Commentary

Waste Contaminated with Radioactive Material from the Fukushima Dai-ichi Nuclear Power Plant Accident

–Relation between Amount of Radioactive Material in Waste and Related Laws–

Japan Radioisotope Association, **Shoji Futatsukawa**

In the Fukushima Daiichi Nuclear Power Plant Accident, a considerable amount of unplanned radioactive materials were emitted into the environment, creating waste contaminated by radioactive materials. To address this situation, the "Act on Special Measures for Debris Management" was established on August 26th 2011, paving way for managing waste and soil contaminated by radioactive materials. However, specific management and disposal methods have not been clearly defined. Waste management planning is steadily advancing, which will likely lead to reasonable and realistic methods for restoration. This commentary explains the relation between the waste contaminated by radioactive materials in the Fukushima Daiichi Nuclear Power Plant Accident and the related laws as they stand today.

I. Generation of Waste

On March 11th 2011, the unprecedented Great East Japan earthquake caused Tokyo Electric Power's Fukushima Daiichi Nuclear Power Plant accident (referred to as the Fukushima Nuclear Plant Accident), which led to a considerable amount of unplanned radioactive materials being emitted into the environment. These materials were deposited over a wide range of areas depending on the topographical and meteorological conditions, contaminating soil, crops, and water and creating various wastes contaminated by radioactive materials. Before the Fukushima Nuclear Plant Accident, an emission of such a large amount of radioactive material outside of the radiation facility was not anticipated and there were no laws for regulating it. On August 26th 2011, the first law regarding management of environmental pollution due to nuclear accidents, the "Act on special measures for managing environmental pollution by radioactive material released by Nuclear Power Plants Accident" (hereinafter, the Act on Special Measures for Debris Management), was established, paving way to manage debris and soil contaminated by radioactive material; however, specific management and disposal methods have not been clearly defined.

DOI : 10.15669/fukushimainsights.Vol.1.151

Originally published in Journal of the Atomic Energy Society of Japan (ISSN 1882–2606), Vol. 53, No. 12, p. 813–816 (2011) in Japanese. (Japanese version accepted: September 12, 2011)

1. The Waste Management Act and Disaster Waste

The law regarding general waste management is the "Waste Management and Public Cleansing Act" (hereafter, the Waste Management Act). This law defines "waste" as "garbage, over-sized garbage, cinder, sludge, human waste, waste oil, waste acid, waste alkali, animal carcass, and other garbage and worthless materials in solid and liquid forms (excluding radioactive materials and materials contaminated by the same)," and as such, "radioactive waste" is excluded from the subjects of regulation of this act. The Waste Management Act designates "general waste," which must be treated by the local municipality, and "industrial waste," which must be treated by companies, but treatment of industrial waste is often entrusted to waste management companies. If industrial waste forms majority of waste, which includes small amounts of general waste, it is treated as "industrial waste," and in the opposite case, it is treated as "general waste."

Waste generated by disasters, e.g., earthquakes, tsunamis, and floods (which is left outside), including debris and wood chips from destroyed buildings, concrete, and metal pieces, is called "disaster waste." The management responsibility of it is held by the municipality in which the disaster occurred. In the Han-Shin Awaji Earthquake disaster in 1995, more than 8 million tons of disaster waste was generated, leaving the many issues to be solved, such as securing of disposal sites and transportation routes and inter-municipality collaboration. The management of disaster waste incurs tremendous costs, making it difficult for the affected municipalities to take on the full responsibility. Thus, it was necessary for the government and community as a whole to manage the issue.

Furthermore, since the Waste Management Act is a general law, wastes subject to the regulation of a special measures law are managed according to special regulations.

2. Radioactive Waste

Radioactive waste is generated from the use of nuclear energy in Nuclear Power Plants and nuclear fuel cycle facilities as well as from the use of radioisotope in universities, research facilities, and hospitals. "High-level radioactive wastes" refers to vitrified high-level radioactive liquid waste generated from reprocessing of spent nuclear fuel, while other types are called "low-level radioactive waste." Radioactive waste is primarily regulated by Act on the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors (hereafter, the Nuclear Reactor Regulation Act), and Act on Prevention of Radiation Hazards due to Radioisotopes, etc. (hereafter, the Radiation Hazard Prevention Act).

3. Contaminated Waste Generated by Radioactive Materials from Fukushima Nuclear Plant Accident

Table 1 shows the waste contaminated by radioactive material from the Fukushima Nuclear Plant Accident, categorized by generation type.

