From Hiroshima and Nagasaki to Fukushima 3

Nuclear disasters and health: lessons learned, challenges, and proposals

Akira Ohtsuru, Koichi Tanigawa, Atsushi Kumagai, Ohtsura Niwa, Noboru Takamura, Sanae Midorikawa, Kenneth Nollet, Shunichi Yamashita, Hitoshi Ohto, Rethy K Chhem, Mike Clarke

Past nuclear disasters, such as the atomic bombings in 1945 and major accidents at nuclear power plants, have highlighted similarities in potential public health effects of radiation in both circumstances, including health issues unrelated to radiation exposure. Although the rarity of nuclear disasters limits opportunities to undertake rigorous research of evidence-based interventions and strategies, identification of lessons learned and development of an effective plan to protect the public, minimise negative effects, and protect emergency workers from exposure to high-dose radiation is important. Additionally, research is needed to help decision makers to avoid premature deaths among patients already in hospitals and other vulnerable groups during evacuation. Since nuclear disasters can affect hundreds of thousands of people, a substantial number of people are at risk of physical and mental harm in each disaster. During the recovery period after a nuclear disaster, physicians might need to screen for psychological burdens and provide general physical and mental health care for many affected residents who might experience long-term displacement. Reliable communication of personalised risks has emerged as a challenge for health-care professionals beyond the need to explain radiation protection. To overcome difficulties of risk communication and provide decision aids to protect workers, vulnerable people, and residents after a nuclear disaster, physicians should receive training in nuclear disaster response. This training should include evidence-based interventions, support decisions to balance potential harms and benefits, and take account of scientific uncertainty in provision of community health care. An open and joint learning process is essential to prepare for, and minimise the effects of, future nuclear disasters.

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This is the third in a **Series** of three papers about Hiroshima and Nagasaki to Fukushima

Department of Radiation Health Management (Prof A Ohtsuru MD, S Midorikawa MD), **Fukushima Global Medical Science Center** (Prof K Tanigawa MD, Prof O Niwa PhD, Prof K Nollet MD), **Education Center of Disaster Medicine** (A Kumagai MD) **and Radiation Medical Science Center** (Prof H Ohto MD), **Fukushima Medical University, Fukushima, Japan; Department of Radiation Medical Sciences,**

Introduction

The effects of nuclear disasters on individuals and society can be diverse and long lasting. The atomic bombings of Hiroshima and Nagasaki in 1945, and the Chernobyl nuclear power plant (NPP) accident in 1986, showed that radiation can pose substantial health risks for many people.[1,2] Additionally, many other serious issues not directly related to the health effects of radiation can arise.[3] Among these negative effects are mental illness, poor perceptions of health, stigma, lifestyle-related health problems, and discord within families and society.[3]

The rarity of nuclear disasters limits opportunities to undertake rigorous research, such as randomised trials, to provide an evidence base for effective interventions and strategies; however, priorities have been identified.[4] Nuclear disasters might occur in the context of a wider disaster that has placed strain on emergency responders, health-care practitioners, and public health decision makers, further limiting the likelihood of empirical research. Despite these challenges to development of a robust evidence base, questions need to be answered about how to protect people who are, or who might be, exposed to radiation, and how to minimise other potential harms to their physical and mental health after a nuclear disaster. Emergency workers responding to a nuclear disaster are the highest risk group for radiation injuries, and an effective plan is needed to mitigate their radiation exposure. Additionally, strategies are needed to minimise effects of evacuation on people for whom this

Key messages

- Individual exposure doses of emergency personnel should be reduced by mobilisation of skilled personnel from a sufficiently large pool of personnel with the requisite specialised technical expertise
- Medical facilities for provision of emergency physical and mental health care for injured or sick people who might have been exposed to radiation should be located outside the planned evacuation area
- Residents in areas surrounding a nuclear power plant should be given information about the spread of the radioactive plume and should be protected by use of effective countermeasures, including indoor sheltering, proper clothing, and food or water restrictions; if ordered, evacuation should be implemented in a controlled manner
- Adequate medical support is needed during evacuation of hospitals and nursing care facilities; if such support is not available, sheltering in place might be preferred to avoid the health risks of evacuation
- Various medical needs arise and should be anticipated because the effects of a nuclear disaster can be diverse and long lasting, and can include mental health and family or social issues; community physicians need to respond appropriately and have the necessary skills and knowledge
- Health-care professionals are expected to enable residents' understanding of the health risks of radiation and other health risks associated with evacuation to help residents to make well informed decisions about adaptation of their lifestyles; as community leaders, physicians have a particularly important role in promotion of public health
- Opportunities to assess interventions, actions, and strategies during a nuclear disaster and the subsequent recovery stage should be taken, and relevant research studies and medical education should be planned in advance to fill the evidence gap, inform the response during an ongoing crisis, and prepare for a future disaster

