Chapter 17
Health Issues of Workers Engaged in Operations Related to the Accident at the Fukushima Daiichi Nuclear Power Plant

Koji Mori, Seiichiro Tateishi and Koh Hiraoka

Abstract A nuclear accident occurred in northern Japan at the Fukushima Daiichi Nuclear Power Plant of the Tokyo Electric Power Company (TEPCO) following a mega-earthquake and subsequent tsunami in March 2011. A large number of workers were engaged in the related works, which has shifted from emergency response to cooling of the fuel bars, stabilization of nuclear reactors by establishing cooling systems, and decommissioning of the nuclear reactors. In addition, a lot of workers were also engaged in rehabilitation of contaminated areas. Various health issues occurred among the workers. An emergency-care system for workers, including transportation to hospitals, has been one of the highest concerns, and an occupational health system did not function well. It took a few months to establish the systems. The workers were exposed to multiple health hazards, such as radiation, heat stress and psychological stress, and there were trade-offs among the hazards. Outbreak of infectious diseases and fitness for duties of temporary workers were also significant concerns from expert viewpoints. Experts in occupational health, emergency medicine, and other specialties did their best to manage the situations in cooperate with the Japanese government and TEPCO. There are several lessons learned from the experiences. Emergency response plans at national, local, and company levels should be reviewed and be improved for disasters in the future.

Keywords Decommision work · Decontamination work · Emergency work · Fukushima Daiichi Nuclear Power Plant · Nuclear disaster

---

K. Mori (✉)
Department of Occupational Health Practice and Management, Institute of Industrial Ecological Sciences, University of Occupational and Environmental Health, Kitakyushu, Japan
e-mail: kmori@med.uoeh-u.ac.jp

S. Tateishi · K. Hiraoka
Occupational Health Training Center, University of Occupational and Environmental Health, Kitakyushu, Japan

A. Shimazu et al. (eds.), *Psychosocial Factors at Work in the Asia Pacific*,
DOI 10.1007/978-3-319-44400-0_17

Introduction

A nuclear accident occurred in northern Japan at the Fukushima Daiichi Nuclear Power Plant (NPP) of the Tokyo Electric Power Company (TEPCO) following a mega-earthquake and subsequent tsunami in March 2011. Several types of operations related to the accident were performed as a result.

Since the accident, work in the NPP has shifted from emergency response to cooling of the fuel bars, stabilization of nuclear reactors by establishing cooling systems, and decommissioning of the nuclear reactors. A large number of TEPCO workers, manufacturers of nuclear reactors, construction companies and their contractors were engaged in the work and were consequently exposed to various health risks. TEPCO contracted various tasks to more than 20 companies (primary contractors), and each of them outsourced parts of tasks to multiple layers of subcontractors. This complex structure hindered consistent implementation of occupational health rules and programs that protected workers' health. In addition, for rehabilitation of contaminated areas following the accident, the Japanese government undertook decontamination work and management of the waste resulting from decontamination and contaminated goods. This work was assigned to private companies by central or local governments.

An emergency-care system for workers, including transportation to hospitals, has been one of the highest concerns among health-related issues at the Fukushima Daiichi NPP since the accident occurred. In addition, there were several occupational health issues, such as radiation exposure, heat stress, psychological stress, concern over the outbreak of infectious diseases, and fitness for work of temporary workers. In this complex situation, the participation of occupational health experts was essential in managing the issues.

In the chapter, we review the health issues occurred among the workers and describe the actions taken to solve them. And then, we summarize the lessons learned from the experience for the disasters in the future.

Establishment of Emergency Medical System for Workers

The radiation emergency medical system had consisted of the off-site center and radiation emergency hospitals on three levels (primary, secondary, tertiary), but it became nonfunctional just after the disaster.

On March 12, 2011, the off-site center (local response headquarters) had to be evacuated because everywhere within a 10-km radius of the Nuclear Power Plant (NPP) was designated an evacuation zone by government order; three of five of the initial hospitals had to be evacuated when the evacuation zone was expanded to a 20-km radius from the plant. The earthquake also damaged the essential facilities of Fukushima Prefecture Medical University Hospital (FMUH), a secondary radiation emergency hospital. The Japanese government and Fukushima Prefecture made every effort to reestablish the system in cooperation with the Tokyo Electric Power Company (TEPCO) and medical societies (Yasui 2014), such as the Japanese Association for Acute Medicine (JAAM) (Morimura et al. 2013), University of Occupational and Environmental Health, Japan (UOEH) (Mori et al. 2013).

The emergency medical system was reestablished gradually (Ojino and Ishii 2014). On March 13, the Fukushima Prefecture Radiation Emergency Medical Coordination Council was established and it was voluntarily organized by members who were familiar with radiation emergency medicine. On March 14, the Fukushima Medical University Hospital (FMUH), a designated secondary emergency hospital, started accepting radiation emergency patients. It takes 2.5 h by car or 15 min by helicopter to travel from the NPP. Although there were other hospitals nearer to NPP, they were not equipped to provide radiation emergency care. At 11:00 on the same day, a hydrogen explosion occurred in Unit 3 of the NPP, injuring 11 people, FMUH accepted 4 of them. On April 2, a facility for initial radiation emergency medicine was established in J-Village. J-Village is a sports training center located 20 km from the NPP that was used as a support base for the accident (Fig. 17.1). A total of 8 hospitals in Fukushima prefectures were prepared to provide general medical care for non-contaminated patients from April 2 to June 23. At this point in the reestablishment process, patients with high-dose exposure or heavy contamination were transported to the designated radiation emergency hospital, whereas patients in a severe condition with moderate, minor, or no exposure were transported to other hospitals.

