IRSN
INSTITUT
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ET DE SÛRETÉ NUCLÉAIRE

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Fukushima Daiichi accident

Information note concerning the evolution of the environmental contamination and the contamination of foodstuffs produced in Japan

This information note, particularly intended for French nationals resident in Japan, was drawn up by IRSN, the French Institute for Radiological Protection and Nuclear Safety. It updates the information and recommendations of the previous information note dated the 6 August 2012 and takes into account the most recent data published in Japan concerning the evolution of the environmental contamination and the contamination of foodstuffs produced in Japan. The English translation

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This latest information note focuses on two particular aspects, developed respectively in appendices 1 and 2:

- The evolution of radioactive deposits in the terrestrial environment since the year of the accident, and its incidence on the zoning put in place by the Japanese authorities around the Fukushima Daiichi nuclear power plant.
- The evolution of the levels of contamination observed in the different categories of foodstuffs produced in Japan and IRSN's assessment of the risks for consumers.

For illustrative purposes, appendix 3 outlines the results of radiametric measurements carried out by IRSN in February 2013 along a route followed in Fukushima city. These measurement results demonstrate the variability in practice of the radioactive ambiance that may be observed at a local scale and the reasons to explain this variability.

This latest information has led to the recommendations made in the previous information note to be updated.

1. Evolution of radioactive deposits and contamination of foodstuffs

1.1 Residual radioactive deposits (see details in appendix 1)

Two years after the Fukushima accident, the residual contamination in Japan results almost exclusively from caesium 134 and 137, the half-lives[1] of which are respectively 2.1 and 30 years.

[1] The radioactive half-life, specific to each radionuclide, designates the time in which the radioactivity of the radioactive element is reduced by half (through the phenomenon of radioactive decay). Thus, the shorter the half-life, the quicker the radionuclide considered disappears.

Given the radioactive decay of these two radionuclides, around 95% of the caesium 137 and 52% of the caesium 134 initially deposited during the Fukushima accident still remain, whereas radionuclides of shorter half-life, such as iodine 131, have dropped sharply or have totally disappeared. Caesium 137 today represents 64% of the activity of the residual radioactive deposits.

The updating of the radioactive deposit maps published recently in Japan shows, as expected, a reduction in the radioactivity of surface deposits. Apart from radioactive decay (particularly of caesium 134), the following mechanisms may be involved in this reduction in residual radioactivity: the vertical migration of radionuclides in the ground, the erosion of surface soils where most of the contamination is found, the processes of recycling by plants within forest ecosystems (the impact of which in dosimetric terms can be significant), the removal of contaminated harvests and, finally, the clean-up actions initiated in Japan, principally in agricultural and inhabited areas (ploughing, burying, stripping of soils, cleaning of built-up areas).

Local variations in radioactive deposits continue to be observed. Only radiametric measurement campaigns carried out in the field enable them to be properly characterised. As an illustration, a "radiametric route" in Fukushima city is presented in appendix 3; it was carried out during an IRSN mission to this city.

Superficial radioactive deposits permanently emit gamma radiation (radiation comparable to X-rays), leading to an ambient dose rate that contributes to the external exposure of people present in the contaminated areas. The doses received by this exposure pathway depend on the time spent outside (the radiation being significantly attenuated inside buildings) and obviously the areas frequented. IRSN has updated its estimations of the doses potentially received via this exposure pathway over different periods following the formation of the deposits (15 March 2011): 1st month, 1st year following the first month, 2nd year. Given the prudent hypotheses retained to establish these estimations, the theoretical doses thus calculated are dose envelopes actually received by the populations who live in these areas, as the results of dosimetric surveillance campaigns carried out in Japan seem moreover to confirm. Even if their efficiency is entirely relative, the clean-up actions undertaken in inhabited areas by the Japanese authorities (national or local, depending on the areas concerned) can partly explain this more favourable situation.

With the progressive disappearance of caesium 134 (radioactivity halved every 2.1 years), the ambient gamma radiation in the contaminated areas should continue to drop over coming years. This reduction will thereafter be slower, due to the longer radioactive half-life of caesium 137 (30 years).

1.2 Evolution of the contamination of foodstuffs produced in Japan (see details in appendix 2)

Since April 2012 (the date the standard applicable to foodstuffs in Japan was changed) and up to the end of March 2013, i.e. in the course of the 2nd year following the accident, the Japanese Ministry of Health (MHLW) has published on its website the results of measurements of 280,000 samples of foodstuffs from all the prefectures of Japan. They mainly, but not exclusively, involve foodstuffs from farming, particularly 32,000 samples of rice and 172,000 samples of beef.

Only 23,000 out of the 280,000 samples controlled, i.e. less than 10%, had a caesium 134 and 137 contamination above the detection limit of the measurement equipment used. This signifies that, for the other samples, radioactive caesium was present in too low quantities to be quantifiable.

The sales standard of 100 Bq/kg wet weight of caesium (134+137), which has been in force since the 1st April 2012 for the majority of solid foodstuffs, was only exceeded for 2,300 samples, i.e. 0.8% of the 280,000 samples analysed. The number of cases of the limit being exceeded has dropped over time: it was 3% in April 2012, following the tightening of the standards, then it stabilised at 0.65% a month as of the end of 2012. This percentage overshoot obviously varies at the country scale. It is zero in the majority of the 47 prefectures of Japan, whereas it is 4% for Fukushima prefecture, in which are found the areas the most affected by the radioactive deposits.

Finally, 172 out of the 280,000 samples measured between April 2012 and March 2013 showed a contamination of caesium (134+137) greater than 1,000 Bq/kg wet weight (10 times the standard), i.e. 0.06% of the 280,000 analyses. To a very large extent, these samples concern products from hunting, gathering and fishing: 108 wild game meats (including 106 from wild board), 19 fish, 16 mushrooms (mainly wild), 11 mainly wild plant shoots and plants (aralia, bamboo, koshiabura, ferns, etc.).

To estimate the health risk for consumers of foodstuffs produced in Japan, IRSN has evaluated the theoretical doses that a person who consumes foodstuffs contaminated by radioactive caesium could receive, taking account of the measurement results published over the past year and the restrictions put in place in Japan. To do this, two major scenarios have been considered. The first concerns the case of a person who permanently consumes foodstuffs in which the caesium concentration lies just below the limit applicable in Japan of 100 Bq/kg. The second concerns the case of a person who consumes one kilogram of a foodstuff in which the caesium concentration corresponds to the highest value in 2012 for the category of foodstuff considered.

The doses thus estimated are low, around 1 mSv in a year at the most[2]. Given the evolution of the caesium concentration levels in foodstuffs in 2012 and the surveillance and restriction measures put in place by the authorities in Japan, it is in reality unlikely that such doses have been attained over the past year, except perhaps for persons having a particular dietary mode (regular consumption of foodstuffs collected directly from the wild in contaminated areas without any control measures).

Thus, IRSN considers that the health risk for consumers of foodstuffs distributed in Japan is very low.

Given the persistence of radioactive caesium in the environment (in the soil and sediments), the continuation of regular surveillance of foodstuffs produced in Japan and the maintaining of sales or consumption restrictions in the areas the most impacted are necessary. Although contamination has decreased sharply since 2011 for most foodstuffs, the reduction will be slower in years to come, especially for products from the wild, gathered from the land or the sea, where there are contaminated deposits or sediments: mushrooms, wild game, plant shoots, certain species of fish, etc.

Whatever the case, if the restriction and control measures put in place in Japan are maintained, the health risks for consumers will continue to be very low, even in the case of the occasional consumption of foodstuffs containing radioactive caesium at levels above the standards.

2. Orders and recommendations decreed by the Japanese authorities

2.1 With regard to the marketing and sale of foodstuffs

The past year has been marked by:

- The application of a more stringent food sales standard than that initially set in 2011, which only concerns caesium 134 and 137, the only radionuclides still present in certain foodstuffs.
- The continuation of the surveillance of the contamination of foodstuffs placed on the market, extended to all 47 prefectures of Japan.
- The maintaining, or even the extension, of sales or consumption restrictions in areas where the standard is exceeded for certain categories of foodstuffs. The evolution of restrictions is regularly updated on the Japanese Ministry of Health's website at the following address:

  http://www.mhlw.go.jp/english/topics/2011eq/index.html.

[2] As a comparison, in France, the regulatory annual dose limit for the public likely to be exposed to ionising radiation due to authorised nuclear activities, within the scope of their normal operations, is set at 1 mSv/year. This limit does not apply to doses received due to natural radioactivity, which are on average 2.4 mSv/year and can exceed 5 mSv/year in regions at altitude or in areas having high radon levels, or doses received during medical interventions using ionising radiation, which is on average 1.3 mSv/year.

More information on the surveillance and restriction measures is provided in appendix 2 of this information note.

2.2 With regard to living in contaminated areas

Thanks to better knowledge of the distribution of radioactive deposits and given the progressive reduction in the doses potentially received in contaminated areas, the Japanese authorities have initiated, as of April 2012, an approach leading to a progressive evolution of the status of the evacuated areas decided in 2011, with the perspective of a return of the populations in the parts of these areas where the levels of radioactivity allow it. Thus, the restricted access areas (within a radius of 20 km) and deliberate evacuation areas (outside of the 20 km radius circle, where radioactive deposits are the highest) have been progressively reduced over the course of 2012. In their place, three new categories of areas have been created, the status of which depends on the level of ambient radioactivity (see appendix 1 for more details and the location of these areas):

- **Type 1 areas, where the ban on the population staying has been lifted** on account of projected doses below 20 mSv/year. This concerns certain sectors of the municipalities of Kawauchi, Tamura, Okuma, Nahara, Minamisoma and two sectors of Iitate.
- **Type 2 areas, where the ban on the population staying remains in force in the short term** because the doses likely to be received in the event of permanent stay could exceed 20 mSv/year. Only occasional returns authorised and supervised by the Japanese public authorities are possible at the present time. The Japanese authorities are anticipating a return of the population to these areas in several years.
- **Type 3 areas, where the population staying in the long term is difficult to envisage** since the doses are likely to exceed a value of 50 mSv/year. Only very occasional access is possible, subject to the authorisation of the Japanese public authorities and the wearing or protective equipment. This concerns certain sectors of the municipalities of Minamisoma, Okuma and Iitate.

In type 1 areas, the return of the population is not yet effective. Only short stays are authorised to take up certain professional activities again and for the restoration of living conditions. Furthermore, contamination reduction operations are underway in the communities concerned.

The question of the return of the public to these "liberated" areas is not limited just to radiation protection aspects. In fact, two years after the accident, the economic, social and even cultural conditions of such a return are the subject of debate within the populations concerned and opinion polls show that, with time, there exists an increasing uncertainty regarding a possible return in more than 50% of persons interrogated. The viewpoints seem to diverge depending on the generations, the oldest people, attached to their lands and to their traditions, being more favourable to a return. Despite the clean-up actions and surveillance measures that make it possible to ensure a low exposure level to the ambient radioactivity, reticence and hesitations are manifesting themselves, linked to the potential risks for health, particularly the health of children, the living conditions in these areas and the long term outlook in an environment that will remain necessarily different to that which existed before the accident.

3. IRSN's recommendations for French nationals considering visiting or living in areas in Japan impacted by the accident of the Fukushima Daiichi nuclear power plant

Five prefectures are concerned by persistent radioactive deposits, to various degrees, caused by the Fukushima Daiichi accident: Miyagi, Ibaraki, Tochigi, Gunma and especially Fukushima.

All of IRSN's recommendations, proposed hereafter, naturally do not prejudice the application of the instructions and recommendations decreed by the Japanese authorities, resumed below.

3.1 Recommendations for staying or living in contaminated areas

The information collected by IRSN on the radiological situation in Japan, summarised in this information note, clearly shows that the level of radioactivity in the contaminated areas has decreased compared to the first year; furthermore, the Japanese authorities have taken measures that make it possible to reduce the exposure of the populations concerned. Today, the doses likely to be received by external exposure in the areas where the ban on staying has been lifted are low on average, in the upper bracket of the doses due to natural radioactivity in the world. Generally speaking, IRSN estimates that there is no longer any real risk in returning to the prefectures affected by fallout from the accident, with the exception of areas where staying restrictions or instructions to keep away have been maintained by the Japan Ministry of Trade, Economy and Industry (METI) (cf. paragraph 2.2 above and appendix 1).

As is recommended by the Japanese government, clean-up work to reduce contamination levels may be envisaged for persons living in individual housing. These works essentially consist in removing the mud and dead leaves accumulated in gutters, ditches, streams, accumulation areas, and cleaning ventilation screens. The waste produced by these operations needs to be stored outside of areas of passage while awaiting their disposal in accordance with the method recommended by the local authorities.

3.2 Recommendations for good dietary practices

Generally speaking, for French nationals resident in Japan, IRSN recommends:

- Limiting as much as possible the consumption of foodstuffs collected directly from the wild (hunting, fishing, gathering), from vegetable plots or from family reared livestock, unless appropriate controls have been carried out.
- Thoroughly washing fruit and vegetables that have been in contact with the ground.

Furthermore, **IRSN recommends retaining a certain prudence regarding the consumption of the following foodstuffs**:

- **Wild plants and mushrooms and game, particularly wild boar meat**: these products come from the forest environment in which no actions for reducing contamination have been undertaken.
- **Mushrooms, particularly shiitake mushrooms:** the number of communities affected by the ban has increased regularly since the new food standards have come into force. In addition, the areas concerned are more and more distant from Fukushima prefecture.
- **Certain fish (sea water and fresh water)** which have constant contamination levels and even, regularly, above the standards.

