Table 12. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) up to attained age 89 for the general population (both sexes and three different ages at exposure) for thyroid cancer incidence

Location groups	Locations	Lifetime attributable risk (LAR x 10^{-2})			Lifetime attributable risk (LAR x 10^{-2})		
		Males			Females		
		Adults 20y	Children 10y	Infants 1y	Adults 20y	Children 10y	Infants 1y
Group 1	①	0.019	0.054	0.118	0.088	0.245	0.524
	②	0.010	0.029	0.071	0.048	0.133	0.317
Group 2	③	0.005	0.016	0.046	0.025	0.072	0.207
	④	0.005	0.015	0.044	0.025	0.070	0.194
	⑤ to ⑩	0.005	0.013	0.040	0.021	0.061	0.177
	⑪ to ⑭	0.003	0.011	0.035	0.016	0.049	0.154
Group 3	Rest of Fukushima prefecture (less affected)**	0.003	0.009	0.030	0.012	0.039	0.135
	Neighbouring prefectures	*	*	*	*	*	*
	Rest of Japan	*	*	*	*	*	*
Group 4	Neighbouring countries	*	*	*	*	*	*
	Rest of the world	*	*	*	*	*	*
LBR (X 10^{-2}) for cancer incidence in Japan* **		**0.21**	**0.21**	**0.21**	**0.76**	**0.77**	**0.77**

* Mathematical calculations of LAR were not performed for Group 3 and Group 4 locations, where the risks would be much lower than the normal temporal and spatial fluctuation of the baseline cancer incidence risks.

** Exceptionally the HRA Expert Group performed mathematical calculations of LAR for the rest Fukushima prefecture less affected area, even though it was included within Group 3. Thyroid doses in this area were calculated with very conservative assumptions. In practice, doses are considered to be much lower in this area and therefore, the thyroid cancer risks would be also lower than those presented in this table.

*** Based on Japan cancer incidence rates in 2004 from Matsuda et al (*104*).

Figure 10. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) for leukaemia in Group 1 Location ① for males and females exposed at 1, 10, 20 year-old.

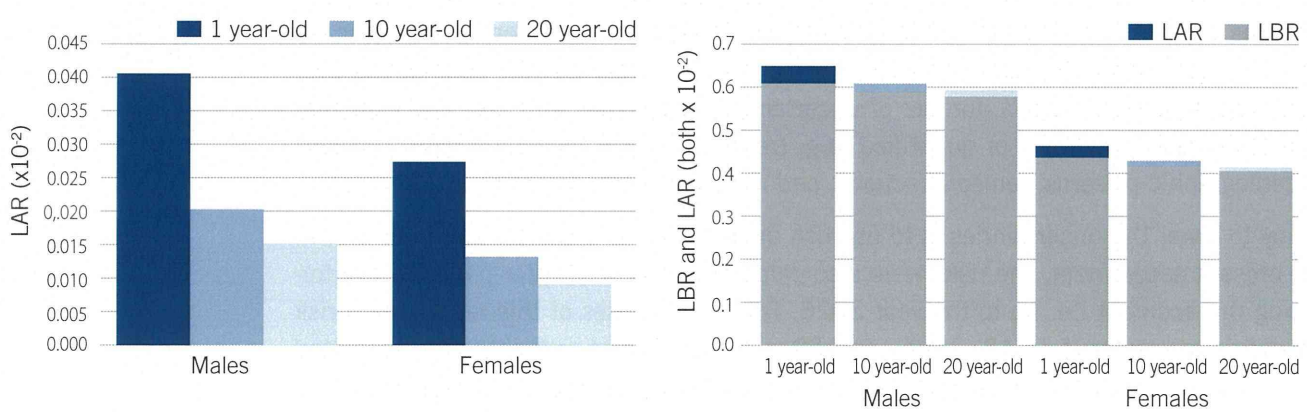


Figure 11. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) for all solid cancer in Group 1 Location ① for males and females exposed at 1, 10, 20 year-old.

