Overview

Emergency Responses and Health Consequences after the Fukushima Accident; Evacuation and Relocation

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Abstract

The Fukushima accident was a compounding disaster following the strong earthquake and huge tsunami. The direct health effects of radiation were relatively well controlled considering the severity of the accident, not only among emergency workers but also residents. Other serious health issues include deaths during evacuation, collapse of the radiation emergency medical system, increased mortality among displaced elderly people and public healthcare issues in Fukushima residents. The Fukushima mental health and lifestyle survey disclosed that the Fukushima accident caused severe psychological distress in the residents from evacuation zones. In addition to psychiatric and mental health problems, there are lifestyle-related problems such as an increase proportion of those overweight, an increased prevalence of hypertension, diabetes mellitus and dyslipidaemia and changes in health-related behaviours among evacuees; all of which may lead to an increased cardiovascular disease risk in the future. The effects of a major nuclear accident on societies are diverse and enduring. The countermeasures should include disaster management, long-term general public health services, mental and psychological care, behavioural and societal support, in addition to efforts to mitigate the health effects attributable to radiation.

Key words: Evacuation; health effects; medical response; mental effects; nuclear accident; relocation

Statement of Search Strategies Used and Sources of Information

This paper reflects expert opinion and current literature accessed by the authors; no formal search strategy has been defined.

Introduction

The Three Mile Island nuclear power plant (NPP) accident in 1979, the Chernobyl accident in 1986 and the Fukushima accident in 2011 have issues in common that were not directly related to the physical effects of radiation exposure. Of course, in the Chernobyl accident, acute radiation injuries in acute phase and thyroid cancer in the paediatric population were reported [1]. However, the other health effects, such as mental health issues, behavioural changes and lifestyle-related health problems, have become more significant as those have not been properly addressed as general health risks after major nuclear accidents [2]. An extreme example was the loss of life in the evacuation of hospital inpatients in the Fukushima accident [3]. Evacuation of the inpatients and elderly residents of nursing care facilities was hurriedly carried out by buses shortly after the accident. No medical personnel accompanied the evacuees who were laid down on the seats of the jam-packed buses with full protective suits on. No medical care, even food or water, was provided for many hours during the evacuation. As a result, scores of patients died in an evacuation that was...
supposedly intended to minimise radiation exposure. The life-threatening risk to these people was not radiation, but discontinuation of daily medical care. A recent study indicated that the severe health risk associated with the rapid evacuation of elderly residents from nursing care facilities after the Fukushima accident was 30 times higher than the radiation risk of the reference levels for evacuation that are recommended by the International Committee for Radiological Protection.

Presently, more than 400 NPPs are operated in the world, and more will be built in developing countries in search of efficient and stable energy sources. Of course, we should never underestimate the menace of nature that can lead to a compound disaster, such as in Fukushima. We need to prepare for the worst case scenario even if the chance of a severe nuclear accident is quite rare. We need to clarify what we have learned from the Fukushima accident and how we will utilise it, what are the unanswered questions we are faced with and what we need to share with the next generation.

This overview describes the initial medical responses after the Fukushima accident and the health consequences encountered in the evacuation and relocation of residents, with a special emphasis on not only medical but also psychological and societal perspectives related to the Fukushima accident.

Fukushima Daiichi Nuclear Power Plant Accident

Before the Fukushima accident, there were 54 NPPs in operation, producing one third of the electricity in Japan. On 11 March 2011, a 9-magnitude earthquake occurred off the east coast of Japan, generating massive tsunamis, which severely damaged coastal areas. The earthquake and tsunami also hit the NPPs located in the coastal area in Tohoku and led to the loss of the entire core cooling capacity of the three reactors of Fukushima Daiichi NPP and severe damage to the nuclear cores. Consequently, substantial amounts of radioactive substances were released into the environment.

Emergency Responses after the Nuclear Power Plant Accident

In Fukushima, the radiation emergency medical system had been developed within the framework of the national radiation emergency medical system. Six hospitals were designated as primary radiation emergency medical facilities, which assumed roles in providing initial treatment and decontamination; one was designated as a secondary radiation emergency hospital to provide advanced treatment of radiation injuries.

