, 35 and 36 in [WHO, 2013])

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities

Population group exposed as	*Lifetime breast dose (mGy)*	*Baseline risk*	*Radiation-associated risk*
Adult	24	5.6×10^{-2}	0.13×10^{-2}
Girl	26	5.5×10^{-2}	0.22×10^{-2}
Infant	28	5.5×10^{-2}	0.36×10^{-2}

B. Assumptions

29. *Assumption 16*. Considering the small relative risk implied by table 18, the total number of notional radiation-related cases will be the deciding quantity in the power calculations. Thus, as for leukaemia, not only persons in the group with the uppermost levels of dose, but larger populations groups of size $P_{>4\mathrm{mGy}}$ (defined by first-year doses to the breast exceeding 4 mGy) are considered here.

30. *Assumption 17*. Numerical values of effective dose (in millisieverts) may reasonably also be used to approximate the absorbed dose to the breast (in milligrays).

31. *Assumption 18*. Lifetime dose to the breast may be estimated from the first-year dose to the breast by multiplication with the ratio of lifetime effective doses and first-year effective doses as derived from table 2.

32. *Assumption 19*. Numbers of notional radiation-associated cases of breast cancer may be estimated using a linear dose response with a risk per unit dose, R_{bc} (derived from table 18):

$$N_{\mathrm{bc,attr}} = P_{>4\mathrm{mGy}}\, D_{80}\, R_{\mathrm{bc}}$$

33. *Assumption 20*. An upper estimate of the lifetime dose to the evacuees who followed the scenario leading to the highest first-year dose may be obtained by adding the difference of the lifetime dose and the first-year dose in the district to the highest first-year dose.

C. Results

Table 19. Estimated numbers of baseline and notional radiation-associated cases of breast cancer during the lifetime of the most exposed population groups as defined in table 16

The number of significant figures presented in the table are for purposes of calculation only; they do not imply such a degree of accuracy in the underlying quantities. Note that calculations are based on radiation-associated risks per unit dose for the scenario of relocated people (table 18), which are slightly higher than those for non-evacuated people and slightly lower than those for evacuated people

Population group	$N_{bc,base}$	$N_{bc,attr}$	*ERR*	*Power*
Non-evacuated women	7 011	74	0.011	–*
Non-evacuated girls	2 157	47	0.022	–*
Non-evacuated female infants	1 729	52	0.030	35%
Evacuated women	1 221	15	0.012	–*

* <30%.

ACKNOWLEDGEMENTS

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REFERENCES

Breslow, N.E. and N.E. Day. Statistical methods in cancer research. Volume II - The design and analysis of cohort studies. IARC Scientific Publications no. 82. International Agency for Research on Cancer, Lyon, 1987.

Jacob, P., J.C. Kaiser and A. Ulanovsky. Ultrasonography survey and thyroid cancer in the Fukushima Prefecture. Radiat Environ Biophys 53(2): 391-401 (2014).

Katanoda, K., W. Ajiki, T. Matsuda et al. Trend analysis of cancer incidence in Japan using data from selected population-based cancer registries. Cancer Sci 103(2): 360-368 (2012).

Program G*Power. Program G*Power, version 3.1.9.2. Written by Franz Faul, University of Kiel, Germany. [Internet] Available from (http://www.gpower.hhu.de/) on August 2014.

UNSCEAR. Sources and Effects of Ionizing Radiation. Volume II: Effects. UNSCEAR 2000 Report. United Nations Scientific Committee on the Effects of Atomic Radiation, 2000 Report to the General Assembly, with scientific annexes. United Nations sales publication E.00.IX.4. United Nations, New York, 2000.

UNSCEAR. Sources, Effects and Risks of Ionizing Radiation. Volume I: Report to the General Assembly and Scientific Annex A. UNSCEAR 2013 Report. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations sales publication E.14.IX.1. United Nations, New York, 2014.

WHO. Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation. World Health Organization, Geneva, 2013.