

Radiation Regulations Relevant to the Fukushima Daiichi Nuclear Power Plant Accident

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On March 11, 2011, a serious accident began at the Fukushima Daiichi Nuclear Power Plant after a huge tsunami hit the plant as a result of the M9.0 earthquake. The regulation values for the radiation and radioactivity in an emergency were noticed, and were not adequate serve for this situation. The existing regulation values concerning the notification criteria for occurrence of an unusual situation and the judgment criteria of an emergency, the radiation dose limits of workers in an emergency, sheltering and evacuation of residents, and oral administration of stable iodine tablet are first described. The regulation values set after the accident are concerned with the intake of foods and drinks, the paddy field soil, going to school and engaging in outdoor activities for kindergarten and school age children, swimming beaches, and ash and fly ash from incinerators, sludge from sewage disposal plants and residual matter from water purification plants.

Key words: emergency, radiation regulation, existing regulation values, regulation values after accident, Fukushima Daiichi Nuclear Power Plant accident,

1. Introduction

The installation standards of nuclear reactors and the radiation standard levels for normal operations in Japan have changed over the years, reflecting progress of nuclear applications and technologies¹⁾. The regulations for nuclear severe accidents have also been fixed, and likewise changed. Following the U.S. TMI accident, the Chernobyl nuclear power plant accident, and the Tokai JCO accident, statutes were revised and updated to reflect the new information obtained in dealing with these events and accident measures

were strengthened. Periodic inspections of facilities check of security regulation observance, allocation of security inspectors, and introduction of a proposed system for improving the existing situation have been made according to the Act on the Regulation on Nuclear Source Material, Nuclear Fuel Material and Reactors. The Act on Special Measures Concerning Nuclear Emergency Preparedness has been enacted in order to strengthen emergency response. The legislation is fixed about clarification of a notification standard and duty of notification by an entrepreneur, reservation of cooperation between the national government and the local government, installation of an offsite center, decision of a accident prevention plan by local government and implementation of an emergency drill, and technical advice of the Nuclear Safety Commission. Moreover, this legislation requires that a Senior Specialist for Nuclear Emergency Preparedness is appointed in every

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Table 1. Notification criteria for occurrence of an unusual situation and judgment criteria of an emergency

	Notification criteria	Judgment criteria
Near boundary of nuclear facilities		
Dose rate at one point, in 10min	5 μ Sv/h	500 μ Sv/h
At more than two point, same time	5 μ Sv/h	500 μ Sv/h
Stack and Discharge locations		
Release of radioactivity at boundary	\geq 5 μ Sv/h	\geq 500 μ Sv/h
Fire and Explosion		
Dose rate at outside RMZ	\geq 50 μ Sv/h	\geq 5 mSv/h
Release of radioactivity at inside RMZ	\geq 5 μ Sv/h	\geq 500 μ Sv/h

RMZ: radiation management zone

nuclear facility. Furthermore, the guidance for handling a nuclear accident was also revised, and the guidance for preventing an accident occurrence, spread of the effect of an accident, and restoration of the situation to normal was included in the guidance for the fuel processing plants, the storage facilities, and the radioactive waste handling facilities. The monitoring organization, maintenance of materials to provide radiation protection, and sheltering and evacuation procedures were fixed. Moreover, the regulation levels of radiation and radioactivity were set for target nuclides.

However, on March 11, 2011, a serious accident began at the Fukushima Daiichi Nuclear Power Plant (Fukushima-1 NPP) after a huge tsunami hit the plant as a result of the M9.0 earthquake. The existing nuclear countermeasures and the regulation values of radiation and radioactivity were not adequate serve for this situation. This paper looks at the regulation values for the radiation and radioactivity in an emergency. The existing regulation values are first described and the regulation values set after the Fukushima-1 NPP accident are described in detail.

2. Notification criteria of an unusual situation and judgment criteria of a nuclear emergency

Table 1 shows the notification criteria for occurrence of an unusual situation and the judgment criteria of an emergency. These criteria are explained below.