At the time of the accident, up to 76 000 people lived within an area of a 20 km radius from the Fukushima Daiichi NPP. After the accident occurred, more than 97% of residents living in the 20 km radius had evacuated by 15 March, when the highest amount of radioactive plume was released from the plant. However, the evacuation of residents did not go well. As the situation of the nuclear reactors became more unsure the government progressively expanded evacuation zones from within a radius of 3, 10 and 20 km of the NPP. More than 20% of evacuees were obliged to relocate more than six times as the evacuation zone expanded, due to the lack of evacuation plan, which extended greater than a 10 km radius from the NPP. In addition, information about radiation levels and the evacuation process itself were not available, i.e. how to prepare, how long it may last; nor were instructions on how to protect oneself from radiation exposure or how to vacate their homes provided. Insufficient transportation and disruptions in electricity, water, gas supply, telecommunications and radiation-monitoring systems caused by the earthquake made it more difficult to implement an organised evacuation.

On 12 March, the first hydrogen explosion took place at the Unit 1 reactor building and five workers sustained injuries. Although most of the injuries were not severe, no field triage or initial treatment was carried out. On 14 March, the Unit 3 reactor building exploded and 11 workers sustained injuries. In this explosion, an emergency doctor, who coincidentally stayed at the off-site centre located 5 km from the NPP, triaged the injured individuals. However, it was quite difficult for the injured workers to access medical services because local emergency medical hospitals had either closed or were not functional.

Japan’s radiation emergency medical system was developed to address work-related accidents, not for such large-scale natural disasters as with Fukushima. Accordingly, after the accident, six hospitals designated as primary radiation emergency hospitals closed or failed to function properly owing to evacuation or indoor sheltering orders, damaged facilities and infrastructure disruption caused by the earthquake and the outflow of medical staff in fear of radiation danger. Fukushima Medical University, which was designated as a secondary radiation emergency hospital, was the only hospital to respond to emergency medical needs. To support Fukushima Medical University’s efforts, a nationwide network of radiation emergency medical services was established by the end of March 2011.

Evacuation of Hospitals and Nursing Care Facilities

The Fukushima accident underscored critical issues regarding the evacuation of hospitals and nursing care facilities. After the government issued evacuation orders, the emergency evacuation of about 2200 inpatients and elderly people at nursing care facilities was arranged. On 14 March, more than 800 patients, who were hospitalised and remained behind at medical or nursing facilities located within a 20 km radius from the plant, were urgently evacuated. Information on the patients, i.e. patients’ names, conditions, even the exact number of patients, was not available. They were transported by buses or police vehicles for a relatively long time, in some cases for more than 48 h. However, no medical personnel were in attendance and no...
medical care, not even water or food, was provided during or after the evacuation. Unfortunately, at least 50 elderly patients died in this evacuation. Hypothermia, deterioration of underlying medical problems and dehydration were suspected as the causes of death [3]. The lack of medical support before, during and after the evacuation was regarded as the major reason for the loss of life during the evacuation.

Another evacuation of hospital patients was planned after the evacuation of the 20 km radius from the plant. On 15 March, the national government issued an order for indoor sheltering in the 20–30 km radius [6]. After this sheltering order, the flow of daily necessities to the region stopped owing to concerns over radiation exposure expressed by delivery personnel. The 20–30 km region became virtually isolated. Hospitals and nursing facilities suffered seriously because medical supplies, gasoline and other daily commodities could not be obtained. Soon, a decision to evacuate hospitals and nursing care facilities in this area was made. However, this time, medical support teams, such as the disaster medical assistance team, transport vehicles, adjustment of transport routes and arrangement of admitting hospitals and facilities were organised in advance under the control of headquarters. Although the evacuation of patients took 4 days, from 18 to 22 March, no lives were lost during the evacuation of 509 inpatients and elderly people from nursing care facilities [14,15]. This emphasises the importance of medical support in evacuating hospitals and nursing care facilities.

**Medical Needs for the Emergency Workers**

In response to the accident, the re-establishment of temporary cooling facilities for the three damaged reactors and the spent fuel pool of the Unit 4 reactor building was the first priority, followed by development of stable cooling systems to achieve a stable cold shutdown of the reactors, removal of radioactive debris and rubble, establishment of breakwaters and installation of a covering container over the Unit 1 reactor building [6]. These operations continued until the end of 2011. From 11 March 2011 to 31 March 2012, 20 961 workers were involved in the restoration operations at the Fukushima Daiichi NPP [16,17].

In the first month after the accident occurred (March 2011), 67 workers sought emergency medical care, including those injured in two hydrogen explosions. Of note, most of them complained of medical problems, such as general fatigue and sickness, which were not attributable to radiation exposure. By 30 June 2012, 264 workers had been treated at the site [16]. Three deaths occurred in April, August 2011 and January 2012. Two deaths were due to cardiac arrest associated with acute myocardial infarction. Another individual with uncontrolled diabetes died of severe sepsis.

