United Nations Scientific Committee on the Effects of Atomic Radiation

ATTACHMENT C-15

COMPILATION OF INGESTION DOSE RESULTS

UNSCEAR 2013 Report, Annex A, Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, Appendix C (Assessment of doses to the public)

Content

This attachment describes the results of ingestion dose estimation for the public exposed to radiation from the accident at the Fukushima Daiichi nuclear power station (FDNPS) in March 2011. The assessment was conducted for the UNSCEAR 2013 Report, although this paper describing the detailed results was issued subsequently.

The population data were taken from the Japan Census [MIC, 2011].

Notes

Contents

I. MAIN ASSESSMENT RESULTS[a]

1. The ingestion dose estimates for members of the public were derived from two primary sources. Dose estimates for the first year were based on the FAO/IAEA/MAFF database of activity concentrations in food (attachment C-8), while dose estimates for subsequent years were based on the application of the FARMLAND model [Brown and Simmonds, 1995] to measured deposition rates to the ground. Doses were estimated for Fukushima Prefecture, the five neighbouring or nearby prefectures combined (Chiba, Gunma, Ibaraki, Miyagi and Tochigi) and for the rest of Japan; in each case three age groups were considered and effective doses and equivalent doses to the thyroid and red bone marrow were calculated. Account was taken of the restrictions on food supplies introduced by the Japanese authorities. These dose estimates were subsequently combined with estimates of doses due to other exposure pathways to obtain the total estimated doses for the representative individuals of the public with average dietary habits.

[a] Please note throughout this compilation, although results are given to two or three significant figures, this degree of precision do not imply such a level of accuracy for the estimated doses, which are considerably more uncertain.

Table 1. Ingestion doses for characteristic individuals in Fukushima Prefecture

Values in brackets assume only 25% consumed is locally marketed

Time period	*Age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	Effective dose (mSv)	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*
1 year	1.90 (0.61)	32.8 (10.0)	1.16 (0.39)	15.2 (4.7)	0.94 (0.32)	7.78 (2.3)
10 year	1.96	32.9	1.24	15.3	1.01	7.86
Lifetime	2.00	32.9	1.27	15.4	1.04	7.89

Time period	*Age group*		
	Infant (1-year old)	*Child (10-year old)*	*Adult*
	Absorbed dose to red bone marrow (mGy)	*Absorbed dose to red bone marrow (mGy)*	*Absorbed dose to red bone marrow (mGy)*
1 year	0.23 (0.09)	0.36 (0.14)	0.55 (0.20)
10 year	0.28	0.43	0.63
Lifetime	0.31	0.46	0.66

Table 2. Ingestion doses for characteristic individuals in 5 prefectures (Chiba, Gunma, Ibaraki, Miyagi and Tochigi) neighbouring Fukushima Prefecture

Values in brackets are assume only 25% consumed is locally marketed

Time period	*Age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	Effective dose (mSv)	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*
1 year	0.53 (0.27)	9.38 (4.3)	0.31 (0.18)	4.34 (1.96)	0.21 (0.13)	2.11 (0.92)
10 year	0.55	9.40	0.33	4.36	0.22	2.13
Lifetime	0.55	9.40	0.33	4.37	0.23	2.13

Time period	*Age group*		
	Infant (1-year old)	*Child (10-year old)*	*Adult*
	Absorbed dose to red bone marrow (mGy)	*Absorbed dose to red bone marrow (mGy)*	*Absorbed dose to red bone marrow (mGy)*
1 year	0.05 (0.05)	0.08 (0.07)	0.10 (0.09)
10 year	0.07	0.10	0.12
Lifetime	0.07	0.10	0.12

Table 3. Ingestion doses for characteristic individuals in the rest of Japan

Time period	*Age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	Effective dose (mSv)	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*	*Effective dose (mSv)*	*Absorbed dose to thyroid (mGy)*
1 year	0.18	2.57	0.13	1.17	0.11	0.53
10 year	0.19	2.58	0.14	1.17	0.11	0.53
Lifetime	0.19	2.58	0.14	1.17	0.11	0.53

Time period	*Age group*		
	Infant (1-year old)	*Child (10-year old)*	*Adult*
	Absorbed dose to red bone marrow (mGy)	*Absorbed dose to red bone marrow (mGy)*	*Absorbed dose to red bone marrow (mGy)*
1 year	0.05	0.07	0.09
10 year	0.05	0.07	0.09
Lifetime	0.05	0.07	0.09

2. The following should be noted for tables 1 to 3:

(a) The use of two decimal places does not imply this degree of accuracy;

(b) All doses include the effects of ageing on the dose estimation, i.e., the lifetime dose for adult (assumed to be 20 years old at the time of the accident) was for a period of 60 years, for the 10-year old child it was for a period of 70 years and for a 1-year-old infant it was for a period of 80 years; this assumed average length of life was 80 years;

(c) All dose estimates included the effects of food restrictions (simulated using the FARMLAND model) or were for foods as marketed (based on the FAO/IAEA/MAFF database);

(d) The first year dose estimates were based on the values from the database on activity concentration in food and any food that was not marketed was assumed not to be consumed in the region of interest. The additional ingestion doses for subsequent years were estimated based on modelling from measured deposition densities and assume that 25% of food consumed was locally produced and 75% was produced elsewhere in Japan. The values in brackets for the first year show the effect of assuming that 25% of the food consumed was locally produced in the assessment of doses using the database. In all cases account was taken of the amount of particular foods that were imported into Japan;

(e) Dose estimates did not include contributions from ingestion of drinking water, which is considered separately below.

3. The following points could be noted:

– Effective doses for one-year-olds were up to about a factor of two higher than the calculated doses for adults, with doses for 10-year-old children in between these two values;

– Absorbed doses to the thyroid were about a factor of 4 higher for the one-year-old than the calculated doses for adults;

– Estimated doses for Fukushima Prefecture were about a factor of 4 higher than those calculated for the 5 neighbouring prefectures and a factor of 10 higher than those for the rest of Japan;

– Nearly the entire estimated dose was delivered in the first year, with little increase in the estimate after integration over 10 years or over a lifetime;

– The main doses presented in tables 1 to 3 for the first year assumed that the food sampled was representative of the food eaten in the prefecture and no allowance was made for a proportion of the food being consumed from elsewhere in Japan. If, as for the dose assessment based on modelled activity concentration in food, it was assumed that only 25% of food was locally produced and the remaining 75% was from the rest of Japan, then the dose estimates would be lower. The estimates for the first year's doses assuming that 25% of food only is locally marketed are given in brackets in tables 1 and 2 above.

II. ADDITIONAL RESULTS FOR FIRST YEAR BASED ON DATABASE ON ACTIVITY CONCENTRATIONS IN FOOD

4. Using the database of activity concentrations in food, ingestion doses were calculated as a function of time for the first year following the accidental releases from FDNPS for a range of organs and age groups. The full results are given in the following tables, all based on food marketed in the location of interest allowing for the proportion of each food type that is imported into Japan.

5. The following points could be noted in relation to table 4:

– The doses from ingestion in the first month following the accident contributed the major part of the doses for the first year. For example, for infants, over 90% of the first year's effective dose was delivered in the first month and for adults, over 80% of the effective dose was delivered in the first month.

– The doses for each month after the first month were all significantly lower than the doses for the first month and showed some fluctuation from month to month. The values for months 2 to 4 and then for 5 to 12 were essentially the same given the uncertainties in the dose assessment. Variations would be expected that reflect the uncertainties in the measurement data combined with some variability depending on which foods were produced at different times. However, of more importance is likely to be the use of a constant value of 10 Bq/kg for measurements below the limits of detection. This value was used for ^{131}I, ^{134}Cs and ^{137}Cs for the first four months following the accident, but only for the two caesium isotopes after 4 months; this was probably the reason for the observed reduction in doses in the fifth and subsequent months, particularly for the absorbed dose to the thyroid.

– These results also reflect the impact of the restrictions on food supplies because the products from the areas most affected by the accident were excluded from the market and these would likely have been above limits of detection and therefore showed the greatest variation with time.