(Prof S Yamashita MD) **and Department of Global Health, Medicine and Welfare, Atomic Bomb Disease Institute** (Prof N Takamura MD), **Nagasaki University, Nagasaki, Japan; Cambodia Development Resource Institute, Phnom Penh, Cambodia** (Prof R K Chhem MD); **and Centre for Public Health, Queens University Belfast, Royal Hospitals, Belfast, UK** (Prof M Clarke DPhil)

Correspondence to: Prof Akira Ohtsuru, Department of Radiation Health Management, Fukushima Medical University, Fukushima 960-1295, Japan **ohtsuru@fmc.ac.jp**

Search strategy and selection criteria

Grey literature sources included reports of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2008 and 2013, the official report of the Fukushima Nuclear Accident Independent Investigation Commission (FNAIIC), and publications of the International Commission on Radiological Protection (ICRP). We used the UNSCEAR report on the Chernobyl accident and the websites of the Nuclear Regulation Authority, Japan, Japanese Ministry of Health, Labour and Welfare, Radiation Emergency Medicine Network, and Fukushima Health Management Survey. We searched for papers published from 1990 to 2014 in PubMed and Medline with the keywords “disaster” and “hospital evacuation”, “nuclear accident”, “disaster public health”, and “nuclear power plant, population density”. We searched for articles published in English or Japanese. Relevant articles were used to prepare the sections of this report entitled Introduction, Protection of emergency and recovery workers from radiation and medical issues, Protection of citizens from radiation exposure, Decision making for a large-scale evacuation, and Evacuation of hospitals and nursing facilities. We searched PubMed, Medline, Scopus, and Google Scholar with the terms “disaster risk communication”, “nuclear”, “disaster”, “community resilience”, “community health care”, and “nuclear accident” with “trust” and “nuclear accident” for material for the sections entitled Psychological responses during nuclear disasters, Risk communication, and Challenges and proposal.

might pose serious health risks, such as hospital inpatients and the elderly. These effects relate to short-term health and long-term wellbeing, which might be adversely affected by displacement.[3] Medical management of these people is of paramount importance. In the long term, effective mental and public health care might be needed for hundreds of thousands of people.

A reliable and robust evidence base is needed, as is the case for disasters generally,[5] and priorities need to be tackled in future research.[6]

Additionally, local health-care professionals are likely to experience difficulties as main sources of information and communicators of risk for the public after a nuclear disaster. Residents in affected areas will have various concerns about the health effects of radiation-contaminated food, water, and soil, and might ask health-care professionals for advice.[7] Even concerns that seem trivial or unfounded to specialists can have substantial effects on people’s way of life, education, residence, and employment, irrespective of whether residents articulate their concerns. To care for people with these concerns,[8] community health-care workers need to know what and how to tell residents to protect them not only from the effects of radiation, but also from other health risks associated with evacuation and other changes in lifestyle.

The health effects of nuclear disasters discussed in papers 1 and 2 in this Series[1,3] inform this paper, in which we propose a conceptual framework defining the roles of health-care professionals in a nuclear disaster. Planning for a complex nuclear disaster should take into account the condition of the NPP, weather information, traffic control, transparency,[9] public notification via mass media and internet,[10] business continuity management,[11] coordination of local and central government, and a diagnosis and treatment network for patients with acute radiation syndrome (ARS).

Protection of emergency and recovery workers from radiation and medical issues

Despite personal protective equipment and training, emergency workers in an NPP accident are at high risk of radiation exposure because of the harsh and unpredictable environment after an accident and a shortage of skilled workers, which can lead to raised individual cumulative doses. Skilled emergency personnel have an extremely important role, especially immediately after an accident, when they work to contain radiation sources and to cool heated nuclear fuel. Injuries due to fire and explosion often occur in this phase. Additionally, in Chernobyl, 134 of 600 emergency workers had ARS.[1] In Fukushima, no cases of ARS were reported. The highest exposure dose among emergency workers was 679 mSv, with most exposure through inhalation in the immediate aftermath of the accident,[12,13] which was lower than the minimum dose of 1000 mSv to develop ARS symptoms. The worker with the highest exposure dose wore a mask equipped with a filter for radioactive caesium, but which did not contain charcoal to absorb radioactive iodine. Additionally, he removed the mask to smoke tobacco outdoors on the grounds of the NPP. In such a serious and confused situation, shortage of protective equipment and failure to observe protective protocol were observed.

Implementation of personal protection by workers is crucial. Emergency workers need to understand basic measures of protection from radiation exposure. Protective equipment, including masks with effective and appropriate filtration, should be stored in readily accessible places. To mitigate external exposure, workers should limit their time in the environment. In a nuclear event, many skilled workers need to be mobilised, which might need an influx of personnel from other NPPs, nationally and internationally. Regional electric utilities and related organisations should coordinate their efforts to ensure availability of workers with the necessary specialised technical expertise in a nuclear disaster.

