

Review

Review of health issues of workers engaged in operations related to the accident at the Fukushima Daiichi Nuclear Power Plant

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Abstract: Review of health issues of workers engaged in operations related to the accident at the Fukushima Daiichi Nuclear Power Plant: Koh HIRAOKA, *et al.* Occupational Health Training Center, University of Occupational and Environmental Health, Japan—**Objectives:** The aim of this review was to summarize the lessons learned from the experience in protecting the health of workers engaged in operations following the accident at the Fukushima Daiichi Nuclear Power Plant (NPP). **Methods:** We reviewed all types of scientific papers examining workers' health found in Medline and Web of Sciences as well as some official reports published by the Ministry of Health, Labour and Welfare of Japan and other governmental institutes. **Results:** The papers and reports were classified into those investigating workers at the Fukushima Daiichi and Daini NPPs, workers engaged in decontamination operations in designated areas, and other workers. Regarding workers at the NPPs, many efforts were made to establish an emergency-care and occupational health system. Risk management efforts were undertaken for radiation exposure, heat stress, psychological stress, outbreak of infectious diseases, and fitness for work. Only a few reports dealt with decontamination workers and others; however, the health management of these workers was clearly weaker than that for workers at the NPPs. **Conclusions:** Many lessons can be learned from what occurred. That knowledge can be applied to ongoing decommissioning work and to future disasters. In addition, it is necessary to study the long-term health effects of radiation exposure and to accumulate data about the health of workers engaged in decontamination work and other areas.

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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 have been performed as a result. Actions at the NPP shifted from emergency response to cooling of fuel rods, stabilization of the reactors by establishing cooling systems, and decommissioning of the reactors. A large number of employees of TEPCO, manufacturers of the nuclear reactors, construction companies, and their contractors were engaged in those actions¹. Members of the Self-Defense Forces², firefighters, police, and medical personnel^{3,4} were dispatched to the disaster area, including inside the NPP; they were engaged in various operations, such as cooling nuclear reactors, rescue work, and evacuating residents, at the early stage of the disaster. Municipal employees working close to the NPP also helped evacuate residents⁵. For rehabilitation of contaminated areas following the accident, the Japanese government undertook decontamination work⁶ and management of the waste resulting from decontamination and contaminated goods⁷. Following reorganization of the restricted area in April 2012, business activities were allowed in areas where the annual integral dose was 20 mSv or less⁸. The people listed above were thus exposed to radiation and other health risks. When taking numbers of workers, characteristics, and other factors of works into account, it was considered to be appropriate to classify the workers into workers at the Fukushima Daiichi or Daini NPPs, workers engaged in decontamination work in designated areas, and other workers in the restricted area in this review.

The Ministry of Health, Labour and Welfare (MHLW) established an epidemiological study group on the long-term health effects of workers engaged in emergency actions at Fukushima Daiichi NPP⁹⁾. However, few studies have described the health issues for workers engaged in related operations in the acute and subacute phases. Accordingly, we reviewed published scientific papers and official documentation from the Japanese government to summarize lessons that the parties involved in health care of workers, such as the government, companies and occupational health (OH) experts, could learn from the experience and to clarify the areas that demand further study.

Methods

We included in this review all types of papers addressing the health of workers engaged in actions related to the accident at the Fukushima Daiichi and Daini NPPs. We excluded papers that examined only theoretical models of radiation effects, compared the NPP disaster with previous accidents, or investigated non-work-related health issues of workers. In this review, we also used official information from the Japanese government.

In November 2014, we searched two electronic databases (Medline, Web of Sciences) to identify relevant publications. We limited papers to those in English or Japanese. To identify as many studies as possible on the health effects of workers engaged in actions related to the accident at the Fukushima NPP, the key words we used in the search were “Fukushima”, “atomic”, “nuclear”, “work*”, and “health”: (Fukushima [TW] AND (atomic [TW] or nuclear [TW]) AND work* AND health [TW]). After duplicates were removed, this strategy initially led to 99 results.

After screening the abstracts, we retrieved the full texts of these publications. We also added the full texts of the publications without the abstracts whose titles were obviously related to the topic under investigation. We then read the papers in full to assess whether they met the selection criteria. We also added some related reports published by the MHLW, other governmental institutes, and Japanese-language publications containing information about workers involved at the NPPs, when the information they included met the selection criteria and was not included in any of the retrieved papers. As a result of the study selection procedure, we extracted 36 publications and reports for review (Fig. 1).

Results

Among the extracted publications, 22 (five original papers, two research reports, eight case reports, four governmental reports, one review, two pieces of correspondence) described examinations of the health of

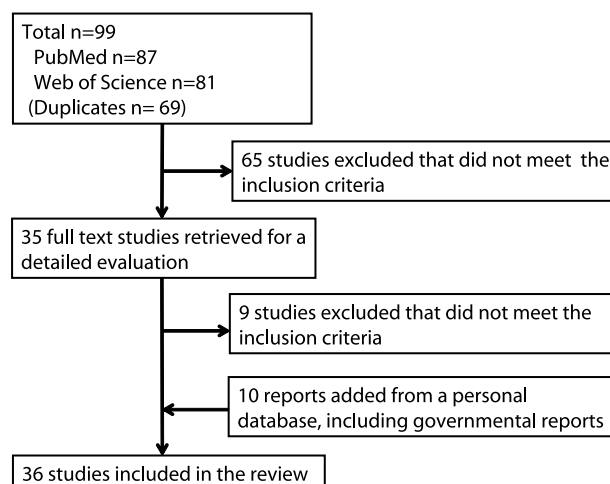


Fig. 1. Flowchart of study selection.

workers at the Fukushima Daiichi or Daini NPP; eight (four case reports, three governmental reports, one conference abstract) described investigations of the health of workers engaged in decontamination work in designated areas; one (governmental report) described a study of both workers at the NPPs and decontamination workers; and five (one original paper, one short communication, three case reports) described examinations of other workers in the restricted area. We analyzed these papers according to the three types of workers. The type and abstract of each paper are shown in Table 1 for workers at the NPPs, those for decontamination workers are shown in Table 2, and those for other workers area are shown in Table 3.

1. Workers at Fukushima Daiichi NPP

Implementation of an emergency medical system for workers, including transportation to hospitals, has been one of the highest concerns among the health-related issues at the Fukushima Daiichi NPP since the accident occurred.

