REPORT

ASSESSMENT ON THE 66TH DAY OF PROJECTED EXTERNAL DOSES FOR POPULATIONS LIVING IN THE NORTH-WEST FALLOUT ZONE OF THE FUKUSHIMA NUCLEAR ACCIDENT

- OUTCOME OF POPULATION EVACUATION MEASURES -

Report DRPH/2011-10

DIRECTORATE OF RADIOLOGICAL PROTECTION AND HUMAN HEALTH

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EXECUTIVE SUMMARY

On April 8, 2011, 28 days after the nuclear accident at the Fukushima nuclear power plant (NPP), IRSN published on its website the first worldwide map of doses likely to be received by the Japanese population as a result of external irradiation occurring the 1st year following the accident. This map was derived from dose rate data collected by the US DoE/NNSA based on airborne measurements and published on their website on April 7, 2011. The IRSN map revealed significant external doses in a northwest zone from the NPP, about 20 km in width and 50 to 70 km in depth. Other dose maps were then produced and published by DoE/NNSA on April 18, 2011 and more recently by the Japan "Ministry of Education, Culture, Sports, Science and Technology" (MEXT), on the 44th day after accident. These dose maps were consistent with the first dose assessment carried out by IRSN and show dose values of the same order of magnitude (difference less than a factor of 2.5).

On the 56th day after the accident, MEXT published the first maps of caesium depositions. They revealed high values comparable with the most contaminated areas of Chernobyl, even beyond the initial 20 km-radius evacuation zone around the Fukushima plant. A new dose assessment was carried out by IRSN on the 66th day after the accident to estimate projected doses due to external exposure from radioactive deposits, for exposure durations of 3 months, 1 year and 4 years before evacuation.

The estimated projected doses reach particularly significant values, some of them even above 200 mSv, which are no longer in the range of "low doses" according to UNSCEAR definition. Moreover these dose levels do not take into account neither the doses received from other pathways such as immersion within the plume and inhalation of particles in the plume during the accident nor the doses already received or to be received from ingestion of contaminated foodstuffs. The total effective doses to be received (external + internal) could be much higher according to the type of deposit (dry or wet), diet and source of food.

The number of Japanese people living in the most contaminated areas outside the initial 20 km-radius evacuation zone around the Fukushima plant (874 km^2 with caesium 134+137 deposits higher than 600,000 Bq/m^2) was estimated to 70,000 people including 9,500 children of 0-14 years in age. This significant number reaches about 26% of that of Chernobyl (270,000 people) for a surface area only 8.5% of that of Chernobyl (10,300 km^2).

IRSN have also studied:

- the impact of the selection of a dose reference level, within the range of 20 to 100 mSv recommended by ICRP in emergency situations, on the number of people to be evacuated;
- averted doses for these populations resulting from an evacuation according to 3 different scenarios: evacuation 3 months, 1 year or 4 years after the accident.

The level of projected external doses in upcoming years - up to 4 Sv lifetime dose in the most contaminated areas (30 million Bq/m^2 of caesium-137 + 134) - requires the implementation of protective actions such as evacuation of population.

According to the ICRP recommendations in emergency situations, the selection of the highest protective reference level, i.e. 20 mSv, would avert external doses above this level for 15,000 to 20,000 people.

If the Japanese authorities decide to take an even more protective reference level, for example 10 mSv for the 1st year, the averted external doses for the affected populations (70,000 people) would be much higher if the evacuation is quickly prescribed. An evacuation one year after the accident would result in a 59% decrease of the projected external dose for this population; evacuation three months after the accident would result in an 82% decrease.

This policy for preventing the risk of developing long-term leukaemia and radiation-induced cancer has been clearly understood by the Japanese authorities as shown in the map of population evacuation beyond the initial zone of exclusion of 20 km brought to the IRSN knowledge on May 16, i.e. the 66th day after the accident. The prescribed evacuation area seems to meet the 20 mSv reference level - the most protective dose value within the range recommended by ICRP in an emergency situation. This decision made by the Japanese authorities proves retrospectively the relevance of the IRSN's radiological assessment map - the first to have been published worldwide, 28 days after the accident.

1 Introduction

The radiological consequence of the nuclear accident in Fukushima was not estimated in the days following the accident due to the lack of reliable data from Japan about the composition of release, the environmental measurements and the individual monitoring performed in the affected population by the radioactive fallout in the neighbourhood of the nuclear plant.

The only health-related information available at that time was concerning the evacuation of the Japanese population within a radius of 20 km around the plant and the sheltering of the population in a 20-30 km area as well as the instructions from U.S. authorities to evacuate their nationals within a radius of 80 km, a precautionary measure that was rather tricky to interpret.

Airborne dose rate measurements performed by the US DoE/NNSA[1] and published on their website on April 7, 2011 enabled IRSN to publish on its own website, on April 8, 2011, the first map of doses likely to be received by the population via external exposure during the 1st year following the accident in the fallout zone to the northwest of the plant. Other maps were then published by the DoE/NNSA and more recently by the "Ministry of Education, Culture, Sports, Science and Technology" (MEXT) of Japan.

The purpose of this report is to provide insight on all radiological assessments performed to our knowledge to date and the impact of population evacuation measures to be taken to minimize the medium and long-term risks of developing leukaemia or other radiation-induced cancers. This report only considers the external doses already received as well as the doses that may be received in the future from fallout deposits, regardless of doses received previously from the radioactive plume. It should be noted that as regards the risk of developing thyroid cancer in children and adolescents, doses to this organ have already been received. As a result, the impact of protective measures, such as the administration of stable iodine within hours after exposure at the latest, can no longer be considered.

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

2 First-year external dose assessments from the Fukushima accident

2.1 First-year external dose estimate carried out by IRSN 28 days after the accident

The first assessment of projected doses[2] from the Fukushima accident published worldwide to our knowledge, was carried out by IRSN from airborne measurements of external dose rates performed between March 30 and April 3, 2011 by the American National Nuclear Security Administration (NNSA) and published on the U.S. Department of Energy's website the 7th of April 2011. The American map (Figure 1) shows higher dose rates in a zone of about 20 km in width and 50 to 70 km in depth in a northwest direction. In this area, deposits of radionuclides seem to have been significantly higher than elsewhere, probably because of precipitation (rain and snow), which fell while the radioactive plume was dispersing.

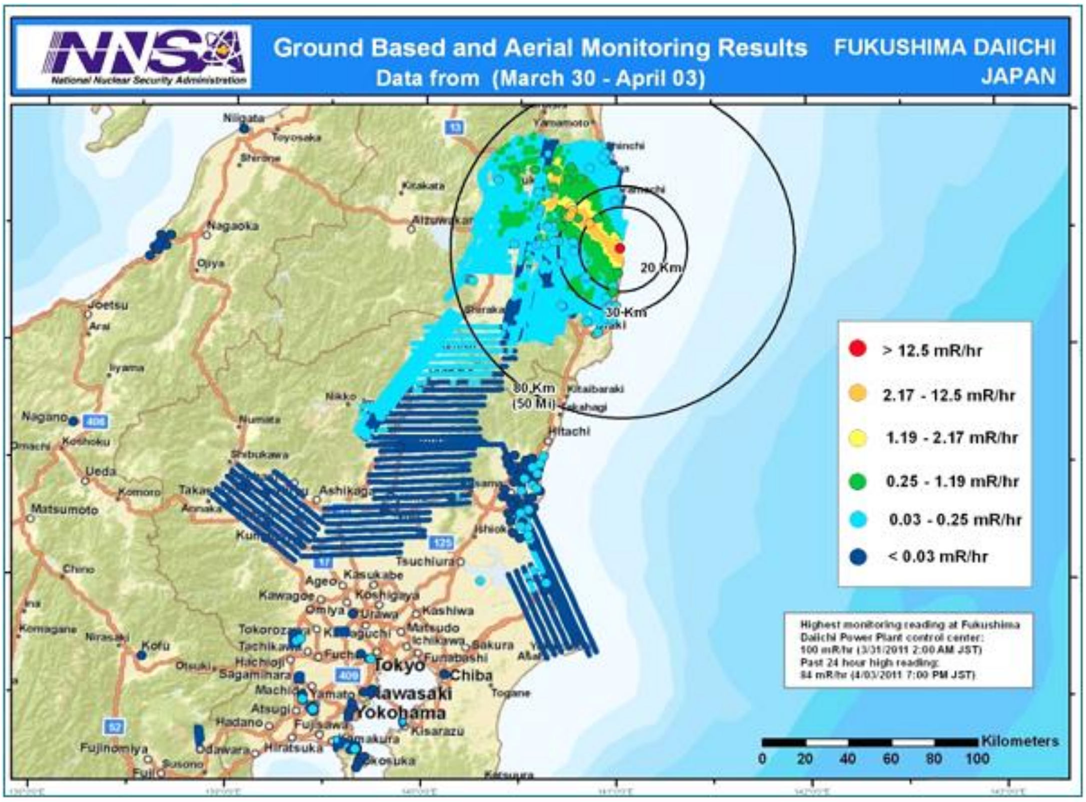

Figure 1: Dose rates in mRoentgen/hr measured by the NNSA between March 30 and April 3, 2011 *(map published on the DoE website on April 7, 2011)*

