

Effects of the Fukushima nuclear meltdowns on environment and health March 9th, 2012

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Abstract

The Tōhoku earthquake on March 11th, 2011 led to multiple nuclear meltdowns in the reactors of the Fukushima Daiichi nuclear power plant in Northern Japan. Radioactive emissions from the plant caused widespread radioactive contamination of the entire region. The vast majority of the nuclear fallout occurred over the North Pacific, constituting the largest radioactive contamination of the oceans ever recorded. Soil and water samples, as well as marine animals have been found to be highly contaminated. Increased levels of radioactivity were recorded at all radiation measuring posts in the Northern Hemisphere. Fallout contaminated large parts of Eastern Honshu island, including the Tokyo metropolitan area. Within a 20 km radius, up to 200,000 people had to leave their homes. Outside of this evacuation zone, the radioactive fallout contaminated more than 870 km² of land, home to about 70,000 people who were not evacuated. These people were exposed to harmful radioisotopes and now have an increased risk to develop cancer or other radiation-induced diseases. Many people still live in areas with high contamination. Food, milk and drinking water have been contaminated as well, leading to internal radiation exposure. Most severely affected are children, as their bodies are more susceptible to radiation damage. Preliminary tests have shown internal radioactive contamination of children with iodine-131 and caesium-137. It is too early to estimate the extent of health effects caused by the nuclear disaster. Taking into consideration the studies on Chernobyl survivors and the findings of the BEIR VII report, scientists will be able to estimate the effects once the true extent of radioactive emissions, fallout and contamination are better studied. Large-scale independent epidemiological studies are needed in order to better help the victims of this catastrophe. Claims by scientists affiliated with the nuclear industry that no health effects are to be expected are unscientific and immoral.

The nuclear meltdowns

On the 11th of March, 2011, a magnitude 9.0 earthquake hit Northern Japan. This so-called Tōhoku earthquake led to a tsunami on the Eastern coast of Northern Japan, leading to further destruction. More than 15.000 people died as a direct result of the earthquake and tsunami, more than 500.000 had to be evacuated.¹ The Fukushima Daiichi nuclear power plant was severely damaged by the quake and the tsunami. With no electricity to power the cooling systems, water inside the reactors began to boil off, causing meltdowns of the uranium fuel rods inside of reactor cores 1 to 3. TEPCO, the company responsible for the plant, began to vent steam from the reactors in order to relieve pressure and prevent a giant explosion. This steam carried radioactive particles out to the Pacific Ocean.

Since it became evident that a nuclear meltdown was possibly taking place in the reactor cores, a 20 km zone around the power plant (with an area of about 600 km²) was declared an evacuation zone and a total of 200,000 people were forced to leave their homes.² While evacuations were commencing, multiple explosions destroyed reactor 1, 2 and 3 and caused a fire of the spent fuel pond of reactor 4. To cool off the cores, TEPCO took the controversial decision to pump seawater into the reactor. This could not prevent the temperatures from rising even further, as the nuclear fuel rods were left partially uncovered. According to TEPCO, all fuel rods in reactor 1 melted, as well as 57% of the fuel rods in reactor 2 and 63% of those in reactor 3.³ Also, as a result, massive amounts of radioactively contaminated water flowed into the groundwater and back into the ocean.

On March 25th, people living in the 30 km radius were asked to voluntarily evacuate their homes and leave the contaminated areas. On April 12th, the Fukushima nuclear meltdowns were categorized as a level 7 nuclear accident – the highest level on the International Nuclear Event Scale (INES), which had previously only been reached by the Chernobyl disaster.

Radioactive emissions into the atmosphere

The four large explosions, the fire of the spent fuel pond, smoke, evaporation of sea-water used for cooling and deliberate venting of the pressurized reactors all caused the emission of radioactive isotopes into the atmosphere. Measurements of radioactivity taken outside of the power plant reached a maximum of 10.85 mSv/h, or about 38,000 times the normal background radiation. Further deliberate venting of block 2 and 3 on March 16th led to additional air-borne releases of radioactivity in similar magnitudes.⁴ Radioactivity doses around the plant a week after the earthquake reached levels of up to 1,930 µSv/h – more than 6,000 times normal background radiation.⁵

Using data from radioactivity measuring posts set up under the Comprehensive Test Ban Treaty (CTBT), the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) calculated the amount of radioactivity released by the Fukushima meltdowns to be between 360-390 PBq of iodine-131 and around 50 PBq of caesium-137 for the period of March 12th – March 14th. According to their calculations, the iodine-131 emissions from Fukushima in those three days amounted to 20% of the total iodine-131 emissions from Chernobyl (1,760 PBq), while the emissions of caesium-137 in those three days amounted to about 60% of the total caesium-137 emissions from Chernobyl (85 PBq).⁶

A study by the Norwegian Institute for Air Research (NILU) found that around 16,700 PBq of xenon-133 (250% of the amount released at Chernobyl) were emitted by the Fukushima power plant between March 12th and 19th. This constitutes the largest release of radioactive Xenon in history. Xenon-133 is a radioactive gas with a half-life of 5.2 days, which emits beta- and gamma-radiation and cause harm upon inhalation. Additionally, the NILU study found that 35.8 PBq of caesium-137 (42% of the amount released at Chernobyl) were emitted by the Fukushima power plant between March 12th and 19th. Their study found that radioactive emissions were first measured right after the earthquake and before the tsunami struck the plant, showing that the quake itself had already caused substantial damage to the reactors. The NILU report also suggests that the fire in the spent fuel pond of reactor 4 may have been the major contributor of airborne emissions, since emissions decreased significantly after the fire had been brought under control.⁷

