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Review Article

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Review Article

Post-crisis efforts towards recovery and resilience after the Fukushima Daiichi Nuclear Power Plant accident

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Abstract

One of the well-known radiation-associated late-onset cancers is childhood thyroid cancer as demonstrated around Chernobyl apparently from 1991. Therefore, immediately after the Fukushima Daiichi Nuclear Power Plant accident on March 2011, iodine thyroid blocking was considered regardless of its successful implementation or not at the indicated timing and places as one of the radiation protection measurements, in addition to evacuation and indoor sheltering, because a short-lived radioactive iodine was massively released into the environment which might crucially affect thyroid glands through inhalation and unrestricted consumption of contaminated food and milk. However, very fortunately, it is now increasingly believed that the exposure doses on the thyroid as well as whole body are too low to detect any radiation-associated cancer risk in Fukushima. Although the risk of radiation-associated health consequences of residents in Fukushima is quite different from that of Chernobyl and is considerably low based on the estimated radiation doses received during the accident for individuals, a large number of people have received psychosocial and mental stresses aggravated by radiation fear and anxiety, and remained in indeterminate and uncertain situation having been evacuated but not relocated. It is, therefore, critically important that best activities and practices related to recovery and resilience should be encouraged, supported and implemented at local and regional levels. Since psychosocial well-being of individuals and communities is the core element of resilience, local individuals, health professionals and authorities are uniquely positioned to identify and provide insight into what would provide the best resolution for their specific needs.

Key words: Fukushima, Chernobyl, thyroid cancer, radiation, resilience

Introduction

This year, 2015, is the 70th anniversary of the atomic bombings of Hiroshima and Nagasaki, which sadly demonstrated not only the vast and massive destruction of both cities with large number of casualties but also acute and chronic effects of radiation exposure on human lives, physically, psychosocially and mentally. Based on valuable lessons learned from the atomic bombings of Hiroshima and Nagasaki, and from the Chernobyl Nuclear Power Plant (NPP) accident, radiation protection criteria for external and internal exposure have been established once nuclear accident happened (1). Unfortunately in Japan, an atmosphere of radiation safety and protection culture was not well established before the Fukushima NPP accident because of the illusion of a myth of nuclear safety (2). Therefore, a lack of or inadequate knowledge and education on radiation protection and radiation health risk management has evoked a serious confusion and adverse reaction on information from the different communication tools such as social media that low-dose radiation effects still contain uncertainty, thus complicating risk perception of the general public (3,4).

Once radiological or NPP accidents happen, impact on health damage is categorized either into acute and chronic radiation effects (long-term health consequences) or principally, into two target populations: the first group is nuclear and emergency workers who should be prioritized to be protected and cared, and the second one is the general public which is relatively large in number and is prone to radiation fear and anxiety despite a reality of radiation risk.

This review will focus mainly on the difference and similarity of environmental public health disaster and post-crisis response between Chernobyl and Fukushima, and then on the difficult challenge of recovery countermeasures. Fortunately, there was no acute radiation syndrome observed after the Fukushima NPP accident in contrast to Chernobyl. However, disaster-related deaths in the middle of and after evacuation, especially in elderly people and in patients with severe problems were unfortunately reported in Fukushima (5). Among possible radiation-induced health consequences, childhood thyroid cancer has been attracting a special attention, probably due to initially unknown thyroid exposures in Fukushima (6). A solid evidence of the relationship between exposure to radioactive iodine and a drastic increase of childhood thyroid cancers is Chernobyl. Furthermore, huge areas have been contaminated after Chernobyl, when compared with the map of Japan, by massive fallouts of radioactive ^{137}Cs (Fig. 1).

It is important to understand the relationship between radiation exposure and cancer risks epidemiologically, we therefore first discuss this issue and make a comparison between Chernobyl and Fukushima. Then, we will address the feasibility of effective post-crisis countermeasures of recovery and resilience of individuals and communities in Fukushima. In the middle of the recovery phase, we should take into account and pay more attention to the different value of risk in view of uncertainty in information, while continuing to use risk estimates for straightforward evaluation of compliance with regulatory requirements.