TEPCO had basically have responsibilities for first-aid services. They made efforts to station a physician every daytime at the early stage of the accident, but it became difficult for them to secure it. UOEH was requested by TEPCO and the Nuclear and Industrial Safety Agency, and it dispatched physicians for on-site first-aid services to a quake-proof building at the NPP (Fig. 17.2). In addition, the

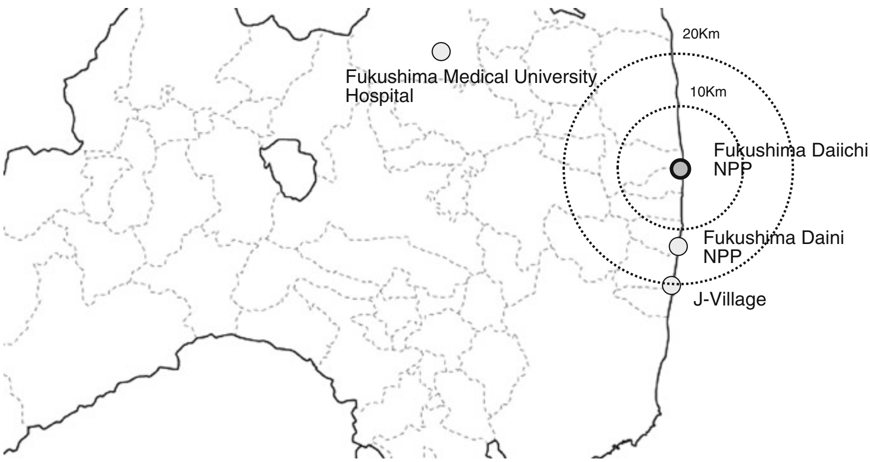


Fig. 17.1 Locations of Fukushima Daiichi NPP and other facilities

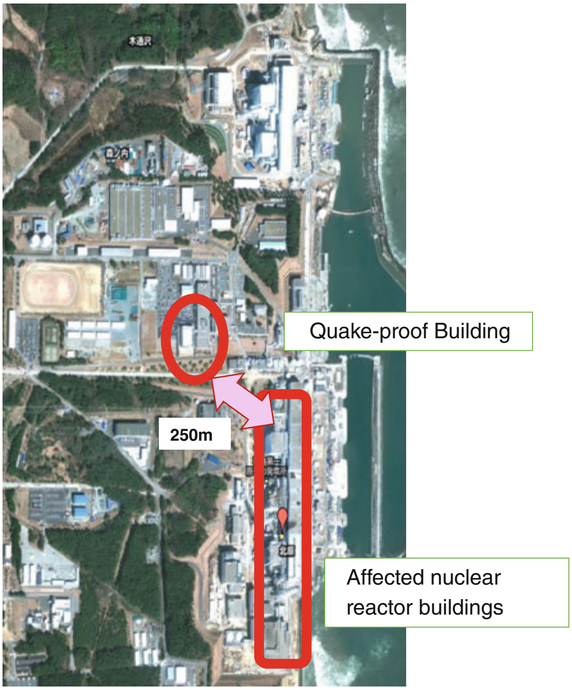


Fig. 17.2 Locations of affected nuclear reactor buildings and quake-proof building

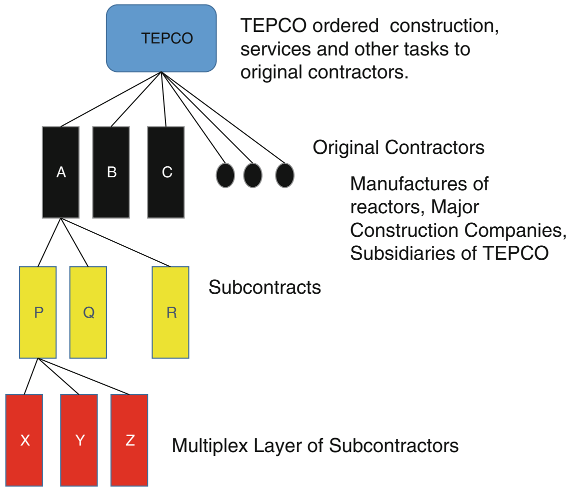
government decided to establish 24-h system in cooperation with UOEH and the Japan Labor Health and Welfare Organization (Yasui 2014). The medical facility, so-called 5/6ER, was established in the service building of 5/6 nuclear reactors, and TEPCO reorganized an in-plant emergency medical system network to enhance preventive medicine and emergency medicine.

To facilitate the emergency medical system network, the TEPCO Fukushima Daiichi NPP Emergency Medical System Network was established, and network meetings were held periodically. Daily web meetings led by FMUH held for communication among the off-site center, on-site clinic, and the institutes concerned (Mori et al. 2013).

Establishment of Occupational Health System

A large number of workers belonging to various companies including the Tokyo Electric Power Company (TEPCO) were engaged in operations to stabilize the plant. The potential radiation exposure of these workers was the foremost concern. Some were exposed to more than 250 mSv of radiation during the initial response phase. However, their radiation exposures were carefully monitored and controlled thereafter. All of the workers at the plant were required to wear a standardized set of

Fig. 17.3 Relationship among Companies Involved



personal protection equipment, i.e., chemical protection clothing made of polyolefin materials, a full-face respirator equipped with both dust and charcoal filters, double sets of gloves and shoe covers. Despite the relatively cool climate in the Fukushima area, a few cases of mild heat illness among the workers at the plant were reported between the end of March and early April, 2011.