In its report to the IAEA, the Japanese government states that the total amount of fission products released into the atmosphere amounts to 840 PBq, a number even higher than previous estimates. Their calculations for the emission of iodine-131, caesium-137 and xenon-133 show results in the same magnitude as those calculated by the ZAMG and NILU scientists. In addition to the emission of iodine-131, caesium-137, strontium, plutonium and xenon-133 listed below in Table 1, a number of other radioactive isotopes were also released, namely caesium-134, barium-140, tellurium-127m, tellurium-129m, tellurium-131m, tellurium-132, ruthenium-103, ruthenium-106, zirconium-95, cerium-141, cerium-144, neptunium-239, yttrium-91, praseodymium-143, neodymium-147, curium-242, iodine-132, iodine-133, iodine-135, antimony-127, antimony-129 and molybdenum-99.⁸

Table 1: Estimated amounts of total emissions

Radioactive Isotope	Value	Period of time	Reference
Iodine-131	360-390 PBq 319 PBq	March 12 th -14 th March 12 th -15 th	ZAMG ⁹ TEPCO ¹⁰
Caesium-137	50 PBq 35.8 PBq 30.3 PBq	March 12 th -14 th March 12 th -April 20 th March 12 th -15 th	ZAMG ¹¹ NILU ¹² TEPCO ¹³
Strontium-89/90	4.24 PBq	March 12 th -15 th	TEPCO ¹⁴
Plutonium-238/239/240/241	2.500.000 MBq	March 12 th -15 th	TEPCO ¹⁵
Xenon-133	16,700 PBq 22,300 PBq	March 12 th -April 20 th March 12 th -15 th	NILU ¹⁶ TEPCO ¹⁷

The radioactive particles were carried away by prevailing wind currents in the form of radioactive clouds, similar to the phenomenon after the Chernobyl disaster. According to the Norwegian Institute for Air Research (NILU), precipitation from the radioactive clouds released approximately 79% of the total caesium-137 above the North Pacific Ocean. Approximately 19% of the caesium-137 (6.4 million MBq) precipitated above the landmass of Eastern Honshu Island.¹⁸ While western Japan was sheltered by mountain ranges, large areas of north-eastern Honshu Island, including the Tokyo metropolitan area, were radioactively contaminated by nuclear fallout. The radioactive cloud created a trace of contamination more than 40 km in length and about 20 km width with hot-spots where precipitation was highest.¹⁹ The remaining 2% were spread further East, as the radioactive cloud reached North America on March 15th and Europe on March 22nd.²⁰ Three weeks after the earthquake, all CTBT-measuring posts in the Northern Hemisphere recorded increased atmospheric radioactivity. By the middle of April, these measurements began to decrease, as radioactive particles had precipitated over land and water.²¹ Yet even after almost a year, the release of radioactive isotopes has not been brought under control. According to a TEPCO status report from January 27th 2012, atmospheric emission of radioactive caesium was still measured with 60 MBq per hour – that's 1,440 MBq each day.²²

Soil contamination

The nuclear fallout included different types of radioactive particles, each with its own characteristics. The Japanese Ministry of Science and Technology (MEXT) conducted soil surveys in 100 locations within 80 km of the Fukushima power plant in June and July of 2011. In the entire prefecture, they found contamination with various radioactive substances. While the list of radioactive isotopes released during the meltdowns included more than 30 (see previous chapter), the most well-known for causing damage to human tissue are the following:

- **Strontium-90:** Strontium-90 with a physical half-life of 28 years is a beta-emitting radioactive particle. Upon ingestion, it is metabolized similar to calcium. This means that it is incorporated into the bone, where it can remain for many decades (biological half-life of 50 years). In the bone, strontium irradiates the sensible blood-producing bone-marrow and can cause leukemia and other malignant diseases of the blood.²³ The MEXT survey found strontium-90 in concentrations of 1.8-32 Bq/kg in places outside the 30 km evacuation zone like Nishigou, Motomiya, Ootama or Ono.²⁴
- **Iodine-131:** This radioisotope has a relatively short half-life of 8 days. If ingested, it behaves like normal iodine and is incorporated into the thyroid gland. Here, it damages surrounding tissue with beta- and gamma-radiation until its full decay, causing thyroid cancer, especially in children.²⁵ Radioactive iodine has been found in milk, drinking water, vegetables and water around Northern Japan (see section on food and drink below). According to the IAEA, iodine-131 deposition in Tokyo reached 36,000 Bq/m² on March 22nd and 23rd.²⁶ Soil samples in the municipalities of Nishigou, Izumizaki, Ootama, Shirakawa, Nihonmatsu, Date, Iwaki, Iitate, Ono, Minamisoma and Tamura showed concentrations of radioactive iodine-131 between 2,000 and 1,170,000 Bq/kg. In the municipality of Ono, 40 km southwest of the Fukushima plant, MEXT scientists found up to 7,440 Bq/kg of iodine-131 in rainwater samples.²⁷ In August of 2011, MEXT scientists still found iodine-131 concentrations of more than 200 Bq/kg in most of the above-mentioned municipalities, with maximum ranges found in Namie and Iitate of 1,300 and 1,100 Bq/kg, respectively.²⁸ As iodine-131 has a half-life of 8 days, measurements this high, 145 days after the initial fallout on March 15th, either suggest extremely high initial contamination of the soil of more than 288,000,000 Bq/kg or, additional contamination of the area with iodine-131 after the initial fallout on March 15th.
- **Caesium-137:** This radioisotope has a half live of 30 years. Upon ingestion, it is metabolized similar to potassium. This means that it is fairly evenly distributed in the body. Caesium is mainly a beta-emitter, but its decay product barium-137m also produces gamma-radiation. It can cause solid tumors in virtually all organs. Caesium-137 has a biological half-life of 70 days and is secreted through urine similar to potassium. It therefore accumulates in the bladder, where it can cause irradiation of the adjacent uterus and fetus in pregnant women.²⁹ In its comprehensive report of May 2011, the French Institute for Radiation Protection and Nuclear Safety IRSN states that around 874 km² of the area outside of the 20 km evacuation zone must be considered highly contaminated with radioactive caesium. They estimated