[2] The projected dose is defined by the International Commission on Radiological Protection (ICRP) as the dose that would be expected to be incurred if no protective measure(s) were to be taken. (ICRP Publication No. 103, 2007)

From this map of measured dose rates, IRSN derived a mapping of doses that could be received by the population in the 1st year following the accident, and which result from the external irradiation from deposited radionuclides in the contaminated areas in the northwest zone described above. The methodology used to calculate these projected doses from dose rates have taken into account the following assumptions:

- The temporal evolution of dose rates measured by the radiation monitors located in the Fukushima prefecture has shown that the radioactive releases occurring **between 15 and 16 March** 2011 are at the main origin of these deposits.
- The projected doses were calculated from the dose rates measured by the U.S. aircraft and have considered also the radioactive decay of these dose rates over time (from 30 March to 3 April 2011). The dose received by a person living in the contaminated area for a year has been calculated by integrating the hourly dose rate over the year.
- To estimate the dose rate decay over time, the relative contributions of the various deposited radionuclides to the measured dose rate have to be known, because the activity of each radionuclide decreases over time according to its half-life.
- The relative contributions of different radionuclides to the measured dose rate were estimated based on an assessment of the activity of radionuclides released into the atmosphere by the damaged reactor; this estimation was carried out by the nuclear facility assessment unit of the IRSN emergency response centre.
- According to this assessment, the dose rates measured 2 weeks after the accident result mainly in the presence of caesium (Cs-137 and Cs-134), iodine-131, tellurium-132/iodine-132, ruthenium-103/rhodium-103, barium-140/lanthanum-140 and niobium-95.
- A shielding factor of 0.3 applied for 12 hours per day was assumed to take into account shielding by buildings.

This assessment of the composition of radionuclide deposits has been used to derive a mapping of external doses potentially received during the first year from 16 March 2011 to 16 March 2012 (Figure 2).

Figure 2 published on the IRSN website on April 8, 2011 shows that the external doses received the first year are very high: in some areas outside the inhabited exclusion zone doses are above 30 mSv, i.e. 12.5 times the annual average dose due to natural sources in Japan.

It is of the utmost importance to remind that these dose estimates only refer to external exposure due to deposits, and do not take into account the additional dose that could be received as a consequence of consumption of contaminated foodstuffs produced locally.

It is estimated that the effective dose from ingestion may be significantly higher than the external dose according to the deposit conditions and depending on the effectiveness of implemented food restrictions.

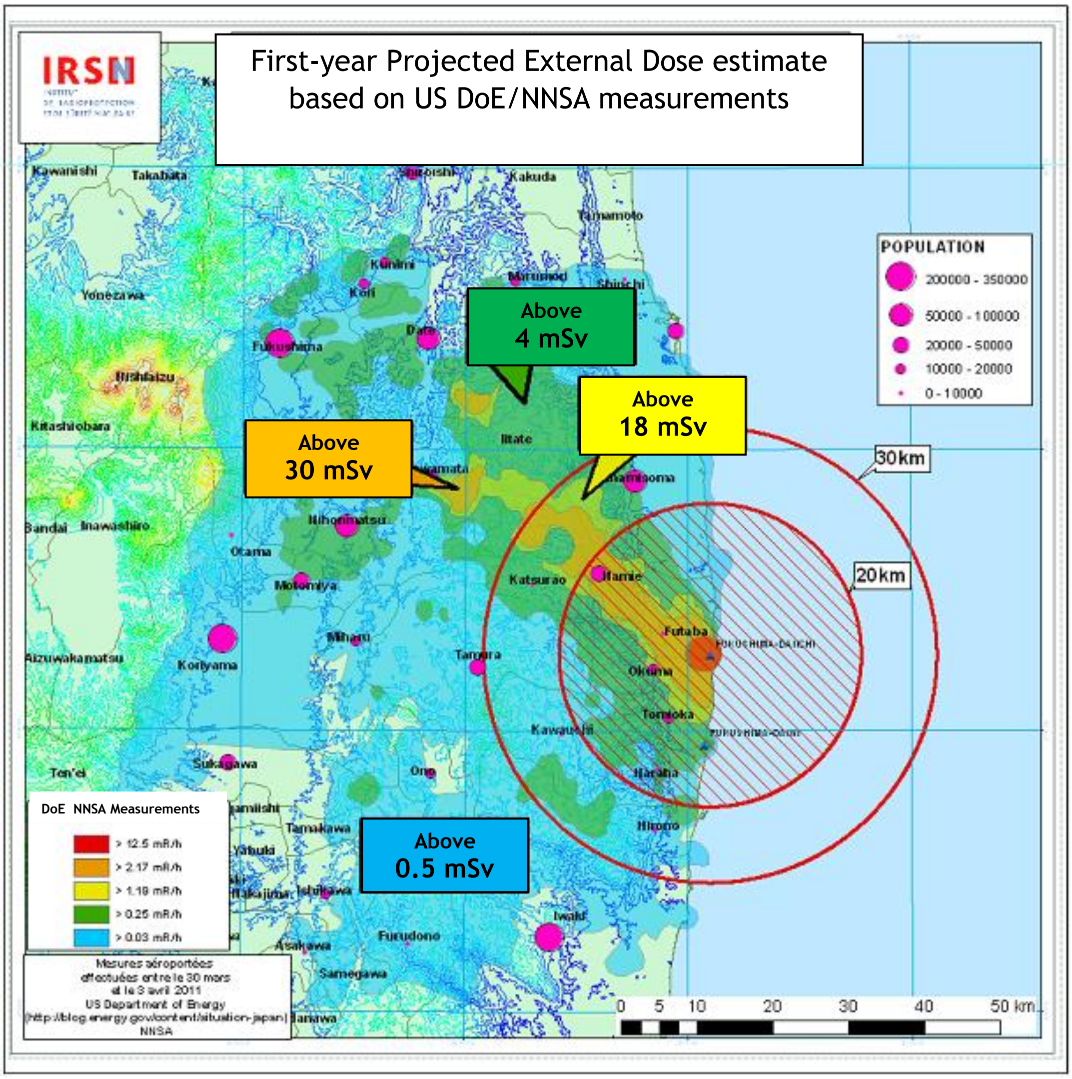

Figure 2: IRSN Mapping of external doses received during the 1st year derived from airborne measurements of dose rates carried out by the DoE/NNSA from March 30 to April 3, 2011 *(map published on the IRSN website on April 8, 2011)*

2.2 First-year external dose estimate carried out by United States DoE/NNSA 38 days after the accident

On April 18, 2011, 38 days after the accident, DoE/NNSA published an assessment of external doses for the 1st year based on airborne measurements of dose rates performed from March 30 to April 3, 2011 (Figure 3). This mapping of doses potentially received during the 1st year is similar the one that IRSN published on April 8, 2011. The only noticeable difference in the mapping representation concerns the choice of the upper limit of the doses received, i.e. > 20 mSv for the US-DoE and > 30 mSv for IRSN.