With respect to the companies involved in the nuclear power plant (NPP) accident, TEPCO at the early stage contracted the services of over 20 primary contractors, each of which outsourced groups of workers to subcontractors in multiple layers (Fig. 17.3). The number of primary contractors increased thereafter. TEPCO's and the primary contractors' legal responsibilities to the subcontractors' heath care were limited. However, it was essential to establish an occupational health management system, in which TEPCO and the primary contractors had broader responsibilities to protect the health of all individuals involved in the serious conditions during the early phase of the work. However, TEPCO had no effective systems for managing the other occupational health risks, and few occupational health professionals contributed to health risk management. Under these circumstances, the potential for cases of fatal heat illness resulting from increased temperatures became a great concern.

One month after the accident, TEPCO requested University of Occupational and Environmental Health, Japan (UOEH) to dispatch physicians for first-aid services to a quake-proof building, as mentioned before. However, it was not expected to give professional advice about managing occupational health risks. Moreover, little time was left before the onset of the high temperature and humidity season. UOEH regarded the support opportunity as the entrance of professional support on occupational health, and decided to dispatch physicians. Then, UOEH took a three-step strategic approach to contribute to protecting workers from existing health hazards (Mori et al. 2013).

The objective of step 1 was to develop trustful relationships with the staff of TEPCO and outside contractors by providing sincere services for first-aid and health check-ups at the plant. The objective of step 2 was to develop and recommend practical occupational health programs based on our understanding of the real situation at the plant. UOEH requested every dispatched physician to report the work conditions at the plant and the services they provided. In addition, UOEH established a private study group to discuss necessary occupational health programs with UOEH graduates who were involved in the operations, mainly as occupational physicians of TEPCO or major primary contractors. UOEH then developed practical recommendations about the occupational health systems and programs specific to prevention of heat illness that should be implemented at the plant and presented them to the government and TEPCO. Based on our recommendation, the Ministry of Health, Labour, and Welfare (MHLW) issued guidelines on occupational safety and health at the plant for summer 2011 to TEPCO and the contractors on June 10. The objective of step 3 was to provide the necessary technical materials and advice on occupational health. UOEH provided training materials on heat stress, checklists on necessary occupational health practices at the plant for contractors, and so on. UOEH also implemented fitness for duty assessment programs and provided advice to workers who were beginning response or recovery operations at the plant.

Although severe heat illness was successfully prevented in summer 2011, the management system did not include a method by which to evaluate how each contractor implemented the occupational health programs, making continuous improvement difficult. TEPCO and the primary contractors had held weekly safety liaison meetings in the NPP in which they mainly discussed work processes and safety-related issues. One occupational health expert of TEPCO or UOEH attended the meeting every week and gave input from the viewpoint of occupational health in the discussion in August 2011.

TEPCO and the government announced that the nuclear reactors of the plant reached cold shutdown on December 16, 2011. The work phase moved from stabilization to decommissioning. This phase was expected to continue for more than 30 years. Therefore, an occupational health management system based on this condition should have been established. In this system, each company involved should have taken basic responsibilities to protect their own workers' health, and the occupational health experts should have provided technical support. A new liaison meeting with the primary contractors in charge of occupational health was held in October 2012 and was repeated once every 3 months. Occupational health issues in each season and work phase were discussed in each meeting. Occupational health experts from UOEH also attended each meeting and provided technical education and information. Because the contractors in charge of occupational health often changed, these efforts were made repetitively (Mori et al. 2014).

Challenge for Managing Multiple Health Risks

Workers in the nuclear power plant (NPP) were exposed multiple health hazards, such as radiation exposure, heat stress, psychological stress, concern over the outbreak of infectious diseases, and fitness for work of temporary workers. In addition, trade-offs were sometimes made among risks associated with the health hazards. The main health hazards were categorized into radiation, heat stress, psychosocial factors, biological agents, and fitness for workers' duties.

Radiation Exposure

The Japanese government increased the dose limit from 100 to 250 mSv exclusively for the emergency work performed at the affected NPP on March 14, 2011. Application of that emergency dose limit was abolished on December 16, 2011—except for specialists that were highly trained and experienced in operating and maintaining the facilities. During that period of emergency work, the effective dose of 172 workers exceeded 100 mSv, and that of six workers exceeded 250 mSv; the maximum dose was 678.8 mSv (Table 17.1). There are two ways of radiation exposure, internal exposure, i.e., intake of radioactive material orally or through airway, and external exposure. Internal exposure was the most significant influence on high doses (Yasui 2015). Significant leakage of air to the Tokyo Electric Power Company (TEPCO) employees was observed (average of 17.4 %) while testing of the fitness of the full-face respirators with dust filters and charcoal filters in September 2011. Internal exposure would have been prevented if the respirators had been properly fitted and the workers had followed respiratory protection usage guidelines for respirators (National Institute of Occupational Safety and Health, Japan 2011).