Radiation and cancer risk

The accumulated knowledge from the data on the atomic bomb survivors has, for a long time, been a basis of our understanding of the dose–response relationship for the risk of late health effects, including various malignancies such as leukaemia and solid cancers (7–9), which provided the fundamental principle of the linear non-threshold (LNT) model for radiation protection criteria (10,11). The hypothesis of LNT demonstrates that the cancer risk will increase linearly, depending on the dose at the standpoint of radiation protection. The recent epidemiological report from the Life Span Study of Radiation Research Effects Foundation has clearly indicated a relative increase in cancer risk in the study population due to the external radiation at a given dose and also that in the dose range 0–150 mSv, the excess risk of solid cancer is not statistically significant, especially below 100 mSv (12). Concerning the risk of thyroid cancer, it is well known that not only external but also internal exposure to radioactive iodine can increase it (13–15). The most important modifier of radiation-induced thyroid cancer risk is age at exposure, and elevated risk faints among survivors exposed after the age of 30. Although the LNT model has been in use for many years, there is still uncertainty about the linear relationship of low-dose exposure such as to doses below 100 mSv at the standpoint of real health risk. One of the reasons for this uncertainty is insufficient mechanistic evidence available from the studies (16,17). Another important point is that since the risk estimates have been discussed

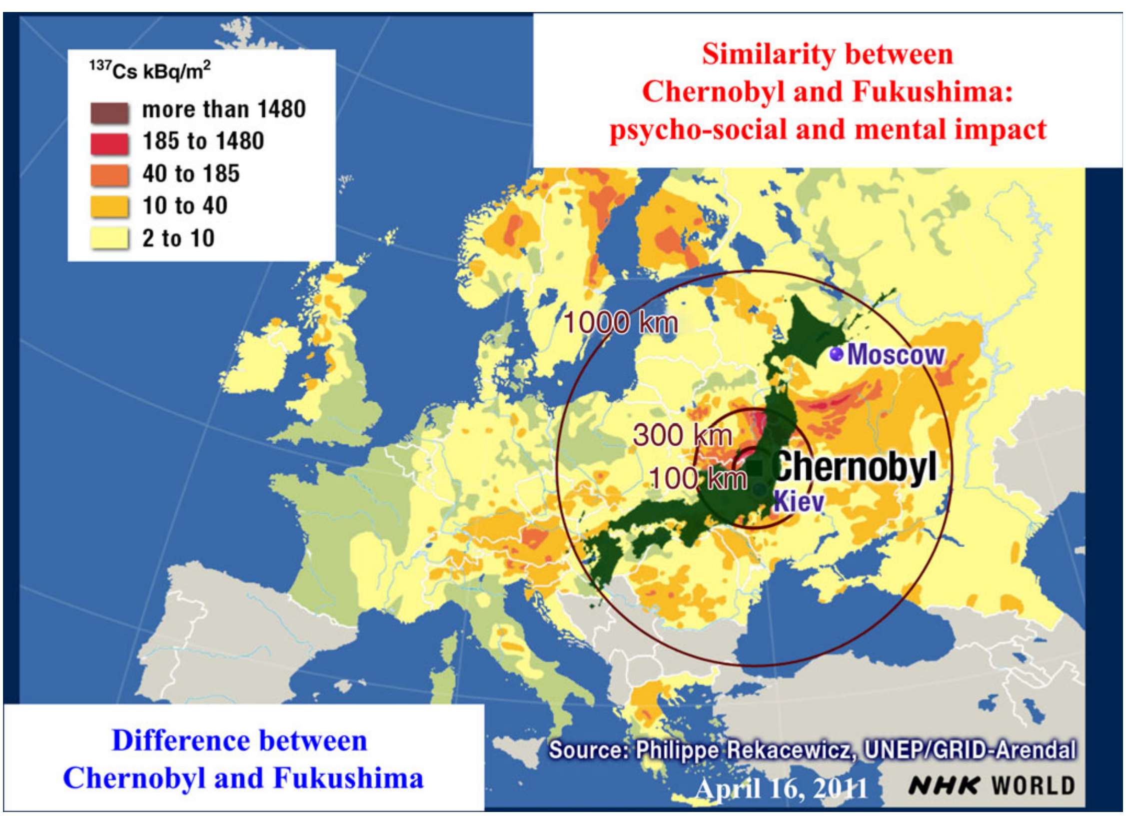

Figure 1. Soil map of ^{137}Cs radiocontamination obtained from the emergency authority of the former USSR. The same reduction sized map of Japan is overlaid.

mainly from the epidemiological data obtained from atomic bomb survivors, who received moderate-to-high doses at extremely high-dose rate, these risk estimates may not be appropriate to be applied for populations receiving radiation dose at lower dose and low-dose rates as cautioned by UNSCEAR 2000 report (18). To overcome such inadequate clinical data interpretation, there is an urgent need to reconcile the recent observations of stem cell radiation biology that challenge the persistence of stochastic oncogenic events in tissues and organs (19). The genetic alterations in radiation-associated thyroid cancer have been reported (20,21), which may contribute to the difference of individual risk but no clear characteristic radiation signature genes are established (22).

