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Aims and Scope

The International Commission on Radiological Protection (ICRP) is the primary body in protection against ionising radiation. ICRP is a registered charity and is thus an independent non-governmental organisation created at the 1928 International Congress of Radiology to advance for the public benefit the science of radiological protection. ICRP provides recommendations and guidance on protection against the risks associated with ionising radiation from artificial sources such as those widely used in medicine, general industry, and nuclear enterprises, and from naturally occurring sources. These are published approximately four times each year on behalf of ICRP as the journal *Annals of the ICRP*. Each issue provides in-depth coverage of a specific subject area.

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The Main Commission consists of a Chair and twelve other members. Committees typically comprise just over 15 members each. Task Groups are usually chaired by an ICRP Committee member and usually contain a number of specialists from beyond the Main Commission and Committees. They are assigned the responsibility for drafting reports on various subjects, which are reviewed and finally approved by the Main Commission. These reports are then published as *Annals of the ICRP*.

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Annals of the ICRP

Proceedings of the International Conference on Recovery after Nuclear Accidents: Radiological Protection Lessons from Fukushima and Beyond

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Editorial

RECOVERY AFTER NUCLEAR ACCIDENTS

Perhaps the most important lesson of the accident at Fukushima Daiichi nuclear power plant is that we were not fully prepared to handle the long-term consequences of a major nuclear accident. This is not entirely surprising as the Chernobyl accident, a quarter of a century earlier, was the only other example of a major, widespread release of radioactive materials from a nuclear power plant.

Coincidentally, the International Commission on Radiological Protection (ICRP) released *Publication 111* 'Application of the Commission's recommendations to the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency' (ICRP, 2009), based largely on experience from the Chernobyl accident, just a year before the Fukushima accident occurred. One reason it took so long is that many people felt that the Chernobyl accident was an anomaly. In the decades since Chernobyl, progress had been made to prepare for the immediate emergency response to another large accident, but little consideration had been given to the aftermath.

In March 2011, we learned that the large uncontrolled release from Chernobyl was not a unique event. The spread of radioactive materials from Fukushima Daiichi nuclear power plant into the environment and populated areas had enormous consequences.

Over the last decade, many experts and organisations have acted to reduce the chance that there will be another accident like Chernobyl and Fukushima. Nonetheless, we must still be prepared.

ICRP has focused on learning from the Fukushima and Chernobyl accidents to improve the System of Radiological Protection, the basis of standards, regulations, and practice worldwide. A key result was *Publication 146* 'Radiological protection of people and the environment in the event of a large nuclear accident', released in late 2020. This work is not just theoretical. It is based solidly on the experience of those faced with the challenges in Japan and Europe following the accidents. Most notably, ICRP organised a series of public dialogue meetings in Japan to help those affected, where we could, and to deeply understand the issues in order to improve our recommendations for the world.

In addition, understanding the need for all of us to be better prepared, ICRP organised 'The International Conference on Recovery After Nuclear Accidents: Radiological Protection Lessons from Fukushima and Beyond', hosted by Japan Atomic Energy Agency (JAEA), and supported by many organisations: Institute for Radiation Protection and Nuclear Safety (France); Radiation Effects Association; PESCO Co., Ltd. (Japan); Ascend Co., Ltd. (Japan); Inspection Development Company Ltd. (Japan); Nuclear Engineering Co., Ltd. (Japan); EX Research Institute Ltd. (Japan); Chiyoda Technol Corporation (Japan); Aoba Science Co., Ltd. (Japan); Takarakaseikiki Co., Ltd. (Japan); and Mirion Technologies (Canberra) KK (Japan).

It was a distinct honour to prepare this conference in cooperation with a large group of highly distinguished Japanese and international organisations: Burnasyan Federal Medical Biophysical Centre of Federal Medical Biological Agency (Russia); Centre for the Study of Protection in the Nuclear Field (France); European Commission; European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery; Heads of European Radiological Protection Competent Authorities; International Atomic Energy Agency; Nuclear Energy Agency; United Nations Scientific Committee on the Effects of Atomic Radiation; World Health Organization; Cabinet Office (Japan); Reconstruction Agency (Japan); Ministry of Foreign Affairs of Japan (Japan); Ministry of Education, Culture, Sports, Science, and Technology (Japan); Ministry of Economy, Trade, and Industry (Japan); Ministry of Agriculture, Forestry, and Fisheries (Japan); Ministry of Environment (Japan); Nuclear Regulation Authority (Japan); Fukushima Prefecture (Japan); Minamisoma City (Japan); Iwaki City (Japan); Okuma Town (Japan); Tomioka Town (Japan); Naraha Town (Japan); Kawauchi Village (Japan); National Institutes for Quantum and Radiological Science and Technology (Japan); National Institute for Environmental Studies (Japan); Fukushima University (Japan); Fukushima Medical University (Japan); Nagasaki University (Japan); National Institute of Technology, Fukushima College (Japan); Japan Health Physics Society (Japan); NPO Fukushima Dialogue (Japan); Fukushima Prefectural Union of Agricultural Co-operatives (Japan); Fukushima Prefecture Tourism and Local Products Association (Japan); Japan Nus Co., Ltd. (Japan); and Reprun Fukushima (Japan).

The objective was to share experiences and lessons related to radiological protection aspects of recovery from the Fukushima accident, the Chernobyl accident, and other events to improve international understanding of the current state of recovery in Japan, consider strategies that may accelerate recovery, and improve preparedness for recovery from possible future major nuclear accidents.

Originally planned to be held in Iwaki City, Fukushima Prefecture, Japan, restrictions imposed by the pandemic meant a rapid shift to a fully virtual event.

Although it was disappointing not to be able to gather in Fukushima, shifting to a virtual conference had the very positive consequence of opening participation to a much broader audience. In addition, thanks to the generosity of JAEA and the supporting organisations listed above, no registration fee was charged. During the first half of December 2020, well over 2500 people from more than 100 countries participated in the conference.

One challenge of shifting to a virtual format was that it was not possible for people to come in person to see recovery in action, as planned. So, our partners graciously prepared virtual site tours. Our intention is to keep these available indefinitely at www.icrprecovery.org, allowing you to 'visit' Fukushima Daiichi nuclear power plant, the Interim Storage Facility and Reprun Fukushima, Kawauchi Village, Suetsugi Community, Iitate Village, the Great East Japan Earthquake and Nuclear Disaster Tradition Centre, and JAEA Research and Development.

We have the same intention to keep the video recordings of the scheduled sessions, complementary presentations, press conference, and Special Lecture of Akira Endo free to view online indefinitely.

These proceedings complement this rich visual and audio record of the conference. Reflecting the complexity of recovery after nuclear accidents, you will find papers taking lessons from both the Fukushima and Chernobyl accidents covering a wide variety of topics. Some are highly technical or academic, others more practical, and a few are very personal. All such viewpoints are needed to complete the picture.

Facing challenges like these requires not only our minds, but also our hearts. It is sometimes necessary to have an objective and abstract view, especially when dealing with complex consequences of enormous scope that require huge projects to counteract. However, we cannot forget that at the centre of every disaster are individual people in difficult situations trying to do their best for themselves and their community.

CHRISTOPHER H. CLEMENT
EDITOR-IN-CHIEF

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ICRP recommendations for recovery

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Abstract–In 2020, the International Commission on Radiological Protection (ICRP) issued *Publication 146* which provides a framework of the radiological protection of people and the environment in the case of a large nuclear accident. Mitigation of radiological consequences is achieved using the fundamental principles of justification of decisions and optimisation of protection. These recommendations emphasise the importance of the optimisation of protection for the rehabilitation of living and working conditions in the affected areas during the intermediate and long-term phases. They underline the role of co-operation between the authorities, experts, and the affected population in the co-expertise process to facilitate informed decisions about their own protection. ICRP defines reference levels to be selected within generic bands of exposure considering the induced risk of radiation, as well as the feasibility of controlling the situation.

Keywords: Justification; Optimisation; Reference levels; Co-expertise process; Stakeholder involvement

1. INTRODUCTION

In 2020, the International Commission on Radiological Protection (ICRP) issued *Publication 146* titled 'Radiological protection of people and the environment in the event of a large nuclear accident' (ICRP, 2020). This publication updates and supersedes *Publications 109* and *111* (ICRP, 2009a,b) in light of experience of the accidents at Chernobyl and Fukushima nuclear power plants. The objective of radiological protection is to mitigate radiological consequences for people and the environment. The recommendations of *Publication 146* acknowledge the key role of both

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radiological and non-radiological factors in managing the consequences of an accident. This article focuses mainly on the long-term phase, often called 'post-accident recovery', including relevant general considerations.

2. GENERAL CONSIDERATIONS

2.1. Timeline for managing a nuclear accident

The 2007 Recommendations of ICRP (ICRP, 2007) introduced three types of exposure situation: existing, planned, and emergency. The situation-based approach is a basis of current radiological protection. To manage a large nuclear accident, it is convenient to distinguish between the early and intermediate phases, and the long-term phase. For implementation of the system of radiological protection, ICRP considers the early and intermediate phases as emergency exposure situations, and the long-term phase as an existing exposure situation. The transition from an emergency exposure situation to an existing exposure situation does not necessarily take place at the same time in all affected areas.

2.2. Consequences of a large nuclear accident

A large nuclear accident causes a breakdown in society, affecting all aspects of individual and community life. It has large and long-lasting societal, environmental, and economic consequences. Radiation-related consequences are radiation-induced health effects, such as tissue reactions, cancer, and heritable diseases. In the environment, there are consequences for fauna and flora. In addition to radiation-induced health effects, there may be other health impacts due to changes in lifestyle attributable to protective actions taken to avoid radiation exposure. A large nuclear accident has societal, economic, and psychological consequences. These consequences affect the disturbances to daily life and the well-being of people.

2.3. Principles for protection of people and the environment

The objectives of radiological protection are achieved using the fundamental principles of justification of decisions and optimisation of protection. The principle of justification ensures that decisions regarding the implementation of protective actions result in a benefit for the affected people and the environment. The principle of optimisation of protection applied with reference levels aims to limit inequity in the distribution of individual exposures, and to maintain or reduce all exposures to as low as reasonably achievable, taking into account societal, environmental, and economic factors. Justification and optimisation are applied in mitigating radiological consequences during all phases of an accident, and should take careful account of all non-radiological factors in order to preserve or restore the living and working conditions of all those affected, including decent lifestyles and livelihoods.

The application of dose limits is not appropriate in emergency and existing exposure situations following an accident. ICRP defines reference levels to be selected within generic bands of exposure considering the induced risk of radiation as well as the feasibility of controlling the situation.

2.4. Justification of protective decisions

Responsibility for making decisions on the justification of protection is usually the role of authorities and responsible organisations. The aim is to ensure an overall benefit, in the broadest sense, to society and not necessarily to each individual. There are many aspects of the justification of decisions that can be usefully informed by organisations or individuals outside the authorities. Therefore, ICRP recommends involving key stakeholders in public processes for the justification of decisions whenever possible. ICRP considers that the justification of decisions should be re-assessed regularly as the overall situation resulting from the accident evolves. Therefore, justification is not a 'one-off' consideration taken during planning or during the management of an accident. It should question whether the decisions already taken continue to do more good than harm in the broadest sense. The decision to allow people to stay in affected areas should only be taken when the necessary conditions are met, particularly protection against the potential health consequences, and the achievement of suitable living and working conditions, including sustainable lifestyles and livelihoods.

2.5. Optimisation of protective actions

Implementation of optimisation of protection is a process that requires good understanding of the exposure situation to choose the best protective actions given the particular circumstances. It should reflect the views and concerns of stakeholders, and the ethical values that govern radiological protection. Prudence, justice/equity, and dignity are universal core ethical values that underlie the system of radiological protection, particularly the optimisation principle. The optimisation process inevitably has to cope with conflicts of interest among stakeholders, and must seek to reconcile their different expectations and needs.

One of the characteristics of radiation exposure is the large distribution of exposures received by responders and people living and working in the affected areas. ICRP therefore pays particular attention to equity in the distribution of exposures within groups, and recommends that optimisation of protection should aim to reduce the exposure of the most exposed individuals as a priority.

2.6. Reference levels

Reference levels are used as guiding values to select protective actions. At the beginning, a fraction of the individual exposures may be above the reference level. A priority should be to identify the most exposed people in order to prevent or reduce their exposure. The protective actions should progressively reduce the number of people receiving exposures above the reference level. When conditions evolve and the dose distribution changes, it may be appropriate to re-evaluate the reference level.

For the protection of responders on-site during the long-term phase, the reference level should not exceed 20 mSv year^{-1}. For the protection of responders off-site, the reference level should be selected within the lower half of the recommended band of 1–20 mSv year^{-1}. The Commission recommends that responsible organisations should adopt a lower reference level whenever possible. For the long-term phase, the reference level should be selected in the lower half of the recommended band of 1–20 mSv year^{-1} for existing exposure situations, taking into account the actual distribution of doses in the population and the societal, environmental, and economic factors influencing the exposure situation. The objective of optimisation of protection is a progressive reduction in exposure to levels towards the lower end of the band, or below if possible. ICRP reiterates that the process for selecting the reference level should result from a careful balance of many inter-related factors, including the sustainability of social life and economic activities, as well as the quality of the environment, and should appropriately reflect the views of all relevant stakeholders.