For these foodstuffs, it is advisable to be attentive to the information with regard to their source and, if applicable, the results of contamination controls. More generally, it is recommended to vary one's diet (particularly in terms of the source of food) in order to efficiently limit internal contamination through ingestion.

No limitations on the consumption or the use of tap water for the preparation and the cooking of foodstuffs is envisaged.

It is important to note that the occasional or accidental consumption of contaminated foodstuffs, even at levels slightly above the authorised standards, does not present any significant risk for health (cf. paragraph 1.2 above and appendix 2).

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Appendix 1 - Evolution of radioactive deposits and the zoning put in place around the Fukushima nuclear power plant

This appendix presents a summary of information on the evolution of radioactive deposits in Japan, two years after the Fukushima accident, and on the evolution of the status of certain parts of the evacuated areas, decided by the Japanese authorities. It has been drawn up by IRSN on the basis of technical data published in Japan and its own evaluations of the situation in the contaminated areas.

1. Updating of maps of radioactive deposits in Japan

Two years after the Fukushima accident, the residual contamination in Japan results almost exclusively from caesium 134 and 137, the half-lives[3] of which are respectively 2.1 and 30 years. Given the radioactive decay of these two radionuclides, there remains around 95% of the caesium 137 and 52% of the caesium 134 initially deposited during the Fukushima accident, whereas radionuclides of short half-life, such as iodine 131, have sharply diminished or even totally disappeared. Caesium 137 today represents 64% of the activity of residual radioactive deposits.

These residual radioactive deposits lead to the persistence of a more or less high ambient dose rate, adding to that of natural origin (telluric and cosmic).

1.1 Mapping of radioactive deposits and the ambient dose rate in Japan

Numerous measurement campaigns have been conducted in Japan since the end of March 2011 to map radioactive deposits following the Fukushima accident, particularly using airborne measurement techniques. Coordinated and organised by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT[4]), these airborne measurement campaigns have been carried out by the Japanese Atomic Energy Agency (JAEA[5]) and the Nuclear Safety Technology Centre (NUSTEC[6]), with the technical support of the US Department of Energy (US-DOE/NNSA[7]). Four campaigns were carried out in 2011, the first in April, and two in 2012, in order to specifically map out the deposits of caesium 134 and 137 as well as the resulting ambient dose rate, in a radius of 80 km around the Fukushima Daiichi nuclear power plant where the most important deposits are concentrated. Other campaigns of the same nature have also been carried out to map deposits further away from the site, in the different prefectures affected by radioactive fallout.

Furthermore, **in June-July 2011 a consortium of Japanese universities, under the coordination of JAEA, undertook to characterise the contamination of the environment in a radius of 80 km around the damaged Fukushima Daiichi power plant**, with the support of MEXT. This land based measurement campaign involved taking soil samples which were analysed in the laboratory and taking ambient dose rate measurements at 2,200 points in the environment. A second similar campaign was carried out from 13 December 2011 to 29 May 2012; apart from the technical

[3] The radioactive half-life, specific to each radionuclide, designates the time it takes for the radioactivity of the radioactive element to be reduced by half (through the phenomenon of radioactive decay). Thus, the shorter the half-life, the quicker the radionuclide considered disappears.

[4] Ministry of Education, Culture, Sports, Science and Technology

[5] Japan Atomic Energy Agency

[6] Nuclear Safety Technology Centre

[7] US Department of Energy, National Nuclear Security Administration

protocols employed during the first campaign, *in situ* gamma spectrometry measurements[8] have been carried out on a surface area of around 60,000 km^2 (1,000 points). **This second campaign took place with the participation of IRSN, which dispatched a team of seven persons in December 2011 and a team of four persons in April 2012**.

The results of these different campaigns make it possible to monitor the evolution of radioactive deposits since the accident occurred.

1.2 Comparison of maps of deposits between 2011 and 2012

The maps of figures 1 and 2 show the evolution of the deposits of caesium 134 and caesium 137 in a radius of 80 km, published by MEXT at the end of the 4th airborne measurement campaign (carried out between 22 October and 5 November 2011) and the 6th airborne measurement campaign (carried out between 31 October and 16 November 2012).

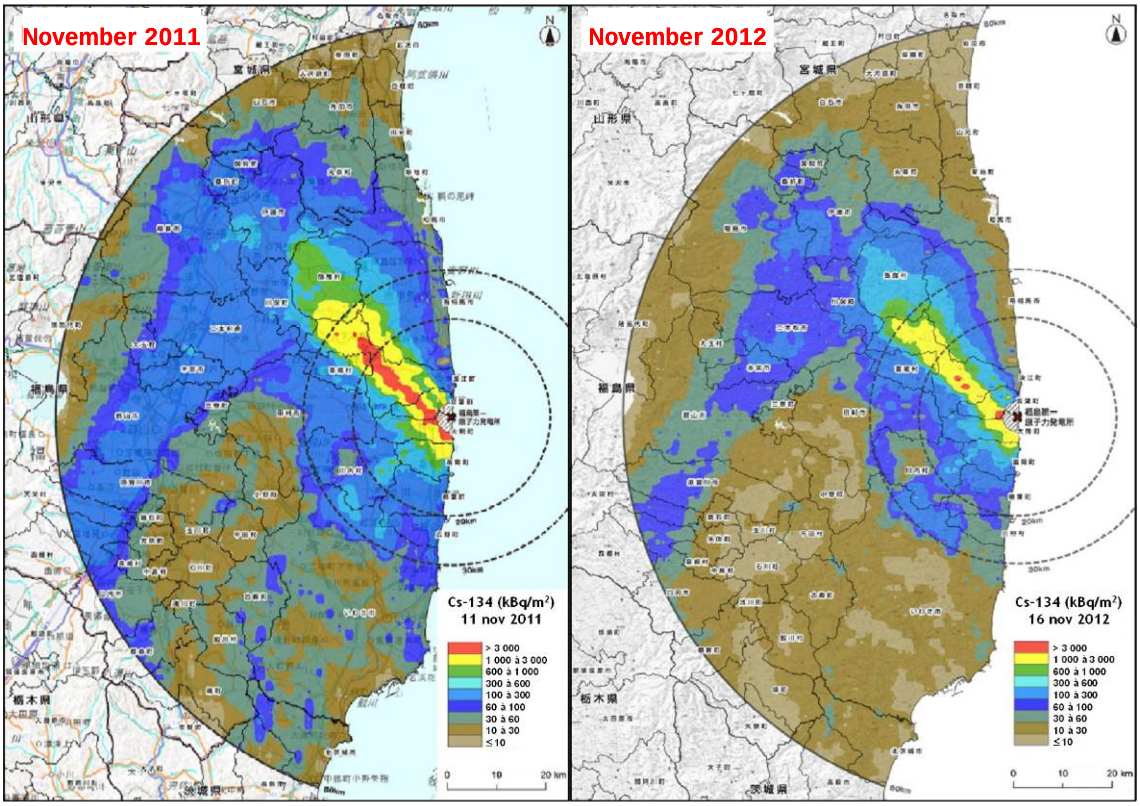

Figure 1 - Comparison of the mapping of persistent deposits of caesium 134 in November 2011 and in November 2012, obtained respectively from the 4th and 6th airborne measurement campaigns carried out under the aegis of MEXT in Japan (according to the MEXT reports of the 16th December 2011 and the 1st March 2013).

8 *In situ* gamma spectrometry is a quick method to employ since it enables the acquisition and the processing of results directly on the spot. In addition, its smooths out local heterogeneities due to the integration of a signal over an important surface area.

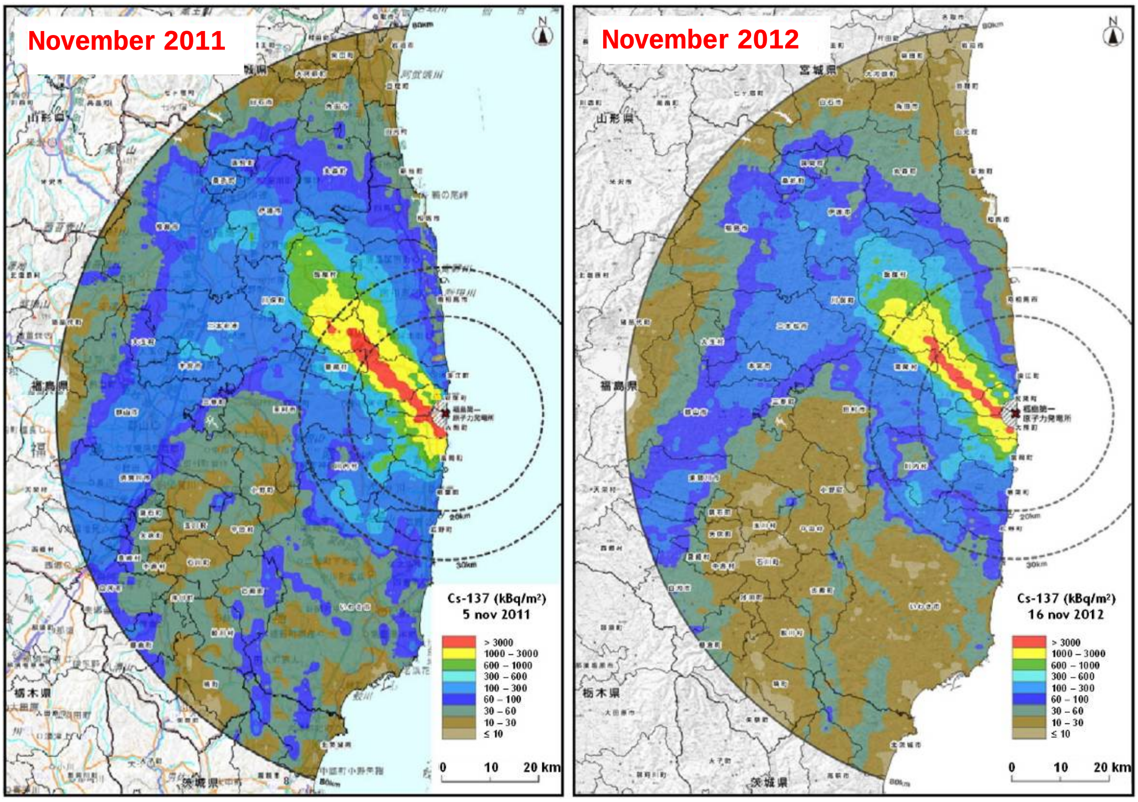

Figure 2 - Comparison of the mapping of persistent deposits of caesium 137 in November 2011 and in November 2012, obtained respectively from the 4th and 6th airborne measurement campaigns carried out under the aegis of MEXT in Japan (according to the MEXT reports of the 16th December 2011 and the 1st March 2013).

As expected, a significant reduction in the extent of the deposits of caesium 134 is observed, on account of the radioactive decay of this radionuclide (half-life of around 2 years); nevertheless, a substantial reduction, although lower, is also observed for the deposits of caesium 137, despite its insignificant radioactive decay at this timescale (less than 3% between November 2011 and November 2012).

Obviously, **this downward evolution is also reproduced on the dose rate maps for 1 m above the ground** (figure 3). According to the MEXT note published on the 1st March 2013, taking account of the 6th airborne measurement campaign, the reduction in the dose rate due to the radioactive deposits between November 2011 and November 2012 would be around 40 %, of which only 21% can be explained by the radioactive decay of the two types of caesium. According to MEXT, the rest of the reduction could be explained by the effect of run-off by meteoric water or other non-specified environmental factors.

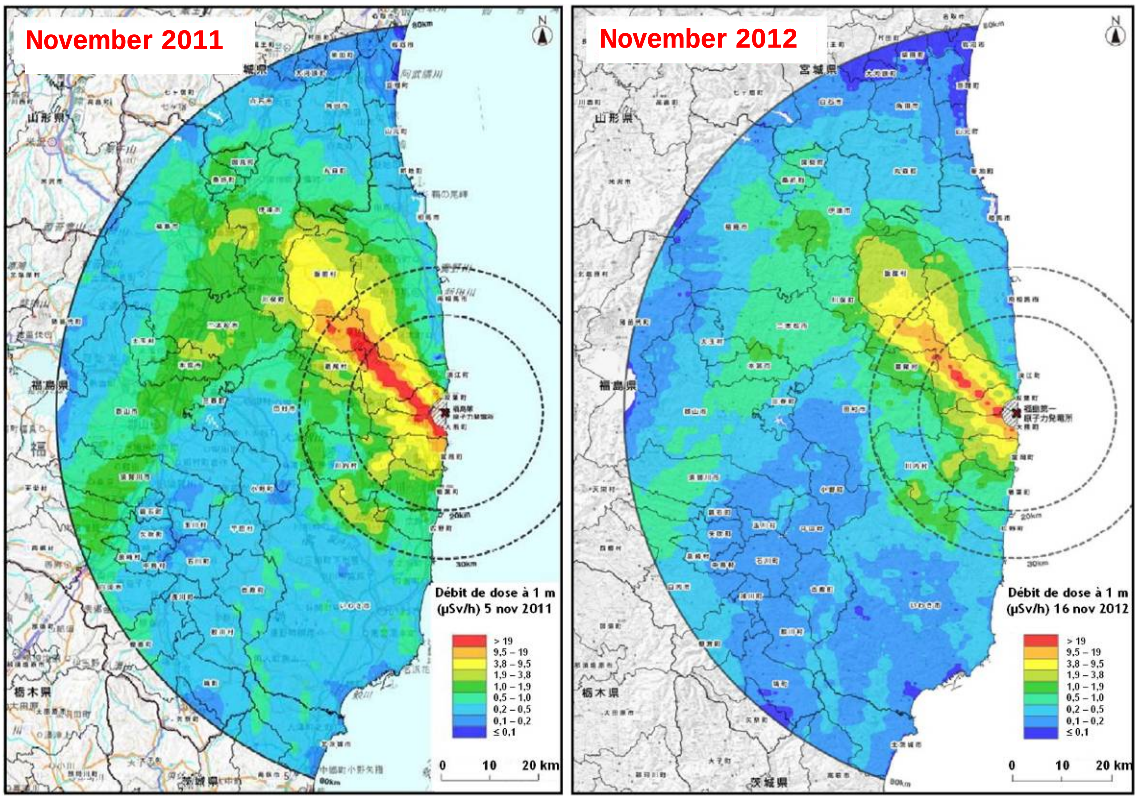

Figure 3 - Comparison of the mapping of the dose rate at 1 m above the ground in November 2011 and in November 2012, obtained respectively from the 4th and 6th airborne measurement campaigns carried out under the aegis of MEXT in Japan (according to the MEXT reports of the 16th December 2011 and the 1st March 2013).