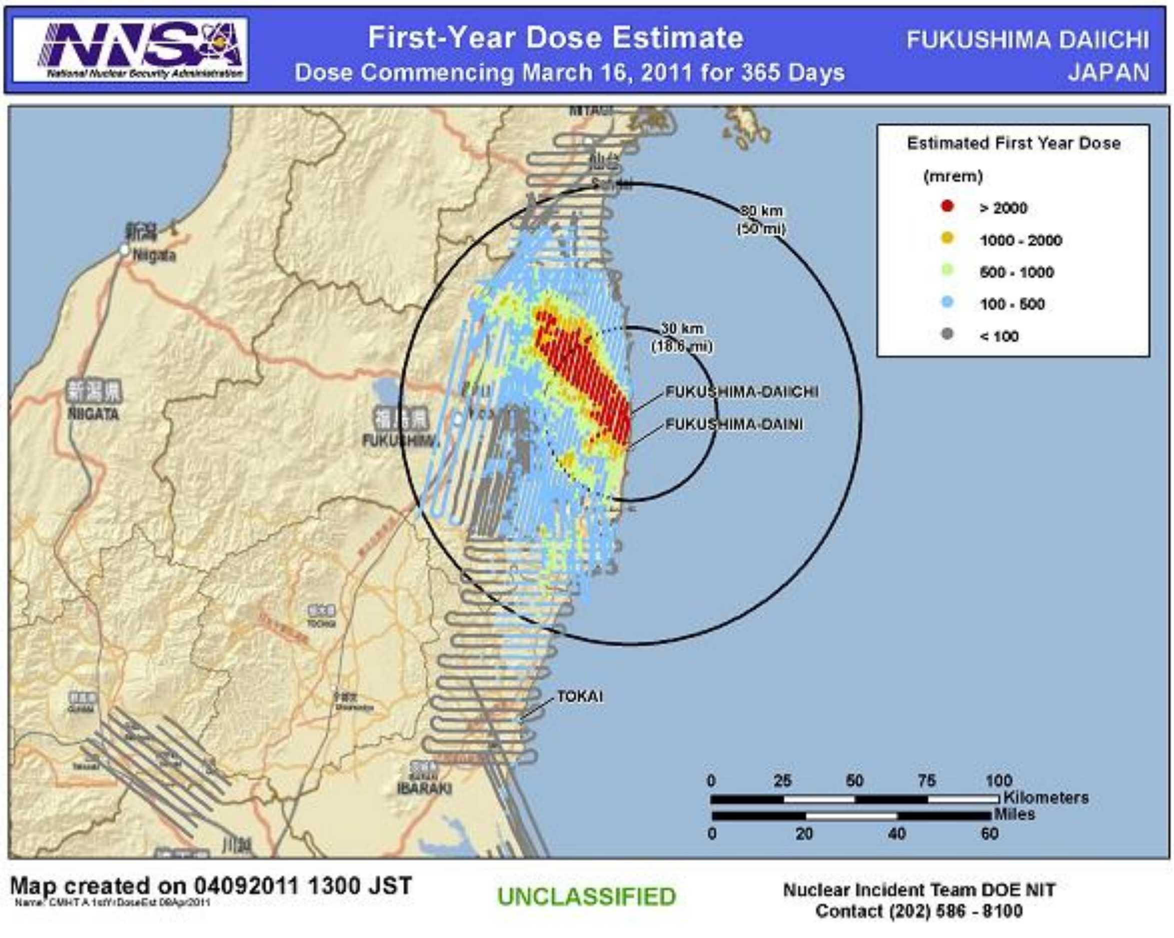

Figure 3: DoE/NNSA mapping of external doses for the 1st year derived from airborne measurements of dose rates carried out by the DoE/NNSA from March 30 to April 3, 2011

2.3 First-year external dose estimate carried out by the Japanese "Ministry of Education, Culture, Sports, Science and Technology" (MEXT) 44 days after the accident

On April 26, 2011, 56 days after the accident, MEXT published on its website a map of dose rates in the northwest zone ranging from 1 to 50 µSv/h (Figure 3A) as well as the first official Japanese map of projected doses in mSv from external irradiation due to deposits for the first year following the accident. This assessment assumed a shielding factor of 0.4 for 16 hours per day, i.e. a dose reduction by a factor of 0.6. This value is to be compared to the value of 0.65 (0.3 for 12 hours per day) considered in the IRSN assessment.

External doses for the 1st year are between 10 and 200 mSv (Figure 3B). This is the first time that an external dose likely to exceed 100 mSv is published, a value that corresponds to the limit above which a significant excess risk of radiation-induced cancer was shown by epidemiological studies.

Figure 3A: Mapping of external dose rates (µSv/h), published by MEXT on April 26, 2011

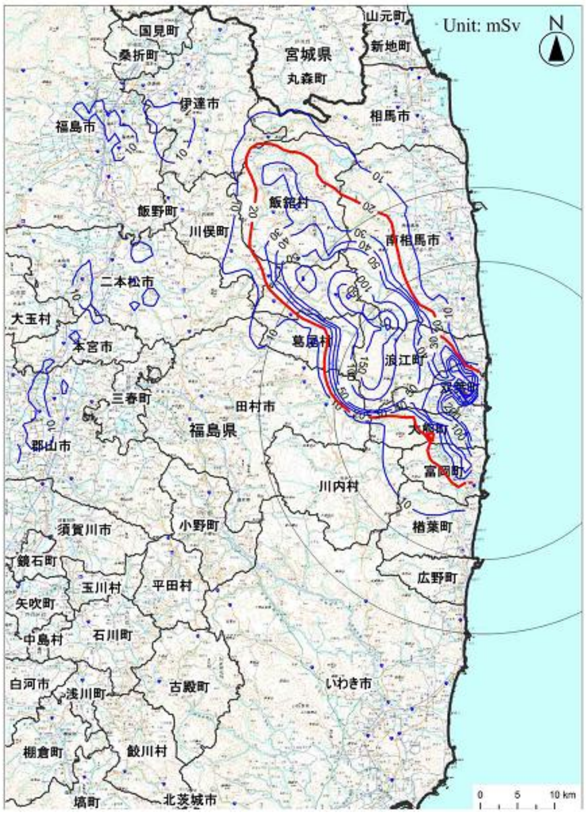

Figure 3B: Map of external doses (mSv) for the 1st year following the accident (map produced by MEXT and published on April 26, 2011)

In order to make easier the comparison of MEXT and IRSN maps, IRSN produced a new version of the "MEXT map" by reducing to 5 values the isodoses considered: 5; 10; 20; 50; 100 mSv (Figure 4).

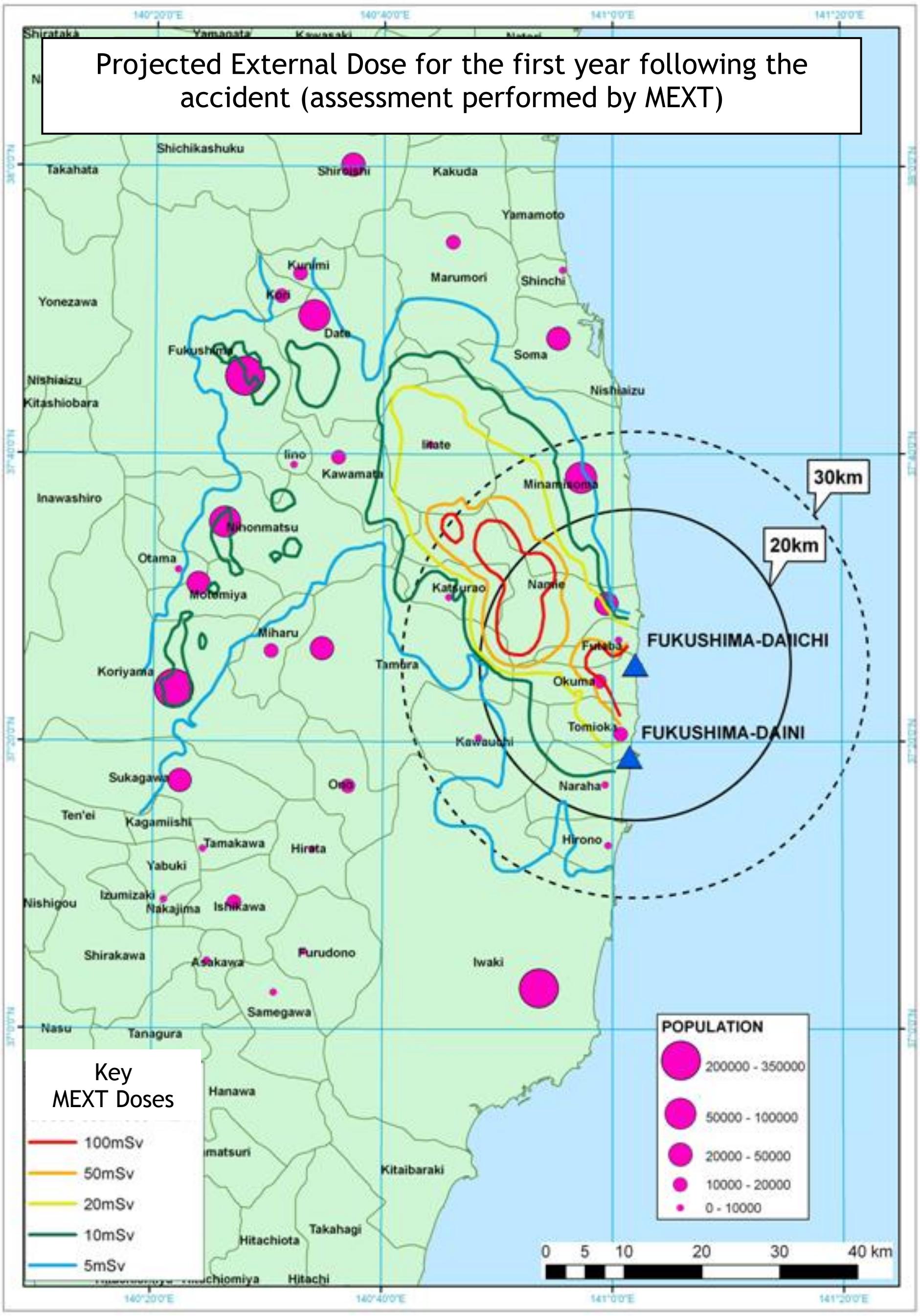

Figure 4: Map of external doses for the 1st year (mSv) based on the MEXT map (Figure 3B) after reducing the isodoses to 5 values: 5, 10, 20, 50 and 100 mSv (adapted by IRSN)

The 5 mSv isodose (blue line) in Figure 4 does not appear in the original MEXT map (Figure 3B). This 5 mSv isodose was derived by IRSN from the 1 µSv/h dose rate curve appearing in Figure 3A, assuming a conversion factor of 5 between the dose rate (in µSv/h) and the annual dose (in mSv), given that the 20 mSv dose curve matches the 4 µSv/h dose rate curve.