Depending on the accident scenario, this could take several years, or even decades, because exposure of people living and working in contaminated areas largely depends on their habits and living conditions, which cannot be strictly controlled. It is therefore not possible to guarantee that all individual doses will be kept below the reference level in the long term. Selection of the reference level to manage the long-term phase is a complex decision that should be informed by societal and ethical value judgements. Due to this complexity, ICRP recommends that stakeholders who will be confronted with the situation should be involved as much as possible when selecting the value of the reference level.

3. POST-ACCIDENT RECOVERY

3.1. Moving from the intermediate phase to the long-term phase

Protective actions implemented during the early and intermediate phases should be lifted, adapted, or complemented when authorities and stakeholders consider that these actions have achieved their expected effect, or when their continued application is no longer justified.

Decisions on allowing those who have been temporarily relocated to return to their homes involve an extensive dialogue with the affected people and the authorities and professionals in their communities. ICRP emphasises that individuals have a basic right to decide about their future. All individual decisions about whether to remain in or leave an affected area, or to return home or not, including those of voluntary evacuees, should be respected as a matter of dignity, and supported by the authorities.

The decision by the authorities to allow people to live permanently in an area should be taken in close consultation with representatives of the local communities and all other stakeholders when the following conditions are met. Characterisation of the radiological situation of the environment, foodstuffs, goods, and people in affected areas is sufficiently well achieved. Mechanisms are established for the involvement of local stakeholders in decision-making processes. A system for radiological monitoring of the environment and measurement of individual external and internal doses has been established, as well as a health surveillance system. Appropriate mechanisms (e.g. co-expertise process) have been put in place to involve affected people in improving their well-being and quality of life.

3.2. Long-term phase

The accidents at the nuclear power plants in Chernobyl and Fukushima demonstrated that management of the long-term phase based solely on radiological principles and criteria was not sufficient to respond to the challenges faced by individuals and communities in affected areas. While radiological principles and criteria are an essential input to the management of the long-term phase, they should be used appropriately and with due flexibility to accompany the rehabilitation of the living and working conditions of affected individuals and communities.

It is the government's responsibility to provide relevant guidance to the population on how to protect themselves, and the conditions, means, and resources to implement this protection effectively.

3.3. Protection of responders during the long-term phase

The aim on-site is to dismantle the damaged installation, including management of the corresponding waste. The exposure situation is mainly characterised and the source is mostly under control, although some technical difficulties may remain, and unforeseen situations may occur at any time. Circumstances on-site may require planning for exposures above the reference level. In that case, ICRP recommends special arrangements limited in time, which should be prepared with the greatest care after deliberation between concerned parties. The exposure of these residents should be considered as public exposure, and should be managed using the same requisites as for the general population in affected areas.

When an occupationally exposed worker is involved as a responder, the exposure received during the response should be accounted for and recorded separately from exposures received during planned exposure situations. Arrangements for dose records of responders based on agreement between the responsible authorities, operators, employers, and workers should be made in advance as part of the plan for nuclear installation accidents at the preparedness stage. ICRP recommends that occupationally exposed workers who wish to return to their regular activities when the intermediate phase is over should not be prohibited from doing so. The decision should be taken by the authority responsible for the installation on a case-by-case basis.

3.4. Protection of the public and the environment

Management of the protection of people in affected areas in the intermediate and long-term phases is a complex process involving not only radiological factors, but also societal, environmental, and economic considerations. This process includes actions implemented by national and local authorities, and self-help protective actions taken by residents of the affected areas. ICRP recommends that the authorities, experts, and stakeholders should co-operate in the so-called 'co-expertise process' to share experience and information, promote involvement in local communities, and develop practical radiological protection.

3.5. Co-expertise process

This process of co-operation between experts, professionals, and local stakeholders aims to share local knowledge and scientific expertise for the purpose of assessing and better understanding the radiological situation, developing protective actions to protect people and the environment, and improving living and working conditions. The co-expertise process is effective in empowering individuals and communities affected by radiation to know how to protect themselves, and thus to develop a practical radiological protection culture needed to face the consequences of a nuclear accident. It enables people to restore their autonomy regarding decisions that affect them, which has been seriously impaired at the time of a nuclear accident. Furthermore, it contributes to reconnecting people, helps to develop their solidarity, and provides an opportunity for them to look to the future with more confidence.

4. CONCLUSIONS

Given the complexity of the situation created by a nuclear accident and the extent of its consequences, radiological protection only represents one dimension of the contributions that are likely to need to be mobilised to cope with the issues facing all affected individuals and organisations. They should be elaborated with the objective of putting radiological protection at the service of rehabilitating living and working conditions and the quality of life of affected communities. To achieve this objective, ICRP emphasises the crucial importance of involving stakeholders. Experts should adopt a prudent approach to manage exposures, seek to reduce inequities in exposures, take care of vulnerable groups, and respect the individual decisions of people while preserving their autonomy of choice.

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The institutional structure for decommissioning Fukushima Daiichi nuclear power plant

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Abstract–This article describes the institutional structure established for decommissioning Fukushima Daiichi nuclear power plant. To deal with the aftermath of the unprecedented nuclear accident in Fukushima, several responsible institutions such as Ministry of Economy, Trade and Industry (METI), Ministry of Education, Culture, Sports, Science and Technology (MEXT) have worked together at the initiative of the Government of Japan. In this structure, Tokyo Electric Power Company Holdings (TEPCO) implements the decommissioning due to its legal responsibility, while the essential direction and milestones are set by the Nuclear Emergency Response Headquarters of the Government of Japan. Nuclear Damage Compensation and Decommissioning Facilitation Corporation, a government-affiliated organisation, oversees and facilitates the decommissioning by TEPCO, and the Nuclear Regulatory Authority regulates safety from an independent standpoint. The main basic elements essential for the success of this long-term project have been developed, such as the technical strategy, financial system, and organisational capability. Decommissioning is making progress.

Keywords: Fukushima Daiichi; Decommissioning

1. JAPAN'S EFFORTS AFTER THE ACCIDENT

In the aftermath of the accident at Fukushima Daiichi nuclear power plant, government-wide efforts have been made for both social remediation and technical response to the consequences of the accident. For social remediation and support for

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the victims, such as compensation to the victims, reconstruction of society, and environmental remediation of the contaminated environment, large-scale measures have been made by the Government of Japan and local governments, and great progress has been made in the 10 years since the accident. However, from the mid- to long-term perspective, decommissioning of the damaged and contaminated facilities at Fukushima Daiichi nuclear power plant needs to be carried out to ensure the safety of the region, and various measures have been taken to accelerate the decommissioning project.

1.1. Response to the accident and current status

The actions taken at Fukushima Daiichi nuclear power plant after the accident can be broadly divided into emergency measures taken by the end of 2011, and subsequent measures for stabilisation and clean-up from the mid- and long-term perspectives. In the former, various emergency measures were taken to address the extreme situation caused by the accident, such as cooling the damaged cores and stopping leakage of highly contaminated water into the ocean. From December 2011 onwards, in line with the newly formulated government decommissioning policy (Government of Japan, 2011, 2013, 2015, 2017, 2019), a series of stabilisation measures and clean-up operations were implemented, including recovery of spent fuel, internal inspection of reactors, measures to control contaminated water, and management of radioactive solid waste. As a result, the four damaged reactors can now be controlled quite safely, and a certain level of stability for controlling risk at the site has been reached. As such, the site has entered the next stage (mid- and long-term clean-up). Japanese post-accident responses have undergone international peer review by the International Atomic Energy Agency five times to evaluate their appropriateness from a neutral and comprehensive standpoint (IAEA, 2013a,b, 2015, 2018, 2020).

1.2. Background of the organisational structure to underpin the decommissioning

Under Japanese law related to compensation for nuclear damage, while nuclear accident insurance covers just a portion of compensation for victims, compensation beyond the insurance coverage is the responsibility of the nuclear operator. In addition, under the law regulating nuclear reactors, decommissioning of nuclear facilities is also the responsibility of the operator. However, as the consequences of the accident at Fukushima Daiichi nuclear power plant were so enormous, the amount of compensation was expected to exceed the solvency of Tokyo Electric Power Company Holdings (TEPCO), so the Government of Japan hastily established a new legal system to secure compensation funds and to support the continuation of TEPCO's business. Furthermore, recognising that this decommissioning project was extremely difficult and required a response at national level, the Government of

Japan decided to provide administrative guidance on the decommissioning in the frame of the Act on Special Measures Concerning Nuclear Emergency Preparedness.

To actualise this administrative initiative and facilitate compensation and decommissioning for which TEPCO takes responsibility as a nuclear operator, the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) was founded by legislation.

1.3. Overall organisational structure

Fig. 1 shows the overall organisational structure that is currently in place. Regarding the decommissioning, with recognition that the site is still in a state of emergency, the Nuclear Emergency Response Headquarters of the Government of Japan takes a strong administrative lead in deciding on a policy for the 1F decommissioning in the frame of the Nuclear Disaster Act. The Ministry of Economy, Trade, and Industry (METI) is working as the secretariat to lead this interministerial mechanism. A policy named the 'Mid- and Long-term Roadmap' (Government of Japan, 2011, 2013, 2015, 2017, 2019) serves as the main pillar of the cooperative activities, and TEPCO and all other relevant organisations ought to follow this.

In the first place, TEPCO has a fundamental duty to move forward decommissioning safely and steadily as well as compensation, while doing its best to achieve

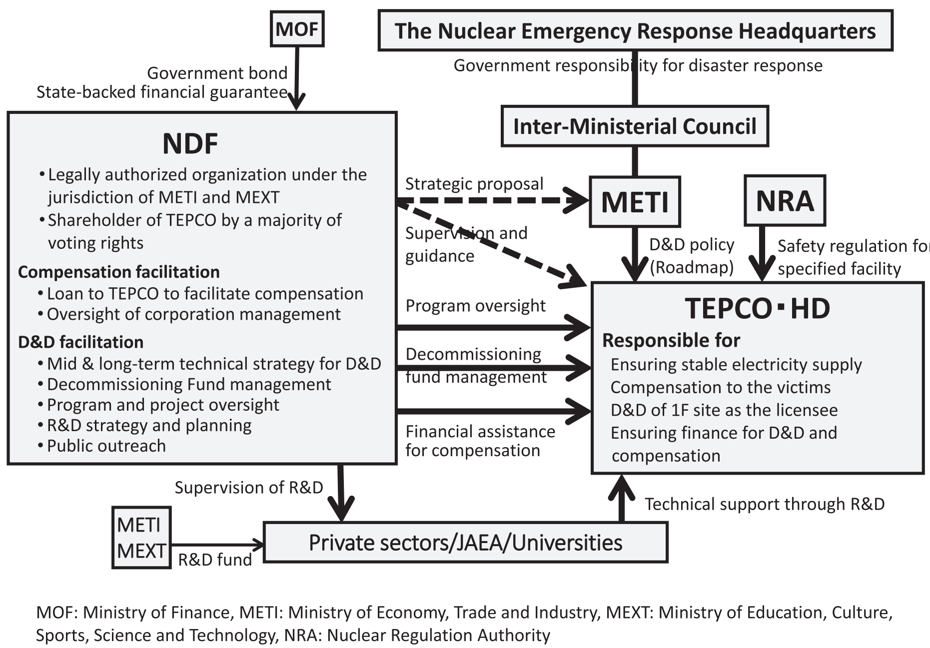

Fig. 1. The organisational structure for decommissioning Fukushima Daiichi nuclear power plant.

reconstruction of the region. For the purpose of accelerating the decommissioning, the Fukushima Daiichi D&D Engineering Company (FDEC), an in-house company specialising in Fukushima Daiichi nuclear power plant, was established.

NDF plays a special role in facilitating this cooperative organisational structure. By accepting the government bonds, NDF supplies a huge amount of money to TEPCO to compensate the victims, and at the same time, NDF invests in TEPCO to obtain the majority voting rights, through which NDF oversees TEPCO's business management.

For TEPCO's decommissioning project, NDF provides TEPCO with guidance and advice on its project management, and is also responsible for managing the funding of TEPCO's decommissioning project. In addition, NDF has voluntarily formulated and published a technical strategy (NDF, 2015, 2016, 2017, 2018, 2019, 2020) for the decommissioning of Fukushima Daiichi nuclear power plant from the mid- and long-term perspective so that decommissioning can proceed successfully in accordance with government guidance. This technological strategy has been referred to in the deliberations for the Government of Japan's roadmap and in TEPCO's decommissioning project plans. In addition, NDF supervises and coordinates the relevant research and development (R&D) subsidised by the Government of Japan.

In terms of ensuring safety, the Nuclear Regulation Authority regulates the safety of the decommissioning from an independent standpoint. Regarding the

Table 1. Timeline of organisational evolution over the past decade.

2011	Mar.	Fukushima Daiichi nuclear accident occurred
2011	Mar.	Emergency Response Headquarters established
2011	Aug.	Nuclear Damage Compensation Facilitation Corporation established
2011	Dec.	1st edition of Mid-and-Long-term Roadmap issued
2012	Sep.	Nuclear Regulation Authority established
2013	Aug.	IRID, founded by private sectors
2013	Sep.	Interministerial Council for Decommissioning and Contaminated Water Management established in Government of Japan
2014	Feb.	Fukushima Advisory Board established
2014	Feb.	Fukushima Daiichi D&D Engineering Company founded in TEPCO
2014	Aug.	NDF re-organised due to the new mission of decommissioning facilitation
2015	Sep.	1st edition of Technical Strategic Plan published by NDF
2017	Oct.	Decommissioning Reserve Fund established in NDF
2019	Dec.	5th edition of Mid-and-Long-term Roadmap issued
2020	Mar.	Mid-and-Long-term Decommissioning Action Plan formulated by TEPCO
2020	Oct.	Latest Technical Strategic Plan (2020) published

IRID, International Research Institute for Nuclear Decommissioning; TEPCO, Tokyo Electric Power Company Holdings; NDF, Nuclear Damage Compensation and Decommissioning Facilitation Corporation.

reinforcement of technical insufficiency, motivated private sectors, institutes, and universities have been contributing by accepting subsidies from the Government of Japan.

