I. Dose estimates likely to be received by the Japanese population

Dose estimates likely to be received during the discharge phase

Within the context of the work conducted in 2011 concerning the evaluation of atmospheric discharge and modelling their dispersion over Japan, IRSN evaluated the doses likely to be received by a one-year-old child (representing the most sensitive group to radioactive exposure) assumed to have remained in the same location from 12th March (start of discharge) to midnight on 25th March (end of the significant discharge phase) without implementation of protective actions (i.e. outdoors).

To evaluate these doses, IRSN considered the three main exposure pathways during this discharge phase:

- External exposure to gamma radiation emitted by the radioactive plume,
- Internal exposure by inhalation of radionuclides present in the air,
- External exposure to gamma radiation emitted by the radioactive deposit that is gradually formed according to the trajectories of the radioactive plume and the rain.

The dose likely to be received via ingestion of contaminated foodstuffs is not taken into account here, because IRSN does not have sufficient data to make a reliable estimate of this dose.

As expected, the highest doses likely to be received occurred on the local scale. Whatever the scale, the estimates show that the marine environment suffered of the greatest impact. This obviously refers to virtual doses, because there are no full-time human inhabitants of that environment (especially not a one-year-old child). Moreover, in the absence of direct measurements in the environment at the time of the discharge, the dose estimate is particularly inaccurate in this sector.

In the terrestrial domain, the highest doses during the discharge phase could have been taken by the coastal areas, to the north and especially to the south of the Fukushima Dai-ichi power plant. According to this simulation, an effective dose above 10 mSv might have been received, assuming continuous outdoor presence up to forty kilometres to the south. Effective doses above 50 mSv might only have been reached inside a 20 km radius, corresponding to the emergency evacuation zone on 12th March. Concerning the equivalent doses received by the thyroid, theoretical values above 50 mSv could have been received as far as sixty kilometres to the south of the power plant, in Iwaki. These correspond to discharge from Reactor 2 occurring on 15th March from midnight to 5 AM, when the wind was blowing towards the south.

It should be emphasised that there is some uncertainty concerning the position of the radioactive plume in the southern sector because of the imprecise nature of the data and the modelling of meteorological conditions on the local scale, particularly for the discharge episode occurring on 15th and 16th March 2011. The plume heading south might therefore have been positioned more over the marine domain.
Further away, the doses likely to be received during the discharge phase, in the absence of implementation of protective actions, would have been significantly lower:

- Below 10 mSv for the effective dose, and of the order of 0.1 mSv in the Tokyo metropolitan area;
- Below 50 mSv for the equivalent thyroid dose, and of the order of 1 mSv in the Tokyo metropolitan area.

It should be emphasized that the areas most affected by radioactive deposits, located to the north-west of the Fukushima power plant, are not the areas where the doses due to exposure to the plume were highest. This can be explained by the strong influence of rainfall or snowfall, which caused these deposits during the night of 15-16 March, whereas in the areas with greater exposure to the plume, the deposits consisted mainly of dry deposits in a lesser quantity.

On the local scale, for equal levels of dose likely to be received, there is a large disparity from one location to another concerning the contribution of the various exposure pathways and the dose intake kinetics during the discharge phase from 12th to 25th March 2011.

Dose estimates likely to be received by external exposure to radioactive deposits during the first year following the accident

On 8th April 2011, IRSN made an initial estimate of the doses that could be received by the population living in the contaminated territories in Japan as a result of external exposure to gamma radiation emitted by the radioactive deposits, by interpreting the airborne dose rate measurements performed by the American DoE/NNSA and published on its website on 7th April 2011. On that date, IRSN had no measurement data concerning the isotopic composition of the radioactive deposits, and the forecasts of doses likely to be received during the first year following the accident used the isotopic composition of the source term estimated by IRSN at the time and the analysis of the decay profiles of the dose rate measured at various points in the territory concerned. In late April 2011, MEXT published new maps showing dose rates and caesium 134 and 137 deposits, as well as a map of estimated doses due to external exposure to the deposit during the first year. MEXT then updated this dose forecast map periodically, taking into account outcomes from new measurement campaigns that were carried out, but without any significant change from the first map published at the end of April 2011. As expected, the highest dose levels concerned the territories that had received the largest deposits, formed between 15th and 16th March 2011 over an area tens of kilometres north-west of the Fukushima Dai-ichi power plant during heavy rainfall and snowfall at the time of the atmospheric dispersion of a discharge from Reactor 2.