2.1. Notification Criteria in an Unusual Situation

The operator of a nuclear facility is obligated to notify immediately the manager of the facility when an unusual situation occurs, and the manager is obligated to notify the national and local governments. The bench mark dose recognized as occurrence of an unusual situation is shown by the following three cases.

(1) Boundary of the Nuclear Facility

Notification of occurrence of an unusual situation is made when 5 μ Sv/h is measured for the radiation dose rate during 10 minutes or more at one point in near the boundary of nuclear facility, or when 5 μ Sv/h is simultaneously measured at two or more points. In addition, when gamma-ray dose rate is above 1 μ Sv/h, neutron dose rate is measured, and notification is made when their sum is 5 μ Sv/h.

(2) Stack and Discharge Locations

Notification of occurrence of an unusual situation is made when the activity level of radioactive materials at stack or discharge locations corresponds to above a dose rate of 5 μ Sv/h or more near the boundary of facility after exhaust gases diffuse from the discharge locations.

(3) Fire and Explosion

Notification of occurrence of an unusual situation is made when a dose rate over 50 μ Sv/h is measured at the outside of a radiation management zone or the activity level of the radioactive materials corresponds to more than 5 μ Sv with occurrence of a fire or explosion in the nuclear facility.

2.2. Judgment Criteria of Emergency

The bench mark dose used to judge an emergency occurrence is defined in the following three cases and the operator is obligated to notify immediately the manager of the facility and the manager is obligated to notify the national and local governments.

(1) Boundary of Nuclear Facility

Judgment of occurrence of an emergency is made when 500 μ Sv/h is measured for the radiation dose rate during 10 minutes or more at one point in near the boundary of nuclear facility, or when 500 μ Sv/h is simultaneously measured at two or more points. In addition, when the gamma-ray dose rate is above 5 μ Sv/h, the neutron dose rate is measured, and judgment of occurrence is made when their sum is 500 μ Sv/h.

(2) Stack and Discharge Locations

Judgment of occurrence of an emergency is made when the activity level of radioactive material at stack or discharge locations corresponds to a dose rate of 500 μ Sv/h or more near the boundary of the facility after an exhaust gases diffuse from the discharge locations.

(3) Fire and Explosion

Judgment of occurrence of an emergency is made when a dose rate over 5 mSv/h is measured outside the radiation management zone or the activity level of radioactive materials correspond to more than 500 μ Sv/h with occurrence of a fire or explosion generates in a nuclear facility.

Table 2. Radiation dose limits in an emergency for radiological workers

Effective dose limit	100 mSv
Equivalent dose limit of the eye lens	300 mSv
Equivalent dose limit of skin	1,000 mSv

Table 3. Radiation dose limits in an emergency for first responders and workers dealing with control of the emergency

Effective dose limit	50 mSv
Equivalent dose limit of the eye lens	300 mSv
Equivalent dose limit of skin	1,000 mSv
Equivalent dose limit when: Preventing expansion of the emergency Engaging in lifesaving work	100 mSv

Table 4. Prospective doses in an emergency and prevention measures

Prospective doses (mSv)		Prevention measures
Effective dose from external exposure	Equivalent dose of thyroid, bone surface & lung (for U and Pu)	
10-50	100-500	Sheltering & Evacuation
≥ 50	≥ 500	Sheltering in concrete building & Evacuation

3. Dose limits of workers in an emergency

3.1. Radiation Dose Limits for Radiation Workers

The radiation dose limits of radiation workers operating the facility in an emergency are shown in Table 2.

3.2. Radiation Dose Limits for Emergency Action Workers

The radiation dose limits of emergency action workers first responders, which include police, firefighters et al. not normally working at the facility and workers dealing with control of the emergency are shown in Table 3.

3.3. Special Case Restriction for the Fukushima-1 NPP Accident

The effective dose limit of radiation workers in an emergency was raised to 250 mSv as a special case restricted to Fukushima-1 NPP accident²⁾. The Radiation Council Basic Committee had already accepted the recommendation of ICRP2007 before this accident occurred, and the Committee had reported that the effective dose of radiation workers in an emergency should be set between 500 to 1000 mSv³⁾, but the dose limit for persons carrying out rescue and lifesaving tasks was not set.