Table 1 shows the timeline of organisational evolution over the past decade.

2. BASIC ELEMENTS SUPPORTING THE DECOMMISSIONING

In order to succeed in this difficult challenge, basic elements are needed to underpin this long-term project, such as decommissioning strategy and planning, organisational capabilities of project management and engineering, financing, technologies, and methods. However, as neither TEPCO nor the Government of Japan could prepare for such a large nuclear accident, these elements had to be developed from scratch. As a result of the cooperative efforts, these elements have been gradually created and strengthened over the 10 years since the accident.

2.1. Decommissioning plan and strategy

Internationally, the decommissioning steps following an accident at a facility (IAEA, 2014) are divided into four stages: emergency response; stabilisation; clean-up; and final stage with demolition and remediation. At Fukushima Daiichi nuclear power plant, it is considered that the emergency response and stabilisation stages have been completed, and we have reached the beginning of the clean-up stage. Fig. 2 shows a simplified timeline defined by the latest roadmap (Government of Japan, 2011, 2013, 2015, 2017, 2019). We are currently in Phase 2, and removal of spent fuel from Unit 3 and preparation for the start of fuel-debris retrieval have progressed successfully. Phase 2 is expected to end in 2021, and trial retrieval and gradual expansion of fuel-debris retrieval will start at the first implementing unit within Phase 3. In the first decade of Phase 3, removal of spent fuels

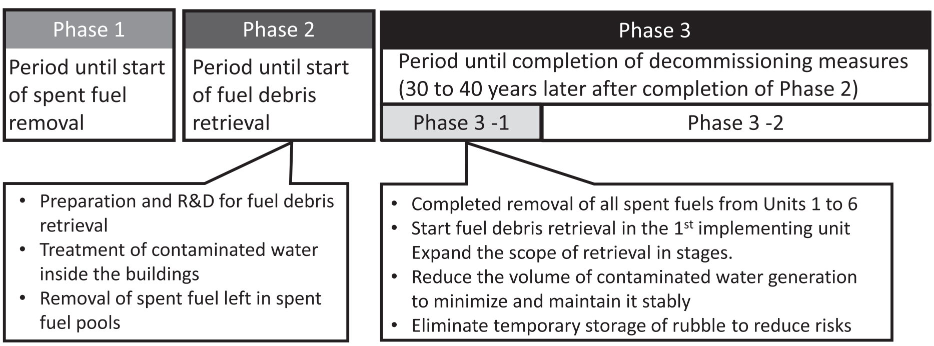

Fig. 2. Future view of the Mid-and-Long-term Roadmap (Government of Japan, 2019). R&D, research and development.

from all reactor units will be completed, and small-scale fuel-debris retrieval will start at the first implementing unit. This will be scaled-up gradually, aiming to start full-scale operation in approximately 2031. In Phase 3-1, the milestones for certain important operations have been defined, such as reducing the volume of contaminated water generation, reducing stagnant contaminated water in the buildings, and enhancing storage of contaminated solid wastes.

The first Mid-and-Long-term Roadmap was issued in late 2011 (Government of Japan, 2011, 2013, 2015, 2017, 2019), providing a holistic and basic approach to the mid- and long-term challenge. The first edition of the Technical Strategic Plan issued by NDF was issued in 2015 (NDF, 2015), and this presented the basic concept and directions based on risk-based strategy. This has resulted in updated strategic directions with specific technical measures.

Technical Strategic Plan 2017 (NDF, 2017) proposed a fuel-debris retrieval policy based on a step-by-step approach, requiring TEPCO to begin the preliminary engineering for fuel-debris retrieval. In 2019, NDF proposed that Unit 2 should be the first implementing unit for small-scale fuel-debris retrieval (NDF, 2019). The latest edition of the Technical Strategic Plan (NDF, 2020) focuses on the significance of enhancing TEPCO's attitude towards responsible full-scale delivery in the future.

The roadmap of the Government of Japan has been revised five times since 2011, updating the key directions with the latest important milestones in major processes, such as the start of fuel-debris retrieval, completion of spent fuel removal, and reduction of stagnant contaminated water in the buildings. In response to these requests from NDF and the Government of Japan, TEPCO's first Mid-and-Long-Term Decommissioning Action Plan 2020 was issued in March, 2020.

2.2. TEPCO's capability to execute the decommissioning project

As TEPCO is a power generation company, it lacked experience in executing a long-term decommissioning project. Also, the domestic supply chain that supported TEPCO's nuclear power generation had no experience in designing and engineering such special decommissioning projects. For this reason, NDF has urged TEPCO to change its operations to a project management style, and to improve its own engineering capability to manage and utilise the technical capabilities of the supply chain. In response, FDEC reconfigured the Work Breakdown Structure (WBS) of the entire decommissioning process, and changed the organisation to a project-oriented one in 2019. Furthermore, FDEC is strengthening its internal engineering efforts. FDEC has also been strongly promoting Kaizen activities to eliminate waste in engineering and procurement.

2.3. Financial base

In order to secure a continuous and steady supply of funds for this long-term challenge, a new fund system was legally established in 2017, called the 'reserve fund for decommissioning'. In this new system, TEPCO is obliged to deposit approximately 2 billion dollars every fiscal year from its business revenue into the special reserve account managed by NDF. The expense for the annual delivery is to be withdrawn based on the annual plan for decommissioning, which is formulated in collaboration with NDF. The excess of the annual deposit is to be accumulated in the reserve account to prepare for future large operations, such as fuel-debris retrieval from the damaged reactors. It is expected to accumulate several tens of billion dollars and will cover completion of fuel-debris retrieval over 30–40 years.

The unique feature of this funding system is that the plan for use of the decommissioning funds must be jointly prepared by both TEPCO and NDF, and the plan requires the approval of the Minister of Economy, Trade and Industry. This means that the plan for the delivery of decommissioning steps needs to be agreed upon by the Government of Japan supervised by NDF, ensuring alignment with the strategic direction.

2.4. Research and development

In view of the urgency and need for development to enable accelerated decommissioning, two ministries – METI and the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) – have subsidised technical entities with motivation. The larger fund comes from METI, which provides approximately 130 million dollars per year to applicants for private companies and institutes, such as the International Research Institute for Nuclear Decommissioning, Japan Atomic Energy Agency (JAEA), and some other domestic and international companies. The major R&D subjects granted with this funding are small-scale fuel-debris retrieval and its scale-up, further scaled-up fuel-debris retrieval for the future, and waste management in terms of solid waste processing and disposal.

In parallel, MEXT subsidises JAEA to conduct an open call research fund for basic research and human resource development by universities. MEXT has tried to close the distance between the needs of TEPCO and the potential technology seeds from the universities. Recently, TEPCO has started preparation to enhance its management of R&D in the frame of its engineering work. NDF is responsible for planning and managing R&D with the METI fund, and coordinating the entire R&D system supported by the Government of Japan. This subsidised R&D system is expected to be improved to meet the first-hand needs from implementations at the site to increase the use of potential seeds for technical entities.

3. CONCLUSION

In Japan, although the accident was very sudden and no preparation was in place to respond to the aftermath, great efforts have been made to develop a solid organisational structure within the legal framework. As a result, under the strong initiative of the Government of Japan, a pragmatic and workable institutional system has been established to enable TEPCO and other related organisations to cooperate systematically. In this system, NDF is playing a special role in coordinating, facilitating, and supporting the entire system. At present, the elements that should support the long-term project, such as government policies, technical strategy, project plans, TEPCO's organisational capability, securing of finance, and R&D with government support, have been developed and strengthened. The decommissioning of Fukushima Daiichi nuclear power plant is making steady progress.

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Fukushima Daiichi decontamination and decommissioning: current status and challenges

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Abstract–It has been nearly 10 years since the accident at Fukushima Daiichi nuclear power plant. With the cooperation of those involved, the site, which was once in a crisis situation, has improved to the point where it is possible to look ahead and proceed with work on schedule. In the off-site area, conditions for returning home have been progressed, and evacuation orders for some areas have been lifted by the Japanese Government. This article describes, in respect of the various efforts being made on site at the moment, the current status of fuel removal from the spent fuel pools, preparations for fuel debris retrieval, improvement of the working environment, and future plans. Removal of fuel from the spent fuel pool for Unit 4 was completed in December 2014, and work is continuing with Unit 3 in order to complete by March 2021. The decision was made to install a large cover in advance for Unit 1 in consideration of the risk of dust scattering, and to conduct fuel removal for Unit 2 from the south side without dismantling the existing upper section of the building. The target is for fuel removal from the pools, including Units 5 and 6, to be complete by 2031. Regarding fuel debris retrieval, progress in various investigations has made it possible to grasp the distribution of debris in the reactor containment vessels of Units 1–3 to a certain extent, and it was decided that the first retrieval will start with the most-investigated unit (Unit 2). A robot arm will be used for retrieval; initially, a trial retrieval will be started, and once the retrieval method has been verified and confirmed, the scale of retrieval will be expanded in stages using a device with the same mechanism. The working environment of Fukushima Daiichi nuclear power plant has also improved. By reducing the stirring up of radioactive materials due to facing (paving), etc., it became possible to reduce the degree of protective clothing needed, and the area in which people can work with simple clothing such as general work clothes now represents 96% of the entire site. Due to various reduction measures, the effective dose of workers is currently approximately 0.2–0.4 mSv $month^{-1}$ on average per person. The work environment will

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

continue to be improved steadily in the future. Finally, I would like to briefly mention the direction of future decommissioning efforts. The decommissioning of Fukushima Daiichi nuclear power plant and contaminated water management are being implemented based on the national Mid-and-Long-Term Roadmap. The latest edition (5th revision) sets out the milestones until 2031, and we are on target to achieve the goals set forth here and the goals set forth in the Nuclear Regulatory Commission's risk map. To that end, the Mid-and-Long-Term Decommissioning Action Plan 2020, which shows the main work processes of the decommissioning, was announced. This will enable us to proceed with decommissioning work more systematically in the future while looking ahead. Local people who sometime are concerned about risk arising from Fukushima Daiichi may grasp the future work plan concretely in relief, and can consider taking part in the decommissioning work. The key lies in how we can contribute to the reconstruction of Fukushima through the decommissioning of Fukushima Daiichi nuclear power plant, and we will continue to take responsibility for decommissioning of the power plant and contaminated water management under the principle of 'striking a balance of reconstruction and decommissioning'.

Keywords: Decommissioning; Fuel removal; Fuel debris retrieval; Work environment improvement; Striking a balance between reconstruction and decommissioning

1. BACKGROUND TO THE ACCIDENT AND PURPOSE OF THE DECOMMISSIONING WORK

It has been nearly 10 years since the Great East Japan Earthquake on 11 March 2011. At the time, Units 1–3 were in operation in the six reactor/turbine buildings at Fukushima Daiichi nuclear power plant, and operation was safely discontinued immediately after the earthquake. However, the tsunami that struck approximately 50 min later caused the power plant to lose all power. The reactor lost its cooling function and the fuel melted. The hydrogen generated in the process caused an explosion at Units 1, 3, and 4, where the exhaust pipe was connected to Unit 3. In addition, radioactive materials diffused from the containment vessel, which was no longer airtight due to the increase in internal temperature and pressure, to the surrounding area, resulting in the evacuation of many people.

The Japanese Government declared a 'cold shut-down status' in December 2011, and each unit has since maintained a stable cooling state due to the decrease in decay heat of fuel debris and spent fuel. The evacuation area has been reduced gradually due to decontamination and the restoration of infrastructure by the national and local governments. In April 2019, residents began to return to the town where Fukushima Daiichi nuclear power plant is located.

The purpose of the decommissioning of Fukushima Daiichi nuclear power plant is based on the principle of 'striking a balance between reconstruction and decommissioning' so that the return of residents can proceed smoothly, and those who have already returned can live with peace of mind and rebuild the area. To that end, efforts are being made to reduce the risk of radioactive substances continuously in order to protect people and the environment.

2. FUEL REMOVAL FROM THE SPENT FUEL POOL

As with general nuclear power plants, fuel will be taken out first during the decommissioning of Fukushima Daiichi nuclear power plant. However, unlike ordinary reactors, the impact of the hydrogen explosion and meltdown represent a major obstacle in the preparations for removal.

Fuel will be removed from the spent fuel pool on each refuelling floor in the following order: (i) removal of rubble (excluding Unit 2 where there was no hydrogen explosion); (ii) decontamination/shielding; (iii) installation of fuel handling machine; (iv) fuel removal; and (v) storage in a shared pool, etc. on the premises.

With the exception of Unit 4 where fuel removal was completed in December 2014, the doses on all of the refuelling floors at Units 1–3 (where core meltdown happened) are high. As it is necessary to pay particular attention to the exposure of workers, most of the work is done remotely.