In addition, 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 have also been concern. In this complex situation, establishment of occupational health management systems in which occupational health experts were involved was essential in managing the issues.

(1) Emergency medical system

It was of utmost importance to enhance the emergency and disaster medical system for frontline workers. In previous planning for a disaster, NPP operators like TEPCO were responsible for on-site medical care, and prefectures would manage the radiation emergency medical system in conjunction with

Table 1. Summary of publications and reports on workers health at the Nuclear Power Plants

Ref.	Authors	Type of paper	Abstract
1	Mori, K., <i>et al.</i>	Original	To clarify the occupational health (OH) issues that arose, what actions were taken, and the OH performances during the disaster involving the Daiichi NPP and thus improve the OH management system with respect to long-term decommissioning work and preparation for future disasters. OH issues transitioned as work progressed and seasons changed. They were categorized into OH management system establishment, radiation exposure control, heat illness prevention, infectious disease prevention and control, and fitness for workers' duties. OH management systems involving OH experts should be implemented to manage multiple health risks with several conflicts and trade-offs after a disaster.
3	Morimura, N., <i>et al.</i>	Original	The Japanese Association for Acute Medicine (JAAM) contributed to the radiation emergency medical system. It launched its "Emergency Task Force on the Fukushima Nuclear Power Plant Accident" and decided to send personnel as "disaster medical advisors" to the off-site center medical team. In addition, it sent physicians to direct and manage the medical team at J Village, originally the national training center for football, the medical frontline of the NPP restoration project and the temporary primary radiation emergency medical center. The role of the JV directing physician was to conduct triage, decontamination, and initial treatment and to connect patients with secondary and radiation emergency hospitals.
4	Tanigawa K., <i>et al.</i>	Case report	A series of hydrogen explosions occurred in the NPP, and 15 workers were injured. The radiation emergency medical system did not function properly, and great difficulties were encountered in treating those with radioactivity contamination. From the experience, it is recommendable to develop emergency medical systems for radiation exposure further and to educate medical staff and students about radiation emergency medicine.
9	Ministry of Health, Labour and Welfare	Reports of government	MHLW held an expert committee and discussed how to make a plan for an epidemiological study for emergency workers in the NPP accident. The major recommendations were as follows; 1) The subjects should be all the registered emergency workers (about 2 million), 2) the period of the study should be their lifetimes. 3) the end point should be solid cancers, leukemia and other non-cancer diseases that are possibly related with radiation exposures, 4) cumulative exposure dose should be used as the exposure factor, 5) psychological effects due to work-related factors and experiences during the disasters should be considered, 6) the basic design should be a prospective cohort study and a nested case-control study should be considered and 7) both significant and no significant findings should be reported.
10	Yasui, S.	Case report	Based on the experiences and lessons learned, the MHLW recognized that the proper management and implementation of medical and health-care management in response to a similar accident would require sufficient measures and systematic preparation, including the following: 1. In case of large-scale nuclear accidents, the government needs to assist in dispatching medical staff. 2. Nuclear facility operators, medical facilities, and fire departments should clarify the division of the roles played prior to the accident and should conduct emergency drills. 3. Operators need to develop a support base in the safety area and to prepare to develop makeshift lodgings in case of emergency. 4. Operators need to share food stocks among closely located nuclear plants and prepare cooking equipment to provide warm food to many workers. 5. It is necessary to conduct long-term follow-up for emergency workers, including health care system, medical examination and mental health consultations.
11	Ministry of Health, Labour and Welfare	Reports of government	The dose limit for emergency work, which was originally 100 mSv, was temporarily increased to 250 mSv from 14 March to 16 December 2011, the day on which the Japanese Government declared that the affected plant had been stabilized. This document outlines the problems that occurred during the emergency response to the accident and the measures taken by the MHLW and TEPCO, such as issue of a series of compulsory directives and administrative guidance to TEPCO. It also outlines the new regulation and guidelines to protect the decontamination workers.
12	Task Force on the Fukushima Nuclear Power Plant Accident of the Japanese Association of Acute Medicine	Case report	JAAM set up the task force on the Fukushima Nuclear Power Plant Accident on March 28, 2011. They communicated with the fire department, self-defense forces, TEPCO and other parties concerned and dispatched doctors who were familiar with radiation medicine and emergency medicine. This paper describes their activities and efforts for establishment of the emergency care system.

Table 1. Summary of publications and reports on workers health at the Nuclear Power Plants (Continued)

Ref.	Authors	Type of paper	Abstract
13	Ojino, M., <i>et al.</i>	Case report	Reconstruction of the radiation emergency medical system was achieved in six stages; stage 1: re-establishment of an off-site center (March 13); stage 2: re-establishment of a secondary radiation emergency hospital (March 14); stage 3: reconstruction of the primary radiation emergency care system (April 2); stage 4: reinforcement of the off-site center and the stationing of disaster medical advisors at the off-site center (April 4); stage 5: reinforcement of medical system and an increase in the number of hospitals for non-contaminated patients (from April 2 to June 23); stage 6: enhancement of the medical care system within the Fukushima Nuclear Power Plant and the construction of a new medical system, involving both industrial medicine and emergency medicine (July 1).
14	Mori, K., <i>et al.</i>	Case report	TEPCO implemented programs to prevent radiation exposure, but had no effective systems for managing the other health risks and few occupational health professionals contributed to the health risk management. University of Occupational and Environmental Health (UOEH) dispatched physicians to a quake-proof building at the plant to provide first-aid services from mid-May, 2011, and took a strategic approach to protecting workers' from existing health risks. The MHLW issued guidelines to TEPCO, and TEPCO implemented a comprehensive program against heat stress according to the guidelines and in cooperation with UOEH. As a result, severe heat illness was successfully prevented during summer 2011. From the experiences, the following recommendations should be considered: 1) the role of OH and the participation of experts should be defined in emergency response plans; 2) regulations should allow the national government and main companies involved to lead safety and health initiatives for all workers at disaster sites; and 3) OH professionals, response manuals and drills should be organized at a national level.
15	Yasui, S.	Case report	TEPCO and the Japanese government experienced various problems in radiological exposure management for emergency workers during the emergency work at the NPP. These included inappropriate exposure monitoring because of a shortage of personal dosimeters, inappropriate dosimeter circulation management and insufficient implementation of exposure control, workers who were out of contact, delayed internal exposure monitoring and exceeding emergency dose limits. To improve the implementation of appropriate radiological protection, MHLW issued a series of compulsory directives and provided administrative guidance to TEPCO. Based on the experiences and lessons learned, the MHLW recognized that to properly manage radiological exposure should a similar accident occur at another NPP, sufficient measures and systematic preparation for radiological management should be ensured, including the following: a) should an APP accident occur, 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 sub-contractors; c) APP operators should compile an operations manual, stockpile personal protective equipment and personal alarm dosimeters (PADs) and prepare emergency systems and whole body counters (WBCs); and d) the labor standards authorities should compile an emergency operations manual.
16	Yasui, S.	Case report	TEPCO and the Japanese government experienced various problems in radiological exposure management for emergency workers during the emergency work at the NPP. These included internal exposure that a variety of responses TEPCO and the government took against the problems. To reduce the exposure dose, the following lessons should be shared with other NPPs and various stakeholders: (a) to prevent internal exposure, it is necessary to monitor the radioactive concentration of the workplace indoor air during an emergency, to stockpile and use appropriate respiratory protection, and to 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; and (d) earlier deployment of remote-controlled vehicles and the utilization of tungsten shielding vests can contribute to exposure reduction.