However, it was not decided whether the radiation dose for radiation workers exposed in an emergency should be given special treatment or combined with the dose for normal situations; this must be deliberated by the national government from now on. Moreover, it is also necessary to consider the radiation dose for workers if emergency overlapped.

4. Dose regulation in sheltering and evacuation for nearby residents

4.1. Sheltering and Evacuation

Nuclear facilities are required to take measure immediately when a radioactive material or radiation is abnormally discharged in order to mitigate exposure of residents around the facilities. The size of the effects on the circumference

environment due to the abnormal discharge, the duration of the discharge, and duration of the effects need to be flexibly considered though there are some common features regarding aspects of the emergency, characteristics of the type of facility, the surrounding geographical features, weather conditions, and residents' lifestyles and habits.

Therefore, an Emergency Planning Zone (EPZ) is defined as: "the area which should have substantial accident measures" that are prepared advance. The items which should be implemented in this EPZ include: establishing ways to provide information quickly to nearby residents when an emergency occurs: maintaining environmental radiation monitoring during the emergency, preparing and maintaining radiation protection equipment for use during the emergency, ensuring residents know methods of sheltering and evacuation, and providing clear information on evacuation routes and evacuation sites.

The size of the EPZ changes depending on the nuclear facility and its purpose, such as whether it is a reactor for generating electric power, a research reactor, a fuel re-processing facility, a radioactive waste facility, etc. In the EPZ, sheltering and evacuation of residents is called for when the radiation dose is 10 to 50 mSv. The air-tightness of the sheltering buildings must be sufficient. Moreover, residents may be required to shelter in concrete buildings or to evacuate for radiation doses over 50 mSv. These doses are shown in Table 4 along with the judgment dose of a thyroid equivalent dose for iodine.

4.2. Administration of Iodine Tablets

The protection measure provided together with sheltering and evacuation is oral administration of stable iodine tablets. Prospective dose of 100 mSv which is a child's thyroid equivalent dose for iodine is uniformly set for every one independently of sex and age.

5. Regulations for foods and drinks for the public

5.1. Intake Restriction Indices of Accident Preparedness

Table 5. Intake restriction indices for drinking water and foods set by the Nuclear Safety Commission

Category	Iodine I-131 Bq/kg	Cesium Cs-134,-137 Bq/kg	Uranium U-235,-238 Bq/kg	TRU* Pu-239, etc Bq/kg
Drinking water	300	200	20	1
Milk, Dairy products	300	200	20	1
Powered milk formula for infant	100	—	20	1
Vegetables	2,000	500	100	10
Grains	—	500	100	10
Fish & Shell fish	2,000	500	100	10
Meat, Eggs, etc	—	500	100	10

* TRU: trans-uranium elements

Guideline of the Nuclear Safety Commission

The process by which the intake restriction indices of the guideline for accident preparedness is described next in some detail, since this is used for the intake restriction values of foods.

The Nuclear Safety Commission sets the indices for intake restrictions of foods and drinks, since it will be aid to reducing exposure of the public. However, the Nuclear Safety Commission does not examine whether the regulation values are appropriate for the indices. The guideline for the intake restriction of foods and drinks is made by the headquarters for countermeasures against a nuclear accident.

The decision procedure for the indices is as follows. First, the maximum of an annual dose (intervention judgment dose) is set to 50 mSv for the thyroid equivalent dose for iodine and to 5 mSv for other elements including cesium. These figures are the same as used by ICRP, IAEA, and WHO. Next, Results of a nationwide investigation concerning the personal amount of food-and-drink intake per day (national survey on nutrition 1986) were picked up. After summarizing the amount per day (kg/d) for intake of 14 items to depend in six categories and setting these as survey values, the values are rounded up as the first safety margin and considered as index derivation values. Furthermore, they are rearranged in 5 categories after drinking water is added to this. The respect intake amounts per day are respectively computed for an adult, a small child, and an infant. Finally, the induced intervention concentration (Bq/kg) is gotten for guidance using the intervention judgment dose, the amount of intake and dose conversion coefficient (Sv/Bq).

