II. Overview of Accident at the Fukushima Dai-ichi Nuclear Power Station

1. Overview of the Fukushima Dai-ichi Nuclear Power Station

(1) Plant overview: dimensions, capacity, citing history, etc.

The Fukushima Dai-ichi Nuclear Power Station (hereinafter referred to as the "Fukushima Dai-ichi NPS") is located in the towns of Okuma and Futaba, which are in the county of Futaba, Fukushima Prefecture. The plant faces the Pacific Ocean on the east. The plant site has a half oval shape with its long axis laid along the beach. The site has a total area size of about 3.5 million m^3.

The Fukushima Dai-ichi NPS is the first of the nuclear power stations built and operated by Tokyo Electric Power Company (TEPCO). The construction of Unit 1 started in April, 1967. The nuclear power station now has six boiling water reactors (BWRs) as a result of reactor units being added one after another. The operation of Unit 1 began in March of 1971. The total installed capacity of the whole plant, including Units 1 through 6, amounts to 4,696,000 kW. For the dimensions, capacity and other details of generation facilities at each unit, see Attachment II-1.

For the principle of power generation by BWR, see Attachment II-2.

(2) Plant layout and structures

Units 1 through 4 are located in the town of Okuma, which is in the county of Futaba, Fukushima Prefecture. Units 5 and 6 are located in the town of Futaba in the same county. For the layout of these reactor units, see Attachment II-3.

Facilities for each reactor unit comprise several buildings including the reactor building (R/B), turbine building (T/B), control building, service building, radioactive waste treatment building and others. Some of these buildings are shared between adjoining reactor units. For the layout of these buildings, see Attachment II-4.

(3) Plant operating organizations, etc.

a. Organizational arrangements during normal operation

For the organization chart of TEPCO as of March 11, 2011, see Attachment II-5.

At the Fukushima Dai-ichi NPS, Site Superintendent supervises two Unit Superintendents and three Deputy Superintendents. At a lower organizational level, there exist the Administration Department, the Emergency Planning & Industrial Safety Department, the Public Relations Department, the Quality and Safety Management Department, the Engineering Management Department, the Operation Management Departments I & II and Maintenance Departments I & II (See Attachment II-6). The operation of reactor facilities is handled by shift teams of TEPCO employees. The manager of Operation Management Department I supervises the shift teams for Units 1 and 2 and the shift teams for Units 3 and 4, while the manager of Operation Management Department II supervises the shift teams for Units 5 and 6. A shift team normally is a team of eleven persons: a shift supervisor, an assistant shift supervisor, two senior operators, an assistant senior operator, two main equipment shift operators and four auxiliary equipment shift operators. By rotation of five such shift teams, the power station manages the 24-hour operation of reactor facilities (See Attachment II-7).

About 1,100 employees of TEPCO work at the Fukushima Dai-ichi NPS. In addition, about 2,000 persons work at the power station on a permanent basis; they are the employees of plant manufacturers or the employees of TEPCO-associated companies that are in charge of fire protection and security guarding, for example. At the time of the 2011 earthquake off the Pacific coast of Tohoku (herein after referred to as the "Tohoku District - off the Pacific Ocean Earthquake"), about 750 employees of TEPCO were on duty in the premises of the power station. In addition, about 5,600 workers were on duty in the premises of the power station, including the permanently stationed employees of TEPCO-associated companies like those who were engaged in the periodical inspection of Units 4 through 6.

b. Organizational arrangements in emergency

According to Article 7, Paragraph 1 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (hereinafter referred to as the "Nuclear Emergency Preparedness Act"), the Fukushima Dai-ichi Nuclear Operator Emergency Action Plan had been established for the Fukushima Dai-ichi NPS. When having reported the occurrence of a specified event according to Article 10 of the Nuclear Emergency Preparedness Act, the nuclear operator must make emergency response arrangements of Level 1. When having reported a specified event according to Article 15 of the Nuclear Emergency Preparedness Act or after the Declaration of the State of Nuclear Emergency made on account of a specified event according to provisions in the same article of the same law, the nuclear operator must make emergency response arrangements of Level 2. Thus, depending on the severity of nuclear emergency, the nuclear operator is required to proceed promptly and smoothly to remove the causes of accident, prevent the spread of damage, and take other necessary actions.

Upon a call for emergency response arrangements of Level 1, the emergency response center must be set up at the Fukushima Dai-ichi NPS (“Fukushima Dai-ichi NPS ERC,” or simply, if clear, “NPS ERC”). The emergency response center (NPS ERC) comprises the intelligence team, communication team, public relations team, engineering team, health physics team, recovery team, operation team, procurement team, infrastructure team, medical treatment team, general affairs team and guard-guidance team. With each of the groups fulfilling its function in emergency response, the power station should ensure readiness for nuclear emergency response activities (See Attachment II-6). The same organizational structure can respond to a call for emergency response arrangements of Level 2, too.

The operation of reactor facilities are continued by shift operators who are included into the operation team, and the organizational arrangements made for them do not differ from the arrangements made under normal plant conditions.

Chapter III-1 describes more about emergency response activities envisaged by the Nuclear Emergency Preparedness Act, etc.

(4) Mechanism for the assurance of safety at nuclear reactor facilities

At nuclear reactor facilities, highly radioactive materials, produced by the fission of uranium, are contained inside the reactors. In order to prevent the external release of radioactive materials due to reasons such as abnormality and failure, nuclear reactor facilities employ multiple safety features based on the concept of defense in depth.

Specifically, the idea is to prevent the radiation exposure of nearby communities by "preventing the occurrence of abnormality[1]," by "preventing the escalation of abnormality and development into an accident," and by "preventing the abnormal release of radioactive materials." For preventing the escalation of abnormality and development into an accident", nuclear reactor facilities are designed to have the capability for quick shutdown of the reactor after the detection of abnormality (shutdown capability). For "preventing the abnormal release of radioactive materials", nuclear reactor facilities are designed to be capable of continuing, after the shutdown of the reactor, the cooling of the reactor core to prevent damage to the fuel that will continue to produce heat through the decay of radioactive materials (cooling capability), and also are designed to prevent the excessive leakage of radioactive materials to the external environment (containment capability) (See Fig. II-1).

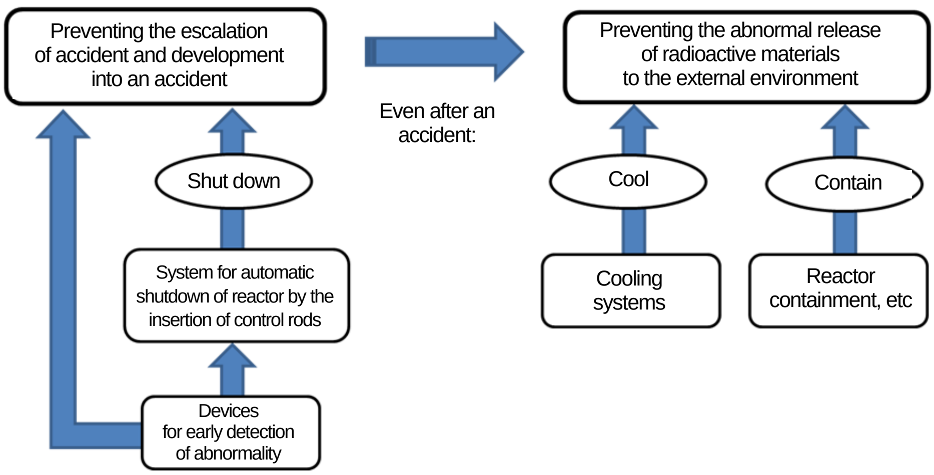

Fig. II-1 Mechanism for assuring the safety of nuclear reactor facilities by ensuring the capabilities of shutdown, cooling and containment

a. Shutdown capability (capability for emergency shutdown of a reactor)

The shutdown of a reactor is managed by the reactor shutdown system. Following the detection of an anomaly the reactor shutdown system adds a large amount of negative

[1] According to "Textbooks for Common Basic Lectures" produced by the Nuclear Technology Safety Center (linked from the Disaster Prevention and Nuclear Safety Network for Nuclear Environment, prepared by the Nuclear Safety Division of the Ministry of Education, Culture, Sports, Science and Technology), effort to prevent the occurrence of abnormality is made in all of the design phase, construction phase and operation phase of nuclear reactor facilities. In the design stage, this is the effort to ensure the sufficiency of safety margin, for example. In the construction phase, this is the effort in safety assurance activities that are conducted to verify the construction of plants according to design, for example. In the operation phase, this is the effort to strictly ensure the completeness of monitoring, inspection and maintenance activities for reactors, for example.

reactivity[2] to the reactor core to quickly decrease the output by stopping nuclear fission reactions in the reactor core.

Major instruments used by the reactor emergency shutdown system include control rods. Control rods are composed of neutron absorbing materials, which bring down the reactivity inside the reactor, and structural materials. The insertion of control rods between the fuel assemblies decreases the reactor output because nuclear fission reactions are controlled by the absorption of neutrons. Following the detection of an anomaly in the reactor, the control rods are quickly inserted into the reactor core to achieve emergency shutdown of the reactor (often referred to as a “scram”).

Another example of facilities used by the reactor shutdown system is the standby liquid (borated water) control system. The system consists of components such as a borated water storage tank, a pump system, a test tank, piping and valves. In the event that the control rods cannot be inserted into the reactor core, it shuts down the reactor by adding negative reactivity by means of injecting borated water, which absorbs neutrons, into the reactor.

b. Cooling capability (capability for cooling the reactor)

Even after the reactor has been shut down by the insertion of control rods into the reactor core, large amounts of radioactive materials in fuel rods continue to generate heat through decay. Therefore, it is necessary to continue the cooling of reactor core to prevent damage to the fuel. Because of this, reactor facilities are equipped not only with feedwater systems for normal use but also with other various types of water injection systems. Such water injection systems inject water into the reactor either by turbine-driven pumps (driven by steam generated by the reactor) or by motor-driven pumps (driven by electric motor). Water injection systems fall into two categories: high pressure systems that can inject water into the reactor even at high reactor pressure, and low pressure systems that can inject water into the reactor only when the reactor pressure has been sufficiently decreased.

The following describe major systems with reactor cooling capability provided for the respective reactor units at the Fukushima Dai-ichi NPS:

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[2] Negative reactivity is an index of margin up to the critical state of the reactor. The presence of negative reactivity indicates a subcritical state of the reactor, which leads to the decrease of reactor output.

(a) Unit 1

Major systems at Unit 1 that have reactor cooling capability include the two trains of core spray (CS) system, two trains of isolation condenser (IS) system, one train of high pressure coolant injection (HPCI) system, one train of reactor shutdown cooling (SHC) system and two trains of containment cooling system (CCS) (See Attachment II-8).