A comparison of the first official Japanese map to the first IRSN map (Figure 2) shows higher doses on the MEXT map (Figure 5).

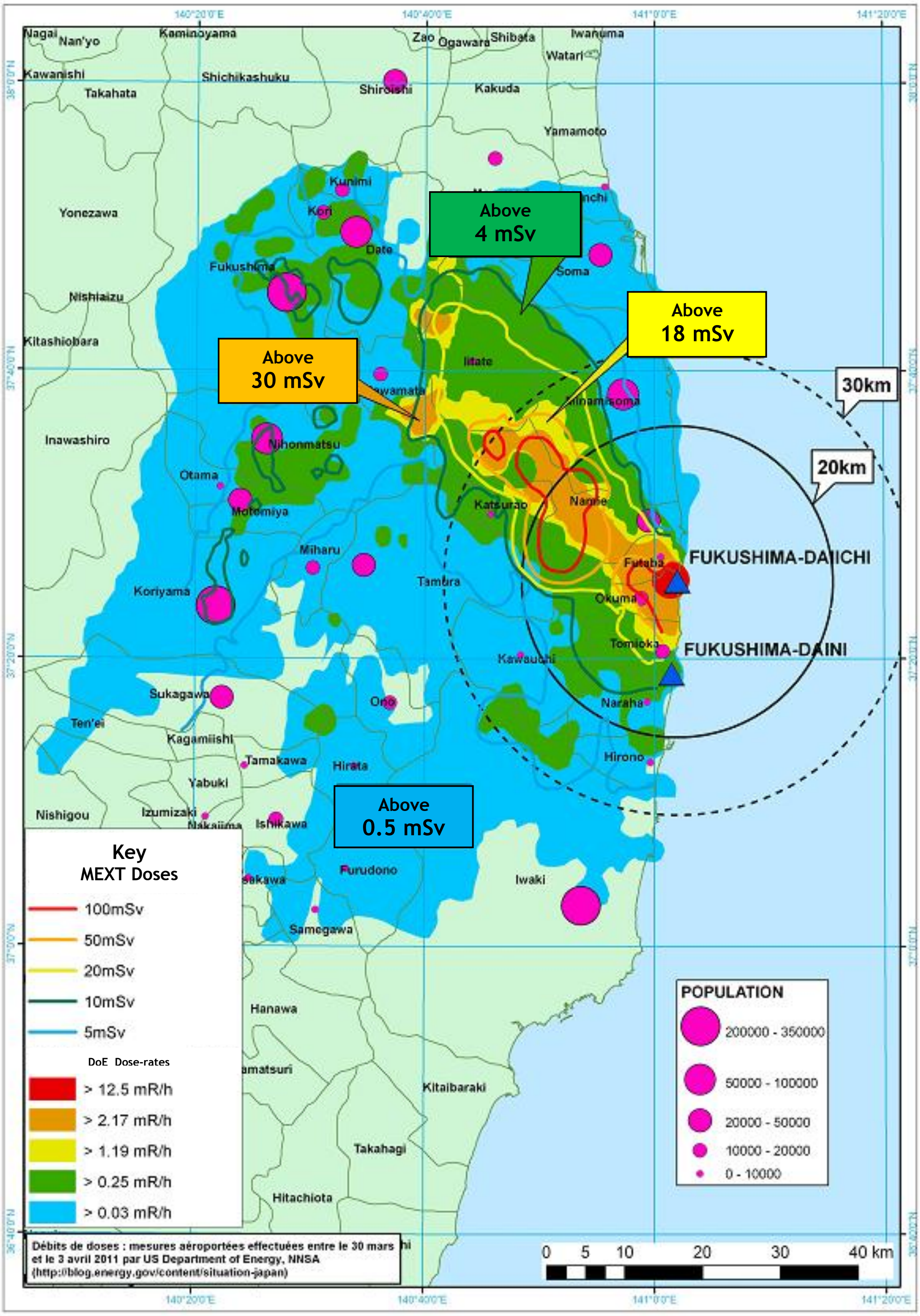

Figure 5: Comparison of the map of external doses for the 1st year produced by IRSN (Figure 2) to the MEXT map published on 24 April (Figure 4)

The comparison of the MEXT 10 mSv isodose (green line) to the IRSN green zone (> 4 mSv) shows that the factor between the two assessments is about of 2.5.

One reason that might explain this discrepancy between the two assessments could stem from an overestimation of the barium-140/lanthanum-140 ratio initially assessed by IRSN.

2.4 First-year external dose estimate from the mapping of caesium deposits (MEXT)

On May 6, 2011 MEXT published on its website maps of deposits of Cs-134, of Cs-137 and the sum of both activities in Bq/m^2 (Figure 6A) in the northwest zone, as well as a map of external dose rates in μSv/h (Figure 6B) resulting from these deposits. It should be noted that the Cs-134/Cs-137 ratio is equal to 1 in this assessment.

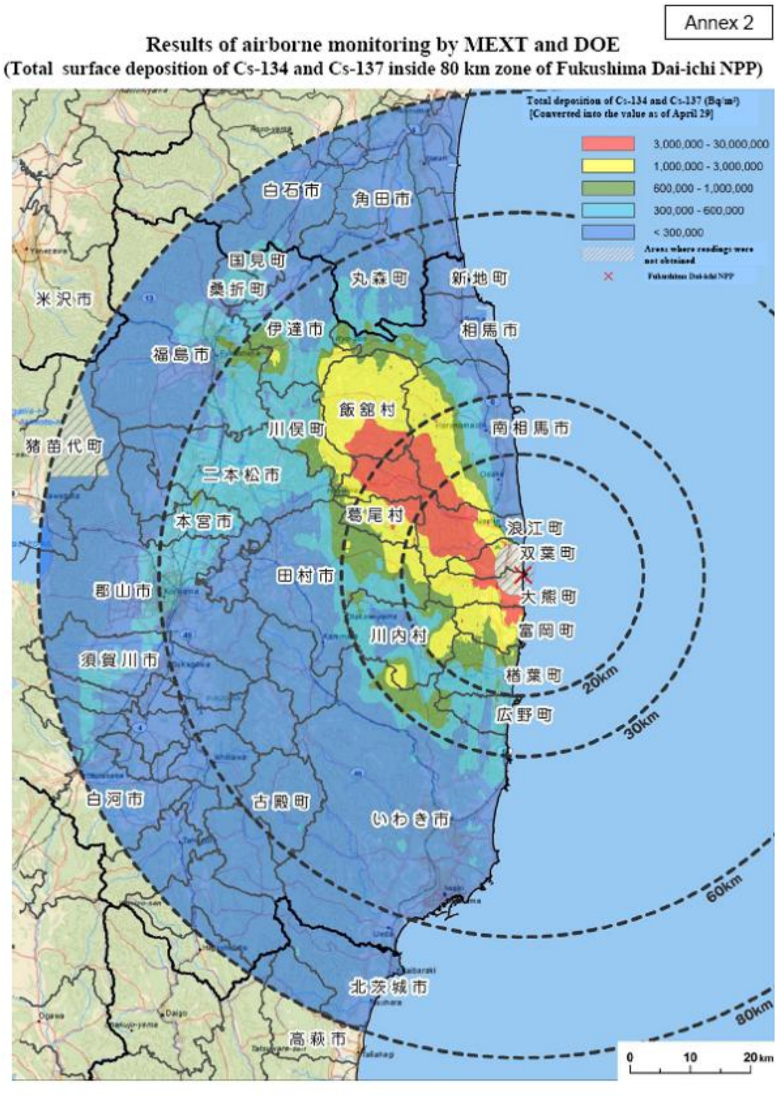

Figure 6A: MEXT and DoE map of deposits on the ground surface (Bq/m^2) of Cs-137 and Cs-134 (map established from airborne measurements collected between April 6 and April 29, 2011)