At Unit 1, the removal of rubble on the north side of the refuelling floor commenced in January 2018 and has already been completed. On the south side, where the spent fuel pool is located, rubble is piling up and covering the spent fuel pool, such as the fuel handling machine, overhead crane, steel frames, and slabs of collapsed roofs. Installation of a cover over the gate of the spent fuel pool, curing of the spent fuel pool, and props that support the fuel handling machine and overhead crane from below were conducted recently in order to reduce the risk as much as possible of steel frames, slabs, etc. falling into the spent fuel pool and scattering dust. In the future, a large cover will be installed, the rubble on the refuelling floor will be removed, and fuel removal will begin in approximately 2027–2028.

In Unit 2, in June 2020, the condition of fuel, etc. in the spent fuel pool was confirmed using a remotely operated underwater vehicle, and it was confirmed that there were no new issues that would hinder fuel removal. A preparation work for a platform to be installed on the south side of the reactor building is going on. And in the future, there will be an opening on the south side of the building to access the refuelling floor from this platform. Removal will start in approximately 2024–2026 (Fig. 1).

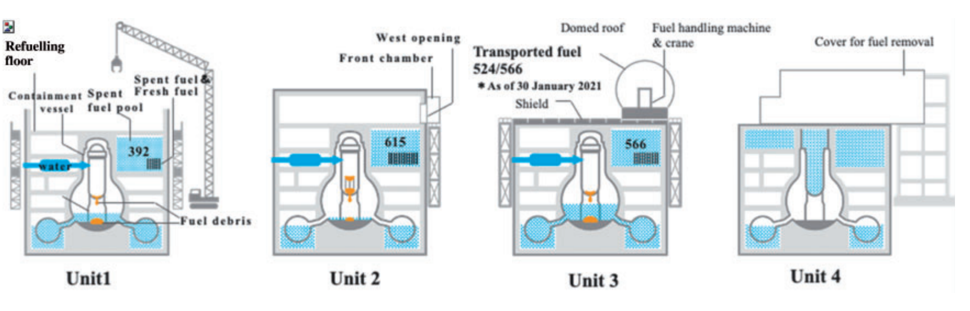

Fig. 1. Status of each unit.

Fuel removal for Unit 3 commenced in April 2019. As of 30 January 2021, 524 of 566 fuel assemblies have been taken out, and the remaining 42 are scheduled to be taken out by March 2021.

3. AIMING FOR FUEL DEBRIS RETRIEVAL

The retrieval of fuel debris at Units 1–3 will be an initiative that has never been experienced before. The retrieval work will proceed in the following order: (i) internal investigation of the reactor containment vessel; (ii) fuel debris retrieval; and (iii) storage. However, as this work needs to be undertaken in an extremely high-dose environment, most work will be carried out remotely.

In order to determine the extraction method and proceed with the development of specific extraction equipment, it is first necessary to grasp the position and properties of the fuel debris.

The distribution of fuel debris is estimated as follows from the above survey results and accident transient analysis results:

- Unit 1: Most fuel debris is at the bottom of the containment vessel.
- Unit 2: A large amount of fuel debris remains at the bottom of the pressure vessel, and a certain amount is present at the bottom of the containment vessel.
- Unit 3: Somewhere in between Unit 1 and Unit 2.

As such, it was decided that retrieval will start in Unit 2. The main reasons for this decision are that the dose in Unit 2 is lower compared with the other units, more information has been obtained from internal investigations in Unit 2, and there is no interference with fuel removal work.

The equipment to be used in the upcoming trial retrieval is being developed in the UK and will be put into actual operation after testing and training at a mock-up facility. The plan is to use a robot arm with a maximum length of approximately 22 m to access the inside of the containment vessel. This robot arm is made of high-strength stainless steel so it will not bend even when stretched. Moreover, the plan is that a gold brush or a vacuum container type recovery device will be attached to the tip of the robot arm to recover grained fuel debris.

After the trial, once the retrieval method has been verified and confirmed, the scale of retrieval will be expanded in stages using devices with the same mechanism.

Tokyo Electric Power Company Holdings (TEPCO) was aiming to start fuel debris retrieval in 2021, but the development of these devices has been delayed due to the spread of coronavirus disease 2019 in the UK. We would like to continue to give top priority to safety while making efforts to keep the delay to approximately 1 year.

4. IMPROVEMENT OF WORK ENVIRONMENT

Immediately after the accident, reducing the effective dose of workers was an important issue at Fukushima Daiichi nuclear power plant. As such, in addition to dose reduction measures such as removal of high-dose rubble scattered by the explosion, removal of topsoil contaminated by fallout, logging of contaminated trees, and purification of contaminated water stored in the on-site tank, ground surface facing (mortar spraying and asphalt pavement) has been conducted.

As these efforts to improve the working environment reduced the stirring up of radioactive materials, the premises surrounding Units 1–4 were categorised as 'highly contaminated areas' (red zone and yellow zone) and 'other areas' (green zone) in March 2016 in order to optimise protective equipment. Currently, the green zone, where an individual can work wearing general work clothes and a disposable dust respirator, has been expanded to cover approximately 96% of the entire site.

In March 2011, the effective dose reached 21.55 mSv month^{-1} (average) as a result of the response immediately after the accident; this subsequently reduced significantly, and the latest measurement was in the range of 0.2–0.4 mSv month^{-1}. Meanwhile, the average effective dose for the last year was 2.54 mSv month^{-1} (April 2019 to March 2020).

In recent years, management and measures regarding the equivalent dose to the lens of the eye have been strengthened. TEPCO has addressed the issues based on the Ionising Radiation Hazard Prevention Regulations, and also introduced a management value of $\leq$ 50 mSv year^{-1} in April 2018 without waiting for the revision of the law in 2021 in order to further improve the safety of workers (current 150 mSv year^{-1} will be revised to 50 mSv year^{-1} and 100 mSv for 5 years). Furthermore, regarding the 5-year dose management of the equivalent dose to the lens of the eye, an arrangement such as the aggregation method (system) was conducted, and an operation with an annual average of 20 mSv for 5 years was introduced in April 2019.

As a specific reduction measure on site, it has been essential to wear a full-face respirator when working in a place where beta rays are dominant and the crystalline lens is exposed. In addition to this, since April 2018, additional measurements near the eyes have been conducted if the equivalent dose to the lens of the eye exceeds 15 mSv. Not only that, when workers are working in a place where beta rays dominate, regardless of 15 mSv, a dosimeter is worn inside the full-face respirator to measure the dose near the eyes to evaluate the equivalent dose to the lens of the eye more accurately. In order to carry out these works, a jig for attaching a dosimeter near the eyes in the full-face respirator has been developed.

Regarding the equivalent dose to the lens of the eye, 64 people exceeded 20 mSv in fiscal year (FY) 2019. However, due to thorough implementation of these efforts, no workers exceeded 20 mSv in the first half of FY2020. It is expected that a similar result will be seen by the end of the year.

From April 2021, if the annual dose exceeds 12 mSv, a dosimeter will be worn near the eyes, and operations to finely control the dose to which workers are exposed will be commenced to ensure their safety.

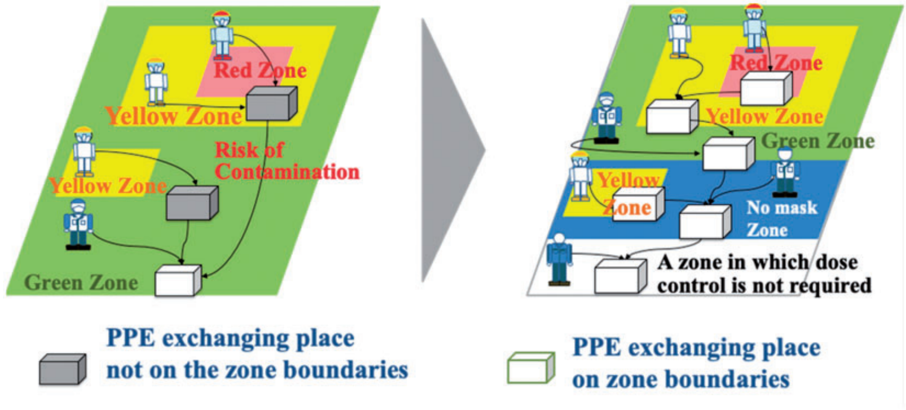

Fig. 2. Improvements to the working environment. PPE, personal protective equipment.

5. THE BLUEPRINT OF AN IMPROVED WORK ENVIRONMENT

In the future, work will be pursued based on 'further improvement of the work environment' and 'strengthening of radiation management targeting fuel debris retrieval'.

As a further improvement of the work environment, exchange places for personal protective equipment will be established at each area boundary to prevent the spread of contamination, while in less-contaminated areas, areas where respirators (including the DS-2 respirator) are not required will be established. Furthermore, areas will be set that do not require radiation control, such as dose control and contamination control, in a bid to enable work to be carried out more comfortably in a way that is easily understandable to the workers (Fig. 2).

On the other hand, there is concern that alpha nuclides could spread as fuel debris retrieval gathers momentum. In response to this, in addition to stricter on-site management, such as on-site monitoring and measures to control the spread of contamination at the boundary of the alpha-controlled area, lung monitors and bioassay facilities will be installed so that exposure evaluation can be possible, even if an internal intake should happen.

6. CONCLUSION – AIMING TO BALANCE RECONSTRUCTION AND DECOMMISSIONING

TEPCO is proceeding with the decommissioning work based on the Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1–4 compiled by the Japanese Government in December 2011 (hereinafter 'Mid-and-Long-Term Roadmap'). The first phase in this roadmap is defined as the period before the start of spent fuel removal, and the second phase is defined as the period until the start of retrieval of melted fuel debris. The final (third) phase will be a long period lasting until the decommissioning is complete, and the Mid-and-Long-Term Roadmap revised in December 2019 repositioned the first 10 years of the third phase as a new period (3-1). This period is defined as the time when TEPCO will proceed systematically with multiple processes, such as fuel removal and contaminated water management, in order to carry out more full-scale decommissioning work (i.e. fuel debris retrieval). The main milestones have also been defined for the various fields.

With this in mind, in March 2020, the key process to achieve these milestones and the goals set out in the Nuclear Regulatory Authority's Risk Map was developed and announced. It is referred to as the 'Mid-and-Long-Term Decommissioning Action Plan 2020'. From now on, the plan is that it will be revised every year, and the Mid-and-Long-Term Decommissioning Action Plan 2021 will be published in March 2021. The Mid-and-Long-Term Decommissioning Action Plan enables TEPCO to undertake the decommissioning work more systematically while looking to the future. Local people will be able to understand the future decommissioning work in detail, and may consider joining the decommissioning work. The Mid-and-Long-Term Roadmap revised in December 2019 clearly states 'balancing reconstruction and decommissioning' as another pillar. Bearing this in mind, TEPCO will continue to take responsibility for decommissioning Fukushima Daiichi nuclear power plant and contaminated water management, so that the decommissioning work will enable reconstruction of the region.

Status of research and development conducted by the International Research Institute for Nuclear Decommissioning

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Abstract–Since the International Research Institute for Nuclear Decommissioning (IRID) was established as a technology research association in August 2013, it has been engaged in research and development (R&D) for decommissioning the Fukushima Daiichi nuclear power plant, which is currently an urgent issue, to strengthen the platform for decommissioning technology for the future. The work of IRID R&D is classified into three main pillars: removal of spent nuclear fuel from the pool; retrieval of fuel debris; and technological development for treatment and disposal of solid radioactive waste. This article describes an overview of R&D as of the first half of the fiscal year 2020, mainly focusing on investigation inside primary containment vessels and retrieval of fuel debris.

Keywords: Investigation inside primary containment vessels; Retrieval of fuel debris

1. OVERVIEW OF IRID

1.1. Organisation of IRID

The International Research Institute for Nuclear Decommissioning (IRID) is an organisation currently composed of the following Japanese organisations, the so-called 'all-Japanese structure':

- Two national research and development agencies: Japan Atomic Energy Agency and National Institute of Advanced Industrial Science and Technology.

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- Four plant manufacturers: Toshiba Energy Systems & Solutions Corporation; Hitachi-GE Nuclear Energy, Ltd; Mitsubishi Heavy Industries, Ltd; and ATOX Co., Ltd.
- Twelve electric utility companies: Hokkaido Electric Power Co., Inc.; Tohoku Electric Power Co., Inc.; Tokyo Electric Power Company (TEPCO) Holdings, Inc.; Chubu Electric Power Co., Inc.; Hokuriku Electric Power Company; Kansai Electric Power Company, Inc.; Chugoku Electric Power Co., Inc.; Shikoku Electric Power Company, Inc.; Kyushu Electric Power Company, Inc.; Japan Atomic Power Company; Electric Power Development Co., Ltd.; and Japan Nuclear Fuel Ltd.

1.2. Roles of IRID

Four organisations are working closely together as one team to decommission Fukushima Daiichi nuclear power plant. The Ministry of Economy, Trade, and Industry (METI) of the Japanese Government has determined the major policy and is undertaking overall progress management in accordance with the mid- and long-term roadmap. The Nuclear Damage Compensation and Decommissioning Facilitation Corporation is planning decommissioning strategies and developing research and development (R&D) to support the government activities. TEPCO Holdings and Fukushima Daiichi D&D Engineering Company are undertaking the work on-site, and IRID is in charge of implementing R&D.