The environment for workers in an NPP after an accident is likely to be stressful.[14] During uncertainty about plant conditions, hundreds of workers might need to stay on site (inside the nuclear facility) for a long period of time without immediate medical help or advice.[15] These circumstances make emergency workers more susceptible than the general affected population to psychological trauma.[3,14]

After nuclear accidents, recovery workers participate in decontamination, establishing long-term stability of the nuclear reactor and decommissioning the NPP after the reactor has been stabilised. Additionally, recovery workers work on site and in contaminated areas outside the facility, and are at risk of exposure to a low dose of radiation for a long period of time. After a major NPP accident, many recovery workers are likely to be involved, making tracking and management of exposure doses for each individual difficult. For example, 600 000 workers were involved in recovery operations at Chernobyl, but the external exposure was recorded appropriately for only 250 000.[1] Similarly, difficulties were encountered in tracking of radiation exposure doses of employees and contractors immediately after the Fukishima Daiichi NPP accident.[16] Ideally, a robust system is needed to manage individual workers' exposure doses from the acute response to recovery. However, development of such a system might be challenging because it relies on national protection regulations for workers, effectiveness of plans for a major NPP accident, and availability of essential resources, such as monitoring devices.

During a major NPP accident, thousands of workers will be involved in emergency and recovery work daily. Therefore, the medical system around the plant has an important role in provision of care for injured or sick people with possible radiation exposure. However, in Fukushima, establishment of evacuation areas around the NPP led to forced closure of local hospitals, and even hospitals that were not evacuated had outflow of medical personnel and disruption of supply chains for medical equipment and other necessities.[3] Therefore, long delays were encountered with transport of injured workers to medical facilities because the local radiation emergency medical system was disrupted (panel 1).[17] When a major NPP accident occurs, designated hospitals are very likely to become unusable because they are likely to be in the evacuation zone.

How can another major NPP accident be prepared for? In view of the widespread and diverse effects of radiation plumes, many hospitals and medical personnel will be needed to respond to emergency medical needs. Education in radiation emergency medicine is needed for medical personnel in a wide variety of specialties[15] and as part of the curriculum of medical, nursing, and radiology technology schools (panel 2).

Panel 1: Japanese disaster medical hospitals

The Japanese disaster medical system was developed after the Great Hanshin-Awaji earthquake (6434 deaths and 43 792 injured people) in 1995, and more than 600 hospitals throughout the country were designated disaster medical centres as of January, 2015.[18] These centres have an earthquake-resistant structure, medical stockpiles, and trained medical personnel constituting a Disaster Medical Assistance Team (DMAT).[19] However, the radiation emergency medical system in Japan, which was developed independently from the disaster medical system, was intended to respond to nuclear work-related accidents.[20] In January, 2010, before the Fukushima Daiichi nuclear power plant (NPP) accident, only 33 (6%) of 538 disaster medical centres were designated radiation emergency medical facilities.[19] In Fukushima, four of the six disaster medical centres were not designated radiation emergency hospitals. Therefore, these four medical centres could not respond to injures sustained at the Fukushima Daiichi NPP immediately after the accident because they were not prepared for radiation emergency medicine.

Panel 2: Training of doctors and students

The Fukushima Daiichi nuclear power plant (NPP) accident created an impetus to update the medical curriculum. Three new innovative training programmes have been established to provide physicians with the knowledge and skills needed to deal with the medical and social effects of a nuclear accident. The first is a training module in radiation medicine for medical students at Fukushima Medical University, Fukushima, Japan. The second is a science and technology studies module at Fukushima Medical University to enrich the existing medical programme, aimed to equip physicians with skills (eg, public communication of science and technology, and social and psychological effects of radiation anxiety) to comprehend and address complex situations after NPP accidents. The third is the Phoenix Leader Program at Hiroshima University, Hiroshima, Japan, which leads to a PhD degree. This programme aims to train future leaders in nuclear disasters, addressing medical, environmental, and social factors. Since a developed and comprehensive disaster medicine curriculum was not available, Pfenninger and colleagues[21] developed a German medical student disaster medicine curriculum, including an evacuation exercise, decontamination procedures at an NPP accident, and an interactive review of professional ethics, stress disorders, and psychosocial interventions. The Japanese Ministry of Education, Culture, Sports, Science and Technology has also edited the reading text for radiation disasters for medical students from a more global perspective. A new attempt to deliver radiation science education has started from elementary school (age 6–12 years) in Japan.