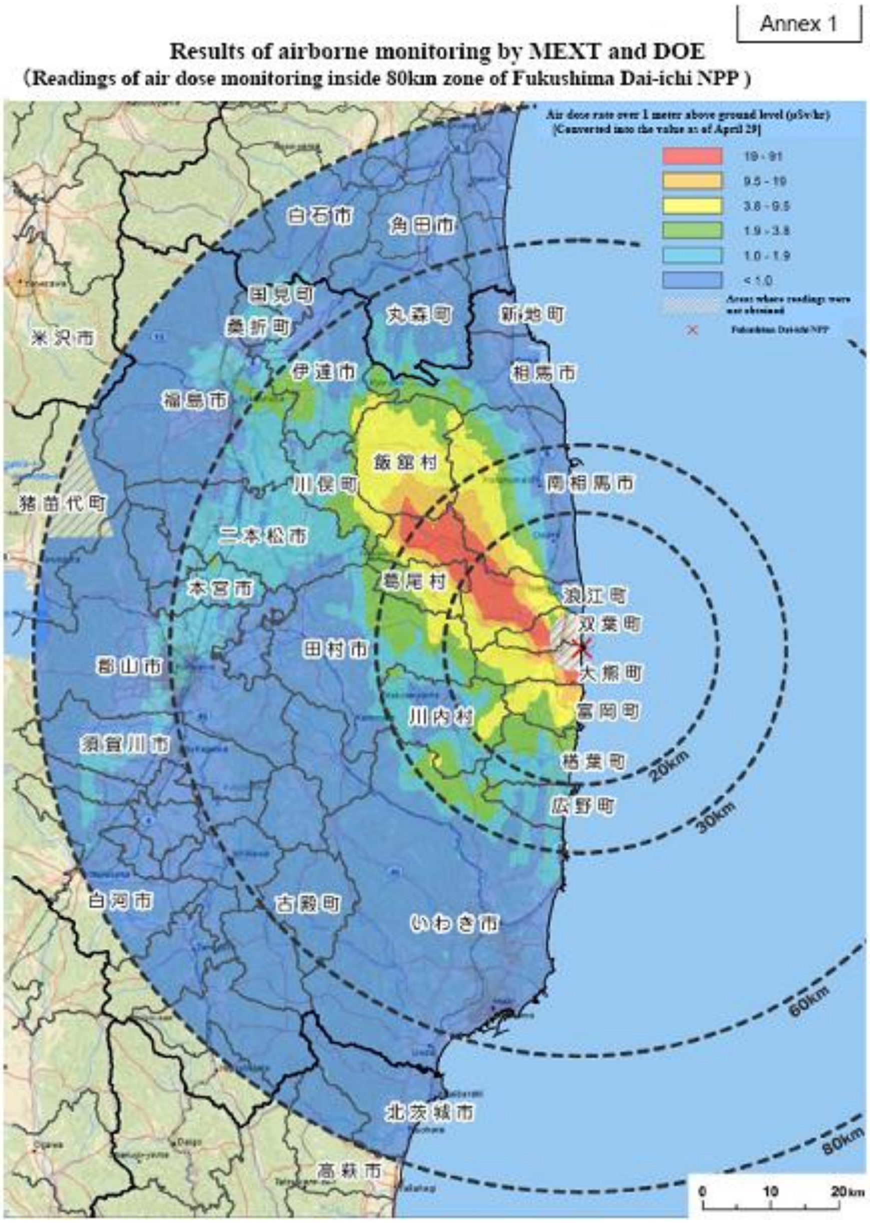

Figure 6B: MEXT and DoE map of dose rates from airborne measurements collected between April 6 and April 29, 2011

The map of caesium deposits (Cs-134 + Cs-137) shows 5 levels of surface activity ranging from <0.3 to 30 MBq/m^2, i.e. < 0.3, 0.3, 0.6, 1, 3 MBq/m^2. The map of dose rates shows 6 levels: < 1, 1, 1.9, 3.8, 9.5 and 19 µSv/h.

The comparison of both maps shows that the dose rate conversion factor from surface activity is around 300,000 Bq/m^2 by µSv/h.

A new map of caesium deposits was designed by IRSN (Figure 7). It uses the same levels of deposits as the MEXT map between 0.3 and 3 MBq/m^2. An additional level was also added: this new level corresponds to 6 MBq/m^2 and was determined applying to the dose rate value of 19 µSv/h the conversion factor mentioned above (300,000 Bq/m^2 per µSv/h).

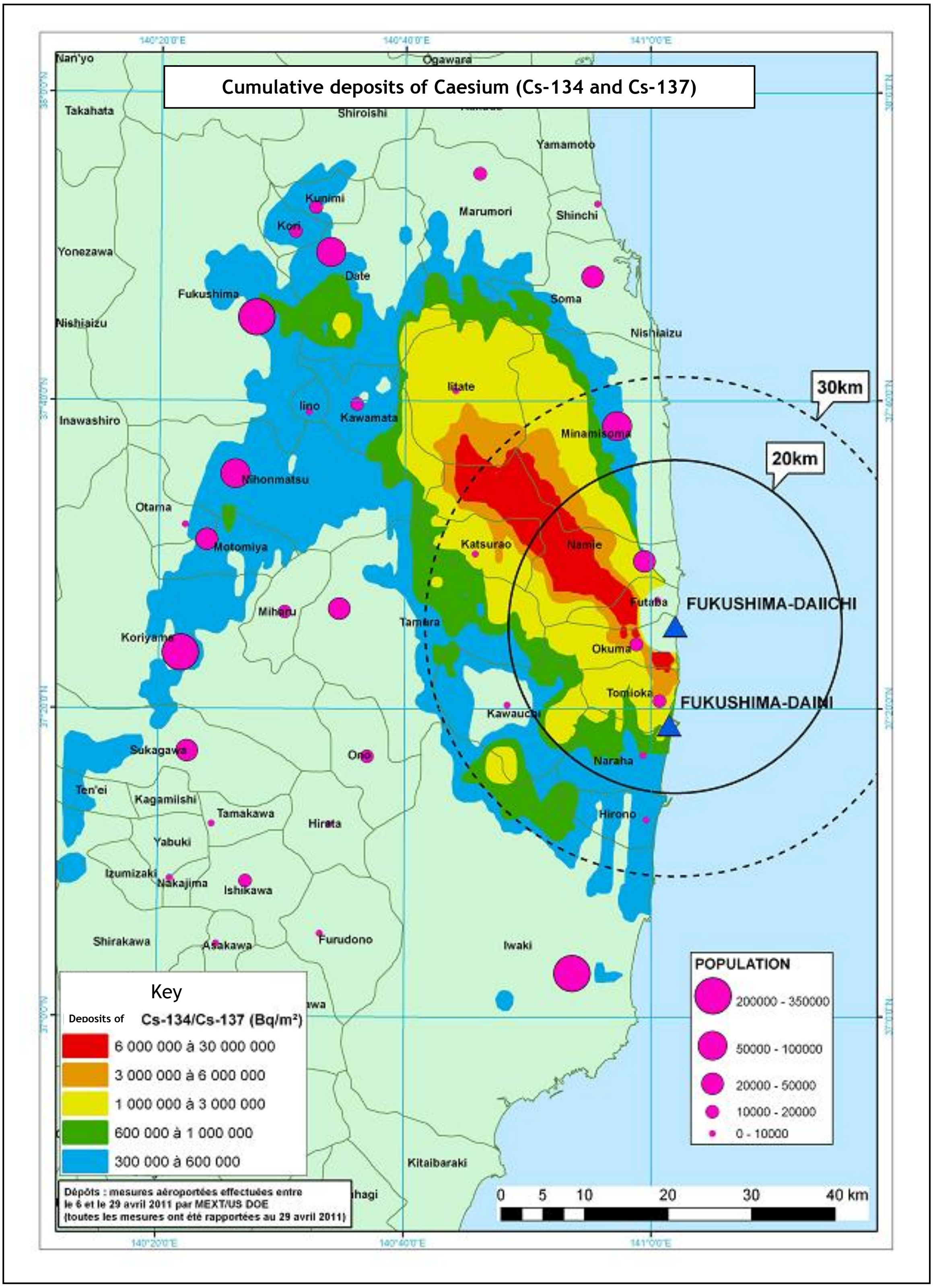

Figure 7: Map showing the data from MEXT on cumulative deposits of caesium 137 and 134 from 0.3 to 30 MBq/m^2 and in which IRSN added the 6 MBq/m^2 level

Comparing this caesium deposits map to the MEXT map of external doses potentially received during the 1st year following the accident (Figure 4) enables to derive a conversion factor between the activity of caesium deposits and the projected external dose for the first year of living in these contaminated areas. Figure 8 shows these two maps (deposits and doses) considering 3 levels of external dose: 5, 10 and 20 mSv.