Table 17.1 Radiation exposure at the early phase

mSv	TEPCO	Contractors	Total
>250	6	0	6
200–250	1	2	3
150–200	24	2	26
100–150	117	20	137
50–100	398	298	696
20–50	645	2160	2805
10–20	484	2716	3200
<10	1615	11,104	12,719
Total	3290	16,302	19,592
Max (mSv)	678.8	238.4	678.8
Av. (mSv)	24.82	9.63	12.18

Total dose distribution among respond worker between March and December 31, 2011 (reevaluated in April 2013)

On March 24, 2011, several incidents of beta-ray exposure to the feet occurred during the emergency work when workers stepped into 30-cm-deep contaminated water. Investigation revealed that the workers did not monitor the ambient dose immediately before the work, did not wear long protective boots, and continued to work after a personal alarm dosimeter had sounded. Several other problems on the control and management of radiation exposure for emergency workers were observed: they included inappropriate exposure monitoring through a shortage of personal dosimeters, inappropriate dosimeter use and insufficient implementation of exposure control, and delayed internal exposure monitoring. The Ministry of Health, Labour and Welfare (MHLW) issued a series of compulsory directives and provided administrative guidance to TEPCO (Yasui 2013).

The possibility of radioactive material inhalation was considered to be low with the exception of some specific areas after announcement of the cold shutdown in December 2011. There were trade-offs associated with the risks, and countermeasures against radiation exposure increase the risk of heat illness (Fig. 17.4). The rules regarding respirator use, such as the use of half-face respirators, should have been eased in early 2012. However, workers were still concerned about radiation exposure, and they tended to continue using the full set of personal protective equipment after the rule was eased. Education and risk communication about radiation became important again. Nevertheless, it was expected that working in a high-dose environment would be necessary again when the decommissioning work progressed. Radiation protection measures should have been reviewed after June 2013 (Mori et al. 2014).

The MHLW published guidelines about long-term health care for emergency workers in October 2011[1]. The following is an overview of the guidelines: (1) establish a scheme of health management at each workplace according to its scale and conduct appropriate medical examinations; (2) conduct the following

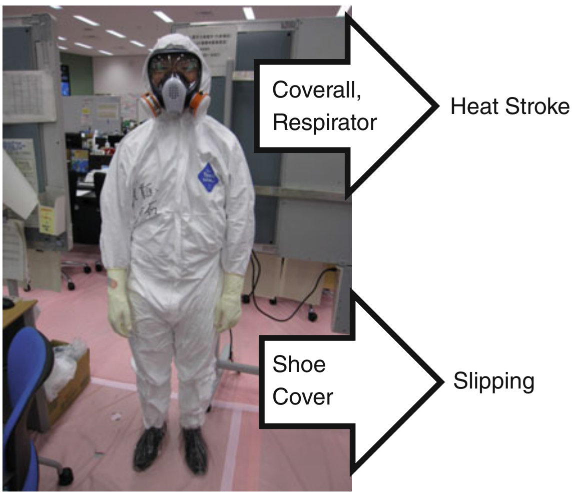


Fig. 17.4 Trade-offs between radiation protection and other hazards

once a year for individuals who participated in emergency work—eye examination for cataracts with a slit-lamp in people with an exposure dose (effective dose) above 50 mSv, cancer screening, and thyroid tests for individuals with an effective dose of over 100 mSv; (3) provide health guidance for emergency workers.

The MHLW published a report written by a committee of experts, which included a long-term epidemiological study with a database for emergency staff who worked from March 14 to December 16, 2011 (Ministry of Health, Labour and Welfare 2014a). The exposure dose level of emergency workers was registered in the MHLW database, and they were periodically surveyed. The report stated that based on previous studies, the health effects were expected to include solid cancers, leukemia, noncancer diseases, and psychological distress.

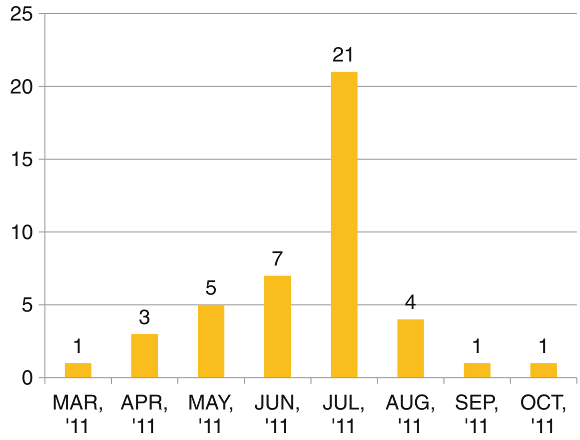
Heat Stress

Heat illness was one of the major health risks for workers at the NPP in summer. All plant workers were required to wear standardized personal protection equipment to prevent radiation exposure and contamination. The equipment comprised chemical protective clothing made of polyolefin materials, a full-face respirator equipped with dust and charcoal filters, and a double set of gloves. This equipment obviously increased the risk of heat illness.

As mentioned in establishment of occupational health system, some cases of heat stress were reported at the end of March and beginning of April 2011, when the temperature was relatively cool in the Fukushima area. However, there were few concerns then about risks other than those associated with radiation. The MHLW issued an administrative guidance for preventing heat illness, which recommended the following: (1) since previous outbreaks of heat illness were concentrated at 14:00–17:00, discontinue work during that time; (2) begin work early in the morning; (3) set a limit on the number of consecutive working hours; (4) implement health checks before work; (5) provide workers with air-conditioned rest places where they can remove respiratory masks; (6) conduct education on preventing heat illness; (7) establish medical systems to treat heat illness patients (Yasui 2014).