It is true that the epidemiological studies in human health risk from low-dose and low-dose-rate radiation exposure are essentially important, as well as those on the atomic bomb survivors follow-up cohort data, but the identification of cause-and-disease relationship is very difficult after any radiological and nuclear accidents because many confounding and modifying factors affect the chance of late malignancy. The dose evaluation is another important issue to be further considered for the evaluation of dose–responsive relationship. The comprehensive health check-up is also an indispensable tool for achieving resilience and a countermeasure against public fear and anxiety about radiation in the case of environmental public health disasters.

Thyroid cancer risk: difference between Chernobyl and Fukushima

The Chernobyl NPP accident on 26 April 1986 released a massive amount of various radioactive materials, which resulted in radiation exposure of a large number of residents living in the affected regions (23). Immediately after the accident, radioactive iodine-contaminated grass and milk were detected in the surrounding Chernobyl areas. Owing to insufficient restrictions on food and milk consumption by the USSR government, internal exposure, especially to the thyroid gland became a problem for nearby residents exposed indirectly to radioactive fallout. People particularly from baby to children continued to consume the contaminated milk (24). As a consequence, >6000 cases of thyroid cancer were surgically operated until 2005 among children and adolescents under 18 years old at the time of accident, 1986 (25). The epidemiological studies demonstrated a positive dose–response relationship between radioactive iodine exposure to the thyroid and risk of thyroid cancers up to 1.5–2 Gy, although statistically significant increase in risk was not observed below 200 mGy (13, 26). Recent studies obtained from Belarus and Ukraine also demonstrated a linear dose–response below 5 Gy in thyroid equivalent dose with an excess risk of 2.15 and 1.91 per Gy, respectively, and also confirmed no statistically significant increase in risk at doses below 100 mGy (27,28).

During the former USSR period from 1986 to 1991, data on thyroid cancer after the Chernobyl accident officially reported by the government were hardly believed because of doubts in accuracy, reproducibility and even reliability (the so-called data quality problem) due to a lack of systematic approach to diagnosis and standardization of data collection and analysis (29). However, data from Belarus, Ukraine and Russia have consistently demonstrated important findings of radiation-associated thyroid cancers and even surgically operated thyroid cancers since the collapse of the USSR (30–32).

In contrast to Chernobyl, although both cases were in the same level 7 of International Nuclear Event Scale, immediately after the Fukushima NPP accident, appropriate countermeasures including evacuation, sheltering and control of food chain were implemented in a timely manner by the Japanese government (33). There is a need for improvement in the management of radiation health risk during and even after the accident, however, to date there have been no acute radiation injuries in Fukushima. Concerning the dose received by evacuees and local residents, there are several official preliminary reports from WHO (34,35) and UNSCEAR (36), respectively. According to more precise estimated data from the local residents in Fukushima (37), the whole body absorbed doses are <3 mSv in general during the first 4 months after the accident. The most important point is the thyroid dose evaluation in Fukushima suggesting the maximum not exceeding 35 mSv in thyroid equivalent dose in a realistic manner (38) in comparison with the data obtained from the Chernobyl study (26) (Fig. 2).