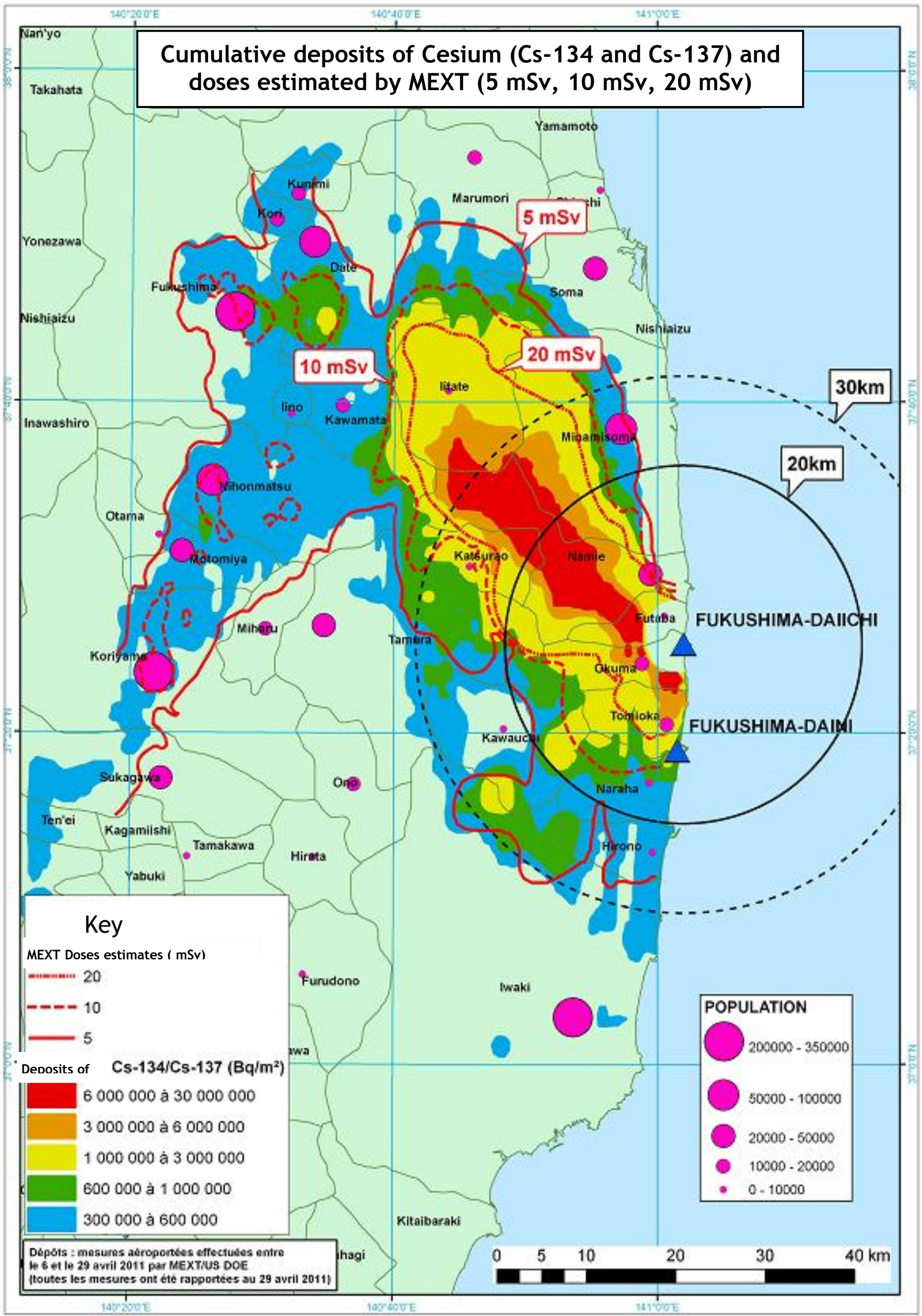

Figure 8: Map of caesium 137 + 134 deposits (Figure 7) superimposed on the map of projected doses for the 1st year (Figure 4) for 3 dose levels (5, 10 and 20 mSv)

Deposits of 300,000 to 600,000 Bq/m^2 correspond to the external dose values of 5 to 10 mSv projected for the 1st year. The conversion factor from the surface activity of caesiums to the projected external dose for the 1st year is **<u>16.6 mSv/year per MBq/m^2.</u>** The correspondence between caesium deposit levels and projected external doses for the 1st year is shown in Table 1.

The size of the populations located in the different contaminated areas is also given in Table 1. They are based on demographic data of the Fukushima Prefecture from the Statistics Bureau, Ministry of Internal Affairs and Communications, Japan (website http://www.stat.go.jp/);

The number of people in each contaminated zone is assumed to be proportional to the concerned districts surface area and based on an average population density for each district. For Minamisoma and Namie districts where urban areas aren't concerned, the average density used was derived from the rural part of these districts. The administrative limits of the districts used in the calculations of surface areas come from the "Global Administrative Area database" (website www.gadm.org).

Table 1: Deposits, projected external doses for the 1st year and affected populations

<table>
<tr><th>Deposits of caesium (137 + 134) (Source MEXT)</th><th>> 300,000 Bq/m^2</th><th>> 600,000 Bq/m^2</th><th>> 1 million Bq/m^2</th><th>> 3 millions Bq/m^2</th><th>6 - 30 millions Bq/m^2</th></tr>
<tr><td>External dose 1st year (16.6 mSv by MBq/m^2)</td><td>> 5 mSv</td><td>> 10 mSv</td><td>> 16 mSv</td><td>> 50 mSv</td><td>100 - 500 mSv</td></tr>
<tr><td rowspan="3">Affected population (excluded the no-entry zone)</td><td rowspan="3">292,000</td><td colspan="4">69,400</td></tr>
<tr><td rowspan="2">43,000</td><td colspan="3">26,400</td></tr>
<tr><td>21,100</td><td>3,100</td><td>2,200</td></tr>
</table>

Projected doses for the 10-year and 70-year periods after the accident in Fukushima considering the deposits of caesium and affected populations are presented in Table 2. These doses were derived from:

- the projected dose for the first year calculated by MEXT,
- the ratios between the projected doses for 10 and 70 years, and the projected dose for the 1st year. These ratios were determined using a new IRSN term source. According to this new source term, the dose rates measured 2 weeks after the accident result from:
    - 43% caesium (Cs-137, Cs-136 and Cs-134),
    - 17% iodine-131,
    - 13% tellurium-132/iodine-132,

- 10.5% ruthenium-103/rhodium-103,
- 9.5% barium-140/lanthanum-140,
- 4% niobium-95.

Table 2: Deposits, external doses projected at 10 and 70 years and affected populations

Deposits of caesium (137 + 134) (Source MEXT)	> 300,000 Bq/m^2	> 600,000 Bq/m^2	> 1 million Bq/m^2	> 3 millions Bq/m^2	6 - 30 millions Bq/m^2
External dose at 10 years (70 mSv by MBq/m^2)	> 19 mSv	> 38 mSv	> 63 mSv	> 190 mSv	380 - 1,900 mSv
External lifetime dose (70 years) (160 mSv par MBq/m^2)	> 41 mSv	> 82 mSv	> 136 mSv	> 408 mSv	816 - 4,080 mSv
Affected population (excluded the no-entry zone)	292,000	69,400			
		43,000	26,400		
			21,100	3,100	2,200

Projected external doses for the people living lifetime in contaminated areas show significant values, even beyond values of low doses according to UNSCEAR[3] definition, i.e. less than around 200 mSv. The number of people affected could also be high, around 70,000 including 9,500 children from 0-14 years, assuming that children represent 13.7% of the total Japanese population in 2005.

These dose levels do not take into account other exposure pathways such as external exposure by immersion within the plume and internal contamination resulting from inhalation of particles in the plume, and internal doses already received or to be received as a result of ingestion of contaminated food.

The total effective doses (external + internal) could be increased considerably according to the type of deposit (dry or wet), diet and source of food.

First-year external dose estimates, surface areas and populations in the heavily contaminated zones impacted by the accident in Fukushima can be put into perspective with those of the Chernobyl accident (see Table in Appendix).

[3] United Nations Scientific Committee on the Effects of Atomic Radiation

Heavily contaminated territories located outside the initial evacuation zone of 20 km around the Fukushima plant were 8.5% in surface of those in Chernobyl (874 km^2 compared to 10,300 km^2) and the order of magnitude of the affected population size would be 26% of that of Chernobyl (69,400 compared to 270,000).

3 Impact of evacuation measures on projected external doses

Lessons learnt from the Chernobyl accident led ICRP to develop a doctrine for the protection of population in emergency situations, which was introduced in publication 103[4] (2007) and described in more detail in publication 109[5] (2009).
Any evacuation measure to protect the population which are or that will be implemented in Japan should be based on ICRP recommendations 103 and 109.

3.1 Impact of evacuation measures on population sizes according to the prescribed reference levels

Publication 103 of the International Commission on Radiological Protection (ICRP) provides a conceptual framework for the protection of the population in an emergency radiation exposure situation. The recommendations were specified by the ICRP in its Publication 109 and the primary concern must be to avoid or reduce doses received by the population. However, the accident that led to this situation may have consequences going far beyond the health effects of radiation (e.g. economic, psychological and social consequences).

The implementation of any protection action shall be justified, i.e. should maximise the margin of benefit over harm (individual or societal benefit should be sufficient to offset the detriment it causes), and shall be optimized to ensure that the magnitude of individual doses, the number of individuals subject to exposure are as low as reasonably achievable, economic and social factors being taken into account.

To do this, ICRP recommends the use of reference levels. These reference levels represent the level of residual dose or risk:

- above which exposure is judged unacceptable and requires the implementation of protective actions,

[4] Recommendations 2007 of the International Commission on Radiological Protection. Publication 103. Editions Tec&Doc (2009)

[5] Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations. ICRP Publication 109. Ann. ICRP 39 (1) (2009)

- below which protection should be optimized, by taking into account all exposure pathways.

ICRP suggested reference levels in terms of effective dose in a range from 20 to 100 mSv received in one year for radiation emergency situations. The selection of the reference level value should be adapted to the situation and to the protection strategy.

The resources required to implement protective measures are not the only factors that might interact within an overall protection strategy. Other such factors include individual and social disruption, anxiety and reassurance, and indirect economic consequences. In particular, the prolonged evacuation of a population requires relocation in acceptable conditions.

The comprehensive protection strategy selected must provide more benefits than harms and it is important that relevant stakeholders (or their representatives) are involved at the preparedness stage of the decision making process.