By comparing the dose map published by MEXT to the map of cumulative deposits of caesium 134 and 137, it is possible to deduce a conversion factor relating the dose by external exposure due to deposits, accumulated over the first year, to the surface activity of caesiums 134 and 137: 16.6 mSv per Bq/m$^2$ of $^{134+137}$Cs. Moreover, using the demographic data concerning the Fukushima district provided by the Statistics Bureau, Ministry of Internal Affairs and Communications, Japan, IRSN deduced that, outside the emergency evacuation zone 20 km around the Fukushima Dai-ichi power plant, close to 70,000 persons living in areas with a $^{134+137}$Cs deposit exceeding 600,000 Bq/m$^2$ could have received a dose greater than 10 mSv in the first year due to external exposure to the deposit. If the most contaminated areas (dose exceeding 20 mSv) had not been evacuated, as the Japanese authorities decided to do on 22nd April 2011, this dose could even have exceeded 50 mSv for approximately 5,300 persons. Inside the 20 km exclusion zone, even higher doses, above 200 mSv, could have been reached, according to the maps published by MEXT. These estimates confirm that it would have been unthinkable to allow the return of the people urgently evacuated from this zone at the time of the accident.

The estimates made show that the doses likely to be received during the first month by external exposure due to the deposits represent approximately one third of the doses accumulated over the subsequent 12 months. These results confirm the importance of protective actions for the population as promptly as possible, by removing persons from the most contaminated areas because they could be exposed to significant doses in the initial months following the formation of deposits. As an illustration, in the territory (excluding the 20 km exclusion zone) where a dose exceeding 10
mSv could have been received between 15th March and 15th April 2011, the doses could have gone beyond 25 mSv, without considering doses due to exposure to the radioactive plume between 12\textsuperscript{th} and 25\textsuperscript{th} March or doses due to any consumption of contaminated foodstuffs. This zone includes part of the municipalities of Minamisoma (south-west), Iitate, Namie, and Katsurao (east).

Likewise, the estimates show that a dose exceeding 10 mSv could have been received between 15th April 2011 and 15th April 2012 in the zone corresponding approximately to the planned displacement zone set up on 22\textsuperscript{nd} April by the Japanese authorities (except for a small sector in the In the most contaminated parts of this zone, the doses that could have been received during this period if evacuation had not taken place are estimated at more than 75 mSv, in addition to the doses already received during the first month following the formation of deposits or by other exposure pathways (inhalation, ingestion of contaminated foodstuffs, unintentional ingestion).

II. Epidemiological monitoring studies of the Japanese population

Principle of the studies

Late June 2011, the Japanese health authorities devised and set up epidemiological studies to evaluate the health status of persons exposed to radioactive discharge and to monitor its evolution over time. According to the group concerned, these studies are based on a questionnaire, to be completed in certain cases by conducting medical examinations. The results of these epidemiological studies will provide information concerning the incidence base rate of certain pathologies in the Japanese population (cancer, leukaemia, psychological disorders, thyroid disorders, liver or kidney disease, diabetes, etc.) and allow an evaluation of any health effects on the population due to exposure to radioactive fallout. The planned duration of these studies is 30 years, and they are conducted under the leadership of Fukushima Medical University in collaboration with other Japanese medical centres.

These studies consist of the following tasks:

- Conducting a basic survey for all persons present in the Fukushima district during the discharge phase. The aim of this survey is to estimate the external dose likely to be received by the persons exposed, to gather information concerning the administration of stable iodine tablets and the consumption of foodstuffs and drinking water, and to identify the persons for whom long-term medical monitoring might be necessary. This survey is to be carried out on 2,057,053 persons.

- Performing a thyroid examination in all children under the age of 18 years who were present in the Fukushima district during the discharge phase. The main aim of this study is to detect any increase in the occurrence of thyroid cancer as observed in children exposed to radioactive fallout from the Chernobyl accident. This study will concern approximately 360,000 children born up to 1\textsuperscript{st} March 2012.

