Chapter

1

Overview of the Great East Japan Earthquake

1. Overview of the damage

1) Occurrence of the Great East Japan Earthquake

At 2:46 pm on March 11, 2011, a massive magnitude 9.0 earthquake originated off the coast of Sanriku, in northeastern Japan. On the Japanese scale of 0 to 7, the earthquake was 7 in Kurihara City, Miyagi Prefecture, and 6+ in Shirakawa City, Sukagawa City, Kunimi Town, Ten-ei Village, Tomioka Town, Okuma Town, Namie Town, Kagamiishi Town, Naraha Town, Futaba Town, and Shinchi Town in Fukushima Prefecture. Along with violent shaking of the earthquake, a massive tsunami was generated, hitting the Pacific coast from Aomori to Chiba Prefectures, and devastating the cities and towns of Hamadori, the coastal area of Fukushima Prefecture (Figure 1).

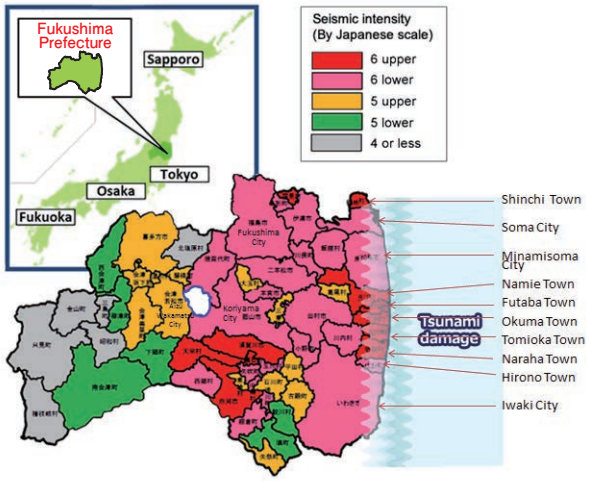

Figure 1. Seismic intensities recorded in Fukushima Prefecture

Source: Fukushima Prefecture. "Fukushima Revitalization Station" (http://www.pref.fukushima.lg.jp/site/portal-english/en03-01.html)

The earthquake and tsunami severely damaged the Fukushima Daiichi Nuclear Power Plant (hereinafter "Fukushima Daiichi", one of two nuclear plants on the Fukushima coast operated at that time by TEPCO, the Tokyo Electric Power Company), located in the towns of Okuma and Futaba in Futaba County, causing hydrogen explosions in the reactor buildings and releasing radioactive materials into the atmosphere and ocean. For the first time in Japan's history of nuclear accidents, residents were directed to evacuate, and many had to live in shelters.

2) Occurrence of a compound disaster in Fukushima Prefecture

In Fukushima Prefecture, in addition to the earthquake and tsunami damage, a nuclear accident occurred, and furthermore, harmful rumors emerged about radioactive contamination (Table 1).

A major characteristic of the disaster in Fukushima Prefecture is the complex combination of four disasters, which required a wide range of countermeasures to address the problems associated with long-term evacuation, damage from rumors, inability to return to one's hometown, and health-related anxieties[1].

3) Nuclear crisis

(1) Occurrence of the nuclear power plant accident

The earthquake caused tremendous damage to a wide area of eastern Japan, mainly in the prefectures of Fukushima, Miyagi, and Iwate. Among them, the Fukushima Daiichi Nuclear Power Plant accident, which occurred in conjunction with the

Table 1. Major damage in Fukushima Prefecture

Major damage	Instances
Earthquake	Human casualties, long-term evacuation, collapse of houses and buildings, damage to infrastructure and agricultural, forestry, and fishery facilities
Tsunami	Human casualties, long-term evacuation, destruction of houses and buildings, salt damage to agricultural land, accumulated debris
Nuclear Accident	Human casualties, long-term evacuation, health concerns, radioactive contamination, entry restriction to former residential areas
Reputational Damage	Boycott against and price decline of Fukushima products, decrease in tourism, descrimination and stigma

Source: Fukushima Prefecture. "Record of the Great East Japan Earthquake and Steps for Revitalization" p. 86, 2013

earthquake and tsunami, was of particular significance to Fukushima Prefecture.