Although there is an obvious difference between thyroid exposure dose in Chernobyl and Fukushima, the Fukushima Health Management Survey has been implemented since July 2011, which includes a basic survey for the estimation of the external doses that were received during the first 4 months after the accident and four detailed surveys (39). One of the detailed surveys is thyroid ultrasound examination, which was conducted from October 2011 until March 2014 as the first round of screening in ~300 000 individuals aged <18 years among a total of 367 687 in Fukushima prefecture (Table 1). Approximately, 0.8% of children needed confirmatory secondary examinations. A total of 108 children of those were diagnosed as suspicious for malignancy or actually malignant by fine needle aspiration biopsy and 84 cases were operated and confirmed as thyroid cancers (81 papillary thyroid carcinoma and 3 poorly differentiated thyroid carcinomas). The male-to-female sex ratio was almost 1:2 and the mean age was 17.2 ± 2.7. The mean size of tumours was 14.1 ± 7.3 mm (5.1–40.5). The average radiation dose during the first 4 months after the accident was <1 mSv. The first round of thyroid examination is intended to establish the underlying disease frequency (baseline incidence) of the thyroid ultrasound screening in Fukushima; such a large-scale study has been performed for the first time in the country (40). Similar study has been independently performed using the protocol identical to one of the Fukushima thyroid ultrasound examinations in children from three other prefectures in Japan to provide relevant information (41). We need a long-term follow-up of the health of growing children in order to shed light on the existence of causal relationship between low-dose radiation and thyroid abnormal findings in the future. Since a high detection rate of childhood thyroid cancers is observed by ultrasound screening, the appropriate guidelines on the usefulness of thyroid ultrasound examination itself are also needed. Now the clinical management of early detected childhood thyroid cancer is carefully performed, and the results of a large-scale survey programme as a whole are expected to bring a breakthrough of elucidation of natural history of thyroid tumour development during childhood-to-adulthood growing period.

The second round of thyroid ultrasound examination in Fukushima was started in April 2014 targeting the same cohort subjects plus newborns in 2011 at the accident, ~385 000 in total. The original plan is that even if the fixed group of this population attains an age of >20 years, thyroid ultrasound examination will continue to be conducted every 5 years. Through scientific analysis and international peer-reviewed process, the prevalence and trend of thyroid diseases including cancers should be clarified in order to protect the health of residents in the long term and to continue careful correspondence.

Towards the recovery from the nuclear accident

One of the lessons learned from Chernobyl is that children's thyroid glands are particularly vulnerable to development of cancer after

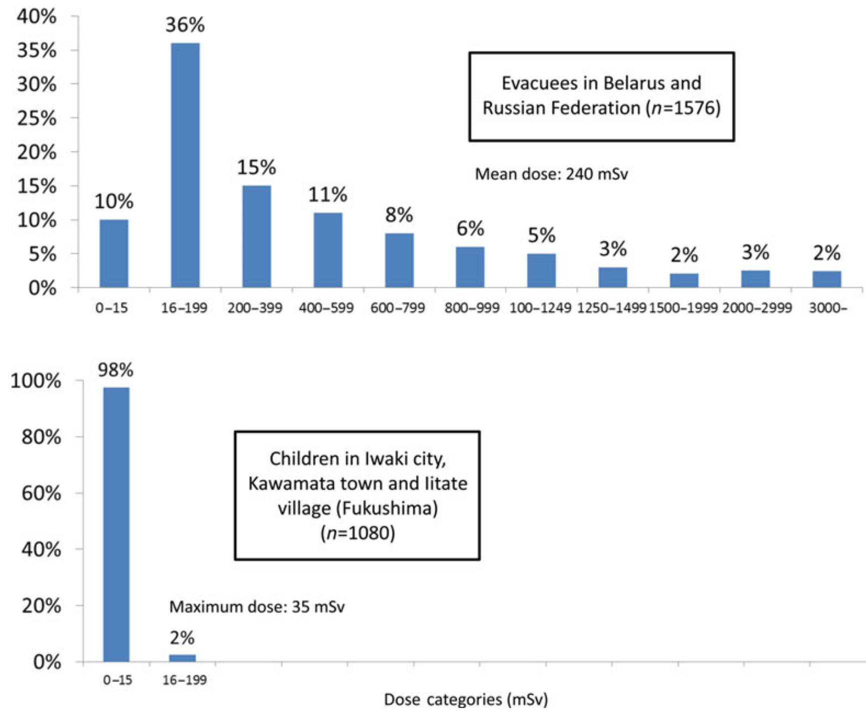

Figure 2. Thyroid radiation doses in Chernobyl (Belarus and Russian Federation) in the upper panel and in Fukushima in the lower panel.

