Annex V of Technical Volume 4
UNSCEAR ASSESSMENT OF THE DOSE TO THE PUBLIC

V–1. UNSCEAR ASSESSMENT OF EXTERNAL EXPOSURE

V–1.1. External exposure during passage of the plume

There were not enough environmental radiation measurements in the first days of the Fukushima Daiichi accident to assess external exposures from radionuclides in the air based on either measured ambient dose equivalent rates or activity concentrations in the air. Therefore, for areas which were not evacuated, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) adopted an approach where the doses from external exposures were calculated using estimated activity concentrations in air and established models to estimate doses using a semi-infinite cloud approach [V–1]. It was assumed that people were mostly out of doors during the short duration (a few hours) of the passage of the radioactive plume. This is likely to have overestimated the actual doses received, due to the shielding effects of buildings during the time spent inside.

The activity concentrations in air were derived from the results of ground deposition measurements (as described in Section 4.1.2). The Atmospheric Transport Dispersion and Deposition Model (ATDM) results were used to obtain ratios of the time integrated activity concentrations in air to the deposition density for each radionuclide for each location. The estimates of concentrations in air were averages for the grid cells of approximately 5 km square for which deposition data were available. For people in the areas that were evacuated, the same exposure modelling was used, but the activity concentrations in air were taken directly from the results of atmospheric dispersion modelling.

The dose from this exposure pathway is generally small compared to that from deposited material [V–1].

V–1.1.1. Radionuclides deposited on the ground

For areas which had not been evacuated, UNSCEAR based the assessment of doses from deposited activity on the measurements of the deposition density of radionuclides on the ground. An established model, which was shown to be valid for the assessment of doses from external exposure following the Chernobyl accident, was used to estimate doses as a function of time. Measurements of ambient equivalent dose rates were not used directly, because there was insufficient information available on the background doses (which needed to be subtracted) and on the contribution from different radionuclides. The model takes into account radioactive decay and the migration of radionuclides in the environment for each radionuclide. Account was also taken of reductions in doses due to the type of ground and, in particular, the shielding effect of houses during the time spent indoors. A number of different combinations of social/age groups with different occupancies and house types were considered. For example, it was assumed that typical adults spent 60% of their time in wooden houses and 30% of their time at work in multi-story buildings, while pre-school children spent 80% of their time in wooden houses and 20% outdoors. Doses were also calculated for representative persons (intended to represent those people in the populations who are likely to receive the highest doses) who were assumed to be outdoor workers living in a wooden house.

For the people who were evacuated, the UNSCEAR assessment adopted occupancy factors and building types that reflected the nature of the activities undertaken and the information available from survey results and assessments undertaken by the National Institute of Radiological Sciences (NIRS). For these groups of evacuated people, the deposition data applied were those estimated from the results of atmospheric dispersion modelling. The assessment took into account the doses resulting from a range of radionuclides. A different pattern of dose versus time is therefore observed for different locations [V–1]. Doses from external irradiation from radionuclides deposited on the ground were found to be by far the most important contributors to the total effective dose in the first and subsequent years for people who were evacuated, and they also contributed significantly to the total effective doses elsewhere. The most important radionuclides contributing to external exposure were ^{131}I, ^{134}Cs and ^{137}Cs but, in the first weeks following the accident, there were also contributions from other short lived radionuclides, notably ^{132}Te and ^{132}I. The dose rate due to deposited material fell by about a factor of 10 in the first month, and, after two months, the dose rate was mainly from ^{134}Cs and ^{137}Cs. External irradiation from deposited radionuclides was also found to be a significant contributor to the total dose to the thyroid.

V–2. UNSCEAR ASSESSMENT OF INTERNAL EXPOSURE

V–2.1. Inhalation

For assessing doses from inhalation, activity concentrations in air are required together with a breathing rate and the dose coefficient for intake by inhalation for each radionuclide. As discussed in Section 4.1.2, there are few measurements of activity concentrations in air so UNSCEAR used a modelling approach [V–1]. For areas from which the residents were not evacuated, the measured deposition on the ground were used to estimate concentrations in air using radionuclide and location specific ratios obtained from the results of atmospheric dispersion modelling. Within the evacuated areas, the results of atmospheric dispersion modelling were used directly to estimate inhalation doses. Standard dose coefficients recommended by the International Commission on Radiological Protection (ICRP) for members of the public were used, based on a default particle size of 1 µm. No allowance was made for any reduction of concentrations in air indoors compared to those outdoors. Intakes by inhalation were only significant for a short period following the release although the radionuclides taken into the body may continue to give a radiation dose for some time after intake.