Table 4. Ingestion doses for the first year following the accident based on the database of activity concentrations in food — results for Fukushima Prefecture

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
1st month	Lower large intestine wall	4.32×10^{-4}	3.97×10^{-4}	5.23×10^{-4}
	Colon	3.37×10^{-4}	3.49×10^{-4}	4.82×10^{-4}
	Red bone marrow	1.61×10^{-4}	2.59×10^{-4}	4.15×10^{-4}
	Lungs	1.70×10^{-4}	2.58×10^{-4}	4.02×10^{-4}
	Thyroid	3.12×10^{-2}	1.45×10^{-2}	7.42×10^{-3}
	Effective dose	1.74×10^{-3}	1.01×10^{-3}	7.85×10^{-4}
2nd month	Lower large intestine wall	1.58×10^{-5}	1.40×10^{-5}	1.53×10^{-5}
	Colon	1.23×10^{-5}	1.23×10^{-5}	1.41×10^{-5}
	Red bone marrow	5.95×10^{-6}	9.12×10^{-6}	1.21×10^{-5}
	Lungs	6.25×10^{-6}	9.08×10^{-6}	1.18×10^{-5}
	Thyroid	5.37×10^{-4}	2.35×10^{-4}	9.13×10^{-5}
	Effective dose	3.37×10^{-5}	2.15×10^{-5}	1.66×10^{-5}
3rd month	Lower large intestine wall	1.78 × 10-5	1.51 × 10-5	1.74 × 10-5
	Colon	1.39 × 10-5	1.33 × 10-5	1.60 × 10-5
	Red bone marrow	6.70×10^{-6}	9.85×10^{-6}	1.38×10^{-5}
	Lungs	7.03×10^{-6}	9.81×10^{-6}	1.34×10^{-5}
	Thyroid	5.26×10^{-4}	2.30×10^{-4}	8.95×10^{-5}
	Effective dose	3.41×10^{-5}	2.20×10^{-5}	1.81×10^{-5}
4th month	Lower large intestine wall	2.01×10^{-5}	1.78×10^{-5}	2.32×10^{-5}
	Colon	1.57×10^{-5}	1.57×10^{-5}	2.14×10^{-5}
	Red bone marrow	7.56×10^{-6}	1.16×10^{-5}	1.84×10^{-5}
	Lungs	7.94×10^{-6}	1.16×10^{-5}	1.78×10^{-5}
	Thyroid	5.00×10^{-4}	2.20×10^{-4}	8.93×10^{-5}
	Effective dose	3.37×10^{-5}	2.33×10^{-5}	2.26×10^{-5}
5th month	Lower large intestine wall	1.17×10^{-5}	1.02×10^{-5}	1.05×10^{-5}
	Colon	9.16×10^{-6}	8.95×10^{-6}	9.69×10^{-6}
	Red bone marrow	4.46×10^{-6}	6.65×10^{-6}	8.35×10^{-6}
	Lungs	4.67×10^{-6}	6.62×10^{-6}	8.08×10^{-6}
	Thyroid	5.36×10^{-6}	7.11×10^{-6}	8.37×10^{-6}
	Effective dose	5.45×10^{-6}	7.16×10^{-6}	8.62×10^{-6}
6th month	Lower large intestine wall	1.70×10^{-5}	1.51×10^{-5}	1.65×10^{-5}
	Colon	1.33×10^{-5}	1.33×10^{-5}	1.52×10^{-5}
	Red bone marrow	6.47×10^{-6}	9.87×10^{-6}	1.31×10^{-5}
	Lungs	6.77×10^{-6}	9.83×10^{-6}	1.27×10^{-5}
	Thyroid	7.62×10^{-6}	1.05×10^{-5}	1.31×10^{-5}
	Effective dose	7.91×10^{-6}	1.06×10^{-5}	1.35×10^{-5}

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
Months 7 to 9	Lower large intestine wall	4.45×10^{-5}	3.85×10^{-5}	4.12×10^{-5}
	Colon	3.48×10^{-5}	3.39×10^{-5}	3.79×10^{-5}
	Red bone marrow	1.69×10^{-5}	2.52×10^{-5}	3.27×10^{-5}
	Lungs	1.77×10^{-5}	2.51×10^{-5}	3.17×10^{-5}
	Thyroid	1.99×10^{-5}	2.68×10^{-5}	3.27×10^{-5}
	Effective dose	2.07×10^{-5}	2.71×10^{-5}	3.37×10^{-5}
Months 10 to 12	Lower large intestine wall	4.87×10^{-5}	4.21×10^{-5}	4.55×10^{-5}
	Colon	3.80×10^{-5}	3.70×10^{-5}	4.19×10^{-5}
	Red bone marrow	1.84×10^{-5}	2.75×10^{-5}	3.61×10^{-5}
	Lungs	1.93×10^{-5}	2.74×10^{-5}	3.50×10^{-5}
	Thyroid	2.17×10^{-5}	2.92×10^{-5}	3.61×10^{-5}
	Effective dose	2.25×10^{-5}	2.96×10^{-5}	3.72×10^{-5}
Total dose in the first year	Lower large intestine wall	6.08×10^{-4}	5.49×10^{-4}	6.92×10^{-4}
	Colon	4.74×10^{-4}	4.83×10^{-4}	6.38×10^{-4}
	Red bone marrow	2.27×10^{-4}	3.59×10^{-4}	5.49×10^{-4}
	Lungs	2.40×10^{-4}	3.58×10^{-4}	5.32×10^{-4}
	Thyroid	3.28×10^{-2}	1.52×10^{-2}	7.78×10^{-3}
	Effective dose	1.90×10^{-3}	1.16×10^{-3}	9.35×10^{-4}

6. The following points could be noted in relation to table 5:

- Again the dose for the first month was the major contributor to the overall dose for all age groups and organs but this was slightly less marked than for Fukushima Prefecture. For example, for infants, over 70% of the first year’s effective dose was due to ingestion in the first month, while, for adults, this fraction was just less than 50%. This difference might reflect the lower levels of activity concentration in measured foodstuffs outside Fukushima Prefecture, and hence the substitution of a measurement value of less than the limit of detection with an assumed value of 10 Bq/kg (this assumption that the minimum concentration was given as the lower detection limit is called ‘MDL assumption’ hereafter) affects a larger proportion of measurements, and hence the implied dose.
- The same pattern in dose beyond 4 months was seen for these prefectures as for Fukushima Prefecture, probably reflecting the inference that for after 4 months all measurements of ^{131}I less than limits of detection were considered to be zero rather than 10 Bq/kg.

Table 5. Ingestion doses for the first year following the accident based on the database of activity concentrations in food — results for 5 prefectures neighbouring Fukushima Prefecture