For iodine, one third of intervention judgment dose is considered as the second safety margin and the two thirds remaining is from drinking water, milk and dairy products, and vegetables (excluding root vegetables and potatoes). For cesium and other radioactive elements, intervention judgment dose is computed by assuming and equal distribution in five categories. Fish and shellfish are included in the category with meat and eggs. Minimum values for an adult, a small child and an infant are rounded to still smaller values to provide the third safety margin, and these are given as the intake restriction indices. The intake restriction indices are shown in Table 5 for iodine, cesium, uranium, and trans-uranium elements.

5.2. Provisional Regulation Values for Foods and Drinks Intake by the Food Safety Commission

Based on the Food Sanitation Act, provisional regulation values on radioactivity in foods were set on March 17 following the start of the Fukushima-1 NPP accident⁴. The intake restriction indices of foods and drinks, described in Section 5.1 and set by the Nuclear Safety Commission, were directly used as provisional regulation values without change. Then, as specified by the Food Sanitation Act, the public was advised not to consume drinks and foods exceeding these regulation values. On April 5, in view of the large amounts of intake to fish and shellfish eaten by Japanese, a separate category from meat and eggs was set at 2,000 Bq/kg for fish and shellfish. Furthermore, a provisional regulation value of 500 Bq/kg was set for raw green tea leaves and semi-processed tea leaves on May 16, and a provisional regulation value of 500 Bq/kg was intermittently set for semi-processed tea leaves and processed tea on June 2. These are summarized in Table 6 and were based on consideration of Japanese eating habits.

On March 20, the Minister of Health, Labor and Welfare requests that the Food Safety Commission consider food healthy effects of certain foods since the provisional regulation values were defined without evaluating their positive health effects. The Food Safety Commission issued a report on the urgent adjustment of regulatory values for radioactive elements in foods to the minister on March 29.

The Subcommittee of food sanitation of the Pharmaceutical Affairs and Food Sanitation Council of the Ministry of Health, Labor and Welfare announced that the present provisional regulation values set on April 4 were appropriate. The Food Safety Commission confirmed the urgent adjustment on July 26, and additional lifetime exposure to 100 mSv including external and internal exposures as total exposure and excluding exposure to natural radiation was deemed appropriate⁵.

On October 28, the Food Safety Commission stated that the additional lifetime exposure to 100 mSv excluding both exposure to natural radiation and external exposure was appropriate and that a new regulation would be set spring of 2012⁶. In the regulation, an upper limit of dose for setting regulation values is expected to be 1 mSv/y and therefore new regulation values in the existing situation (i.e. after the Fukushima-1 NPP accident) will be smaller than the present provisional value.

Table 6. Summary of Provisional Regulation Values Set after the Fukushima-1 NPP Accident

Item & Nuclide	Activity (Bq/kg)	Set date*	Remarks	
Drinking water	I	300		
	Cs	200		
	U	20	3/17	
Milk & Dairy products	Pu	1		
	I	300		
	Cs	200	3/17	≥ 100 Bq/kg: except for infants
Vegetables	U	20		
	Pu	1		
	I	2000		
Grains	Cs	500	3/17	Exceptions: root crops & potatoes
	U	100		
	Pu	10		
Meat, Eggs, Fish & Others	Cs	500		
	U	100	3/17	I : 2000 Bq/kg for fish & shell fish (4/5)
	Pu	10		
Food for infants	U	20	3/17	
	Pu	1		
Tea (Raw leaf · Semi-produced tea leaf)	Cs	500	5/16	Semi-produced tea leaf & Processed tea : set on 6/2
Paddy field	Cs	5000	4/8	Transfer coefficient: 0.1
Ash & Fry ash	Cs	≤ 8000	6/23,	Can be disposed of underground
		8000-100000	28	Can store in an ordinary waste facility
		100000 <		Can be stored in facility with radiation shielding
Accident waste	Cs	10 μSv/y	6/23	Can be recycled
		≤ 8000 μSv/y		Can be disposed of underground
Beach	I	30	6/24	
	Cs	50		
Forage for beef cattle	Cs	3000	8/1	Cattle cannot be shipped to market at the present
Forage for cows, horses, pigs and poultry	Cs	300	8/1	Water content in forage : 80% Others: Product weight
Forage for fish	Cs	100	8/1	Product weight
Soil for filling and reinforcement	I, Cs	400	8/1	Product weight