Protection of citizens from radiation exposure

The main objective of evacuation of the public after the release of radionuclides in an NPP accident is to avoid stochastic effects (cancer risks later in life) due to radioactive plumes and ground deposits. The extent of effects of radioactive plumes changes moment-to-moment owing to factors such as amount of radioactivity released, wind direction, weather, and terrain. Radioactive plumes do not propagate simultaneously in a concentric manner.[22]

Were residents evacuated successfully in Fukushima? Although 97% of the population living within 20 km of the NPP were evacuated within 4 days of the accident,[23] the evacuation was not orderly. First, no designated locations for evacuees outside the 10 km zone had been assigned in the plan and, therefore, more than 20% of the evacuees had to relocate at least seven times as the evacuation zone expanded.[16] Second, evacuated residents did not have sufficient information about radiation levels or the evacuation procedure. Evacuated residents were not given information about how to prepare, how to protect themselves, or how long to leave their houses. Third, evacuation shelters were located in areas northwest of the NPP, where high levels of radioactive deposition were recorded.[16,22] This failure to implement organised evacuation was mainly because adequate plans

For the **training module in radiation medicine** see http://www.fmu.ac.jp/home/cmecd/ecdm/purpose.html (in Japanese)

For the **Phoenix Leader Program** see http://www.hiroshima-u.ac.jp/en/lp/po/ra/

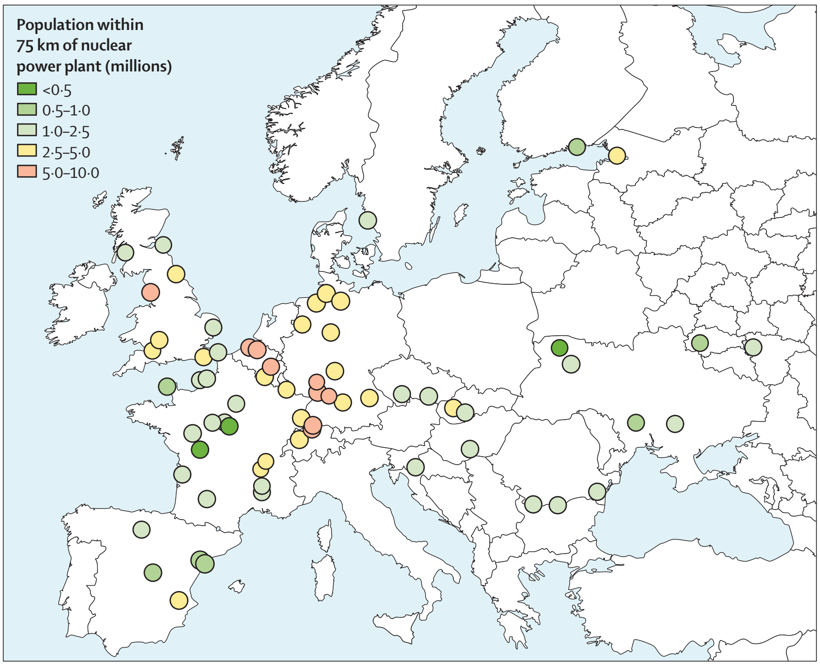

Figure 1: **Population living within 75 km of nuclear power plants in Europe**

were not made, information about radiation levels was insufficient, communication was disrupted, and the local nuclear emergency response headquarters at the off-site centre lost function.[24]

Administration of stable iodine is an important issue for radiation protection after an NPP accident because it inhibits incorporation of radioactive iodine to the thyroid gland when taken just before or after intake of radioactive iodine. Although residents who need to be given stable iodine tablets are reported with projected thyroid dose of 100 mSv (not dependent on age),[25,26] an important question is whether thyroid exposure can be predicted accurately in difficult situations, such as a nuclear disaster. Additionally, several myths exist about stable iodine since, although potassium iodide can only provide protection for the thyroid gland from an intake of radioiodine, it is sometimes misunderstood to protect people from other radiomaterials.[27] Whether residents in Fukushima needed stable iodine tablets caused confusion.[16] According to the previous nuclear disaster prevention plan in Fukushima prefecture, administration of stable iodine should be recommended by the national government through the local government when the predicted dose exceeds 100 mSv, based on dose projections provided by the System for Prediction of Environmental Emergency Dose Information (SPEEDI), emergency monitoring, and estimated duration of ^{131}I release. Protection of children should be prioritised, because they are most susceptible to the effects of radioiodine. However, power failure, structural damage to monitoring posts, and absence of data for NPP conditions meant that accurate data were not available from SPEEDI.[16] Therefore, a key lesson is that decisions about administration of stable iodine should not include a complicated flow of orders, rather, local headquarters should decide about prophylactic administration of stable iodine on the basis of circumstances at the NPP or the air dose rate, irrespective of predictions by thyroid radiological screening or SPEEDI.[25,28] To consider the balance between risk and benefit of iodine prophylaxis at an early phase after a nuclear accident is also important even if the frequency of adverse effects from stable iodine is low.[25]