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
1st month	Lower large intestine wall	1.55×10^{-5}	1.11×10^{-5}	1.13×10^{-5}
	Colon	1.17×10^{-5}	9.56×10^{-6}	1.03×10^{-5}
	Red bone marrow	4.91×10^{-6}	6.93×10^{-6}	8.85×10^{-6}
	Lungs	5.47×10^{-6}	7.08×10^{-6}	8.58×10^{-6}
	Thyroid	7.81×10^{-3}	3.62×10^{-3}	1.79×10^{-3}
	Effective dose	3.95×10^{-4}	1.95×10^{-4}	9.97×10^{-5}
2nd month	Lower large intestine wall	8.19×10^{-6}	6.97×10^{-6}	6.55×10^{-6}
	Colon	6.39×10^{-6}	6.14×10^{-6}	6.04×10^{-6}
	Red bone marrow	3.06×10^{-6}	4.55×10^{-6}	5.20×10^{-6}
	Lungs	3.23×10^{-6}	4.54×10^{-6}	5.04×10^{-6}
	Thyroid	4.91×10^{-4}	2.13×10^{-4}	8.34×10^{-5}
	Effective dose	2.81×10^{-5}	1.57×10^{-5}	9.35×10^{-6}
3rd month	Lower large intestine wall	9.58×10^{-6}	8.13×10^{-6}	7.79×10^{-6}
	Colon	7.46×10^{-6}	7.16×10^{-6}	7.18×10^{-6}
	Red bone marrow	3.58×10^{-6}	5.31×10^{-6}	6.18×10^{-6}
	Lungs	3.77×10^{-6}	5.30×10^{-6}	5.98×10^{-6}
	Thyroid	5.45×10^{-4}	2.35×10^{-4}	8.71×10^{-5}
	Effective dose	3.14×10^{-5}	1.76×10^{-5}	1.05×10^{-5}
4th month	Lower large intestine wall	8.95×10^{-6}	7.64×10^{-6}	7.19×10^{-6}
	Colon	6.98×10^{-6}	6.73×10^{-6}	6.63×10^{-6}
	Red bone marrow	3.35×10^{-6}	4.99×10^{-6}	5.71×10^{-6}
	Lungs	3.53×10^{-6}	4.98×10^{-6}	5.53×10^{-6}
	Thyroid	4.92×10^{-4}	2.12×10^{-4}	7.67×10^{-5}
	Effective dose	2.85×10^{-5}	1.61×10^{-5}	9.51×10^{-6}
5th month	Lower large intestine wall	8.76×10^{-6}	7.67×10^{-6}	7.55×10^{-6}
	Colon	6.86×10^{-6}	6.77×10^{-6}	6.96×10^{-6}
	Red bone marrow	3.34×10^{-6}	5.03×10^{-6}	6.00×10^{-6}
	Lungs	3.50×10^{-6}	5.01×10^{-6}	5.81×10^{-6}
	Thyroid	3.93×10^{-6}	5.34×10^{-6}	6.00×10^{-6}
	Effective dose	4.08×10^{-6}	5.41×10^{-6}	6.19×10^{-6}
6th month	Lower large intestine wall	1.41×10^{-5}	1.24×10^{-5}	1.39×10^{-5}
	Colon	1.10×10^{-5}	1.09×10^{-5}	1.28×10^{-5}
	Red bone marrow	5.36×10^{-6}	8.12×10^{-6}	1.11×10^{-5}
	Lungs	5.62×10^{-6}	8.09×10^{-6}	1.07×10^{-5}
	Thyroid	6.32×10^{-6}	8.63×10^{-6}	1.11×10^{-5}
	Effective dose	6.56×10^{-6}	8.74×10^{-6}	1.14×10^{-5}
Months 7 to 9	Lower large intestine wall	3.85×10^{-5}	3.40×10^{-5}	3.71×10^{-5}
	Colon	3.02×10^{-5}	3.00×10^{-5}	3.43×10^{-5}
	Red bone marrow	1.47×10^{-5}	2.23×10^{-5}	2.95×10^{-5}
	Lungs	1.54×10^{-5}	2.22×10^{-5}	2.86×10^{-5}
	Thyroid	1.73×10^{-5}	2.37×10^{-5}	2.95×10^{-5}
	Effective dose	1.79×10^{-5}	2.40×10^{-5}	3.04×10^{-5}

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
Months 10 to 12	Lower large intestine wall	3.66×10^{-5}	3.23×10^{-5}	3.44×10^{-5}
	Colon	2.87×10^{-5}	2.85×10^{-5}	3.17×10^{-5}
	Red bone marrow	1.40×10^{-5}	2.12×10^{-5}	2.73×10^{-5}
	Lungs	1.46×10^{-5}	2.11×10^{-5}	2.64×10^{-5}
	Thyroid	1.64×10^{-5}	2.25×10^{-5}	2.73×10^{-5}
	Effective dose	1.71×10^{-5}	2.28×10^{-5}	2.82×10^{-5}
Total dose in the first year	Lower large intestine wall	1.40×10^{-4}	1.20×10^{-4}	1.26×10^{-4}
	Colon	1.09×10^{-4}	1.06×10^{-4}	1.16×10^{-4}
	Red bone marrow	5.22×10^{-5}	7.84×10^{-5}	9.98×10^{-5}
	Lungs	5.51×10^{-5}	7.82×10^{-5}	9.66×10^{-5}
	Thyroid	9.38×10^{-3}	4.34×10^{-3}	2.11×10^{-3}
	Effective dose	5.29×10^{-4}	3.05×10^{-4}	2.05×10^{-4}

7. The following points could be noted in relation to table 6:

- Again the dose received in the first month was the major contributor to the overall dose for all age groups and organs, but this is less marked than in Fukushima Prefecture. For example, for infants, over 30% of the first year's effective dose was from ingestion in the first month while for adults this was less than 20%. This difference probably reflected the lower levels measured outside Fukushima Prefecture and hence the employment of the MDL assumption as a greater proportion of measurements were less than the limit of detection and were ascribed an assumed value of 10 Bq/kg value.

- The same change in monthly effective dose beyond 4 months was seen as for Fukushima Prefecture and the neighbouring prefectures. This reflects the inference that after 4 months all measurements of ^{131}I that were less than the limits of detection were considered to be 0 rather than 10 Bq/kg, and this finding is borne out by considering the doses for other organs. For example, doses to the thyroid were two orders of magnitude greater in months 1 to 4 than in month 5. As ^{131}I was the major contributor to the thyroid dose, this was not surprising. After month 5 the dose to the thyroid was very similar to the value for the dose to all other organs, which reflected the uniform distribution of radiocaesium in the body. For other organs the step change in dose from 4 to 5 months was not seen to any extent, which is consistent with the doses being due to the caesium isotopes, for which the MDL assumption (i.e., adoption of 10 Bq/kg as the minimum concentration) continued to be used.

- The possible impact of the inference can be seen by considering the potential dose if all food had been consumed with the limit of detection value. Allowing for the food imports and only including ^{131}I for the first four months then the total effective dose to a one year old in a year could be 0.21 mSv with the dose to the thyroid being 2.9 mGy. These estimates include rice but it is known that rice was not harvested in the early months following the accident. If rice is excluded completely then the annual doses to a one year old decrease to 2 mGy to the thyroid (due to ^{131}I only) and 0.15 mSv effective dose (summed for the three radionuclides). For comparison with the tables above the monthly thyroid dose due to ^{131}I at 10 Bq/kg is estimated to be 0.5 mGy without rice (0.725 mGy with rice) while the monthly effective dose in the first four months would be 0.029 mSv (summed for the three radionuclides) without rice and for the last

8 months would be 0.0058 mSv per month from the two caesium isotopes with rice. These doses are slightly higher than the doses presented in the tables above for the rest of Japan as they assume that all food is contaminated at the 10 Bq/kg level but show that the estimated doses beyond the first month are significantly affected by the assumption that all reported measurements at or below the limit of detection are treated as 10 Bq/kg.

Table 6. Ingestion doses for first year following the accident based on the database of activity concentrations in food — results for the rest of Japan

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
1st month	Lower large intestine wall	9.52×10^{-6}	7.85×10^{-6}	7.29×10^{-6}
	Colon	7.39×10^{-6}	6.90×10^{-6}	6.71×10^{-6}
	Red bone marrow	3.48×10^{-6}	5.10×10^{-6}	5.78×10^{-6}
	Lungs	3.70×10^{-6}	5.11×10^{-6}	5.60×10^{-6}
	Thyroid	1.17×10^{-3}	5.28×10^{-4}	2.38×10^{-4}
	Effective dose	6.24×10^{-5}	3.26×10^{-5}	1.78×10^{-5}
2nd month	Lower large intestine wall	8.13×10^{-6}	6.86×10^{-6}	6.27×10^{-6}
	Colon	6.34×10^{-6}	6.05×10^{-6}	5.78×10^{-6}
	Red bone marrow	3.05×10^{-6}	4.49×10^{-6}	4.98×10^{-6}
	Lungs	3.22×10^{-6}	4.48×10^{-6}	4.82×10^{-6}
	Thyroid	4.69×10^{-4}	2.03×10^{-4}	7.81×10^{-5}
	Effective dose	2.70×10^{-5}	1.51×10^{-5}	8.86×10^{-6}
3rd month	Lower large intestine wall	8.54×10^{-6}	7.17×10^{-6}	6.68×10^{-6}
	Colon	6.66×10^{-6}	6.31×10^{-6}	6.16×10^{-6}
	Red bone marrow	3.20×10^{-6}	4.68×10^{-6}	5.31×10^{-6}
	Lungs	3.37×10^{-6}	4.67×10^{-6}	5.13×10^{-6}
	Thyroid	4.84×10^{-4}	2.08×10^{-4}	7.68×10^{-5}
	Effective dose	2.79×10^{-5}	1.56×10^{-5}	9.12×10^{-6}
4th month	Lower large intestine wall	8.57×10^{-6}	7.39×10^{-6}	6.82×10^{-6}
	Colon	6.69×10^{-6}	6.51×10^{-6}	6.30×10^{-6}
	Red bone marrow	3.22×10^{-6}	4.83×10^{-6}	5.42×10^{-6}
	Lungs	3.39×10^{-6}	4.82×10^{-6}	5.25×10^{-6}
	Thyroid	4.10×10^{-4}	1.77×10^{-4}	6.73×10^{-5}
	Effective dose	2.42×10^{-5}	1.41×10^{-5}	8.75×10^{-6}
5th month	Lower large intestine wall	8.17×10^{-6}	7.09×10^{-6}	6.64×10^{-6}
	Colon	6.40×10^{-6}	6.25×10^{-6}	6.13×10^{-6}
	Red bone marrow	3.12×10^{-6}	4.65×10^{-6}	5.28×10^{-6}
	Lungs	3.26×10^{-6}	4.63×10^{-6}	5.11×10^{-6}
	Thyroid	3.93×10^{-6}	5.02×10^{-6}	5.31×10^{-6}
	Effective dose	3.82×10^{-6}	5.01×10^{-6}	5.45×10^{-6}
6th month	Lower large intestine wall	1.01×10^{-5}	8.71×10^{-6}	8.48×10^{-6}
	Colon	7.83×10^{-6}	7.58×10^{-6}	7.75×10^{-6}
	Red bone marrow	3.74×10^{-6}	5.60×10^{-6}	6.69×10^{-6}
	Lungs	3.90×10^{-6}	5.57×10^{-6}	6.51×10^{-6}
	Thyroid	4.37×10^{-6}	5.93×10^{-6}	6.69×10^{-6}
	Effective dose	4.57×10^{-6}	6.02×10^{-6}	6.86×10^{-6}