IRSN considers that multiple mechanisms of natural origin, without doubt anthropogenic, can explain this reduction in the levels of the ambient dose rate, the extent of which varies from place to place. Apart from radioactive decay, the following mechanisms could be involved: the vertical migration of radionuclides in the ground, the erosion of the surface soil where most of the contamination is found, the processes of recycling by plants within forest systems (the impact of which in dosimetric terms may be significant), the removal of contaminated harvests and, finally, the clean-up actions initiated in Japan, mainly in farming and inhabited areas (ploughing, burying, stripping of soil, cleaning of built-up areas).

Given the conditions in which these deposit and ambient dose rate maps were established, **they only give an indication of the average level of soil deposits at the kilometre scale, but they do not allow a precise knowledge of local variations of deposits** which can result in particular from run off and the build-up of contaminated rainwater at the time of the formation of the deposits or the melting of snow that fell at that time. Only radiametric measurement campaigns carried out in the field enable such characterisations. **As an illustration, a "radiametric route" in Fukushima city is presented in appendix 3**; this route was following during an IRSN mission to the city.

2. Exposure of populations to ambient gamma radiation emitted by radioactive deposits and evolution of evacuated areas

The surface radioactive deposits continuously emit gamma radiation (radiation comparable to X rays) which is behind an ambient dose rate contributing to the external exposure of persons present in the contaminated areas. In the areas where the deposits are the highest, the Japanese authorities have designated evacuation areas to shield the population from exposure to ambient radiation. Given the improvements in the mapping of the deposits and the evolution of these deposits, as seen in the previous paragraph, the authorities have undertaken to change this zoning over the past year.

2.1 Reminder of the evacuation areas designated in 2011 by the Japanese authorities

The map of figure 4 shows the different evacuation areas designated by the Japanese authorities. The additional evacuation zone, decided on the 22 April 2011, concerns areas situated beyond the emergency evacuation zone in a radius of 20 km, where the projections of doses due to external exposure to radioactive deposits are likely to exceed 20 mSv in the year to come, according to the estimations of the Japanese authorities.

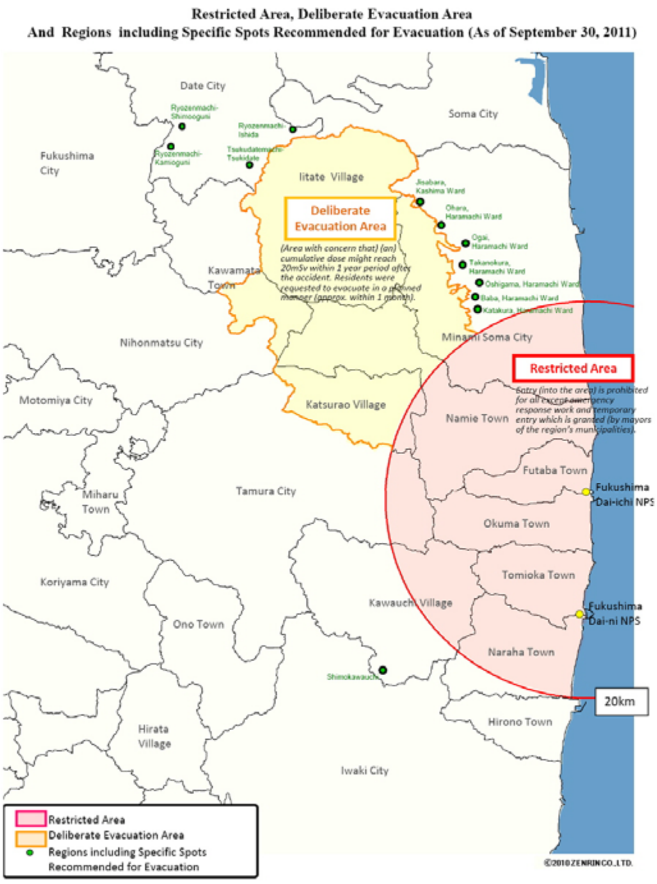

Figure 4 – Evacuation area designated by the Japanese authorities in 2011 (source METI). The restricted area corresponds to the emergency evacuation area at the time of the accident, decided as of the 12 March 2011. The deliberate evacuation area, decided on the 22 April 2011, concerns the areas where the projected annual doses due to radiation from radioactive deposits could exceed 20 mSv.

As a comparison, the map of figure 5 shows the doses potentially received by external exposure to deposits from the 15 April 2011 to the 15 April 2012, considering the case of a fictive person permanently living at the same spot over the period in question, spending 8 hours a day outside. This map was drawn up by IRSN using the dose rate data measured during the 5th airborne measurement campaign (28 June 2012) and taking account of the radioactive decay of caesium 137 and especially caesium 134. It is a theoretical estimation based on prudent hypotheses, which gives no direction indication of the doses actually received by people present in these areas.

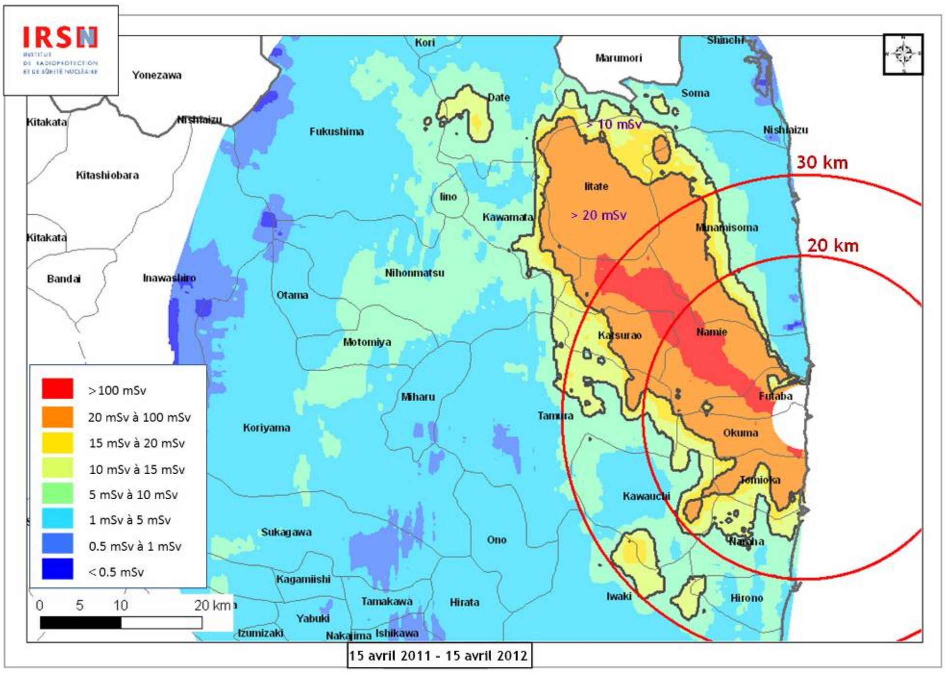

Figure 5 - Evaluation by IRSN of the dose potentially received by external exposure to ambient radiation between the 15 April 2011 and the 15 April 2012 in Fukushima prefecture.

2.2 Evolution of the zoning in the course of 2012

Thanks to better knowledge of the distribution of radioactive deposits and taking account of the progressive reduction in the doses potentially received in the contaminated areas, the Japanese authorities initiated, in April 2012, an approach leading to a progressive evolution of the status of the evacuation areas, with the perspective of the return of the population to the parts of these areas where the levels of radioactivity allow it (figure 6). Thus, the restricted access areas (in a radius of 20 km, circled in red) and deliberate evacuation area (in yellow, outside of the circle of 20 km radius) have been progressively reduced in the course of 2012. In their place, three new categories of areas, the status of which depends on the level of ambient radioactivity, have been created:

- In type 1 areas (in green), the ban on the population staying in the area has been lifted due to projected doses below 20 mSv/year. This concerns certain sectors of the municipalities of Kawauchi, Tamura, Okuma, Nahara, Minamisoma and two sectors of Iitate.
- In type 2 areas (in orange), the population is still banned from staying in the short term because the doses likely to be received in the case of permanent stay could exceed 20 mSv/year. Only occasional returns authorised and supervised by the Japanese public authorities are possible at the present time. For these zones, the Japanese authorities are aiming for the return of the population in several years.
- In type 3 areas (in pink), the staying of populations in the area in the long term is difficult to envisage since the doses are likely to exceed a value of 50 mSv/year. Only very limited

access is possible, subject to authorisation by the Japanese public authorities and the wearing of protective equipment. This concerns certain sectors of the municipalities of Minamisoma, Okuma and Iitate.

In type 1 areas, the return of the population is not yet effective. Only short stays are authorised for taking up certain professional activities again or for restoring living conditions. Furthermore, contamination reduction operations are underway in the communities concerned.

What remains of the "deliberate evacuation area" and the restricted access area should in the future be re-qualified in one or the other of the above categories.

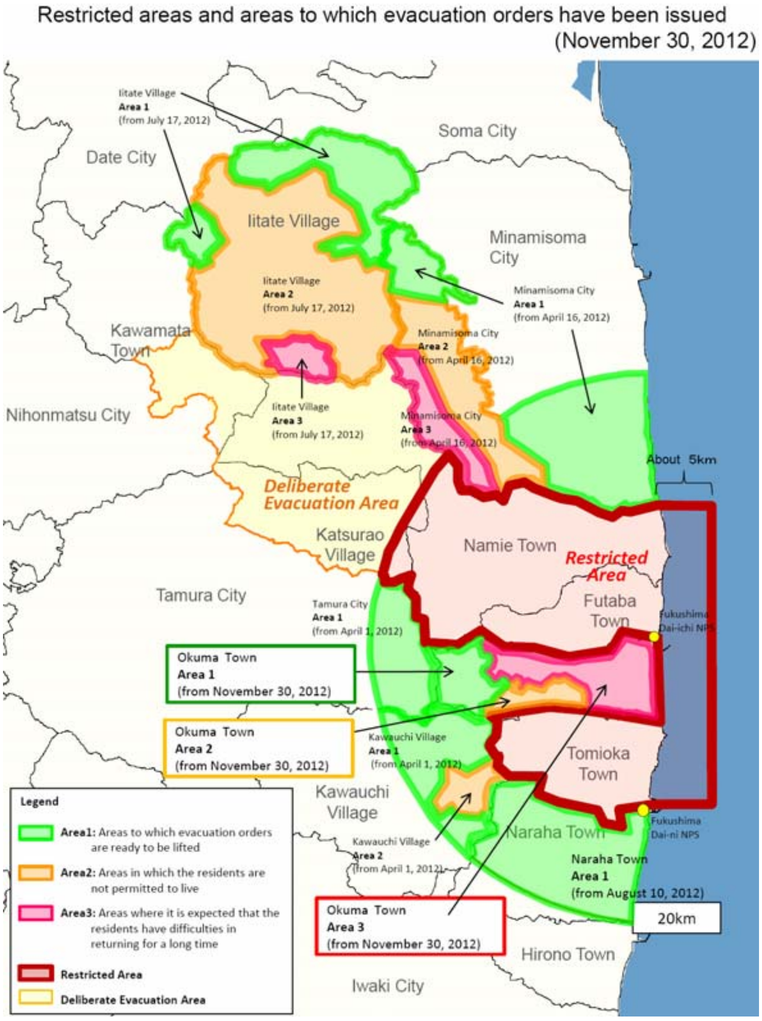

Figure 6 – Evolution of post-accident zoning in Fukushima prefecture (source METI).

As a comparison, IRSN has estimated projected doses due to the exposure to gamma radiation emitted by the radioactive deposits, for the period from the 15 April 2012 to the 15 April 2013 (figure 7). This map, drawn up with the same data and the same hypotheses as that of figure 5, takes account of the continuation of radioactive decay of caesium during this period. It shows very logically the reduction in the extent of the areas where a same dose level could theoretically be reached.