The recommendations of the ICRP publication 103 for the Fukushima situation would entail different number of people to evacuate according to the reference level selected by the Japanese authorities.

Table 3, an excerpt from Table 2, exhibits the number of people to evacuate, for a range of reference levels from 20 to 100 mSv.

Table 3: External doses for the 1st year, affected populations and reference levels recommended by the ICRP in an emergency radiation situation

ICRP 103 and 109
20 - 100 mSv

<table>
<tr><th>1st year external dose</th><th>> 5 mSv</th><th>> 10 mSv</th><th>> 16 mSv</th><th>> 50 mSv</th><th>100-500 mSv</th></tr>
<tr><td rowspan="3">Population outside the evacuation zone</td><td rowspan="3">292,000</td><td colspan="4">69,400</td></tr>
<tr><td rowspan="2">43,000</td><td colspan="3">26,400</td></tr>
<tr><td>21,100</td><td>3,100</td><td>2,200</td></tr>
</table>

Table 3 shows that 2,200 people whose external dose would exceed 100 mSv for the 1st year should be evacuated. Depending on the level selected between 20 and 100 mSv the number of people to evacuate could range between 2,200 and about 15,000 to 20,000. **These data prove the need to evacuate at least 2,200 people that would likely receive doses above 100 mSv the 1st year**.

3.2 Impact of evacuation measures on projected external doses according to implementation times

The Fukushima population living in the northwest fallout zone and likely to exceed external dose of 10 mSv for the 1st year has been distributed in subgroups according to the range of projected external doses for the 4 first years after the accident if no evacuation action is prescribed. The number of people in these subgroups follows an exponential decrease curve (blue line in logarithmic scale in Figure 9A).

The comparison with Chernobyl in terms of external doses received in the same period puts the radiological impact of the Fukushima accident into perspective compared to that of Chernobyl for three scenarios: evacuation after 4 years (Figure 9A), evacuation after 1 year (Figure 9B) and evacuation after 3 months (Figure 9C).

The distribution of the 270,000 people who lived in the most contaminated areas by the Chernobyl fallout[6] (> 555,000 Bq/m^2) in subgroups according to the external dose received in 4 years also decreases exponentially as illustrated by the red line in logarithmic scale in Figure 9A. The comparison of external doses received during the 4 first years by 270,000 people who lived in the heavily contaminated territories by the Chernobyl accident with those who are likely to be delivered, for the same period, to 70,000 people residing in the northwest zone of the Fukushima Daiichi plant, shows that a fraction of the Japanese population would be more impacted than those for Chernobyl. For the highest doses (above 100 mSv over 4 years), the size of population impacted in Fukushima (3,100+2,200 = 5,300) is higher than that of Chernobyl (2,800 +530+120= 3,450).

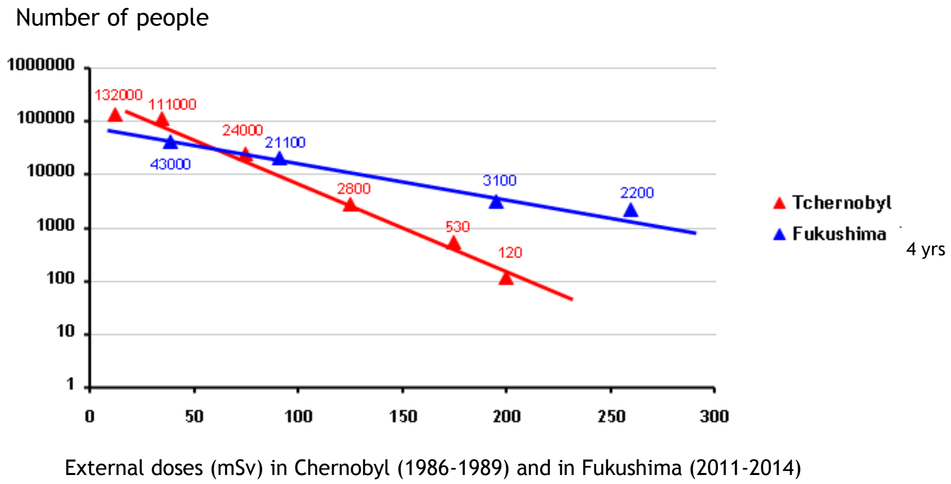

Figure 9A: Distribution of Fukushima and Chernobyl populations based on external doses projected and received during the four years following the accident

6 Chernobyl: Assessment of Health and Radiological Impact. 2002 Update of Chernobyl Ten Years On, for OECD Nuclear Energy Agency Table 11 p. 77

A risk indicator that takes into account both the radiological impact and the size of the population is the collective dose (in person.Sv), product of the dose multiplied by the number of affected people.

The external collective dose received over 4 years by the population of 270,000 people in **Chernobyl** was **7,300 person.Sv**.
The projected external collective dose over 4 years for the 70,000 people in **Fukushima** is **4,400 person.Sv**. Therefore, without evacuation during the 4 years after the accident, the radiological consequence of the Fukushima accident from external exposure would reach **60%** of that of Chernobyl and could be in the same order of magnitude.

Figure 9B illustrates the distribution of first-year external dose estimate following the accident in Fukushima. This distribution has shifted towards lower doses compared to the dose distribution of Chernobyl (1986-1989).

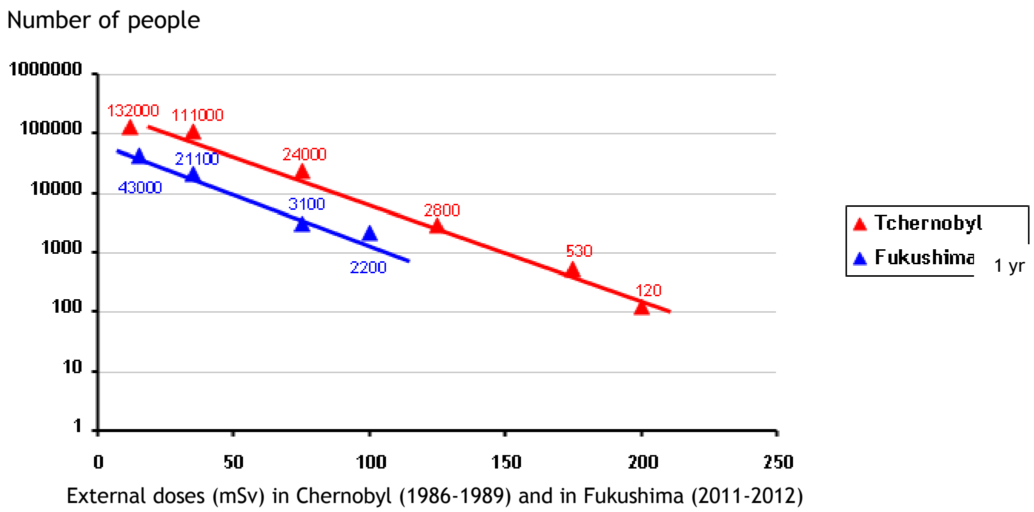

Figure 9B: Distribution of Chernobyl populations according to 4 years of external doses and Fukushima populations following evacuation one year after the accident

The evacuation of Japanese population one year after the accident would significantly reduce this radiological consequence as shown in Figure 9B. The collective dose would decrease to **1,800 person.Sv**, i.e. **a reduction of 59 %** of the accident's dosimetric consequence.

Figure 9C illustrates the external dose estimate for the 3 months following the accident in Fukushima. This distribution has very clearly shifted towards lower doses compared to the dose distribution of Chernobyl (1986-1989).

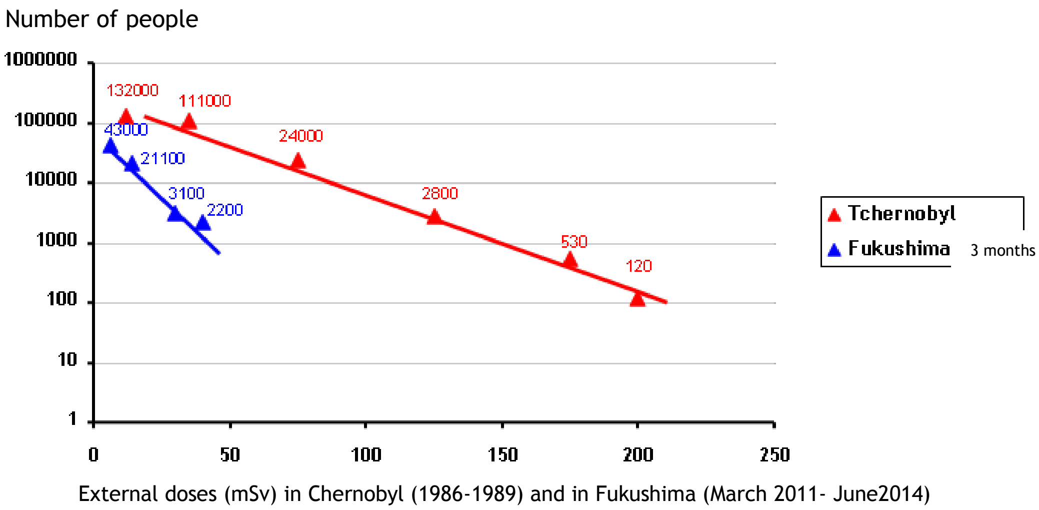

Figure 9C: Distribution of Chernobyl populations according to 4 years of external doses and Fukushima populations following evacuation 3 months after the accident

The evacuation of Japanese populations 3 months after the accident would drastically reduce the radiological consequence. The new collective dose would be **800 person.Sv**, i.e. **a reduction of 82%** of the accident's dosimetric consequence.