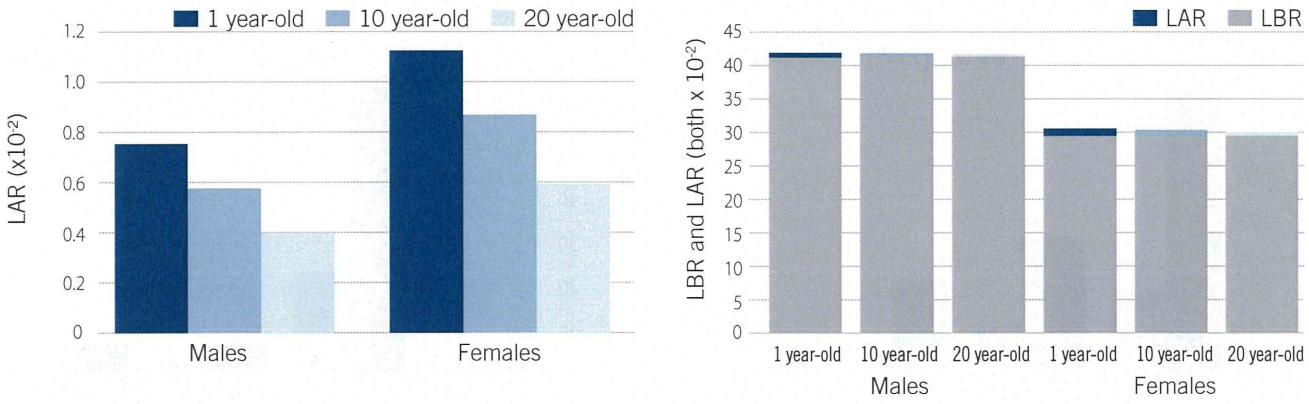


Figure 12. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) for thyroid cancer in Group 1 Location ① for males and females exposed at 1, 10, 20 year-old.

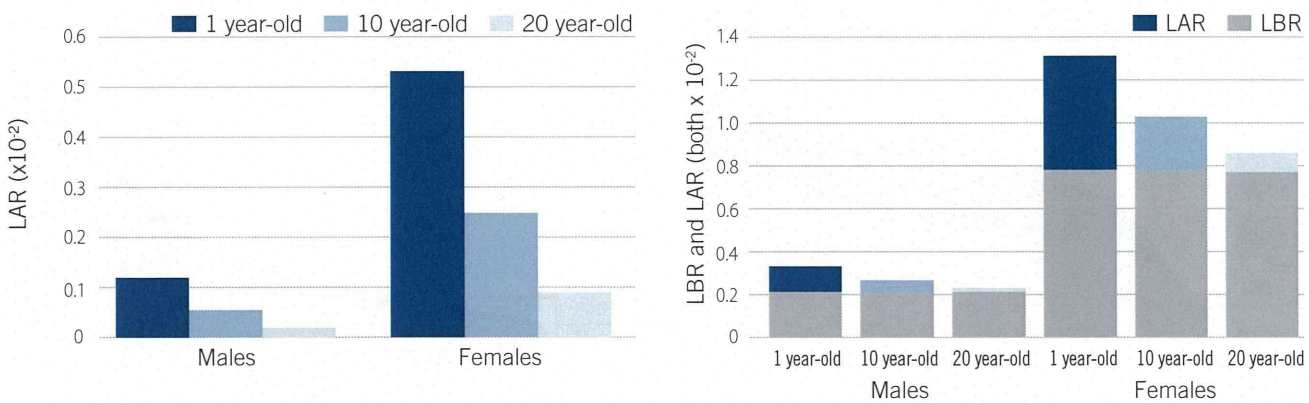


Figure 13. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) for breast cancer in Group 1 Location ① for females exposed at 1, 10, 20 year-old.

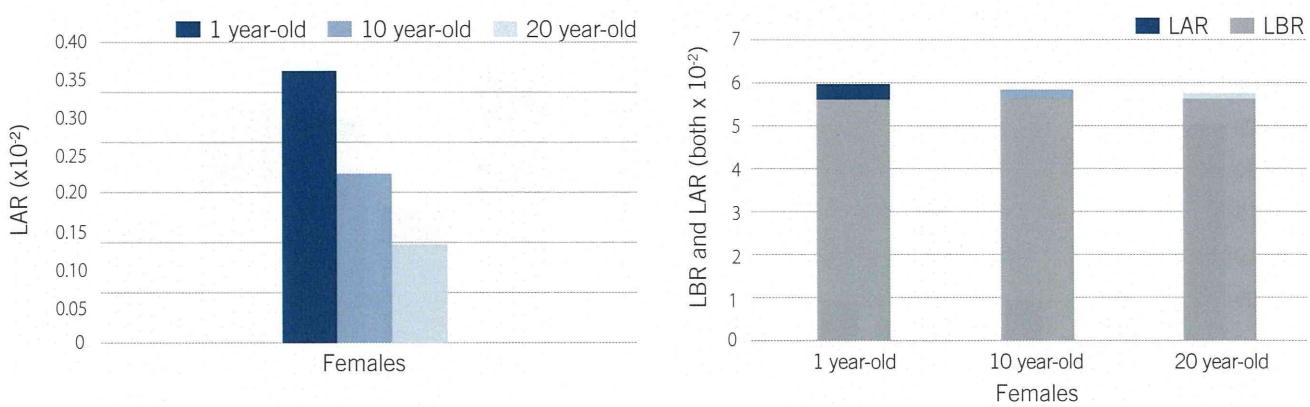


Figure 14. Lifetime Attributable Risk (LAR) for the studied cancer sites in a female, 1-year old at exposure in Group 1 and Group 2 locations