The core spray (CS) system is used when the reactor core is exposed due to the occurrence of a Loss-of-Coolant-Accident. To prevent overheating of the fuel that may cause damage to the fuel or to the fuel rod cladding, the CS system cools the reactor core by spraying water on the fuel from nozzles above the reactor core. The water used in this operation is taken from the pressure suppression chamber (S/C).

The isolation condenser (IC) is used when the main condenser is rendered inoperable due to fracture of the main steam pipe, for example. The IC cools the reactor core without using a pump as it condenses steam inside the reactor pressure vessel into water using a condenser tank for emergency use, and feeds that water back into the reactor. In this case, the atmosphere serves as the ultimate heat sink.

The high pressure coolant injection (HPCI) system is used after the occurrence of a Loss-of-Coolant-Accident due to piping fracture, for example. The HPCI system runs on a turbine-driven pump system, operated using a portion of steam generated in the reactor pressure vessel, to cool the reactor core through the injection of water into the pressure vessel. The water used in this operation is taken from the condensate storage tank or from the S/C.

The reactor shutdown cooling (SHC) system is used to continue the cooling of the reactor after its shutdown by removing the decay heat generated in the reactor core as well as the heat held in the reactor pressure vessel or by the coolant.

The containment cooling system (CCS) is used after the occurrence of a Loss-of-Coolant-Accident. It cools the reactor containment vessel by spraying water inside the reactor containment vessel. The water used in this operation is taken from the S/C.

(b) Units 2 through 5

Major systems with reactor cooling capability at Units 2 through 5 include, like Unit 1 mentioned above, two trains of CS system and one train of HPCI system (per reactor unit). In addition, each reactor unit has one train of reactor core isolation cooling (RCIC) system and two trains of residual heat removal (RHR) system (See Attachment II-8).

The reactor core isolation cooling (RCIC) system is used after the occurrence of failure in feedwater systems, for example. The RCCI system continues the cooling of the reactor core as it runs on a turbine-driven pump system, operated using a portion of steam generated in the reactor pressure vessel, and compensates for the loss of coolant due to evaporation using the supply of water from the condensate storage tank or from the S/C.

The residual heat removal (RHR) system is used to remove residual heat after the shutdown of the reactor. Through the switching of valves, it can function in different modes such as SHC, low pressure coolant injection (LPCI) system or CCS.

(c) Unit 6

Major systems with reactor cooling capability at Unit 6 include one train of RCIC system and three trains of RHR system (both of these systems have been explained above). In addition, Unit 6 has one train of high pressure core spray (HPCS) system and one train of low pressure core spray (LPCS) system (See Attachment II-8).

The high pressure core spray (HPCS) system is used after the occurrence of a Loss-of-Coolant-Accident due to piping fracture, for example. The HPCS system cools the reactor core by spraying water onto the fuel. The water used in this operation is taken from the condensate storage tank or from the S/C.

The low pressure core spray (LPCS) system is used also when a Loss-of-Coolant-Accident has occurred due to piping fracture, for example. The LPCS system cools the reactor core by spraying water onto the fuel from nozzles above the reactor core. The water used in this operation is taken from the S/C.

c. Containment capability (capability for the containment of radioactive materials)

The potential danger of reactor facilities comes from the very strong radioactivity of materials inside the reactor. Therefore, reactor facilities are designed to be capable of preventing excessive release of radioactive materials to the external environment. This is referred to as containment capability.

The first layer of containment is provided by fuel pellets themselves. The pellets of nuclear fuel are fabricated by baking the powder of chemically stable uranium dioxide into hard pellets as in the production of earthenware. The pellets are capable of containing much of the radioactive materials they have without allowing dispersion.

The second layer of containment is provided by the claddings around fuel rods. Pellets are covered by the cladding (tubes) as they compose fuel rods. Since the cladding is airtight, it can contain radioactive materials that are released from the pellets.

The third layer of containment is provided by the reactor pressure vessel that contains the fuel rods. Even though accidental fracturing of the fuel cladding may lead to the release of radioactive materials into the coolant, the reactor pressure vessel can contain such releases because it is designed to withstand high pressure and is highly airtight.

The fourth layer of containment is provided by the reactor containment vessel that contains the reactor pressure vessel. The containment vessel is made of steel and houses major parts of reactor facilities including the reactor pressure vessel.

The fifth layer of containment is provided by the R/B in which the reactor containment vessel exists.

2. Tohoku District - off the Pacific Ocean Earthquake and Tsunami Produced by the Earthquake

(1) Overview of the Tohoku District - off the Pacific Ocean Earthquake

At 14:46 on March 11, 2011, a 9.0-magnitude (M) earthquake in Richter scale occurred with the hypocenter off the coast of the Sanriku region.[3] This was the largest of earthquakes in the history of earthquake observation in Japan. According to the scale used by the Japan Metrological Agency (JMA), a seismic intensity of Level 7 was observed in the city of Kurihara, Miyagi Prefecture. A seismic intensity of Level 6 strong was observed in 37 municipalities in the four prefectures of Miyagi, Fukushima, Ibaraki and Tochigi. A seismic intensity of Level 6 weak to Level 1 was observed in many parts of Eastern Japan and in wider areas of Japan

[3] The hypocenter was located at a distance of about 130 km from the Oga Peninsula in the direction of east-southeast (38°06.2’N, 142°51.6’E) at a depth of about 24 km.

including Hokkaido and Kyushu.[4]

The name of the earthquake chosen by JMA is the "2011 off the Pacific coast of Tohoku Earthquake."[5] By a cabinet decision, the Japanese government has approved the use of the expression "Great East Japan Earthquake" in reference to the disaster caused by this earthquake.[6]

This earthquake was identified as a reversed fault type earthquake, with the pressure axis of the reversed fault running in the WNW-ESE direction, caused by the occurrence of destruction affecting wide areas along the boundary between the Pacific plate and the continental plate (See Fig. II-2).

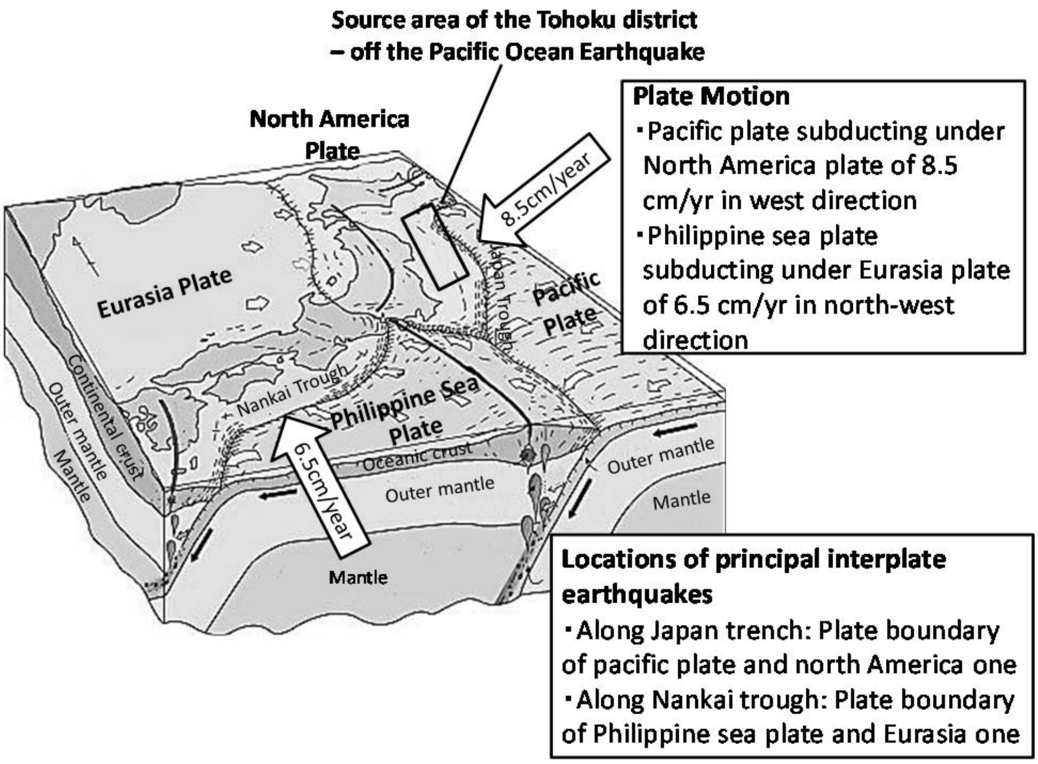

Fig. II-2 Plate structure around Japan and the source area of the Tohoku District - off the Pacific Ocean Earthquake
Source: "Japan as seen from the viewpoint of plate tectonics" on the JGCA homepage with some comments by the Japan Nuclear Energy Safety Organization (JNES)

Seismic activities have been following the pattern of main shock being followed by

[4] JMA issued an emergency earthquake report at 14:46.48.8 on March 11, 2011.
[5] - omitted -
[6] This was done by approval of an agenda titled "On the Nomenclature of the Tohoku District - off the Pacific Ocean Earthquake" on April 1, 2001, through a collection of signatures by the cabinet ministers.

aftershocks. Aftershock activities have been very intense: aftershocks with a seismic intensity of 7.0 or above have been observed five times; aftershocks with a seismic intensity of 6.0 or above have been observed 82 times; aftershocks with a seismic intensity of 5.0 or above have been observed 506 times.[7]

The sources of aftershocks are densely located in an area that stretches over a distance of about 500 km in the NNE-SSW direction, from off the coast of Iwate Prefecture to off the coast of Ibaraki Prefecture, with a width of about 200 km. The sources of aftershocks are also found in wide areas outside the above-mentioned area, such as the eastern side of the axis of an ocean trough that exists near the earthquake source area and shallow points in land areas of Fukushima and Ibaraki Prefectures. The greatest aftershock observed so far was at 15:15 on March 11. The aftershock had a seismic intensity of 7.7 and the hypocenter was located off the coast of Ibaraki Prefecture.

(2) Overview of tsunami produced by the Tohoku District - off the Pacific Ocean Earthquake

Following the Tohoku District - off the Pacific Ocean Earthquake, a tsunami was observed along the coast in wide areas from Hokkaido to Okinawa. The tsunami was particularly eminent along the Pacific coast of the Tohoku and northern Kanto areas.[8]

A very high tsunami was observed particularly at tsunami observation facilities along the Pacific coast of the Tohoku and northern Kanto areas: a tsunami height of 9.3 m[9] was observed in Soma, Fukushima Prefecture, and a tsunami height of 8.6 m was observed in the Ayukawa area of the city of Ishinomaki, Miyagi Prefecture. A tsunami with a wave height of 1m or more was observed along the Pacific coast in wide areas from Hokkaido to Kagoshima Prefecture, and also at the Ogasawara Islands.

The JMA's field survey on tsunami damage and the extent of flooding at tsunami observation facilities and surrounding areas revealed that tsunami with a wave height of more than 10 m had

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[7] These figures are based on statistics for the period up to June 11, 2011, announced by JMA on August 17, 2011.