Fukushima Daiichi is located in the center of coastal Hamadori, in Futaba County, with four reactors (Units 1 through 4) in the town of Okuma and two reactors (Units 5 and 6) in the town of Futaba to the north, all facing the Pacific Ocean to the east. The total power generation capacity of the six reactors was 4,699,000 kW.

When the earthquake struck on the afternoon of March 11, 2011, Units 1, 2, and 3 were in normal operation while Units 4, 5, and 6 were undergoing routine inspections, for which the fuel had been removed from Unit 4. Immediately after the earthquake, reactor scram (emergency shutdown) was initiated as designed at Units 1 through 3. Although external power was interrupted by damage to transmission lines inside and outside Fukushima Daiichi, on-site emergency diesel generators were activated and served as a backup power source for reactor cooling and other safety systems.

However, the tsunami that accompanied the earthquake reached Fukushima Daiichi at 3:35 pm, 49 minutes after the earthquake, with waves 15 meters high hitting the plant. The breakwater, only 6 meters above sea level, and the main buildings, about 10 meters above sea level, were engulfed.

The tsunami almost completely destroyed the power supply for Units 1 through 3. Thus, the cooling systems shut down, leading to meltdowns of nuclear fuel in the reactor cores.

The melting fuel generated a large amount of hydrogen gas, which accumulated in the reactor buildings and caused hydrogen explosions in Unit 1 on March 12 and Unit 3 on March 14. Hydrogen gas, presumably from the adjacent Unit 3, also caused an explosion in Unit 4 on March 15.

On April 12, 2011, the Nuclear and Industrial Safety Agency (NISA) declared that Fukushima had a Major Accident, Level 7 on the 1 to 7 International Nuclear Event Scale (INES). The 1986 Chernobyl accident was also Level 7 on the INES scale.

(2) Release of Radioactive Materials

At dawn on March 12, the day after the earthquake, measurements taken by monitoring cars at Fukushima Daiichi showed that the air dose rate had risen, clear evidence that radioactive materials had been released.

At that time, the containment pressure in Unit 1 rose abnormally and then dropped slightly. It is presumed that there was a leak of radioactive materials from the containment vessel and that it escaped into the atmosphere.

After that, temporary increases in air dose rates were detected many times, due to the effects of venting operations and building explosions.

Air dose rates at several locations around Fukushima Daiichi increased substantially from March 12 until after March 20. This indicated massive release of radioactive materials into the environment. The highest air dose rate of about 12 mSv/h was observed by a monitoring car near the main gate of Fukushima Daiichi at 9:00 am on March 15.

Figure 2 shows the distribution of air dose

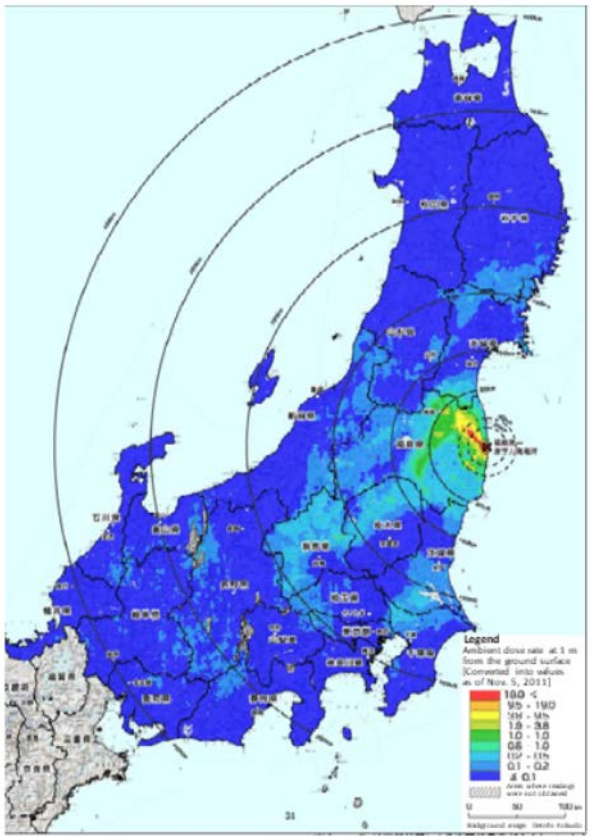

Figure 2. Distribution of ambient dose rates in Fukushima Prefecture and neighboring prefectures

Source: Ministry of the Environment. "BOOKLET to Provide Basic Information Regarding Health Effects of Radiation" (FY2018 Edition)

rates in Fukushima Prefecture and neighboring prefectures as of November 2011, seven months after the nuclear accident.