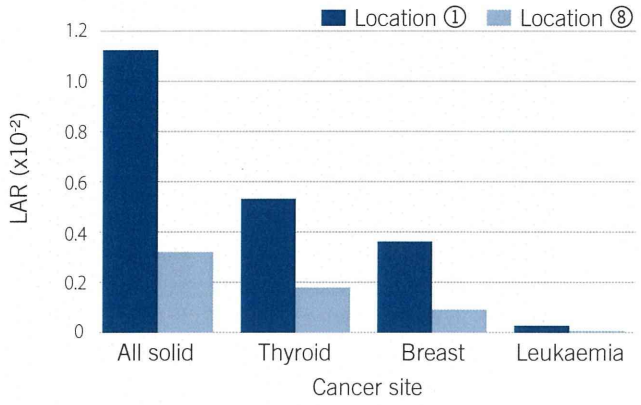


Figure 15. Lifetime Fractional Risk (LFR) for the studied cancer sites in a female, 1-year old at exposure in Group 1a and Group 2 locations

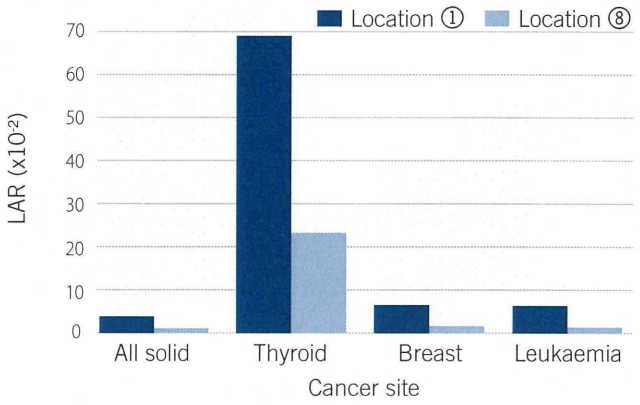


Figure 16. Cumulative attributable risk (AR_{15}) and lifetime attributable risk (LAR) for leukaemia as a function of attained age for a female, one year age-at-exposure, in Location ①.

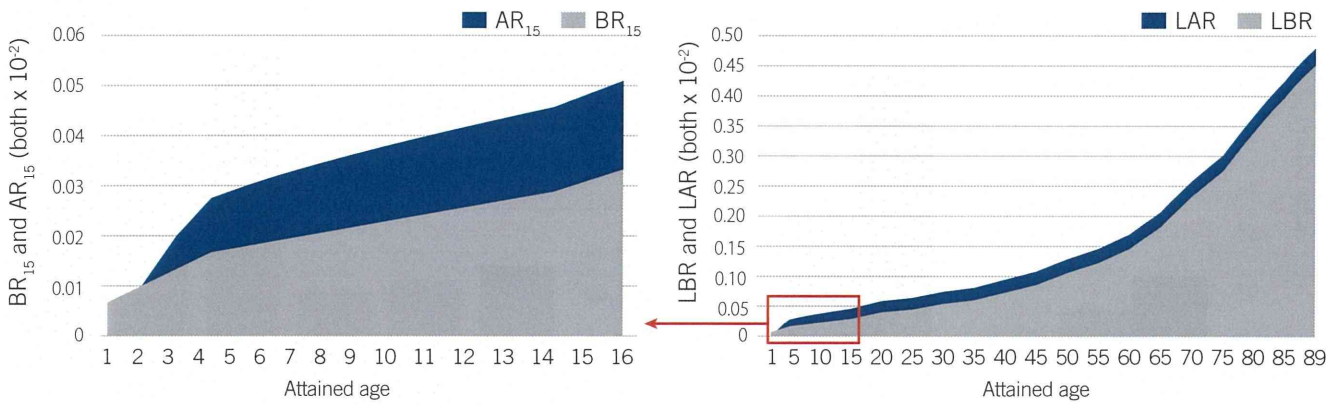


Figure 17. Leukaemia: cumulative attributable cancer risk over 15 years after exposure (AR_{15}) (a) for both genders and 3 age groups (infants, children and adults) in locations ① and ⑧; and (b) with cumulative baseline risk (BR_{15}) in location ①