[8] At 14:49 on March 11, 2011, JMA issued a great tsunami warning (the first one), alarming the residents of Iwate, Miyagi and Fukushima Prefectures.

[9] Data collection was interrupted as the tsunami observation facility suffered damage from tsunami. The maximum tsunami height might have been greater because the sea might have swelled higher after the equipment had failed.

hit the coast of Iwate Prefecture. In addition, traces of tsunami as high as several meters were found at many points along the Pacific coast in wide areas from Hokkaido to Shikoku.

A tsunami produced by the Tohoku District - off the Pacific Ocean Earthquake was observed also along the Pacific coast of Canada, the United States (hereinafter referred to as the "US"), Central America and South America. A tsunami with a maximum height of more than 2 m was reported from countries like the US and Chile.

(3) Overview of damage caused by the Tohoku District - off the Pacific Ocean Earthquake and tsunami produced by the earthquake

According to a survey conducted by the Geospatial Information Authority of Japan (GSI), the size of the areas flooded by tsunami waves was greatest in Miyagi Prefecture (327 km^2), followed by Fukushima Prefecture (112 km^2) and Iwate Prefecture (58 km^2). In 62 municipalities of the six prefectures of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba, the total size of the areas flooded by tsunami waves has amounted to 561 km^2.

As to the victims of the Tohoku District - off the Pacific Ocean Earthquake and tsunami produced by the earthquake,[10] 15,840 persons were announced dead in 12 prefectures (including Tokyo and Hokkaido) and 3,547 persons have been announced missing in the six prefectures mentioned above. The number of persons who suffered injury has amounted to 5,951 in 20 prefectures (including Tokyo and Hokkaido). (These statistics are as of December 1, 2011.)

As to the damage to buildings, 1,009,074 buildings and houses were damaged in 20 prefectures including Tokyo and Hokkaido.[11] (These statistics are as of December 1, 2011.)

For more statistics about the damage caused by the Tohoku District - off the Pacific Ocean Earthquake and tsunami produced by the earthquake, see Attachment II-9.

[10] Since many people remain missing even today, the whole picture of loss and injury is still not very clear.
[11] The whole picture of loss and injury is still not very clear because some areas were totally submerged and destroyed by the tsunami.

(4) Overview of damage at the Fukushima Dai-ichi NPS

a. Operation status of the Fukushima Dai-ichi NPS before the occurrence of the Tohoku District - off the Pacific Ocean Earthquake

Unit 1 was operated in rated electric power operation mode.[12] According to records taken by shift operators before the earthquake, the spent fuel pool was fully filled with water and the water temperature was 25°C.

Units 2 and 3 were operated in rated thermal power operation mode.[13] According to records taken by shift operators before the earthquake, the spent fuel pools at both units were fully filled with water, which was at the temperature of 26°C in Unit 2 and 25°C in Unit 3.

Unit 4 had been in scheduled outage since November 30, 2010. In anticipation of the replacement of the shroud and other works to be conducted inside the reactor pressure vessel, all fuel assemblies had been unloaded from the pressure vessel and were kept in the spent fuel pool. According to records taken by shift operators before the earthquake, the spent fuel pool was fully filled with water and the water temperature was 27°C.

Unit 5 had been in scheduled outage since January 3, 2011. The pressure inside the reactor had been raised to 7.2 MPa because the reactor, with fuel loaded and control rods fully inserted, was undergoing a leak and hydrostatic test that involved the injection of nitrogen into the reactor pressure vessel. According to records taken by shift operators before the earthquake, the spent fuel pool was fully filled with water and the water temperature was 24°C.

Unit 6 had been in scheduled outage since August 14, 2010. The reactor was in cold shutdown status with fuel loaded and control rods fully inserted. According to records taken by shift operators before the earthquake, the spent fuel pool was fully filled with water and the water temperature was 25°C.

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[12] In this operation mode, the reactor's electrical output is maintained at rated level, which is a level that permits year-round operation of the reactor. Reactor operation in this mode requires certain adjustments to maintain the electrical output at the same level (e.g. reducing the reactor's thermal output to prevent the overshoot of electrical output).

[13] In this operation mode, the reactor's thermal output is maintained at rated level, which is the maximum output permitted by the license for reactor establishment. Since the thermal efficiency of the reactor improves naturally in winter thanks to lower seawater temperature, it then becomes possible to obtain greater electrical output from the same thermal output. Even though the advantage of rated thermal power operation differs from plant to plant, rated thermal power operation can achieve an electrical output that is greater than in the case of rated electric power operation by 101 to 108 percent.

b. Ground motion and tsunami observed at the Fukushima Dai-ichi NPS

(a) Ground motion

At the time of the Tohoku District - off the Pacific Ocean Earthquake, a maximum seismic intensity of Level 6 strong (JMA scale) was observed in the towns of Okuma and Futaba, where the Fukushima Dai-ichi NPS is located. (Both towns exist in the country of Futaba, Fukushima Prefecture.) The main shock was followed by a number of aftershocks with a seismic intensity of Level 5 weak or less. For more data about the earthquake, see Attachment II-10.

At the Fukushima Dai-ichi NPS, ground motion is monitored with seismometers installed at 53 points; they are distributed to different locations including the ground under the premises and the R/B, T/B and earthquake monitoring room for each reactor unit. As an example of observation data from those seismometers, Table II-1 below shows the maximum acceleration values reported by the seismometers located above the bottom floors of R/Bs (Units 1 through 6).

The observation data shows that, at Units 2, 3 and 5, the maximum acceleration in the EW direction exceeded the maximum response acceleration[14] against the design basis earthquake ground motion (Ss)[15]

[14] This is the maximum acceleration determined by seismic response analysis assuming the design basis earthquake ground motion (Ss).

[15] The design basis earthquake ground motion (Ss) is defined for each of the different types of earthquakes that may happen in areas around reactor facilities: earthquakes originating from an inland crust (active fault), inter-plate earthquakes, earthquakes originating from an oceanic plate, etc. The design basis earthquake ground motion is defined as the acceleration of a ground motion when the seismic vibration from the source reaches a hard ground surface (open ground surface) where the sheer wave velocity becomes 700 m/s or more.

Loc. of seismometer (bottom floor of reactor bld.)		Record Max. acc. (Gal)			Max. response acceleration to the DBGM Ss (Gal)		
		NS	EW	UD	NS	EW	UD
Fukushima Dai-ichi	Unit 1	460	447	258	487	489	412
	Unit 2	348	550	302	441	438	420
	Unit 3	322	507	231	449	441	429
	Unit 4	281	319	200	447	445	422
	Unit 5	311	548	256	452	452	427
	Unit 6	298	444	244	445	448	415

Table II-1 Maximum acceleration recorded at the Fukushima Dai-ichi NPS during the Tohoku District - off the Pacific Ocean Earthquake compared with the maximum response acceleration against the design basis earthquake ground motion (Ss)
The table was prepared using data from TEPCO "Effects of the Tohoku District - off the Pacific Ocean Earthquake on Reactor Facilities at the Fukushima Dai-ichi Nuclear Power Station" (September 2011).

(b) Tsunami

The first tsunami wave produced by the Tohoku District - off the Pacific Ocean Earthquake reached the Fukushima Dai-ichi NPS at around 15:27 on March 11. The second tsunami wave reached the plant at around 15:35 on the same day. Subsequent tsunami waves continued to reach the plant intermittently.

For more information about the tsunami released by the JMA, etc., see Attachment II-10.

Due to these tsunami attacks, the seaside area and major building areas in the premises of the Fukushima Dai-ichi NPS were almost entirely flooded. For details on flooded areas, inundation heights and water depths, see Attachment II-11.

In the area where major buildings for Units 1 through 4 are located, the inundation height (above the Onahama Port base tide level, or "O.P.") reached a level between about 11.5 m and 15.5 m. Since the elevation of this area was 10 m above O.P., the water depth (distance between the ground surface and the water surface) was between about 1.5 m and 5.5 m. It has been confirmed that the inundation height had reached a level between about 16 m and 17 m above O.P. at some points in the southwest corner of this area, which means a water depth of between about 6 m and 7 m.

In the area where major buildings for Units 5 and 6 are located, the inundation height reached a level between about 13 m and 14.5 m above O.P. Since the elevation of this area was 13 m above O.P., the water depth was about 1.5 m or less.

3. Overview of Damage at the Fukushima Dai-ichi NPS as Revealed by Investigation So Far

As already mentioned in 2 (4) b. of this chapter, the Fukushima Dai-ichi NPS was struck by the Tohoku District - off the Pacific Ocean Earthquake and tsunami produced by the earthquake. Among the capabilities that have been described in 1 (4) of this chapter, which were to ensure the safety of reactor facilities, the shutdown capability is believed to have fulfilled its intended purpose by scramming the reactors after the occurrence of earthquake. However, the cooling capability was impaired because many power supply systems and related facilities at the plant were rendered inoperable due to damage caused by the earthquake or flooding caused by the tsunami. It is evident that the containment capability was also impaired because there took place the release of radioactive materials to the external environment as will be discussed in 4 (1) of this chapter.

It is assumed that many of the systems and facilities at the Fukushima Dai-ichi NPS were physically damaged or rendered inoperable due to the earthquake or tsunami, or due to the progress of damage to reactor cores, or otherwise due to explosions in R/Bs that are believed to be hydrogen explosions. However, in very many of such cases, the details of damage have hardly been confirmed by direct observation because the radiation dose level is still high in the R/Bs and surrounding areas and highly radioactive contaminated water still remains inside the R/Bs (See Attachment II-12). Using the result of investigation conducted so far under such restrictions, the following describes as much as possible the damage received by major systems and facilities at the Fukushima Dai-ichi NPS.

For the location of major facilities in R/Bs, T/Bs and other areas, see Attachment II-12.

(1) Buildings and systems with radioactive material containment capability

a. Reactor pressure vessel (seismic design class: S[16])

[16] The seismic design class attached to the name of a plant component is based on the Regulatory Guide for Reviewing Seismic Design of Nuclear Reactor Facilities (after revision by NSC Japan), which rates the importance of seismic design for each given component (by categorization into class S, B or C) based on the evaluation of the risk of radioactive materials released to the external environment as a result of failure caused by earthquake. Class S is assigned to components the failure of which is likely to cause a release of radioactive materials to the external environment because they contain radioactive materials or interact directly with some

(a) Overview

The reactor pressure vessel (RPV) is made of low-alloy steel as a base material and lined internally with stainless steel for the prevention of corroding (See Attachment II-1 for design specifications and Attachment II-13 for structural configuration). The RPV head (rid) is fixed to the body using flanges to facilitate opening; double O-rings are used to prevent leakage from the interface between the head and body. The RPV is supported at its lower end by a skirt-like structure.