Radioactive waste within Tokyo Electric Power's Fukushima Daiichi Nuclear Power Plant is generated as a by-product of the operation of the Nuclear Power Plant and is regulated by the Nuclear Reactor Regulation Act. The Act on Special Measures for Debris Management requires that the management plan for waste generated in restricted areas and planned evacuation areas and contaminated by radioactive materials to such an extent must be set by the Minister for the Environment and that the waste must be managed by the government. Waste beyond the criteria of radiation level generated outside the restricted and planned evacuation

areas is also managed by the government. Other low-contamination waste contaminated by radioactive materials is managed according to the Waste Management Act. In other words, such waste is managed by the municipality or the related companies themselves. According to the Act on Special Measures for Debris Management, the low-contamination radioactive waste generated inside the radiation facility due to the Fukushima Nuclear Plant Accident can be treated by the Act on Special Measures for Debris Management, but there is no clear definition of the act.

Table 1 Waste contaminated by radioactive materials from the Fukushima Nuclear Plant Accident

Location	Subject waste	Regulation
Inside nuclear power plant	Radioactive waste	Nuclear Reactor Regulation Act
Inside restricted area and planned evacuation area	Waste potentially contaminated to an extent that requires special management	Act on Special Measures for Debris Management
Outside restricted area and planned evacuation area	Waste exceeding certain criteria of radiation level	Act on Special Measures for Debris Management
Unspecified	Low-contamination waste from Fukushima Nuclear Plant Accident	Waste Management Act
Radiation facility	Low-contamination waste from Fukushima Nuclear Plant Accident	Nuclear Reactor Regulation Act or Radiation Hazard Prevention Act (no definition in Act on Special Measures for Debris Management)

II. Radionuclide and Concentration in Waste

1. Radionuclide from Fukushima Nuclear Plant Accident

According to the "Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety" created in June 2011 by the Government Nuclear Emergency Response Headquarters, the total activities of radionuclides emitted into the atmosphere from the Fukushima Nuclear Plant Accident were 1.6×10^{17} Bq for ^{131}I and 1.5×10^{16} Bq for ^{137}Cs; in addition, after the beginning of April, the emission activity of ^{131}I reduced to 10^{11} Bq–10^{12} Bq.

At that time, the major issue was the surface contamination of crops by radioactivity due to rain and snow. The subject radionuclide was ^{131}I, which has a high level of emission. However, the half-life of ^{131}I is 8 days and the current subject radionuclides of issue are ^{134}Cs and ^{137}Cs. The contaminated materials are leaves, soil, and sewage in areas with a relatively high concentration of radionuclides and incinerated ash with concentrated radionuclide from incinerating general waste. On August 29, 2011, the Ministry of the Environment published a report "On the management of waste potentially contaminated by radioactive materials in general waste incineration facilities," which contains a "Table of measurement results of radioactive cesium concentration in incinerated ash in general waste incineration facilities in 16 prefectures" up to August 24, 2011, which shows that the maximum ^{134}Cs and ^{137}Cs concentrations in the prefectures ranged widely from 196 to 95,300 Bq/kg. Based on the report, the number of cases with higher than 8,000 Bq/kg and with higher than 100,000 Bq/kg, and a maximum concentration in 16 prefectures are shown in **Table 2**. The management of soil with concentrated radioactive materials due to decontamination of top soil is also an issue. **Table 3** shows the radioactive cesium in agricultural soil in the prefectures shown in the report "Making a distribution map (radioactive cesium concentration map in soil) of radiation by the Ministry

of Education, Culture, Sports, Science and Technology" announced by the Ministry of Education, Culture, Sports, Science and Technology on August 30, 2011.

Table 2 Radioactive cesium concentration in incinerated ash in general waste incineration facilities (number of cases and maximum concentration)

($^{134}Cs + ^{137}Cs$)

Prefecture	Over 8,000 Bq/kg (cases)	Over 100,000 Bq/kg (cases)	Maximum (Bq/kg)
Iwate	0	0	30,000
Miyagi	0	0	2,581
Akita	0	0	196
Yamagata	0	0	7,800
Fukushima	23	0	95,300
Ibaraki	10	0	31,000
Tochigi	3	0	48,600
Gunma	2	0	8,740
Saitama	0	0	5,740
Chiba	8	0	70,800
Tokyo	1	0	12,920
Kanagawa	0	0	3,123
Niigata	0	0	3,000
Yamanashi	0	0	813
Nagano	0	0	1,870
Shizuoka	0	0	2,300
Total	49	0	