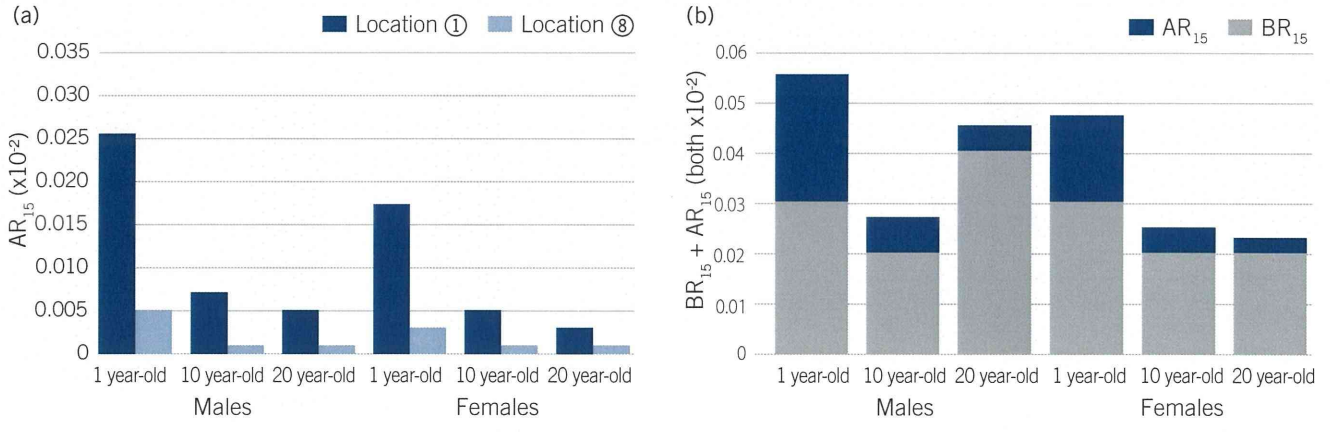


Figure 18. All solid cancer: cumulative attributable cancer risk over 15 years after exposure (AR_{15}) (a) for both genders and 3 age groups (infants, children and adults) in locations ① and ⑧; and (b) with cumulative baseline risk (BR_{15}) in location ①

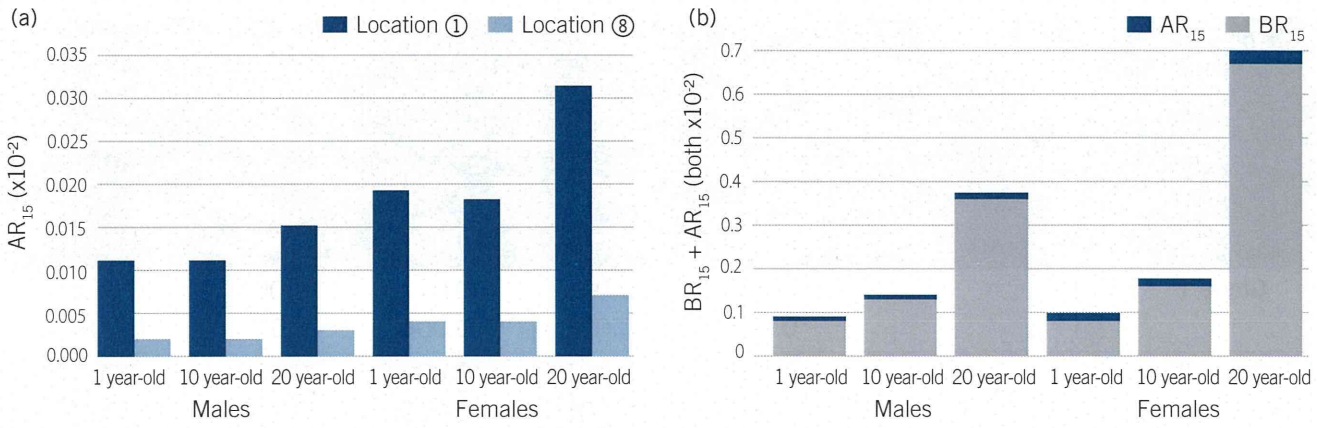


Figure 19. Thyroid cancer: cumulative attributable cancer risk over 15 years after exposure (AR_{15}) (a) for both genders and 3 age groups (infants, children and adults) in locations ① and ⑧; and (b) with cumulative baseline risk (BR_{15}) in location ①