concentrations of the radioisotope of more than 600,000 Bq/m², similar to the evacuation zone around the Chernobyl power plant. Caesium-137 levels in Fukushima prefecture even reached up to 30,000,000 Bq/m² in the radioactive trace north-west of the plant and up to 10,000,000 Bq/m² in the neighboring prefectures.³⁰ Soil samples between 20,000 and 220,000 Bq/kg of caesium-137 were found by the scientists from MEXT in the municipalities of Iitate, Kawamata, Name, Katsurao and Nihonmatsu in April 2011.³¹ Even higher values, reaching up to 420,000 Bq/kg of caesium-137 were recorded four months later and in August of 2011.³² According to the IAEA, caesium-137 deposition in Tokyo reached 340 Bq/m² on March 22nd and 23rd.³³ Radioactive caesium was also found in large quantities in beef, rice, milk, fish, drinking-water and other foodstuff after the Fukushima meltdowns (see section on food and drink below).

Table 2: Half-lives of radioactive isotopes³⁴:

Isotope	Physical half-life	Biological half-life	Effective half-life
Iodine-131	8 days	80 days	7.3 days
Caesium-137	30 years	70 days	70 days
Strontium-90	28 years	50 years	18 years

Contamination of the marine environment

Massive amounts of water were used in a desperate attempt to cool the reactors and the burning spent fuel ponds. This led to equally large amounts of radioactive waste water, which was continually discharged into the sea, seeped into soil and ground-water deposits or evaporated into the atmosphere. Between April 4th and 10th, TEPCO deliberately released 10,393 tons of radioactive water according to the official report by the Japanese government.³⁵ After initial estimates of the total contamination of the ocean by TEPCO were 4.7 PBq, scientists from the Japan Atomic Energy Agency and Kyoto University calculated the total to be 15 PBq, as the amount of radioactive contamination by secondary fallout had been ignored in the initial estimations.³⁶ Calculations by the IRSN even reached an amount of 27 PBq.³⁷ Regardless of which calculation is ultimately agreed upon, the Fukushima fallout constitutes the single highest radioactive discharge into the oceans ever recorded.³⁸ ³⁹ Together with the atmospheric nuclear weapons tests, the fallout from Chernobyl and the radioactive discharge of nuclear reprocessing plants like Sellafield or La Hague, the Fukushima disaster already ranks as one of the prime radioactive pollutants of the world's oceans according to a comprehensive report by the IAEA.⁴⁰

Measurements by the IAEA and the German Society for Reactor Safety showed levels of radioactive iodine in the water close to the Fukushima nuclear power plant of 130,000 Bq/l, while radioactive caesium was detected with concentrations of up to 63,000 Bq/l.⁴¹ ⁴² Activity of radioactive caesium in bottom sediments amounted to 910 Bq/kg in the vicinity of the plant.⁴³ According to the Japanese Atomic Industrial Forum, the levels of radioactive iodine-131 were found to be 7.5 million times the safety limit near reactor No. 2.⁴⁴ Concentrations of caesium-137 28 km off shore were much higher than those measured in the ocean after Chernobyl.⁴⁵ Even 60 km away from the coastline, radiation readings still reached 100 Bq/l, both on the surface and in deep water.⁴⁶ By July 2011, levels of caesium-137 in the coastal waters off Japan were still more than 10,000 times higher than levels measured in 2010.⁴⁷

The waters north-east of the Fukushima plant are amongst the busiest fishing zones in the world. Half of Japan's sea-food comes from this area. Fish and other marine animals in Ibaraki prefecture showed elevated levels of radioactive isotopes and had to be treated as radioactive waste (see section on food and drink below).⁴⁸ ⁴⁹ It is often stated that the dilution effect of the radioactive waste discharged into the ocean decreases the effects on the environment and the food chain. It has to be noted, however, that the radioactive particles do not disappear through dilution but are only distributed over a larger area. This is dangerous for two reasons: Due to the spread of radioactive contamination in the Pacific Ocean, more people are potentially affected, as there is no safe minimum threshold for radioactivity.⁵⁰ Even the smallest amount can cause cancer in human beings when ingested with water or food (see section on health effects below). Secondly, the trophic cascade leads to an accumulation of radioactivity in fish higher up the food chain, which are then eaten by humans. Radioactive caesium levels in sea bass caught in the North Pacific continually rose from March until September, for example, with a maximum contamination found on September 15th of 670 Bq/kg.⁵¹