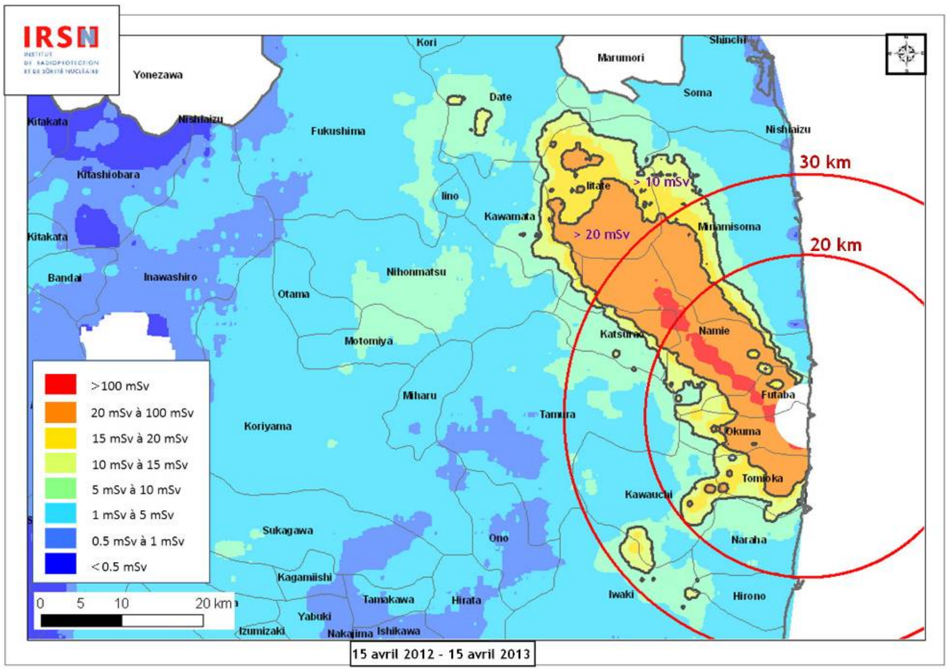

Figure 7 - Evaluation by IRSN of the dose potentially received by external exposure to ambient radiation between the 15 April 2012 and the 15 April 2013 in Fukushima prefecture.

3. Perspectives

With the progressive disappearance of caesium 134 (radioactivity halved every 2.1 years), the ambient gamma radiation in contaminated areas should continue to drop over the coming years. This reduction will be subsequently slower, on account of the longer radioactive half-life of caesium 137 (30 years).

The forecast doses estimated by IRSN and represented in the maps of figures 5 and 7 are based on prudent hypotheses concerning the time spent outside, assumed to be 8 h/d every day, and the protective effect of buildings, with a relatively low value retained. They are thus dose envelopes actually received by the populations who live in these areas, as the results of dosimetric surveillance campaigns carried out in Japan seem moreover to confirm. This situation, *a priori* more favourable than the forecasts, may also be linked to the clean-up actions in the inhabited areas undertaken by the Japanese authorities (national or local, depending on the areas concerned), even if their efficiency is entirely relative.

The question of the return of the population to part of the evacuated areas is not limited to radiation protection aspects. In fact, two years after the accident, the economic, social and even cultural conditions of such a return are the subject of debate within the populations concerned and opinion polls show that, with time, there exists an increasing uncertainty regarding a possible return in more than 50% of persons interrogated. The viewpoints seem to diverge depending on the generations, the more elderly, attached to their lands and to their traditions, being more favourable to a return. Despite the clean-up actions and the surveillance measures that make it possible to ensure a low exposure level to the ambient radioactivity, reticence and hesitations are manifesting themselves, linked to the potential risks for health, particularly the health of children, the living conditions in these areas and the long term perspectives in an environment that will remain necessarily different to that which existed before the accident.

Appendix 2 - Evolution of the contamination of foodstuffs produced in Japan and risks for consumers

This appendix presents a summary of the information collected and analysed by IRSN concerning the evolution of the contamination of foodstuffs produced in Japan and the control and restriction measures put in place by the Japanese authorities to ensure that any foodstuffs marketed are of satisfactory quality (compliance with standards). From the measurement results of the different types of foodstuffs controlled, IRSN has carried out dose evaluations for two disadvantageous consumption scenarios, in order to provide an indication of the health risk to which a potential consumer of foodstuffs contaminated by radioactive caesium could be exposed.

1. Controls of foodstuffs and restriction measures in Japan

After the Fukushima accident, which occurred in March 2011, restriction measures for the marketing and consumption of foodstuffs produced in Japan were put in place, as of the 17 March 2011, by the "*Director-General of the Nuclear Emergency Response Headquarters*" to limit the risk of exposure of the Japanese population by ingestion of contaminated foodstuffs. These restriction measures are based on controls of the radioactivity of foodstuffs produced in the prefectures affected by the radioactive fallout from the accident and on compliance with food standards (values of radionuclide concentrations for different categories of foodstuffs) defined relative to a level of exposure risk acceptable for the local population, in terms of radiation protection.

At the start of 2012, by applying an optimisation approach aiming to reduce the levels of exposure of the population to a level as low as reasonably possible, the Japanese authorities decided to apply much tighter standards than those initially set in March 2011. In fact, the contamination of the environment in the areas affected by the Fukushima accident has considerably decreased; contamination with radioactive iodine, very high during the first months, has disappeared on account of the radioactive decay of its principal isotope, iodine 131, the half-life of which is 8 days.

In coherence with the situation observed in the environment, the new standards applied as of the 1st April 2012 (cf. table 1) only refer to the radioactive isotopes of caesium. In order to put in place the transition phases between the two systems of standards, the coming into force of these new standards was staggered over 2012, depending on the foodstuffs in question.

Tableau 1 – Food standards in Japan (as regards radioactive caesium), established following the Fukushima accident and revised on the 1st April 2012.

Foodstuff group	Standards before 01/04/2012 (Bq of Cs134+137/kg)
Drinking water	200
Milk	200
Vegetables Cereals Meat, eggs, fish	500

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Foodstuff group	Standards after 01/04/2012 (Bq of Cs134+137/kg)
Drinking water	10
Milk	50
Other general foodstuffs	100
Food for unweaned infants	50

Furthermore, the Japanese authorities have put in place sales or consumption restrictions in areas where levels of contamination exceeding the standards have been recorded, as well as in fishing areas (for certain fish species) on the coasts of the prefectures of Ibaraki, Fukushima and Miyagi. In detail, the restriction areas vary as a function of the category of product and, obviously, only concern areas where there actually exits a production of the type of foodstuff considered (which explains the often discontinuous distribution of the areas concerned by the restrictions; cf. figure 8). These restriction areas may be extended for foodstuffs particularly sensitive to contamination by caesium (such as for example the meat of game animals, certain wild plants and mushrooms). With the tightening of the standards on 1st April 2012, the areas concerned by sales restrictions have tended to become more extended. Communities having seen their restrictions lifted are not very numerous; they mainly involve communities forming part of the prefectures of Chiba, Tochigi, Ibaraki, Kanagawa and Gunma, as regard tea leaves, and Miyagi, Fukushima, Ibaraki and Aomori for various species of fish. As an illustration, the maps of figure 8 show the areas concerned by restrictions for two categories of foodstuffs particularly sensitive to contamination (koshiabura shoots and wild boar meat).

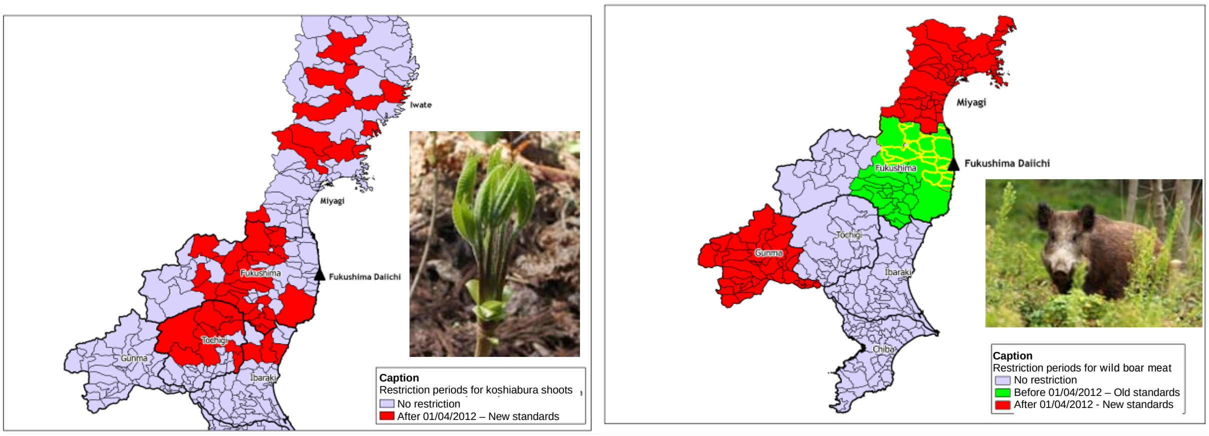
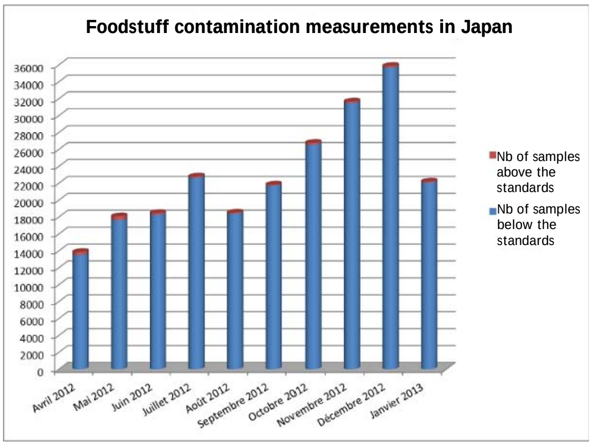


Figure 8 – Maps of areas where sales restrictions have been introduced for two categories of foodstuffs: koshiabura shoots (left) and wild boar meat (right). The areas newly concerned following the tightening of the standards of 1st April 2012 are in red. Those which were already affected by restrictions before this date are in green. The municipalities where local consumption restrictions are in force are circled in yellow.

2. Review of the contamination of Japanese foodstuffs and cases of the new standards of the 1st April 2012 being exceeded

Since April 2012 (the date the standards applicable to foodstuffs in Japan were changed) and up to end March 2013, i.e. in the course of the 2nd year following the accident, the Japanese Ministry for Health (MHLW) has published on its website the results of measurements of 280,000 samples of foodstuffs coming from all the prefectures of Japan. It mainly, but not uniquely, involves foodstuffs from farming, particularly 32,000 samples of rice and 172,000 samples of beef. According to the available information, it seems that the surveillance carried out by the Japanese authorities is not based on a strictly defined plan concerning the type of foodstuffs to be controlled or instead the locations that need to be monitored as a priority. It is thus necessary to retain a certain prudence regarding the comparison of the different results obtained over time. In fact, the measured foodstuffs are not always the same from one month to the next and the samplings are not always located at the same spots (the number of sampling points in the communities depends on the type of foodstuff and the measurement results obtained previously).



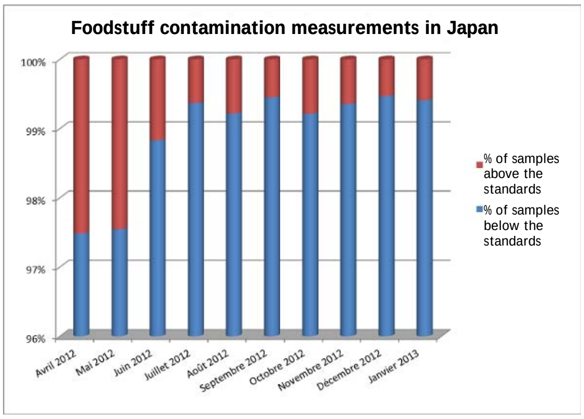


Figure 9 - Statistics, from April 2012 to January 2013, of contamination measurements including all types of foodstuffs, in Japan, following the Fukushima accident of the 11 March 2011.

Only 23,000 out of the 280,000 samples controlled from April 2012 to the end of March 2013, i.e. less than 10%, had a caesium 134 and 137 contamination exceeding the detection limit of the measurement equipment used. This signifies that for the other samples, radioactive caesium was either absent or present in too small quantities to be quantifiable.

The sales standard of 100 Bq/kg wet weight of caesium (134+137), in force since the 1st April 2012 for most solid foodstuffs, was only exceeded for 2,300 samples, i.e. 0.8% of the 280,000 samples analysed. The level of overshoot has dropped over time: it was 3% in April 2012, following the tightening of the standards, then stabilised at 0.65% monthly from the end of 2012. This percentage of overshoot obviously varies on the country scale. It is zero in the majority of the 47 prefectures of Japan, whereas it is 4% for Fukushima prefecture, in which are found the areas the most affected by the radioactive deposits of March 2011.