Among the emitted radionuclides, the ones considered to have the most impact on exposure are ^{131}I (iodine 131), ^{134}Cs (cesium 134), and ^{137}Cs (cesium 137).

Although the half-life of ^{131}I is short (8.04 days), its significance arises from the large amount emitted and its propensity to accumulate in the thyroid gland.

The amounts of ^{134}Cs and ^{137}Cs released were less than one-tenth that of ^{131}I, but with half-lives of 2 years and 30 years, respectively, ^{134}Cs and ^{137}Cs have long-term potential for external exposure.

The estimated amounts of ^{131}I and ^{137}Cs released from Fukushima Daiichi are said to be about 10% and 20%, respectively, of the corresponding amounts released during the Chernobyl accident.

^{89}Sr (strontium) and ^{239}Pu (plutonium) were also released, but in very low amounts. The effects of other radionuclides are thought to be small, owing to their very short half-lives.

The releases that largely determined the levels and patterns of terrestrial radionuclide distribution in Fukushima Prefecture occurred on March 12 and 14-16, during which the meteorological conditions were as follows.[2)]

The release on the afternoon of March 12, resulting from the hydrogen explosion at Unit 1, first spread northward along the east coast of Honshu. It then turned north-northeast and spread to the coastal area of Miyagi Prefecture. In response to this, air dose rates at monitoring posts installed in Minamisoma City, north of Fukushima Daiichi, rose rapidly, from pre-accident levels of around 0.05 μSv/h to as high as 20.0 μSv/h.[3)]

Radioactive materials released late in the night of March 14 moved in a southerly direction and were deposited along the southeastern coastal area of Fukushima Prefecture and the northeastern area of Ibaraki Prefecture on the morning of March 15. As a result, air dose rates detected by monitoring posts installed in Iwaki City rose rapidly, with values around 0.06 μSv/h before the accident rising to a maximum of 23.7 μSv/h. These radioactive materials spread to Tokyo and the surrounding prefectures of Saitama and Kanagawa. In Tokyo's Shinjuku Ward, typical air dose rates of 0.035 μSv/h rose to a maximum of 0.81 μSv/h.[4)]

During the releases from March 12 and 14 to the morning of March 15, there was almost no precipitation (rainfall or snowfall) in Fukushima Prefecture, so the deposition of radioactive materials occurred through a mechanism called dry deposition.

Radioactive fallout by dry deposition is less than that of wet deposition, where radioactive materials fall to the ground along with rain or snow.

The next large release occurred on the morning of March 15. The radioactive materials were being carried to the south, but gradually changed direction to move northwest. The afternoon of March 15 coincided with rain and snow falling in Nakadori, resulting in wet deposition with high radioactivity in the northwest direction from Fukushima Daiichi.

In conjunction with this, detected air dose rates in Fukushima City, which is located northwest of Fukushima Daiichi, rose rapidly from pre-accident levels around 0.05 μSv/h to a maximum of more than 20 μSv/h.[3)]

In areas affected by the deposition of radioactive materials, radionuclides such as ^{131}I, ^{134}Cs, and ^{137}Cs were detected in food, drinking water, and crops.

Monitoring of food and drinking water by the government and prefectures began on March 16. Following guidance issued from the Ministry of Health, Labour and Welfare (MHLW) on March 17, the distribution of certain foods (milk, vegetables, grains, meat, fish, and others) containing radioactive materials exceeding the provisional regulation values was banned on March 21, and their consumption was also banned two days later on March 23.