1.3. R&D projects conducted by IRID

In general, R&D consists of four stages: fundamental research; basic research; applied research; and practical application. The scope of R&D conducted by IRID includes basic research, applied research, and practical application. Fig. 1 presents R&D projects conducted by IRID. These projects are being undertaken under subsidy projects of the Decommissioning and Contaminated Water Management granted by METI, and in collaboration with international organisations.

2. PROGRESS AND PROSPECTS OF RESEARCH

2.1. Investigative technology for PCV interior

Radiography using a cosmic ray muon was applied to Units 1–3 to investigate the conditions inside the primary containment vessel (PCV) for each unit. Fig. 2 depicts the overviews of muon measurement technology and investigative results of Unit 3. The results of estimation and investigation of the conditions of the reactor interior in each unit (evaluation results through the analysis code, analysis results obtained from actual measurement and experimental data, and results of the site investigation) were summarised as an integrated estimation figure of the PCV interior.

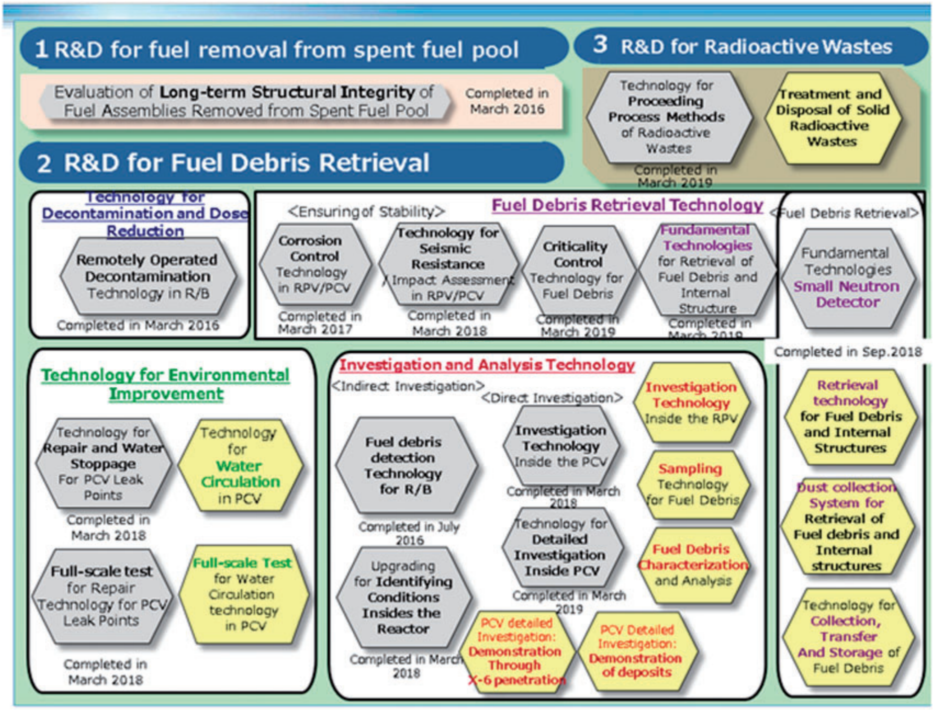

Fig. 1. International Research Institute for Nuclear Decommissioning research and development projects.

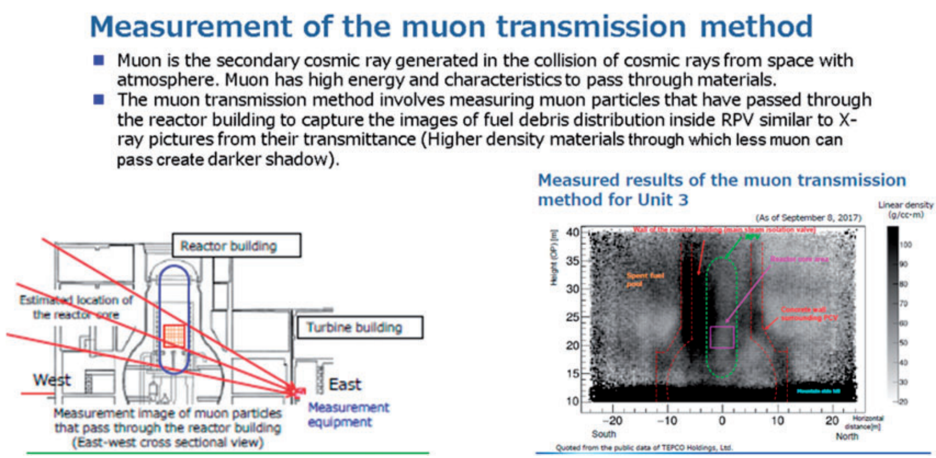

Fig. 2. Results of measuring inside the reactor using muons.

IRID have developed investigative robots to investigate the damaged conditions inside the PCVs and the spread of fuel debris depending on the investigation required for each unit. Fig. 3 shows robots developed for the investigation of PCV interiors.

A site verification test was performed to investigate Unit 2 in January 2018, and the investigative robot successfully obtained an image of the basic structure of the reactor pressure vessel (RPV), i.e. the RPV pedestal (Fig. 4).

Fig. 4 depicts an image of sediment spreading at the bottom of the RPV pedestal, obtained by accessing the lower part of the RPV inside the pedestal. Currently, IRID

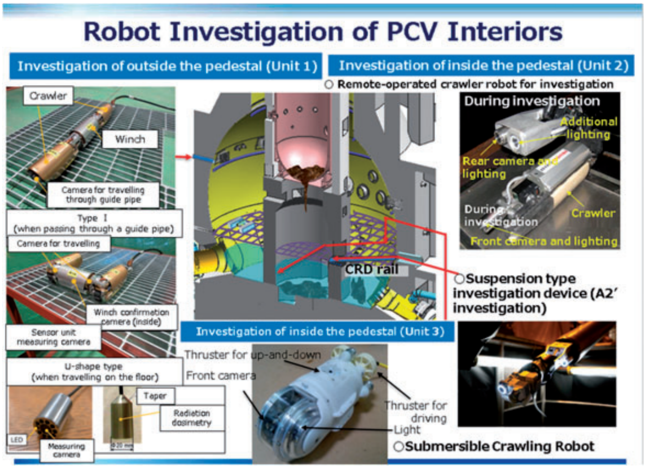

Fig. 3. Robot investigation of primary containment vessel interiors.

Fig. 4. Inside the bottom of the primary containment vessel, adjacent to the inner wall of the pedestal, in Unit 2.

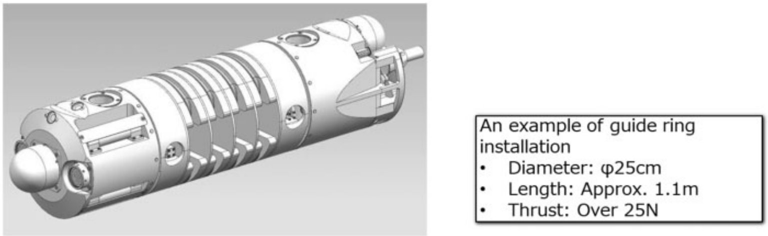

Fig. 5. Apperance of the boat type access device.

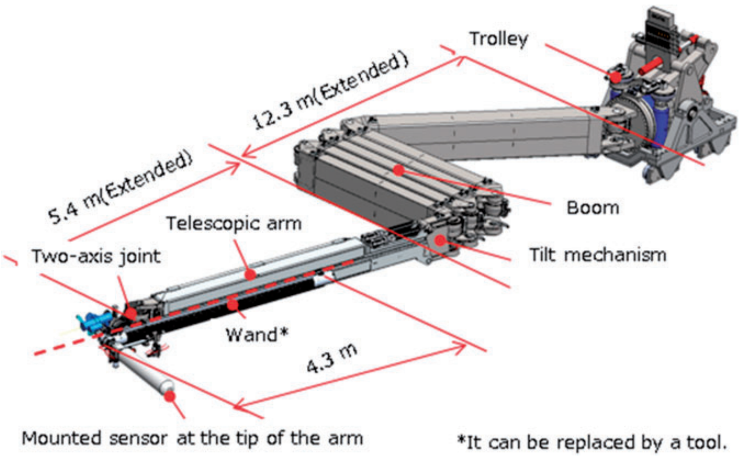

Fig. 6. Arm-type access apparatus.

is undertaking the development of new investigative apparatus able to acquire substantially more information. New boat-type access and investigative apparatus with submersible functions has been developed as a water level of approximately 2 -m length for the PCV of Unit 1 (Fig. 5). This apparatus is cylindrical in shape, with an approximate length of 1.1 m and diameter of 25 cm. It is equipped with various sensors to acquire information: a scanning-type ultrasonic distance metre to obtain shape data of the sediment accumulated at the bottom of the PCV; a high-power ultrasonic sensor to measure the thickness of the sediment; and a radiation detector to identify the distribution of fuel debris.

To investigate Unit 2, arm-type access apparatus (Fig. 6) has been developed for test retrieval of fuel debris, while accessing the inside of the PCV through the existing X-6 penetration (PCV penetration).

The arm-type access apparatus, with a total length of 22 m, can be folded and stored in the enclosure that is connected to the PCV, situated outside, before use. When using the arm, it can be unfolded and inserted into the PCV. Investigative

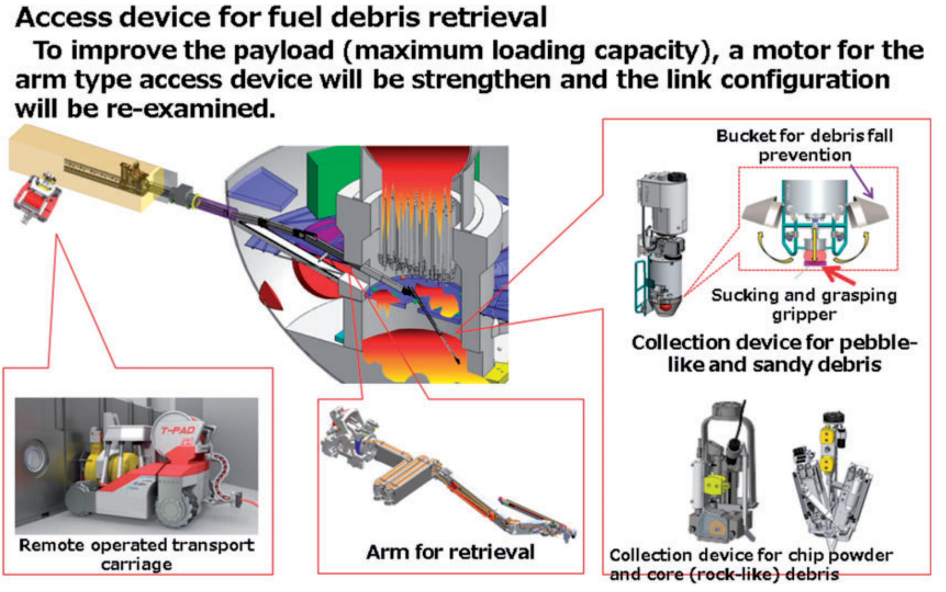

Fig. 7. Increasing the scale of retrieval of fuel debris.

equipment up to 10 kg can be loaded on the arm head. Fig. 7 shows an overview of the investigation inside the PCV using the arm-type access apparatus. The arm stored in the enclosure is designed to pass through X-6 penetration via the PCV connection structure, and enter the PCV accordingly.

2.2. Technological development of retrieval of fuel debris

Retrieval of fuel debris is planned to take a step-by-step approach in a flexible manner based on information obtained from test retrieval of fuel debris, increasing the scale of retrieval of fuel debris, and further increasing the scale of retrieval of fuel debris while proceeding with retrieval. Various technologies for apparatus have been developed for use in each stage. IRID has been developing methods applicable to the site in cooperation with relevant organisations while studying various methods.

R&D of JAEA for the decommissioning of TEPCO's Fukushima Daiichi nuclear power station

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Abstract–Since the accident at Fukushima Daiichi nuclear power station in March 2011, Japan Atomic Energy Agency (JAEA) has been contributing actively to the environmental recovery of Fukushima and the decommissioning of Fukushima Daiichi nuclear power station from a technical aspect, through a wide range of research and development (R&D) activities including fundamental research and applicational technology development. JAEA has been conducting R&D such as the characterisation of fuel debris, and treatment and disposal of radioactive wastes based on the 'Mid-and-Long-Term Roadmap' authorised by the Japanese Government. This R&D is mainly promoted by Collaborative Laboratories for Advanced Decommissioning Science (CLADS) in Tomioka Town, and CLADS has also been promoting cooperation with domestic and foreign research institutes, related companies, universities, etc. In addition, Naraha Centre for Remote Control Technology Development in Naraha Town commenced full operation in April 2016 for the development and demonstration of remote control technologies planned for use in the decommissioning of Fukushima Daiichi nuclear power station and disaster response. Okuma Analysis and Research Centre in Okuma Town is under construction for the analysis and characterisation of fuel debris and various radioactive wastes. Ten years have passed since the Great East Japan Earthquake and the accident at Fukushima Daiichi nuclear power station, and environmental conditions in Fukushima have been improving. The evacuation zone has been lifted, and preparation of specific recovery areas in the difficult-to-return zone has progressed. However, the reconstruction of Fukushima and the decommissioning of Fukushima Daiichi nuclear power station are still in progress, and JAEA will continue its R&D for the decommissioning of Fukushima Daiichi

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nuclear power station with domestic and international expertise in order to further contribute to the reconstruction of Fukushima.