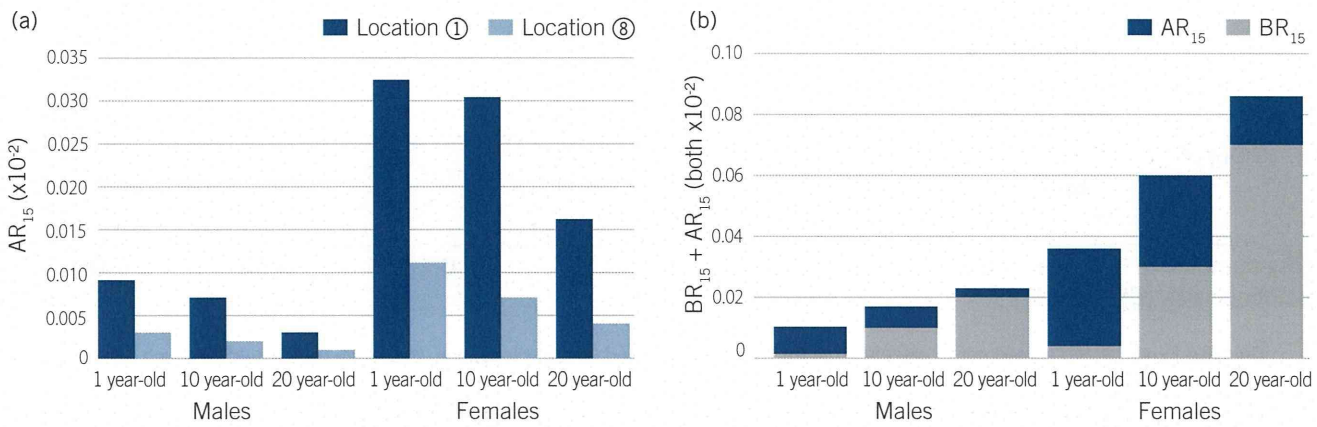
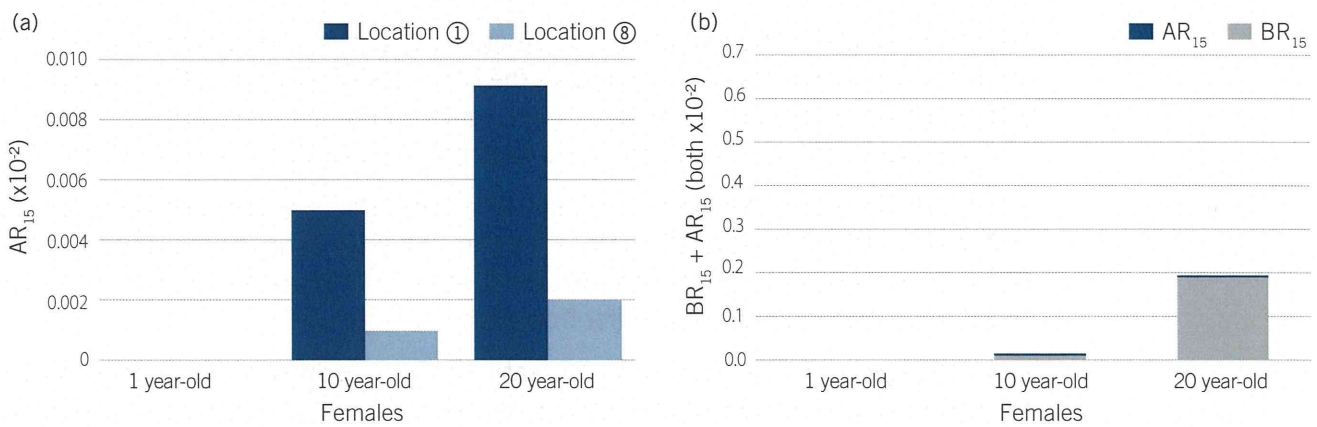


Figure 20. Breast cancer: cumulative attributable cancer risk over 15 years after exposure (AR_{15}) (a) and 3 age groups (infants, children and adults) in locations ① and ⑧; and (b) with cumulative baseline risk (BR_{15}) in location ①



Note that AR_{15} is not calculated for a 1 year-old (age-at-exposure) because existing evidence shows no breast cancer before an attained age of 20 years (section 2.2.1).

Table 13. Cumulative attributable risk over 15 years after exposure (AR_{15}) and cumulative baseline risk over the same segment of life (BR_{15}) for the general population (both sexes and three different ages at exposure) for all solid cancers, breast cancer and leukaemia incidence

Location groups	Locations	Cumulative attributable risk over 15 years (AR_{15} x 10^{-2})					
		Males					
		Adults 20y		Children 10y		Infants 1y	
		All solid	Leukaemia	All solid	Leukaemia	All solid	Leukaemia
Group 1	①	0.015	0.005	0.011	0.007	0.011	0.025
	②	0.008	0.003	0.006	0.004	0.006	0.014
Group 2	③	0.003	0.001	0.002	0.001	0.002	0.005
	④	0.004	0.001	0.003	0.002	0.003	0.006
	⑤ to ⑨	0.003	0.001	0.002	0.001	0.002	0.005
	⑩ to ⑭***	0.003	0.001	0.002	0.001	0.002	0.005
Group 3	Rest of Fukushima prefecture (less affected)	*	*	*	*	*	*
	Neighbouring prefectures	*	*	*	*	*	*
	Rest of Japan	*	*	*	*	*	*
Group 4	Neighbouring countries	*	*	*	*	*	*
	Rest of the world	*	*	*	*	*	*
15-y cumulative baseline cancer incidence risk (BR_{15} X 10^{-2}) ****		**0.36**	**0.04**	**0.13**	**0.02**	**0.08**	**0.03**

* The HRA Expert Group agreed not to calculate the AR15 for Group 3 and Group 4 locations, where the risks would be much lower than the normal temporal and spatial fluctuation of the baseline cancer incidence risks.