Table 1. Summary of publications and reports on workers health at the Nuclear Power Plants (Continued)

Ref.	Authors	Type of paper	Abstract
17	National Institute of Occupational Safety and Health, Japan	Reports of government	The results of ultrasonic examination were compared between the exposed group (emergency workers exposed to radiation exceeding a thyroid equivalent dose of 100 mSv) and a control group. The percentage of those to whom a secondary examination was recommended was relatively higher for examinees with high doses, but this was not statistically significant. On the other hand, the percentage of those for whom a secondary examination was judged unnecessary was higher for examinees with high doses, and this was statistically significant. The same result was obtained when limiting the analysis targets to examinees who had not received an ultrasonic examination of the thyroid gland before or when excluding from analysis targets the examinees whose evaluated thyroid equivalent doses due to internal exposure were less reliable.
18	Tanimoto, T., <i>et al.</i>	Correspondence	It is important to prepare medical care providers to respond in cases of accidental high radiation exposure. The danger of future accidental radiation exposure has not passed, since these operations are estimated to take month to years. In case of radiation exposure of more than 5 Gy, haemopoietic stem-cell rescue is essential. The authors propose collection and storage of autologous peripheral-blood stem cells for the nuclear workers in Fukushima.
19	Gale, R.P., <i>et al.</i>	Correspondence	Blood-cell banking was well intentioned but ill-advised from two main reasons. First, the Chernobyl accident suggests that less than 2% of a typical population of people exposed to high-dose whole-body radiation are likely to benefit from transplantation of bone-marrow cells. Second, transplantation of bone-marrow cells addresses only haemopoietic radiation toxicity.
20	Suto, Y., <i>et al.</i>	Original	The Natural Institute of Radiation Sciences (NIRS) assessed the exposure doses of twelve workers who were suspected being overexposed to acute radiation. Biological dosimetry was performed by the dicentric chromosome assay (DCA). The results indicated that the estimated exposure doses for all individuals were lower than 300 mGy. Up to now, no accidents requiring treatment of acute radiation syndrome have occurred.
21	Etherington, G., <i>et al.</i>	Original	World Health Organization's Health Risk Assessment (HRA) was used to evaluate cancer incidence from radiation exposure dose data released by TEPCO. HRA constructed four exposure scenarios to estimate worker radiation doses. For the highest dose scenario, Lifetime Attributable Risks (LAR) values for thyroid cancer of up to 3.5% were estimated, but a radiation-related increase in thyroid cancer incidence was unlikely to be observed because of the small number of workers. For the two intermediate dose scenarios, a small number of cancer cases might occur, but these are unlikely to be observed because the variability in baseline rates of cancer incidence were much larger than the predicted radiation-related incidence rates.
22	Sobue, T., <i>et al.</i>	Reports of government	The leakage rates based on tests of the fit of respiratory protective equipment for six NPP workers of TEPCO were investigated experimentally. The leakage rates of the 6 workers were between 1.1 and 56% (average 17.4%), and those of 4 workers exceeded 10%. The following countermeasures were recommended to TEPCO: (a) the countermeasures for workers who wear glasses, (b) choice of appropriate equipment, (c) practice to prevent leakage, (d) installation of PAPR, and (e) improvement of the education content for new workers.
23	Wada, K., <i>et al.</i>	Review	The hazards at the NPP varied as containment measures were put in place. However, there were four major hazards identified: radiation, heat, stress and machine operation and manual handling. Initially, high radiation exposure of the workers was the most serious hazard. As from May, heat exposure became an extremely important hazard because of the hot summer weather and workers having to work outdoors wearing double-layer protective coveralls and full face respirators, which inhibit evaporative cooling. Workers were exposed to multiple stressors, both work-related and personal. Workers were also at risk of injury from machine operation, manual clean-up of the tsunami rubble and stabilization of the nuclear reactor for cold shutdown.

Table 1. Summary of publications and reports on workers health at the Nuclear Power Plants (Continued)

Ref.	Authors	Type of paper	Abstract
24	Tsuji, M., <i>et al.</i>	Research report	From March 22 to September 16, 2011, the Fukushima Labor Bureau assessed 43 cases of NPP workers with heat illness. The results of this assessment showed that heat illness occurred most frequently in subjects in their 40s (30.2%), followed by those in their 30s (25.6%), mostly in July (46.5%) between 7 am and 12 pm (69.8%). Heat illness occurred most frequently in environments with temperatures of more than 25°C and humidity of 70–80% (39.5%). Heat illness of Grade 2 or higher occurred in 10 cases, 5 of which were in June. According to statistical analysis, there were no significant differences in severity of heat illness for any factors, i.e., age, temperature, humidity, and wearing a cooling vest.
25	Shigemura, J., <i>et al.</i>	Case report	This paper describes the initiation of mental support activities by psychiatrists for the TEPCO employees in the Daiichi and Daini NPPs. The psychiatrists entered the restricted zone and visited the Daini NPP's gymnasium, which is the place where the Daiichi NPP workers had to spend their nights. The workers showed a myriad of posttraumatic stress responses, and other symptoms. They showed immense grief and guilt owing to the deaths of their colleagues and loved ones. They were severely discriminated against. The government eventually ordered continuation of their support.
26	Shigemura, J., <i>et al.</i>	Original	A self-report questionnaire was administered to 1,411 NPP workers. The results of the questionnaire could be used to develop a path model for the PTSR and peritraumatic distress of TEPCO employees at the Daiichi NPP and Daini NPP with the same data. It suggested that peritraumatic distress was a major predictive factor of PTSR in both groups.
27	Shigemura, J., <i>et al.</i>	Research report	The psychological statuses of NPP workers was examined 2 to 3 months after the disaster. The subjects were full-time NPP workers from the Daiichi (n=1,053) and Daini NPPs (n=707). The authors reported that Daiichi NPP workers were more often exposed to disaster-related stressors than Daini NPP workers. Experiencing discrimination or slurs was not statistically significantly different between groups. Daiichi NPP workers had 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 both groups included tsunami evacuation and major property loss with psychological distress and preexisting illness and major property loss with PTSR.
28	Sano SY. <i>et al.</i>	Case report	Interviews were conducted with 399 workers (TEPCO employees) at the Daiichi and Daini NPPs. The complexity of the huge disaster and individuality of suffering from it were discussed. Like local residents, many workers experienced loss (death or missing) of family members, loss of housing, refugee life, and dispersion of family. They were suffering as a result of various criticisms and slanders against TEPCO. They were struggling with the coexistence of a sense of guilt and a sense of victim in their minds.