Keywords: Fukushima environmental recovery; Fukushima Daiichi nuclear power station decommissioning; Infrastructure development of research and developmental bases

1. OVERVIEW OF JAPAN ATOMIC ENERGY AGENCY

Japan Atomic Energy Agency (JAEA), the only comprehensive nuclear research and development (R&D) institution in Japan, aims to contribute to the welfare and prosperity of human society through nuclear science and technology. The focus areas of JAEA are as follows, in accordance with the Medium/Long-Term Plan:

- response to the accident at Fukushima Daiichi nuclear power station;
- research on improving the safety of atomic energy;
- R&D of the nuclear fuel cycle; and
- development of radioactive waste treatment/disposal technology.

In parallel with the various efforts of the Japanese Government in the fields of science and technology, JAEA has compiled a vision for the future – 'JAEA 2050+' – on what to aim for and what to do by 2050.

1.1. R&D bases for JAEA

JAEA has R&D bases all over Japan, from Hokkaido in the north to Okayama Prefecture in the south (Fig. 1). The largest bases are located in Tokai Village and Oarai Town in Ibaraki Prefecture, and include research reactors and accelerators, as well as hot laboratory facilities that can handle nuclear fuel materials. Originally, JAEA did not have R&D bases in Fukushima Prefecture, but following the accident at Fukushima Daiichi nuclear power station, efforts have been made to develop bases needed for R&D related to decommissioning.

1.2. Structure of JAEA

Fig. 2 shows the structure of JAEA. JAEA adopted the R&D sector system, and the basic structure has six sectors. The Sector of Fukushima R&D is the main player for R&D for decommissioning Fukushima Daiichi nuclear power station, and other sectors (e.g. Sector of Nuclear Science Research, and Sector of Nuclear Fuel, Decommissioning, and Waste Management Technology Development) work together with the Sector of Fukushima R&D to fully activate the potential ability of JAEA R&D.

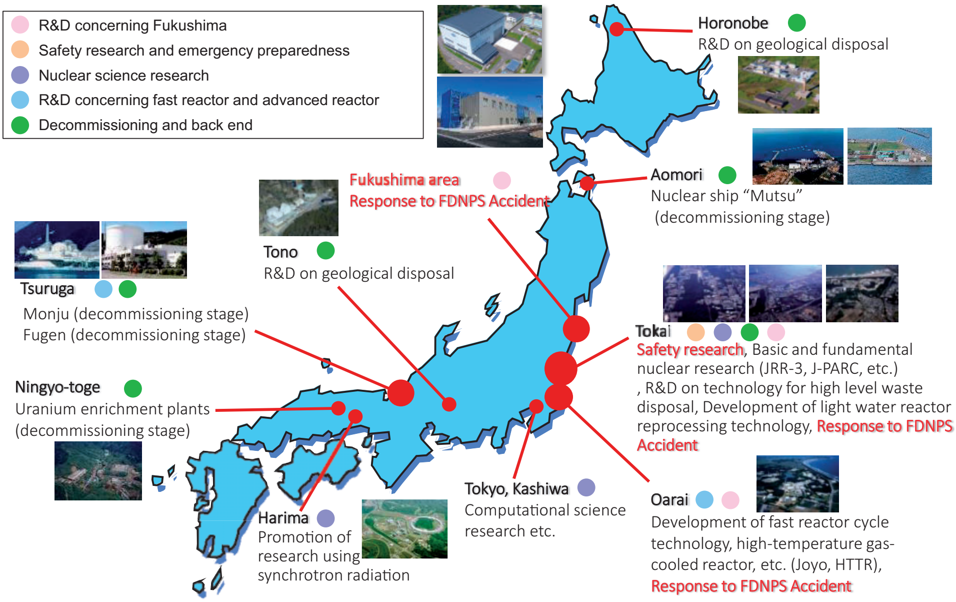

Fig. 1. Research and development (R&D) bases of Japan Atomic Energy Agency. FDNPS, Fukushima Daiichi nuclear power station.

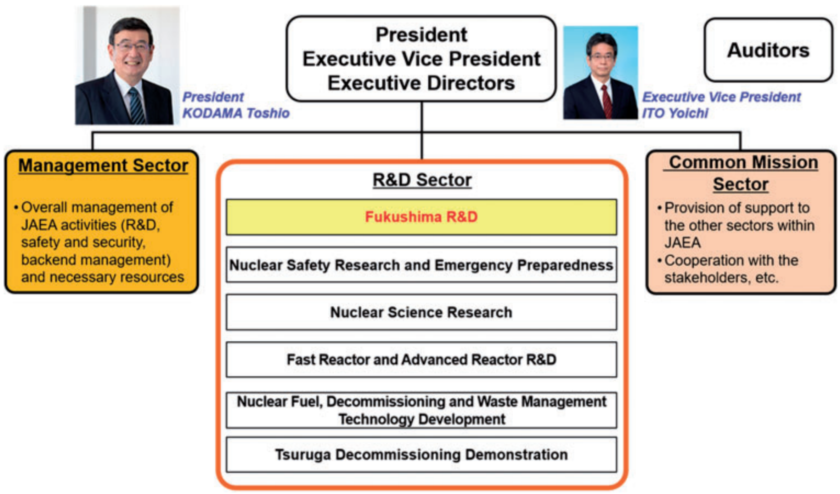

Fig. 2. Structure of Japan Atomic Energy Agency (JAEA). R&D, research and development.

2. RESEARCH AND DEVELOPMENT ACTIVITIES THAT CONTRIBUTE TO THE DECOMMISSIONING OF FUKUSHIMA DAIICHI NUCLEAR POWER STATION

JAEA is conducting R&D on the decommissioning of Fukushima Daiichi nuclear power station and environmental recovery based on three pillars. The first is the infrastructure development of R&D in Fukushima Prefecture, the second is R&D for decommissioning Fukushima Daiichi nuclear power station, and the third is R&D for environmental restoration in Fukushima. The third pillar is not related directly to decommissioning Fukushima Daiichi nuclear power station, but radioactive materials were scattered around Fukushima Prefecture due to the accident at the power station. As such, environmental dynamics research, such as environmental monitoring and how radioactive substances (e.g. caesium) move, is being carried out with the aim of recovery of the environment in Fukushima, which is thought to be important for the reconstruction of Fukushima.

2.1. History of the Sector of Fukushima R&D

JAEA is designated as a supporting public institution under the Act on Special Measures Concerning Nuclear Emergency Preparedness. Therefore, immediately after the accident at Fukushima Daiichi nuclear power station caused by the Great East Japan Earthquake, JAEA's experts were dispatched to Fukushima Prefecture for the implementation of environmental monitoring, decontamination demonstration projects, measurement of internal exposure of residents using whole-body counters in Fukushima Prefecture, and public meetings for those who were concerned about the health effects of radiation.

Subsequently, in response to the Japanese Government's formulation of a Mid-and-Long-Term Roadmap for decommissioning Fukushima Daiichi nuclear power station in December 2011, JAEA began full-scale R&D on decommissioning. In 2014, the Sector of Fukushima R&D was established as a formal organisation to tackle these issues. Since then, the infrastructure for R&D has improved. Naraha Centre for Remote Control Technology Development (NARREC) started operating in 2016, followed by the Collaborative Laboratories for Advanced Decommissioning Science (CLADS) in 2017, and the Administration Building of Okuma Analysis and Research Centre in 2018.

2.2. R&D bases in Fukushima and their infrastructure

Three centres and five bases have been established for R&D in Fukushima Prefecture. CLADS is conducting R&D for environmental recovery, such as monitoring and environmental dynamics at the bases established by Fukushima Prefecture in Miharu Town and Minamisoma City. R&D for decommissioning is being carried out by NARREC, CLADS, and the Okuma Analysis and Research Centre at bases in Hamadori district such as Naraha, Tomioka, and Okuma Town.

NARREC is a large facility where mock-ups (actual size models) can be installed, and it is possible to empirically verify the work planned on site in advance. For example, the pilot debris removal work scheduled for Unit 2 of Fukushima Daiichi nuclear power station will be pre-checked here. A virtual reality system to enable the working environment to be checked without going to site is also being developed (JAEA, 2018).

The Okuma Analysis and Research Centre is a facility that analyses radioactive waste and fuel debris from Fukushima Daiichi nuclear power station, and is currently under construction on the land next to the power station to facilitate transportation of analytical samples. In order to handle high-radiation samples, the plan is to install equipment such as concrete cells and iron cells that can block radiation, and equipment such as glove boxes that can contain radioactive substances (JAEA, 2017).

2.3. R&D structure of the decommissioning of Fukushima Daiichi nuclear power station

R&D for the decommissioning of Fukushima Daiichi nuclear power station is being carried out with funding from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) and the Ministry of Economy, Trade, and Industry (METI). The R&D under the jurisdiction of MEXT is medium- to long-term basic research, and is called the 'World Intelligence Project'. This brings together domestic and foreign wisdom with operations mainly carried out by JAEA. The R&D under the jurisdiction of METI is technological development that is close to on-site application, and the strategy is established by the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF). JAEA is proceeding with lean R&D by exchanging information with NDF.

2.4. CLADS activities for decommissioning Fukushima Daiichi nuclear power station

CLADS conducts basic research, exchanges opinions with NDF and Tokyo Electric Power Company Holdings, and organises research issues that will be needed in the future as 'basic foundational research'. CLADS functions as a hub to promote collaboration with domestic and international institutions and universities, but also carries out its own R&D. R&D into nuclear fuel analysis and its evaluation, reproduction/simulation technology of what happened in the accident reactor, analysis and its concept for the treatment and disposal of radioactive waste, and technology for measuring radiation remotely are underway, taking advantage of the strengths of JAEA. Furthermore, in advancing the decommissioning of Fukushima Daiichi nuclear power station, cooperation with foreign organisations, such as the Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) and the International Atomic Energy Agency, and cooperation with advanced nuclear power countries, such as the USA, the UK, and

France, are extremely important. As well as benefitting from international cooperation, new knowledge is also being incorporated.

2.5. Human resource development

The decommissioning of Fukushima Daiichi nuclear power station will be a long-term effort taking 30–40 years. Therefore, it is very important to develop the next generation in order to continue the effort. The following have commenced:

- Human resources development programme for students – in addition to implementing various human resource development programmes, research collaboration with universities and technical colleges is being promoted.
- Creative robot contest for decommissioning – this is held every year at NARREC. College students manufacture robots that reflect the problems and solutions that are expected in decommissioning work, and compete in terms of performance.
- Fukushima research conference – young researchers are invited from Japan and overseas to Fukushima to announce the current state of R&D on various topics, and also to discuss future directions for R&D.

3. FUTURE PROSPECTS

As shown in the Mid-and-Long-Term Roadmap, JAEA needs to utilise its technology and knowledge as follows:

- Based on the analysis results of radioactive waste, a technical method for storage, treatment, and disposal of waste will be proposed.
- Based on the results of R&D and analysis of fuel debris, a technical method for storing, processing, and disposing of debris will be proposed.
- Utilising the analysis results of radioactive waste and fuel debris, the accident progress at Fukushima Daiichi nuclear power station will be analysed, and the results will be fed back in order to improve reactor safety.

Moreover, the framework of international cooperation, including joint projects sponsored by OECD/NEA, is important in terms of both the contribution to decommissioning of Fukushima Daiichi nuclear power station and research into safety. JAEA will continue to implement and further develop projects such as PreADES and ARC-F.

JAEA will continue to carry out activities such as R&D and human resource development, and will contribute to the support of local companies in Fukushima Prefecture and the reconstruction of Fukushima.

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Radiocaesium in the environment of Fukushima

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Abstract–It has been 10 years since the accident at Fukushima Daiichi nuclear power plant in 2011. Large quantities of ^{131}I, ^{134}Cs, and ^{137}Cs were released into the environment, and 80% of ^{137}Cs still remains. In addition to the decrease by attenuation, the transfer of ^{137}Cs to plants, animals, and humans is decreasing due to movement and changing fractions with elapsed time. The activity concentration of ^{137}Cs in the atmosphere has decreased drastically, and the internal radiation dose due to inhalation is negligible. The activity concentration of ^{137}Cs in agricultural plants is decreasing due to decontamination of soil, application of potassium, and lower levels in irrigation water. The activity concentration of ^{137}Cs in wild animals is decreasing, and shows seasonal variation in wild boars. The activity concentration of ^{137}Cs in offshore seawater has decreased to 0.01 Bq l^{-1}. Therefore, the radiation dose is <1 mSv of the additional radiation dose.

Keywords: Atmosphere; Soil; Irrigation water; Rice; Marine; Wild animal; Radiation dose exposure

1. INTRODUCTION

The most powerful earthquake in Japanese recorded history, with an epicentre offshore from Tohoku region, occurred on 11 March 2011. An associated tsunami on the northern Pacific coast of Japan brought catastrophic damage. Fukushima Daiichi nuclear power plant (NPP), a subsidiary of Tokyo Electric Power Company Holdings (TEPCO), lost all power due to damage caused by the tsunami, and the cooling systems shut down completely. Large quantities of radionuclides were released into the environment and deposited to the north-west and around of

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Fukushima Daiichi NPP in March 2011 (Chino et al., 2011). Caesium-137 was the main radionuclide released and has been present for a long-term. It is an important radionuclide for the assessment of radiation exposure of the public. Ambient dose rates have been decreasing with the passsge of time (Nuclear Regulation Authority, 2020) due to attenuation of radiocaesium activity concentration and movement of radiocaesium in the environment. This study describes changes in the ^{137}Cs activity concentration in the environment and in fractions, and calculates internal radiation doses from the ingestion of food.