In order to prevent the distribution of rice with radioactivity in excess of standard allowable values, all rice produced in Fukushima Prefecture, including rice for private consumption and other uses, has been subjected to an all-bag inspection of unpolished (brown) rice for eight years starting in 2012. Since no brown rice has

exceeded standard allowable values since the 2015 crop, the all-bag inspection has been conducted in limited areas since 2020.[2)]

The radioactive materials deposited on the ground included many radionuclides with short half-lives, such as ^{131}I, so as they decayed, air dose rates also rapidly decreased at a relatively early stage. The air dose rate in Fukushima City also dropped to about 3 μSv/h by the end of March.[3)] ^{131}I, which had been detected in food and drinking water, gradually became undetectable. At first, ^{131}I was detected in tap water in 13 of Japan's 47 prefectures, but since April, only very small amounts of ^{131}I had been detected in some areas.[6)]

After the radionuclides with short half-lives gradually weakened and disappeared, mainly cesium (^{134}Cs and ^{137}Cs) remained. These nuclides also decrease according to their half-lives, and also the amount of cesium remaining on or in the ground is now considerably less than immediately after the accident because of weathering effects such as wind and rain, as well as decontamination work that started some time later.

With the passage of time and the progress of decontamination work, radiation levels in Fukushima Prefecture have been decreasing (Figure 3).

On the other hand, radioactive materials were released not only into the terrestrial environment but also into the marine environment. There are two pathways for the release of radioactive materials into the ocean. One is for radioactive materials released into the atmosphere to diffuse over the North Pacific Ocean with seasonal winds and then fall to the ocean surface. The other pathway is for contaminated water containing radioactive materials to flow directly into the ocean from the nuclear power plant.

The concentration of radioactive materials near Fukushima Daiichi rose to 100,000 Bq/L (of seawater) immediately after the accident, dropping to 100 Bq/L a month and a half later, then to 10 Bq/L a year and a half later, and now to less than 1 Bq/L.[6)]

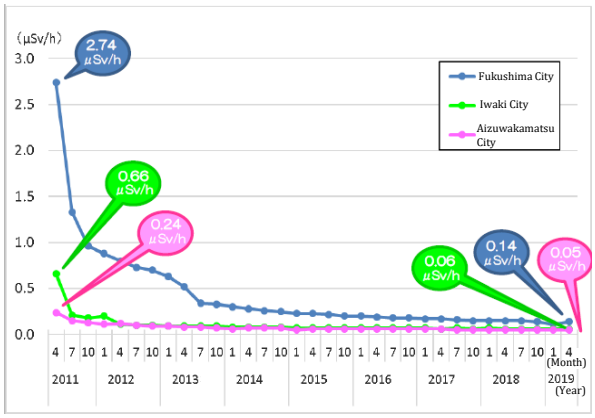

Figure 3. Change of ambient dose rates in Fukushima City, Iwaki City, and Aizuwakamatsu City

Source: Reconstruction Agency. "Current Situation of Damage from Harmful Rumors and Countermeasures." 2019

(3) Evolution of evacuation orders, etc. after the occurrence of the nuclear accident

A) Designation of evacuation zones, etc.

a. Issuance of evacuation orders

The national government and Fukushima Prefecture issued evacuation orders and related measures in response to ongoing risks of the release and diffusion of radioactive materials as a result of the nuclear accident.

The evolution of the evacuation orders was as follows.

[March 11, 2011]

7:03 pm at Fukushima Daiichi

A nuclear emergency situation was declared.

8:50 pm at Fukushima Daiichi

The Fukushima prefectural government issued an evacuation order to those within a 2 km radius of Fukushima Daiichi.

9:23 pm at Fukushima Daiichi

The national government issued an evacuation order for a radius of 3 km and an order to shelter indoors within a radius of 10 km.

[March 12, 2011]

5:44 am at Fukushima Daiichi

The national government issued an evacuation order for a 10 km radius.

7:45 am at Fukushima Daini (TEPCO's nuclear power plant located in Naraha Town)

A nuclear emergency was declared.

The national government issued an evacuation order for a 3 km radius and an order to shelter indoors within a 10 km radius.

5:39 pm at Fukushima Daini
The national government issued an evacuation order for a 10 km radius.
6:25 pm at Fukushima Daiichi
The national government issued an order to shelter indoors within a 20 km radius.

[March 15, 2011]
11:00 am at Fukushima Daiichi
The national government issued an order to shelter indoors within a 20-30 km radius.