* Set day: all in 2011

I: radioactive iodine, Cs: radioactive cesium, U: uranium, Pu: plutonium,

5.3. Provisional Regulation Value for Paddy Fields

On April 6, the Ministry of Agriculture, Forestry, and Fisheries gave 5000 Bq/kg for the regulation value of the paddy field soil as a measure to regulate radioactive contamination of the rice which is the staple in the Japanese diet (Appendix Table 1). This value is decided from the provisional regulation value of 500 Bq/kg for grain considering the transfer coefficient from soil to brown rice referred to as 0.1. The rice planting is not permitted in the contaminated paddy field beyond this value. As well, rice ear samples are collected one week before harvesting and their radioactivity measured. Rice tested to exceed 200 Bq/kg is subjected to a second radioactivity measurement after harvest and then the provisional regulation value of 500 Bq/kg of grain is applied.

Provisional regulation values of other agricultural products, such as vegetables, have not been defined.

6. Regulations for residents affected by the Fukushima-1 NPP accident

6.1. Setting Values in Evacuation Arias

The following zones were set in response to the situation after the Fukushima-1 NPP accident⁷⁾.

(1) Planned Evacuation Area: An inner 20 km zone from the Fukushima-1 NPP, which has a possibility of exceeding an exposure of 20 mSv in one year was set on April 22. Entry to this area is impossible without government permission. As of October 11, this area was being continued.

(2) Sheltering and Evacuation Preparation Zone: An area of 20-30 km from the Fukushima-1 NPP which has the possibility for providing sheltering or evacuation in a future emergency was set on April 22 and habitation was possible in this area. On September 22, a newly Planned Sheltering and Evacuation Area was set for the whole region that includes administered by some of surrounding five local governments and the existing Sheltering and Evacuation Preparation Zone of 20 km was canceled on September 30.

(3) Recommended Specific Refuge Points: Eleven points on the perimeter of a planned refuge zone (in the northwest direction from the Fukushima-1 NPP) were set on September 30.

It should be noted that, 20 mSv is the lower value which the ICRP is assumes for the dose limit for the general public, 20-100 mSv in one year in the emergency situation.

6.2. Provisional Regulation Values for Kindergarten and School Age Children

The Ministry of Education, Culture, Sports, Science and Technology set 3.8 $\mu\text{Sv/h}$ as provisional regulation value for going to school and engaging in outdoor activities for kindergarten and school age children. This is drawn from an annual dose of 20 mSv⁸⁾. The calculation condition is follows that the occupancy factor outdoors is 8 hours and indoors for 16 hours, and are setting the shielding effect of a building as 0.6 (the dose from the outdoors decreases to 40%). On May 27, this value was replaced by an annual dose of 1 mSv aiming at a dose decrease through decontamination measures⁸⁾.

6.3. Provisional Regulation Value of Swimming Beaches

On June 24 the Ministry of Environment decided the provisional regulation value at swimming beaches as below 50 Bq/L water for cesium and 30 Bq/L water for iodine (Table 6)⁹⁾. These values were based on provisional regulation values of drinking water as 200 Bq/L for cesium and 300 Bq/L for iodine, and they are 1/4 of drinking water, and 1/10, respectively. This calculation was done as follow; a person swims every day for 5 hours per day during two months. It is set so that it is less than 1 mSv on the assumption of drinking 1 liter of water every time when swimming. Although it is an unreal assumption and moreover leads to only a value about 0.1 mSv, it is carried out from the consideration of being additional factor after external exposure and internal exposure by intake of foods and drinks.