- Monitoring any genetic or congenital abnormalities that might appear in children born from women who declared their pregnancy between 1st August 2010 and 31st July 2011. This study will concern approximately 20,000 women. This study will supplement the study launched in 2010 in a dozen regions of Japan by the Japanese Ministry of the Environment, concerning approximately 100,000 pregnant women; the objective of this study (JECS : Japan Environment and Children’s Study) is to evaluate the consequences of exposure to chemical and physical environmental agents in children born of those mothers. From the time it was implemented, this study included places near the Fukushima Dai-ichi power plant (Fukushima, Minami Souma, Namie). In August 2011, the Japanese authorities decided to include in the study a group of 6,900 women from some of the towns with greatest exposure to radioactive fallout (Kawamata, Koori, Date, Kunimi). All the children born of mothers recruited into the JECS study will be monitored until the age of 12.

- Special medical check-ups for persons who were evacuated from the most exposed areas to radioactive fallout. This study will concern approximately 210,000 persons and will provide information concerning lifestyle (smoking, alcohol consumption), psychological disorders based on a questionnaire, the incidence basic rate of pathologies such as cancer, leukaemia, diabetes, or liver and kidney disorders, and the carrying out of radiological examinations that could affect the
external dose received (particularly CT-scans). Moreover, the Japanese Ministry of Health will implement special additional monitoring over a ten-year period of psychological disorders in approximately 30,000 persons from the districts of Fukushima, Iwate, and Miyagi.

Progress report and initial results of the ongoing studies

**Dosimetric questionnaire**
- Since late June 2011, 29,097 questionnaires have been sent to persons who were in the towns of Namie, Iitate, and Kawamata at the time of the radioactive discharge. As of the 20th of January 2012, the response rate was 50.2%. The lowest response rate concerned persons aged from 21 to 30 years (36.5% of questionnaires completed), and the highest response rate was from persons aged between 61 and 70 (63.1% of questionnaires completed).
- Based on the completed questionnaires, the external doses received were calculated using a dedicated software developed by the NIRS (National Institute for Radiological Sciences) for 1,589 persons from Namie, Iitate, and Kawamata: for 62.1% of them, the external dose calculated was below 1 mSv, and maximum dose calculated was 14.5 mSv.
- From the end of August 2011, questionnaires were sent out more widely, to all 2,057,053 persons who were in the Fukushima district at the time of the radioactive discharge. As of the 20th of January 2012, the response rate was 20.8%.

**Evaluation of thyroid disorders in children exposed to radioactive discharge**
- Between October and December 2011, 19,715 children who were in Namie, Iitate, and Kawamata at the time of the radioactive discharge received invitations to undergo a thyroid examination. 4,908 children were examined at Fukushima Medical University, and 14,807 were examined at other medical centres in the Fukushima district.
- As of the 31st of December 2011, thyroid examinations had been carried out on 14,442 children. These initial tests consisted essentially of an ultrasound examination of the thyroid, possibly supplemented by biological and histological tests if any pathological abnormality was detected. 23.7% of the children examined were aged from 0 to 5 years, 27.3% from 6 to 10 years; 29.6% from 11 to 15 years; 19.4% above the age of 16.
- Out of the 3765 children examined by Fukushima Medical University, the thyroid examination showed normal results for 69.6%. At least one liquid cyst considered as subnormal (diameter less than 20 mm) was detected in 28.8% of the children. 1.5% of the children had at least one nodule, again considered as subnormal (diameter less than 5 mm). At least one nodule of diameter greater than 5 mm was found in 0.7% of the children examined, but without any additional tests being necessary in the opinion of the physicians. Finally, no liquid cyst greater than 20 mm in diameter was detected.
- Between January and March 2012, invitations to a thyroid examination will be sent to 27,467 children who were in Date, Tamura, Hirono, Naraha, Tomioka, Kawaulchi, Okuma, Futaba, or Katsurao at the time of the radioactive discharge. The remainder of the children concerned by the study will receive invitations sequentially between April 2012 and March 2014.
- Starting in April 2014, follow-up thyroid examinations will be performed in the 360,000 children concerned once every two years until age 20, and then every five years above the age of 20.

*No information is currently available concerning the progress of the studies planned for pregnant women and evacuees.*
III. The situation of workers involved in the operations carried out at the Fukushima Dai-ichi power plant

Doses received by workers

The only information currently available concerning doses received by the workers involved in the operations carried out at the Fukushima Dai-ichi power plant are those provided by the TEPCO company, which has been publishing a monthly report since April 2011. This information concerns employees of TEPCO and its subcontractors only. No precise information concerning the other categories of worker exposed (firemen, police officers, municipal employees, self-defence personnel) has yet been obtained, even though at least some of those workers have undergone dosimetric monitoring.