Table 1. Results of thyroid examinations conducted by the Fukushima Medical University (October 2011–March 2014) (http://www.pref.fukushima.lg.jp/uploaded/attachment/101599.pdf)

Primary and secondary thyroid examination					First round (October 2011–March 2014)	Proportion
Number of subjects examined					367 687	100.0
Number of subjects in primary examination					298 577	81.2
Number of examinees with primary results					297 046	80.8
Designation			Definition	Number of subjects	Proportion	
Nothing abnormal detected	A	(A1)	No abnormal findings	153 017	51.5	99.2
		(A2)	Nodule(s) ≤5.0 mm or Cyst(s) ≤20.0 mm	141 778	47.7	
Required secondary examination		B	Nodule(s) ≥5.1 mm or Cyst(s) ≥20.1 mm	2250	0.8	
		C	Immediate examination needed	1	0.0	

radioactive iodine exposure (42). Although it is still too early to ascertain the true risk of thyroid cancer to the exposed children, tentative dose evaluation to thyroid glands in Fukushima is speculated to be too low to detect any positive relationship. However, since atomic bomb survivors' data suggest that the excess thyroid cancer risk associated with childhood exposure has persisted for >50 years after the instant exposure to >100 mGy (43), the Japanese people including Fukushima's residents are facing such health fears, again despite different exposure patterns and even different doses from atomic bomb survivors.

A primary health concern, especially maternal concern, is the most serious and important consideration as for children's health in future. Lessons learned from Chernobyl also demonstrate that the uncertainty of low-dose-rate radiation effects makes it difficult to communicate the risk to the public (44). Moreover, since public perception of radiation risk is easily influenced by other sources of information such as mass media and groundless rumors, during the recovery and rehabilitation from the NPP accident, especially in the middle of environmental high background residency, the unnecessary threat of radiation as well as over- and underestimation of radiation risk should be avoided. It is, however, natural and reasonable that the public fears radiation itself which cannot be recognized by the five senses and so it is needed to comprehend the anywhere existence of radiation logically, for example, by measuring using appropriate monitoring instruments.

To assist such risk communication to the public, continued monitoring and characterization of the level of radioactivity in the environment and foods in Fukushima are vital for obtaining informed consent to the decisions on residing in the radio-contaminated areas and returning to the evacuated areas once re-entry permitted such as in Kawauchi village, located within 30 km from the Fukushima Daiichi NPP (Fig. 3) (45,46). The information sharing and consultation of thyroid findings and other health-related issues are necessary using various approaches because of the difference of target background such as age, sex, residency and sense of value.

At first, the results of thyroid ultrasound findings have been mailed back to the participants' parents or to the subjects with a routine stereotyped explanation sheet, which might worsen their fear and

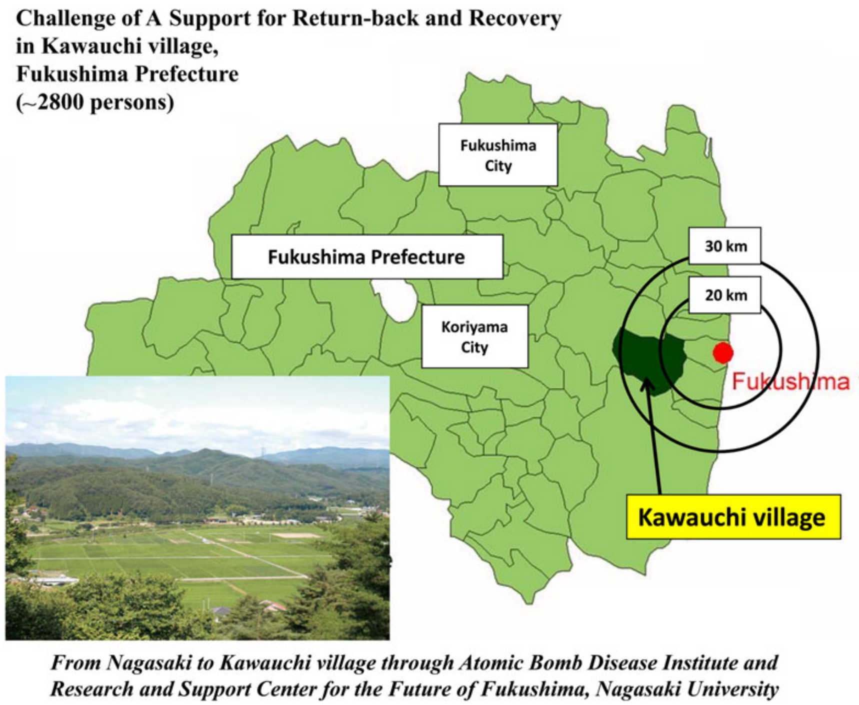

Figure 3. Map of Kawauchi village in Fukushima.