Time after the accident	*Organ*	*Absorbed to organ (Gy) or Effective dose (Sv)*		
		Infant (1-year old)	*Child (10-year old)*	*Adult*
Months 7 to 9	Lower large intestine wall	3.57×10^{-5}	3.15×10^{-5}	3.26×10^{-5}
	Colon	2.80×10^{-5}	2.78×10^{-5}	3.01×10^{-5}
	Red bone marrow	1.36×10^{-5}	2.07×10^{-5}	2.59×10^{-5}
	Lungs	1.43×10^{-5}	2.06×10^{-5}	2.51×10^{-5}
	Thyroid	1.61×10^{-5}	2.20×10^{-5}	2.59×10^{-5}
	Effective dose	1.67×10^{-5}	2.23×10^{-5}	2.67×10^{-5}
Months 10 to 12	Lower large intestine wall	3.61×10^{-5}	3.19×10^{-5}	3.30×10^{-5}
	Colon	2.83×10^{-5}	2.81×10^{-5}	3.04×10^{-5}
	Red bone marrow	1.38×10^{-5}	2.09×10^{-5}	2.62×10^{-5}
	Lungs	1.44×10^{-5}	2.08×10^{-5}	2.54×10^{-5}
	Thyroid	1.63×10^{-5}	2.22×10^{-5}	2.62×10^{-5}
	Effective dose	1.69×10^{-5}	2.25×10^{-5}	2.71×10^{-5}
Total dose in the first year	Lower large intestine wall	1.25×10^{-4}	1.09×10^{-4}	1.08×10^{-4}
	Colon	9.76×10^{-5}	9.56×10^{-5}	9.94×10^{-5}
	Red bone marrow	4.72×10^{-5}	7.10×10^{-5}	8.56×10^{-5}
	Lungs	4.96×10^{-5}	7.07×10^{-5}	8.29×10^{-5}
	Thyroid	2.57×10^{-3}	1.17×10^{-3}	5.25×10^{-4}
	Effective dose	1.83×10^{-4}	1.33×10^{-4}	1.11×10^{-4}

8. An analysis was also carried out to determine which foods and radionuclides contributed to the doses. This was complicated, because of the way that the database results were used to assess the doses and because results were only available for the different periods in the year that were considered and not for the year as a whole. The breakdown by food type was also only available for each radionuclide separately. The following table shows the contribution of the different radionuclides to the effective doses in Fukushima Prefecture for particular periods for the three age groups considered.

Table 7. Percentage contribution of different radionuclides to effective doses from ingestion in Fukushima Prefecture based on the database of measurement results

Time period	*Infants (1-year old)*			*Adults*		
	^{131}I	^{134}Cs	^{137}Cs	^{131}I	^{134}Cs	^{137}Cs
Month 1	88.9	6.3	4.8	45.7	32.2	22.1
Month 4	72.8	15.2	12.0	16.1	48.5	35.4
Month 6	0	55.7	44.3	0	57.7	42.3
Months 10–12	0	54.5	45.5	0	56.4	43.6

9. The differences in contributions for the different age groups is because of differences in the relative magnitudes of the dose coefficients for the three radionuclides with age, as well as — to a lesser extent — differences in the diets with age. In all cases ^{131}I was the main contributor to dose in the first four months, but then owing to radioactive decay (and the assumptions on limits of detection) its contribution became negligible. The slightly higher contribution of ^{134}Cs was because of its higher dose coefficient than that for ^{137}Cs, but the effect was slightly reduced with time owing to the faster radioactive decay of ^{134}Cs (initially there were roughly equal proportions of the two radionuclides).

10. The contribution of different foods to effective dose was only available for each radionuclide, age group and time period separately. The following table gives some illustrative results to show the contribution of the major foods at different times.

Table 8. Percentage contribution of different foods for each radionuclide to effective doses from ingestion in Fukushima Prefecture based on the database of measurement results

Time period	*Key foods*	*Infants (1-year old)*			*Adults*		
		^{131}I	^{134}Cs	^{137}Cs	^{131}I	^{134}Cs	^{137}Cs
Month 1	Leafy vegetables	73.1	84.8	85.1	77.1	87.5	87.7
	Root and other vegetables	25.0	13.6	13.4	21.8	11.7	11.5
Month 4	Milk	38.5	16.4	15.5	15.1	4.3	4.1
	Crustacea and molluscs	1.9	41.4	42.4	3.9	57.2	57.9
	All vegetables	32.6	15.5	15.0	49.3	15.8	12.2
	Fruit	6.8	7.8	8.1	6.3	4.9	5.0
Month 6	Milk	No dose	19.7	18.6	No dose	6.3	5.9
	Mushrooms		15.7	17.7		20.2	22.5
	All vegetables		17.6	16.9		21.5	20.6
	Rice		21.9	21.2		26.5	25.3
Months 10–12	Fruit	No dose	8.3	9.3	No dose	6.5	7.1
	Milk		20.8	18.6		6.9	6.1
	All vegetables		31.7	34.2		38.7	40.9
	Rice		23.3	21.7		29.1	26.8

11. Different foods contributed at different times with various types of vegetables contributing relatively significantly to the dose for both age groups at all times. For 6 months and later rice was an important contributor to the total dose, reflecting its importance in the Japanese diet and the fact that nearly all rice consumed in Japan was produced in Japan [MAFF, 2012]. Crustaceans were important for only a limited period, while the contribution from fish was very variable from month to month, being greater for the caesium radioisotopes than for those of iodine and making a minor contribution overall. In the database considerable attention had been paid to concentrations of radionuclides in beef, but the contribution to the doses from ingestion of beef were relatively small. Milk was a significant contributor to dose, particularly for 1-year-old infants and for ^{131}I, except in the first month after the releases; this fitted with the known agricultural practices, where in March cows are kept indoors and given stored feed, which would have had relatively low levels of activity.

III. RESULTS OBTAINED USING FARMLAND MODEL AND MEASURED DEPOSITION DENSITIES FOR JAPAN

12. The primary set of results assumed that restrictions on food consumption had been successful and that for domestically produced food, 25% had been locally produced with the remaining 75% coming from the rest of Japan. The proportion of imported food was based on 2010 national data and imported food was [MAFF, 2012] considered to have no activity. Results are available for each prefecture of Japan where measurements of deposition density were available. Tables 9 to 11 give the calculated ingestion doses for Fukushima Prefecture, the average range for the five neighbouring prefectures, and the average for the rest of Japan, for comparison with the results based on the FAO/IAEA/MAFF database. The results beyond the first year were used to develop tables 1 and 3. Tables 12 to 14 give the same set of results, but for absorbed dose to the thyroid.