See Attachment II-14 for the positions of reactor water level and reactor pressure instrumentation systems inside the RPV and for information about the measuring principle.

(b) Location

In the R/B of each reactor unit, the RPV occupies a space that stretches vertically between the first floor and the fourth floor of the building (See Attachment II-15).

(c) Details of damage and the level of functionality

The details of damage that has occurred to RPVs and the level of their functionality have not yet been confirmed.

With regard to the RPVs of Units 1 through 3, it is assumed that, within these RPVs, all control rods were fully inserted shortly after the occurrence of earthquake, causing a scram in corresponding reactors. No evidence has been found to suggest the occurrence of damage to an RPV before the arrival of the tsunami (For more information, see Chapter IV-1).

b. Reactor containment vessel (seismic design class: S)

(a) Overview

The reactor containment vessel (RCV) is a steel container that contains major reactor

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component that contains radioactive materials. Class B is assigned to components that, compared with class-S components, have a smaller risk of causing a release of radioactive materials to the external environment. Class C is assigned to the components other than the above, and these components are expected to achieve a level of safety that is normally required of industrial facilities.

system components including the RPV. The space inside the RCV is divided into the dry well (D/W) and the suppression chamber (S/C). The RCV is designed to contain radioactive materials and prevent their external release in the event of a Loss of Coolant Accident, for example.

(b) Location

In the R/B of each reactor unit, the RCV occupies a space that stretches vertically between the first basement and the fourth floor of the building (See Attachment II-15).

(c) Details of damage and the level of functionality

The details of damage that has occurred to RCVs and the level of their functionality have not yet been confirmed.

With regard to the RCVs of Units 1 through 3, the trend analysis of D/W pressure, S/C pressure and S/C water level measurements suggests no damage.

c. Reactor building (R/B) (seismic design class: S)

(a) Overview

With all reactor units at the Fukushima Dai-ichi NPS, the R/B has five floor levels above ground. The R/Bs of Units 1 through 5 have one basement level each while the R/B of Unit 6 has two basement levels. Each R/B contains RCV and auxiliary reactor system components. Negative pressure is maintained inside each R/B to prevent the external release of radioactive materials even when they have escaped from the RCV or elsewhere following an accident.

(b) Location

For the location of R/Bs (Units 1 through 6), see Attachment II-3.

(c) Details of damage and the level of functionality

An explosion (or a series of explosions), which is believed to be a hydrogen explosion, took place in the Unit 1 R/B at around 15:36 on March 12, in the Unit 3 R/B at around

11:01 on March 14, and in the Unit 4 R/B between around 06:00 and 06:10 on March 15. These explosions caused severe damage to the fifth floor portion of the R/Bs of Units 1 and 3, and to the fourth and fifth floor portion of the Unit 4 R/B (See Attachment II-16).

According to the result of an investigation conducted later by TEPCO, the fifth level floor structure of the Unit 4 R/B was deformed by an upward thrust while the fourth floor structure was deformed by a downward thrust. Therefore, it is assumed that the explosion in the Unit 4 R/B produced high pressure mainly in the space on the fourth floor.

d. Summary of damage to and the level of functionality of buildings and systems with radioactive material containment capability

As mentioned already in c. (c) above, the R/Bs of Units 1, 3 and 4 were severely damaged by explosions, which are believed to be hydrogen explosions. These R/Bs lost their containment capability when they were damaged by these explosions, assuming that they had not lost it even earlier.

(2) Cooling systems

a. Isolation condenser (IC) system at Unit 1 (seismic design class: S)

(a) Overview

The IC system is designed to continue the cooling of the reactor core by repeating the cycle of condensing steam inside the RPV into water, using the condenser tank, and feeding that water back into the reactor.

As shown in Attachments II-12 and II-17, the plant (Unit 1) has two trains of IC systems: Train A and Train B. Each train comprises components such as a condenser tank (filled with cooling water), piping for leading reactor steam from an upper part of the reactor to the condenser tank (steam supply piping), piping for returning water (yielded by the condensing of steam into water in the condenser tank) to a lower part of the reactor (return piping), and isolation valves (both the steam supply piping and the return piping have a pair of them).

(b) Location

The IC system exists only in Unit 1. Each of the two trains of the IC system (Trains A and B) has a condenser tank, which is a main component of the IC system. The two condenser tanks are installed on the fourth floor of the R/B (See Attachment II-12).

(c) Details of damage and the level of functionality

i. In the period between the occurrence of the earthquake and the arrival of the tsunami

The IC system was activated automatically soon after the occurrence of earthquake. Shift operators repeatedly operated the isolation valves in an attempt to control the reactor pressure. There is no evidence that suggests the damage to any of the IC system components inside and outside the RCV that could have impaired the functionality of the IC system before the arrival of the tsunami.

ii. After the arrival of the tsunami

It is very probable that the activation of the fail-safe function following the total loss of AC and DC power led to the closure of all isolation valves or the arising of a situation close to that, almost completely disrupting the cooling capability of the IC system (For details, see Chapter IV-2 and -3).

The details of damage to the IC system have not yet been confirmed.

b. Reactor core isolation cooling (RCIC) systems at Units 2 through 6 (seismic design class: S)

(a) Overview

The reactor core isolation cooling (RCIC) system is activated by an Abnormally Low Reactor Water Level Alarm Signal following accidental failure of the feedwater system. It continues cooling the reactor core as it runs on a turbine-driven pump system, operated using a portion of steam generated in the RPV, and supplies cooling water to the reactor compensating for loss of coolant due to evaporation.

As shown in Attachment II-18, the RCIC system comprises components such as a pump, steam-driven turbine, piping and isolation valves (actuated using DC power). It normally uses water from the condensate storage tank but can also use water in the S/C.

(b) Location

In the case of Units 2 through 5, major RCIC system components exist in the first basement of the respective R/Bs, while in the case of Unit 6, major RCIC system components exist in the second basement of the R/B. (See Attachment II-12.)

(c) Details of damage and the level of functionality

i. In the period between the occurrence of the earthquake and the arrival of the tsunami

At Units 2 and 3, shift operators manually activated the RCIC system soon after the occurrence of the earthquake in an attempt to control the reactor pressure. Therefore, it is assumed that there occurred no damage at Units 2 and 3 that could have impaired the cooling capability of the RCIC system before the arrival of the tsunami.

ii. After the arrival of the tsunami

(i) At Unit 2, the tsunami caused the loss of actuation power in the isolation valves, which had been in the open position, before the activation of the fail-safe function. Thanks to this, the isolation valves remained open. Therefore, the RCIC system might have maintained its cooling capability for a certain period of time after the arrival of the tsunami.[17] The system, however, was rendered uncontrollable.

(ii) At Unit 3, the DC power distribution panel escaped damage due to the flooding. Therefore, shift operators deliberately activated the RCIC system using DC power at around 16:03 on March 11 and continued to operate the system, checking the discharge pressure and pump revolution (RPM) from time to time, until the system was deactivated at around 11:36 on March 12. It is therefore assumed that, during the given period, the RCIC system at Unit 3 suffered no damage that could have impaired its cooling capability.

[17] We don’t know exactly how long it maintained its cooling capability.

(iii) Units 4 to 6 had been shut down for scheduled outage. Therefore, the RCIC system was not activated in these units. The details of damage that might have happened to the RCIC systems in these units and the level of their functionality have not yet been confirmed.

c. High pressure coolant injection (HPCI) systems at Units 1 through 5 (seismic design class: S)

(a) Overview

The HPCI system is designed to continue cooling the reactor core by injecting cooling water into the reactor at high pressure using a high pressure pump driven by a steam turbine.

As shown in Attachment II-19, the HPCI system comprises components such as a turbine-driven pump, high-pressure piping and isolation valves (actuated using DC power). It normally uses water from the condensate storage tank but can also use water in the S/C.

(b) Location

Major HPCI system components exist in the first basement of the respective R/Bs (For the exact location, see Attachment II-12).

(c) Details of damage and the level of functionality

(i) At Unit 3, the HPCI system was activated automatically at around 12:35 on March 12 and was manually deactivated by shift operators at around 02:42 on March 13. In the given period of time, shift operators continued to operate the system, adjusting the flow from time to time according to the measurements displayed by the reactor water level instrumentation system, the flow control system (flowmeters), etc. Therefore, it is assumed that there occurred no damage that could have impaired the cooling capability of the HPCI system in this period of time.

(ii) At Units 1, 2, 4 and 5, the HPCI systems were not activated. It is assumed that, at Units 1 and 2, the HPCI system lost its cooling capability due to the total loss of power that occurred after the arrival of the tsunami, which included the loss of DC power required for the actuation of the HPCI system. Units 4 and 5 had been shut down for scheduled outage. Therefore, the HPCI system was not activated in these units. The details of damage that might have happened to the HPCI systems in these units and the level of their functionality have not yet been confirmed.

d. Emergency seawater system pumps (seismic design class: S)

(a) Overview

Emergency seawater system pumps are used for the delivery of cooling seawater required for the removal of heat from the heat exchangers of CCS (at Unit 1) and RHR systems (at Units 2 through 6). The CCS is cooled by the containment cooling system seawater (CCSW) system; the RHR system is cooled by the residual heat removal seawater (RHRS) system. (Pease remember the earlier descriptions of the CCS and RHR systems in 1 (4) of this chapter.)

Each reactor unit has two trains (Trains A and B) of the CCSW or RHRS system. Each train has two emergency seawater system pumps connected in parallel (See Attachment II-20).

Each emergency seawater system pump requires 6,900V AC power for operation.

(b) Location

All emergency seawater system pumps are located outdoors in seaside areas (at an elevation of 4 m above O.P.) (See Attachment II-20).

(c) Details of damage and the level of functionality

i. In the period between the occurrence of the earthquake and the arrival of the tsunami

(i) Even though the CCSW system is designed to deliver seawater to the heat exchanger of CCS for cooling, the CCS may be activated and operate without the activation of the CCSW system. The CCS (at Unit 1) was activated approximately between 15:07 and 15:10 on March 11, but it is not clear whether the CCSW system operated at the same time or not. Therefore, it has not been possible to confirm the damage that the

CCSW system might have suffered or the level of its functionality.

(ii) Each of the two trains of the RHR system at Units 2 through 5 is designed to terminate operation several minutes after the deactivation of both of the two emergency seawater system pumps of the RHRS system that delivers seawater to its heat exchanger.

At Unit 2, the RHR system was activated[18] and there is no evidence that suggests its deactivation before the arrival of the tsunami. Therefore, it is assumed that at least one of the two RHRS emergency seawater system pumps that were to deliver seawater to the operating train of the RHR system was operative and free from damage that could have impaired its cooling capability. On the other hand, the RHR system was not activated at Units 3 through 5. Therefore, it has not been possible to confirm the damage that the RHRS emergency seawater system pumps for these reactor units might have suffered or the level of their functionality.