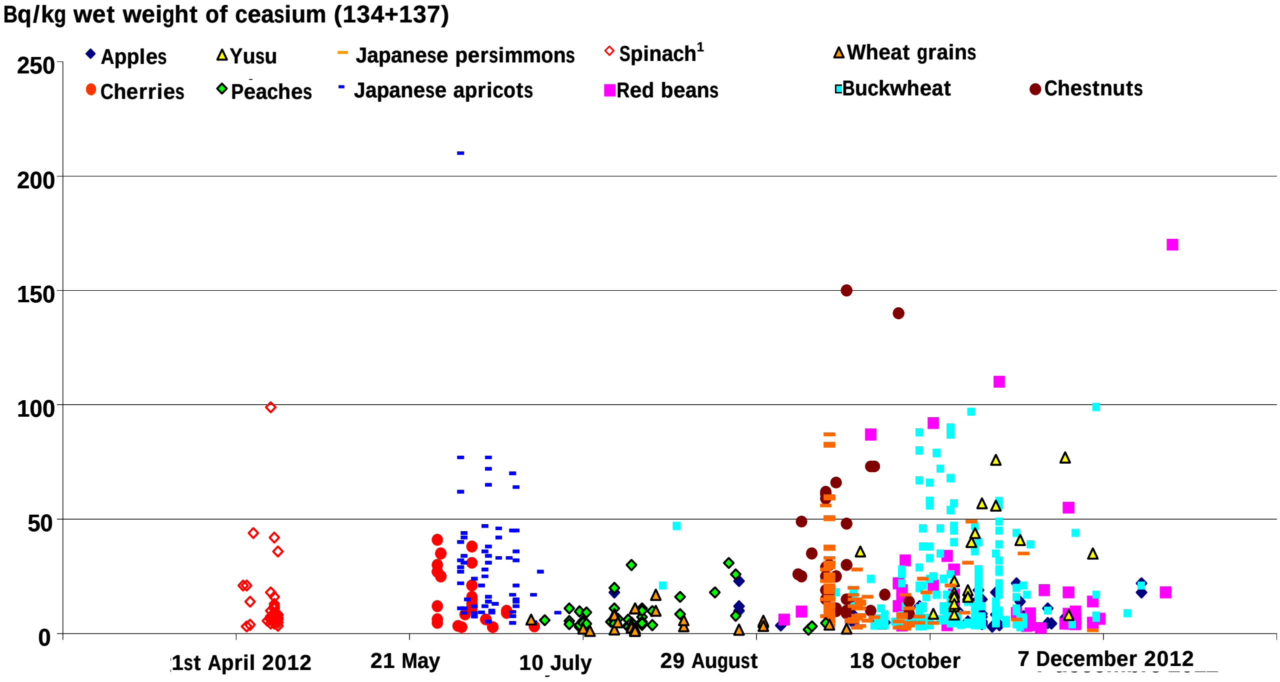
Finally, 172 out of the 280,000 samples measured between April 2012 and March 2013 had a contamination in caesium (134+137) above 1,000 Bq/kg wet weight (10 times the standard), i.e. 0.06% of the 280,000 analysed. These mainly involve products from hunting, gathering and fishing: 108 wild game meat (of which 106 wild boar), 19 fish, 16 mushrooms (mainly wild), 11 mainly wild plant shoots and plants (aralia, bamboo, koshiabura, ferns, etc.).

2.1 Situation of crop agricultural productions

For crop agricultural productions, the number of samples analysed has increased over time, reflecting a progressive reinforcement in the control measures, given the results already obtained and the tightening of food standards. It attained its maximum in the autumn of 2012 and dropped sharply between November 2012 and January 2013, due perhaps to the season (winter).

Generally speaking, the monthly rate of overshoot of the standards for crop foodstuffs has considerably decreased, reaching an average value of 0.6% at the end of 2012.

As an illustration, the graph of figure 10 shows the concentrations of radioactive caesium measured in 2012 in various agricultural foodstuffs produced in Fukushima prefecture. Cases of exceeding the standard of 100 Bq/kg are not very frequent and the values attained in these cases remain moderate in comparison with what was observed in March -April 2011.



(1) This graph does not include a singular value (520 Bq/kg) attributed to a sample of spinach, which clearly stands apart from the other values measured in this type of foodstuff. Although this result corresponds to a reality and does not result from an analysis or data recovery error, it is difficult to explain.

Figure 10 – Mass concentrations of radioactive caesium (Cs-134 and Cs-137) measured in 2012 in various agricultural foodstuffs produced in Fukushima prefecture.

- ## Case of rice and other cereals

Out of 32,000 analyses of samples of **rice**, 2,200 showed values of contamination above the detection limits (7%) and 120 (0.4%) reached or exceeded 100 Bq/kg. The levels of caesium contamination of rice are higher than those of the other cereals. This stems from the fact that the growing of rice requires the flooding of paddy fields. Thus, apart from absorption through the roots, caesium can be transferred to the plant via irrigation water, itself contaminated by the soil. **Other cereals** such as wheat and barley have caesium levels generally below those of rice, not exceeding 10 Bq/kg wet weight.

Apart from cereals in the strict sense, the case of **soy beans** merits particular attention: out of 3,400 analyses, 1,400 showed caesium levels above the detection limits, i.e. 40%, and 20 (0.5%) of them exceeded the sales limit of 100 Bq/kg.

- ## Case of bamboo shoots and other wild shoots

Certain samples of bamboo shoots continued in 2012 to show caesium levels above the sales standard (figure 11). Thus, 25% of the 366 samples of bamboo shoots analysed between April and June 2012 had caesium levels exceeding the detection limits and 7 of them (i.e. 1.9%) exceeded the sales limit of 300 Bq/kg wet weight. The persistence of significant contamination in these foodstuffs is explained by the capture of radioactive fallout by the leaves at the time of the accident; the caesium intercepted in this way has remained in the plant and some of it has then been transferred into the new shoots in 2011 as well as in 2012. The case of bamboo shoots should be considered with that of other wild plant shoots that are consumed whose leaves also intercepted the radioactive deposits of March 2011: Aralia and Koshiabura shoots, fiddleheads (up to 1 100 Bq/wet weight measured in 2012 in a fiddlehead).

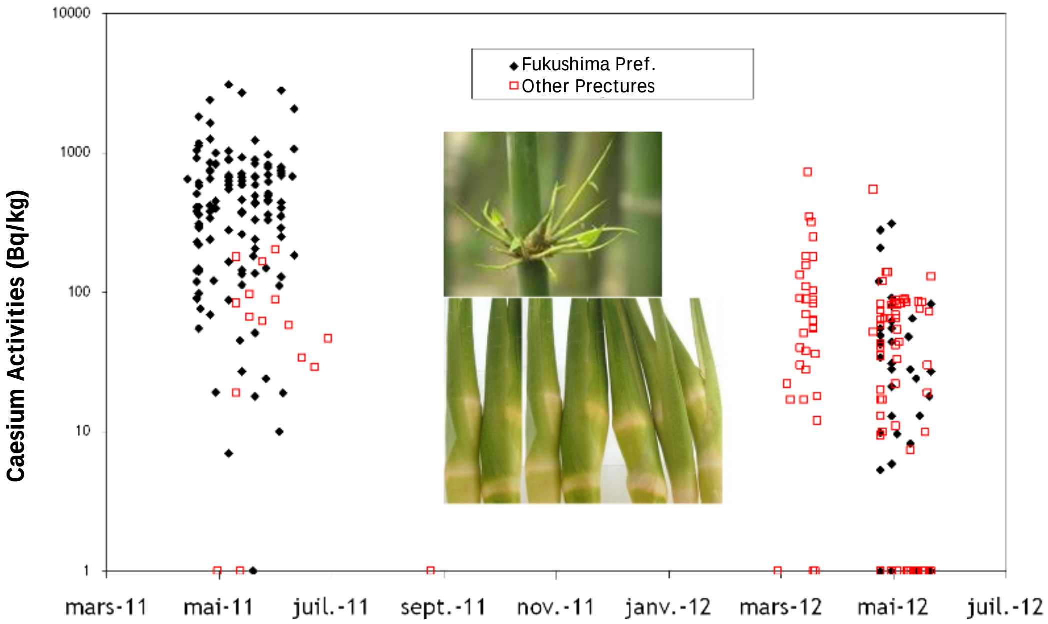


Figure 11 – Mass concentrations of radioactive caesium (Cs-134 and Cs-137) in bamboo shoots between March 2011 and May 2012 (source: MHLW, 2013). By convention, the values are expressed on the basis of wet weight and the non-detectable values are represented at 1 Bq/kg wet weight.

- ## Case of mushrooms

The contamination of mushrooms with radioactive caesium is practically identical to that observed in 2011, and can attain several tens of thousands of Bq/kg (31,000 Bq/kg wet weight in a wild mushroom gathered in August 2012 in Tochigi prefecture). Consequently, mushrooms constitute the category of foodstuff that most frequently exceeds the standard of 100 Bq/kg, which came into force on the 1st April 2012. The tightening of this standard has also had the effect of widening the spread of the areas concerned by restrictions of sales of shiitake mushrooms and wild mushrooms, including in distant prefectures (Nagano, Saitama, Shizuoka, etc.).

- ## Case of fruits

Japanese apricots, persimmons and yusu harvested in 2012 in the Fukushima prefecture showed levels of contamination around 10 times lower than those observed in 2011. Generally speaking, the radioactive caesium levels of fruit from this prefecture did not exceed 50 Bq/kg wet weight, with several rare exceptions. Those of fruits from other prefectures only exceptionally exceeded the detection limits of the measurement instruments. This low level of contamination of fruits can be explained by the effect of the date of the accident, at the end of winter, whereas the leaves of trees had still not developed[9]. These circumstances have made it possible to relatively spare the first harvest of fruit productions, in 2011, and, by a moderate contamination of the trees, sparing the following harvests.

[9] The presence of leaves in abundance favours the capture of radioactive fallout by trees. The radioactive substance intercepted in this way can then be transferred to the rest of the plant, particularly in the reserve tissues, then at a later stage in the fruits when they are formed.

2.2 Situation of foodstuffs of animal origin

- **Meat from livestock and milk**

The current practice in Japan of importing fodder, with well-established supply lines, reinforced by the caesium contamination limit set for fodder, have made it possible to control the contamination of foodstuffs coming from farmed animals, such as milk and meat. Thus, out of 132,600 analyses carried out on beef between April 2012 and end January 2013, only 600, i.e. 0.5%, had caesium 134+137 levels above the detection limits. The caesium levels of other types of meat (pork, poultry, horse, etc.) only very rarely exceed 10 Bq/kg wet weight (one 10th of the standard). The contamination of milk is still very low; out of 3,410 analyses of cow milk, only 140 showed caesium 134+137 levels above 0.5 Bq/L (one 100th of the standard set at 50 Bq/L for milk) and all were less than 12 Bq/L.

- **Meat from wild game**

The Japanese Ministry for Health (MHLW) has published numerous results of analyses of wild game meat. Wild boar meat in particular attains very high caesium concentration levels (figure 12; see also figure 8, concerning the restriction areas).

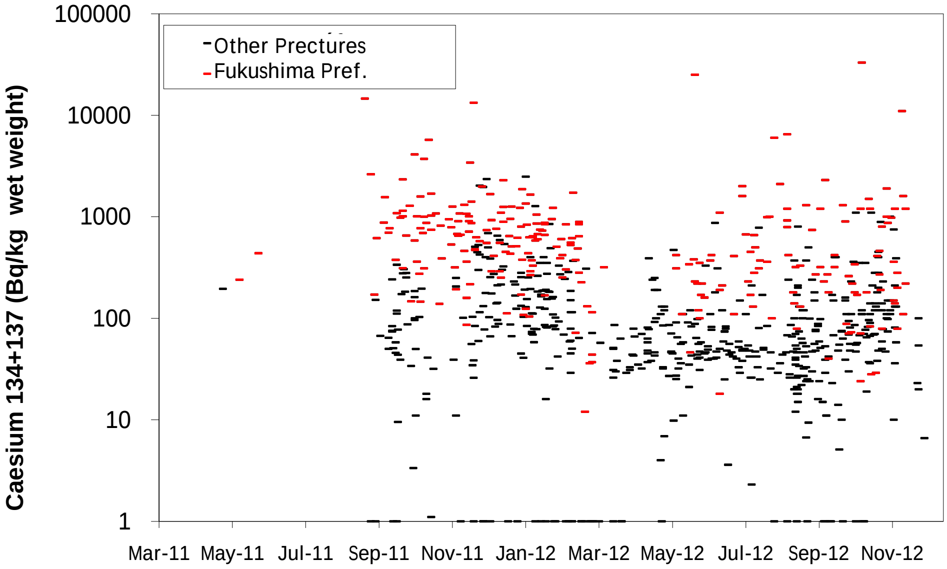


Figure 12 – Mass concentrations of radioactive caesium (Cs-134 and Cs-137) in the meat of wild boar hunted in different prefectures in 2011 and 2012 (source: MHLW, 2013). By convention, the values are expressed on the basis of the wet weight and non-detectable values are represented at 1 Bq/kg wet weight.

Out of all of the meat analysed in the second half of 2012, the maximum activity in caesium was attained for a wild boar hunted in October 2012 in Iwaki (Fukushima prefecture): 20,700 Bq/kg wet weight of caesium 137, 12,300 Bq/kg wet weight of caesium 134, i.e. a total of 33,000 Bq/kg. In March 2013, there was a particular sampling effort for wild boar meat in Fukushima prefecture, with 95 samplings, of which only 2 had caesium mass activities below 100 Bq/kg, whereas 5, all hunted in Minamisoma, exceeded 20,000 Bq/kg of caesium, including a maximum value of 61,000 Bq/kg.