Table 9. Effective doses from ingestion for characteristic individuals in Fukushima Prefecture, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Effective dose (mSv) for each age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	0.10	6.40	0.076	3.48	0.061	2.00
10 years	0.17	6.50	0.16	3.61	0.14	2.10
Lifetime	0.20	6.53	0.19	3.64	0.17	2.13

Table 10. Effective doses from ingestion for characteristic individuals in the five neighbouring prefectures, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Effective dose (mSv) for each age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	0.12	0.70	0.080	0.40	0.057	0.25
10 years	0.13	0.72	0.10	0.42	0.074	0.26
Lifetime	0.14	0.72	0.11	0.43	0.080	0.27

Table 11. Effective doses from ingestion for characteristic individuals in the rest of Japan, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Effective dose (mSv) for each age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	0.038	0.074	0.025	0.043	0.016	0.027
10 years	0.040	0.076	0.028	0.046	0.018	0.029
Lifetime	0.041	0.076	0.028	0.046	0.019	0.030

Table 12. Absorbed dose to the thyroid from ingestion for characteristic individuals in Fukushima Prefecture, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Thyroid dose (mGy) for each age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	1.49	120	0.71	55.6	0.35	27.6
10 years	1.55	120	0.79	55.8	0.43	27.7
Lifetime	1.58	120	0.82	55.8	0.46	27.7

Table 13. Absorbed dose to the thyroid from ingestion for characteristic individuals in the five neighbouring prefectures, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Thyroid dose (mGy) for each age group*					
	Infant (1-year old)		*Child (10- year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	1.82	12.6	0.86	5.89	0.44	2.94
10 years	1.83	12.6	0.88	5.91	0.45	2.96
Lifetime	1.84	12.6	0.89	5.92	0.46	2.96

Table 14. Absorbed dose to the thyroid from ingestion for characteristic individuals in the rest of Japan, based on the FARMLAND model and measured deposition densities with and without restrictions

Time period	*Thyroid dose (mGy) for each age group*					
	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	With restrictions	*No restrictions*	*With restrictions*	*No restrictions*	*With restrictions*	*No restrictions*
1 year	0.63	1.31	0.29	0.61	0.14	0.31
10 years	0.63	1.31	0.30	0.62	0.14	0.31
Lifetime	0.63	1.31	0.30	0.62	0.15	0.31

13. The following points can be noted in relation to the results in tables 9 to 14:

(a) The introduction of restrictions on food supplies had a significant impact on the estimated doses. For example, in Fukushima Prefecture for a 1-year-old infant, the effective dose due to ingestion in the first year would have been 6.4 mSv without restrictions, but if the restrictions had been completely introduced then this would have been reduced to 0.1 mSv. For the more distant prefectures there was still a reduction in the estimated doses because of the restrictions, but this was less marked than for Fukushima Prefecture (e.g. a reduction of about a factor of two in the effective dose to a 1-year old child in the rest of Japan);

(b) The doses estimated for the first year using the modelling approach and assuming restrictions were completely effective were lower than the doses estimated using the database. However, the estimated doses assuming no restrictions in Fukushima Prefecture were significantly higher than the doses based on the measurement database. For example, for a 1-year-old infant in Fukushima Prefecture the estimated effective dose using the database was 1.9 mSv, using the model the estimated dose was 0.1 mSv assuming full restrictions and 6.4 mSv assuming no restrictions. For the five neighbouring prefectures the corresponding results were: 0.53, 0.12 and 0.7 mSv, respectively, while for the rest of Japan they were: 0.18, 0.038 and 0.074 mSv, respectively. There are a number of different factors that may have lead to these differences;

(c) The main contribution to the doses estimated from the database of measurements was from intakes of ^{131}I in the first month, particularly for Fukushima Prefecture. However, there were limited numbers of these early measurements and attention had been necessarily focussed on the areas with highest deposition densities where restrictions were or might have been required. This could have led to some overestimation of doses

from ingestion based on measurements, because levels of radionuclides in food from other areas would have been lower;

(d) The database does contain some measurements in marketed foods that were above the levels introduced for restrictions because it was not possible to make these completely effective in the early period after the accident. This leads to higher estimated doses from the database than from the modelling where restrictions were assumed to be completely effective;

(e) For areas away from Fukushima Prefecture assuming that all measurements at or below limits of detection were 10 Bq/kg is likely to have overestimated the actual levels and hence doses. If it were assumed that all foods eaten had 10 Bq/kg of ^{131}I for the first four months and 10 Bq/kg of both ^{134}Cs and ^{137}Cs throughout the year then the estimated effective doses for a 1-year-old infant would have been between 0.15 and 0.21 mSv depending on whether rice was included in the estimate. This result is similar to the doses obtained using the database and indicates that they might be overestimates.

14. The estimated doses for the first year based on modelling were not used in the main assessment for combining with the estimated doses from other pathways. However, the estimated doses for beyond the first year based on modelling were used and are included in tables 1 to 3. The increase in integrated doses from 1 to 10 years or over a lifetime was generally small. For the thyroid doses the lifetime dose was virtually all delivered in the first year following the accident. The increase in the integrated dose was greatest for effective doses in Fukushima Prefecture when restrictions were taken into account. This is because the estimated dose for the first year was significantly reduced. The increase in the integrated dose was a factor of two to three over a lifetime. Without restrictions the first year's dose provided most of the lifetime dose. This was particularly the case for the thyroid dose to a 1-year-old infant in Fukushima Prefecture where the doses for the first year, integrated to 10 years and over a lifetime were estimated to be the same if restrictions were not applied.

IV. VARIABILITY AND UNCERTAINTY IN ESTIMATED DOSES FROM INGESTION BASED ON MODELLING

15. For the standard modelling results presented in section III it was assumed that 25% of food was from the prefecture where the individual lived and 75% from elsewhere in Japan; allowance was also made for foods being imported into Japan. Results were also obtained for Fukushima Prefecture assuming that 100% of the food was locally produced both with and without allowing for imported food. The effect of this on adult effective doses is seen in table 15.

Table 15. Adult effective doses for Fukushima Prefecture assuming 100% of food is locally produced (using modelling approach)

Time (a)	*Adult effective dose (mSv) with food restrictions values without restrictions in brackets*		
	Standard result: 25% local	*100% local but allowing for imports*	*100% local no allowance for imports*
1 year	0.061 (2.0)	0.20 (7.91)	0.27 (12.8)
10 years	0.14 (2.1)	0.50 (8.33)	1.38 (14.0)
Lifetime	0.17 (2.13)	0.62 (8.45)	1.55 (14.2)

16. Assuming all foods consumed (but allowing for imports) were produced locally increased the estimates of adult effective doses by about a factor of 4 when restrictions are taken into account. If no allowance was made for food imports, the increase in estimated doses

was up to a factor of 9 for lifetime doses with a smaller effect in the first year. This reflects an increased estimated dose in each year when more locally produced food is assumed to be eaten. If restrictions on food supplies were not taken into account then there was still a significant increase in the estimated doses at all times. In Japan, the vast majority of people eat food from supermarkets which would have been sourced and distributed throughout Japan and which would contain significant amounts of imported produce [MAFF, 2012]. Therefore, the above dose estimates do not apply to characteristic individuals. However, some individuals might have consumed food that they produced themselves or obtained locally and their doses might theoretically approach the values shown above. Table 16 gives similar results for infant thyroid doses in Fukushima Prefecture showing the effects of assuming 100% local food consumption. For doses to the thyroid the contribution from the dose in the first year was dominant and so only the first year results were estimated assuming greater local food consumption.

Table 16. Absorbed doses to thyroid for infants in Fukushima Prefecture assuming 100% of food is locally obtained (using modelling approach)

Time (a)	*Infant thyroid dose (mGy) with food restrictions values without restrictions in brackets*		
	Standard result: 25% local	*100% local but allowing for imports*	*100% local no allowance for imports*
1 year	1.49 (119)	4.07 (474)	4.97 (587)
10 years	1.55 (119)	-	-
Lifetime	1.58 (120)	-	-

17. It should be recognized that in addition following the accident many people avoided produce from Fukushima Prefecture or even from Japan, and for these individuals the doses from ingestion would have been much lower than those given above and for some would have been effectively zero.