(iii) At Unit 6, each train of the RHR system may be activated and operate without the activation of the corresponding train of the RHRS system that delivers seawater to its heat exchanger. Hence, it is not possible to surmise the activation of the RHRS system from the activation or operation of the RHR system.[19] Therefore, it has not been possible to confirm the damage that the Unit 6 RHRS emergency seawater system pumps might have suffered or the level of its functionality.

ii. After the arrival of the tsunami

Since all the emergency seawater system pumps were located outdoors in seaside areas, it is probable that they were damaged in one way or another due to flooding caused by the tsunami.

Moreover, at Units 1 through 5, the total loss of AC power disabled the supply of AC power needed for the operation of emergency seawater system pumps in the CCSW or RHRS system. The Investigation Committee may conclude, therefore, that these

[18] Shift operators activated the RHR system for Unit 2 at some time between 15:00 and 15:07 on March 11 to begin operation in S/C cooling mode and activated the S/C spray at around 15:25 on the same day (See Chapter IV-1 (2) b).

[19] In fact, the Unit 6 RHR system was not activated.

emergency seawater system pumps had lost their cooling capability.

e. Summary of damage to and the level of functionality of cooling systems

(a) In the period between the occurrence of the earthquake and the arrival of the tsunami

With regard to the IC system, the RCIC systems at some reactor units and some emergency seawater system pumps that operated in this period of time, there is no report of significant abnormality in operation. Therefore, it is assumed that there occurred no damage that could have impaired their cooling capability.

With the rest of the cooling systems that did not operate in this period of time, it has not been possible to confirm the damage that they might have suffered or the level of their functionality.

(b) After the arrival of the tsunami

(i) The RCIC and HPCI systems for Unit 3 retained their cooling capability. With this as an only exception, it is probable that, at Units 1 through 3, the IC system, the HPCI system and the emergency seawater system pumps lost all or part of their cooling capability. The RCIC system for Unit 2 may have maintained its cooling capability for a certain period of time but is supposed that the system was uncontrollable.

(ii) It is assumed that, at Units 4 through 6, the total loss of AC power would have disabled the emergency seawater system pumps. As to the other systems, which were not activated, it has not been possible to confirm the damage that they might have suffered or the level of their functionality.

(3) Power supply systems

a. Emergency diesel generators (DGs) (seismic design class: S)

(a) Overview

Emergency diesel generators (DGs) are diesel-driven emergency generators that are used to supply AC power (6,900V) to reactor facilities following the loss of external power. Even after the loss of external power, the emergency DGs can supply the power necessary to safely shut down the reactors. The power from the emergency DGs is distributed using metal clad switchgears (M/C) for emergency use.

In the past, TEPCO decided to provide each reactor unit with two dedicated emergency DGs as part of its accident management initiatives and completed the installation of emergency DGs at all reactor units by March 1999 (See Chapter VI-4 (5) a. (d)).

Emergency DGs are seawater-cooled or air-cooled. Seawater-cooled emergency DGs are used with seawater pumps.[20] Among the emergency DGs provided for Units 1 through 6, the ones used in Unit 2 Train B, Unit 4 Train B and Unit 6 Train B are air-cooled. All other emergency DGs are cooled using seawater.

(b) Location

For the location of emergency DGs in the respective reactor units, see Attachments II-12 and II-21. For the location of seawater pumps used with seawater-cooled emergency DGs, see Attachment II-20.

(c) Details of damage and the level of functionality

i. In the period between the occurrence of the earthquake and the arrival of the tsunami

Immediately after the occurrence of the earthquake, following the disruption of external power supply from the Shin Fukushima Power Substation, all except for the Unit-4 Train-A DG, which was under periodical inspections, started up. This successfully restored normal voltage to the emergency M/Cs at Units 1 through 6. It is therefore assumed that the emergency DGs did not suffer any damage from the ground motions of the earthquake that could have led to the impairment of their power supply capability.[21]

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20 A system that supplies seawater required for the cooling of an emergency DG is called the diesel generator seawater (DGSW) system.

21 The normal operation of seawater-cooled emergency DGs requires the operation of the seawater pumps of the DGSW systems that are used for cooling. In the initial period after the occurrence of the earthquake, all seawater-cooled emergency DGs operated, and it is assumed that they suffered no damage that could have led to the impairment of their capability. Therefore, it is similarly assumed that the seawater pumps of the DGSW systems operated as well, and that they did not suffer any damage that could have led to the impairment of their

ii. After the arrival of the tsunami

While there were a total of 13 emergency DGs at the power station (Units 1 through 6), it is assumed that all except the Unit-2 Train-B DG, Unit-4 Train-B DG and Unit-6 Train-B DG were rendered inoperable[22] after the arrival of the tsunami. The following describes the damage suffered by emergency DGs at different locations (For more information, see Attachment II-21).

(i) Since the emergency DGs for Unit 1 (Trains A and B) are in the first basement of the Unit 1 T/B, they were immersed in floodwater from the tsunami and rendered inoperable. According to observations made in the early evening of March 11 by the members of the recovery team members (hereafter referred to as the "recovery team members") at the emergency response center of the Fukushima Dai-ichi NPS (the NPS ERC), there were indications that the Unit-1 Train-A DG had been covered by floodwater from the tsunami to a height of about 1.5 m and that the Unit-1 Train-B DG was immersed in water to a height of about 1 m.

(ii) The Unit-2 Train-A DG exists in the first basement of the Unit 2 T/B. Even though recovery team members have not inspected this emergency DG, they have reported that the place was flooded to a height of about 1.3 m. Moreover, a total loss of AC power (including power from the emergency DGs) occurred soon after the arrival of the tsunami. Therefore, it is assumed that this emergency DG was damaged by flood water from the tsunami and rendered inoperable. The Unit-2 Train-B DG exists on the first floor of the common auxiliary facility building (hereinafter referred to as the "common pool building") and therefore was not damaged by floodwater. (However, take note of information in b. (c) ii. below, which describes the damage to and the functionality of the M/C that receives power from this emergency DG.)

(iii) The emergency DGs for Unit 3 (Trains A and B) are in the first basement of the Unit 3 T/B. It is assumed that they were immersed in floodwater from the tsunami and rendered inoperable.

capability.

[22] This includes the state of inoperability caused by the flooding of seawater pumps required for the cooling of DGs or the flooding of some other components due to the tsunami even while the DGs may have remained undamaged.

(iv) The Unit-4 Train-A DG was unable to start up because it was under periodical inspection. The Unit-4 Train-B DG exists on the first floor of the common pool building and therefore was not damaged by floodwater. (However, take note of information in b. (c) ii. below, which describes the damage to and the functionality of the M/C that receives power from this emergency DG.)

(v) The emergency DGs for Unit 5 (Trains A and B) are in the first basement of the Unit 5 T/B. These emergency DGs were not damaged by floodwater, but it is assumed that they were rendered inoperable as some associated components were damaged by floodwater.

(vi) At Unit 6, the Train-A DG[23] and the DG for the HPCS system are in the first basement of the Unit 6 R/B. These emergency DGs were not damaged by floodwater. However, it is assumed that they were rendered inoperable due to the failure of seawater pumps (required for the cooling of DGs) due to flooding. The Train-B DG exists on the first floor of the diesel generator 6B building. This emergency DG was not damaged by floodwater and remained operable.

b. Metal clad switchgears (M/Cs) and power centers (P/Cs) (seismic design class: S)

(a) Overview

Metal clad switchgears (M/Cs) are switchboards used by the 6,900V high voltage circuits within the power station. They contain components such as circuit breakers, protective relays and associated instruments. There are M/Cs for three different types of circuits: normal-use circuits, common circuits and emergency circuits.

Power centers (P/Cs) are switchboards used by the 480V low voltage circuits within the power station, which receive power from the M/Cs via a transformer that brings down the voltage. They contain components such as circuit breakers, protective relays and associated instruments. There are P/Cs for three different types of circuits: normal-use

[23] The DGSW system used for the cooling of the Unit-6 Train-A DG was initially inoperable but operators confirmed its operability on March 18 even though it is unknown how it recovered, and they started up the Unit-6 Train-A DG at 04:22 on March 19. Since no action had been taken to restore the Unit-6 Train-A DG system for a considerable period of time after the arrival of the tsunami, it is believed that the system had remained inoperable during that period.

circuits, common circuits and emergency circuits.

Normal-use M/Cs and P/Cs distribute power to systems and components that are used in normal plant operation. Among the circuits that are used in normal plant operation, those which distribute power adjoining reactor units, for example, are called common circuits.

Emergency M/Cs and P/Cs are powered by emergency DGs following the loss of external power. These M/Cs and P/Cs distribute power to systems and components that are used in emergency and also to systems and components that are used both in normal plant operation and in emergency.

(b) Location

For the location of M/Cs and P/Cs at the power station (Units 1 through 6), see Attachments II-12 and II-21.

(c) Details of damage and the level of functionality

i. In the period between the occurrence of the earthquake and the arrival of the tsunami

At all reactor facilities (Units 1 through 6), emergency DGs started up to supply power to emergency M/Cs and P/Cs, and there is no report of any significant problem in starting up the systems and the components that are powered by them. It is assumed therefore that at least those emergency M/Cs and P/Cs, which receive power from emergency DGs, were not damaged by seismic motions from the earthquake. On the other hand, normal-use M/Cs and P/Cs lost their power supply capability due to the loss of external power that occurred almost immediately after the occurrence of the earthquake (For more information, see c. (C) below).

ii. After the arrival of the tsunami

(i) While there were a total of 15 emergency M/Cs at the power station (Units 1 through 6), all were damaged by floodwater from the tsunami and lost their power supply capability except the Train-C M/C, Train-D M/C and HPCS M/C at Unit 6 (See Attachment II-21).

(ii) Among the few emergency M/Cs mentioned in (i) above that were not damaged by floodwater, the Unit-6 Train-D M/C was capable of receiving power from the Unit-6 Train-B DG. As to the Train-C M/C and HPCS M/C at Unit 6, their reliability is unknown as it is assumed that they could not be used because the Train-A DG and HPCS DG at Unit 6, which should serve as the source of power, were rendered inoperable on account of the failure of seawater pumps (required for the cooling of DGs) due to flooding, as already described in (3) a. (c).

(iii) While there were a total of 15 emergency P/Cs at the power station (Units 1 through 6), all were damaged by floodwater from the tsunami and became unavailable except the Unit-2 Train-C and Train-D P/Cs on the first floor of Unit 2 T/B, the Unit-4 Train-D P/C[24] on the first floor of Unit 4 T/B, the Unit-6 Train-C P/C in the second basement of the Unit 6 R/B, the Unit-6 Train-D P/C in the first basement of the same building and the Unit-6 Train-E P/C in the first basement of the Unit-6 diesel generator building (See Attachment II-21).

