Lessons Learned: Radiation Protection for Emergency Response and Remediation / Decontamination Work Involved in TEPCO Fukushima Daiichi NPP Accident

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Abstract. The paper described problems that occured during emergency work at TEPCO Fukushima Daiichi NPP in 2011 and extracted lessens learned from the experiences for radiation protection and provided guidance regarding preparedness for a similar accident. The paper also provided information as a reference to persons responsible for legislation regarding radiation protection in an existing exposure situation.

1.Introduction

In response to the Fukushima Daiichi Nuclear Power Plant (NPP) accident that resulted from the East Japan Earthquake on March 11, 2011, the Tokyo Electric Power Company (TEPCO) undertook emergency work to which an emergency dose limit applied. The Japanese government increased the emergency dose limit from 100 mSv to 250 mSv exclusively for the emergency work performed at the affected NPP from March 14 to December 16, 2011.

During the emergency work, the Japanese government experienced various problems in management, control and reduction of radiation exposure, and medical and health care management for emergency workers. For the proper implementation of radiation protection and health care management, the Ministry of Health, Labour and Welfare (MHLW) issued a series of compulsory directives and administrative guidance to TEPCO.

Furthermore, the accident released a large amount of radioactive material. To rehabilitate the contaminated areas, the government of Japan decided to carry out decontamination work (e.g., cleanup of buildings and remediation of soil and vegetation) and to manage the waste resulting from the decontamination and unmarketable contaminated goods. To prevent radiological hazards, the government needed to provide sufficient radiation protection for the decontamination workers.

The paper aims to describe the lessons learned from the experiences of those responsible for radiological protection and to provide guidance regarding preparedness for a similar accident. The paper also aims to provide useful information as a reference to lawmakers and government officials responsible for legislation regarding radiological protection in an “existing exposure situation.”

2. Methodology

On August 10, 2012, the MHLW summarized lessons learned from the TEPCO Fukushima Daiichi NPP and issued a notification document regarding emergency preparations to all operators of nuclear facilities [1]. The MHLW established new regulation and amended the existing general regulation for radiation protection of decontamination workers, based on the report from experts meetings. As a summary of relevant information, the MHLW published a booklet which explains actions taken by the MHLW on November 2013 [2]. Factual information described in the paper was based on the summary, the notification and the reports, unless otherwise specified in the references. Given length limitations, the paper could not describe detailed actions taken by the MHLW and TEPCO, actions which are described in the MHLW booklet.

3. Problems that occurred in radiation protection and health care management

3.1. Trend of workers' dose at the emergency stage and current status at the affected plant

During the emergency period from March to November 2011, the maximum monthly dose and average monthly dose were 21.51 mSv and 4.69 mSv, respectively. The average number of monthly workers who were exposed to more than 5 mSv was 1,236 (Figure 1). From December 2011 to August 2014, the maximum and average monthly dose decreased to 1.40 mSv and 1.04 mSv. The average number of monthly workers who were exposed to more than 5 mSv were 245 (Figure 2). [3]

3.2. Radiation Protection

During the emergency work, the MHLW observed the following radiation protection problems. [4,5]

(a) *Inappropriate Exposure Monitoring because of a Shortage of Personal Dosimeters:* The tsunami damaged a large number of electronic personal alarm dosimeters (PADs). The surviving dosimeters could not be recharged because of the electrical blackout at the site. The number of usable dosimeters decreased to approximately 320 on March 15, 2011, whereas the number of emergency workers increased progressively. Under these circumstances, from March 15 to March 31, 2011, TEPCO could not supply PADs to all

workers but only one dosimeter for each work group and regarded the monitored exposure dose as the common dose of the group.

(b) *Inappropriate Dosimeter Circulation Management and Exposure Control:* Given the breakdown of the electronic exposure management system, TEPCO implemented paper-based dosimeter circulation management at the plant until April 4 (until June 8 in the support facility known as J-Village). However, certain workers wrote down only their family names, writing in illegible characters. As a result, TEPCO faced the difficulty of conducting name-based aggregation of doses and a calculation of accumulated individual doses.

(c) *Workers Who Were out of Contact:* During the process of name-based aggregation, on June 20, 2011, it was revealed that several workers whose identities could not be confirmed appeared on the circular list. The number of workers who were out of the rosters reached 174 at maximum. (MHLW or TEPCO?)

(d) *Delayed Internal Exposure Monitoring:* Because of the accident, TEPCO could not operate the whole body counters (WBCs) that were located in the affected plant because of the increase in the background radiation level. In response, on March 22, 2011, TEPCO started to operate two vehicle-mounted WBCs. However, the capacity of the WBCs was insufficient to cover all of the emergency workers.

(e) *Exceeding Emergency Dose Limits:* The exposure doses of six emergency workers had exceeded the emergency dose limit (250 mSv), which the Japanese government increased from 100 mSv on March 14, 2011.

(f) *Internal Exposure That Resulted From the Inappropriate Use of Protective Masks:* Internal exposure beyond record levels were repeatedly found until September, which was six months after the accident.