2. METHODS

Environmental samples including airborne particles, soil, agricultural crops, irrigation water, wild animals, marine water, and marine biota were collected as mentioned in each publication. After pre-treatment and pulverising, samples were compressed into plastic vessels and measured with a Ge detector connected to a multi-channel analyser system. A more detailed methodology is given in each reference with data.

3. RESULTS AND DISCUSSION

The activity concentration of ^{137}Cs in the atmosphere decreased drastically within a few months of the accident (Fig. 1; Kitayama et al., 2014, 2016; Namie Town, 2020). The activity concentration of ^{137}Cs was $>10\,\text{mBq}\,\text{m}^{-3}$ in Fukushima-shi in April 2011, and then decreased rapidly to approximately $0.1\,\text{mBq}\,\text{m}^{-3}$. The activity concentration of ^{137}Cs near Fukushima Daiichi NPP is higher depending on the distance from the NPP. The level remains similar at each site.

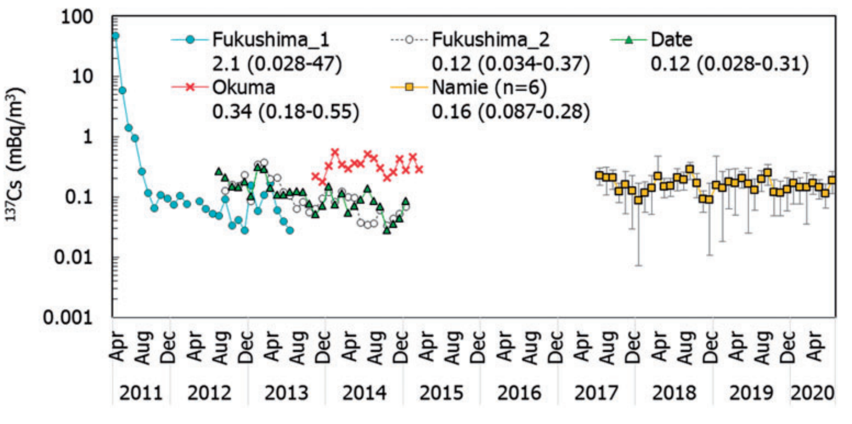

Fig. 1. Trend in the activity concentration of ^{137}Cs in the atmosphere, 2011–2020. Values are mean (range) activity concentration.

Most ^{137}Cs deposited in forest soil still remained on the surface 5 years after the 2011 accident (Fig. 2). The ^{137}Cs in paddy fields is evenly distributed in the cultivated layer (depth of 0–15 cm) due to ploughing. Radiocaesium in paddy field soil is strongly bound-to-clay in the frayed edge sites (Tsukada et al., 2008, 2011; Yamaguchi et al., 2017). Distribution of ^{137}Cs in the exchangeable fraction decreased with time since the accident (Takeda et al., 2013; Tsukada, 2014).

The activity concentration of ^{137}Cs derived from global fallout of atmospheric nuclear weapons tests in paddy field soil decreased gradually with the passage of time before the accident in 2011 (Fig. 3). The mean activity concentration of ^{137}Cs in

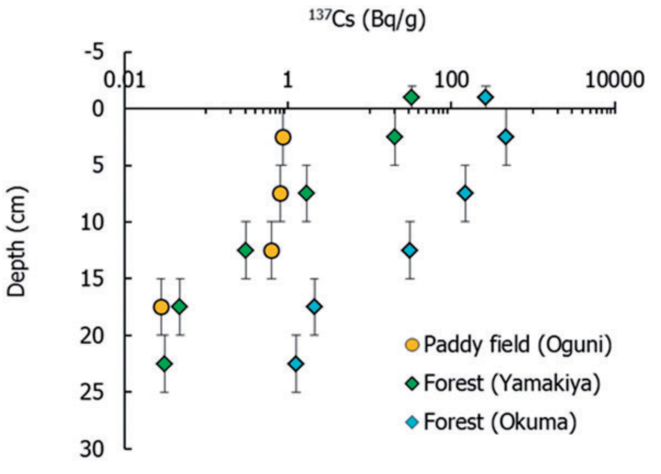

Fig. 2. Vertical distribution of the activity concentration of ^{137}Cs in paddy field and forest soil in 2016.

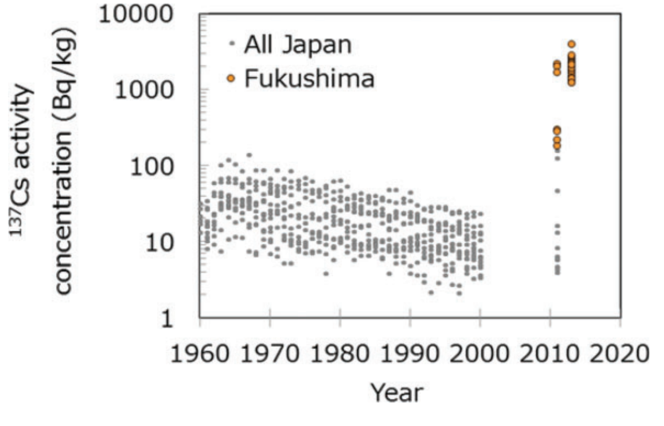

Fig. 3. Trend in the activity concentration of ^{137}Cs in paddy field soil before decontamination lack of Fig. 3.

paddy fields collected throughout Japan increased to 43 $Bq\,kg^{-1}$ in 1963 and then decreased to 8.4 $Bq\,kg^{-1}$ in 2000 (Komamura et al., 2005). The mean activity concentration of ^{137}Cs in 2011 increased to 43 $Bq\,kg^{-1}$ (MEXT, 2013). The reported activity concentration of ^{137}Cs in a few paddy fields from Fukushima in 2011 and 2013 before decontamination was several hundreds to thousands of $Bq\,kg^{-1}$ (Saito et al., 2014; Tsukada and Ohse, 2016).

Rice is a staple food in Japan and huge amounts of irrigation water are used in paddy fields. There are approximately 3700 water reservoirs for supplying irrigation water for rice paddy fields in Fukushima Prefecture. Radiocaesium in water exists as dissolved and suspended fractions. More than 95% of ^{137}Cs in the suspended fraction is in the strongly-bound fraction, which is limited to uptake by rice plants (Tsukada and Ohse, 2016). Fifty-four samples of irrigation water within an 80-km zone from Fukushima Daiichi NPP were used to determine the activity concentration of ^{137}Cs in dissolved and suspended fractions (Tsukada et al., 2017). The range of activity concentrations of ^{137}Cs in the dissolved fraction varied over three orders of magnitude from 0.0075 to 6.7 $Bq\,l^{-1}$, with higher values in the samples taken within the 20-km zone (Table 1). The ^{137}Cs in the dissolved fraction was in a monovalent cationic form (Cs^{+}) and therefore potentially mobile.

Inspection of radionuclides has been undertaken in Japan. Approximately 10 million 30-kg bags of unpolished rice in Fukushima were measured every year, and no rice samples have been over the standard limit (100 $Bq\,kg^{-1}$) since 2015. Rice harvested in general paddy fields has been collected throughout Japan and monitored for levels of ^{137}Cs and ^{90}Sr since 1965 (Fig. 4). The mean activity concentration of ^{137}Cs in unpolished rice decreased from 1.5 $Bq\,kg^{-1}$ fresh weight in 1965 to 0.10 $Bq\,kg^{-1}$ fresh weight in 2010, and the level of ^{137}Cs collected from Fukushima was within the range in Japan. The mean concentration of ^{137}Cs in unpolished rice in Fukushima was up to 10 $Bq\,kg^{-1}$ fresh weight in 2011. However, it has been <1 $Bq\,kg^{-1}$ fresh weight since 2013, which is similar to values from the 1960s and 1970s. The activity concentration of ^{90}Sr in crops collected from Fukushima was similar to that in crops collected throughout Japan, which suggested that ^{90}Sr was not derived from the 2011 accident but the global fallout in the 1950s and 1960s (Tsukada et al., 2016).

Table 1. Activity concentration of ^{137}Cs in dissolved and suspended fractions collected from 80-km zone around Fukushima Daiichi nuclear power plant.

Sampling location	Number	Suspended fraction ($Bq\,l^{-1}$)	Dissolved fraction ($Bq\,l^{-1}$)
20-km zone	27	1.1 ± 2.9*	1.1 ± 1.6*
20–80-km zone	27	0.20 ± 0.19*	0.22 ± 0.23*

*one standard deviation.

Wild animal populations have been increasing in the evacuation zone of Fukushima (Lyons et al., 2020). The activity concentration of radiocaesium in wild animals increased after the 2011 accident (Fig. 5), and it is forbidden to hunt wild animals for food. The activity concentration of radiocaesium in wild boar is higher and has a wider range compared with other wild animals. However, the activity concentration of radiocaesium in wild boar decreased from 1160 Bq kg^{-1} fresh weight in 2011 to 113 Bq kg^{-1} fresh weight in 2020 (Fig. 6).

Nemoto et al. (2018) indicated that the activity concentration of ^{137}Cs in wild boar and Asian black bear collected from Fukushima shows seasonal variation. This

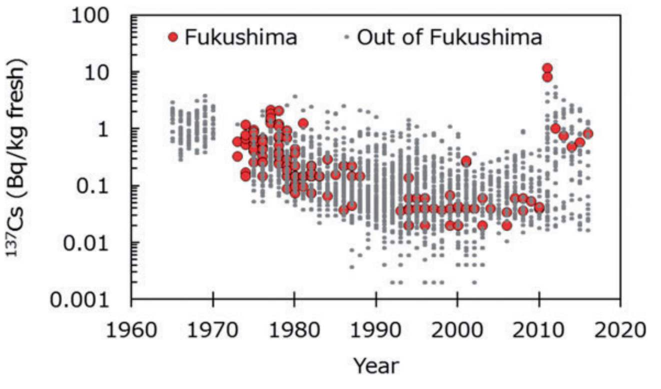

Fig. 4. Trend in the activity concentration of ^{137}Cs in unpolished rice in Japan (Tagami et al., 2018).

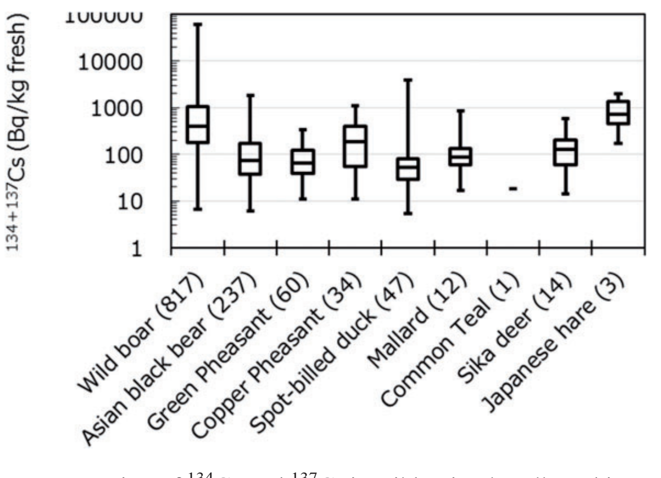

Fig. 5. Activity concentration of ^{134}Cs and ^{137}Cs in wild animals collected in Fukushima from 2011 to 2015. Values in parentheses indicate the number of samples (Fukushima Prefecture, 2000).

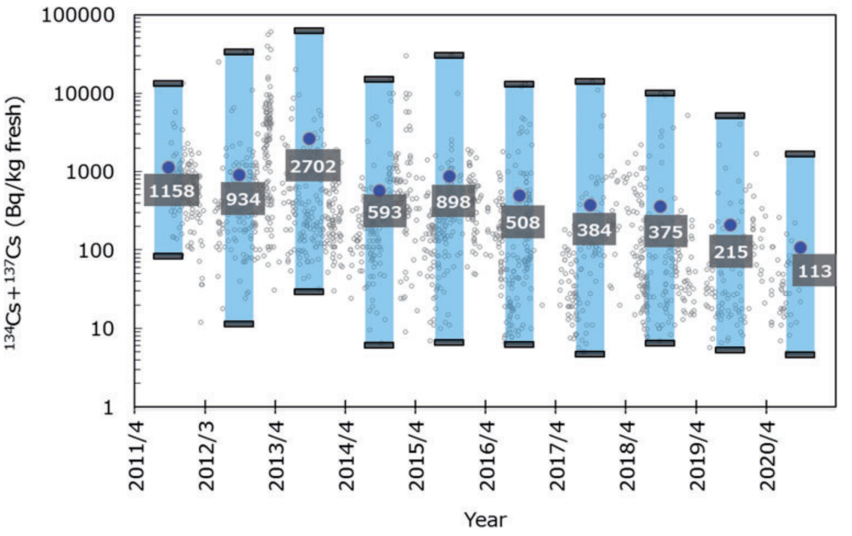

Fig. 6. Trend in the activity concentration of ^{134}Cs and ^{137}Cs in wild boar collected from Fukushima (Fukushima Prefecture, 2000).