(Based on "Management of waste potentially contaminated by radioactive materials in general incineration facilities")

Table 3 Analysis of value of radioactive cesium in agricultural soil (Concentration of radioactive cesium corrected on June 14)

	Number of measurement subjects	Bq/kg($^{134}Cs + ^{137}Cs$)
Miyagi	65	24–2,215
Fukushima	361	ND–27,981
Ibaraki	62	ND–632
Tochigi	48	ND–3,971
Gunma	13	55–688
Chiba	30	19–777

(From "Making of a distribution map (radioactive cesium concentration map in soil) of radiation by the Ministry of Education, Culture, Sports, Science and Technology")
ND: "no detection" but not zero. This report does not indicate the detection limit.

2. Regulated Concentration

The Radiation Hazard Prevention Act defines radioisotopes as "those with the quantity and concentration exceeding that specified by the Ministry of Education, Culture, Sports, Science and Technology." In cases involving multiple radioisotopes, they become subjects of regulation if the sum of the ratio of their quantity to the specified quantity exceeds 1. The subject quantity is the total quantity in one facility. For various scenarios, the regulation values are set such that public exposure dose becomes less than 10 μSv/year under normal operations and 1 mSv/year for accidents. Each regulation concentration (exemption level) of ^{134}Cs and ^{137}Cs is 10 Bq/g.

According to "Ideas for the future treatment of by-products such as the water supply and sewage from which radioactive materials were detected" proposed by the Government Nuclear Emergency Response Headquarters on June 16, 2011, "Points to be cautious about storage, temporary storage, and transporting dehydrated sludge" include abiding by the related regulations on Regulation on Prevention of Ionizing Radiation Hazard (Ionizing Radiation Regulation). In the Ionizing Radiation Regulation, the regulation concentrations of both ^{134}Cs and ^{137}Cs are 10 Bq/g.

Radioactive waste exempted from the regulation include those contaminated by nuclides for positron computerized tomography (PET-nuclides), or the so-called PET wastes. Waste contaminated only by PET-nuclides whose half-lives are between 2 and 110 min, such as ^{15}O and ^{18}F, can be removed from radioactive waste when the number of atoms of the subject nuclides is below 1. According to the Radiation Hazard Protection Act, "PET-nuclides and radioactive wastes contaminated by PET-nuclides after 7 days of storage are not regarded as radioactive wastes." In this case, radioactive wastes can be removed from regulation subjects only through decay storage at storage facilities.

The Reactor Regulation Act has a clearance policy which states that radioactive waste can be removed from subject waste if the quantity of activity in the radioactive waste goes below a certain threshold due to decay and decontamination. The clearance policy makes it possible to recycle radioactive waste, or if recycling is not reasonable, dispose of the same as waste for which there is no need for considering radiation protection. The clearance standards are set such that, no matter how the materials are reused and disposed, the level does not exceed the annual exposure dose for public of 10 μSv (1 mSv for scenarios with a low probability of occurrence). Each clearance concentration of ^{134}Cs and ^{137}Cs is 0.1 Bq/g. According to the Reactor Regulation Act, to implement clearance, it is necessary for the nuclear company to determine that the radiation concentration of the waste materials does not exceed the clearance standard and for a regulatory organization such as the government to verify (verification evaluation system). In other words, verification for execution of clearance requires decisions by both the nuclear company and regulatory organization such as the government. A similar clearance policy will be implemented for the Radiation Hazard Prevention Act as well.

Standard concentrations related to the Fukushima Nuclear Plant Accident include the temporary standard value for radioactive cesium in food. With an annual exposure dose of 5 mSv, the sum of ^{134}Cs and ^{137}Cs is 200 Bq/kg for drinking water, milk, and dairy products and 500 Bq/kg for vegetables, grains, meat, egg, fish, and others. In addition, the index for the transfer of radioactive cesium from paddy soil to rice is 0.1 and the maximum allowed value of radioactive cesium concentration in soil for planting is 5,000 Bq/kg. **Table 4** shows the regulation concentrations of ^{134}Cs and ^{137}Cs and those related to the Fukushima Nuclear Plant Accident.