Among the emergency care required, trauma accounted for 49.6% (131 cases). Most of them occurred in the first 5 months after the accident occurred (from 12 March to July 2011). With respect to the severity of trauma, only one patient exceeded an injury severity score of 15. Fortunately, no deaths from trauma occurred during this period. Radiological contamination was observed in six cases, all of which occurred in March 2011 [16].

Heat stroke was one of the major concerns as the summer season approached. The workers needed to wear personal protective equipment with a full face mask. An increase in the incidence of heat illness was observed in May, June and July 2011. Among 44 workers who presented with heat illness, only two cases required hospital admission. Repeated advice was provided by the Tokyo Electric Power Company to all workers in the Fukushima Daiichi NPP, such as wearing cooling jackets under protective suits, taking rest and sufficient fluids regularly, considering the wet-bulb globe temperature and avoiding any activities between 2 and 4 pm [16].

Regarding radiation exposure, 96% of the workers at Fukushima Daiichi NPP were exposed to less than 50 mSv. All of those whose radiation doses were greater than 100 mSv were exposed very shortly after the accident. A total radiation dose of greater than 200 mSv was observed in nine workers. Of these, two workers were exposed to greater than 600 mSv, with 679 mSv being the highest (external exposure, 89 mSv; internal exposure, 590 mSv). The workers who had doses greater than 100 mSv were regular employees hired by the Tokyo Electric Power Company. Most of those with less than 20 mSv radiation dose were hired by other companies. Fortunately, no acute radiation syndrome had been observed among the affected people in the Fukushima accident to date [18].

To coordinate efforts for emergency medical care and to provide an adequate working environment for NPP personnel, the Emergency Medical System Network was established: its purpose is to examine occupational environments, institute preventive medicine, particularly in summer to prevent heat stroke, in winter to control infections, and to conduct follow-ups of workers with chronic illnesses and mental health problems [16].

**Major Public Health Consequences due to Dislocation**

The establishment of a restricted zone in a radiation disaster forces large numbers of residents out of the area, where they stay in temporary shelters or other places for long periods of time [19,20]. Life conditions in shelters may lead to various types of health issues, such as outbreaks of communicable diseases, mental stress and cardiovascular diseases [21–23]. Sudden changes in lifestyle in unfamiliar places may result in behavioural problems due to poor adaptation to new circumstances. Medical attention will be required from various healthcare disciplines.

In Fukushima Prefecture alone, the number of displaced residents was 86 308 in March 2011, and it reached the peak at 99 205 in June 2011 [24]. In addition, the number of residents who voluntarily moved out of Fukushima Prefecture increased from 38 896 in March 2011 to 62 831 in 12 months [25]. The Fukushima accident highlighted the importance of non-radiation-related health issues, such as severe health risks during evacuation, as described above, and long-term displacement of vulnerable people, and the magnitude of problems related to mental, psychological and social factors.
Disaster-related Death

After the Great East Japan Earthquake, more than 460,000 people were displaced to about 2400 shelters throughout Japan. According to the report on disaster-related death (DRD) in the Great East Japan Earthquake issued by the Reconstruction Agency of Japan (2012), 2688 people died at shelters or temporary houses by 31 March 2013; these were DRDs [26]. DRD is defined as a death caused by the deterioration of underlying medical problems due to poor medical access or illnesses arising from poor living environments, such as temporary shelters, in a disaster. About 90% of DRDs were over 66 years old, and more than one third died within 1 month after the earthquake. The number of deaths among three Tohoku prefectures was the highest in Fukushima (1914 deaths) [27]. The government report indicated that the effects of the nuclear accident might be the major reason for a higher mortality of displaced elderly in Fukushima. Another study reported that the effect of the disaster on the excess mortality of institutionalised elderly in Fukushima was most significant in the immediate aftermath because of undesirable living conditions and poor access to medical care. After the accident, the mortality rate among evacuated elderly people requiring nursing care tripled in the first 3 months after the evacuation and continued to be higher at about 1.5 times afterward compared with before the accident [28–30] (Figure 1). Relocation of these elderly people was unavoidable because of the shortage of medical resources in the region, which had a lasting effect on mortality due to continuing changes in nutritional, hygiene, medical and general care conditions.