TEPCO undertook measures following the MHLW instructions in cooperation with occupational health specialists from UOEH (Mori et al. 2013). At daily meetings held in the quake-proof building at 9:00 and 18:00, executives emphasized the importance of preventing heat illness. An air-conditioned rest room was installed near the operation site for the workers. For personal protection, workers wore a cool vest under a coverall and were required to drink an oral rehydration solution before the shift and after each 1-h shift. Workers at the site were allowed to do several shifts, with 1 h's work and a 40-min break. The latter involved removing protective clothing after checking for radioactive contamination, resting, and donning protective clothing again before work (Wada et al. 2012a, b). As a result, 43 cases of heat illness were reported between the end of March and early October 2011 (Fig. 17.5), but no severe heat illness was observed (Mori et al. 2013).

Fig. 17.5 Heat stroke occurrences in summer 2011



The program established in summer 2011 was enhanced and implemented in 2012 and 2013. For summer 2012, the program was prepared in March and implemented in early May. The program was further improved in 2013. Consequently, 23 and 17 cases of heat illness occurred in 2012 and 2013, respectively (Mori et al. 2014).

Psychosocial Factors

Psychological distress was one of major health hazards for the NPP workers, especially TEPCO employees. Some psychiatrists voluntarily provided counseling services for the TEPCO workers in the NPP at their lodging spaces in the Fukushima Daini NPP. Then, the National Defense Medical College began dispatching teams of critical incident stress specialists on July 10, 2011; they provided mental health services on a monthly basis (Sano et al. 2012). For contracted workers, occupational physicians provided healthcare services, including mental health support; the MHLW also offered toll-free telephone mental health services for all workers (Wada et al. 2012a, b).

Various psychological effects and the factors that affected them were reported by the psychiatrists. They examined general psychological distress, peritraumatic distress, and posttraumatic stress response (PTSR) in NPP workers in May and June 2011 (Shigemura et al. 2012). The subjects were full-time workers from Daiichi and Daini NPPs and reported that Daiichi workers were more often exposed to disaster-related stressors than Daini workers. The results for experiencing discrimination or slurs showed no statistically significant difference between the groups. Daiichi workers showed significantly higher rates of psychological distress and PTSR. For both groups, discrimination or slurs were associated with high psychological distress and high PTSR. Other significant associations in the two groups included tsunami evacuation and major property loss with psychological distress, and preexisting illness and major property loss with PTSR. They also developed a path model for the PTSR with the same data and peritraumatic distress of TEPCO employees (Shigemura et al. 2014).

Biological Agents

There were high risks of infectious disease outbreaks because many workers shared limited spaces for lodging and resting. Implementation of measures against influenza and norovirus infection was considered for winter 2011 (Mori et al. 2014). TEPCO provided free vaccination to all workers, including contractors. Additionally, it placed bottles of alcohol-based sterilization liquid extensively around Daiichi, Daini, and J-Village and put up posters to encourage workers to use the bottles. This program was continued almost unchanged in 2012. For November 2011 to May 2012 and November–May 2012, 182 and 195 influenza cases, respectively, were diagnosed at the NPP emergency clinic and other TEPCO-operated clinics.

With respect to norovirus infection countermeasures, TEPCO encouraged workers to wash their hands; it created a kit and a manual to deal with floors or other surfaces becoming contaminated by vomit or feces. UOEH developed and distributed a checklist to TEPCO and contractors to help them evaluate current practices and encouraged them to make improvements. An outbreak of norovirus affected 52 employees of the same primary contractor in December 2011. Excluding that outbreak, from November 2011 to March 2012 and November 2012 to March 2013, nine and 37 norovirus cases, respectively, were reported. No other outbreak was reported.

Tuberculosis was also a concern. The driver of a transportation bus for workers was diagnosed with tuberculosis in June 2011. Fortunately, tuberculosis was not transmitted to other workers. To prevent food poisoning, TEPCO provided refrigerators in resting spaces when it and contractors arranged lunch boxes for the workers in summer 2012; TEPCO enhanced refrigerators when workers were allowed to bring their own food in summer 2013.

Fitness for Duties of Workers

Nuclear power plant (NPP) workers were requested to work with multiple layers of personal protection equipment under stressful conditions. It took several hours to transport a sick person to a secondary or tertiary emergency hospital. Therefore, a higher fitness level was required of plant workers. However, workers were temporarily hired by contractors nationwide, and many began operations without judgment of their fitness for work.

The Tokyo Electric Power Company (TEPCO) understood the importance of fitness for the workers' duties. However, they hesitated to implement an assessment program because they were concerned that the limitations of the workers and the complicated procedures would affect their efforts to secure enough manpower. A procedure in which new plant workers were required to be judged "fit for duty" by a doctor was recommendable. Instead, however, the following procedure was implemented in October 2011. New workers completed a checklist regarding their own health condition, and doctors confirmed the details for workers with poorly controlled illnesses. However, this protocol was not effective enough to detect ill workers. The procedure was improved in April 2012, and the primary contractors were requested to confirm whether each new worker was judged "fit for duty" by a doctor according to pre-employment or recent periodic health check-ups. TEPCO provided these services in the J-Village clinic for small contractors that could not find an appropriate doctor at the time. TEPCO terminated these services in October 2012 because they determined that all of the contractors had secured doctors (Mori et al. 2014).

Though not a direct indicator, the effectiveness of assessment of fitness for duties was reflected in the number of reported deaths due to illness and that of ill workers transported to hospital by air ambulance. The numbers of reported deaths due to illness among the workers were one from March to June 2011, two from July to December 2011, one from January to June 2012, one from July to December 2012, and one from January to June 2013. Three of six cases were diagnosed as acute myocardial infarction. The numbers of ill workers transported to hospitals by air ambulances were four, zero, one, one, and zero for each period, respectively (Mori et al. 2014).