The last report published on 31st January 2012 concerned 3,368 TEPCO employees and 16,226 employees of companies subcontracted by TEPCO. The average dose received by those workers between 11th March and 31st December 2011 was 23.53 mSv for TEPCO employees, and 9.06 mSv for subcontractor employees.

To date, six workers, all employed by TEPCO, have received a dose exceeding 250 mSv. According to TEPCO, 85% of the dose received by those six workers was caused by inhalation of iodine 131 due to not wearing suitable protective masks. The maximum recorded dose was 678.80 mSv.

Note that very little precise information is available concerning the methods used to evaluate the doses received by the workers, in particular for those who were not wearing dosimeters in the days immediately following the accident. The United Nations Committee in charge of studying the effects of exposure to ionising radiation (UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation) has recently sent requests for additional information to the Japanese authorities.

Effects observed and monitoring the health of workers

Effects observed

According to the information provided by the Japanese authorities, no health effect attributable to exposure to ionising radiation has been observed to date in the workers involved in operations conducted at the Fukushima nuclear power plant. However, according to statements made by NIRS physicians, recognizing the nature of the operations remaining to be carried out, the appearance in the coming months of effects on workers’ health directly related to radiation exposure cannot be excluded.

To date, the deaths of six workers have been recorded. Apparently none of these deaths could be attributed to exposure to ionizing radiation. According to the Japanese authorities:

- Two workers died on 11th March 2011 as a direct result of the tsunami and the earthquake,
- Two workers died from heart failure, on 14th May 2011 and 9th January 2012 respectively,
- One worker died from acute leukaemia in August 2011,
- One worker died from septic shock on 6th October 2011.

Moreover, hyperthermia (increased body temperature) has been observed in 43 workers, probably due to insufficient cooling of their work clothing.

Health monitoring

A database to contain all the information concerning the monitoring of workers’ health is currently being set up. Every worker, including those no longer involved in the operations underway at Fukushima Dai-ichi, will receive a basic medical check-up including tests of their eyesight, hearing, lungs, cardiovascular system, and digestive system, as well as biological tests and an evaluation of the person’s psychological and psychiatric condition.
In addition, workers who have received a dose exceeding 50 mSv will receive special monitoring aimed at detecting the formation of cataracts, and those whose dose exceeds 100 mSv will undergo additional tests to monitor the onset of thyroid disorders and certain types of cancer (lung, stomach, and colon).

According to the observations recorded, the medical monitoring could be revised in three years’ time.

IV. IRSN involvement in UNSCEAR operations

At its annual session in May 2011, the United Nations Scientific Committee on the Effects of Atomic Radiation decided to start writing an initial report on the accident at the Fukushima Dai-ichi power plant and its consequences on the health of persons exposed to the radioactive fallout.

In order to complete this task, UNSCEAR called upon all governments to nominate experts, who would be appointed to write this report on a voluntary basis. A total of nearly 60 experts, from Europe, Japan, Canada, the USA, Brazil, Korea, Russia, Belarus, Ukraine, and Australia, were appointed. There are nine experts from France: five from IRSN and four from the CEA.

The experts have been divided into four working groups:

- The first group, led by an American delegate, is responsible for collecting measurement data and checking its quality. IRSN is represented by an expert in charge of one of the three sub-groups of this working group;

- The second group, led by a German delegate, is responsible for evaluating the atmospheric and marine dispersion of the radioactive discharge. IRSN is represented by one expert in this working group;

- The third group, led by an Australian delegate, is responsible for evaluating the doses received by the population and their consequences on the persons thus exposed and on non-human species. IRSN is represented by two experts in this working group;

- The fourth group, led by a French delegate from IRSN, is responsible for evaluating the doses received by workers and the consequences on their health.

Moreover, a coordination group consisting of the Chairman of UNSCEAR, the Chairman of the Japanese delegation to UNSCEAR, the leaders of the four working groups, and the Scientific Secretary of UNSCEAR and his colleagues, ensures the smooth progress of the report drafting process.

A first interim report will be presented at the 59th annual session of UNSCEAR in May 2012, and the final report, whose publication is expected at the end of 2013, will be presented at the 60th annual session of UNSCEAR in May 2013.

This UNSCEAR report will also benefit from contributions by the main international organisations, most notably the World Health Organisation and the World Meteorological Organisation.