Source: Fukushima Prefecture, Records of the Great East Japan Earthquake and Steps for Revitalization, 123, March 2013. (in Japanese)

Moreover, in Kawauchi Village and Hirono Town, evacuation orders were issued in areas outside of the nationally designated evacuation zone, at the discretion of the town and the village.

b. Establishment of planned evacuation zones and emergency evacuation preparation zones

On April 22, 2011, the national government established a 20 km radius from Fukushima Daiichi (including the sea area) as a "restricted zone" and strongly restricted entry.

In addition, on the same day, the national government established a "planned evacuation zone" for areas outside the 20 km radius of Fukushima Daiichi where the cumulative effective dose received by the residents was likely to reach 20 mSv within one year of the nuclear accident, and directed residents to take shelter and be ready to evacuate. At the same time, the government designated the area within the existing "indoor evacuation zone" that does not fall into the above-mentioned "planned evacuation zone" as an "emergency evacuation preparation zone," and directed residents to be prepared to evacuate or shelter in place in case of an emergency (Figure 4). (The designation of the "emergency evacuation preparation zone" was lifted on September 30 of the same year.)

c. Establishment of specific spots recommended for evacuation

From June 30, 2011 to November 25, 2011, the government designated some spots outside of the "planned evacuation zone" and the "restricted zone" where the cumulative effective dose for one year after the accident was estimated to exceed

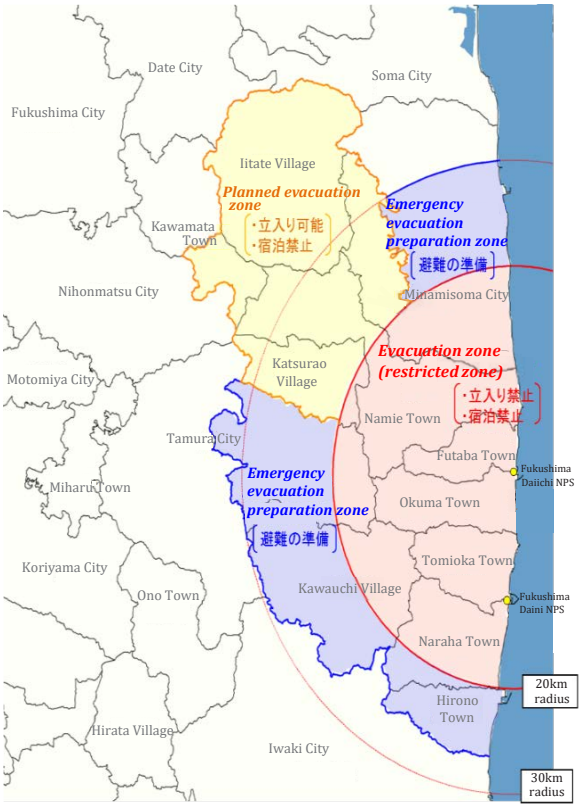

Figure 4. Map of designated evacuation zones as of April 22, 2011

Source: Ministry of Economy, Trade and Industry website.

20 mSv but the size was not large enough to be designated as a planned evacuation zone as "specific spots recommended for evacuation" (Figure 5). (The designation of "specific spots recommended for evacuation" was lifted in Kawauchi Village and Date City on December 14, 2012, and in Minamisoma City on December 28, 2014.)