Many healthcare professionals headed for the disaster-stricken areas. Less than 2 months after the quake, about 24,000 medical personnel were involved in medical activities in Tohoku regions (Health and Labor Ministry 2011). However, these medical resources may not have been utilised effectively in Fukushima because of concerns over radiation; information on radiation and the situation of vulnerable people was not properly shared nor was sufficient communication among related personnel established during the disaster response [13,31].

Mental Health Problems and Poor Health Perceptions

Fukushima residents showed deep concerns about the potential health effects of exposure to radiation, even though their dose was estimated to be very low [32–35]. The Fukushima Health Management Survey, which was commissioned by the Fukushima government, revealed the various effects on mental health as well as physical health among evacuated residents [36]. The results suggested that severe mental health problems and poor health perceptions existed among adult Fukushima evacuees, and also indicated that severe traumatic factors may have affected the mental health of adult evacuees. Not surprisingly, emergency workers were more susceptible to psychological trauma than the general affected population [37–39].

In addition to the psychiatric problems, complicated psychosocial issues arose in or out of Fukushima. Discordance exists among families and society due to displacement, fear of radioactive exposure, compensation, employment and other personal reasons [40]. Stigma was another issue among the evacuees as well as the public. The variety of psychosocial reactions among those affected by the accident can be summarised within five main issues [41]: post-traumatic stress response, chronic anxiety and guilt, ambiguous loss, separated families and communities, and stigma (Table 1). With the exception of post-traumatic stress responses, four of the five main issues are unique in Fukushima and have never been seen in other Tohoku areas affected by the tsunami. Furthermore, these psychosocial reactions may contribute to more serious consequences, such as suicide or alcohol abuse. In fact, after the Fukushima accident, the standardised suicide mortality ratio decreased initially (107 in 2011, 94 in 2012, 96 in 2013) but then rose to 126 in 2014, thus exceeding the pre-disaster level [42]. To prevent suicide or other self-destructive behaviours, countermeasures such as facilities and care networks providing targeted psychiatric interventions are needed, in order to enhance existing resources.

![Fig 1. Changes in mortality rates before and after the disaster [28].](image-url)
Lifestyle-related Problems

Because many evacuees in the Fukushima Prefecture were forced to change several aspects of their lifestyles, including diet, physical exercise and smoking and alcohol habits, risk factor for cardiovascular disease, such as obesity, hypertension, diabetes mellitus and dyslipidaemia, would be expected to increase. As part of the Fukushima Health Management Survey, a longitudinal study examined data collected from 41,633 Japanese men and women (mean age 67 years) sourced from general health check-ups conducted in 13 communities near the Fukushima Daiichi NPP between 2008 and 2010. Follow-up examinations were conducted from June 2011 to March 2013 and 27,486 men and women received follow-up examinations after the disaster (follow-up proportion 66%), with an average follow-up of 1.6 years. The proportion of overweight people (body mass index ≥ 25 kg/m²) significantly increased in both evacuees (n = 9,671) and non-evacuees (n = 17,815) after the disaster, with greater changes in the proportion among evacuees than non-evacuees. The proportions of overweight evacuees before and after the disaster were 31.8% and 39.4%, respectively, whereas proportions among non-evacuees were 28.3% and 30.3%, respectively [43]. A significantly increased prevalence was observed in hypertension (from 53.9% to 60.1%), diabetes mellitus (10.2% to 12.2%), dyslipidaemia (44.3% to 53.4%), polycythaemia (0.9% to 1.5%) and atrial fibrillation (1.5% to 2.4%) among evacuees when compared before and after the evacuation [44–48]; these were associated with increases in body weight. Furthermore, the evacuees had a 1.3–1.6-times higher risk of dyslipidaemia, diabetes mellitus, and being overweight compared with the non-evacuees in a prospective analysis [43,45,46].

The National Health and Nutrition Survey reported that the proportion of overweight people was unchanged from 2003 to 2012 among men aged 20–69 years and decreased among women aged 40–69 years; the proportions of overweight people in 2003 and 2012 were 29.5% and 29.6% for men and 25.0% to 20.5% for women, respectively. Therefore, the change in body weight in evacuees in Fukushima after the disaster must be greater compared with those in other areas of Japan. Results of a mental health and lifestyle survey by the Fukushima Health Management Survey showed that those who evacuated in response to governmental direction tended to be less physically active, consume more alcohol, experience greater psychological stress and have difficulty sleeping after the disaster [36]. Thus, health-related behaviours could be an important factor mediating the influence of evacuation on increased cardiovascular disease and cancer risk factors. To prevent future lifestyle-related diseases occurring secondarily to long-term evacuation, urgent action is required from researchers, together with local governments and communities, to determine the adverse physical effects of evacuation and to establish appropriate intervention programmes for targeting weight gain among evacuees.