** The HRA Expert Group considered that the minimum attained age for breast cancer risk expression is 20 years. Note that the baseline female cancer rates in Japan used in the present assessment indicate no baseline incidence before age 20 (i.e. rate = zero).

are compared with the risk that could be observed in the next decades, mainly during the second half of the 21st century.

Figure 16 illustrates the impact of the use of risk quantities over a different period of life (i.e. 15 years vs. lifetime). It presents the LFR (LAR/LBR) vs. AR_{15}/BR_{15} for leukaemia, as a function of the attained age for one location of Group 1 for females exposed at 1 year of age. Note that the latency period is particularly visible in the inset of Figure 16.

Some data about LBRs for infants, children and young adults of both sexes are provided in Annex L. Note that these LBR data are based on cancer incidence data for Japan in 2004. They are representative of the lifetime baseline risks expected for the forthcoming decades but might substantially differ from them.

It is interesting to note in Figures 10–13 that LBR does not differ much at different ages for any of the cancer sites, while it does differ between sexes: it is generally lower in females than in males except for the LBR for thyroid cancer incidence, which is about 3.5 times higher in females. Figures 17–20 illustrate the contribution of AR_{15} and BR_{15} for

Cumulative attributable risk over 15 years (AR_{15} x 10^{-2})								
Females								
Adults 20y			Children 10y			Infants 1y		
All solid	Breast cancer	Leukemia	All solid	Breast cancer	Leukemia	All solid	Breast cancer	Leukemia
0.031	0.009	0.003	0.018	0.005	0.005	0.019	**	0.017
0.018	0.005	0.002	0.010	0.003	0.003	0.011		0.010
0.007	0.002	0.001	0.004	0.001	0.001	0.004	**	0.003
0.009	0.002	0.001	0.005	0.001	0.001	0.005		0.004
0.007	0.002	0.001	0.004	0.001	0.001	0.004		0.003
0.007	0.002	0.001	0.004	0.001	0.001	0.004		0.003
*	*	*	*	*	*	*	**	*
*	*	*	*	*	*	*		*
*	*	*	*	*	*	*		*
*	*	*	*	*	*	*		*
*	*	*	*	*	*	*		*
*	*	*	*	*	*	*		*
0.67	**0.19**	**0.02**	**0.16**	**0.01**	**0.02**	**0.08**	**0.00**	**0.03**

*** For locations ⑩ to ⑭ no separate calculations were performed and AR_{15} was assumed to be the same as locations ⑤ to ⑨.
**** Based on Japan 2004 cancer incidence rates from Matsuda et *al.* (*104*).

different ages and cancer sites and for both sexes. The BR_{15} differs among cancer sites; the values are much lower at younger ages for solid cancers, female breast and thyroid. The BR_{15} for leukaemia shows a different trend with age (baseline risks in 1-year-old infants are comparatively higher than in 10-year-old children). The BR_{15} does not show important sex-related differences for leukaemia. It is interesting to note that for all solid cancer and female breast cancer, the AR_{15} is higher for 20-year-old adults. These are mostly adulthood cancers sites, with longer latency. In contrast, thyroid cancer and leukaemia have a shorter latency and are considered more relevant in childhood.

5.3 Cancer risk characterization for the emergency workers

The HRA Expert Group assessed cancer incidence risks in workers as (i) LAR assessed for the entire life (up to 89 years attained age) and (ii) cumulative attributable risks assessed over 15 years after exposure. Risks of leukaemia, thyroid cancer and all solid cancers were assessed as a function of the first-year radiation dose to the relevant organs

Table 14. Cumulative attributable risk over 15 years after exposure (AR_{15}) and cumulative baseline risk over the same segment of life (BR_{15}) for the general population (both sexes and three different ages at exposure) for thyroid cancer incidence

Location groups	Locations	Cumulative attributable risk over 15 years (AR_{15} x 10^{-2})					
		Males			Females		
		Adults 20y	Children 10y	Infants 1y	Adults 20y	Children 10y	Infants 1y
Group 1	①	0.003	0.007	0.009	0.016	0.030	0.032
	②	0.002	0.004	0.005	0.009	0.016	0.020
Group 2	③	0.001	0.002	0.003	0.004	0.009	0.013
	④	0.001	0.002	0.003	0.004	0.008	0.012
	⑤ to ⑩	0.001	0.002	0.003	0.004	0.007	0.011
	⑪ to ⑭	0.001	0.001	0.003	0.003	0.006	0.009
Group 3	Rest of Fukushima prefecture (less affected)**	***	0.001	0.002	0.002	0.005	0.008
	Neighbouring prefectures	*	*	*	*	*	*
	Rest of Japan	*	*	*	*	*	*
Group 4	Neighbouring countries	*	*	*	*	*	*
	Rest of the world	*	*	*	*	*	*
15-y cumulative baseline thyroid cancer incidence risk (BR_{15} X 10^{-2})**		**0.02**	**0.01**	**0.0014**	**0.07**	**0.03**	**0.0040**

* Mathematical calculations of AR_{15} were not performed for Group 3 and Group 4 locations, where the risks would be much lower than the normal temporal and spatial fluctuation of the baseline cancer incidence risks.