Effects on food and drinking water

As stated above, there is no safe level of radioactivity in food and drinking water. Potentially, even the slightest amount of radioactivity can cause genetic mutation and cancer.⁵² According to the German Society for Radiation Protection, it is estimated that a person is normally exposed to about 0.3 mSv per year through ingestion of food and drink. This should be considered the permissible level of ingested radioactivity in order to prevent excessive health risks. In order not to surpass this level, the amount of radioactive caesium-137 should not exceed 8 Bq/kg in milk and baby formula and 16 Bq/kg in all other foodstuff. Radioactive iodine with its short half-life should not be permitted in food at all.⁵³ In Japan however, the permissible level of radioactive caesium in milk and baby formula was set at 200 Bq/kg and 500 Bq/kg for all other foodstuff. For radioactive iodine, the permissible level was set at 300 Bq/kg for milk and drinking water and 2,000 Bq/kg for vegetables.^{54, 55}

The Fukushima nuclear meltdowns caused a major contamination of food and drink in Japan. According to the IAEA, nearly all vegetable and milk samples taken in Ibaraki and Fukushima prefectures one week after the earthquake revealed levels of iodine-131 and caesium-137 exceeding the radioactivity limits set for food and drink in Japan.⁵⁶ In the months after the catastrophe, contamination was found to be even higher in certain foods:

- **Vegetables and fruits:** Outside of the evacuation zone in Fukushima prefecture, the MEXT survey one week after the earthquake found contaminated vegetables in the municipalities of Iitate, Kawamata, Tamura, Ono, Minamisoma, Iwaki, Tsukidate, Nihonmatsu, Sirakawa, Sukagawa, Ootama, Izumizaki and Saigou, some with iodine-131 concentrations as high as 2,540,000 Bq/kg and caesium-137 concentrations of up to 2,650,000. One month after the meltdowns, concentrations were still found to be above 100,000 Bq/kg for iodine-131 and 900,000 Bq/kg for caesium-137 in some regions.⁵⁷ In Ibaraki prefecture, about 100 km south of the Fukushima plant, the prefectural government announced finding spinach with radioactive iodine-levels of up to 54,100 Bq/kg and radioactive caesium-levels of up to 1,931 Bq/kg. Beside spinach, most other vegetable samples also included more or less radioactivity, most notable mustard plants with 1,200 Bq/kg of iodine-131, parsley with 12,000 Bq/kg of iodine-131 and 2,110 Bq/kg of caesium-137 and Chichitake mushrooms with 8,000 Bq/kg of caesium-137. Lesser amounts of radiation were found on lettuce, onions, tomatoes, strawberries, wheat and barley.⁵⁸
- **Milk:** On March 20th, the IAEA first warned of milk from Fukushima prefecture containing significant amounts of radioactive iodine-131 and caesium-137.⁵⁹
- **Beef:** Distribution of beef continues to be restricted due to radioactive materials exceeding provisional standards in the prefectures Fukushima, Tochigi, Miyagi, Iwate.⁶⁰
- **Rice: Japanese Atomic** According to the Fukushima prefectural government, contaminated rice was found in Onami district and in Date city with caesium-levels reaching 1,050 Bq/kg.⁶¹
- **Drinking water:** The IAEA warned that permissible levels of iodine-131 were exceeded in drinking water samples taken in the Fukushima, Ibaraki, Tochigi, Gunma, Chiba and Saitama prefectures between March 17th and 23rd.⁶² Even in a northern district of Tokyo, tap water contained 210 Bq/l of iodine-131.⁶³
- **Fish and sea-food:** Radioactive caesium in fish and sea-food caught close to the nuclear power plant was found to reach levels of 500-1,000 Bq/kg.⁶⁴ In April of 2011, the Japanese Fishing Ministry measured radioactive iodine and caesium in sand lance from Fukushima prefecture each with an activity of up to 12,000 Bq/kg.⁶⁵ In its "Analysis of Matrices of the Marine Environment", the independent French radioactivity laboratory ACRO found radioactivity readings of more than 10,000 Bq/kg in algae fished outside of the 20 km evacuation zone. One sample even showed levels of 127,000 Bq/kg of iodine-131, 800 Bq/kg of caesium-134 and 840 Bq/kg of caesium-137.⁶⁶
- **Tea:** According to the prefectural government of Shizuoka, a prefecture about 400 km away from Fukushima, local tea leaves were found to be contaminated with 679 Bq/kg of radioactive caesium-137. Radioactive Japanese green tea was discovered in France in June 2011.⁶⁷

Case report: litate village

The village of litate is an example of the effects of radioactive fallout on a typical residential area. The explosion of reactor 2 and the burning spent fuel pond of reactor 4 on March 15th, 2011 led to a massive emission of radioisotopes that were carried 40 northwest by a radioactive cloud, where they precipitated over the village of litate at around 18:00 in the evening. As the village lay outside the concentric 20 km evacuation circle around the plant, no evacuation measures were undertaken.⁶⁸

Two weeks after the nuclear fallout occurred, scientists from the Japanese Ministry of Science MEXT, the university of Hiroshima and the university of Kyoto found radioactivity levels of 2-3 $\mu\text{Sv/h}$ in dust samples inside of buildings and between 2-44.7 $\mu\text{Sv/h}$ on the outside.^{69, 70} A child living in litate and spending about 8 hours of the day outside and 16 hours inside would be exposed to about 148 mSv in the course of a year - 100 times the natural background radiation in Japan of 1.48 mSv per year.⁷¹ Even five months after the fallout, radioactivity levels of around 16 $\mu\text{Sv/h}$ were still recorded in dust samples in litate.⁷² Soil samples taken by MEXT scientists in litate showed radioactive caesium concentration as high as 227.000 Bq/kg, radioactive strontium-90 with concentrations of 32 Bq/kg and radioactive iodine concentrations of up to 1,170,000 Bq/kg. Scientists calculated an individual external exposure dose over the 90 days after the radioactive fallout of 30-95 mSv, depending on movement patterns and habits.⁷³ This amounts to 20-64 times the natural background radiation level or the equivalent of 300-950 chest x-rays over three months (one chest x-ray causes a dose of about 0,1 mSv).⁷⁴ Levels this high are especially dangerous for pregnant women, children and people with reduced immune systems who are more susceptible to the development of cancer.

