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Transport of disaster waste radioactively contaminated by accident at Fukushima Daiich Nuclear Power Station

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ABSTRACT

The Tohoku District-off the Pacific Ocean Earthquake and the resulting tsunami generated a huge amount of disaster wastes on March 11, 2011. After that, radioactive materials were discharged into the environment by the severe accident at Fukushima Daiichi NPS of TEPCO and some of the waste was contaminated. Furthermore, a large amount of contaminated soil and materials will be generated by future decontamination activities.

In this paper, the current situation of radioactive contaminated wastes, the strategy of handling them, the guideline for transporting the waste will be explained. JNES investigated radiation exposures of people from living activities and restoration activities for the disaster upon requests from the LNERH. They include contamination of a car running on the contaminated land, an investigation of methods to measure radioactivity of massive wastes quickly and exposure of worker involving restoration activity for railroad. Results of those investigations will be also briefly described in this paper

1. INTRODUCTION

The Tohoku District-off the Pacific Ocean Earthquake and the resulting tsunami on March 11, 2011 inflicted massive damage in Eastern Japan. About 400,000 buildings were fully or partially collapsed and about 16 million tons of disaster wastes were generated. About 68 % of the disaster wastes were processed until May, 2013[1]. The tsunami caused serious accidents of Fukushima Daiich Nuclear Power Site (NPS) of Tokyo Electric Power Company (TEPCO) and a large amount of radioactive materials were discharged into the environment. As a result, large areas around the damaged plants were contaminated and about 100,000 people were forced to be evacuated. The disaster wastes were contaminated by the radioactive materials and huge quantities of contaminated wastes and soils will be generated by future decontamination activities.

Ministry of Environment (MOE) established a new act of special measures [2] on January, 2012 in order to promptly reduce the impacts of environmental pollution by instituting measures taken by interested parties, especially, the national and local governments and TEPCO. According to the new act, radioactively contaminated materials with more than 8,000 Bq/kg are specified to the designated waste and they will be disposed of under responsibility of the government. The MOE issued Basic Principle on the Act on Special Measures, Nov. 11, 2011 [3], stipulating that the radioactively contaminated material should be disposed in each prefecture. At a time, the MOE issued Basic Principle on interim storage [4], stipulating that the interim storage facility will be constructed in Fukushima prefecture and the stored materials will be finally disposed of in other prefecture within 30 years from the initiation of the storage.

In this paper, status of contaminated materials in Fukushima prefecture, strategy of their management and some issues on transportation of them are described. Furthermore, some results of investigations relating to transportation in Fukushima prefecture conducted by Japan Nuclear Energy Safety Organization (JNES) upon requests from the Local Nuclear Emergency Response Headquarters (LNERH) will also briefly described. .

2. RADIOACTIVE CONTAMINATED MATERIAL IN FUKUSHIMA PREFECTURE

Cesium-137 is dominant nuclide for long term contamination of land and an amount of them discharged is estimated 1.1×10^{16} ~ 1.5×10^{16} Bq in 4 days after the accident [5]. As a result, some of eastern Japan was contaminated as shown in Fig. 1. In the Act on the special measures, contaminated materials with more than 8,000 Bq/kg are specified to the designated waste and disposed under responsibility of the government. JNES investigated radioactive concentrations of disaster wastes which are stored at temporal storage sites outside evacuation areas. The result showed that the radioactive concentration of the wastes is correlated with air doses of the site. It is less likely that the average radioactive concentration of a pile of the wastes is more than 8,000 Bq/kg outside evacuation areas [6]. However, at some sewage treatment plants, radioactively contaminated residue was found. The MOE requested the operators to measure the radioactivity if radioactive condensation is possible in the plant and to properly store them if radioactivity is more than the criteria of the designated waste. The designated wastes stored in Fukushima prefectures are roughly 100,000 tons as of March 2013 [7].