** Exceptionally the HRA Expert Group performed mathematical calculations of AR_{15} for the rest Fukushima prefecture less affected area, even though it was included within Group 3. Thyroid doses in this area were calculated with very conservative assumptions. In practice, doses are considered to be much lower in this area and therefore, the thyroid cancer risks would be also lower than those presented in this table.

*** AR_{15}=0.0005

**** Based on Japan cancer incidence rates in 2004 from Matsuda et al (*104*).

using the same risk models derived from epidemiological studies of radiation-induced cancer as for the general population. Background information on recent cancer incidence and mortality data from Japan were used to derive the baseline cumulative risk. The cancer risk was assessed for workers exposed at 20 years, 40 years and 60 years of age. These ages are representative of the workers' population distribution, according to the data provided by TEPCO (see Table 7 and Annex H).

The LAR calculated for male workers under the four assumed exposure scenarios described in section 4.2) are presented in Tables 15 and 16. The complete set of results tables for workers has been included in Annex K. The results are analysed below, with particular emphasis on scenarios 1 and 2, which together represent more than 99% of the total workforce (i.e. 69% and 30% of the workers, respectively). Some particular

Table 15. Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) up to attained age 89 for male workers (four scenarios of exposure and three different ages at exposure) for all solid cancers, thyroid cancer and leukaemia incidence

Scenario		Lifetime attributable risk (LAR X 10^{-2})								
		Age 20y			Age 40y			Age 60y		
		All solid	Thyroid	Leukae-mia	All solid	Thyroid	Leukae-mia	All solid	Thyroid	Leukae-mia
> 99% of the workers	1	0.086	0.001	0.003	0.050	<0.001*	0.002	0.023	<0.001*	0.002
	2	0.413	0.242	0.016	0,242	0.011	0.012	0.111	0.002	0.008
< 1% of the workers (upper bound)	3	3.437	0.060	0.157	2.018	0.016	0.119	0.922	0.003	0.080
	4	1.774	3.558	0.075	1.042	0.918	0.057	0.476	0.191	0.038
LBR (x 10^{-2}) for cancer incidence in Japan		**40.74**	**0.21**	**0.57**	**40.90**	**0.19**	**0.52**	**38.10**	**0.14**	**0.44**

* The calculated LAR values are between 0.0001 and 0.0004

considerations are made about scenarios 3 and 4, which represent less than 1% of the workers.

The LAR for leukaemia is on the order of 0.3 in 10 000 in scenario 1 and on the order of 1 to 2 in 10 000 in Scenario 2. No remarkable age-related differences in the magnitude of LAR were observed. This represents a LFR of around 0.5% and 2.8%in scenarios 1 and 2, respectively. The highest LAR levels are observed in Scenario 3 (LAR around 16 in 10 000, representing a relative increase (LFR) of 27% in the baseline lifetime risk of leukaemia).

Thyroid cancer risks are low in Scenario 1, where LAR is on the order of 0.1 in 10 000 for workers exposed at 20 years of age and one order of magnitude below for workers exposed at 40 and 60 years of age. The LAR for Scenario 2 is on the order of 4 in 10 000, while for scenario 3 is on the order of 6 in 10 000. In general, risks show a strong dependence on age-at-exposure, with much lower risks for workers exposed at 60 years of age compared with 20-year-old workers. For Scenario 1 the LFR was estimated to be below 0.5% for all ages, while under Scenario 2 the LFR was estimated to be markedly age-dependent: around 20%, 5.8% and 1.4% for workers exposed at 20, 40 and 60 years old, respectively). Thyroid cancer is the dominant risk in Scenario 4, which assumes the highest thyroid organ dose and effective dose, resulting primarily from internal exposure to radioactive iodine. The risk is much higher for workers exposed at 20 years old compared with workers exposed at 40 years of age and 60 years of age (LAR values about 356 in 10 000, 92 in 10 000 and 19 in 10 000, respectively. This strong dependence with age-at-exposure is further discussed in section 6.1.1.