MHLW, Ministry of Health, Labour and Welfare; NPP, nuclear power plant; TEPCO, Tokyo Electric Power Company; PTSR, posttraumatic stress response.

Table 2. Summary of publications and reports on health of workers engaged in decontamination around the nuclear power plant and disposal of contaminated soil and wastes

Ref.	Authors	Type of paper	Abstract
6	Yasui, S.	Case report	The Japanese government decided to carry out decontamination projects around the Fukushima Daiichi NPP. For the radiological protection of the decontamination workers, the government needed to establish new regulations that fitted the “existing exposure situations”. The new regulations aim to set the appropriate protection standards in accordance with the risk of the ambient dose rate, radioactivity concentration, and type of radio nucleolus. To maintain practicability, the government employed a validated and simplified measurement methodology for the internal exposure, ambient dose rate, and radioactivity concentration, considering restrictions in human resources and shortages of supplies in the affected areas.
7	Yasui, S.	Case report	The Japanese government decided to carry out decontamination work and manage the waste resulting from decontamination. The existing regulations were not developed to address such a large amount of contaminated wastes. The government had to amend the existing regulations for waste disposal workers. The amendment of the general regulation targeted the areas where the existing exposure situation overlaps the planned exposure situation.

Table 2. Summary of publications and reports on health of workers engaged in decontamination around the nuclear power plant and disposal of contaminated soil and wastes (Continued)

Ref.	Authors	Type of paper	Abstract
11	Ministry of Health, Labour and Welfare	Reports of government	The dose limit for the emergency work, which was originally 100 mSv, was temporarily increased to 250 mSv from 14 March to 16 December 2011, the day on which the Japanese Government declared that the affected plant had been stabilized. This document outlines the problems that occurred during the emergency response to the accident and the measures taken by the MHLW and TEPCO, such as issues of a series of compulsory directives and administrative guidance to TEPCO. It also outlines the new regulation and guidelines to protect the decontamination workers.
29	Wada, K., <i>et al.</i>	Case report	Decontamination of radioactive materials around the Fukushima Daiichi NPP is performed by removing radioactive particles from surfaces of soil, grass and trees, and buildings. Measurement of radiation doses is necessary to reduce exposure, and to determine whether workers can work below dose limits. Protective equipment for decontamination is determined based on the concentration of radiation in contaminated soil and the exposure of dust. Health examinations are mandated for decontamination workers upon hiring and every 6 months. Workers may be anxious about the unclear effects of chronic low level radiation exposure on health. Measures to protect the decontamination workers are the top priority.
30	Tsubokura, M., <i>et al.</i>	Case report	The internal exposure of workers regularly engaged in decontamination activities were measured. The cesium burdens of all the workers were below detection limits. They had reported no acute health problems.
31	Tsuji, M., <i>et al.</i>	Abstract of conference	A mail survey of decontamination workers about measures against heat illness, experience of related symptoms, and countermeasures when they felt the symptoms was conducted in August 2013. Half of the respondents had experiences of related symptoms, but measures against heat illness were insufficient.
32	Ministry of Health, Labour and Welfare	Reports of government	The Fukushima Prefectural Labour Bureau has compiled the results of supervision/instruction of employers involved in decontamination work during the period of January to June 2013. It supervised and instructed 388 employers. Among these employers, a total 264 (violation rate of 68%) were recognized as being in violation of applicable laws such as the Labour Standards Act or Industrial Safety and Health Act. Corrective recommendations were issued to these employers to correct the violations accordingly. The number of violations was 684, among which 211 were those relevant to safety and health, operation leaders and implementation of special medical examinations.
33	Ministry of Health, Labour and Welfare	Reports of government	The Fukushima Prefectural Labour Bureau has compiled the results of supervision/instruction to employers involved in decontamination work during the period of July to December 2013. It supervised and instructed 660 employers. Among them, violations of the Labour Standards Act and regulations were found for 446 employers. The number of violation cases was 1,105, and many violations were found in connection with the payment of increased wages, preparation of payroll books, preliminary surveys, use of protective equipment, and the like.
34	Ministry of Health, Labour and Welfare	Reports of government	The Fukushima Prefectural Labour Bureau has been conducting intensive supervision of employers involved in decontamination work for the purpose of ensuring working conditions as well as industrial safety and the health of decontamination workers. During the period of January to the end of June 2014, the offices supervised and instructed 313 employers. Among them, violations of labour standards laws and regulations (the Labour Standards Act and the Industrial Safety and Health Act) were found for 186 employers. The number of violation cases was 335. Among them, 175 were violations relating to industrial safety and health, such as those in connection with preliminary surveys, dose measurement, and use of protective equipment.

MHLW, Ministry of Health, Labour and Welfare; NPP, nuclear power plant; TEPCO, Tokyo Electric Power Company.