An additional source of radiation is the inhalation of radioactive particles and the ingestion of contaminated food and water. Japanese government samples found vegetables from litate highly contaminated with more than 2,500,000 Bq/kg of iodine-131 and more than 2,600,000 Bq/kg of caesium-137.⁷⁵ Drinking water was found to contain 965 Bq/l.⁷⁶ No epidemiological data has yet been published on the observed health effects of the litate population (birth statistics, morbidity, etc.).

Effects on health

When discussing health effects of the Fukushima disaster, it is important to distinguish several groups with different risk constellations:

- **Employees, rescue- and clean-up workers:** The most acutely affected by high radiation were the workers and emergency personnel in and around the failing nuclear power plant. According to the Japanese Atomic Information Forum, radiation levels inside the plant peaked at 1,000 mSv/h, a dose that is fatal to human beings exposed to it for more than a few hours.⁷⁷
⁷⁸ While initial airborne emissions decreased gradually, massive amounts of radiation still existed on the site, especially through washout effects of the water which was continually pumped into the plant in order to cool the reactors. By August 1st, five months after the earthquake, radiation of 10 Sv/h was still detected around the plant's premises, endangering the workers involved in the clean-up and shut-down of the plant.⁷⁹ According to the Japanese Atomic Information Forum, a total of 8,300 workers have been deployed in the rescue- and clean-up operations since March. In July, TEPCO announced that 111 workers had been exposed to radiation of more than 100 mSv, some as high as 678 mSv.⁸⁰ Not taken into consideration at all are the effects of internal radiation through ingestion or inhalation of radioisotopes, which may cause diseases similar to those occurring in the liquidators of the Chernobyl accident.⁸¹
- **Inhabitants of contaminated areas:** Following the nuclear meltdowns, the government ordered 200,000 people to evacuate their homes as an area of about 600 km² around the plant was deemed to be uninhabitable due to radioactive fallout.⁸² About 70,000 people, including 9,500 children were still living in highly contaminated areas outside of this evacuation zone two months after the Fukushima meltdowns.⁸³

Radiation levels between 16-115 $\mu\text{Sv/h}$ were measured outside of the 20 km evacuation zone by the IAEA radiation monitoring team.⁸⁴ The IAEA's conservative extrapolations from these soil samples calculate the total dose of beta-radiation in the area of 30-32 km from the plant to be 3,800,000-4,900,000 Bq/m^2 .⁸⁵ MEXT scientists confirmed these readings in their soil surveys in April of 2011: Dose rates recorded in several cities of the affected region outside of the evacuation zone still showed radiation levels of more than 2 $\mu\text{Sv/h}$ in Nihonmatsu, Tamura, Souma, Minamisoma and Date, more than 5 $\mu\text{Sv/h}$ in Fukushima city and Katsurao, more than 10 $\mu\text{Sv/h}$ in Kawamata and Hirono, more than 50 $\mu\text{Sv/h}$ in Namie and more than 100 $\mu\text{Sv/h}$ in Iitate.^{86, 87} Four months later, in August of 2011, the MEXT scientists still found radiation doses of up to 34 mSv/h in Namie, up to 16 mSv/h in Iitate and up to 17,5 mSv/h in Katsurao.⁸⁸

The IRSN projected the external exposure of the 70,000 people living in the highly contaminated areas outside of the 20 km evacuation zone can reach up to 200 mSv in the first year and up to 4 Sv over the course of a lifetime, not including additional radioactive exposure through ingestion of contaminated food, air or water. The external collective dose received over 4 years by this population was calculated to be 4,400 person-Sv. This amounts of about 60% of the collective dose received by the population in the highly contaminated regions around Chernobyl. The IRSN concluded in its report that only the evacuation of people from these areas could lead to a decisive reduction of the radioactive exposure.⁸⁹ Data published by MEXT in April of 2011 seems to confirm these calculations. They estimate doses over the course of one year of up to 235.4 mSv in the town of Namie, 61.7 mSv in Iitate, 24.2 mSv in Kawamata, 21.2 in Date, 18 mSv in Katsurao, 15.6 in Minamisoma and more than 10 mSv in Fukushima city and Koriyama – both more than 55 km away from the plant.⁹⁰ The natural background radiation in Japan is 1.48 mSv per year.⁹¹ In April of 2011, the Japanese Ministry of Health calculated that the population in these cities would be exposed to more than 6-160 times the normal background radiation in the year after the catastrophe. In a press release on March 23rd, the Japanese Nuclear Safety Commission estimated the thyroid dose for children of one year to be between 100 mSv and 1000 mSv through inhalation of radioactive iodine-131.⁹²