However, the cases of transportation to hospitals have increased since end of 2013 due to increase double of workers in the NPP. University of Occupational and Environmental Health, Japan (UOEH) developed guidelines on judgement of fitness for duty assessment and advised contractors of TEPCO to communicate with doctors who perform the judgement.

Workers Engaged in Decontamination and Other Related Works

The Japanese government decided to conduct decontamination work for the rehabilitation of contaminated areas. The decontamination work produced huge amounts of contaminated soil and waste. Existing government regulations did not consider situations where radiation sources were dispersed and workers dealt with radioactive materials outdoors ("existing exposure situations"). Therefore, the Ministry of Health, Labour and Welfare (MHLW) established new regulations—Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Wastes Contaminated by Radioactive Materials Resulting from the Great

Table 17.2 Selection criteria for personal protective equipment according to the level of ambient dust and radioactivity of the contaminated materials for decontamination work involving radioactive fallout

Concentration of ambient dust	Radioactivity concentration of contaminated materials	
	Over 50,000 kBq/kg	50,000 Bq/kg or below
Over 10 mg/m^3	Respiratory protective equipment with a filtration efficiency of 95 % or more, HAZMAT suits over long-sleeved shirts, rubber gloves, and rubber boots	Respiratory protective equipment with a filtration efficiency of 80 % or more, long-sleeved shirts, rubber gloves, and rubber boots
10 mg/m^3 or below	Respiratory protective equipment with a filtration efficiency of 80 % or more, long-sleeved shirts, rubber gloves, and rubber boots	Respiratory mask made with non-woven textiles, long-sleeved shirts, cotton gloves, and rubber boots

East Japan Earthquake and Related Works—which provided occupational radiological protection in existing exposure situations. In addition, the MHLW created new regulations for the protection of waste-disposal workers by amending the Ordinance on Prevention of Ionizing Radiation Hazards. The ordinances consisted of structure-based standards, exposure limits, and selection of appropriate personal protective equipment for the risk of internal exposure (Tables 17.2 and 17.3).

The decontamination workers were at risk of being exposed to radiation and other health hazards, such as heat stress in summer, coldness in winter, insect bites, and handling heavy materials (Wada et al. 2012a, b). The results of internal

Table 17.3 Selection criteria for personal protective equipment according to the level of ambient dust and radioactivity of the contaminated materials for work involving radioactive fallout-disposal of contaminated soil and wastes

Concentration of ambient dust	Radioactivity concentration of contaminated materials		
	Over 2000 kBq/kg	Over 500 kBq/kg 2000 kBq/kg or below	500 kBq/kg or below
Over 10 mg/m^3	Respiratory protective equipment with a filtration efficiency of 99.9 % or more, 2 layers of splash-tight HAZMAT suits over long-sleeved shirts, 2 layers of rubber gloves, and rubber boots	Respiratory protective equipment with a filtration efficiency of 95 % or more, splash-tight HAZMAT suits over long-sleeved shirts, rubber gloves, and rubber boots	Respiratory protective equipment with a filtration efficiency of 80 % or more, long-sleeved shirts, cotton gloves, and rubber boots 10 mg/m^3 or below
10 mg/m^3 or below	Respiratory protective equipment with a filtration efficiency of 95 % or more, long-sleeved shirts, rubber gloves, and rubber boots	Respiratory protective equipment with a filtration efficiency of 80 % or more, long-sleeved shirts, rubber gloves, and rubber boots	Respiratory mask made with non-woven textiles, long-sleeved shirts, cotton gloves, and rubber boots

exposure monitoring among decontamination workers who had not been living in Fukushima Prefecture at the time of the incident was reported (Tsubokura et al. 2013). Their cesium exposure levels were below detection limits, but seven workers stated that they did not always wear masks during decontamination work. In a mail survey, more than half of respondents had experienced heat illness symptoms during decontamination work. However, there were few reports published on the situation regarding exposure or health effects on workers presently engaged in decontamination work and waste-disposal workers.

The MHLW reported the results of employer inspections related to decontamination work: 108 of 242 employers were in violation of applicable laws, such as the Labour Standards Act and Industrial Safety and Health Act, as of December 31 2012 (Ministry of Health, Labour and Welfare 2014b); 264 of 388 for January–June 2013 (Ministry of Health, Labour and Welfare 2013); 709 of 1784 for July–December 2013 (Ministry of Health, Labour and Welfare 2014c); and 181 of 313 for January–June 2014 (Ministry of Health, Labour and Welfare 2014d). In its early report, the MHLW described two examples of violation regarding methods for measuring external exposure dose through decontamination. (1) Workers whose total external exposure doses at workplaces were considered average values were selected to wear dosimeters; their measurement results were used as the external exposure doses for all workers at similar workplaces. However, the workers wearing dosimeters left dosimeters left their workplaces even though other workers were still working at the site, and their exposure doses were not measured accurately. (2) Workers are supposed to wear dosimeters on their chest or abdomen, but they put the dosimeters in their pants' pockets.

Lesson Learned from the Experience

The nuclear accident at the Fukushima Daiichi Nuclear Power Plant (NPP) following a mega-earthquake gave rise to an emergency. Though they lacked proper experience, many workers became engaged in difficult tasks. The system for safeguarding their health gradually developed through an ongoing trial-and-error process. There are a lot of lessons learned from our experiences for disasters in future.