Table 3. Summary of publications and reports on health of workers engaged in other works related to the accident at the Fukushima Daiichi Nuclear Power Plant

Ref.	Authors	Type of Paper	Abstract
2	Naoui, Y., <i>et al.</i>	Case report	The Ground Self-Defense Force (GSDF) was dispatched to northeast area in Japan, and the highly trained GSDF members were assigned to various missions for the Fukushima Nuclear Power Plants disaster. Special medical examinations were conducted for the members at risk of radiation exposure. The amounts of internal and external exposure of the GSDF members were reported. A total of 831 members had external radiation exposure that exceeded 5 mSv. The maximum dose was 81.2 mSv.
5	Yokogawa, T., <i>et al.</i>	Short communication	The measures that were in place regarding occupational radiation exposure at 3–4.5 months post disaster were compared between municipal offices and public institutions under central government control. The findings indicate that municipal offices had sub-optimal administrative measures for radiation protection and that such offices were worse in this respect than the other public institutions under central government control.
8	Yasui, S.	Case report	In accordance with the rearrangement of the restricted area in April 2012, the Japanese government decided to allow resumption of business activities. As a result, the government needed regulations for radiation protection for workers engaged in those activities. The issues that arose in the deliberation of the regulations were distilled into two points: 1) whether protection systems established for a planned exposure situation should apply to construction and agricultural work activities in an existing situation and 2) how to simplify the regulation in accordance with the nature of the work activities. Further research and development concerning some issues are warranted.
35	Matsuda, N., <i>et al.</i>	Case report	This report briefly describes what happened around the radiation emergency medical assistance team members who were involved in various activities for six days from March 14, 2011. Radiation exposure of the members was reported. Total external doses in four or five days in Fukushima were within the range of 31.0 uSv–52.0 uSv. As for their internal exposure, multiple incorporations of I-131, Cs-134, and Cs-137 were observed in all of the subjects, and the committed effective doses for the highest cases were 89.0 uSv, 4.6 uSv, and 3.2 uSv, respectively.
36	Matsuoka, Y., <i>et al.</i>	Original	Among disaster medical assistance team workers deployed to the disaster area, radiation exposure was a concern for 9.2% of respondents. Concern over radiation exposure was significantly associated with higher scores on the K6, CES-D, and IES-R. After controlling for possible confounding factors, these associations remained significant in men, but did not remain significant in women for the CES-D and PDI scores. The findings suggest that concern over radiation exposure was strongly associated with psychological distress.

K6, Kessler 6 scale; CES-D, Center for Epidemiologic Studies Depression Scale; PDI, Peritraumatic Distress Inventory; IES-R, Impact of Event Scale-Revised.

government-designated institutes such as tertiary radiation emergency hospitals¹⁰). However, that system did not function in the Fukushima disaster owing to several factors.

Although 2,000–3,000 emergency workers a day were working at the NPP just after March 2011, TEPCO was able to maintain the presence of physicians only in daytime and for a few days a week in the early stages of the accident. The MHLW decided to establish a system of 24-hour on-site physicians and arranged for dispatch of physicians from the University of Occupational and Environmental Health (UOEH) and Japan Labor Health and Welfare Organization. Subsequently, TEPCO was able to establish a 24-hour physician presence in a quake-proof building at the NPP¹¹). TEPCO set up an on-site makeshift medical clinic in the service building of Reactors No. 5 and 6 and established a system of

48-hour physician rotation on July 1, 2011. TEPCO thereby completed an on-site triage and initial treatment system¹⁰). In July 2013, TEPCO set up a new medical clinic in the newly constructed Entering and Leaving Control Building and abolished the makeshift medical clinic.

The radiation emergency medical system before the disaster consisted of an off-site center and radiation emergency hospitals organized in three levels (primary, secondary, tertiary), but it became non-functional just after the disaster¹²). On March 12, 2011, the off-site center (local response headquarters) had to be evacuated because it was located in an evacuation zone designated by government order, which comprised all areas within a 10-km radius of the NPP; three of the five hospitals had to be evacuated when the evacuation zone was expanded to a 20-km radius from the plant¹³). The earthquake also damaged the essential

facilities of Fukushima Medical University Hospital, a secondary radiation emergency hospital. Ojino *et al.*¹³⁾ described how reconstruction of the system was achieved in six stages: stage 1, reestablishment of an off-site center (March 13); stage 2, reestablishment of a secondary radiation emergency hospital (March 14); stage 3, reconstruction of the primary radiation emergency-care system (April 2); stage 4, reinforcement of the off-site center and stationing of disaster medical advisors at that center (April 4); stage 5, reinforcement of the medical system and increase of the number of hospitals for non-contaminated patients (April 2 to June 23); stage 6, enhancement of the medical care system within the NPP and establishment of a new medical system, involving both industrial and emergency medicine (July 1).

Morimura *et al.*³⁾ reported the contribution of the Japanese Association for Acute Medicine to the radiation emergency medical system. It launched its Emergency Task Force on the Fukushima Nuclear Power Plant Accident and sent personnel as disaster medical advisors to assist the off-site center medical team. In addition, it sent physicians to direct and manage the medical team at J-Village, formerly the national soccer training center, which became the medical front line of the NPP restoration project and temporary primary radiation emergency medical center. The role of the J-Village directing physicians was to conduct triage, decontamination, and initial treatment and to connect patients with secondary and radiation emergency hospitals.

To facilitate the emergency medical system network, the TEPCO Fukushima Daiichi NPP Emergency Medical System Network was established, and network meetings were held periodically⁴⁾. Daily Web meetings led by Fukushima Prefecture Medical University were held for communication among the off-site center, on-site clinic, and the institutes concerned.

(2) Occupational health management system

With respect to the companies involved in the NPP accident, TEPCO contracted the services of over 20 primary contractors in 2011, each of which outsourced groups of workers to subcontractors in multiple layers¹⁴⁾. The number of primary contractors increased thereafter. The legal responsibilities of TEPCO and the primary contractors' legal responsibilities to the subcontractors' health care were limited. However, it was essential to establish an OH management system, in which TEPCO and the primary contractors had broader responsibilities to protect the health of all individuals working under the serious conditions during the early phase of the work.

Mori *et al.*¹⁾ reported the process of establishing an OH management system for the actions at the NPP. On June 10, 2011, the Japanese government

issued a guidance paper explaining that TEPCO and the primary contractors were expected to play broader roles in this regard: they thus began developing an OH management system according to the guidance on preventing heat stress. However, the management system did not include a method for evaluating how each contractor implemented the OH programs, which created difficulties for continuous improvement of the system.