V–2.2. Ingestion

For assessing doses from ingestion of radionuclides in food, a different approach was used by UNSCEAR for the first year following the accident and in subsequent years. For the first year, doses from ingestion were based on the food database of the Food and Agriculture Organization of the United Nations and the IAEA, in which measured concentrations of ^{131}I, ^{134}Cs and ^{137}Cs in various foods as marketed were available [V–1]. As discussed in Section 4.1.4, the measurements of food started a few days after the accident. The aim of these measurements was to identify where restrictions on food supplies were required rather than to assess radiation doses. The limits of detection used for the measurements were such that many of the results were at or below limits of detection. It was therefore assumed in the UNSCEAR study that, for these cases, the concentrations of each of the three radionuclides was 10 Bq/kg in each type of food. However, given the short half-life of ^{131}I, all values for this radionuclide were assumed to be zero beyond 4 months after the accident. Also, all values in rice were assumed to be zero until 6 months after the accident, as rice was not assumed to be harvested until then.

There were insufficient data to distinguish between different locations, and it was assumed that the majority of people in Japan obtained their food from supermarkets where food may be sold that was produced anywhere in the country. The assessment of average doses for different groups of people was therefore based on the average concentrations of radionuclides in foods over wide areas. Three sets of results were obtained for Fukushima Prefecture, for five surrounding prefectures (Miyagi, Gunma, Tochigi, Ibaraki and Chiba[1]) and the rest of Japan. Information on the amount of different foods consumed by the three age groups considered were obtained from surveys carried out in Japan, and account was taken of the amount of food that is imported into Japan. At the time of the

[1] In the UNSCEAR assessment [V–1], these five prefectures were considered together in the estimation of ingestion doses, but for the assessment of doses from other pathways, an additional prefecture, Iwate, was also considered. The ingestion doses in Iwate were assumed to be the same as for the rest of Japan.

UNSCEAR assessment, measurements were only available for the first year, and so a modelling approach was used to determine doses from ingestion beyond that year. This assessment was based on information about agricultural practices in Japan and any Japan specific data obtained on the transfer of radionuclides to specific foods [V–1]. A modified version of the FARMLAND model [V–2] was used to estimate ingestion doses beyond the first year. A modelling approach was also used to assess doses from seafood consumption beyond the first year.

Table V–1, based on information produced for the UNSCEAR 2014 study ([V–1] supplementary material 15), shows the estimated effective doses in Fukushima Prefecture from the ingestion of radionuclides in food in different periods following the accident. As noted previously, the doses in the first year are based on measured levels of radionuclides in food while those beyond the first year are based on modelling. Information on the levels of radionuclides measured in key foods presented in Section 4.1.4 indicates that levels, particularly of ^{131}I in green vegetables, were significantly higher in the first month than in later months. This is reflected in the doses presented here.

TABLE V–1. AVERAGE EFFECTIVE DOSES TO POPULATION OF FUKUSHIMA PREFECTURE FROM INGESTION OF FOOD OVER DIFFERENT TIME PERIODS

Time period	Estimated effective dose due to ingestion (mSv)		
	Infant, 1 year	Child, 10 years	Adult
0–1 month	1.74	1.01	0.78
2–12 months	0.16	0.15	0.15
2–10 years	0.07	0.08	0.08

These results show that the majority of the estimated dose from ingestion was delivered in the first month following the accident. The dose in the first month was mainly from ^{131}I, particularly for infants, and the key foods were green vegetables and other vegetables ([V–1] supplementary material 15). Table V–2 shows similar results for the absorbed dose to the thyroid.