18. It took a few days for food restrictions to be introduced in Japan and so it is possible that people did eat food above the restriction levels during this time. However, the accident occurred in March and so there was very limited fresh produce available, and livestock would have been kept indoors and fed on stored feed. The possible exception is that some types of green vegetables, for example spinach, would have been growing at that time and people could have eaten their own vegetables from the garden. This possibility has been examined by considering the effect on the modelled doses of assuming that restrictions were not introduced until 7 days after the time of deposition for two locations in Fukushima Prefecture: Iitate village in the extended evacuation zone and Koriyama City, which is outside the evacuation areas. Tables 17 and 18 show the results for adult effective doses and infant thyroid doses, respectively.

Table 17. Adult effective doses in Iitate village and Koriyama city, assuming restrictions did not occur until 7 days after deposition and only local produce was consumed (based on modelling)

Time (d)	*Adult effective dose (mSv) (with food restrictions)*			
	Bans implemented from 0 days		*Bans implemented from 7 days*	
	Iitate	*Koriyama*	*Iitate*	*Koriyama*
7	0.00	0.00	11.0	1.82
365	0.57	0.15	11.6	1.97

Table 18. Infant thyroid doses in Iitate village and Koriyama city, assuming restrictions did not occur until 7 days after deposition and only local produce is consumed (based on modelling)

Time (d)	*Infant thyroid dose (mGy) (with food restrictions)*			
	Bans implemented from 0 days		*Bans implemented from 7 days*	
	Iitate	*Koriyama*	*Iitate*	*Koriyama*
7	0.00	0.00	731	123
365	0.33	0.08	732	123

19. At both locations considered, there would be a significant increase in estimated doses if local food had been eaten in the first 7 days following the time of deposition, confirming the importance of intakes in the early period after deposition. However, it should be recognized that this is a very cautious estimate because it is assumed that all of the vegetables eaten are freshly produced, which is unlikely. Also the model assumes that the vegetables would have been in the open and so there would have been deposition directly onto the edible portions. The Committee understands that at this time, in Iitate village, for example, vegetables were likely to have been grown in greenhouses or were protected from frost and snow by being covered with soil. For both these situations, levels of radionuclides in the vegetables would have been significantly lower than assumed here. Nevertheless, this analysis shows that it is possible that some individuals could have received considerably higher doses than the characteristic doses assessed in the main study.

20. The contribution of the different radionuclides and foods to the ingestion doses would have varied with location and time, and on whether restrictions were effective. Some illustrative results for Iitate village and Koriyama City making different assumptions are given in the following tables.

Table 19. Contribution of three radionuclides to adult effective doses from ingestion in Iitate municipality (inside extended evacuated area) with and without food restrictions

Time	*Contribution to adult effective dose (with food restrictions)*			
	^{131}I (%)	*^{134}Cs (%)*	*^{137}Cs (%)*	*Total dose (Sv)*
7 days	-	-	-	$0.00 \times 10^{+00}$
1 year	0.1	54.8	45.2	5.69×10^{-4}
60 years	0.0	42.5	57.4	7.52×10^{-3}
Time	*Contribution to adult effective dose (without food restrictions)*			
	^{131}I (%)	*^{134}Cs (%)*	*^{137}Cs (%)*	*Total dose (Sv)*
7 days	80.8	11.3	7.9	1.10×10^{-2}
1 year	31.3	38.1	30.6	4.81×10^{-2}
60 years	26.8	38.7	34.5	5.62×10^{-2}

Table 20. Contribution of three radionuclides to adult effective doses from ingestion in Koriyama municipality (south-west of evacuated area) with and without food restrictions

Time	*Contribution to adult effective dose (with food restrictions)*			
	^{131}I (%)	*^{134}Cs (%)*	*^{137}Cs (%)*	*Total dose (Sv)*
7 days	-	-	-	$0.00 \times 10^{+00}$
1 year	0.0	56.2	43.8	1.48×10^{-4}
60 years	0.0	43.6	56.4	1.29×10^{-3}
Time	*Contribution to adult effective dose (without food restrictions)*			
	^{131}I (%)	*^{134}Cs (%)*	*^{137}Cs (%)*	*Total dose (Sv)*
7 days	82.5	10.3	7.1	1.82×10^{-3}
1 year	33.8	36.8	29.4	7.50×10^{-3}
60 years	29.1	37.6	33.3	8.72×10^{-3}

Table 21. Contribution of different foods to adult effective doses from ingestion in Iitate municipality (inside evacuated area) with and without food restrictions

Time	*Contribution to adult effective dose (with food restrictions)*			
	Rank 1 (%)	*Rank 2 (%)*	*Rank 3 (%)*	*Total dose (Sv)*
7 days	-	-	-	$0.00 \times 10^{+00}$
1 year	Potatoes (49.3)	Green vegetables (37.2)	Rice (12.4)	5.69×10^{-4}
60 years	Grain (58.9)	Green vegetables (10.3)	Pork (9.8)	7.52×10^{-3}
Time	*Contribution to adult effective dose (without food restrictions)*			
	Rank 1 (%)	*Rank 2 (%)*	*Rank 3 (%)*	*Total dose (Sv)*
7 days	Green vegetables (100)	-	-	1.10×10^{-2}
1 year	Green vegetables (47.3)	Grain (34.0)	Pork (5.6) / Milk (5.3)	4.81×10^{-2}
60 years	Green vegetables (41.5)	Grain (37.0)	Pork (6.1) / Milk (5.7)	5.62×10^{-2}

Table 22. Contribution of different foods to adult effective doses from ingestion in Koriyama municipality (south-west of evacuated area) with and without food restrictions

Time	*Contribution to adult effective dose (with food restrictions)*			
	Rank 1 (%)	*Rank 2 (%)*	*Rank 3 (%)*	*Total dose (Sv)*
7 days	-	-	-	$0.00 \times 10^{+00}$
1 year	Green vegetables (63.8)	Potatoes (28.4)	Rice (7.1)	1.48×10^{-4}
60 years	Grain (51.7)	Green vegetables (13.9)	Pork (8.6)	1.29×10^{-3}
Time	*Contribution to adult effective dose (without food restrictions)*			
	Rank 1 (%)	*Rank 2 (%)*	*Rank 3 (%)*	*Total dose (Sv)*
7 days	Green vegetables (100)	-	-	1.82×10^{-2}
1 year	Green vegetables (49.2)	Grain (32.8)	Pork (5.4) / Milk (5.2)	7.50×10^{-3}
60 years	Green vegetables (43.3)	Grain (35.5)	Pork (5.9) / Milk (5.5)	8.72×10^{-3}

21. The effect of the restrictions is marked for both locations and demonstrates that the restrictions would have essentially removed all of the contribution of ^{131}I from the estimated doses and also the initial contribution of green vegetables to the total dose from ingestion. The results in tables 19 to 22 are broadly consistent with the results in tables 7 and 8 above for the doses derived from the database for the first year after the accident.

22. The results above show the importance of the estimated levels of ^{131}I in green vegetables in the first week or so following the accidental releases. Table 23 below shows the estimated peak activity concentrations of ^{131}I in green vegetables at Koriyama City and Iitate village according to the FAO/IAEA/MAFF database. These levels are well above the limits used by the Japanese authorities to introduce restrictions on food supplies and are the same order as some measurements reported for vegetation in the period shortly after the releases.

Table 23. Peak activity concentration of iodine-131 in green vegetables in key locations

Activity concentration in green vegetables (Bq kg^{-1})	
Iitate village	*Koriyama City*
3.4×10^5	5.6×10^4

V. DOSES FROM INGESTION ESTIMATED FROM ATMOSPHERIC TRANSPORT, DISPERSION AND DEPOSITION MODELLING

23. The FARMLAND model results were also used with values for deposition densities derived from the estimated source term and atmospheric transport, dispersion and deposition modelling (ATDM) results (attachment C-9). For Fukushima Prefecture the estimated effective and thyroid doses were generally a factor of 2 to 3 times higher than those based on the measured deposition densities, with some lower ratios because of the effects of food restrictions. These differences demonstrate the known tendency of the atmospheric dispersion results to overestimate the measured deposition densities in many locations in Fukushima Prefecture. In addition, the ingestion dose results for a number of prefectures distant from Fukushima Prefecture were zero because the atmospheric dispersion results predicted no significant deposition. This also applied to the nearby countries where no significant deposition was predicted. Therefore, the Committee considered that the results based on the ATDM were such that no further analysis should be undertaken of these estimated ingestion doses.