The operators were responsible for emergency medical care at the NPP as part of Japan's National Response Plan—Bosai Kihon Keikaku (Cabinet Office, Government Japan 2014). However, it was difficult for function an emergency-care system. In the system, TEPCO basically had responsibility for on-site medical care, but they could not secure physicians at the NPP. The government thus supported to reestablish emergency-care system. In the event of a large-scale nuclear accident, the government needs to lead operations of the system and to assist by dispatching medical staff to affected plants.

The contractors assigned by the Tokyo Electric Power Company (TEPCO) were basically responsible for their workers' safety and health. Under a complex chain of order, however, it was difficult for occupational safety and health measures to disseminate throughout the entire work organization. In addition, trade-offs were sometimes made related to the risks associated with radiation exposure: countermeasures against one particular hazard periodically affected work schedules and increased the chance of other risks. The various countermeasures were implemented under the administrative guidance of the government and included the suspension of work in the afternoon at the early stage of emergency work. If major disasters occur, on-site occupational health involvement by the government is essential in protecting the health of workers engaged in response and recovery actions. According to occupational health experts, it was clear that thorough measures to deal with radiation exposure, heat stress, infectious diseases, psychological stress, and fitness for work were necessary from the early phase of the accident. However, it took a long time for occupational health experts, who were not included in the response plan, to gain a position and influence preventive health measures at the sites. When disasters occur, many workers and volunteers belonging to various organizations become engaged in response and recovery operations. They are often exposed to multiple health hazards, and there are sometimes trade-offs in the associated risks. The involvement of occupational health experts is essential to protect workers' health and lives. It is necessary to review current emergency response plans at national, local, and company levels and to secure their involvement in an emergency response organization.

Many workers engaged in operations at the NPP belonged to companies with insufficient occupational health resources. In the decontamination work, there was a high rate of heat illness symptoms and reported violation of applicable labor laws. It was reported that radiation protection of municipal employees who helped in evacuation and temporary return of residents was much poorer than among employees in public institutions under central government control. In the September 11 attacks on the World Trade Center (WTC) in 2001, a cloud of toxic particles generated by the burning and collapse of the buildings spread over Lower Manhattan and parts of neighboring districts. Rescue workers and community members exposed to those materials developed chronic physical illness and psychological trauma. It was reported that WTC volunteer responders without formal affiliation with a rescue organization had a higher rate of WTC-related accidents, physical illness, and mental illness than affiliated responders (Crane et al. 2014). They can be called a "vulnerable subgroup." It is to be expected of companies and other organizations that they should protect their workers' health—even in disasters. However, it is clear that many workers in the vulnerable subgroups did not receive appropriate support. The protection of workers should be enhanced in the emergency response plan including National Response Plan.

Except for cases of beta-ray burns, no evident adverse effects of radiation exposures have thus far been reported. However, various problems on the control and management of radiation exposure have been identified. The inappropriate fitness of respirators was a major cause of internal exposure exceeding the dose limit. It should be noted that the preparedness and training for dealing with emergency situations were insufficient. Future preparation for disasters, such as training and stocking equipment, should be designed to protect workers' health based on detailed scenarios.

If a major disaster occurs, the workers engaged in recovery operations may become victims. They may also become targets of criticism and discrimination because they are working for a company that is responsible for the accident. TEPCO employees were under such conditions, and psychological care was provided for them. The government opened toll-free telephone services for mental health. Considering that many workers were involved in recovery operations under a complex organization with multiple layers, it cannot be said that the system or services were sufficient. It is necessary to secure adequate numbers of specialists who are able to provide mental health support.

After a large disaster, there are various trade-offs between health risks and other factors. After the Fukushima incident, personal protection against radiation exposure and contamination increased the risk of heat illness and accidents. TEPCO was concerned that implementing a fitness-for-work evaluation program might result in manpower shortage and other issues. However, it is difficult to manage such issues when different departments or organizations share responsibility in a disaster situation. When the necessity for trade-offs becomes clear following a disaster, the departments or organizations concerned need to communicate positively with one another toward making the appropriate decisions.

Conclusion

As the result of nuclear accidents at the Fukushima Daiichi Nuclear Power Plant, we faced to unexpected sever conditions. A lot of workers were engaged in the related works and they were exposed to various health hazards. Experts in occupational health, emergency medicine, and other specialties did their best to manage the situations in cooperate with the Japanese government and the Tokyo Electric Power Company. In the article, we shared several lessons learned from the experiences for disasters in the future.

References

Cabinet Office, Government Japan. (2014). *Bosai Kihon Keikaku*. http://www.bousai.go.jp/taisaku/keikaku/pdf/kihon_basic_plan141128.pdf. Accessed 01 May 2015.

Crane, M. A., Cho, H. G., & Landrigan, P. J. (2014). Implications of the World Trade Center Health Program (WTCHP) for the public health response to the Great East Japan Earthquake. *Industrial Health, 52*, 5–12.

Ministry of Health, Labour and Welfare. (2013). *Results of supervision/instructions to employers of decontamination works (January–June, 2013) and request to the employers*. http://www.mhlw.go.jp/english/topics/2011eq/workers/dr/dr/pr_130724.html. Accessed 01 May 2015.

Ministry of Health, Labour and Welfare. (2014a). *A report of experts committee on the way of epidemiological studies for the workers engaged in emergency work in the TEPCO Fukushima Daiichi nuclear power plant*. http://www.mhlw.go.jp/stf/houdou/0000047387.html. Accessed 01 May 2015.