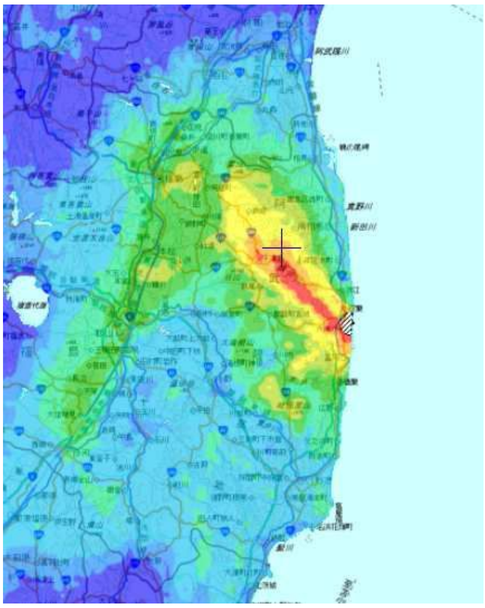

Fig. 1 Radiation level map in Eastern Japan (Nov. 5, 2011)

Combustible waste is usually incinerated for volume reduction and this process could increase the radioactive concentration of the waste. Contaminated wastes and incinerated ash with less than 100,000 Bq/kg are planned to be disposed of at existing disposal sites as much as possible [8]. They with more than 100,000 Bq/kg and soil from decontamination will be stored at the interim storage facility for about 30 years and then they will be finally disposed of in another prefecture.

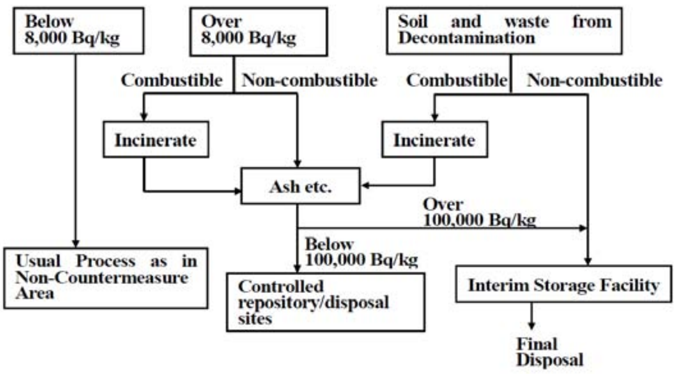

Fig. 2 Flow diagram for treatment of specified waste

Major characteristics of contaminated materials transported in Fukushima prefecture are as follows. Firstly the amount of them is huge. According to preliminary estimation, the amount of stored materials at the interim storage facility are expected 14 ~ 28 million m^3. Secondly contaminated materials generated by decommissioning activities are of great variety, such as soil, rubble, metal, combustible and so on. It is not clear that they will be well separated before transportation. Thirdly the contamination level also ranges widely. For example, using the following correlation between air dose and surface contamination level [9],

$$C = 2.76 \times 10^5 \times Q$$

Where C: Surface contamination level (Bq/m^2)

Q : Air dose (μSv/h)

if soil of 5 cm depth is stripped from the ground surface where air dose is 4 μSv/y which is equivalent to about 20 mSv/h of annual dose under normal life, the radioactivity of the soil is about 17,000 Bq/kg. In forest, the radioactive concentration of trunk of tree, leaf and litter is different. The radioactivity of the litter is usually the highest in them and rages from a few ten thousand to a hundred thousand Bq/kg at location of air dose 1 ~ 2 μSv/h [10]. Combustible materials are usually incinerated for volume reduction. A report shows that if the waste generated at location of 10 μSv/h is incinerated, the radioactivity of the ash could be a few hundred thousand Bq/kg [11]. Another important matter is that cesium in soil is usually hard to leach but it in the ash could easily leach.

These characteristics raise some issues regarding the transportation. For securing the safety of workers involved and people living along the transportation route, the MOE has provided guidelines on the transportation of contaminated waste[12] and they will briefly described in next section. An allocation of access route of large dump truck is another key issue. In selecting the route, traffic jam and noise problem should be considered if it drive on urban or residential street. Quick response measures to the traffic accident will also be considered.