VI. DOSES FROM INGESTION OF MARINE FOODS

24. The estimated doses from ingestion of radionuclides in marine foods are included in the estimated doses derived from the database for the first year following the accident. Their contribution to the total dose was assessed to be not greater than 10% overall (see table 8 above). This reflects the restrictions put in place on seafood from Fukushima Prefecture.

25. Using predictions of the levels of ^{137}Cs in seawater over the next 10 years [Nakano and Povinec, 2012] and beyond based on experience of fallout from nuclear weapons testing in the middle of the twentieth century, it was possible to make very rough predictions of future radiation doses from ingestion of seafood. The predictions in table 24 are given to two significant figures but this is for computational reasons and as elsewhere this degree of accuracy should not be implied.

Table 24. Predicted effective doses to different age groups from consumption of radionuclides in marine foods at various times after accident in 2011

Time after the accident (a)	*Annual effective dose to different age groups (Sv/a)*		
	Infant (1-year old)	*Child (10-year old)*	*Adult*
2	1.4×10^{-8}	2.1×10^{-8}	3.9×10^{-8}
5	3.1×10^{-9}	4.3×10^{-9}	8.2×10^{-9}
10	1.2×10^{-9}	1.7×10^{-9}	3.2×10^{-9}
20	8.6×10^{-10}	1.2×10^{-9}	2.3×10^{-9}
50	3.1×10^{-10}	4.3×10^{-10}	8.1×10^{-10}

26. These estimated effective doses are all very low and are less than the doses that have been estimated from ingestion of terrestrial foods, even 2 years after the accident. This is because of the significant dilution of caesium in the ocean water, which leads to very low concentrations of radiocaesium in seawater and therefore in the marine food away from the immediate area of the FDNPS site. Concentrations of radiocaesium in marine food are predicted to be less than 0.1 Bq/kg two years after the accident, which is 100 times less than the 10 Bq/kg assumed for the first year in the main dose assessment when concentrations were below detection limits. This creates an artificial gap between the doses assessed for the first year, which might be significantly overestimated, in particular for the last few months of the first year when a lot of measurements were below detection limits. However, at the end of the first year, measurements were reported for some fish species that were still significantly above detection limits, which is believed to result from the biological half-life of the radioactive material in these fish species. For those fish species, the concentrations might be underestimated by the present method, at least two years after the accident. Nevertheless, the restrictions still in place ought to prevent such marine foods reaching the market. In later years it is likely that the concentrations in seawater will tend to decrease more slowly and be homogeneous over large areas, reducing the potential for locally high values.

27. Before the accident, the concentration of ^{137}Cs in the western North Pacific Ocean was about 1 to 2 mBq/L. In other words, the impact of the releases from FDNPS became rapidly negligible at the scale of the North Pacific Ocean compared to the pre-existing levels from the atmospheric nuclear weapons tests. The reason is the enormous input of ^{137}Cs from the tests; the inventory was assessed to be about 69 PBq before the accident [Aoyama et al., 2012], which can be compared with the releases from the accident, assessed as a few petabecquerels by most authors (see appendix B).

28. The concentration factors used to estimate the doses are typical of marine food categories, namely algae, fish and crustaceans/molluscs. However, it is known that different species show different concentration factors, e.g. pelagic fish compared to benthic fish or crustacean compared to molluscs. The modelling results for ^{137}Cs dispersion in seawater are given for surface waters of the ocean. The levels may be inhomogeneous on the vertical scale and the concentrations in the marine food may differ from results derived from surface water modelling.

29. The current dose assessment method assumed that concentrations of radionuclides in the seawater was homogeneous in the North Pacific Ocean. Results of the dispersion models showed that the activity levels exhibit local significant horizontal gradients, at least during the first years after the accident.

30. There are several sources of uncertainty and the main ones are discussed here. One of the main sources is in the estimate for the amount of ^{137}Cs discharged into the sea from the FDNPS site. To avoid these uncertainties, the dispersion model is understood to have used the measured concentration of this radionuclide at the release point [Bailly du Bois et al., 2012, 213] as a "boundary condition" in the grid cell where such point is located in the computational mesh. Kawamura et al. [Kawamura et al., 2011] assumed that the observed concentration at the outlet extended over an area of 1.5 km^2 in front of the plant. Since the grid cell surface is larger than 1.5 km^2, a correction factor was introduced to ensure that the total activity in the release grid cell was the same as if the discharge was homogeneous over a 1.5 km^2 area. Given the shallow waters at the outlet point, it was also assumed that the ^{137}Cs concentration there was vertically homogeneous. These assumptions are likely to be sources of uncertainty for this assessment, but they are hard to quantify. Another source of uncertainty is the deposition onto seawater of radiocaesium released to the atmosphere. However, Periáñez et al. [Periáñez et al., 2012] showed that direct releases to the sea dominated those from atmospheric deposition on the surface and this source of uncertainty should be limited. Another factor is the interaction of caesium with sediment. The dispersion model included processes such as radioactive decay, adsorption and desorption of radionuclides by suspended matter, settling to the seabed and resuspension of sediments. The interactions with suspended matter and seabed sediment are sources of uncertainty. The sediment will be a long-term source of ^{137}Cs remobilizing in the marine environment. Periáñez et al. [Periáñez et al., 2012] derived the half-time of ^{137}Cs in the sediment from the assessment of the total inventory of this nuclide in the sediment of the area close to FDNPS where the concentrations were higher. They estimated a half-time of 167 days, a value of the same order of magnitude as the ^{137}Cs half-time for the sediment in the English Channel derived using the same kind of water/sediment interaction model. This secondary source of radiocaesium therefore is expected to become negligible after a few years and thus not considered to be a major long-term source of uncertainty.

VII. DOSES FROM DRINKING WATER

31. The Committee's assessment of doses from drinking water was based on measurements carried out in a number of locations. The doses from drinking water depended on the source of the water, the degree of treatment of the water supply and any measures taken to restrict supplies or provide alternate sources of water. The Committee's assessment was based on the available measurement data and took account of the restrictions applied. Doses were estimated for specific locations and a population-weighted dose was also estimated for Fukushima Prefecture. Some districts within Fukushima Prefecture were evacuated following the accident and therefore no measurement data were available for these locations. No attempt was made to estimate doses for these districts and the citizens of these districts were excluded from the population-weighted averages. Table 25 below shows the range of estimated doses for Fukushima Prefecture.

Table 25. Range of estimated effective and thyroid doses to a characteristic individual drinking water from Fukushima Prefecture

	Infant (1-year old)		*Child (10-year old)*		*Adult*	
	Minimum	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*
Effective dose (Sv)	$0.00 \times 10^{+00}$	4.79×10^{-4}	$0.00 \times 10^{+00}$	1.94×10^{-4}	$0.00 \times 10^{+00}$	1.65×10^{-4}
Thyroid dose (Sv)	$0.00 \times 10^{+00}$	9.57×10^{-3}	$0.00 \times 10^{+00}$	3.72×10^{-3}	$0.00 \times 10^{+00}$	3.20×10^{-3}

32. In each case the maximum dose was assessed to be to people living in Iitate village. A further analysis was carried out for Iitate as shown below. However, in this case the results were decay-corrected assuming that drinking water levels would have been elevated from the time that the radioactive plume was overhead on 16 March 2011. This slightly increases the estimates of dose as shown in table 26.

Table 26. Estimated effective and thyroid doses for Iitate Village allowing for decay correction

Dose (Sv)	*Infant (1-year old)*	*Child (10-year old)*	*Adult*
Total effective dose	7.80×10^{-4}	3.10×10^{-4}	2.63×10^{-4}
Total thyroid dose	1.56×10^{-2}	5.95×10^{-3}	5.12×10^{-3}

33. Assumptions used in the above calculation:

- Drinking water restrictions were followed. For Iitate these were in place from 21 March to 10 May (infants) and 21 March to 1 April 2011 (adults).
- The first recorded measurements of water were taken on 20 March 2011. Modelling data shows the plume passed over Iitate on 15 March 2011. Therefore concentrations of radionuclides in water for 16 March to 19 March were estimated using the concentration in water measured on 20 March and correcting for radioactive decay.
- To back-calculate ^{132}I concentrations, it was assumed that ^{132}I was in equilibrium with ^{132}Te on 20 March 2011. The decay correction was applied using the ^{132}Te half life.