Three Mile Island and Fukushima highlighted some important challenges that accompany evacuation. Simultaneous evacuation of large numbers of people creates traffic congestion and can increase risk of unnecessary exposure to radiation.[3] In Three Mile Island and Fukushima, evacuation areas were expanded without planning beforehand.[16,29] Evacuation without planning can lead to great confusion, increase incidence of road traffic accidents and other causes of injury, and create serious life-threatening conditions for vulnerable people, such as hospital inpatients and elderly people.[30]

Decision making for large-scale evacuation

The Fukushima Daiichi NPP accident resulted in evacuation of 170 000 people, even though the area around the NPP had a fairly low population compared with that around other NPPs. About two-thirds of the world's 221 NPPs have a higher population than that of the Fukushima Daiichi NPP within a 30 km radius.[31] 21 of these NPPs have more than 1 million people, and six have more than 3 million people, living within 30 km. If the evacuation area were increased to a 75 km radius from the NPP, 152 NPPs would need to evacuate more than 1 million people (figure 1). How can such a large number of people be evacuated safely and efficiently, and is simultaneous evacuation appropriate?

Successful public evacuation needs frequently updated information about NPP conditions and the radiation dose rate, availability of sheltering facilities with robust structures, availability of resources needed for life (eg, water, food, gas, means of communication, and power generators), various evacuation routes, and an estimate of the time that individuals will have to stay in designated evacuation areas. In cases in which evacuation is necessary, evacuation should be implemented in a stepwise manner by division of the designated evacuation area into small blocks on the basis of radiation dose rate and administration unit, and evacuation should proceed block-by-block.[32]

Evacuation of hospitals and nursing facilities

Evacuation of hospitals and nursing facilities is difficult and has been problematic in contexts other than the Fukushima Daiichi NPP accident.[16,33] Emergency evacuation when adequate medical support is not available can be dangerous, and is complicated by underlying life-threatening conditions for vulnerable populations, such as hospital inpatients and the elderly. The possibility of public exposure to radiation that will cause ARS is very low. Furthermore, a difference in cancer incidence between those who remained in the contaminated area and those who left it in Chernobyl has not been clearly recognised so far.[2] On the basis of these findings, immediate evacuation might not be the best option, especially for vulnerable populations.

To make long-term sheltering in place an option, the following are needed: suitably structured facilities with effective air-conditioning equipment (filters); good access to up-to-date information about radiation and NPP conditions; supportive medical staff; medical supplies; and supplies necessary to fulfil normal daily needs.

In nuclear accidents in which large-scale evacuation was implemented, the scarcity of information about radiation after the accident made assessment of radiation risks difficult, and an effective evacuation plan could not be established beforehand.[3] A feasible evacuation plan is essential for hospitals and nursing care facilities in each region. These plans should be examined, rehearsed, and, if necessary, revised often. Several factors should be taken into account, including the following: distribution of hospitals and nursing facilities; number of inpatients; evacuation priority order; means of transportation and support of personnel; evacuation route; location and capacity of admitting facilities outside the evacuation area; and necessity of a site for monitoring radiation information. If repeated evacuations are expected, destination facilities for the evacuees need to be identified at an early stage.[33] These preparations should help to avoid unnecessary deaths during evacuation. An effective evacuation plan for hospitals and nursing care facilities should include: advice about discharge of ambulatory and stable patients if families or others can care for them; predictions about the number of staff who have conflicting responsibilities, such as family care; division of patients to enable continuation of care while sheltering in place (ie, to separate those who need discharge, bus transfer, ambulance, or ambulance with intensive medical care); and arrangements to ensure that hospitals and nursing care facilities within and outside the local region are well prepared.[34]

Safe and efficient evacuation of hospitals is not only an issue for nuclear disasters. Natural disasters such as hurricanes have created difficult situations for hospitals in large cities.[35,36] Hurricane Sandy showed the vulnerability of a major city when it struck New York, USA, in 2012, resulting in power outage. Underground power generators supplying hospitals failed because of flooding, and major hospitals that cared for seriously ill patients had to be evacuated.[37] When hospitals become isolated and evacuation is not an immediate option, a continuity plan to maintain medical activities needs to be implemented. This plan should ensure that basic medical needs can be met with limited medical resources. Dispatch of supporting medical staff to hospitals with an imbalance of medical resources and medical needs might be necessary.[38] After the Great East Japan Earthquake that led to the Fukushima Daiichi NPP accident, crucial resources such as water, gas, telecommunications, and transportation were disrupted across coastal regions because of the earthquake and tsunami, and many hospitals became isolated.[38] In a nuclear disaster, medical personnel should be able to protect themselves properly while safely supporting isolated hospitals and assisting in evacuation of hospitals, should the need arise.[39] Additionally, maintenance of a person's medication supply should be planned for. A systematic review[40] highlighted the scale of the problem and some possible solutions.