The LAR values for all solid cancers in Scenario 1 vary from 2 to 9 in 10 000 (60 years of age and 20 years of age at exposure, respectively), which represents a LFR of around 0.1%. The LAR is on the order of 40 in 10 000 in workers 20 years of age exposed under

Table 16. Cumulative attributable risk over 15 years after exposure (AR_{15}) and cumulative baseline risk over the same segment of life (BR_{15}) for male workers (four scenarios of exposure and three different ages at exposure) for all solid cancer, thyroid cancer and leukaemia incidence

Scenario		Cumulative attributable risk over 15 years after exposure (AR_{15} x 10^{-2}) *								
		Age 20y			Age 40y			Age 60y		
		All solid	Thyroid	Leukae-mia	All solid	Thyroid	Leukae-mia	All solid	Thyroid	Leukae-mia
> 99% of the workers	1	0.003	<0.001*	0.001	0.008	<0.001*	0.001	0.013	<0.001*	0.001
	2	0.016	0.008	0.006	0.038	0.004	0.005	0.061	0.001	0.006
< 1% of the workers (upper bound)	3	0.133	0.011	0.055	0.319	0.005	0.052	0.505	0.002	0.056
	4	0.069	0.650	0.026	0.165	0.309	0.025	0.261	0.124	0.026
15-y cumulative baseline cancer incidence risk (BR_{15} x 10^{-2})*		**0.36**	**0.02**	**0.04**	**3.71**	**0.05**	**0.08**	**21.03**	**0.09**	**0.23**

* The calculated AR_{15} values are between 0.0001 and 0.0003.

Scenario 2 and somewhat lower at older ages (11–24 in 10 000). This represents a LFR of less than 1% (all ages).

Some data about LBR for male adults of 20, 40 and 60 years of age are provided in Annex L. They are presented in two ways: (i) as a cumulative baseline cancer incidence over 15 years (BR_{15}) and (ii) as the lifetime baseline cancer incidence up to 89 years of attained age (LBR). It is interesting to note that:

- LBR does not differ much between young and middle-aged adults, and is slightly lower at 60 years of age (the remaining lifespan for a person exposed at 60 years of age is lower than for a person exposed at 20 years of age, and therefore the prospective lifetime risk of developing a cancer will be lower).
- If the lifetime baseline risk is "truncated" at 15 years after exposure (BR15) the age-dependent differences become more evident and younger adults show lower cumulative baselines. This is more evident for leukaemia and all solid cancer, but less for thyroid cancer.
- It is noted that these LBR data are based on cancer incidence data for Japan in 2004. They are therefore representative of the lifetime baseline risks expected for the forthcoming decades. However, it is clear that cancer incidence trends may change over time, and that future true baseline risks will differ from those used in this assessment.

5.4 Non-cancer risk characterization

5.4.1 General population

No acute effects of radiation exposure such as acute radiation syndrome or skin injuries have been observed among the general population. Such acute effects are observed after

exposure to high doses and are not therefore expected among the general public as a result of the Fukushima Daiichi NPP accident. Based on the preliminary dose estimation in the general population both inside and outside Japan, no increase in the frequency of tissue reactions attributable to radiation exposure is expected in the general population; no respective clinical reports were received in Japan or elsewhere. This is supported by current knowledge on radiation biology and existing evidence about threshold doses for deterministic effects (see Annex F).

As a result of this assessment, it was concluded that no increase in the frequency of cataracts, circulatory diseases or any other tissue reaction is expected for the general population, given the range of doses under consideration.

The HRA Expert Group did not perform a quantitative assessment of radiation risks of non-cancer thyroid nodules through mathematical risk models. Instead, a qualitative assessment was supported by the evidence summarized in sections 2.2.2 and Annex F, indicating that even low doses of radiation may increase the risk of non-cancer thyroid nodules in individuals exposed.

The HRA Expert Group gave particular consideration to the assessment of non-cancer risks of radiation exposure of the unborn child. For that purpose it took into consideration the preliminary dose estimation conducted by the Dose Expert Panel and the results of the calculation of first-year organ doses conducted for the present HRA. The HRA Expert Group concluded that, even under the conservative assumptions adopted, the radiation doses in the general population are below the thresholds for the deterministic effects after prenatal radiation exposure, described in chapters 2 and 3. Therefore, no increase is expected in the incidence of congenital or developmental abnormalities, including cognitive impairment attributable to *in utero* radiation exposures during the Fukushima Daiichi NPP accident.

As described in section 2.2, the risk of radiation-induced hereditary effects has not been definitively demonstrated in human populations. Based on animal data, international scientific bodies consider that any risk effect of hereditary effects for the offspring of those who were exposed at reproductive age would be much lower than the additional lifetime risk of cancer for the exposed individual him- or herself (about one order of magnitude lower).

5.4.2 Emergency workers

The HRA Expert Group reviewed the level of doses reported among emergency workers, taking into account current knowledge and new scientific evidence about non-cancer effects provided in sections 2.2.2 and Annex F. Taking into account that 99% of workers were exposed to low doses (< 100 mSv), non-cancer risks are less relevant than cancer risks in terms of health impact. However, the HRA Expert Group considered all the possible health outcomes relevant to the four exposure scenarios assumed in the present assessment.

To date, no radiation injuries have been observed among Fukushima Daiichi NPP emergency workers as a result of the accident (i.e. no cases of acute radiation syndrome or skin injuries). None of the seven reported deaths among emergency workers is attributable to radiation exposure. In the early phase of the emergency three workers were exter-