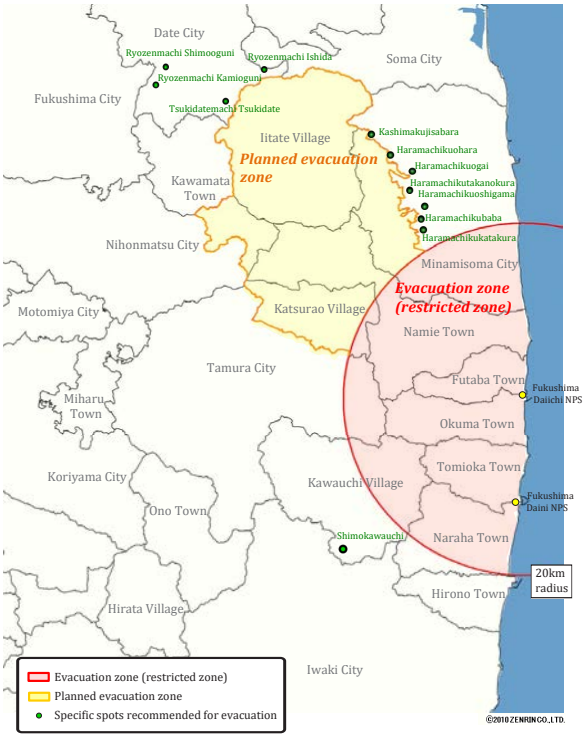

Figure 5. Map of designated evacuation zones as of September 30, 2011
Source: Ministry of Economy, Trade and Industry website.

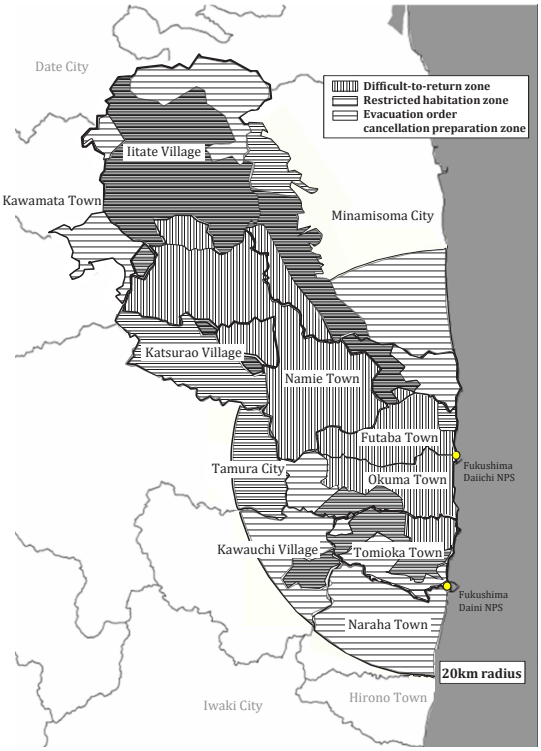

Figure 6. Map of designated evacuation zones as of August 8, 2013
Source: Ministry of Economy, Trade and Industry website.

d. Changes to designated evacuation zones

On December 26, 2011, the Nuclear Emergency Response Headquarters presented the concept of "lifting the designation of restricted zone and changing the designated evacuation zones into difficult-to-return zones, restricted habitation zones, and evacuation order cancellation preparation zones" and the changes to these zones (including planned evacuation zones) were implemented between March 30, 2012 and August 8, 2013 (Figure 6).

B) Elimination of designated evacuation zones

Since the lifting of the designation of the evacuation order cancellation preparation zone in Tamura City on April 1, 2014, the evacuation orders for all the evacuation order cancellation preparation zones and restricted habitation zones were lifted by March 2020, except for the difficult-to-return zone.

The evacuation order for the difficult-to-return zones was lifted for the first time in some areas within the designated reconstruction and revitalization zone set up in Futaba Town, Okuma Town, and Tomioka Town, in conjunction with the full re-opening of the JR Joban Line in March 2020 (Figure 7).

In addition, the evacuation orders that had been issued at the discretion of local authorities were lifted in Kawauchi Village on January 31, 2012, and in Hirono Town on March 31, 2012.