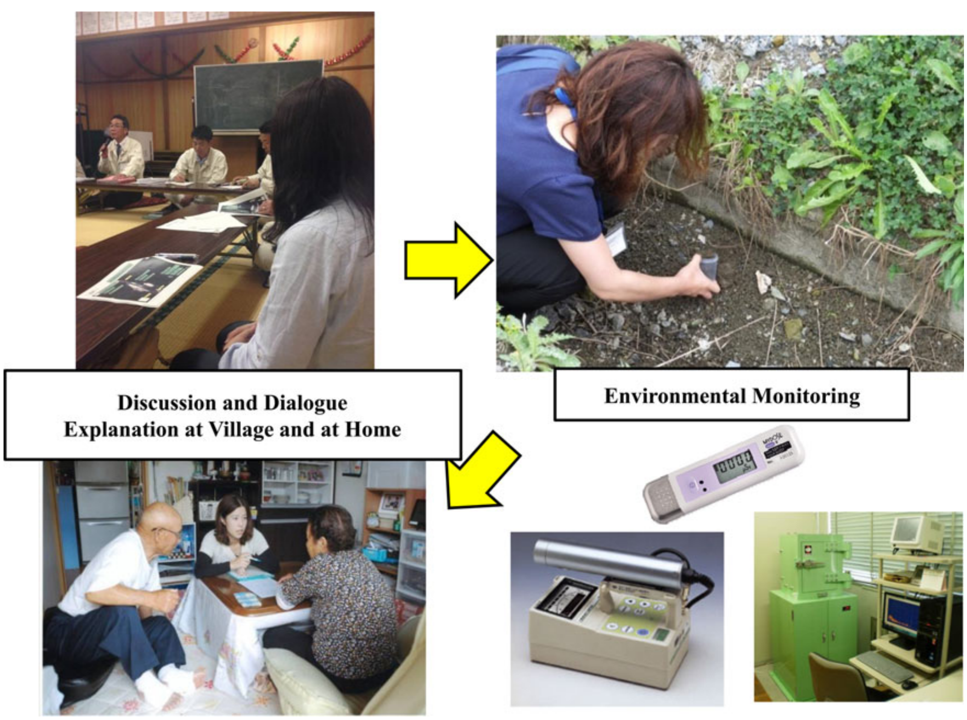

Figure 4. Daily activities of nursing staff in Kawauchi village, Fukushima Prefecture.

anxiety. So, a direct face-to-face explanation may be more effective although it takes a long time to complete. Recently, feedback on the results was evaluated and a consultation protocol has been newly implemented to improve the problematic situation for the local residents in Fukushima.

Another unique challenge is direct commitment of well-educated health workers and nursing staff to local residents, especially aged persons by listening, companioning and evidence-based risk communication together with measurement data of individual dose at homes and local community at the frontline of radiocontaminated areas where permitted, such as Kawauchi village (Fig. 4) (47,48). The bidirectional and dialogue approach, based on mutual trust and creditability, combined with environmental- and food-monitoring results at the housing and local area are very effective to communicate and fasten residents' understanding of the situation, despite the difficulties in radiation risk analysis. Such an approach should be appropriately integrated into the radiation protection system and then expected to emotionally stabilize residents' distress and anxieties. To live together with them closely in Kawauchi village like one nursing staff member dispatched from Nagasaki University for 2 years is one of the models to promote a recovery from the nuclear disaster. Since risk perception is individually different, mitigation of anxiety and fear may be achieved on a case-by-case level; this also helps to narrow an unstable gap between such risk perception and realities of radiation safety and hazard. Intimate and diligent communication is also desirable concerning daily life as well as health issues to overcome radiation fear and anxieties.

Recommendation from the international experts

According to the disaster management cycle, once an accident expands beyond our control and capacity, we face many difficulties and cannot escape the negative impact of disaster. In contrast to Chernobyl, in Fukushima, from the beginning of the accident, we could receive many supports and assistances in a timely manner, especially from the international groups of experts in radiation protection and academic research societies. Especially, the International Commission on Radiological Protection (ICRP) members have intensively cooperated with Fukushima, and proposed the revised ICRP recommendations and guidance (49), which aims not only radiological protection issues arising in the aftermath of the accident but also cooperative approach among stakeholders involved.