3. TRANSPORTAION GUIDELINE OF CONTAMINATAED MATERIAL

The guidelines by the MOE are basically in conformity with the shipping regulations of the IAEA. The outline is as follows:

The Ordinance for Enforcement of the Act on Special Measures Concerning Countermeasures Against Contamination by Radioactive Materials (parts applicable to the criteria for collection and transportation of removed soil) stipulates as follows:

Article 57 The criteria of collection and transportation of removed soil provided by the ordinance of the MOE in Paragraph 1, Article 41 of the Act shall follow the examples provided in Article 23 (except c–(3) of Subparagraph 4, Subparagraph 5, Subparagraph 6 and Paragraph 2). The following is the quotation of the applicable parts.)

Article 23

(i) Collection and transportation shall be conducted as follows:

(a) Damage on human health and living environment by specified waste shall not be caused.

(b) Necessary measures such as putting specified waste in a container shall be taken so that specified waste (including contaminated water arising from specified waste) does not scatter, flow out, or leak from a transportation vehicle.

(c) Necessary measures such as covering the surface of specified waste with an impermeable liner shall be taken so that rainwater does not infiltrate into specified waste.

(d) Necessary measures shall be taken so that the collection and transportation are not detrimental to the conservation of living environment by foul smell, noise or vibration.

(e) Specified waste shall be separated from other materials so that it is not mingled with them.

Pursuant to the Ordinance for Enforcement of the Act on Special Measures Concerning Countermeasures Against Contamination by Radioactive Materials, the following three requirements are specified in the guidelines on the collection and transportation of removed soil:

(1) Requirements for preventing scattering, flowing out, and leaking

Scattering of radioactive materials can be prevented by such measures as putting removed soil in a container such as a sandbag, flexible container and drum (hereinafter called "container"), packing it with a sheet, etc., and transporting it by a box car. In the case of removed soil containing much moisture, draining should be conducted whenever possible to prevent flowing out and leaking. If a container impervious to water is not used, necessary measures such as putting a waterproof sheet should be taken prior to the transportation. Also, to prevent rainwater from infiltrating into removed soil during collection and transportation, it is necessary to take measures such as covering the soil with an impermeable liner if a container impervious to water is not used.

When loading removed soil into a transportation vehicle or unloading it from the transportation vehicle, care should be taken so that removed soil does not scatter or flow out externally. If removed soil should flow out due to overturning or falling of the removed soil during loading, unloading and transportation, it is necessary to immediately inform the nuclear power plant, etc. after taking such measures as stretching a rope to keep people away, collect the removed soil that has flowed out and conduct decontamination. So, an instrument, equipment, etc. for collection is required to be carried. Also, in preparation for vehicle fire, an extinguisher should be carried as well.

When loading removed soil into a transportation vehicle, care should be taken to prevent removed soil from adhering to the surface of the transportation vehicle whenever possible. When the transportation vehicle leaves a place where removed soil has been stored on site or a temporary storage place, the surface, tires, etc. of the transportation vehicle should be washed at a predetermined washing location.

(2) Requirements for shielding

The intensity of radiation differs depending on the concentration and amount of radioactive materials. As it is not realistic to measure radioactivity concentrations of all removed soil, shielding is considered here for safely collecting and transporting removed soil in the maximum concentration assumed. It should also be noted that even if the concentration and amount of radioactivity are the same, the intensity of radiation differs if materials and shapes of containers are not the same.

Under relevant regulations, the maximum dose rate at a location 1 m away from the surface of a transportation vehicle shall not exceed 100 μSv/h. This criterion is considered appropriate from the viewpoint of public protection, etc., so when transporting removed soil, it should be confirmed that the maximum dose rate at a location 1 m away from the surface of a transportation vehicle on which removed soil is loaded does not exceed 100 μSv//h. When the dose rate exceeds this level, shielding measures should be taken. Or measures such as reducing the amount of removed soil to be transported should be taken. As for a vehicle used for transportation, relevant laws and regulations should be observed. When carrying out retrofitting of a transportation vehicle for shielding purposes, etc., it is necessary to consult the nearest transport bureau, etc. in a timely manner.