(g) *Protection against Beta-Ray Exposure From Contaminated Water:* During the emergency work, several incidents of beta-ray exposure occurred in relation to contaminated water, such that workers received beta-ray exposure on their feet after they stepped into 30 cm deep contaminated water while wearing half boots to install electrical cables in a reactor building basement.

(h) *Worker Training:* From the time of the accident until May 2011, TEPCO and the primary contractors conducted training for newcomers to the affected plant for only 30 min.

3.3. Medical and health care management [6]

(a) *Implementation of Emergency Medical Examinations:* On March 16, 2011, the MHLW issued compulsory instruction to TEPCO to implement special medical examinations for screening for acute radiation syndrome or local radiation injuries every month. The implementation rate from March to September rose gradually but remained low: 31.3%, 59.3%, 61.7%, 63.6%, 61.9%, 70.7% and 70.6%, respectively.

(b) *Establishment of On-Site Medical Care Systems:* Although 2,000 to 3,000 emergency workers per day consecutively engaged in emergency work in the affected plant, TEPCO could maintain the presence of physicians and medical staff only during the daytime for a few days each week during the early stages of the accident.

(c) *Patient Transportation from the Affected Plant:* 3 of the 5 initial medical facilities were located in the evacuation zone and a hospital was located in the indoor evacuation zone. At the other hospital , supply of water and electricity were lost or malfunctioned. On March 14, 2011, Fukushima Medical University (FMU) prepared to accept patients. However, the approach from the affected plant took 3-4 hours.

(d) *Prevention of Heat Illness:* The MHLW was concerned that heat illness could develop if emergency workers spent long hours under the blazing sun while wearing full-face respiratory masks and HAZMAT garments.

(e) *Lodging and Food:* During the emergent situation, approximately 400 workers had to sleep on the floor of the Seismic Isolation Building of the affected plant or gymnasium of the Fukushima-Daini NPP, 13 km from the affected plant. For the prevention of internal exposure, TEPCO restricted the food supply to workers to boil-in-bag foods.

4. Establishement of new regulations for radiological protection for decontamination / remediation work

4.1. Decontamination work and recovery and reconstruction work

Existing government regulations assumed that the radiation sources were controlled and collected in indoor restricted areas referred to as “planned exposure situations.” The government had not considered the possibility of a situation where radiation sources were scattered and workers would have to deal with radioactive material outdoors (referred to as an “existing exposure situation”). ICRP Publication 103 states that exposure involving long-term rehabilitation of the contaminated areas should be treated as a part of planned exposure, although it does not provide details regarding exposure management. ICRP Publication 111, which mainly addresses an existing exposure situation, has few recommendations regarding occupational exposure.

Given the insufficient international recommendations, the MHLW decided to establish new regulations on occupational radiological protection in an existing exposure situation by using the protection in a planned situation as a reference. During its deliberation, the MHLW employed the following three principles:[7]

(a) Ensure that the level of protection is equivalent to or greater than the level in a planned situation and adhere

to existing regulations in a planned situation.

(b) Be practical and function smoothly in the situation around the affected plant, which is limited by restricted infrastructure, supplies and resources for the decontamination work.

(c) Be consistent with the radiological protection for the inhabitants around the work sites to avoid anxiogenic effects because decontamination projects have to be carried out in daily living areas, in full view of inhabitants, unlike in the case of works in radiation-controlled areas.

4.2. Disposal of contaminated soil and waste

Disposal of contaminated materials removed by decontamination requires workers to engage in work primarily conducted in indoor radiation-controlled areas. The MHLW therefore applied the existing general regulation for radiation protection to disposal workers. However, those regulations were difficult to apply to the disposal of decontamination-removed materials because this involves the handling of huge amounts of materials, requires large-scale facilities, involves fragmentation processes and landfill operations, and includes operations that must be conducted in high-ambient-dose-rate environments. Thus, the MHLW decided to amend the general regulation and establish new prescribed radiation protections for workers engaged in disposal of materials removed as part of decontamination work.[8]

5. Discussion

5.1. Lessons learned on radiation protection and health care management

On August 10, 2012, the MHLW issued a notice to urge nuclear operators to perform the necessary preparation to avoid similar problems of exposure management in the case of an accident. The major points of the document are as follows:

Sufficient measures and systematic preparation for radiological management should be ensured, including the following: a) Assistance from the power company's corporate office or off-site support facilities outside the evacuation area is indispensable; b) Primary contractors must independently implement exposure management operations for the employees of their subcontractors; c) NPP operators should compile an operations manual, stockpile personal protective equipment and personal alarm dosimeters (PADs), and prepare emergency systems and whole body counters (WBCs).

To reduce the exposure dose, the following lessons should be shared: (a) to prevent internal exposure, it is necessary to monitor the radioactive concentration of the indoor air of the workplace during an emergency, to stockpile and use appropriate respiratory protection and train newcomers how to use, fit and fit-test the respirators; (b) to prevent unnecessary beta-ray exposure, liquid-proof garments should be mandatory when workers handle contaminated water; (c) to reduce external exposure, it is indispensable to develop well-prepared work plans prior to the work and to monitor the ambient dose rate of the work area to develop proper working procedures; (d) the earlier deployment of remote-controlled vehicles and the utilization of tungsten shielding vests can contribute to exposure reduction.