TEPCO and the government announced that the plant's nuclear reactors achieved cold shutdown on December 16, 2011. The work phase thus shifted from stabilization to decommissioning. This phase was expected to continue for over 30 years. It was therefore necessary to establish an OH management system accordingly. In that system, each company involved was basically responsible for protecting its own workers' health. A new liaison meeting with the primary contractors in charge of OH was held in October 2012 and every 3 months thereafter¹⁾. Each season's OH issues and the work phase were discussed. OH experts from UOEH attended each meeting and provided technical guidance and information. Because the contractors responsible for OH often changed, these efforts had to be made repeatedly.

It was clear that the knowledge of OH experts was essential in managing the multiple risks under the complex conditions. Because their function had not been included in the disaster response plan at the site, the involvement of OH experts was not expected in the early phase. Mori *et al.*¹⁴⁾ reported how UOEH covered the latent needs. One month after the accident, UOEH received support requests from TEPCO, and UOEH undertook three strategic steps. In step 1, UOEH dispatched a physician to the quake-proof building at the plant to provide daily first aid and periodic health checkups for TEPCO employees. Through these activities, UOEH was able to develop a trusting relationship with TEPCO staff. In step 2, UOEH developed practical recommendations about the OH systems and programs to be implemented at the plant; these recommendations were based on reports from dispatched physicians and discussions with occupational physicians of TEPCO and the contractors concerned. In step 3, UOEH provided training materials, checklists, and guidelines on OH practices at the plant.

(3) Radiation exposure

TEPCO undertook emergency work for which the emergency dose limit applied. The Japanese government increased the dose limit from 100 mSv 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 facilities¹¹). During that period of emergency work, the effective dose of 167 workers exceeded 100 mSv, and that of six workers exceeded 250 mSv; the maximum dose was 678.8 mSv. Internal exposure was the most significant influence on high doses¹⁵). Internal exposure would have been prevented if respirators had been properly fitted and the workers had followed respiratory protection usage guidelines for respirators¹⁶). The National Institute of Occupational Safety and Health, Japan, investigated the leakage rates by testing the respiratory protective equipment of six TEPCO NPP workers¹⁷). For those six workers, the leakage rates were 1.1–56% (average, 17.4%); those of four workers exceeded 10%.

On March 24, 2011, several incidents of beta-ray exposure to the feet occurred during 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 sounded¹⁵). Several other problems concerning 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 MHLW issued a series of compulsory directives and provided administrative guidance to TEPCO.

Tanimoto *et al.*¹⁸) proposed the collection and storage of autologous peripheral-blood stem cells for the Fukushima workers. However, Gale *et al.*¹⁹) held the opposite view: they believed that blood cell banking was well intentioned but ill-advised for two main reasons. First, the Chernobyl accident suggested that under 2% of a typical population exposed to high-dose whole-body radiation were likely to benefit from transplantation of bone marrow cells. Second, transplantation of bone marrow cells addresses only hematopoietic radiation toxicity.

Suto *et al.*²⁰) assessed the exposed dose of 12 workers who were suspected of having been overexposed to acute radiation. Biological dosimetry was performed using the dicentric chromosome assay. The results indicated that the estimated exposure doses for all individuals were under 300 mGy.

Although serious health problems have not developed, there may be late-onset health effects of radiation, such as cataracts and cancer. Long-term observation of the NPP workers is required. Etherington *et al.*²¹) evaluated the lifetime attributable risk for leukemia, thyroid cancer, and all solid cancers for several

scenarios using the World Health Organization's Health Risk Assessment (HRA) with the radiation exposure dose data released by TEPCO. For the highest-dose scenario, lifetime-attributable risk values for thyroid cancer of up to 3.5% were estimated. However, owing to the small number of workers, it is unlikely that a radiation-related increase in thyroid cancer incidence will be observed.

The MHLW published guidelines about long-term health care for emergency workers in October 2011¹⁰). 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 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; and (3) provide health guidance for emergency workers.

Sobue *et al.*²²) compared the results of ultrasonic examinations between an exposed group (emergency workers exposed to radiation above a thyroid equivalent dose of 100 mSv) and control group. The proportion of individuals for whom a secondary examination was recommended was greater for high-dose examinees, but the difference was not statistically significant. However, the percentage of individuals for whom a secondary examination was judged unnecessary was greater for high-dose examinees, and the difference was statistically significant.

The MHLW⁹) published a report written by a committee of experts that included a long-term epidemiological study with a database of emergency staff who worked from March 14 to December 16, 2011. The exposure dose levels of emergency workers were 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, non-cancer diseases, and psychological distress.

(4) Heat stress

Heat illness was one of the major health risks for workers at the NPP in summer¹). 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.

Some cases of heat stress were reported at the end of March and beginning of April 2011, at which time 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 illness¹⁰⁾, which recommended the following: (1) since previous outbreaks of heat illness were concentrated in the period of 14:00 to 17:00, discontinue work during that period; (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; and (7) establish medical systems to treat heat illness patients.

TEPCO undertook measures following the MHLW instructions in cooperation with an OH specialist from UOEH¹⁴⁾. 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-hour shift. Workers at the site were allowed to do several shifts, with a 40-minute break after each 1-hour shift. The break involved removing protective clothing after checking for radioactive contamination, resting, and donning protective clothing again before work²³⁾. As a result, 43 cases of heat illness were reported between the end of March and early October 2011, but no severe heat illness was observed¹⁴⁾.

Tsuji *et al.*²⁴⁾ analyzed heat illness at the NPP in 2011 in 43 cases reported to the Fukushima Labor Standards Office. Moderate or severe heat illness occurred in 10 cases. Heat illness occurred mostly in July (46.5%) between 7:00 and noon (69.8%) and most frequently in subjects in their 40 s (30.2%), five of whom experienced heat illness in June. Statistical analysis revealed no significant differences in severity of heat illness for all factors—age, temperature, humidity, and wearing a cooling vest.

Mori *et al.*¹⁾ reported efforts to prevent heat illness. 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.

(5) Psychological distress

Psychological distress was a major health hazard for Fukushima Daiichi NPP workers, especially TEPCO employees. Shigemura *et al.*²⁵⁾ instigated mental health support for TEPCO employees at the Daiichi and Daini NPPs; they examined general psychologi-

cal distress, peritraumatic distress, and posttraumatic stress response (PTSR) in NPP workers in May and June 2011²⁶⁾. The authors reported that Daiichi NPP workers were more often exposed to disaster-related stressors than Daini NPP workers. 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 PTSR²⁷⁾. Using the same data, Shigemura *et al.*²⁶⁾ developed a path model for the PTSR and peritraumatic distress of TEPCO employees at the Daiichi and Daini NPPs.