- **People affected through ingestion of contaminated food:** Fukushima caused the greatest radioactive contamination of the world's oceans ever recorded.^{93, 94} This and the large-scale contamination of harvest crops, the pollution of groundwater supplies and the high permissible levels of radioactivity in food and drink have led to the ingestion of radioactive particles like iodine-131, strontium-90 or caesium-137 by people in Japan, in countries around the North Pacific and everywhere contaminated products ended up in markets or on the supermarket shelves. As stated in the section on food and drinks, the MEXT survey found vegetables contaminated with iodine-131 concentrations of more than 100,000 Bq/kg and caesium-137 concentrations of more than 900,000 Bq/kg one month after the meltdowns. The external radiation dose of these vegetables lay between 10 and 30 $\mu\text{Sv/h}$.⁹⁵

Knowing the activity (measured in Bq) and multiplying this by a dose coefficient, it is possible to calculate the dose of internal radiation (measured in Sv). In 2010, the European Committee on Radiation Risks (ECRR) published such dose coefficients specifically for nuclear disasters where internal radiation exposure through ingestion or inhalation plays a large role in the development of cancer diseases.⁹⁶ Using these dose coefficient, listed in detail below, it can be calculated that the internal organs of an adult eating 500g of food contaminated with 100,000 Bq/kg of iodine-131 and 900,000 Bq/kg of caesium-137 would be exposed to about 34,8 mSv . As stated above, the normal exposure to internal radioactivity through food per year is 0.3 mSv .⁹⁷ Eating just 500g of this contaminated food would cause an internal radiation exposure of more than 100 times the normal exposure per year. For a child of 1-14 years, the internal radiation exposure would be double that of an adult and for toddlers and fetuses, the impact of radioactively contaminated food is even more harmful as the different dose coefficients in Table 3 and the exemplary calculation in Table 4 demonstrate:

Table 3: Dose coefficients upon ingestion in Sv/Bq , depending on age⁹⁸

Isotope	Fetus	Child < 1 year	Child 1-14 years	Adult
Iodine-131	5.5×10^{-6}	5.5×10^{-7}	2.2×10^{-7}	1.1×10^{-7}
Caesium-137	3.2×10^{-6}	3.2×10^{-7}	1.3×10^{-7}	6.5×10^{-8}
Strontium-90	4.5×10^{-4}	4.5×10^{-5}	1.8×10^{-5}	9.0×10^{-6}

Table 4: Examples for internal radiation through ingestion of contaminated food in children*

Type of food	Quantity	Activity	Isotope	Child < 1 yr	Child 1-14 yr
Fukushima vegetables March 2011 ⁵⁷	500g	2,540,000 Bq/kg	I-131	698.50 mSv	279.40 mSv
Fukushima vegetables March 2011 ⁵⁷	500g	2,650,000 Bq/kg	Cs-137	424.00 mSv	172.25 mSv
Fukushima vegetables April 2011 ⁵⁷	500g	100,000 Bq/kg	I-131	27.50 mSv	11.00 mSv
Fukushima vegetables April 2011 ⁵⁷	500g	900,000 Bq/kg	Cs-137	144.00 mSv	58.50 mSv
Ibaraki spinach March 2011 ⁵⁸	500g	54,100 Bq/kg	I-131	14.88 mSv	5.95 mSv
Ibaraki spinach March 2011 ⁵⁸	500g	1,931 Bq/kg	Cs-137	0.31 mSv	0.13 mSv
Fukushima rice, November 2011 ⁶¹	500g	1,050 Bq/kg	Cs-137	0.17 mSv	0.07 mSv
Tap water in Iitate March 20th, 2011 ⁷⁶	1 l	965 Bq/l	I-131	0.53 mSv	0.21 mSv
Tap water in Tokyo March 23 rd , 2011 ⁶³	1 l	210 Bq/l	I-131	0.12 mSv	0.05 mSv
Sea bass caught in September 2011 ⁵¹	500g	670 Bq/kg	Cs-137	0.11 mSv	0.04 mSv

As stated before, the greatest health effects of radiation are seen in children. They have a higher surface area, a more permeable skin, their immune systems are not yet fully developed, they breathe in more air per minute than adults, the metabolism of their tissues is higher and their habits like playing on or eating from the ground lead to a higher exposure to radiation. In the womb, the unborn child receives radioactive isotopes through the umbilical vein and is irradiated by gamma-radiation from isotopes collected in the bladder. Radioactive isotopes like iodine-131 are also transmitted through breast-milk. In May of 2011, the MEXT published a list of soil measurements taken in kindergartens, schools and day-care centers. None of the places surveyed had radioactive iodine-131 measurements below 1,200 Bq/kg. The highest measurement was found at an elementary school in Date city: 6,800 Bq/kg of iodine-131.⁹⁹ Concerning caesium-137, the soil concentrations laid between 620 Bq/kg and 9,900 Bq/kg.⁸ After the Fukushima disaster, the Japanese government raised the permissible level of radioactive exposure for children to 3.8 μ Sv/h, which amounts to about 20 mSv per year on April 19th, 2011.¹⁰⁰ After protests by parent organizations, scientists and doctors, the government rescinded the new guidelines on May 27th, distributed dosimeters to all students in the region and returned to the former permissible level of 1 mSv per year.¹⁰¹