### Summary and Conclusion

In the Three Mile Island accident, an excessive load on the telephone network, the lack and chaos of information, as well as a poor evacuation plan of hospitals were identified. In the Chernobyl accident, mental, social and economic effects were serious over a long period of time, with reports on radiation effects including deaths from acute radiation syndrome and the development of thyroid cancer in children caused by exposure to radioactive iodine. In the Fukushima accident, the health effects so far encountered are associated with emergency evacuation of vulnerable people from hospitals and nursing care facilities. Problems common in both the Fukushima and the Three Mile Island accidents included repeated expansions of evacuation areas to the extent not assumed in advance, lack of evacuation planning in advance by hospitals and nursing care facilities, to determine the adverse physical effects of evacuation and to establish appropriate intervention programmes for targeting weight gain among evacuees.

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**Table 1**

Features of psychological impact on the Fukushima people after the accident [41]

<table>
<thead>
<tr>
<th>Psychological impact</th>
<th>Features</th>
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<tbody>
<tr>
<td>Post-traumatic stress responses</td>
<td>Traumatic memories of plant explosion and evacuation</td>
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<tr>
<td>Chronic anxiety and guilt</td>
<td>Hyper-arousal</td>
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<td></td>
<td>Re-experiencing symptoms</td>
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<tr>
<td>Ambiguous loss experience</td>
<td>Fear of radioactive exposure, especially in the case of parents with young children</td>
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<tr>
<td></td>
<td>Negative influence on children’s development</td>
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<tr>
<td>Separated families/communities</td>
<td>Loss of home through evacuation rather than damage</td>
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<td></td>
<td>Uncertainty of nuclear accident evacuees about returning home</td>
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<tr>
<td>Self-stigma</td>
<td>Depressive symptoms</td>
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<td></td>
<td>Increased conflicts within and between families</td>
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<td></td>
<td>Frustration of neighbouring cities that take in evacuees</td>
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<td></td>
<td>Discrimination against workers and young women</td>
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<td>Concealment of history in Fukushima</td>
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<td></td>
<td>Righteous anger</td>
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<td>Loss of self-esteem</td>
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A. Hasegawa et al. / Clinical Oncology 28 (2016) 237–244
The health consequences of the Fukushima nuclear power plant accident

<table>
<thead>
<tr>
<th>Health effects of radiation</th>
<th>Health effects not attributable to radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>* No deterministic effect cases, including acute radiation syndrome, to date [17]</td>
<td>* Deaths in rapid evacuation among inpatients and elderly people at nursing care facilities [3]</td>
</tr>
<tr>
<td>* Stochastic effect would not be expected over the baseline level [33,34]</td>
<td>* Increased mortality of displaced elderly people requiring nursing care [28]</td>
</tr>
<tr>
<td>* Although two to three excess cancers could be inferred over the lifetime among workers with doses greater than 100mSv, it is unlikely that such an increased incidence of cancer due to radiation would be discernible [35]</td>
<td>* Adverse health effects such as mental health and lifestyle-related issues [40–48]</td>
</tr>
<tr>
<td>* No discernible radiation-related increases in rates of leukaemia or breast cancer, nor in other types of solid cancer apart from possibly thyroid cancer among public [35]</td>
<td></td>
</tr>
</tbody>
</table>

If a major NPP accident occurs, uncertainty about the plant’s condition may result in a vacillating response by administrative authorities, which heightens public anxiety and distrust in those authorities. Insufficient information about radiation may exacerbate the situation. Evacuation — intended to minimise the health risks of radiation exposure — may produce other serious health risks, particularly for vulnerable populations. Establishing an evacuation zone around the NPP results in the collapse of the local emergency medical system; this leads to difficulties in responding to mass casualty events, such as explosions at the plant, and common medical emergencies. In the long term, displacing hundreds of thousands of citizens creates a wide range of public healthcare and social issues, as detailed above.

The effects of a major nuclear accident on societies are diverse and enduring. The countermeasures should include disaster management, long-term general public health services, mental and psychological care, behavioural and societal support, and efforts to mitigate the health effects attributable to radiation [49].

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

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