TABLE V–2. AVERAGE ABSORBED DOSE TO THE THYROID TO POPULATION OF FUKUSHIMA PREFECTURE FROM INGESTION OF FOOD OVER DIFFERENT TIME PERIODS

Time period	Estimated dose due to ingestion for the period and age group indicated (mGy)		
	Infant, 1 year	Child, 10 years	Adult
0–1 month	31.20	14.50	7.42
2–12 months	1.60	0.70	0.36
2–10 years	0.06	0.08	0.08

Given the importance of ^{131}I, the difference between the first month and the later ingestion doses is even more marked for doses to the thyroid for all ages. UNSCEAR [V–1] noted that the initial ingestion doses were particularly uncertain, as the concentrations of radionuclides in food used in the analysis may not have been representative of the general levels in food. Intakes and doses would depend on the foods eaten in the first few days after the accident, before the restrictions were fully applied.

The restrictions on food supplies were implicitly taken into account for the first year, as only results for foods marketed were used. For the assessment based on modelling, it was assumed that no foods above the levels specified by the Japanese authorities were or would be eaten [V–1].

Ingestion of radionuclides in drinking water was considered separately and the results were not added to those from other exposure pathways. As described in Section 4.1, levels of radionuclides were measured in drinking water at many locations following the accident and restrictions were introduced in some locations. These measurements formed the basis for the UNSCEAR assessment of doses taking account of any restrictions, which estimated effective doses in the first year from drinking water of up to about 0.5 mSv for a 1 year old infant living in Iitate Village with an absorbed dose to the thyroid of around 10 mGy. Doses in other locations and to other age groups were estimated to be lower ([V–1] Appendix C, Table C9). It should be noted that the measurements did not start until 17 March 2011 or later, and therefore these estimates may have underestimated the actual doses received, although it is known that many people did not drink tap water, which would have led to lower doses than those estimated.

The relative importance of the different exposure pathways was found to vary with location, reflecting the levels and composition of radionuclides in the environment. In the areas with the highest deposition on the ground, the greatest contribution to effective dose was external radiation from deposited material. Inhalation of radionuclides in air was an important exposure pathway for doses to the thyroid. The relative contribution of the ingestion of food in the first year varied and reflected the concentrations of radionuclides averaged over much wider areas than was the case for the other exposure pathways.

V–3. DOSES TO MEMBERS OF THE PUBLIC ESTIMATED BY UNSCEAR

Table V–3 shows the estimated district or prefecture average effective doses and absorbed doses to the thyroid in the first year following the releases from the Fukushima Daiichi NPP. Results are given for the three age groups and three different residential locations from which people were not evacuated. These doses presented are for all exposure pathways.

TABLE V–3. ESTIMATED DISTRICT- OR PREFECTURE-AVERAGE EFFECTIVE DOSES AND ABSORBED DOSES TO THE THYROID FOR THE FIRST YEAR FOLLOWING THE ACCIDENT FOR TYPICAL RESIDENTS OF JAPAN THAT WERE NOT EVACUATED[2]

Residential area	Effective dose (mSv)			Absorbed dose in the thyroid (mGy)		
	Adults	10-year-old	1-year-old	Adults	10-year-old	1-year-old
Non-evacuated areas of Fukushima Prefecture	1.0–4.3	1.2–5.9	2.0–7.5	7.8–17	15–31	33–52
Miyagi, Gunma, Tochigi, Ibaraki, Chiba and Iwate	0.2–1.4	0.2–2.0	0.3–2.5	0.6–5.1	1.3–9.1	2.7–15
Other prefectures of Japan	0.1–0.3	0.1–0.4	0.2–0.5	0.5–0.9	1.2–1.8	2.6–3.3

[2] Reproduced with permission of UNSCEAR. The doses are in addition to the background doses due to natural sources of radiation. The values were the ranges of the district-average doses for Fukushima Prefecture and for the prefectures of Miyagi, Gunma, Tochigi, Ibaraki, Chiba and Iwate. For other prefectures, the prefecture-average doses are presented. These estimates were intended to be characteristic of the average dose received by people living at different locations and do not reflect the range of doses received by individuals within the population at these locations. They may overestimate actual average doses because of assumptions made where data were inadequate (see the UNSCEAR Report [V–1] for more information).