The meat from other wild animal species attained less high maximum levels but remained well above those of other types of foodstuffs:

- spot-billed duck: maximum activity of 4,000 Bq/kg wet weight in $^{134+137}Cs$;
- bear: maximum activity of 1,100 Bq/kg wet weight in $^{134+137}Cs$;
- red deer: maximum activity of 800 Bq/kg wet weight in $^{134+137}Cs$;
- pheasant: maximum activity of 500 Bq/kg wet weight in $^{134+137}Cs$.

- **Products from fishing**

As regards seafood, only species living near to the sediments around the Fukushima nuclear power plant are still very regularly exceeding the sales standard (figure 13). These are in particular greenlings, halibut, rosefish and gurnard. Fish less closely linked to sediments, such as mackerel, sardines, chinchards, as well as molluscs, now show levels of contamination usually below the standard.

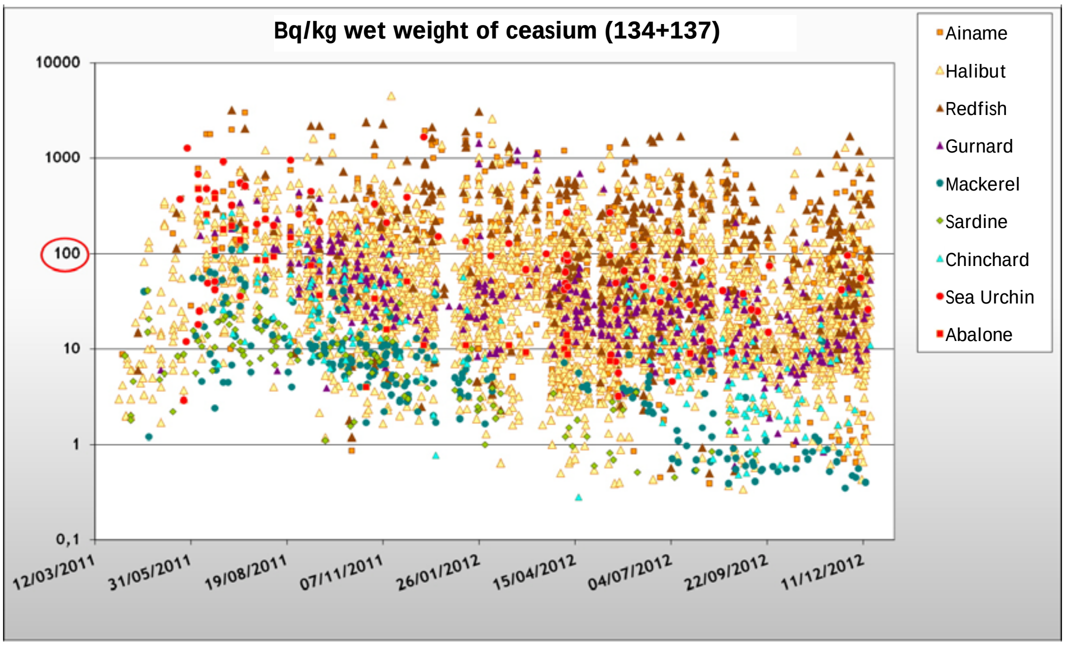


Figure 13 – Evolution over time of radioactive caesium concentrations (Bq.kg^{-1} wet weight of ^{137}Cs+^{134}Cs) in some products from the sea between the 1st April 2011 and the 20th December 2012.

NB: Since the 28 March 2012, TEPCO has implemented a strategy for sampling marine species in the environment near to the Fukushima nuclear power plant. Consequently, in October and December 2012, fish were captured in the port of the power plant, around a point known as "Shallow draft quay". The caesium (137+134) activities in them were very high: from several tens to several hundreds of thousands of Bq/kg wet weight, with a maximum activity observed in a species of rosefish of 254,000 Bq.kg^{-1} wet weight. These activities are linked to the very high level of contamination present in the port of the Fukushima nuclear power plant and in particular to the contamination of sediments for this benthic species (which lives near to sediments).

Concerning freshwater species, nearly 4,000 samplings were made between March 2011 and December 2012 and the results have been made available on official Japanese sites. Among the different species sampled in lakes or rivers, 6 show higher levels of contamination and are subject to regular monitoring (figure 14). They involve big scaled redfin (*Tribolodon hakonensis*), white spotted char (*Salvelinus leucomaenis*), sweetfish (*Plecoglossus altivelis*), masu salmon (*Oncorhynchus masou*), Pacific red salmon (*Oncorhynchus nerka*) and wakasagi (*Hypomesus nipponensis*). Apart from the redfin, all of the other species are species characterised as amphihaline (species that migrate between freshwater and sea water). The variability of the results is important, due to the diversity of the fishing spots. The most contaminated samples were all caught in rivers and lakes in the prefectures of Fukushima, Gunma and Tochigi. The highest caesium concentration (18,700 Bq.kg^{-1} wet weight) was recorded near to the village of Iitate-Mura, in Fukushima prefecture, on the 18 March 2012.

Several other freshwater species have been the subject of more or less regular monitoring, such as species of shrimps, carp, river barbell and trout. Usually caesium is detected in these species at levels below 200 Bq kg^{-1} wet weight (^{137}Cs+^{134}Cs).

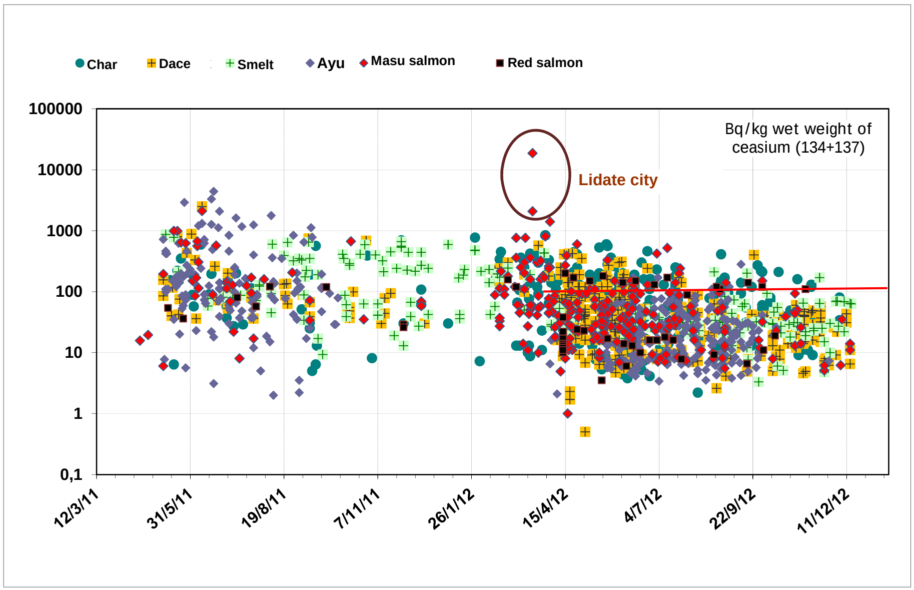


Figure 14 – Mass concentrations of radioactive caesium (Cs-134 and Cs-137) measured in 6 species of fish caught in rivers or lakes in different prefectures. The red line indicates the food standard (100 Bq.kg^{-1} wet weight) in force since the 1st April 2012.

3. Health risk vis-à-vis the consumption of foodstuffs produced in Japan

To estimate the health risk for consumers of foodstuffs produced in Japan, IRSN has evaluated the theoretical doses that a person who consumed foodstuffs contaminated by radioactive caesium could receive, taking account of the measurement results published over the previous year and the restrictions put in place in Japan. To do this, several major scenarios were considered.

The first concerns the case of a person who permanently consumes foodstuffs in which the concentration in caesium lies just below the standard of 100 Bq/kg applicable in Japan. The annual dose received would be around 1 mSv/year.

Given the results of the measurements obtained in Japan within the context of food surveillance, a summary of which was presented in the previous chapter, such a dose, although low[10], has little chance of having been reached over the past year. In fact, less than 10% of the foodstuffs controlled in 2012 had concentrations of radioactive caesium exceeding the detection limits of the measurement equipment used, which ranged from 1 to 50 Bq/kg. In these conditions, the maximum dose likely to have been received by consumers in Japan probably did not exceed 0.1 mSv/year.

The second scenario concerns the case of an individual who consumes one kilogramme of a foodstuff in which the concentration in caesium corresponds to the highest value measured in 2012 for the

[10] As a comparison, in France, the regulatory annual dose limit for the public likely to be exposed to ionising radiation due to authorised nuclear activities, within the scope of their normal operations, is set at 1 mSv/year. This limit does not apply to doses received due to natural radioactivity, which are on average 2.4 mSv/year and can exceed 5 mSv/year in regions at altitude or in areas with high radon levels, nor does it include doses received during medical interventions using ionising radiation, which is on average 1.3 mSv/year.

category of foodstuff considered. One thus makes the hypothesis that the foodstuff consumed has been inadvertently marketed (for example due to insufficient controls) or was harvested directly by its consumer (case of mushrooms or wild game, in particular). Table 2 hereafter provides an estimation of the corresponding doses for the different categories considered.

Tableau 2 – Estimation of the effective dose for a consumer eating 1 kg of the different foodstuffs in which the concentration of caesium would be equal to the highest value measured for each of them between April 2012 and January 2013.

Foodstuff	Bq/kg	mSv/kg ingested
Beef	518	0.008
Japanese apricots	210	0.003
Rice	360	0.005
Reds beans	170	0.003
Bamboo shoots	550	0.008
Chestnuts	410	0.006
Soy beans	530	0.008
Mushrooms	31 000	0.46
Wild boar meat	33 000	0.49
Fish	1 800	0.026

As expected, it is the consumption of mushrooms or wild boar meat that would lead to the highest doses, while remaining low in absolute terms. Even by consuming 1 kg of all these foodstuffs, the dose received would be around 1 mSv.

These two extreme scenarios make it possible to conclude that in regularly consuming foodstuffs commercialised in Japan, in other words having levels below the authorised standard, the doses received would be low. The same would be true in the case of the exceptional consumption of foodstuffs with the highest level of contamination likely to be found in Japan.

These evaluations are consistent with the conclusions of a recent study carried out by a team from Tokyo University[11], on the basis of more than 30,000 anthroporadiametric measurements carried out at the Hirata central hospital of Fukushima between October 2011 and November 2012 on residents of Fukushima city. These measurements have shown that the levels of body contamination measured were lower than those estimated in a theoretical manner from deposition maps, and in particular for children. Out of the 30,000 persons controlled, only several elder residents who regularly consumed local products had a higher contamination, for which a dose of around 1 mSv has been estimated.

Thus, given the evolution of caesium concentration levels in foodstuffs in 2012 and the surveillance and restrictions measures put in place by the authorities in Japan, the health risk for consumers of foodstuffs distributed in Japan may be considered as very low.

[11] Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter surveys. HAYANO et al. Proc. Jpn. Acad., Ser. B 89 (2013)

4. Perspectives

Given the persistence of radioactive caesium in the environment (in the ground and in sediments), the continuation of regular surveillance of foodstuffs produced in Japan and the maintaining of sales or consumption restrictions in the most impacted areas are necessary. Even though contamination has sharply decreased since 2011 for most foodstuffs, justifying the tightening of standards since April 2012, the presence of caesium in certain categories of foodstuffs should continue to be observed in the years to come, with a slow reduction in the levels measured in these products. This concerns in particular wild products, gathered on land or marine areas where there are contaminated deposits or sediments: mushrooms, wild game, plant shoots, certain species of fish, etc.

Whatever the case, if the restriction and control measures put in place in Japan are maintained, the health risks for consumers will continue to be very low, even in the case of occasional consumption of foodstuffs exceeding the consumption standards.

Appendix 3 – Radiametric route travelled by IRSN in Fukushima city

Below are several observations made by IRSN on the 27 February 2013 in the course of a route travelled by foot in Fukushima city, with a radiation meter (FH-40 G-L). This journey makes it possible to illustrate the variations in radioactive deposits at a local scale, to explain the reasons for this and to measure the impact in terms of ambient dose rate. The instrument used measures the dose rate due to gamma radiation emitted by deposits of radioactive caesium (and radioactivity of natural, telluric or cosmic origin); the dose rate is expressed in nanosieverts per hour (nSv/h) or in microsieverts per hour (µSv/h ; 1 µSv/h = 1 000 nSv/h). In a given place, the measured dose rate depends on the extent of the radioactive deposits in the near environment and the distance between the detector and the radiation emission source, as well as any screens between the source and the instrument (case of building materials when one is inside a building).