Thus, in case of total evacuation of the population 1 year and ***especially 3 months after the accident*** in Fukushima, the long-term risk of developing leukaemia and radiation-induced cancer for the Japanese population would be very much lower than in Chernobyl.

4 Conclusions

Since the accident in Fukushima has occurred several dose assessments have been carried out by IRSN, US DoE and Japan MEXT. The results are of the same order of magnitude; a high degree of consistency between these radiological assessments and the magnitude of cesium-137 and cesium-134 deposits is observed.

Projected external doses for the people living lifetime in contaminated areas include significant values, even beyond low doses according to UNSCEAR definition, i.e. less than around 200 mSv. The number of people involved could also be high, around 70,000 including 9,500 children of 0-14 years in age (13.7% of the total Japanese population in 2005).

These dose levels do not take into account other exposure pathways, such as immersion within the plume and internal contamination resulting from inhalation of particles in the plume, as well as internal doses already received or to be received from contaminated food ingestion.

The total effective doses (external + internal) could be increased considerably according to the type of deposit (dry or wet), diet and source of food.

The level of external doses projected in upcoming years - up to 4 Sv lifetime in the most contaminated areas (30 million Bq/m^2 of cesium-137 + 134) - requires the implementation of protective actions such as evacuation of population.

According to the ICRP recommendations in radiation emergency situations, the selection of the highest protective reference level, i.e. 20 mSv, would avert external doses above this level for 15,000 to 20,000 people.

If the Japanese authorities decide to take an even more protective reference level, for example 10 mSv for the 1st year, the averted external doses for the affected populations (70,000 people) would be much higher if the evacuation is quickly prescribed. An evacuation one year after the accident would result in a 59% decrease of the projected external dose for this population; evacuation three months after the accident would result in an 82% decrease.

This policy for preventing the risk of developing long-term leukemia and radiation-induced cancer has been clearly understood by the Japanese authorities as shown in the map of population evacuation beyond the initial zone of exclusion of 20 km reported to the IRSN knowledge on May 16 i.e. the 66th day after the accident (Figure 10). The prescribed evacuation area seems to meet the 20 mSv reference level - the most protective dose value within the range recommended by the ICRP in an emergency situation. This decision made by the Japanese authorities proves retrospectively the relevance of the IRSN's radiological assessment map - the first to have been published worldwide, 28 days after the accident.

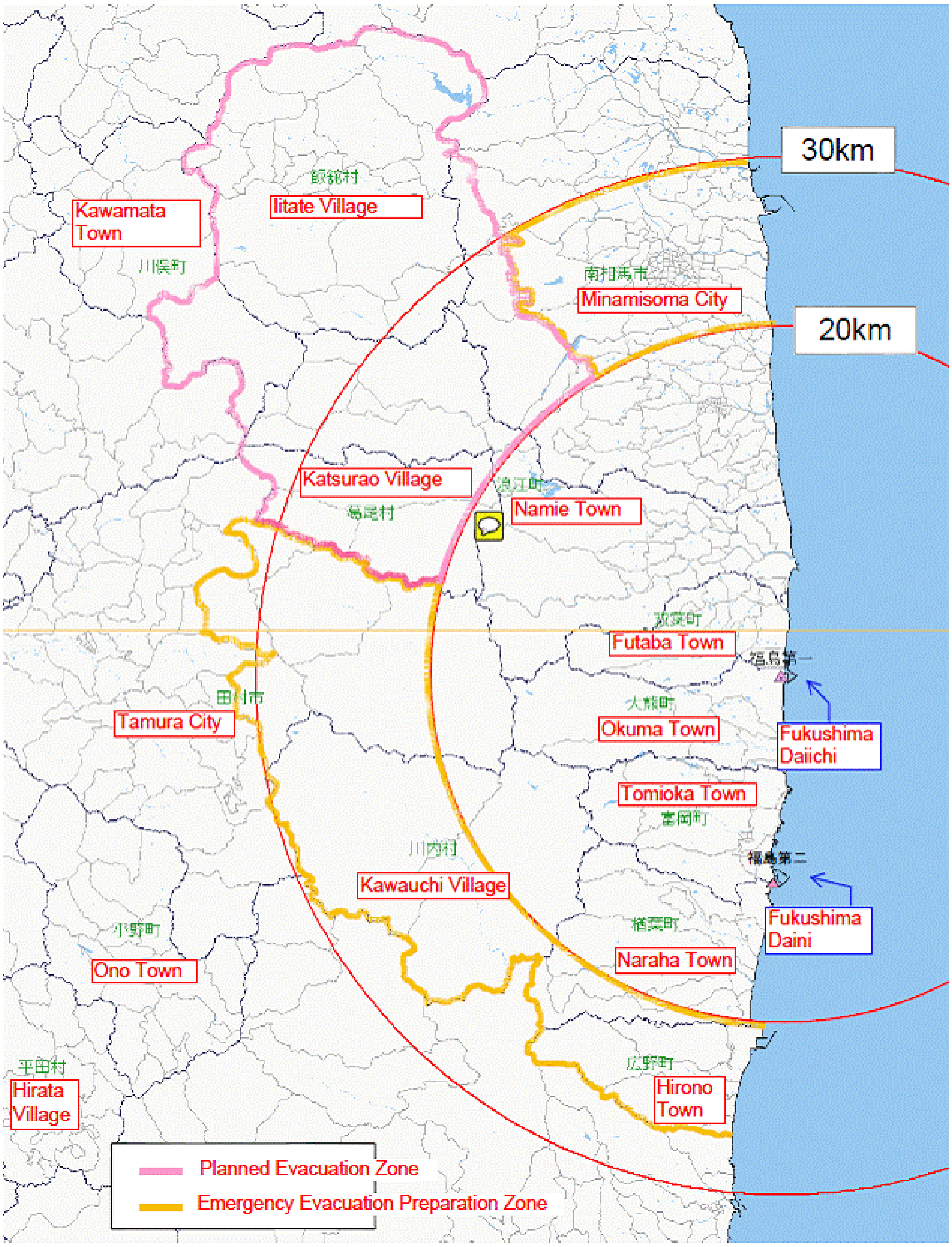

Figure 10: Planned evacuation zones or evacuation preparation zones established by the Japanese competent authorities including the "Nuclear and Industrial Safety Agency" (NISA) and MEXT

APPENDIX

Comparison between Chernobyl (1986) and Fukushima (2011) accidents in terms of Cs 137 deposits, surfaces of contaminated areas, 1st year external doses and population sizes

CHERNOBYL

	Less contaminated areas			Most contaminated areas				
	Control Zone	Voluntary Evacuation Zone		« STRICTLY CONTROLLED ZONES (SCZs) »				INITIAL EVACUATION ZONE 30 km
				EVACUATION ZONE	OBLIGATORY EVACUATION ZONE			
Cs-137 Deposits	37,000 Bq/m^2 (1 Ci/km^2)	185,000 Bq/m^2 (5 Ci/km^2)	370,000 Bq/m^2 (10 Ci/km^2)	555,000 Bq/m^2 (15 Ci/km^2)	1,5 million Bq/m^2 (40 Ci/km^2)	3,7 millions Bq/m^2 (80 Ci/km^2)	7,4 millions Bq/m^2 (200 Ci/km^2)	Up to 37 millions Bq/m^2 (1,000 Ci/km^2)
1st year External Dose (13 mSv par MBq de Cs-137 /m^2)	> 0,5 mSv	> 2,4 mSv	> 5 mSv	> 7 mSv	> 20 mSv	> 50 mSv	> 100 mSv	
Surface	116,000 km^2	19,000 km^2		7,200 km^2	3,100 km^2			2,830 km^2
Population Size	5,281,000 (1995)	1,300,000 (1995)		270,000 (1986)				135,000

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Cs-137 deposits (MEXT)			> 150,000 Bq/m^2	> 300,000 Bq/m^2	> 500,000 Bq/m^2	> 1,5 million Bq/m^2	3 -15 million Bq/m^2	INITIAL EVACUATION ZONE 20 km
1st year External Dose (33 mSv per MBq of Cs-137 /m^2)			> 5 mSv	> 10 mSv	> 16 mSv	> 50 mSv	100 - 500 mSv	
Surface Outside of the Evacuation Zone	?	?	1,241 km^2	320 km^2	384 km^2	91 km^2	79 km^2	628 km^2
Population Size Outside of the Evacuation Zone	?	?	292,000	69,400				85,000
				43,000	26,400			
					21,100	3,100	2,200	