(iv) Among the emergency P/Cs that were not damaged by floodwater from the tsunami, the Unit-2 Train-C emergency P/C and the Unit-4 Train-D emergency P/C were used by recovery team members in their power restoration activities as a means to distribute power cabled from power supply vehicles (See Chapter IV-3 (6) and -4 (7)).

c. Off-site power supply facilities (seismic design class: none)

(a) Overview

The facilities discussed here are used to make available external AC power to the Fukushima Dai-ichi NPS or to transmit power from the Fukushima Dai-ichi NPS.

(b) Location

The Fukushima Dai-ichi NPS receives power mainly from the Shin Fukushima Power Substation, which exists about 9 km away in the southwest direction (See Attachment II-22).

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[24] The Unit-4 Train-C P/C also remained undamaged by floodwater but it had been unavailable due to periodical inspection.

Units 1 and 2 are provided with high voltage AC power (275,000V) from the Shin Fukushima Power Substation via Okuma lines 1L and 2L. The switchyard for Units 1 and 2, which bring down the voltage of this high voltage AC power, exists to the west of the Unit 1 R/B (See Attachment II-3). There also exists a standby line for the supply of power from Tohoku Electric Power Co., Inc., called the Toden Genshiryoku Line, which can be used for the transmission of high voltage AC power (66,000V).

Units 3 and 4 are provided with high voltage AC power (275,000V) from the Shin Fukushima Power Substation via Okuma lines 3L and 4L. The switchyard for Units 3 and 4, which bring down the voltage of this high voltage AC power, exists to the west of the Unit 3 R/B (See Attachment II-3).

Units 5 and 6 are provided with high voltage AC power (66,000V) from the Shin Fukushima Power Substation via Yonomori lines 1L and 2L. A 66kV switchyard[25] used for bringing down the voltage of this high voltage AC power exists to the west of the Unit 6 R/B (See Attachment II-3).

(c) Details of damage and the level of functionality

Off-site power supply facilities that are important to the Fukushima Dai-ichi NPS include towers, cables, circuit breakers, line switches and other components. The earthquake disrupted the supply of power to the Fukushima Dai-ichi NPS by causing damage such as the collapse of towers, the falling of circuit breaker and line switch components, and the leaning of steel structures that supported incoming cables. The following describes the details of damage to off-site power supply facilities and the level of their functionality (See also Attachment II-22).

i. Okuma lines 1L & 2L and TEPCO NPS line (for Units 1 and 2)

Okuma line 1L became unavailable when circuit breaker O-1 in the switchyard for Units 1 and 2 went out of service at around 14:48 on March 11.[26] It is assumed that this

[25] With Units 5 and 6, the switchyard for receiving power is called as the “66kV switchyard” while the switchyard for transmitting power is called as the “switchyard for Units 5 and 6.”

[26] Time given here is according to records kept by the bulk power grid load dispatch system at the TEPCO head office.

circuit breaker went out of service due to the functioning of a transmission line protection device at the Fukushima Dai-ichi NPS, which must have reacted to the occurrence of damage such as the falling of some components from another circuit breaker (O-81) in the same switchyard. It is still unclear, however, which of the transmission line protection devices at the Fukushima Dai-ichi NPS had functioned.

Okuma line 2L became unavailable when circuit breaker O-32 at the Shin Fukushima Power Substation went out of service at around 14:48 on March 11. It is assumed that this circuit breaker went out of service due to the functioning of the Okuma line 2L protection device at the Shin Fukushima Power Substation, which must have reacted to damage from the earthquake such as the falling of some components from circuit breaker (O-82) and disconnecting switch (82) at the switchyard for Units 1 and 2 (See Photos (i) to (iii) in Attachment II-23).

The Toden Genshiryoku Line, which could have provided power from Tohoku Electric Power Co., Inc., became unavailable due to the failure of a cable that provided connection to the Unit 1 M/C. The exact cause of cable failure has not been determined because the area around the cable remains uninspected due to the danger of falling earth.

ii. Okuma lines 3L & 4L and TEPCO NPS line (for Units 3 and 4)

Okuma line 3L became unavailable when circuit breaker O-33 at the Shin Fukushima Power Substation went out of service at around 14:48 on March 11. TEPCO's investigation conducted after the earthquake detected traces of arc discharge (high voltage electric discharge) on tower No. 7 and cables nearby (See Photo (iv) in Attachment II-23). It is therefore believed that the above-mentioned circuit breaker went out of service due to the functioning of the Okuma line 3L protection device at the Shin Fukushima Power Substation, which must have reacted to the contact or loss of a safe distance, caused by the earthquake, between tower No. 7 (for Okuma lines 3L and 4L) and the cables.

Okuma line 4L became unavailable when circuit breaker O-34 at the Shin Fukushima Power Substation went out of service at around 14:48 on March 11. TEPCO's investigation conducted after the earthquake detected traces of arc discharge on tower

No. 11 and on a jumper cable nearby (See Photo (v) in Attachment II-23). It is therefore believed that the above-mentioned circuit breaker went out of service due to the functioning of the Okuma line 4L protection device at the Shin Fukushima Power Substation, which must have reacted to contact or loss of a safe distance, caused by the earthquake, between tower No. 11 (for Okuma lines 3L and 4L) and the cables.

Okuma line 3L has also suffered a breakage of overhead earth wire at the Shin Fukushima Power Substation (See Photo (vi) of Attachment 23). In addition, the earthquake caused the leaning of steel structures inside the Shin Fukushima Power Substation that supported the incoming cables of Okuma lines 3L and 4L even though it is unclear whether or not this was the cause of power transmission failure (See Photo (vii) of Attachment 23).

The switchyard for Units 3 and 4 was flooded by the tsunami.

iii. Yonomori lines 1L & 2L and TEPCO NPS line (for Units 5 and 6)

Yonomori line 1L became unavailable when circuit breaker O-93 at the Shin Fukushima Power Substation went out of service at around 14:49 on March 11. No visible damage was found on this circuit breaker. It is therefore assumed that this circuit breaker went out of service due to the functioning of the Yonomori line 1L protection device at the Shin Fukushima Power Substation, which must have reacted to contact or loss of a safe distance, caused by the earthquake, between cables.

Yonomori line 2L became unavailable when circuit breaker O-94 at the Shin Fukushima Power Substation went out of service at around 14:48 on March 11. No visible damage was found on this circuit breaker. It is therefore assumed that this circuit breaker went of service due to the functioning of the Yonomori line 2L protection device at the Shin Fukushima Power Substation, which must have reacted to contact or loss of a safe distance, caused by the earthquake, between cables.

Tower No. 27 that supported Yonomori lines 1L and 2L at the Fukushima Dai-ichi NPS fell down due to the collapsing of a nearby slope caused by the earthquake. (See Photo (viii) in Attachment II-23.) It is unknown, however, whether or not this was the cause of power transmission failure.

The 66kV switchyard was flooded by the tsunami.

d. Summary of damage to and the level of functionality of power supply systems

Soon after the occurrence of the earthquake, the Fukushima Dai-ichi NPS was cut off from external power due to the failure of the off-site power facilities, which was triggered by the functioning of transmission line protection devices that reacted to damage suffered by some components of the off-site power facilities such as circuit breakers and disconnecting switches.

Almost as soon as the external power was lost, emergency DGs started up throughout the power station (Units 1 through 6) as they should in such an emergency and made available the AC power required for safely shutting down the reactor facilities. However, soon after the arrival of the tsunami, many of the emergency DGs and emergency switchgears lost their power supply capability due to damage caused by floodwater from the tsunami. This resulted in the total loss of AC power at Units 1 through 6. Judging from presently available information, Units 1 and 2 suffered and total loss of power including both AC and DC power.

(4) Alternative means for water injection and the fire protection system (seismic design class: C)

a. Overview

Should a fire break out in the premises of the Fukushima Dai-ichi NPS, the fire protection system is used to deliver water from fire protection water sources such as filtered water tanks to fire hydrants through fire protection system lines. Besides serving this original purpose, these systems can serve also as an alternative means for injecting water into reactors as envisaged by the accident management plans.

The fire protection system comprises components such as filtered water tanks (serving as the source of water), piping (for the distribution of water to the respective reactor units), pumps, hydrants and water delivery ports. There are two types of fire pumps: motor-driven fire pumps (M/DFP) and diesel-driven fire pumps (D/DFP). D/DFPs can remain operable even after a total loss of power.

b. Location

Two filtered water tanks, which serve as the source of water for the fire protection system, exist in the central west section of the premises of the Fukushima Dai-ichi NPS. The fire protection system piping runs above ground as it goes from the filtered water tanks to a point to the north of the main office building, and then goes underground toward different reactor units. There are many fire hydrants in and around the R/Bs, T/Bs and outdoor seaside areas (See Attachment II-24).

The fire protection system piping has branch lines that go into different buildings. A complex network of branch lines ensures the availability of water throughout each building. On the eastern wall of each T/B, there is a water delivery port (with two faucets) connected with the fire protection system (See Attachment II-25).

As to the booster pumps used for adding pressure to water delivered through the piping, each of Units 1, 2, 3 and 5 has two M/DFPs and a D/DFP in the first basement of the T/B (See Attachment II-12). However, at the time of the Tohoku District - off the Pacific Ocean Earthquake, one of the two M/DFPs and the D/DFP at Unit 5 were unavailable because they had been removed for inspection. While no pump existed at Units 4 and 6, the water to Unit 4 was to be pressurized using pumps at Units 1 to 3, and the water to Unit 6 was to be pressurized using pumps at Unit 5.

c. Details of damage and the level of functionality

(a) Damage to outdoor components of the fire protection system and the level of their functionality

Many of the outdoor components of the fire protection system, such as piping, fire hydrants and water intake ports, were damaged in various manners (See Attachment II-26). It is assumed that the damage was caused mostly by seismic motions, the tsunami, the collision of objects carried by the tsunami, and the explosions in R/Bs that are believed to be hydrogen explosions. However, it has not yet been possible to determine the exact causes.[27]

[27] In the early evening of March 11, which is earlier than the occurrence of the explosions in the R/Bs that are believed to be hydrogen explosions, it was found that fire protection piping was fractured at more than one point

(b) Damage to indoor components of the fire protection system and the level of their functionality

According to TEPCO, there was no visible significant damage to fire hydrants or to nearby piping inside the T/Bs of Units 1 through 3 (See Attachment II-27).

(c) Details of damage to fire pumps and the level of their functionality

i. Details of damage to motor-driven fire pumps (M/DFPs) and the level of their functionality

It is unknown whether or not the M/DFPs had functioned in the period between the occurrence of the earthquake and the arrival of the tsunami. After the arrival of the tsunami, the M/DFPs are believed to have been rendered inoperable due to a total loss of AC power at Units 1 through 5.

ii. Details of damage to diesel-driven fire pumps (D/DFPs) and the level of their functionality

(i) The D/DFP at Unit 1 was affected by floodwater from the tsunami. Nevertheless, when plant personnel rechecked it at around 17:30 on March 11 with the idea of using fire protection system water lines to inject water into the reactors, this D/DFP was found operable, and it was started up at around 20:50 on the same day. It is therefore assumed that this D/DFP, at least at that moment, had not been damaged to the point of failure.