Panel 3: Amplification of radiation risks by the media

One result of the amplification of radiation risks by the media is called Fuhyohigai in Japanese, meaning socioeconomic damage caused by a vague and unfounded negative reputation.[45] Fuhyohigai is mainly attributable to media coverage and includes damage such as decreased sales of local products, decreased trade, and decreased tourism. Fuhyo is similar to social amplification of risk,[46] but differs from rumours that are usually generated and passed on among people experiencing anxiety near a disaster area. Higai means damage. Fuhyohigai might occur even if risk is negligible, can spread easily and widely, and can continue long term. Fuhyohigai is not only an economic issue, but can also cause psychosocial problems and stigmatisation. For example, rice is the staple food of east Asia, and Fukushima prefecture is one of the largest high quality rice production areas. To prevent Fuhyohigai, Fukushima prefecture has screened more than 10 million rice bags per year for radioactivity, compared with about 1000 sampling bags in other prefectures. This screening is done despite the absence of any difference in the radioactive caesium level of rice across east Japan. The term Fuhyohigai was originally used in relation to nuclear power generation, to describe situations such as the nuclear testing accident at Bikini (1954), followed by the exposure of Daigo Fukuryu-maru, a Japanese fishing boat, and the Japan Nuclear Fuel Conversion Office (JCO) Tokaimura criticality accident. Fuhyohigai is not limited to nuclear accidents and has been reported in relation to environmental pollution and infectious diseases such as bovine spongiform encephalopathy.

Psychological responses during nuclear disasters

In the cases of the atomic bombs, and the Chernobyl and Fukushima Daiichi NPP accidents, people have had long-term psychological burdens.[1,3,41,42] These psychological burdens raise the question of what would be expected from physicians in the community after a nuclear disaster, and whether this burden is a characteristic only of major accidents at NPPs. Any type of disaster, nuclear or otherwise, can result in post-traumatic stress disorder, depression, anxiety, excessive intake of alcohol, and somatic disorders.[43] Deteriorating mental health after a disaster can cause decreased physical function and provoke various illnesses, and can be an important factor contributing to deterioration of health later in life. Therefore, taking care of mental health issues becomes very important. Standardised techniques might be needed to assess a patient's general living conditions and

Panel 4: Thyroid screening by ultrasonography for children in Fukushima

A thyroid ultrasound survey was launched in October, 2011, as part of the Fukushima Health Management Survey.[49] Although radiation exposure in Fukushima is thought to be much lower than in Chernobyl,[53] the survey was needed not only for scientific investigation, but also in response to requests from the local population. Thyroid ultrasound examinations have been provided to all Fukushima children aged 18 years or younger at the time of the accident (roughly 370 000 children). Thus far, 296 586 (80·7%) of 367 686 children participated in the survey, of which 2236 (0·8%) children needed confirmatory examinations. 108 (0·036%) had possible or confirmed malignancy.[54]

The apparent increase in thyroid cancer prevalence that results from screening[52,55] has caused public concern about the health effects of radiation. However, thyroid cancer is slowly progressive and has a good prognosis and considerable latency. Therefore, attention should be given to the bias of screening effects and possibility of overdiagnosis,[51,56] which might cause anxiety among children and feelings of guilt among their parents. Risk communication, including explanation of the importance of examination is necessary, and discussion of the advantages and disadvantages of cancer screening are needed, to support individual autonomous consent on the basis of sound scientific knowledge and accurate risk perception about thyroid cancer and radiation exposure.