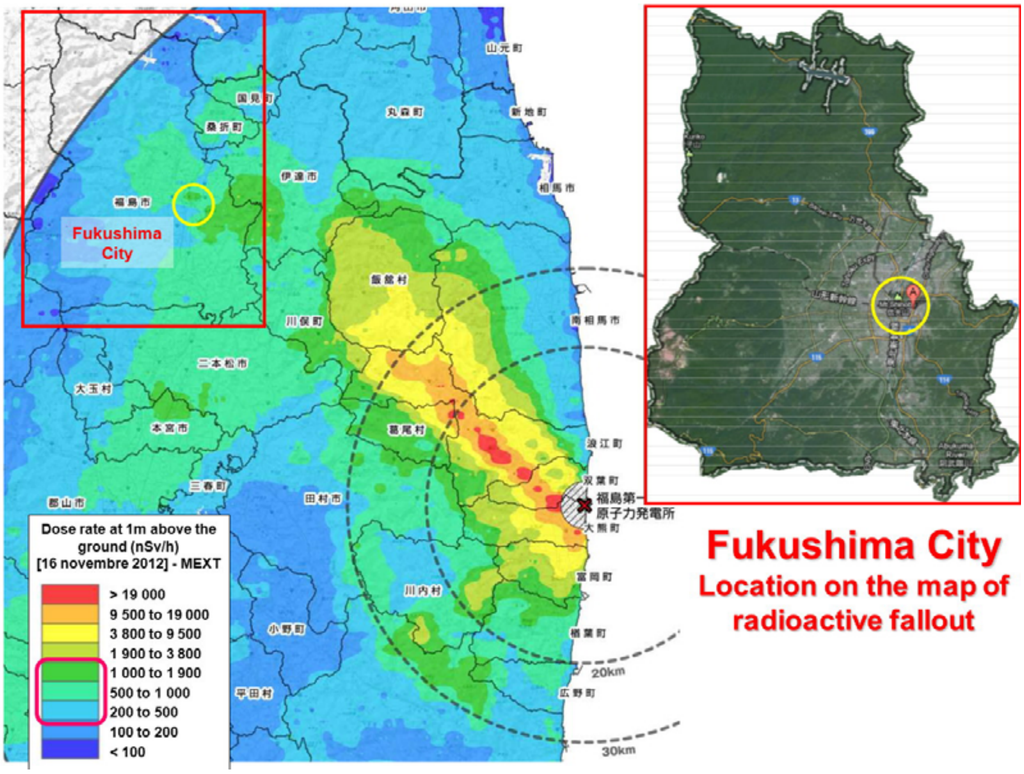
When one places the instrument in contact with the ground, the measurement obtained makes it possible to characterise the intensity of the radioactive source but it is not representative of the exposure of individuals, except in the particular case of a person lying down or seated in contact with the measured surface. This type of measurement makes it possible in particular to search for any “hot spots”, in places where radioactive deposits are the most concentrated.

When the instrument is placed at 1 metre above the ground, an ambient dose rate is measured that is representative of the average exposure of a person situated at the same spot. Obviously, the dose received by this person depends on the exposure time to this ambient dose rate; it can be measured using a dosimeter worn permanently, if possible at chest height (for example in a jacket pocket), which records the dose accumulated throughout the period the dosimeter is worn. As an illustration, the graph presented at the end of this appendix shows the evolution of the cumulative dose during a mission in Japan, recorded by an active dosimeter initialised in France, before leaving for Japan, and analysed after the return from Japan, at the end of the mission.

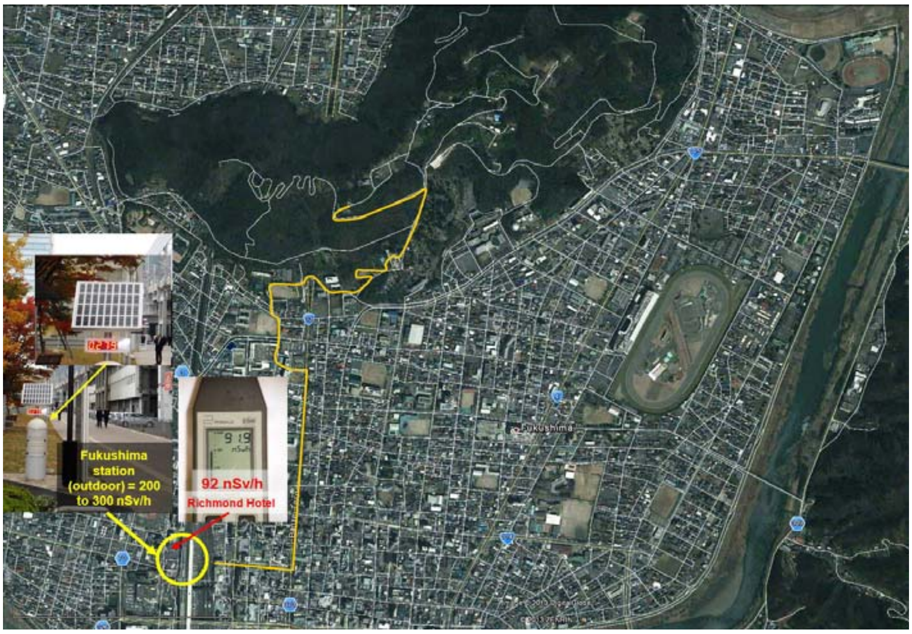
1. General localisation on the map of radioactive deposits in Japan.

The map below locates Fukushima city (in the yellow circle) on the dose rate map on the 16 November 2012, published by MEXT on the 1st March 2013. According to this map, the dose rate values in this sector range from 200 to 1,900 nSv/h, and the persistent deposits of caesium 134 and 137 causing this radiation are between 100,000 and 600,000 Bq/m².

As a comparison, the ambient dose rate in Japan in areas not affected by fallout from the Fukushima accident is around 50 nSv/h. In France, the average dose rate is around 90 nSv/h; it varies as a function of the geological nature of the underlying terrains (influence of telluric radiation) and the altitude (influence of cosmic radiation): from below 60 nSv/h in the plains of sedimentary basins to above 200 nSv/h in mountainous areas or on granitic terrains (300 nSv/h at the summit of the Pic du Midi, at an altitude of 2,877 m).



2. Overview of the route taken and dose rate at the starting point



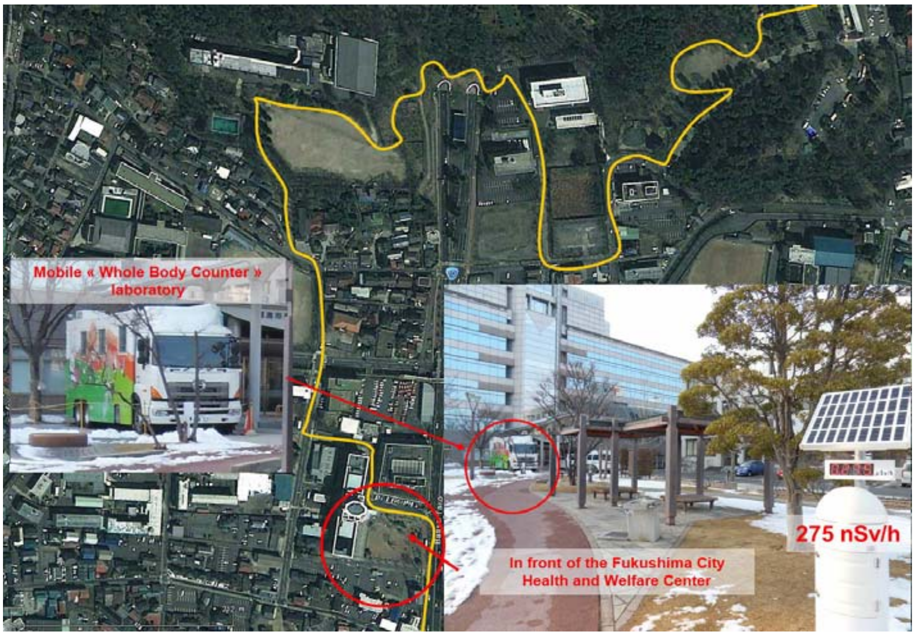
The route (yellow line in the plan above) follows partly an urban area then a wooded hill overlooking the city. The starting point was Fukushima station (yellow circle). Near to the station, a fixed measurement unit installed after the accident indicated a value between 200 and 300 nSv/h (which fluctuates from one day to the next).

Inside a building near to the station, the measured dose rate was around 90 nSv/h, in other words 3 to 4 times less than outside. This shows the protective effect of the walls of the building, but the measured value is indicative: the measurements are at the lower limit of the measuring range of the radiation meter used and the radiation measured in the building stems both from the exterior radiation, attenuated by the construction materials of the building, and the radiation emitted by the latter which can be naturally radioactive. Whatever the case, the dose rate measured inside the building is of the same order of magnitude as that measured in a house in the Île-de-France.

3. Observations in the built up part of the route

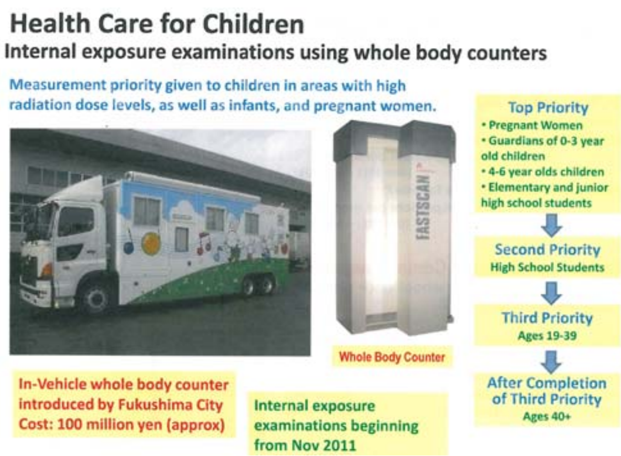
The first part of the journey was in a built-up area, characterised by hard surfaces (walls of buildings, roofs, tarred roads, etc.) on flat terrain.

❶ The first point observed was in front of the Fukushima City Health and Welfare Center.



At this spot there was a fixed measuring unit which indicated a dose rate (275 nSv/h), similar to the dose rate measured near to the station.

In front of the building was parked a decorated lorry, which is a mobile anthroporadiametric measurement laboratory acquired by Fukushima municipality and in service since November 2011 to control the body load in gamma emitting radionuclides (in practice: caesium 134 and 137) in children. The slide below supplied by the Risk Management Bureau of Fukushima city explains the characteristics and use of this laboratory.



❷ At several hundreds of metres from there was a place with a square for children, also equipped with a fixed unit for measuring ambient gamma radiation.

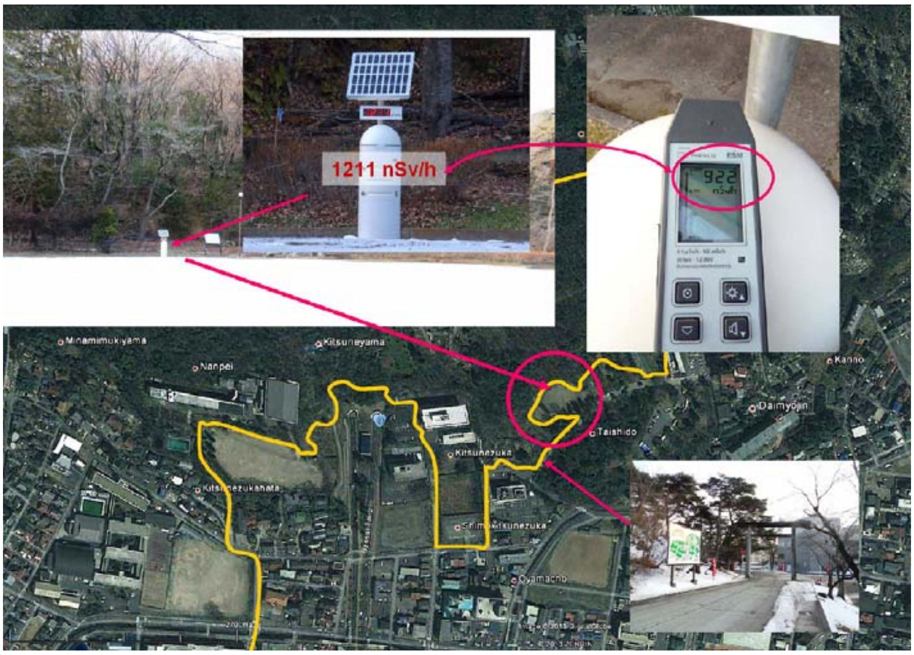
The dose rate here was slightly lower, at 220 nSv/h (effect of cleaning? attenuation of the radiation by the snow?). A measurement taken with the radiation meter laid on a bench near to the unit gave a very similar value.

4. Observations on the wooded hill

❸ The first observation was made in a wooded area at the foot of the hill, near to a secondary school (on the left of the red circle in the plan below).

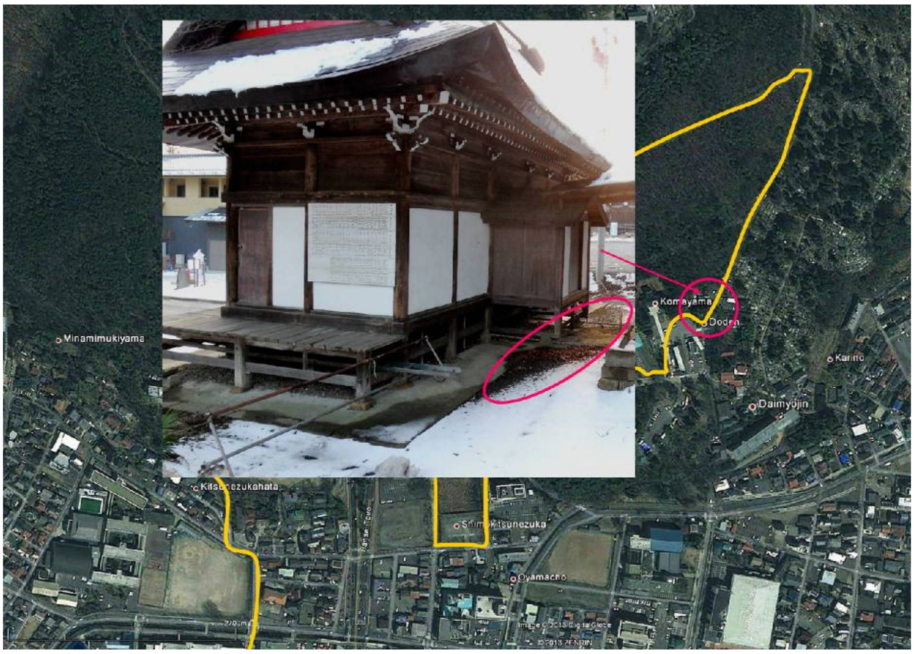
The measurement with the radiation meter set down on the forest bedding gave a value exceeding 1,000 nSv/h. The measurement taken at the same place around 1 m above the ground gave a very slightly lower value of 800 nSv/h. In the present case, the ambient dose rate representative of the exposure of a person (1 m height, i.e. around the centre of the human body) results from an extended source of contamination (ground, trees, reliefs, etc.) and the exposure gradient is low when the instrument is moved away from the surface of the ground.