Later on, at around 01:48 on March 12, it was found that this D/DFP had stopped running and the attempt to restart it did not succeed. We may conclude therefore that this D/DFP had lost its functionality by that time.

(ii) The condition of the D/DFP at Unit 2 has not been checked by direct observation. The details of damage that it might have suffered and the level of its functionality remain unknown.

(iii) The D/DFP at Unit 3 was affected by floodwater from the tsunami. Nevertheless, it

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along the lines that go from the filtered water tanks to each of the T/Bs of Units 1 through 4 or to each of the T/Bs of Units 5 and 6, and it was also reported that water sprouted from more than one fire hydrant. Therefore, at around 19:00 on the same day, plant personnel closed all but one main valve of the filtered water tanks (See footnote in Chapter IV 3 (2) a).

was started up successfully at around 12:06 on March 12 and used for S/C spraying operation. It continued to run until it ran out of fuel at around 22:15 on March 13. Therefore, it is assumed that this D/DFP did not suffer any damage that could have impaired its functionality.

(5) Others

a. Main office building (seismic design class: none)

(a) Function

This building exists in the premises of the Fukushima Dai-ichi NPS and is used as a place for office work in general.

(b) Location

The main office building exists to the northwest of the Unit 1 R/B (See Attachment II-3).

(c) Details of damage and the level of functionality

Confirmed damage includes the breaking of windowpanes, the collapsing of roof structures and the toppling of desks. It is assumed that such damage was caused by seismic motions and the explosions in the R/Bs that are believed to be hydrogen explosions. On the other hand, the main office building suffered no damage from the tsunami because it was not flooded. For details of the damage suffered by the main office building, see Attachment II-28.

As a result of TEPCO's emergency assessment of the risk of earthquake-affected buildings collapsing from the impact of aftershocks, etc., the main office building was declared "dangerous" (a risk level that requires prohibition of entry into the building).

b. Roads (seismic design class: none)

The Fukushima Dai-ichi NPS is served not only by ordinary roads but also by wide-lane "disaster prevention roads" for use by emergency vehicles in emergency, which have improved roadbed structures and are protected by rock-fall prevention nets. For details of the damage to such roads caused by the earthquake and associated hazards, see Attachment II-29.

4. Overview of Damage Caused by the Accident at the Fukushima Dai-ichi NPS

(1) Release of radioactive materials to the environment, etc.

The Nuclear and Industrial Safety Agency (NISA) estimated the total amount of radioactive materials released into the atmosphere from Units 1, 2 and 3 of the Fukushima Dai-ichi NPS as a result of the accident and made the results public on April 12 and June 6. The estimated total amount of release announced on June 6 was about 160,000 tera Bq for iodine-131 and about 15,000 tera Bq for cecium-137. The iodine-equivalent quantity of the total release including both of the above is about 770,000 tera Bq. (See Chapter V-7 (1) a).

The Nuclear Safety Commission (NSC) of Japan estimated the total amount of radioactive materials released into the atmosphere as a result of the accident using a method different from that used by NISA and made announcements on the estimated amount on April 12 and August 24. The estimated total amount of release announced on August 24 was about 130,000 tera Bq for iodine-131 and about 11,000 tera Bq for cecium-137. The iodine-equivalent quantity of the total release including both of the above is about 570,000 tera Bq. (See Chapter V-7 (1) b).

After the occurrence of the accident, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has regularly made reports on the spatial distribution of dose rates and cumulative doses in the area around the Fukushima Dai-ichi NPS. According to these reports, the spatial dose rate distribution around the Fukushima Dai-ichi NPS on November 11, 2011, was as shown in Fig. II-3, the cumulative dose up to the same date was as shown in Fig. II-4, and the cumulative dose in the period up to March 11, 2012, is expected to be as shown in Fig. II-5 (forecast).

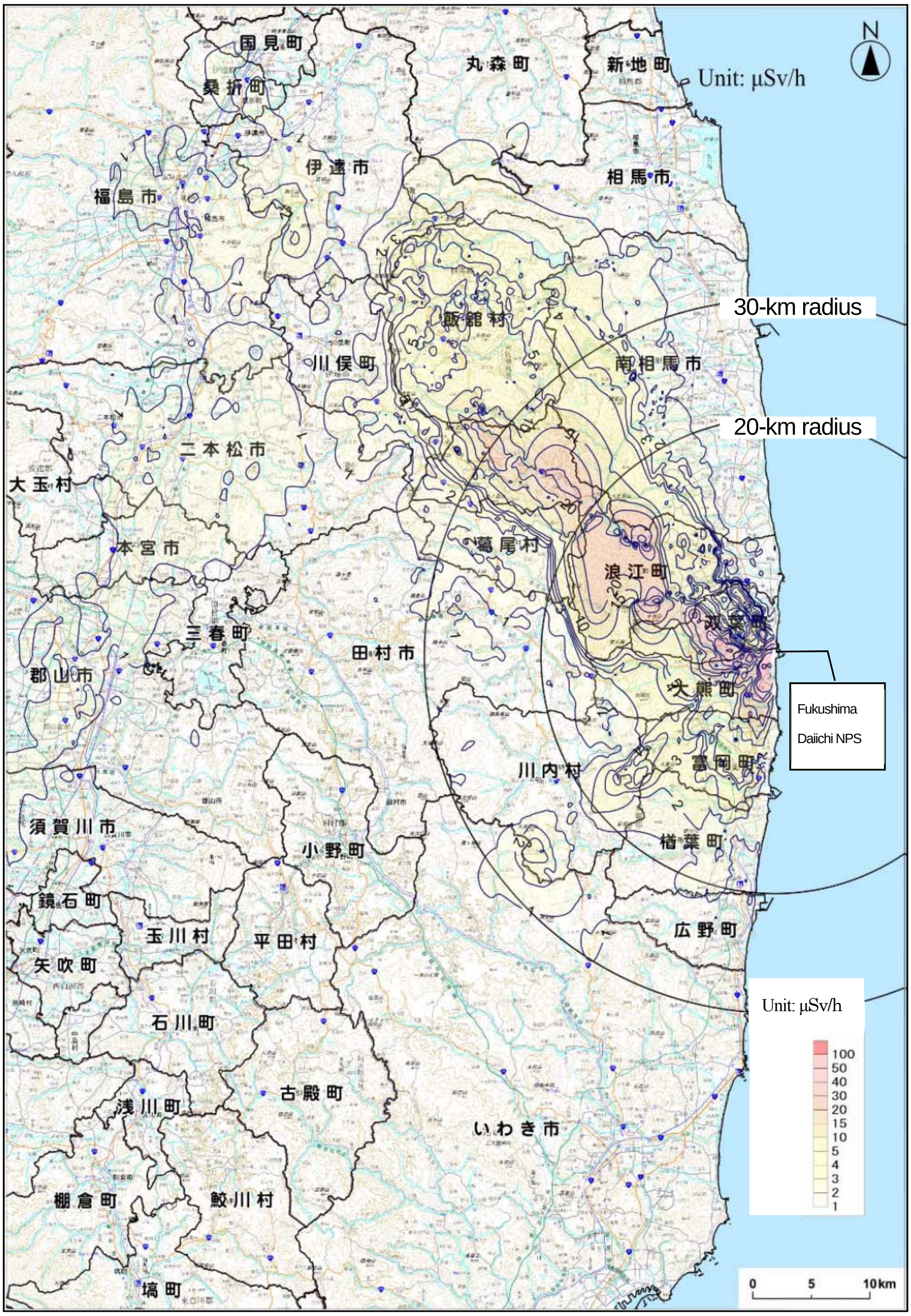

Fig. II-3 Spatial dose map (as of November 11, 2011)

Produced on the basis of MEXT "On Maps Showing the Distribution of Radiation Dose, etc" The map in the background is from Denshi Kokudo (electronic map from GIA Japan).

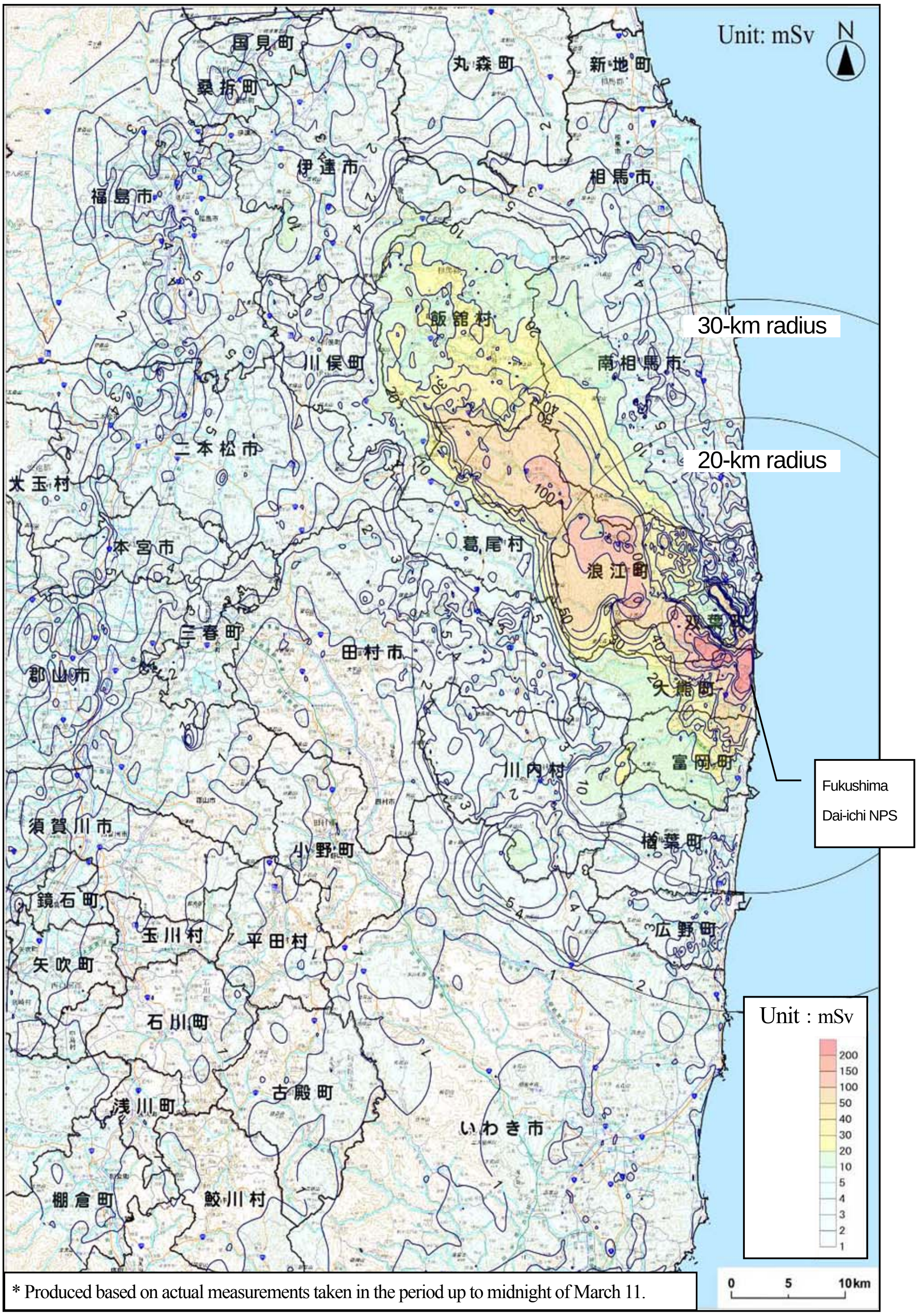

Fig. II-4 Estimated cumulative dose distribution map (cumulative dose in the period up to November 11, 2011)

Produced on the basis of MEXT "On Maps Showing the Distribution of Radiation Dose, etc" The map in the background is from Denshi Kokudo (electronic map from GIA Japan).