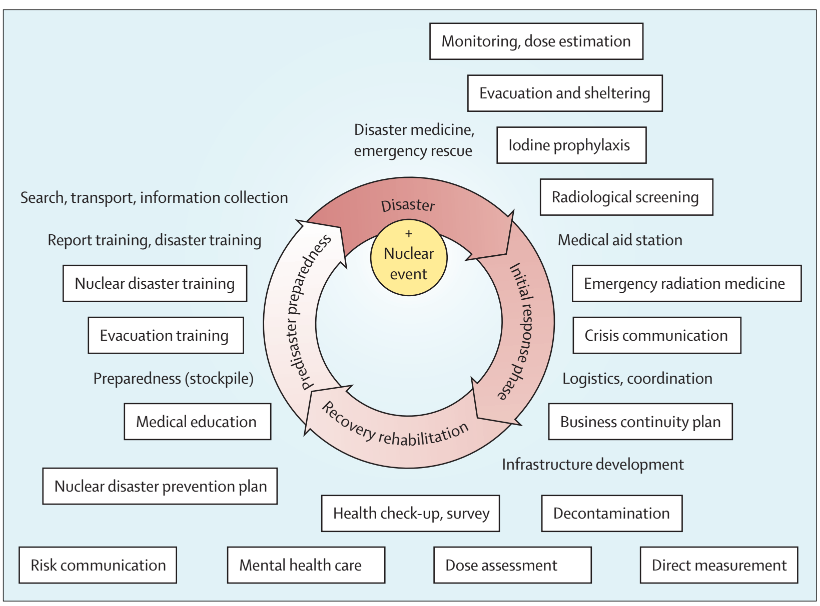

Figure 2: **Nuclear disaster cycle**
Medical issues in a compound disaster. Boxes refer to measures specifically needed in a nuclear disaster, those not in boxes are measures common to any large-scale disasters.

co-occurrence of physical illness and mental disorders.[43] In view of the large number of affected people, education of physicians not in the specialty of psychiatry to be able to screen for mental illness and provide general mental health care is essential.[44]

Risk communication

In Fukushima, parents are very concerned about their children's exposure to radiation and seek measures to reduce their radiation risks.[7] Examples include limitation of outdoor activities, avoidance of local food and breastfeeding, and decontamination of playgrounds. Although the residents' risk perception of radiation is high, other factors affect their behaviour, including scarcity of reliable information, inequity of public support, and distrust of the government (panel 3).[16]

How can concerns raised by residents be addressed? In Fukushima, community physicians and public health nurses took a unique approach for communication with residents.[47,48] When physicians or nurses showed the results of the whole body counter to residents, they explained serial changes of results and suggested ways that the resident might reduce additional radiation exposure. These efforts seemed to improve understanding of radiation risks among the general public.

The Fukushima Health Management Survey started to provide mental and medical support, telephone counselling, and information about health effects of radiation.[49] Although support was provided, negative emotions and anger among residents were sometimes directed towards medical professionals and public health officers.[50] Difficulties of risk communication arose in the thyroid screening programme of the Fukushima Health Management Survey, which was initially expected to reduce excessive anxiety.[49] Contrary to expectation, screening results caused unnecessary concerns among people who were examined.[51] Although thyroid screening showed some benefits of early diagnosis with modern technology, the resulting increase in prevalence of thyroid cancer can cause anxiety among residents unless consideration is given to a clear approach for communication (panel 4).[52]

Risk communication at the time of an NPP accident is challenging and needs to address psychological, sociological, and cultural factors that combine to generate public misperceptions about risks.[57] Health-care professionals need to understand how to communicate with residents who have different perceptions about radiation, and this might become one of their key roles. For example, in July, 2011, Staudenherz and Leitha[58] listed 33 radiation accidents to highlight that the main challenge is not treatment but communication. They wrote that the "premier task of the medical services is to communicate that in most accidents very few people are exposed to an acute life-threatening dose".[58]

Challenges and proposal

Key issues in the health-care system need to be investigated to prepare for a future nuclear disaster in addition to those included in a disaster cycle (figure 2).[59,60] Evidence for radiological protection is mainly based on a long-term cohort lifespan study of atomic bomb survivors.[2] The effects of a nuclear disaster on individuals and societies are diverse, but include health effects due directly to radiation and other effects not directly related to radiation. Although radiation effects on human health were serious in cases such as the atomic bombs and Chernobyl, past experiences of nuclear disasters show substantial effects on health and society, irrespective of the magnitude of radiation effects. Various tasks should be undertaken to promptly mitigate effects on residents' health, livelihood, and the environment, and to enable recovery of the affected area. To plan for the future, uncertainties need to be resolved, and physical and mental health and information needs should be addressed.

Relocation after a disaster can disrupt the health-care system, leading to disease outbreaks and increased mortality.[3,61] In 2014, the Fukushima prefectural government sent a questionnaire to 62 812 evacuated households, of which 20 680 households responded. According to survey results, 49% of respondents remained separated from family, 68% reported mental or physical health problems in their family, 57% reported disturbed sleep, and 47% reported to have depressive mood.[62] These results suggest that substantial issues are unresolved as the affected population recovers from the accident and aftermath.

The effects of disasters vary among countries and societies. However, past disasters, including the few nuclear disasters, show that the largest effects might be on the most vulnerable people in society. As one of the most rapidly ageing societies in the world, Japan faces serious issues related to health care for displaced elderly people in Fukushima and other areas affected by disasters.[63,64]

Evacuation for a large population and vulnerable people needs to be planned carefully.[65] Surrogate emergency systems that support local medical responses should be issued promptly after an accident. Mental and psychological care and behavioural and social support for displaced people need to be established with coordinated approaches by the government, municipalities, academic organisations, and volunteer groups. General public health services are a prerequisite to counteract long-term adverse health effects after a major nuclear disaster. For all of these countermeasures, health-care professionals should balance protection from radiation with other health risks, and make efforts to mitigate the psychological effects that are most strongly associated with risk perceptions of radiation.[43] These challenging tasks constitute the agenda of future research.