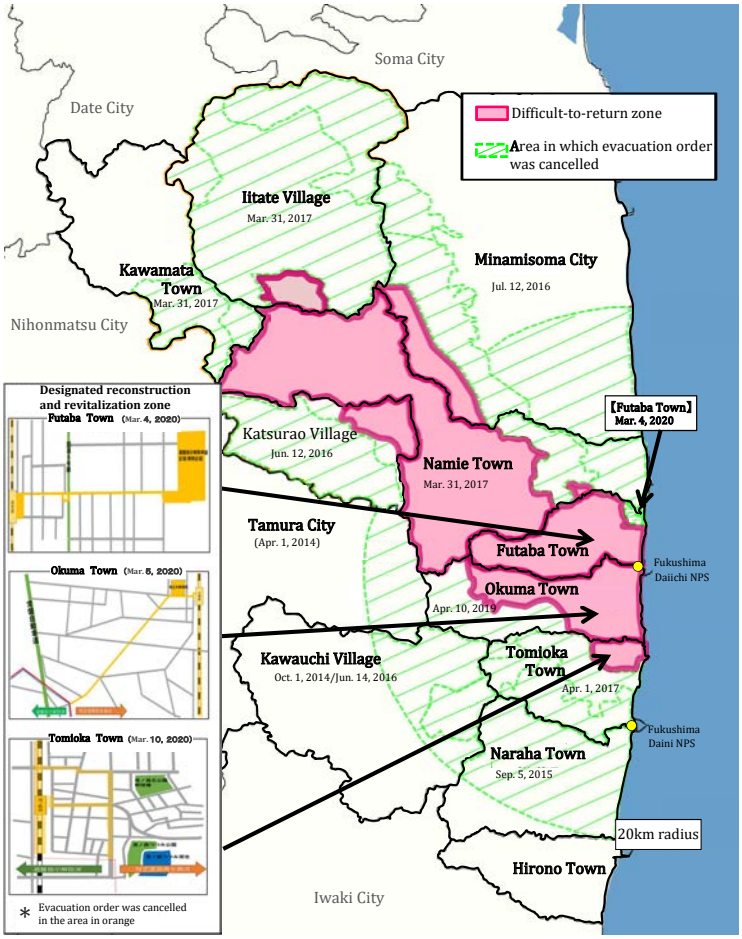

Figure 7. Map of designated evacuation zones as of March 10, 2020

Source: Fukushima Prefecture website.

(4) Number of evacuees

A) Population of Fukushima Prefecture before the earthquake

The population of Fukushima Prefecture before the Great East Japan Earthquake was estimated to be 2,024,401 as of March 1, 2011.

The population by city and county is shown in Figure 8.

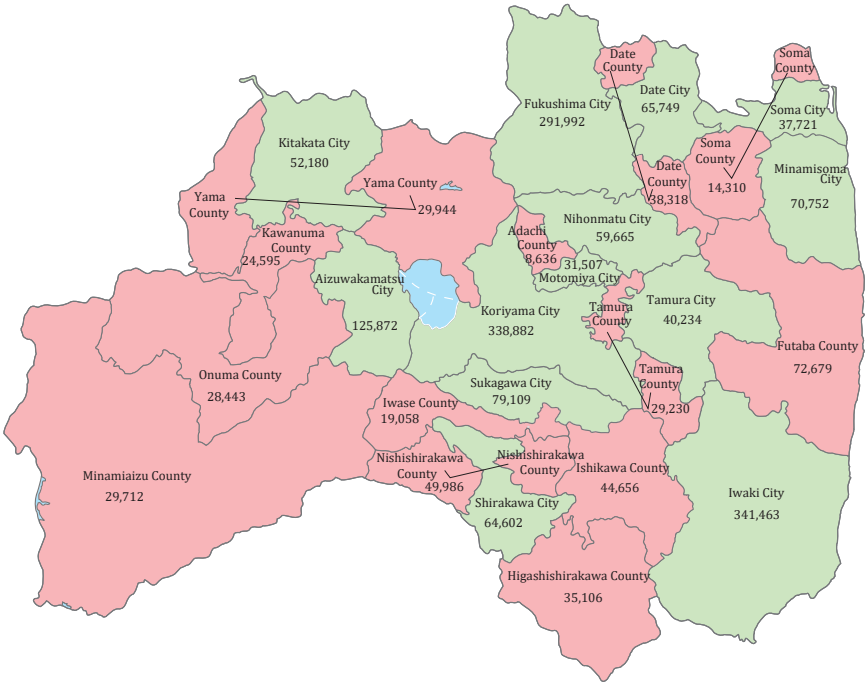

Figure 8. Population of cities and counties in Fukushima as of March 1, 2011

Source: Fukushima Prefecture. "Population Estimates of Fukushima Prefecture FY2011"

B) Changes in the number of evacuees

The number of evacuees reached 164,865 (102,827 in-prefecture evacuees and 62,038 out-of-prefecture evacuees) as of May 2012, one year and two months after the earthquake. Although the number of evacuees has been decreasing year by year since then, as of July 2020, 37,814 people (7,590 in-prefecture evacuees, 30,211 out-of-prefecture evacuees, and 13 people whose evacuation destination was unknown) were still evacuated (Figure 9).