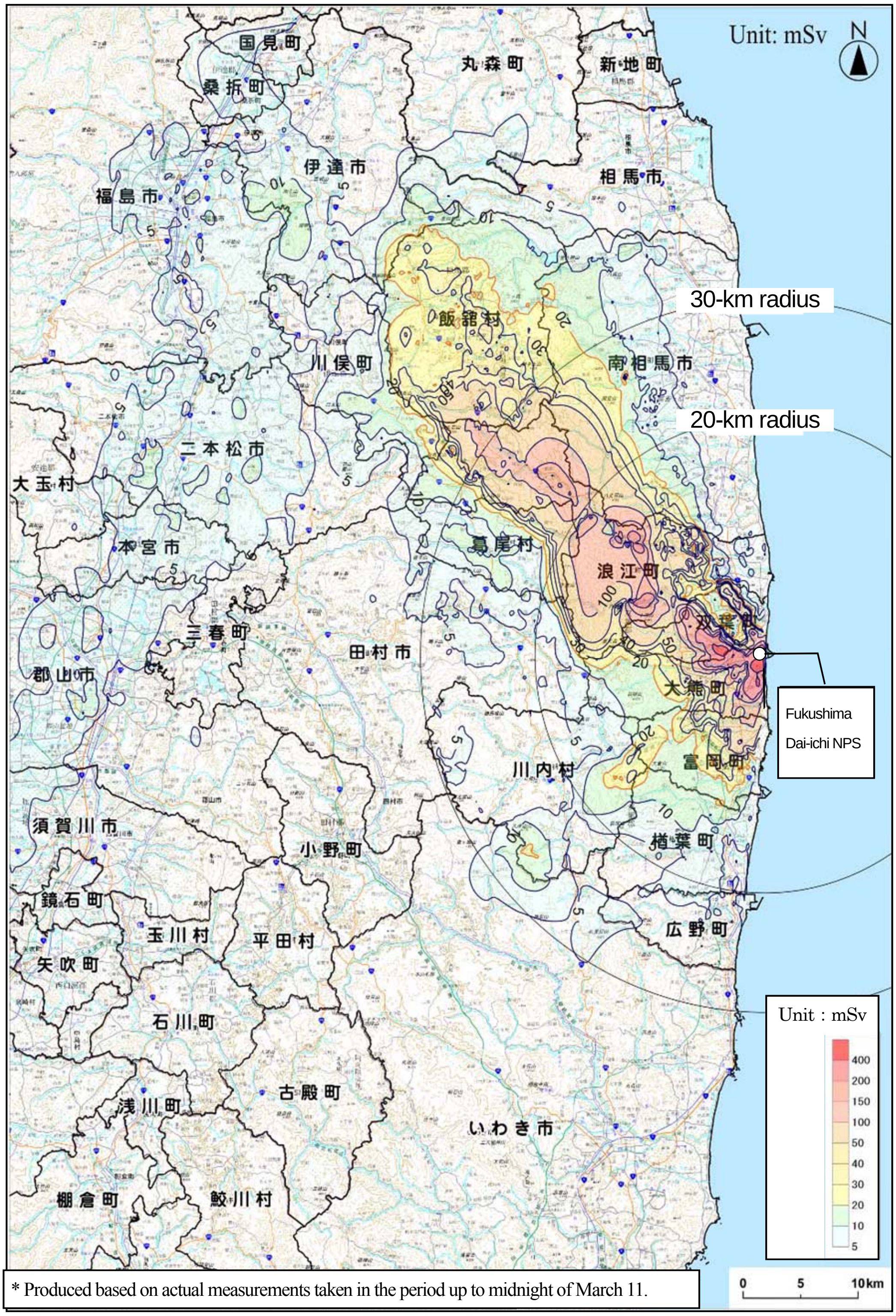

Fig. II-5 Estimated cumulative dose distribution map (cumulative dose in the period up to March 11, 2012)

Produced on the basis of MEXT "On Maps Showing the Distribution of Radiation Dose, etc" The map in the background is from Denshi Kokudo (electronic map from GIA Japan).

(2) Overview of people affected by radiation exposure

a. Exposure of radiation workers

Exposure dose (mSv)	Number of persons	Proportion (%)
Above 250	6	0.04
200 (excl.) to 250 (incl.)	3	0.02
150 (excl.) to 200 (incl.)	20	0.12
100 (excl.) to 150 (incl.)	133	0.79
50 (excl.) to 100 (incl.)	588	3.48
20 (excl.) to 50 (incl.)	2,193	12.96
10 (excl.) to 20 (incl.)	2,633	15.57
10 or less	11,340	67.04
Total	16,916	

Table II-2 Exposure of radiation workers (The information about the number of persons is as reported by TEPCO. The information is as of September 30.)

In the period between March 11 (beginning of the accident) and the end of September, more than 16,900 persons were engaged in emergency work activities.

The legal limit on the maximum dose that is incurred on a worker while being engaged in emergency work activities had been 100 mSv. However, on March 14, a decision was made to permit 250 mSv as the maximum dose for a worker during engagement in particularly demanding work activities conducted in response to the Fukushima nuclear accidents (See Chapter V-4 (2)).

Six workers have exceeded this dose limit of 250 mSv during engagement in work activities conducted in response to the Fukushima nuclear accidents.

b. Causalities from explosions at buildings

At the Fukushima Dai-ichi NPS, an explosion that took place in the Unit 1 R/B at 15:36 on March 12 and an explosion in the Unit 3 R/B at 11:01 on March 14 caused injury to workers and Japan Self-Defense Force members.[28]

The explosion in the Unit 1 R/B caused injury to five persons (mostly the employees of TEPCO and its associated company). The explosion in the Unit-3 R/B caused injury to eleven persons (mostly TEPCO employees and Japan Self-Defense Force members).

c. Exposure of citizens

Exposure dose rate (count rate in cpm)	Number of persons	Proportion (%)
100,000 or more	102	0.04
13,000 (incl.) to 100,000 (excl.)	901	0.39
Less than 13,000	231,838	99.57
Total	232,841	

Table II-3 Exposure of citizens (The information about the number of persons is as reported by the Fukushima prefectural government. The information is as of October 31.)

Since March 12, the Fukushima prefectural government has been conducting a radiological screening of citizens (See Chapter-V 4 (5)). By the end of October, more than 232,000 citizens had been screened.

In the beginning, the Fukushima prefectural government recommended decontamination of the whole body for those who exceeded the criterion of 13,000 cpm (counts/minute)[29] according to measurement taken with a radiation measuring instrument. On March 14, the criterion for decontaminating the whole body was raised to 100,000 cpm considering the result of screening activities that had been conducted by that time (See Chapter V-4 (5) b).

Due to the consequences of the Fukushima nuclear accidents, an exposure dose of 100,000 cpm or above was suffered by 102 citizens and an exposure dose of 13,000 cpm or above was suffered by 1,003 citizens.

[28] There has been no report of casualties from the explosions in the Unit 4 R/B that took place approximately between 06:00 and 06:10 on March 15.

[29] Considering the type of radiation measuring instruments that had been prepared by the Fukushima prefectural government (GM Survey Meters TGS-136 and TGS-146), this is equivalent to about 40 Bq/cm^2.

(3) Overview of evacuees

Following the occurrence of the accident at the Fukushima Dai-ichi NPS, the Government Nuclear Emergency Response Headquarters, in pursuant to the Nuclear Emergency Preparedness Act, designated a 20-km radius zone around the Fukushima Dai-ichi NPS as the access restricted area. In addition, the surrounding area (outside the access restricted area) where the cumulative dose in a year from the occurrence of the accident may reach 20mSv/y was designated as the deliberate evacuation area. The other areas (outside the access restricted area and the deliberate evacuation area) where sheltering or evacuation may be required in the future in emergency were designated as the evacuation-prepared areas in case of an emergency (See Chapter V-3). The emergency evacuation-prepared areas in case of emergency were called off on September 30.)

As shown in Table II-4 below, a total of about 114,460 persons have evacuated in accordance with these measures.[30]

[30] The number of evacuees was calculated by subtracting, from the total population, the number of persons who remained in the given areas (as of November 4.)

	Access restricted area	Deliberate evacuation area	Areas previously designated as the evacuation-prepared areas in case of an emergency	Total	Major destinations (municipalities hosting evacuees)
Okuma Town	11,500	—	—	11,500	Tamura City, Aizuwakamatsu City, etc.
Futaba Town	6,900	—	—	6,900	Kawamata Town, Kazo City (Saitama Pref.), etc.
Tomioka Town	16,000	—	—	16,000	Koriyama City, etc.
Namie Town	19,600	1,300	—	20,900	Nihonmatsu City, etc.
Iitate Village	—	6,200	—	6,200	Fukushima City, etc.
Katsurao Village	300	1,300	—	1,600	Fukushima City, Aizusakashita City, Miharu City, etc.
Kawauchi Village	400	—	2,500	2,900	Koriyama City, etc.
Kawamata Town	—	1,300	—	1,300	Kawamata Town, Fukushima City, etc.
Tamura City	400	—	2,100	2,500	Tamura City, Koriyama City, etc.
Naraha Town	7,700	—	50	7,750	Iwaki City, Aizumisato Town, etc.
Hirono Town	—	—	5,100	5,100	Iwaki City, etc.
Minamisoma City	14,300	10	17,500	31,810	Fukushima City, Soma City, etc.
Total	77,100	10,110	27,250	114,460	

Table II-4 Number of evacuees (approximate)

Produced in reference to materials produced by the Government Nuclear Emergency Response Headquarters (except for information about the major destinations of evacuees)