Following several symposia and workshops, the third International Expert Symposium was held on September 2014 in Fukushima (50) and the following recommendations were directly delivered by hand to the Prime Minister of Japan immediately after agreed by the participants from the international organizations and other academic societies/universities of the world. The recommendations accurately reflect the current situation of Fukushima three and a half years after the accident.

(i) Radiation protection criteria should provide flexibility to address local circumstances and all aspects of everyday individual and community life. Management of local situations of inhabited areas should be based on actual individual doses, rather than on ambient measured doses or on theoretical calculated doses. Individual doses differ considerably according to people's habits within areas with the same ambient dose rate and protection actions.

(ii) Infrastructure should be put in place for individual radiological situations to be shared with each affected person in an understandable manner, to allow them to manage their own situation.

(iii) Decision-making by individuals who have been displaced must be facilitated, so that they can make informed decisions and achieve some closure. A large number of individuals remain in an indeterminate and uncertain situation having been evacuated but not relocated. The rights of those who choose to return to their homes, and those who chose other alternatives, should be respected. Issues to be examined and reassessed include, but are not limited to, revival of local employment, assurance of current and future safety, provision of adequate infrastructure (including education) and compensation strategies.

(iv) Best activities and practices related to resilience, recovery and revitalization should be encouraged, identified, supported, publicized, disseminated and implemented at local and regional levels. Local individuals and authorities are uniquely positioned to identify and provide insight into what would provide the best resolution for their specific needs. A number of individuals and communities have already developed innovative and successful solutions.

(v) It is critical to support the ongoing efforts of the healthcare and local care providers and to greatly increase their numbers in order to promote the psychological and social welfare and resilience of people affected by the Fukushima accident. Psychosocial wellbeing of individuals and communities is the core element of resilience. Three years after the disaster, existing staff has extensive experience and knowledge and can serve as trainers for the required increased number of heath care providers.

(vi) The Fukushima Health Management Survey provides invaluable health information for the local community and should continue to be supported and dynamically assessed. The current survey should be strengthened, with a flexible stakeholder involvement. Provisions should be implemented to address identified health and psychological issues.

Conclusion

In Japan, we unfortunately did not learn a lesson concretely from the Chernobyl NPP disaster before the Fukushima NPP accident. The repeated efforts on radiological emergency medical preparedness had defectively focused on the initial responses to a severe accident. Furthermore, guidance on and countermeasures against the more complex issues such as radiological remediation and population resettlement of long-term recovery have been totally lacking even from medical and healthcare sides. As focused on the difference and similarity between Chernobyl and Fukushima in this review article, the late effects of low-dose and low-dose-rate radiation exposure have intensively influenced human dimension issues beyond the reality of radiation health risk. Recommendations proposed by the international experts are so important that our efforts towards long-term recovery should be enhanced and strengthened as pointed out by the National Council on Radiation Protection and Measurements (NCRP), USA (51). Thus at the standpoint of development of health science and technology, it is necessary to establish a system for long-term follow-up of all children at the time of accident in Fukushima in order to not only overcome the uncertainty of low-dose effects but also to keep their physical and mental health in calm and in peace for a long recovering time.

When we consider radiation risk induced by the NPP accident, the compound and multi-dimensional 11th March 2011 disaster has surely changed the pre-existing and emerging issues such as sense of value on human life and public risk awareness/perception in the existing societies. This is exactly a new challenge to establish a radiation protection culture in Japan. Therefore, there are two important lessons to be preliminarily made that at first a common language is needed to communicate each other on radiation risk and to gain a social trust as well as personal credibility. The second need is human resource training and development to address the complexity of a compound disaster including a nuclear accident.

Finally, it takes a long time to extract a living lesson from Fukushima since we are still in the middle of confusion and absurdity to develop and implement a trustable countermeasure that would cover different and multi-dimensional aspects of a whole human life, somewhat similar to the proverbial six blind men trying to determine an elephant by touch. We can only state that we are now standing at a crossroads to a new paradigm shift of medical radiation education, mental care and risk communication beyond conventional radiation protection criteria.

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Conflict of interest statement

None declared.

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