❹ Further on there was an entrance to a wooded park, which covers the hill dominating the city. A cleared esplanade at the foot of the wooded slope is equipped with a fixed measuring unit indicating an ambient dose rate exceeding 1,200 nSv/h (the radiation meter indicated a lower value around 900 nSv/h).

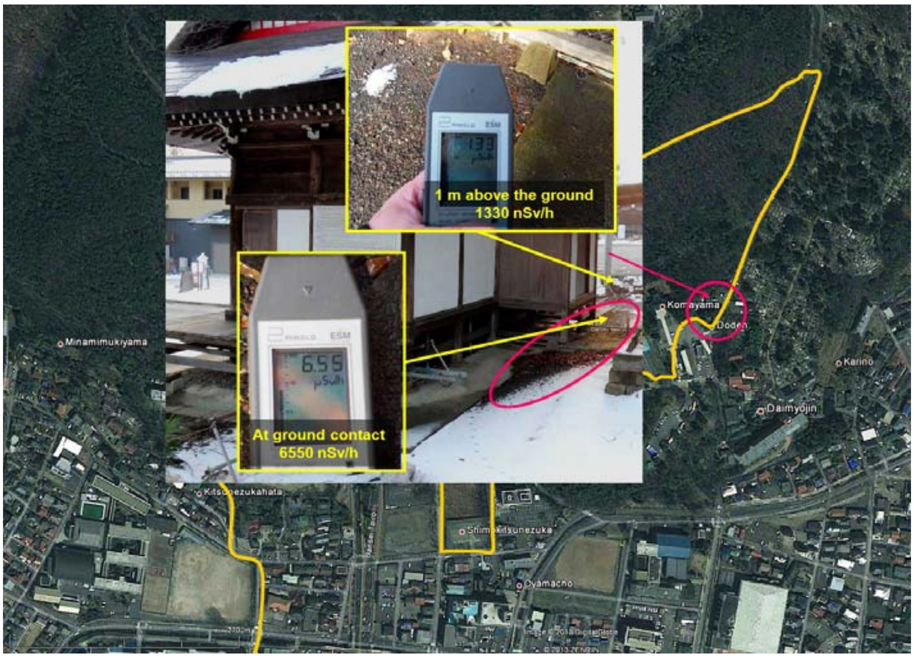


This higher ambient radioactivity is probably explained by the accumulation of caesium at the foot of the slope and on the esplanade, caused by the flow of rainwater from adjacent terrains, at the time when the radioactive deposit was formed, or at a later stage.

❺ The next observation point enables the phenomenon of "hot spot" to be illustrated. The image below shows an area for draining water from the roof of a temple (circled part, at the foot of the building).



When one places the radiation meter in contact with the ground directly in line with this draining zone, the dose rate measured is clearly higher that that recorded previously in contact with the forest bedding. In the present case, the value recorded in contact with the ground exceeds 6,500 nSv/h; this clearly illustrates the effect of concentration of the radioactive deposit due to the flow of water on the roof (or the melting of snow) at the time the deposit was formed in humid form. It is a very localised phenomenon. Thus, when the radiation meter is placed 1 m above this hot spot, the dose rate is around 5 times lower (1,330 nSv/h), bearing witness to a high exposure gradient, contrary to what was seen beforehand in the forest at point ❸.



Such hot spots are probably frequent in the sector but they have little influence on the general radiological ambiance and should not contribute significantly to the dosimetric impact of persons frequenting these areas. In the example shown here, there is no indication of the existence of the hot point, but access is impeded by metal barriers, as shown in the image on the previous page, which limits the probability of frequent passage and even less prolonged stay in this area.

❻ The final observation point measured is located higher up on the side of the hill, at a panoramic viewpoint that dominates Fukushima city. A sign indicated an ambient dose rate of 720 nSv/h; the measurement made with the radiation meter confirmed this value.

This dose rate value is entirely representative of the measurements recorded along the route in the forest, varying between 500 and 800 nSv/h.

5. The lessons learned from this experience

As expected, this route of around 3 km showed a contrasting radiological situation.

Even though the initial radioactive fallout must have been similar at this territorial scale, one notes that the ambient radioactivity is around 2 to 3 times higher in the forest than in nearby built-up areas.

In Fukushima city, the ambient dose rate measured outside stands at the highest level of natural radioactivity existing in France (around 200 to 300 nSv/h). Nevertheless, inside the buildings, the ambient radiation is of the same level as that existing in a building in the Île-de-France (< 100 nSv/h).

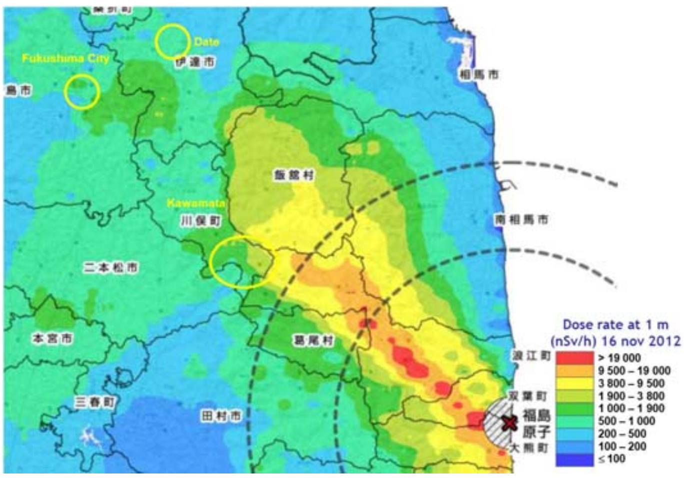
In the forest, the higher ambient radioactivity is explained both by the persistent deposit in the surface soil and by the persistent deposit in trees; the measured dose rate generally lies between 500 and 1,000 nSv/h. Two types of specific situations, showing a higher level of radioactivity, were highlighted along the route:

- Accumulation zones at the foot of the slope (impluvium), where the ambient radiation exceeds 1,000 nSv/h.
- "Hot spots" of limited extent, with a much higher contact dose rate, but with a relatively low incidence on the ambient dose rate 1 m above the ground (representative of the exposure of an individual).

6. Doses received through external exposure during a mission to Fukushima

When IRSN employees conduct a mission in the contaminated areas of Fukushima they are equipped with an electronic dosimeter that records the cumulated effective dose (external exposure to gamma radiation) during the mission. The dosimeter is initialised just before leaving for the mission and analysed once it has been handed back to IRSN which has appropriate software for collecting and analysing the data recorded by the dosimeter. This analysis makes it possible in particular to graphically visualise the dose accumulated over time and to compare the result with the situations encountered during the mission.

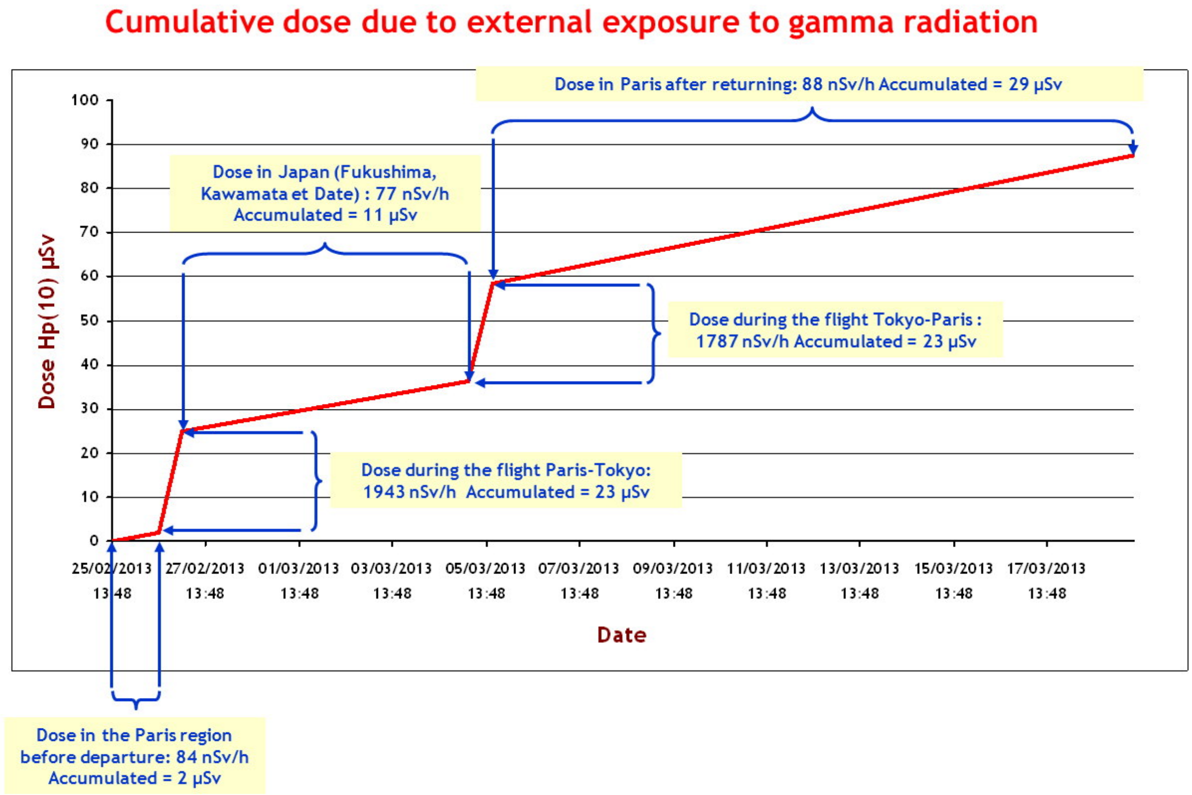
The graph on the following page illustrates this type of recording, for a dosimeter worn during a mission to Fukushima from the end of February to early March 2013. The actual mission took place from the 26 February to the 5 March 2013 (plane journey included). The dosimeter was initialised on the day before leaving (25 February) and analysed when it was handed back (18 March). The stay in Japan was scheduled in this way (see map hereafter to situate the main areas frequented, circled in yellow):



- Arrival in Fukushima city on the 27 February, after a transit to Tokyo.

- Stay in Fukushima city (including the radiological route presented in this appendix) from the 27 February to the 3 March.
- Trip to the evacuated zone of Kawamata municipality (1st March afternoon).
- Trip to Date (2 and 3 March during the day).
- Stay in Tokyo (4 and 5 March).

A priori, the period when the exposure level was the highest corresponds to the time spent in the evacuated part of Kawamata, where the dose rate ranged from several hundreds of nSv/h (cleared areas) to 1 to 2 µSv/h (wooded sectors), with " hot points" exceeding 8 µSv/h on contact. Nevertheless, the time spent outside in this area remained limited (around 2 to 3 hours).



The recording of the accumulated dose makes it possible to distinguish several exposure periods and to calculate the average dose rate for each period:

- The first period (25-26 February) represents exposure in the Paris region (mainly inside buildings), with an average dose rate between 80 and 90 nSv/h.
- The second period (26-27 February), with a steeper slope, corresponds to the Paris-Tokyo flight; the calculated apparent dose rate[12] is close to 2,000 nSv/h (2 µSv/h); this corresponds to exposure to cosmic radiation, much higher at altitude than at ground level due to attenuation by the atmosphere.
- The third period (27 February – 5 March) corresponds to the stay in Japan. The cumulative dose curve over this period is quite regular and does not show any significant modulation, despite the frequentation of areas with more or less high radioactivity. This observation results from the fact that the time spent outside was on the whole limited (less than 2 to 3 hours a day) and most of the time was spent inside buildings, where the dose rate is of the

[12] The dosimeter only measures the "gamma" component of cosmic radiation; other types of ionising radiation (neutrons, heavy ions, etc.) also significantly contribute to the dose received at altitude (10,000 m above sea level).

same order of magnitude as that observed in France. It is for this reason that the calculated average value over the whole of this period is close to 80 nSv/h.

- The fourth period (5 March) corresponds to the return journey to France by air. The apparent average dose rate is similar to that observed on the outward journey, although slightly lower (due to the effect of different flight paths and variations in cosmic radiation).
- The final period (5 March – 18 March) corresponds to the cumulative dose in Île-de-France, after returning from the mission and before analysing the dosimeter. The calculated average dose rate is close to 90 nSv/h.

In conclusion, this recording shows that more than 80% of the dose received during this mission was acquired in the plane, during the Paris-Tokyo return flights. Given the amount of time mainly spent inside buildings, and despite occasionally visiting areas with a dose rate nearly 10 times higher than in France, the average level of exposure during the stay in Fukushima was similar to that observed in France.

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