Table 4 Comparison of radioactive cesium concentrations

		^{134}Cs	^{137}Cs
Radiation Hazard Prevention Act	Regulated concentration	10 Bq/g	10 Bq/g
Ionizing Radiation Regulation	Regulated concentration	10,000 Bq/kg [*1]	10,000 Bq/kg [*1]
Reactor Regulation Act	Clearance standard	0.1 Bq/g	0.1 Bq/g
Food temporary standard	Drinking water	200 Bq/kg [*2]	
	Milk	200 Bq/kg [*2]	
	Vegetable	500 Bq/kg [*2]	
	Grains	500 Bq/kg [*2]	
	Meat/fish	500 Bq/kg [*2]	
Soil allowed for planting	Maximum	5,000 Bq/kg [*2]	
Radiation Hazard Prevention Act	Removal standard of PET waste	Number of atom below 1 (only for PET-nuclides, e.g., ^{15}O and ^{18}F)	

[*1] From "Ideas for future treatment of by-products such as water supply and sewage from which radioactive materials were detected."
[*2] ^{134}Cs + ^{137}Cs

3. Waste Disposal

According to the "Ideas for future treatment of by-products such as the water supply and sewage from which radioactive materials were detected," the following guidelines have been established. Waste such as dehydrated sludge with the total concentration of ^{134}Cs and ^{137}Cs below 100,000 Bq/kg, which are buried under the condition that an appropriate long-term dispersal plan will be established and the site will not be used for residence will cause annual exposure dose for public near the burial site to be below 10 μSv. Because a site where burials of different conditions were created needs long-term management and it is the necessity for examination of environmental conservation, waste such as dehydrated sludge with the total concentration of ^{134}Cs and ^{137}Cs below 8,000 Bq/kg, for which the calculation shows that the annual exposure dose of the operators of the disposal of it will not exceed 1 mSv, can be buried with an appropriate disposal plan for placement of soil layer and waterproof measures (disposal in a control-type landfill site). Until the safety of use of the site will be secured, the management of the site should involve necessary treatments, such as monitoring of radiation and facility management.

Dehydrated sludge with a total concentration of ^{134}Cs and ^{137}Cs higher than 8,000 Bq/kg and lower than 100,000 Bq/kg is to be temporarily placed in a control-type landfill site at a certain distance from the site boundaries depended on the concentration until safe disposal can be secured. However, according to "Management of waste potentially contaminated by radioactive materials in general incineration facilities," as of August 2011, such treatment has not been reported to be appropriately implemented.

The report "On the maximum radiation concentration limits for burial disposal of low-concentration radioactive solid waste" put forth on May 21, 2007, by the Nuclear Safety Commission requires that the maximum concentration limits be set for each disposal method of low-concentration radioactive waste, which can be disposed by burial. The concentrations are set for three types of methods (trench disposal, pit disposal, and subsurface disposal) for low-concentration radioactive waste with different nuclides. The threshold dose for burial disposal is 10 μSv/year. The verification of contents such as nuclides and their quantities in radioactive waste to be dispersed and monitoring after burial are necessary. **Table 5** shows the maximum concentrations limits in trench burial and pit burials, which are obtained in a

relatively near-surface ground, as well as the concentration in the treatment of water purification waste soil.

Table 5 Comparison of ^{137}Cs concentrations for disoposal

		^{137}Cs
Maximum concentration limit [*1]	Trench disposal	1×10^{8} Bq/t
	Pit disposal	1×10^{14} Bq/t
Treatment of water purification waste soil [*2]	Stored in a facility capable of radiation shielding	＞100,000 Bq/kg [*3]
	Temporal storage in control-type landfill site	≦100,000 Bq/kg [*3]
	Burial disposal at control-type landfill site	≦8,000 Bq/kg [*3]

[*1] Based on “On the maximum radiation concentration limits for burial disposal of low-concentration radioactive solid waste”
[*2] From “Ideas for future treatment of by-products such as water supply and sewage from which radioactive materials were detected.”
[*3] $^{134}Cs+^{137}Cs$

III. Future Prospects

Considerable radioactive material was emitted into the environment due to the Fukushima Nuclear Plant Accident, and considerable various waste was generated, including disaster waste contaminated by radioactive material. The conventional laws were not established assuming these events that can generate such waste. As such, various measures were planned and implemented during the emergencies during the accident as well as after matters were settled. As for the future disposal of waste contaminated by radioactive materials, however, the main subject nuclide is ^{137}Cs, which requires long-term management. From the perspective of radiation protection, it is necessary to ensure consistency between the management of “radioactive wastes” and management of waste contaminated by nuclide emitted from the accident, which will lead to the understanding of citizens. Thus, reasonable and effective waste measures are needed.

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