7. Views about decontamination and contaminant processing

7.1. Provisional Regulation Value in Connection with Decontamination

Decontamination operations are various and locations where they must be carried out vary including individual house, circumference of a house, a road, a park, a school, other public facilities, fields, forests, and others are contaminated.

In the case of an individual house, partial decontamination work can be individually performed by owners and other tasks such as roof cleaning can be performed by special contractors. It is likely that there will not be regulation values for decontamination of individual houses. As well regulation values for decontamination are not rigidly decided for other buildings and places. However, an annual dose in the Planned Evacuation Area is over 20 mSv and no one can enter without permission. At the very least, decontamination of the habited areas exceeding this dose should be given top priority, and the designation of the Sheltering and Evacuation Area should be removed as soon as possible.

It should be notified that an annual dose of 5 mSv was put as one regulation value, since the national government has presented a plan which sets cost of decontamination of the area exceeding this value. However, an annual dose of 1 mSv excluding natural radiation contribution obtained by decontamination and natural reduction can be called the

final expected value after decontamination. On October 11, the government announced that the aimed value was reduced to an annual dose of 1 mSv from annual dose of 5 mSv considering decontamination cost burden.

7.2. Provisional Regulation on Sludge Produced by Sewage Disposal Plants

On June 16 the Nuclear Emergency Response Headquarters presented detail for the handling of sludge. These were derived with reference to consideration of provisional handling of sand generated from a water purifying plants in which the radioactive materials were detected and consideration of the tentative handling of secondary products in which radioactive materials were detected. Responsible ministry agencies have showed plans and the notices in response to these^{11, 12)}.

On June 23 and 28, the Ministry of Environment released the provisional regulation values about ash and fly ash from incinerators, sludge from sewage disposal plants, and residual matter from water purification plants (Table 6). An object nuclide is cesium. Recycle is possible for materials with the radioactivity less than 8,000 Bq/kg at a waste disposal facility, since workers do not receive an annual dose over 1 mSv in a trial calculation. Materials can be stored underground at the wastes disposal place for radioactivity of about 8,000-100,000 Bq/kg, based on the limitation of annual dose being less than 1mSv for the public. Beyond 100,000 Bq/kg materials can be kept at a disposal facility that provides radiation shielding.

In addition, even if the activity of the dried sludge etc. is less than 8,000 Bq/kg, when the disposing areas are used for habitation and farming in the future, it is necessary that the drying sludge is disposed of underground so that the dose becomes below a clearance level (0.01 mSv/y) which is more than one order lower level than of 0.4 mSv of annual natural radiation dose. The object nuclide is also cesium for accident waste, and recycling is enabled when the annual dose is below 0.01 mSv. This provisional regulation level is the same as for radioactive waste. Recycling of incombustible materials having activity under 8,000 Bq/kg is the same as for ash.

7.3. Others

As October 11, no decision has been made for disposal of large-sized filters used in air purification in offices, the factories, the hospitals, the huge stores, etc.

8. Conclusion

In connection with the Fukushima-1 NPP accident which began on March 11, 2011, the existing regulation values and the provisional regulation values taken after the accident were described. Progress in setting the decision of provisional regulation values was described in detail. The provisional regulation values set after the accident were collectively shown in the Table 6.

This was the first occurrence of such a large scale

accident and the situation has been very fluid after it. As well, there have been strong requests from the general public for information about the accident, and explanations provided have not necessarily been consistent. Considering the possibility that new regulation values will still continue to come out, the situation will continue to be confusing. It is important that plans are set on the basis of scientific knowledge about radiation protection and that concrete actions are performed. It is necessary to distinguish provisional regulation values in an emergency from regulation values in a subsequent normal situation. It is also very important that the provisional regulation values should be used certainly and quickly without confusion after fully disclosing them to the general public.

The last processing stage of contaminated materials which were classified and defined as to the disposal method is immediately related to the regulation values. Unless this proceeds well, processing of contaminated materials will stagnate and the solution becomes more and more difficult. It is necessary to include the general public in this.

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