Even when removed soil with a high radioactive cesium level (about one million Bq/kg) is loaded on a comparatively large transportation vehicle, the maximum dose rate at a location 1 m away from the transportation vehicle falls below 100 μSv/h. So it is not necessary to measure the dose rate for the transportation vehicle when transporting the removed soil generated with the decontamination in an area where an annual dose is below 200 mSv.

(3) Other requirements

Collecting removed soil and transporting it by a transportation vehicle should be done under relevant laws and regulations such as the Road Traffic Act. It is prohibited to load removed soil together with hazardous materials such as explosive and flammable substances. If soil other than removed soil, even though not dangerous, is mixed with removed soil, it is almost impossible to separate them at a storage site of the destination. So, if materials other than removed soil are loaded together, taking care should be done so that they are easily distinguishable from each other and they are not mixed. Further, in order to transport removed soil to the destination reliably, loading and unloading of removed soil should be conducted by a carrier or the worker appointed by the carrier.

In order to prevent people from approaching a transportation vehicle with no reason and being exposed to radiation during the transportation of removed soil, it is required to stick a sign indicating that the vehicle is for collecting or transporting removed soil together with the name or trade name of a person or a company that conducts collection or transportation to a prominent place outside the body of the transportation vehicle in a manner that it is not easily peeled off.

A transportation vehicle is required to always carry a copy of a service agreement, name of a person who conducts collection or transportation, quantity of removed soil, collection or transportation starting date, name of destination, precautions in handling, matters concerning emergency measures in the event of an accident, etc.

So that damage on human health and living environment is not caused, the following efforts to reduce the impact on local residents are required, for example, avoiding a residential area, shopping street, school zone, and narrow road as much as possible when setting a transportation route, and also try to avoid collection or transportation during rush hours and during hours when children go to school or kindergarten. When loading removed soil, efforts to reduce noise and vibration by choosing low-noise type heavy machinery, etc. are required

4. DOSE EVAULATION REGARDING TRANSPORTATION

(1)In-situ radioactivity measurement of massive waste [6]

If the wastes were radioactively contaminated, they should be properly treated depending on their radioactive level. In order to promptly transport, it is essential to measure its radioactivity at the site with adeptness. JNES investigated methods to measure radioactivity of massive wastes quickly and easily. Three methods were examined. First one is to pick up samples and measure their average and variability. Second one is that investigating correlation between air dose and radioactivity of waste, the radioactivity of the wastes is estimated by the obtained correlation. Third one is direct in-situ germanium semiconductor detector measurement of a stack of the waste. At twenty temporary wastes storage places outside of the evacuation areas, characteristics of the waste were investigated. Figure 3 shows the correlation between the air dose and the

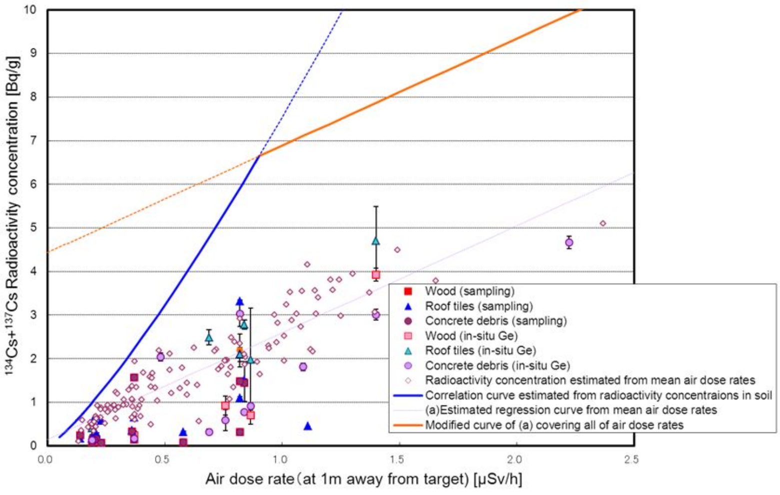

Fig.3 Correlation between air dose and Cesium concentration

radioactivity of the waste. As a conclusion, the method two is suitable for low and middle air dose areas and the method three for high. The method one is mostly not valid, because measured values of samples were very scattered.