34. The estimated adult effective doses from drinking water were slightly less than the estimated doses from ingestion of terrestrial foods in Iitate village assuming that locally produced food is eaten but that restrictions were in place (see table 17) and significantly lower than the effective doses from ingestion of terrestrial foods if it was assumed that locally produced vegetables were eaten in the first week following the accident. For infants, the dose to the thyroid from drinking water was estimated to be higher than the dose due to ingestion of locally produced food if restrictions were applied, but significantly less than the possible thyroid doses if infants ate green vegetables in the first week following the deposition. This further illustrates that there would have been significant variability in the doses received in Iitate Village depending on the behaviour of the individuals. As well as estimating ingestion doses at specific locations a population-weighted dose from ingestion of drinking water was also calculated and the results are given in table 27.

Table 27. Estimated population-weighted, median, minimum and maximum doses for Fukushima Prefecture due to drinking water

Doses	*Effective dose (Sv) (all radionuclides)*			*Thyroid dose (Gy) (all radionuclides)*		
	Infant (1-year old)	*Child (10-year old)*	*Adult*	*Infant (1-year old)*	*Child (10-year old)*	*Adult*
Population-weighted	5.63×10^{-5}	2.82×10^{-5}	2.46×10^{-5}	1.12×10^{-3}	5.34×10^{-4}	4.60×10^{-4}
Median (districts)	2.55×10^{-6}	9.84×10^{-7}	1.37×10^{-6}	4.76×10^{-5}	1.76×10^{-5}	1.52×10^{-5}
Minimum (district)	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$
Maximum (district)	4.79×10^{-4}	1.94×10^{-4}	1.65×10^{-4}	9.57×10^{-3}	3.72×10^{-3}	3.20×10^{-3}

35. The estimated population-weighted dose from drinking water is small compared with the estimated dose from ingestion of food (table 1). For example for a 1-year-old infant in the first year the estimated effective dose from ingestion of food was 1.9 mSv and the weighted dose from ingestion of drinking water was 0.056 mSv. However, for some districts the contribution was more significant, although still less than the estimated dose from ingestion of foods. The main results included in the overall dose assessment therefore do not include any contribution from drinking water.

36. Two papers reported average doses from drinking water to Japanese citizens. Murakami and Oki [Murakami and Oki, 2012] estimated absorbed doses to the thyroid from a number of pathways including ingestion of drinking water for citizens of Tokyo for the year following the Fukushima accident. Amano et al. [Amano et al., 2012] estimated committed effective doses due to inhalation and ingestion of tap water in the two months directly following the accident for Chiba residents. A comparison of these results with the dose estimated in this assessment is given in table 28. The doses estimated for adults and infants in both papers show good agreement with those estimated here. Doses to children do not agree as well. This may be due to the use of different ingestion dose coefficients for children. This report uses dose coefficients for a 10-year-old child. Murakami and Oki [Murakami and Oki, 2012] have defined a child as being aged 0–9 years old while Amano et al. [Amano et al., 2012] define a child as aged 2–7 years. Therefore it is possible that dose coefficients for a 1- or 5-year old have been used for these calculations. There are also slight variations in the start and end date for dose estimates that may have made a difference to the final results.

Table 28. Comparison of doses calculated in this assessment to those in published literature for ingestion of drinking water

With restrictions – Tokyo				
Reference	*Average absorbed dose to the thyroid (mSv)*			*Date*
	Infant (1-year old)	*Child (10-year old)*	*Adult*	
Murakami and Oki [Murakami and Oki, 2012]	0.47	0.54	0.19	2011-03-21 to 2012-03-20
This assessment	0.54	0.21	0.18	2011-03 to 2012-03
With restrictions – Chiba				
Reference	*Average effective dose (mSv)*			*Date*
	Infant (1-year old)	*Child (10-year old)*	*Adult*	
Amano et al. [Amano et al., 2012]	0.043	0.055	0.017	2011-03-15 to 2011-05-14
This assessment	0.044	0.020	0.017	2011-03 to 2012-05

VIII. COLLECTIVE DOSES FROM INGESTION OF TERRESTRIAL FOODS

37. The Committee has made estimates of the collective dose from ingestion of terrestrial foods based on the production of food in different regions of Japan. The activity concentrations were those calculated using the modified FARMLAND model based on the measured deposition density data for Japan. The collective doses were estimated for the population of Japan taking account of the proportion of the population who were adults, children and infants. The collective doses were integrated to 1, 10 and 80 years following the accident and both effective doses and absorbed doses to the thyroid were considered. The effect of introducing food restrictions was also considered (see table 29). The per-caput doses (the collective dose divided by the number of people in the population) are also presented to provide alternative estimates for the average dose to the population of Japan from ingestion.

Table 29. Estimated collective doses due to ingestion of terrestrial foods in Japan

A stable age distribution was assumed as described in attachment C-12: adult 85.1%, child 9.1%, infant 5.8%

Note: The population of Japan was taken as 128 million people to estimate the per caput doses

Integration period	*Effective dose*		*Thyroid dose*	
	Collective dose (man Sv)	*Per caput dose over period (mSv)*	*Collective dose (man Gy)*	*Per caput dose over period (mGy)*
With food restrictions				
1 year	6 500	0.051	49 700	0.39
10 years	10 300	0.080	53 400	0.42
80 years	11 100	0.087	54 200	0.42
Without food restrictions				
1 year	70 400	0.55	931 000	7.3
10 years	75 200	0.59	936 000	7.3
80 years	76 100	0.59	937 000	7.3

38. These estimated per caput doses are less than the doses presented in tables 1 to 3, where the first year's doses were estimated from the measurement database, particularly for Fukushima Prefecture and the neighbouring prefectures. However, the results are broadly consistent with the estimated individual doses given in tables 9 to 14 being greater than the doses estimated for the rest of Japan and less than those for Fukushima Prefecture. These estimates of per caput doses based on the total food production in Japan support allowing for food imports into Japan in the dose estimation.

References

Amano, H., M. Akiyama, B. Chunlei et al. Radiation measurements in the Chiba Metropolitan Area and radiological aspects of fallout from the Fukushima Dai-ichi Nuclear Power Plants accident. J Environ Radioact 111: 42-52 (2012).

Aoyama, M., D. Tsumune and Y. Hamajima. Distribution of 137Cs and 134Cs in the North Pacific Ocean: impacts of the TEPCO Fukushima-Daiichi NPP accident. J Radioanal Nucl Chem 296(1): 535-539 (2012).

Bailly du Bois, P., P. Laguionie, D. Boust et al. Estimation of marine source-term following Fukushima Dai-ichi accident. J Environ Radioact 114: 2-9 (2012).

Brown, J. and J.R. Simmonds. FARMLAND a dynamic model for the transfer of radionuclides through terrestrial foodchains. NRPB-R273. National Radiological Protection Board, Chilton, 1995.

Kawamura, H., T. Kobayashi, A. Furuno et al. Preliminary numerical experiments on oceanic dispersion of ^{131}I and ^{137}Cs discharged into the ocean because of the Fukushima Daiichi nuclear power plant disaster. J Nucl Sci Technol 48(11): 1349-1356 (2011).

MAFF. 2010 Food Self-Sufficiency Table. Ministry of Agriculture, Forest and Fisheries. [Internet] Available from (http://www.e-stat.go.jp/SG1/estat/List.do?lid=000001089812) on March 2013. (Japanese).

MIC. The basic information about the population census for 2010 in Japan. Ministry of Internal Affairs and Communications. [Internet] Available from (http://www.stat.go.jp/data/kokusei/2010/special/english/index.htm) on 6 December 2011.

Murakami, M. and T. Oki. Estimation of thyroid doses and health risks resulting from the intake of radioactive iodine in foods and drinking water by the citizens of Tokyo after the Fukushima nuclear accident. Chemosphere 87(11): 1355-1360 (2012).

Nakano, M. and P.P. Povinec. Long-term simulations of the ^{137}Cs dispersion from the Fukushima accident in the world ocean. J Environ Radioact 111: 109-115 (2012).

Periáñez, R., K.S. Suh and B.I. Min. Local scale marine modelling of Fukushima releases. Assessment of water and sediment contamination and sensitivity to water circulation description. Mar Pollut Bull 64(11): 2333-2339 (2012).