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 basis¹¹⁾. Sano *et al.*²⁸⁾ reported the support activities and psychological conditions of TEPCO employees exposed to discrimination or slurs at both NPPs. For contracted workers, occupational physicians provided health-care services, including mental health support; the MHLW also offered toll-free telephone mental health services for all workers²³⁾.

(6) Infectious diseases

There were high risks of infectious disease outbreaks because many workers shared limited spaces for lodging and resting. Mori *et al.*¹⁾ reported prevention and control of infectious diseases. Implementation of measures against influenza and norovirus infection was considered for winter 2011. TEPCO provided free influenza vaccination to all workers, including contractors. Additionally, it placed bottles of alcohol-based sterilization liquid in shared spaces. This program was continued almost unchanged in 2012. For November 2011 to May 2012 and November 2012 to May 2013, 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, and it created a kit and manual to deal with floors or other surfaces contaminated by vomit or feces¹⁾. UOEH developed and distributed a checklist to TEPCO and contractors to help them evaluate current practices. In December 2011, an outbreak of norovirus affected 52 employees of a primary contractor. 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 reported¹⁾.

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 workers¹⁾.

(7) Fitness for work

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 hospital¹³⁾. 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 work¹⁾.

Mori *et al.*¹⁾ reported efforts to implement an evaluation program for fitness for work in a stepwise manner. TEPCO was concerned that the program might affect manpower. Newly registered workers at the NPP were required to complete a checklist regarding their health condition, and doctors confirmed the details for workers with poorly controlled illnesses in October 2011. However, this protocol was insufficiently effective in detecting sick workers. The procedure was improved in April 2012, and primary contractors were requested to confirm whether each new worker was judged “fit for duty” by a doctor according to preemployment or recent periodic health checkups. Though not a direct indicator, the effectiveness was reflected in the number of reported deaths due to illness and that of ill workers transported to hospital by air ambulance. Six deaths due to illness and six cases of transportation of workers by air ambulance were reported up to the end of 2013.

2. Workers engaged in decontamination and disposal of contaminated soil and waste

The Japanese government decided to conduct decontamination work to rehabilitate contaminated areas. Existing government regulations did not consider situations where radiation sources were dispersed and workers dealt with radioactive materials outdoors (“existing exposure situations”). Therefore, the MHLW decided to establish new regulations—the Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Wastes Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake and Related Works—which provided occupational radiological protection in existing exposure situations⁶⁾.

Yasui⁶⁾ reported the process and related discussions concerning establishment of these regulations. The regulations set appropriate protection standards to ensure that the protection level was equivalent to or greater than that in planned exposure situations and was also practical for the 30,000 workers engaged in decontamination. To maintain practicability, the MHLW employed a valid, simplified measurement methodology for internal exposure, ambient dose rate, and radioactivity concentration. The ordinance went into force on January 1, 2012.

Wada *et al.*²⁹⁾ identified the major hazards other than radiation to which decontamination workers would be exposed: heat stress in summer, coldness in winter, insect bites, musculoskeletal disorder, and fatigue. For villages near the Fukushima Daiichi NPP, Tsubokura *et al.*³⁰⁾ reported the results of internal exposure monitoring among decontamination workers who had not been living in Fukushima Prefecture at the time of the incident. Their cesium exposure levels were below detection limits, but seven stated that they did not always wear masks during decontamination work.

Tsuji *et al.*³¹⁾ reported that more than half of the respondents in a mail survey had experienced heat illness symptoms during decontamination work. Following inspections, the MHLW reported that significant numbers of employers were in violation of applicable laws, such as the Labour Standards Act and Industrial Safety and Health Act^{32–34)}.

The decontamination work produced huge amounts of contaminated soil and waste. In summer 2013, the Ministry of the Environment planned a full-scale waste-disposal process. The MHLW created new regulations for the protection of waste-disposal workers by amending the Ordinance on Prevention of Ionizing Radiation Hazards. Yasui⁷⁾ reported the process and discussions that went into promulgating this ordinance. The ordinance consisted of structure-based standards, exposure limits, and selection of appropriate personal protective equipment for the risk of internal exposure.

No reports have been published on the current situation regarding exposure or health effects on workers presently engaged in decontamination work.

3. Other workers

Naoi *et al.*²⁾ reported the results of external and internal exposure among Self-Defense Forces personnel who participated in work related to the accident. The external exposure of all personnel of the Self-Defense Forces was monitored by means of pocket radiation dosimeters, and individuals with significant external exposure were selected for internal exposure monitoring. The maximum external radiation dose was 81.220 mSv, the minimum external radiation dose was 0.017 mSv, and the average external radiation dose was 7.784 mSv. The maximum total dose of cesium-134 and cesium-137 was 3.8 mSv, the minimum total doses of cesium-135 and cesium-137 was zero (below detection level), and the average total doses of cesium-134 and cesium-137 was 0.087 mSv.

Yokogawa *et al.*⁵⁾ investigated administrative measures for radiation protection of employees in municipal offices of Fukushima Prefecture who had assisted with evacuation and temporary return of

residents; the results were compared with those of employees in public institutions under central government control. The rates of the offices that implemented appropriate measures for radiation protection were much lower than those of public institutions under central government control.

Matsuda *et al.*³⁵⁾ reported the radiation exposure of five members of the Radiation Emergency Medical Assistance Team. On March 14, just after a hydrogen explosion occurred at Reactor No. 1, these personnel were dispatched to the Disaster Countermeasures Office in Fukushima City, which is located approximately 60 km west of the NPP. The total external doses over the following 4 or 5 days in that city were within the range of 31.0–52.0 μSv , and the committed effective dose for the highest case was 96.8 μSv .

Matsuoka *et al.*³⁶⁾ studied the causes of distress in rescue workers with possible exposure to radiation using the Kessler 6 scale (K6), the Center for Epidemiologic Studies Depression Scale (CES-D), Peritraumatic Distress Inventory (PDI), and Impact of Event Scale-Revised (IES-R). Of 424 participants, 9% had significant concern over radiation exposure. After controlling for age, occupation, disaster operation experience, time spent watching earthquake news, and previous history of psychiatric illness, that concern was significantly associated with a higher score for the K6, CES-D, PDI, and IES-R in men and with the CES-D and IES-R in women.