To address the broad social and environmental factors that might affect outcomes of disaster preparedness, response, and long-term recovery efforts, resilient community health care has emerged as a US policy priority after major disasters such as Hurricane Katrina, the terrorist attacks on Sept 11, 2001, and Hurricane Sandy.[66] Additionally, the Fukushima Daiichi NPP accident showed that risk communication has an important role in disaster resilience.

After a nuclear accident, uncertainty about the extent and severity of the accident results in confusing and contradictory information being issued by various sources, including administrative authorities, operators of the NPP, the media, and scientists.[16,29,34,67,68] Restriction of information about the accident might further increase public anxiety, leading to distribution of inaccurate information and public distrust.[69,70] In such a disordered situation, doctors, public health officers, and nurses are often asked to explain the risks and provide scientific information to the community as risk communicators.[71]

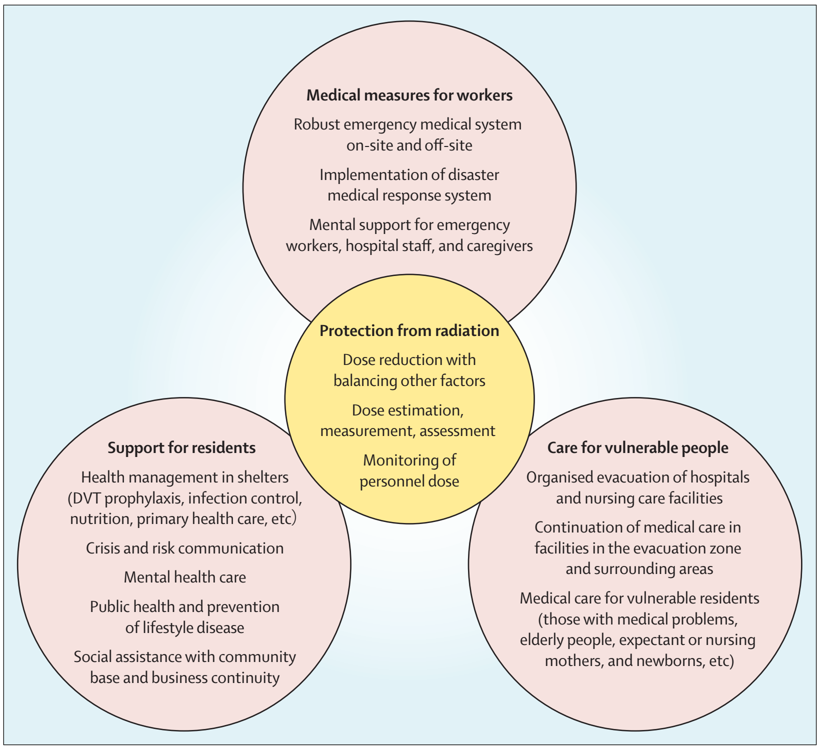

Figure 3: **Framework for community engagement and decision making in a disaster cycle**
Effects of a nuclear disaster on individuals and health-care professionals are sometimes diverse, but should be considered together to balance protection from radiation effects and other effects not directly related to radiation, including the following: medical measures for workers, care for vulnerable people, and support for residents.

Health-care professionals working in the community need to learn how to tell residents how to protect themselves from the effects of radiation and from other health risks. This need increases during the long recovery time after a nuclear disaster,[72] and many factors can affect actual risks to health and risk perception of individuals.[73]

Health-care professionals need to improve residents' understanding of health risks, so that they can adapt their lives accordingly, and provide support for restoration of the community, while preventing further division or decline. Scientific messages based on accumulated evidence from atomic bombings and past nuclear accidents provided by health-care professionals should be used to enhance the public's understanding of the effects of the accident on health.

Implementation of nuclear disaster medical education for physicians and health-care professionals should aid decision making, including evidence-based interventions and balancing of other health issues with radiation protection for workers, vulnerable people, and residents (figure 3). Useful evidence should be readily accessible—for example, through initiatives such as Evidence Aid, which is seeking to make it easier for decision makers to use systematic reviews before, during, and after disasters and other humanitarian emergencies.[74] Furthermore, opportunities to assess interventions, actions, and strategies should be taken to help fill the evidence gap, inform the ongoing response during a nuclear disaster, and prepare for a future disaster.

Contributors

AO, KT, AK, ON, NT, SY, HO, and RKC set the conceptual framework of the report. AO, KT, AK, and SM contributed to the writing of the report. MC and KN critically commented on, and revised, this report. All authors contributed to the discussion and have seen and approved the final version of the report.

Declaration of interests

We declare no competing interests.

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