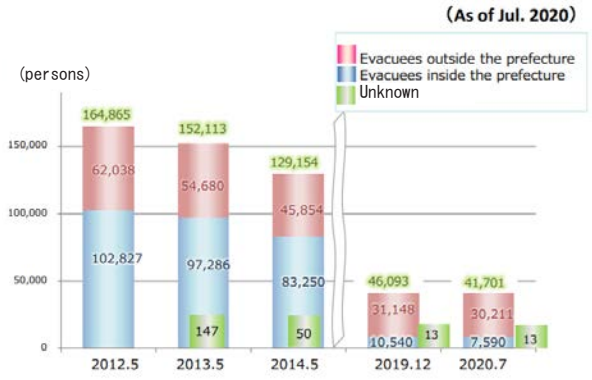

Figure 9. Change in the number of evacuees

Source: Fukushima Prefecture. "Steps for Reconstruction and Revitalization in Fukushima Prefecture." 2020

(5) Situation of first aid following evacuation at the beginning of the disaster

As a result of the nuclear accident, hospitalized patients, care facility residents, and staff had to evacuate. Some of the facilities were unable to evacuate due to the inability to secure transportation, while others evacuated on their own but had to re-evacuate in order to receive the necessary treatment and care because the initial evacuation site was, e.g., a gymnasium. It was necessary to assist in the evacuation of such patients and residents.

The Fukushima Prefecture Disaster Response Headquarters transported 1,310 people (the number known to the prefectural government) from 14 hospitals within a 30 km radius. Of these, approximately 700 were transported to 32 hospitals, including Fukushima Medical University Hospital, and 3 facilities within Fukushima Prefecture, and approximately 600 were transported to 109 hospitals in 8 prefectures.

However, many of the patients and care facility residents transported were in serious condition, some of whom died during transport or at their destination.[7)]

(6) Disaster-related deaths

The number of disaster-related deaths[8)] is substantially higher in Fukushima Prefecture than in Iwate and Miyagi Prefectures, and the confirmed number is still increasing (Figure 10).[9)]

The number of disaster-related suicides is also high in Fukushima Prefecture, and the rate of increase is also high (Figure 11).

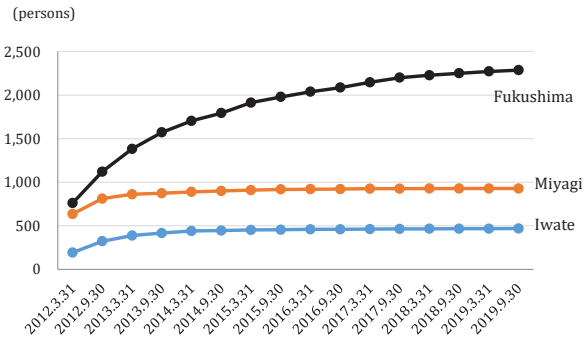

Figure 10. Change in the number of disaster-related deaths in Fukushima, Miyagi, and Iwate

Note: Created based on data from "Number of Disaster-Related Deaths in Great East Japan Earthquake" (the Reconstruction Agency)

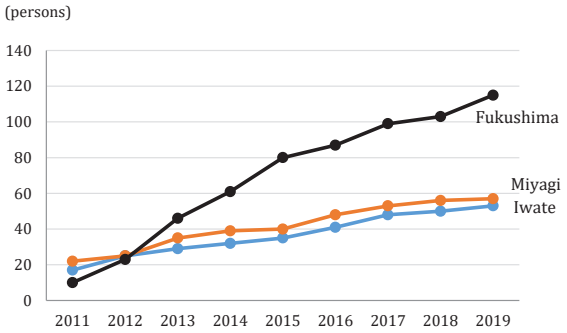

Figure 11. Change in the number of suicides in Fukushima, Miyagi, and Iwate

Note: Created based on data from "FY2018 White Paper on Preventive Measures against Suicide" (Ministry of Health, Labour and Welfare)

Notes and Sources

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