(2) Radiation dose of car mechanics in maintenance of contaminated cars [13]

At the earthquake, approximately 86,000 vehicles were registered in the evacuation areas. Soon after the accident, in order to prevent the secondary dispersion of radioactivity, cars from the evacuation areas were monitored at exits of the evacuation areas and cars satisfying a screening criterion can go out from there. JNES surveyed the contamination status at several positions of cars from the evacuation areas and evaluated the radiation dose of car mechanics in maintenance for cars from the evacuation areas. In the evaluation, monitoring records conducted by TEPCO were also used. From the survey of contaminated cars, it was found out that radioactive material was condensed in some positions such as a drainage path of water from front window as shown in Fig. 4. Most cars from the evacuation areas were easily decontaminated. However, as for cars suffered effects from the blast wave of the accident plants, contamination level is high and it is hard to be decontaminated. Car mechanics' activities in a maintenance factory were examined and air borne dust was measured. Using those data, external and internal exposure doses of car mechanics were estimated. The result showed that the internal dose was not significant and the total dose was well less than 1 mSv/y.

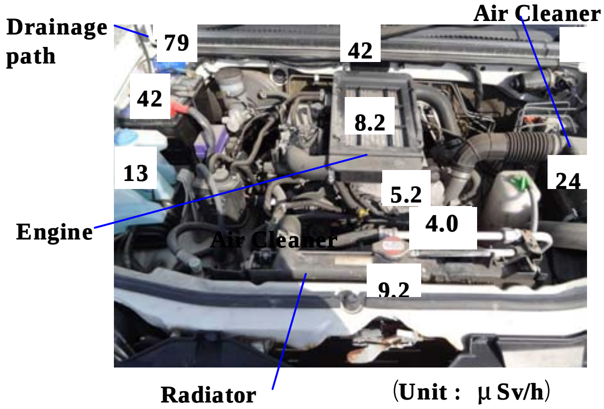

Fig. 4 Contamination status under hood of car

(3)Investigation of contamination of car caused by travelling in contaminated area [14], [15], [16], [17]

Contamination of cars caused by travelling the contaminated areas was investigated. The contamination could be caused by original air born dust and additional dusts which are splattered by own car or other cars. In order to investigate these effects, on fine and rainy days, two cars run tandemly on paved roads in contaminated area where the air dose ranges from 0.5 to 65 μSv/h. The results showed that the contamination of cars is low and there is no significant difference of contamination between two cars. As for weather conditions, there is also little different between fine and rainy days. Major contaminated positions were tires and tires-houses but the contamination of the radiator surface is very small. This suggest that the contamination is mainly caused by the dusts splattered by the own car.

Police cars daily patrol the evaluation area. The contamination of

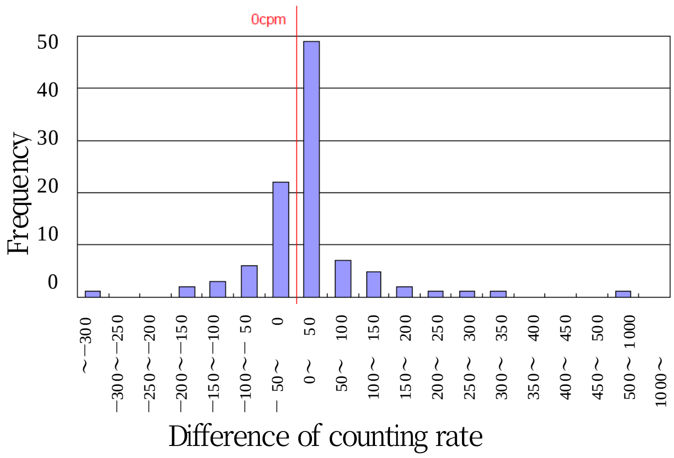

Fig. 5 Difference of counting rate at radiator surface between before and after patrolling

police cars were examined in cooperation with Fukushima Prefecture Police. One hundred and one cars were surveyed. The surveys were conducted at just before going into and after leaving from the evacuation areas. Figure 5 shows a difference of counting rate at radiator surface between before and after patrolling the evacuation areas. The result showed that a significant contamination was not observed in daily patrol.