These doses are intended to be characteristic of the average dose received by people living at different locations and do not reflect the range of doses received by the population. From Table V–3 it can be seen that the highest estimated doses are for some districts in Fukushima Prefecture, where the district-average effective dose to adults varies between 1 mSv and about 4 mSv in the first year. The doses for children are estimated to be greater than those for adults, with the district-average effective dose for a 1-year-old being between 2 and less than 8 mSv. The highest estimated doses are for districts to the north west of Fukushima Daiichi NPP.

The estimated doses for the majority of people in Japan are low, with prefecture-average effective doses to adults in the first year for the rest of Japan between 0.1 and 0.3 mSv and with doses to 1-year-old infants being about twice these levels. The absorbed doses to the thyroid, presented in Table V–4, show the same pattern as the effective doses, but the infant doses can be more than three times those of adults, reflecting the significantly higher dose coefficients for ingestion and inhalation of ^{131}I for a 1-year-old child than for an adult. Further detailed results can be found in the UNSCEAR 2014 report [V–3].

TABLE V–4. ESTIMATED SETTLEMENT-AVERAGE EFFECTIVE DOSES AND ABSORBED DOSES TO THE THYROID FOR EVACUEES FOR THE FIRST YEAR FOLLOWING THE ACCIDENT[3]

Age group	Precautionary evacuated settlements[4]			Deliberately evacuated settlements[5]		
Effective dose (mSv)						
Adults	0–2.2	0.2–4.3	1.1–5.7	2.7–8.5	0.8–3.3	4.8–9.3
Child, 10-year-old	0–1.8	0.3–5.9	1.3–7.3	3.4–9.1	1.1–4.5	5.4–10
Infant, 1-year-old	0–3.3	0.3–7.5	1.6–9.3	4.2–12	1.1–5.6	7.1–13
Absorbed dose to the thyroid (mGy)						
Adults	0–23	0.8–16	7.2–34	15–28	1.0–8	16–35
Child, 10-year-old	0–37	1.5–29	12.0–58	25–45	1.1–14	27–58
Infant, 1-year-old	0–46	3.0–49	15.0–82[6]	45–63	2.0–27	47–83[6]

The range in the estimated average effective doses is between about 1 mSv and 10 mSv, or slightly higher for all age groups. The estimated average absorbed doses to thyroid in the first year were up to 35 mGy for adults and about 80 mGy for 1-year-old infants. UNSCEAR estimated that the evacuation of the settlements within 20 km of the Fukushima Daiichi NPP site averted effective doses to adults of up to about 50 mSv and absorbed doses to the thyroid of 1-year-old infants of up to about 750 mGy.

[3] Reproduced with permission of UNSCEAR. The doses are in addition to the background doses due to natural sources of radiation. The values were the ranges of the settlement average doses for the evacuation scenarios. These estimates of dose were intended to be characteristic of the average dose received by people evacuated from each settlement and do not reflect the range of doses received by individuals among the population of the evacuated settlement. They may overestimate actual average doses because of assumptions made where data were inadequate (see UNSCEAR Report [V–1] for more information).

[4] Precautionary evacuation refers to the evacuation of settlements that was instructed between the 12 and 15 March 2011 as an urgent protective action to prevent high exposure. The dose assessment considered evacuation scenarios 1−12 (see UNSCEAR Report, Appendix C [V–1]) for towns of Futaba, Okuma, Tomioka, Naraha and Hirono, and parts of of Minamisoma City, Namie Town and Tamura City and villages of Kawauchi and Katsurao.

[5] Deliberate evacuation refers to evacuation of settlements (based upon environmental measurements) that was instructed between late March and June 2011. The dose assessment considered evacuation scenarios 13−18 (see UNSCEAR Report Appendix C [V–1]) for Iitate Village and parts of Minamisoma City, Namie Town, Kawamata Town, and of Katsurao Village.

[6] These absorbed doses to the thyroid were principally due to internal exposure from inhalation during the passage of the airborne radioactive material through the affected areas before and during evacuation in the early days of the accident and from ingestion over the subsequent period.

REFERENCES

[V–1] UNITED NATIONS, Sources, Effects and Risks of Ionizing Radiation (Report to the General Assembly), UNSCEAR 2013 Report, Vol. I, Scientific Annex A: Levels and Effects of Radiation Exposure Due to the Nuclear Accident after the 2011 Great East-Japan Earthquake and Tsunami, Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (2014).

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