Iodine-131 is one of the most acute reasons for cancer development in children after a nuclear meltdown. Uptake of radioactive iodine can be prevented by timely medication with stable iodine tablets. While such iodine tablets were handed out to the municipalities and evacuation centers during the first few days of the disaster, the order to distribute these tablets to the population were never issued and hence, except for very few exceptions, no iodine tablets were taken by people exposed to radioactive iodine.¹⁰² This may lead to a large number of cases of thyroid cancer in the future, as experiences from Chernobyl have shown. First studies have been performed to estimate the effect of radioactive iodine-131 on the thyroid glands of children. In the end of March, 2011, a group of researchers around Hiroshima University professor Satoshi Tashiro tested 1,149 children aged 0 to 15 from Iwaki city, Kawamata town and Iitate village. 44.6 % of these 1,080 valid results showed radioactive contamination of up to 35 mSv in their thyroid glands. The results of this study were presented to the Japan Pediatric Society on August 13th, 2011, but have not been published yet.¹⁰³ In October of 2011, the University of Fukushima began with thyroid-examinations on 360,000 children living in the regions affected by radioactive contamination. The university hopes to have finished initial testing of all children by the end of 2014. According to the Japanese Atomic Industrial Forum, the affected children would then have to undergo biannual check-ups until the age of 20 and every 5 years above that age for the rest of their lives.¹⁰⁴

Radioactive caesium is another substance posing a health threat to children. A large-scale urine study performed on 1,500 children from Minamisoma in November of 2011 found caesium concentrations of 20-30 Bq/l and, in the case of a one-year old boy, even up to 187 Bq/l.¹⁰⁵ These measurements do not allow extrapolation of radiation exposure dose, but show that some amount of radioactive caesium had to have been ingested by these children and remained in their systems for it to show up in urine samples eight months after the catastrophe.

*The average annual dose of internal radioactivity through food and drink is about 0.3 mSv, which breaks down to about 0.0008 mSv per day. All of these exemplary calculations result in doses above this daily level.

Not a single epidemiological study on the health effects of the Fukushima nuclear catastrophe has yet been published in a peer-reviewed journal. Except for the unpublished small studies cited above, there is no scientific data to ascertain the extent to which the people of the affected regions will be affected. As for estimations, we have a fairly good idea of the effects of external high-level radiation of more than 100 mSv on the human body from Hiroshima and Nagasaki.¹⁰⁶ We know that a certain dose of radiation can cause acute radiation sickness and can lead to the development of malignant diseases in the long-term.

The studies after Chernobyl have shown however that after a nuclear meltdown, the more relevant mode of radioactive exposure in terms of population health is internal low-level radiation (<100 mSv) through the incorporation of radioactive particles.^{107, 108} These particles remain inside the body, damaging internal organs and causing malignancies many years after initial exposure. The overall health impact of internal radiation is naturally very difficult to ascertain. After the Chernobyl disaster, a study published in the International Journal of Cancer estimated an additional 41,000 cases of cancer and more than 15,000 additional cancer deaths due to radiation from the nuclear fallout.¹⁰⁹ Birth defects, genetic mutations, infertility and still-births also rose significantly after the nuclear catastrophe in 1986. Additionally, numerous studies have been published in recent years, showing a significant rise in the incidence of non-cancer diseases amongst the affected populations.¹¹⁰

The National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) published a lifetime cancer risk model in its report "Health risks from exposure to low levels of ionizing radiation", also known as BEIR-VII. Taking into consideration the effects of ionizing radiation on human tissue, the BEIR committee calculates that exposure to 1 Sv causes cancer in 1 out of 10 people, while exposure to 100 mSv would cause cancer in 1 out of 100 people, exposure to 10 mSv in 1 out of 1,000 people and so on.¹¹¹ This model has been used to calculate expected cancer cases in similar accidents, such as the Chernobyl disaster, and could be used to predict excess cancer cases in the people affected by the Fukushima fallout. For the 70,000 people in the highly contaminated regions outside of the evacuation zone, IRSN calculated a dose of up to 200 mSv in the first year after the catastrophe. If it is assumed that all of these people remained in the region and did not evacuate, the BEIR model roughly estimates a cancer rate of 2%. According to this example, about 1,400 people would be expected to contract cancer due to the additional radiation from Fukushima fallout during this one year. This does not yet take into consideration the effects of internal radiation through ingestion or inhalation of radioactive particles. Also, this model does not take into consideration the higher susceptibility to radiation by children and people with immune deficiencies. As no estimates exist regarding the total amount of internal radiation exposure through ingestion or inhalation and as the amount of radiation discharged from the Fukushima plant continues to rise (according to TEPCO, atmospheric emissions of radioactive caesium still occurred at 1,440 MBq/h on January 27th, 2012)¹¹², calculations of expected cancer cases or deaths are not possible at this stage.

Ultimately, no proper estimates can be made on the basis of the existing data. Large-scale epidemiological studies are needed in order to better understand the effects of internal low-level radiation and to estimate the extent of health effects in the coming decades and possibly even for future generations. It is important that these studies are undertaken by independent researchers and not by organizations with the aim to promote nuclear energy, such as the IAEA.**

As with Chernobyl, the case will not be closed for many decades to come. While short-lived radioisotopes like iodine-131 decay below critical levels within a matter of months, long-lived substances like caesium-137 or strontium-90 will continue to emit radioactivity and endanger human life for many decades. More than half of the total caesium-137 emitted by the Chernobyl disaster in 1986 is still emitting radiation, as the half-life of 30 years has not been reached. Also, latency periods of malignant diseases have to be considered in order to get a complete picture of the health impacts. Considering the victims of this disaster, the claim by several government advisers in Fukushima that the nuclear catastrophe will have little to no effect on people's health is not only unscientific but also deeply immoral.