(4) Investigation of contamination on railroad [18]

Restoration of damaged railroad is important for retuning residents to resume normal living conditions. Preliminary investigation of contamination status of the railroad and radiation dose of tracklayers during restoration works was conducted. Investigation points are located between 20 ~ 30 km from the accident site. Major issues in evaluating the dose of tracklayers are as follows. Until this time, fallout cesium is mostly adsorbed in surface layer of the soil. However, there is no data of cesium depth profile in ballast. Second issue is whether radioactive hot spot exist near railroad, e.g. in cable trench, side ditch. The third issue is whether an internal exposure due to radioactive dust generated by restoration work is significant or not. Typical four structure points were investigated. They are earth fill, cut earth, combination of earth fill and cut earth and bridge. Air dose of those points are 0.2 ~ 1.0 μSv/h. Figure 6 shows the depth profile of cesium in the ballast. The radioactivities are 1,200 ~1,500 Bq/kg on the surface of the ballast and reduce to 200 ~ 600 Bq/kg at depth of 20 cm. In the soil below the ballast, no additional cesium was found. The cesium concentrations on the ground around the railroad are about 3,000 ~ 7,900 Bq/kg and these values are almost equivalent to the value obtained from the correlation between air dose and soil contamination. On the other hand, deposits with high radioactive concentration, about 3,000 ~ 32,000 Bq/kg, were found in side ditches. However, an amount of them is small and air dose near the side ditch is not high. The hot spots are expected not to cause significant external dose of tracklayers. Furthermore, there is no hot spot in the cable trench. Air born dusts generated by simulated restoration work were measured using dust sampler. The measured dust concentration is 2 Bq/m^3 at a maximum. Using these measured data and conservative assumption, estimated exposure of a tracklayer is 0.48 ~ 1.0 μSv/h and the percentage of the internal dose is around 17 %. Following these results, East Japan Railway Company started the restoration work for the section between Hirono and Tatsuta station of JR Joban line.

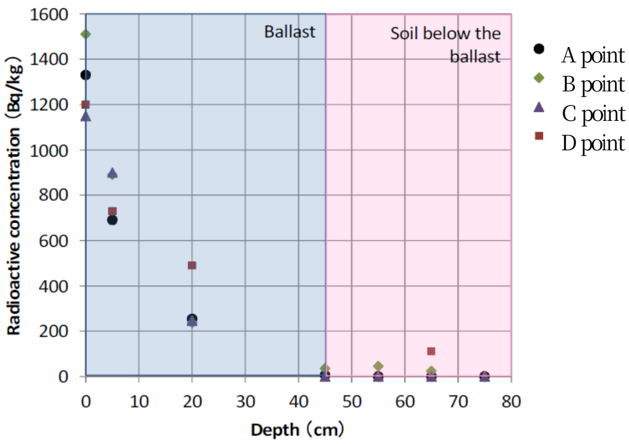

Fig. 6 Cesium depth profile

5. CONCLUSION

The earthquake and the resulting tsunami inflicted massive damage on the Pacific Coast of Tohoku district and the tsunami caused serious damaged at Fukushima Daiich NPS of TEPCO. A large amount of radioactive materials were discharged into the environment. As a result, some of disaster wastes were contaminated by the radioactive materials and huge quantities of contaminated soil and materials will be generated by future decontamination activities. The MOE established the new act of special measures in order to promptly reduce the impacts of the environmental pollution. In Fukushima prefecture, a huge amount of contaminated materials will be stored in interim storage facilities for about 30 years. After that, they will be finally disposed of in other prefecture. The amount of stored materials is estimated to be about 28 million m^3 and the safe and quick transportation will be one of issues in remediation activities. The issue includes an allocation of access route for large dump truck, traffic jam, noise problem, traffic accident and so on. Several investigations of radiation dose regarding transportation were done. The results showed that the radiation dose from those activities were not significant if the proper countermeasures were adopted.

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