In April 2012, the Japanese government established the Nuclear Emergency Response Headquarters (NERH), which divided the restricted area, where only particular individuals were allowed to enter, into three subareas based on the ambient dose rate. These subareas were defined as follows: areas where evacuation orders are ready to be lifted (Area 1); areas where residents currently are not permitted to live (Area 2); and areas where it is expected that residents will not be able to live for a long time in the future (Area 3). In accordance with this arrangement, the NERH decided to allow business activities to resume in Area 1. However, because Area 1 constituted an area where the ambient dose rate was 3.8 $\mu\text{Sv/h}$ or less, it was expected that the people working there would be exposed to a certain dose of radiation⁸⁾.

The MHLW decided to amend the Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Wastes Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake and Related Works to cover the workers engaged in any operations in Area 1. Yasui⁸⁾ reported the discussions at the expert meeting related to the amendment.

Based on the recommendations of the expert meeting, the MHLW designated work that involved

contaminated soil or waste whose radioactivity concentrations were greater than 10 kBq/kg as “work for handling designated contaminated soils and waste (designated contamination work)”, and it identified work that did not involve handling contaminated material but was implemented in an area where the ambient dose rate was more than 2.5 $\mu\text{Sv/h}$ as “work under the designated dose rate (designated dose work)⁸⁾”. Using monitoring methods that were as simplified as practicable, the MHLW regulated the exposure dose control, exposure reduction, worker education, and health care according to the radioactivity concentrations of handled materials and dose in particular areas. However, the actual conditions and exposure of workers engaged in operations related to decontaminated soil and waste have not been reported.

Discussion

The nuclear accident at Fukushima Daiichi NPP following the mega-earthquake gave rise to an emergency. Though they lacked proper experience, many workers were engaged in difficult tasks. The system for safeguarding their health gradually developed through an ongoing trial-and-error process. The present review was conducted to summarize the lessons learned from what happened and from the ongoing decommissioning work. Its aim was also to clarify areas and subjects for future study.

Lessons learned from the experience

The operators were responsible for emergency medical care at the NPP as part of Japan's National Response Plan—*Bosai Kihon Keikaku*³⁷⁾. However, it was difficult for TEPCO to maintain an emergency-care system. The government thus supported emergency care, and it has continued to do so. Yasui¹⁰⁾ noted that in the event of a large-scale nuclear accident, the government needs to provide assistance by dispatching medical staff to affected plants.

The contractors assigned by TEPCO were basically responsible for their workers' safety and health. Under a complex chain of command, 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. Various countermeasures were implemented under the administrative guidance of the government and included suspension of work in the afternoon in the early stage of emergency work¹⁰⁾. If major disasters occur, on-site OH involvement by the government is essential for protecting the health of workers engaged in response and recovery actions.

According to OH 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 OH experts, who were not included in the response plan, to gain a position and influence preventive health measures at the sites¹⁴. When disasters occur, many workers and volunteers belonging to various organizations are 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 OH experts is essential to protect workers' health and lives. It is necessary to review current emergency response plans at the national, local, and company levels and to secure their involvement in an emergency response organization.

Except for cases of beta-ray burns, no evident adverse effects of radiation exposures have thus far been reported. However, various problems concerning the control and management of radiation exposure have been identified¹⁵. Inappropriate fitting of respirators was a major cause of internal exposure exceeding the dose limit¹⁷. It should be noted that the preparedness and training for dealing with emergency situations were insufficient. There has been discussion concerning the use of autologous peripheral-blood stem cells after the accident^{18,19}. This situation is not clear, and it is difficult to draw a firm conclusion for this complex issue after an accident has occurred. Future preparations for disasters, such as training and stocking equipment, should be designed to protect workers' health based on detailed scenarios.

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 issues¹. 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 to make the appropriate decisions.

If a major disaster occurs, the workers engaged in recovery operations may become victims. They may also become targets of criticism and discrimination if they are working for a company that is responsible for the accident. TEPCO employees worked under such conditions²⁶, and psychological care was provided for them. The government opened toll-free telephone services for mental health²³. 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.

Many workers engaged in operations at the NPP belonged to companies with insufficient OH resources. In the decontamination work, there was a high rate of heat illness symptoms³¹ and reported violation of applicable labor laws^{32–34}. The radiation protection of municipal employees who helped in evacuation and temporary return of residents was much poorer than that of employees in public institutions under central government control⁵. 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. Crane *et al.*³⁸ cited a paper reporting 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 and called them a "vulnerable subgroup". In Japan's National Response Plan³⁷—the protection of workers is barely mentioned compared with the protection of ordinary citizens. 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 National Response Plan.

Necessary studies and reports

The Japanese government has launched an epidemiological study about the health effects of radiation exposure at the Fukushima Daiichi NPP based on the recommendation of a report by an expert committee⁹. It is expected that the results will provide evidence concerning the relationship between dose of radiation exposure and health outcomes. McLaughlin *et al.*³⁹ compared the data from the Fukushima Daiichi NPP with those from the Chernobyl recovery operation. The authors found that it was difficult to predict the exact health consequences of NPP workers exposed to significant internal radiation; psychological consequences were thought likely, and future screening should focus on thyroid cancer, hematological malignancy, and cataracts. The currently available evidence on the health consequences is mainly from data concerning the victims of the atomic bombings of Hiroshima and Nagasaki. However, there is a lack of data on internal exposure. In study of the work-

ers at the Fukushima Daiichi NPP, the precious data concerning radiation exposures are crucial.

The Japanese government has established a new ordinance for workers engaged in decontaminating radioactive soil and waste^{6,7)}. However, this regulation is for unexpected situations, and it makes some theoretical suppositions. The present review found that few reports have examined workers' exposures to health hazards and adverse health effects. To evaluate the appropriateness and practicability of regulations, it is necessary to investigate such operations and health issues in greater detail.

Limitations

Most of the studies about the health of workers engaged in operations related to the NPP accident were case reports, and few papers analyzed the data scientifically. We also included reports published by the government on its Web sites in this review. Therefore, the credibility and appropriateness of the information presented in this paper needs to be examined carefully in this regard. However, all the authors of this paper have provided support for the NPP workers as OH specialists since May 2011. One of the authors (Mori, K) participated in the expert meetings with the theme of "Radiological Protection of Decontamination Works-Results from the Fukushima Daiichi NPP Accident" and other related themes held by the MHLW as the chairman. Based on our experience, we are thus in a position that allows us to evaluate the appropriateness of the information presented in papers and reports.

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