The proper management and implementation of medical and health care management would require the following: (a) The government needs to assist in dispatching medical staff to the affected plants; (b) Nuclear facility operators, medical facilities and fire departments should make an agreement to clarify the division of the roles played prior to the accident and should conduct emergency drills periodically with the full attendance of related personnel to identify and resolve problems; (c) Operators need to develop a support base at a safe distance from the plant and to prepare to develop makeshift lodgings in case of emergency; (d) Operators need to come to an agreement to share food stocks among closely located nuclear plants and prepare cooking equipment that can be used in case of blackout to provide warm foods and drinks to as many workers as possible; (e) It is necessary to conduct long-term follow-up for emergency workers, including the health care system, medical examinations and mental health consultations.

5.2. Problems to be resolved in establishing new regulation in existing exposure situation

5.2.1. Decontamination work and recovery and reconstruction work

The MHLW faced difficulties in determining how radiation protection systems intended for planned exposure situations should be applied to the existing exposure situation. The MHLW did not have a sufficient scientific basis and sufficient time to establish new protection systems for the existing exposure situation. Consequently, the MHLW had no alternative but to consider the existing radiation protection systems and make every effort to adapt them to the current situation. To establish new regulation systems for the existing exposure situation, further research and development concerning the following issues is warranted:

(a) The relationship between the radioactive concentrations of materials handled and the risk of internal exposure: The amended regulation requires the use of appropriate personal protective garments and masks, as well as internal exposure monitoring in accordance with exposure estimation, based on the radioactive concentration multiplied by the density of dust at work sites. However, there were no scientific experimental data available to prove the validity of this estimation.

(b) The relationship between the radioactive concentration of the soil and the workers' surface contamination level: Experimental and empirical studies of this relationship would make it possible to establish a standard for when to require contamination screening. Further development of this subject is warranted.

5.2.2. Disposal of contaminated soil and waste

Two issues became controversial. The first was the balance between the competing goals of radiation protection and ensuring work efficiency, which is necessary for the smooth disposal of 30 million tons of contaminated materials. The issue became apparent in the discussion of radiation protection in landfill operations for removed soil. The other issue was the application of the regulation to conventional waste disposal facilities, which were not originally designed to handle radioactive substances.

6. Conclusion

The problems that occurred in the accident would not have occurred or would have remained minor if TEPCO had ensured sufficient and systematic preparation for large scale accidents. Based on the lessons, international guidance documents were warranted to be necessary for the governments and NPP operators to perform necessary preparation for radiation protection for emergency workers.

The areas of the existing exposure situation overlap the areas of planned exposure situation. Thus**,** a demarcation line between the application of existing regulations and new regulations has to be defined and operated in accordance with the situations after accidents. It is desirable for government officials responsible for radiation protection to develop international guidance documents that provide useful information in consideration of the Japanese case**.**

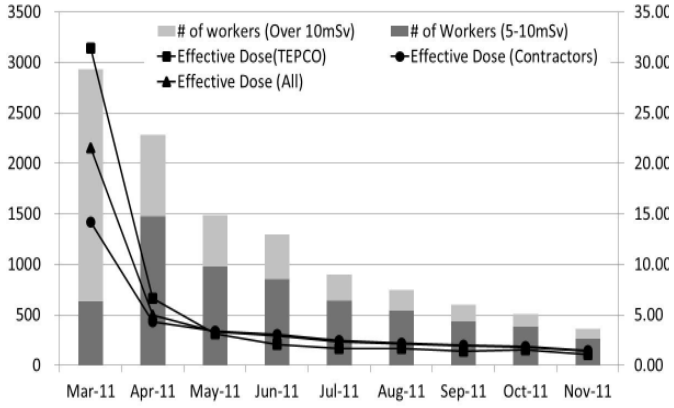

Figure 1. Trend of Radiation Exposure of Wokers at Fukushima Daiichi NPP (March-November 2011).

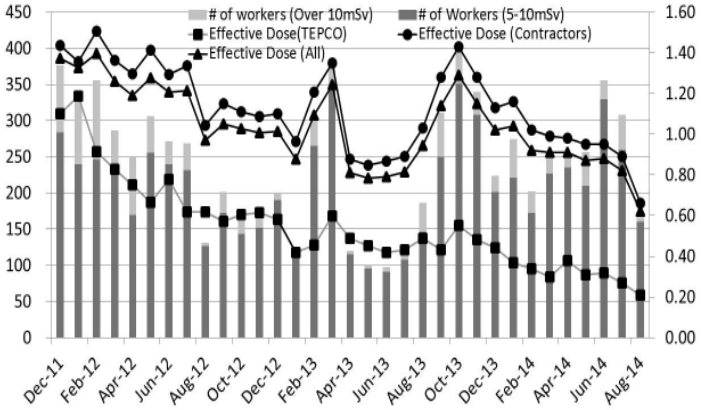

Figure 2. Trend of Radiation Exposure of Workers at Fukushima Daiichi NPP (Decmber 2011-August 2014)

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