** According to Article 1, Paragraph 3 and Article 3, Paragraph 1 of the "Agreement between the International Atomic Energy Agency and the World Health Organization", the WHO is bound by agreement not to publish scientific articles without consent by the IAEA. This agreement was approved by the World Health Assembly May 28th, 1959 in resolution WHA12.40 and can be found on the WHO website at <http://apps.who.int/gb/bd/PDF/bd47/EN/agreements-with-other-inter-en.pdf>

Conclusions:

- The damage to the Fukushima Dai-ichi nuclear power plant leading to the emission of radioactivity was caused primarily by the 9.0 magnitude earthquake. Further damage was incurred by the ensuing tsunami. Overheating of the core due to total power failure then caused separate nuclear meltdowns in reactors 3 and the spent fuel pond of reactor 4
- Atmospheric emissions of more than 30 radioactive isotopes occurred through the explosions in reactors 1-3 and the spent fuel pond of reactor 4, smoke from the ensuing fires, deliberate venting of the reactors to relieve pressure as well as the evaporation of massive amounts of water used for cooling the reactors
- Total emission of iodine-131 in the first three to four days of the Fukushima nuclear disaster amounted to about 20% of the total iodine-131 emissions of the Chernobyl nuclear disaster. Total emission of caesium-137 in the first three to four days of the Fukushima nuclear disaster amounted to about 40-60% of the total caesium-137 emissions of the Chernobyl nuclear disaster
- While iodine-131 and caesium-137 are the most prominent radioactive isotopes emitted by Fukushima, strontium-90, xenon-133, plutonium-239 and more than two dozen more radioactive substances were spread throughout the region as radioactive fallout.
- Marine and groundwater contamination was caused by backflow and deliberate discharge of radioactive waste water from the plant. With approximately 15-27 PBq of radioactive marine discharge, the Fukushima nuclear disaster constitutes the single worst radioactive contamination of the oceans ever recorded. Dilution and dispersion effects may reduce the amount of contamination in the vicinity of the plant, but only causes the long-lived radioactive isotopes to spread out over a larger area, exposing an even greater population to the effects of radioactive contamination.
- Radioactive fallout occurred mainly above the Northern Pacific (79%), with about 19% of the fallout contaminating Eastern Honshu island, including the Tokyo Metropolitan area and leaving an area of more than 1000 km² highly contaminated with radioactive isotopes
- 200,000 people were forced to leave their homes as a 20 km² zone around the plant was evacuated indefinitely
- 70,000 people remained in more than 870 km² of highly contaminated land outside of the evacuation zone, where they were exposed to an external radioactivity 100 times higher than the normal background radiation in the first year after the catastrophe.
- The risk of developing cancer and other radiation-induced diseases increased proportionally to the amount of radioactive exposure. There is no lower threshold, as even the slightest amount of radioactivity can cause harmful tissue damage and genetic mutations.
- Radioactive contamination has been detected in all kinds of fruits and vegetables grown in the affected regions as well as in meat of animals grazing on contaminated land. Radioactivity has also been detected in milk, tea and tap water, even in the Tokyo Metropolitan area. Eating just 500g of contaminated vegetables can cause internal exposure to more than 100 times the normal annual amount of radioactive food content for adults and more than 200 times for children.
- Fish and seafood caught in the North Pacific are highly contaminated, with a clear accumulation of radioactivity in animals higher up the food-chain in the months after the disaster. Washout and bioaccumulation will continue to cause radioactive contamination of marine animals for many years.
- Children are most severely affected by radioactivity, as their bodies have a higher sensibility and as their natural habits expose them to greater dosage. Raising the permissible radioactive dose level to 20 mSv per year and withholding iodine tablets has led to a high exposure of children in Fukushima prefecture.
- It is too early and too little data exists in order to estimate the extent of health effects caused by the nuclear disaster. Large-scale epidemiological studies are required in order to determine the effect and the extent of health consequences for the population. It is important that this research is performed by independent groups not associated with the nuclear industry, such as TEPCO, JAEA, the IAEA or affiliated organizations.
- Claims by scientists affiliated with the nuclear industry that no health effects are to be expected are unscientific and immoral.

Abbreviations:

Scientific units:

- Bq Becquerel, SI unit for radioactivity
- MBq Megabecquerel (1×10^6 Becquerel)
- PBq Petabecquerel (1×10^{15} Becquerel)
- Sv Sievert, SI unit for dose equivalent
- mSv Millisievert (1×10^{-3} Sievert)
- μ Sv Microsievert (1×10^{-6} Sievert)

Acronyms:

- BEIR National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation
- CTBT Comprehensive Test Ban Treaty
- ECRR European Committee on Radiation Risks
- GRS Gesellschaft für Anlagen- und Reaktorsicherheit (German Society for Reactor Safety)
- GS Gesellschaft für Strahlenschutz (German Society for Radiation Protection)
- IAEA International Atomic Energy Agency
- INES International Nuclear Event Scale
- IRSN Institut de Radioprotection et de Sûreté Nucléaire (French Institute for Radiation Protection and Nuclear Safety)
- JAEA Japan Atomic Energy Agency
- MAFF Japanese Ministry of Agriculture, Forestry and Fisheries
- MEXT Japanese Ministry of Education, Culture, Sports, Science and Technology
- NILU Norsk institutt for luftforskning (Norwegian Institute for Air Research)
- TEPCO Tokyo Electric Power Company
- WHO World Health Organization
- ZAMG Zentralanstalt für Meteorologie und Geodynamik (Austrian Central Institute for Meteorology and Geodynamics)

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