Ministry of Health, Labour and Welfare. (2014b). *Response and action taken by the Ministry of Health, Labour and Welfare of Japan on radiation protection for workers involved in the TEPCO Fukushima Daiichi Nuclear Power Plant accident*. http://www.mhlw.go.jp/english/topics/2011eq/workers/tepco/rp/irpw.pdf. Accessed 01 May 2015.

Ministry of Health, Labour and Welfare. (2014c). *Results of supervision/instructions to employers of decontamination works*. http://www.mhlw.go.jp/english/topics/2011eq/workers/dr/dr/pr_140312.html. Accessed 01 May 2015.

Ministry of Health, Labour and Welfare. (2014d). *Results of supervision/instructions to employers of decontamination works (January–June 2014)*. http://www.mhlw.go.jp/english/topics/2011eq/workers/dr/dr/pr_140807.html. Accessed 01 May 2015.

Mori, K., Tateishi, S., Hiraoka, K., Kubo, T., Okazaki, R., Suzuki, K., et al. (2013). How occupational health can contribute in a disaster and what we should prepare for the future—Lessons learned through support activities of a medical school at the Fukushima Daiichi Nuclear Power Plant in Summer 2011. *Journal of Occupational Health, 55*, 6–10.

Mori, K., Tateishi, S., Kubo, T., Okazaki, R., Suzuki, K., Kobayashi, Y., et al. (2014). Transition of occupational health issues associated with stabilization and decommissioning of the nuclear reactors in the Fukushima Daiichi Nuclear Power Plant through 2013. *Journal of Occupational and Environmental Medicine, 56*, 1145–1152.

Morimura, N., Asari, Y., Yamaguchi, Y., Asanuma, K., Tase, C., Sakamoto, T., et al. (2013). Members of the Japanese Association for Acute Medicine, Emergency, Task Force on the Fukushima Nuclear Power Plant Accident (JAAM-TF-FNPPA). Emergency/disaster medical support in the restoration project for the Fukushima nuclear power plant accident. *Emergency Medicine Journal, 30*, 997–1002.

National Institute of Occupational Safety and Health, Japan. (2011). *A report of investigation on fitness of respirators in the TEPCO Fukushima Daiichi Stabilization Center (J-village)*. http://www.mhlw.go.jp/stf/houdou/2r9852000001ri1k-att/2r9852000001ri6e.pdf. Accessed 01 May 2015.

Ojino, M., & Ishii, M. (2014). Reconstruction of the radiation emergency medical system from the acute to the sub-acute phases after the Fukushima Nuclear Power Plant crisis. *Japan Medical Association Journal, 57*, 40–48.

Sano, S. Y., Tanigawa, T., Shigemura, J., Satoh, Y., Yoshino, A., Fujii, C., et al. (2012). Complexities of the stress experienced by employees of the Fukushima nuclear plants. *Seishin Shinkeigaku Zasshi, 114*, 1274–1283. (in Japanese).

Shigemura, J., Tanigawa, T., Nishi, D., Matsuoka, Y., Nomura, S., & Yoshino, A. (2014). Associations between disaster exposures, peritraumatic distress, and posttraumatic stress responses in Fukushima nuclear plant workers following the 2011 nuclear accident: The Fukushima NEWS Project study. *PLoS ONE, 9*, e87516.

Shigemura, J., Tanigawa, T., Saito, I., & Nomura, S. (2012). Psychological distress in workers at the Fukushima nuclear power plants. *Journal of the American Medical Association, 15*(308), 667–669.

Tanigawa, K., Hosoi, Y., Terasawa, S., Kondo, H., Asari, Y., Shishido, F., et al. (2011). Lessons learned from the Fukushima Daiichi nuclear power plant accident; the initial 5 days medical activities after the accident. *Journal of Japanese Association for Acute Medicine, 22*, 782–791. (in Japanese).

Tsubokura, M., Nihei, M., Sato, K., Masaki, S., Sakuma, Y., Kato, S., et al. (2013). Measurement of internal radiation exposure among decontamination workers in villages near the crippled Fukushima Daiichi Nuclear Power Plant. *Health Physics, 105*, 379–381.

Wada, K., Yoshikawa, T., Hayashi, T., & Aizawa, Y. (2012a). Emergency response technical work at Fukushima Daiichi nuclear power plant: Occupational health challenges posed by the nuclear disaster. *Occupational and Environmental Medicine, 69*, 599–602.

Wada, K., Yoshikawa, T., & Murata, M. (2012b). Decontamination work in the area surrounding Fukushima Daiichi Nuclear Power Plant: Another occupational health challenge of the nuclear disaster. *Archives of Environmental & Occupational Health, 67*, 128–132.

Yasui, S. (2013). Engineering case report: Lessons learned: Radiological protection for emergency workers at the TEPCO Fukushima Daiichi APP (part 1). *Journal of Occupational Environmental Hygiene, 10*, D151–D158.

Yasui, S. (2014). Lessons learned: Medical health care management for emergency workers at the TEPCO Fukushima Daiichi APP accident. *Journal of Occupational Environmental Hygiene, 11*, D49–D58.

Yasui, S. (2015). 250 mSv: Temporary increase in the emergency exposure dose limit in response to the TEPCO Fukushima Daiichi NPP accident and its decision making process. *Journal of Occupational Environmental Hygiene, 12*, D35–D42.