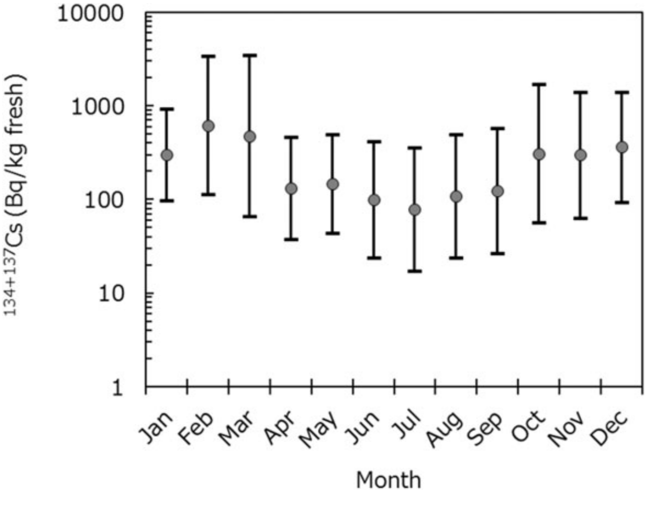

Fig. 7. Seasonal variation in the activity concentration of ^{134}Cs and ^{137}Cs in wild boar (Fukushima Prefecture, 2000).

seasonal variation differed between species, and the variation was assumed to reflect species-specific factors, such as eating habits and behaviour. The activity concentration of radiocaesium in wild boar was lower from April to August, and higher from September to November, and this remained higher until March (Fig. 7).

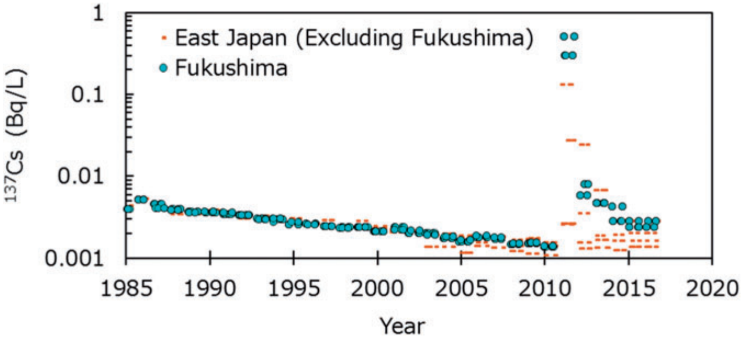

Fig. 8. Long-term trend in the activity concentration of ^{137}Cs in surface seawater off the coast of Fukushima and neighbouring prefectures (Takata et al., 2018).

Long-term trends in the activity concentration of ^{137}Cs in surface seawater (Takata et al., 2018) and marine biota (Takata et al., 2019) have been reported previously. Before the accident at Fukushima Daiichi NPP in 2011, the activity concentration of ^{137}Cs, mainly from the global fallout derived from atmospheric nuclear weapons tests, was decreasing exponentially. Following the accident, the activity concentration of ^{137}Cs in seawater off the coast of Fukushima and neighbouring prefectures increased immediately. Since May–June 2011, the activity concentrations of ^{137}Cs have been declining there, and they are now approaching pre-accident levels (Fig. 8).

The activity concentration of ^{137}Cs in marine biota increased temporarily to 0.74 Bq kg^{-1} fresh weight after the Chernobyl NPP accident in 1986. The following year, the activity concentration of ^{137}Cs returned to the pre-accident level. After the 2011 accident at Fukushima Daiichi NPP, the activity concentration of ^{137}Cs in marine biota increased all around Japan. Almost all fish examined in eastern Japan had remarkably elevated levels of ^{137}Cs after the accident. The influence of the 2011 accident on marine biota varied greatly depending on the distance from the initial deposition area and subsequent transport of contaminated water by ocean currents. The initial activity concentrations in the samples collected from the East Pacific were relatively high, ranging from 0.2 to 110 Bq kg^{-1} fresh weight just after the accident and decreasing to 0.04–3.04 Bq kg^{-1} fresh weight in 2016 (Fig. 9).

The activity concentration of radiocaesium in foods distributed in markets is lower than the standard limit (100 Bq kg^{-1}). Internal radiation doses are decreasing due to several factors, such as market dilution, and food and culinary processing (IAEA, 2020). Internal radiation doses from radiocaesium through food ingestion were estimated from 2012 to 2017 using the activity concentration of radiocaesium in the agricultural and livestock products collected from local markets in Nakadori (Central district) and Hamadori (Pacific Coast district) in Fukushima Prefecture (Table 2). Foods were separated into 14 categories – cereals, rice, potatoes, leafy vegetables, root vegetables, beans, fruit and vegetables, dairy products, beef, pork, chicken, eggs, milk, and others (mushrooms, confectionery, alcoholic and favourite

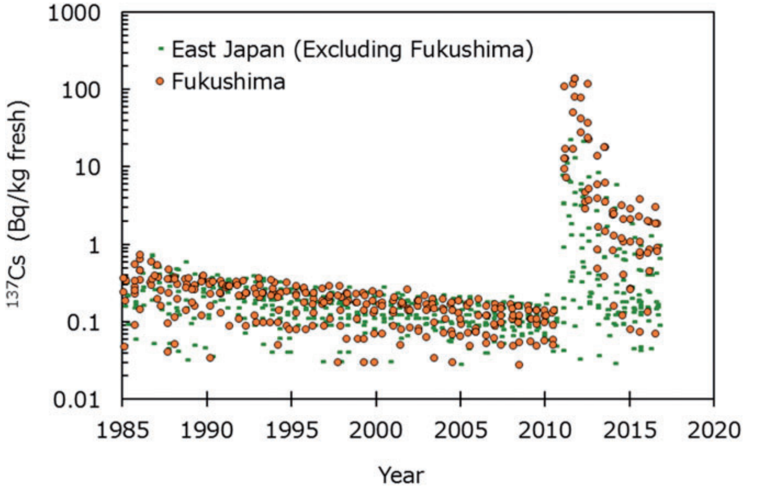

Fig. 9. Long-term trend in the activity concentration of ^{137}Cs in marine biota (mainly fish) collected from off the coast of Fukushima and neighbouring prefectures (Takata et al., 2019).

Table 2. Activity concentration of radiocaesium in crops collected from Nakadori and Hamadori in Fukushima Prefecture, and internal radiation doses from the ingestion of crops.

Year	District	Number of sample	Radiocaesium (Bq/kg fresh) Mean (min–max)	Internal radiation dose (mSv)	
				Adult (male)	Adult (female)
2012	Nakadori	36	7.2 (<0.2–40)	0.066	0.052
2013	Nakadori	42	2.0 (<0.1–14)	0.016	0.012
2015	Nakadori	14	1.9 (0.1–7.3)	0.013	0.0098
2016	Hamadori	27	2.4 (0.03–22)	0.019	0.015
2017	Hamadori	33	0.68 (<0.1–6.6)	0.0064	0.0052

beverages, seasonings, etc.). Drinking water was not included because radiocaesium levels were lower than the limit of detection. The activity concentration of radiocaesium in livestock products used the limit of detection, and that in other products used the mean activity concentration of agricultural production (Tsukada et al., 2016). The activity concentration of ^{134}Cs in the samples for 2015–2017 was determined by the correction of attenuation of the ^{134}Cs/^{137}Cs activity ratio (1 in March 2011).

Internal radiation doses (committed effective dose) for adult males and females (>19 years of age) were 0.066 and 0.052 mSv year^{-1}, respectively, in 2012, and decreased rapidly to 0.016 and 0.012 mSv year^{-1}, respectively, in 2013. The internal radiation dose from radiocaesium in Fukushima Prefecture in 2012 was 0.0039–

0.0066 mSv $year^{-1}$ according to the market basket method (MHLW, 2020), which was one order of magnitude lower than that in this study. This is attributed to the fact that foods collected using the market basket method usually included products from Fukushima Prefecture and elsewhere, and the activity concentration of radiocaesium in the foods decreased by market dilution. The agricultural samples collected in this study were limited to those produced in Fukushima Prefecture and were not influenced by the market dilution effect. Internal radiation doses from radiocaesium by the duplicate diet method in Fukushima Prefecture were reported to be 0.0022 mSv $year^{-1}$ in 2012 (MHLW, 2020), which was still lower than that using the market basket method due to the reduction by food and culinary processing. Internal radiation doses for adult males and females using the activity concentration of radiocaesium in agricultural and livestock products collected from local markets in Fukushima alone were 0.019 mSv (male) and 0.015 mSv (female) in 2016. These values are sufficiently low compared with 1 mSv and are still decreasing dependent on the activity concentration of radiocaesium.

Internal radiation doses due to inhalation using the data described previously had negligible values since 2012. The external radiation dose in Fukushima-shi in 2014 was 0.44 mSv, which represents >95% of the total radiation dose, with the internal radiation dose from ingestion of foods accounting for <5% (Tsukada, 2019).

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Reputational Damage in Radiation Disasters 10 years after the Accident at TEPCO's Fukushima Daiichi Nuclear Power Plant.

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Abstract–Ten years have passed since the accident at Fukushima Daiichi nuclear power plant, and radioactive substances contained in agricultural products and marine products are now below detectable levels. Amidst this, the testing stance is changing from one that guarantees safety to one that guarantees relief, and testing is being reduced for financial reasons. Moreover, the sense of resistance and concern towards food products produced in Fukushima Prefecture is reducing. Anxiety has been reducing along with the development of the inspection system, the inspection results, and the passage of time. However, although there have been fewer requests, demands, and claims to avoid products from Fukushima Prefecture since immediately after the accident, there is a tendency for consumer trends to be forcefully 'surmised'. As a result, the problem of reputational damage, such as the fact that the market ranking of rice and beef has not recovered, remains an issue.

Keywords: Nuclear accident; Reputational damage; Restoration; Fukushima; Radiation protection

1. INTRODUCTION

Generally, reputational damage refers to 'economic damage caused by people discontinuing consumption and tourism because people fear the food, goods, and land that had been considered as ''safe'' because of a certain incident, accident, environmental pollution, or disaster being widely reported' (Sekiya, 2003, 2011).

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

At the initial stage of the accident, goods were officially considered safe if their radiation levels were below the standard set by the Government of Japan. The economic damage caused by people not buying goods with radiation levels below this standard was termed the 'reputational damage'. At the point in time when reputational damage becomes an issue, the fact that goods are 'safe' is a premise that farmers, fishermen, and distributors understand to some extent. However, as this is difficult for all consumers and distributors who conduct business based on consumer trends to understand, economic damage will continue to be incurred. Agricultural products and marine products – the image of which has deteriorated despite having no issues regarding safety – are excluded from consumer options and their commercial value is reduced. If that continues, they will be removed from the distribution route.

Over time, air dose measurement, soil measurement, monitoring of radioactive substances (e.g. agricultural products), and inspection of all rice bags in Fukushima Prefecture have been performed, and the difference in absorption rates between varieties has been made apparent, thus enabling safety to be guaranteed as a result of the various absorption suppression measures. Ten years have passed since the accident at Fukushima Daiichi nuclear power plant, and radioactive contamination above the detection limit has almost disappeared from forest products such as mushrooms and edible wild plants, and agricultural products cultivated in fields, other than wild animals and plants. As for marine products, fish species have not been subject to shipping restrictions since February 2020.

An inspection system has been established, and information on the inspection results has started to be provided. The feeling of repulsion towards the agricultural products themselves has eased. However, distribution will not recover easily due to its long-term stagnation following the accident. As a result, the total shipment value of safe crops is not recovering. As the years passed since the accident, the issue of 'reputational damage' became not just a matter of consumers refusing to buy, but also a problem of distribution that could not be recovered even if there were no food safety issues.

Currently, the main issues in the fight against reputational damage are the influence of changes and downsizing of the inspection system, the issue of contaminated water treated by ALPS and the treatment of removed soil. This paper will not discuss these issues because of limited space, but will summarise the issues related to reputational damage based on the surveys conducted by the author on (1) consumers' awareness of foods produced in Fukushima Prefecture, the significance of the inspection system and its results, and (2) distribution issues.

2. SURVEY ON CONSUMER AWARENESS OF FOODS PRODUCED IN FUKUSHIMA PREFECTURE

First, the results of the survey targeting consumers are presented. All participants were internet monitors of Rakuten Insight Inc. The research used quota sampling so that each prefecture had respondents both of an equal number of male and female

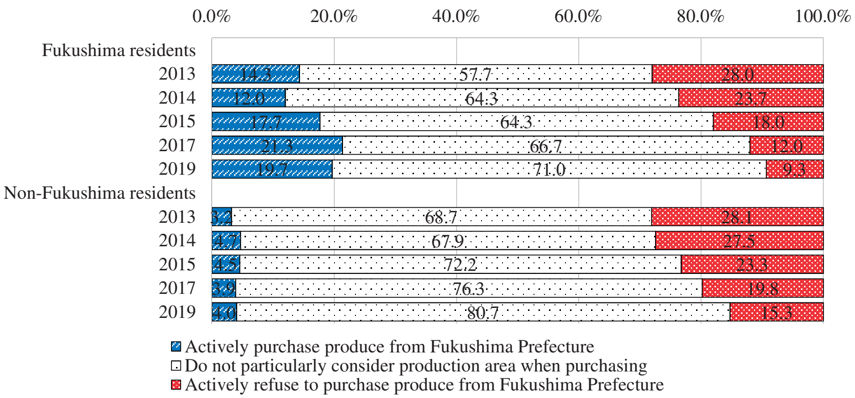


Fig. 1. Awareness of food produced in Fukushima Prefecture.

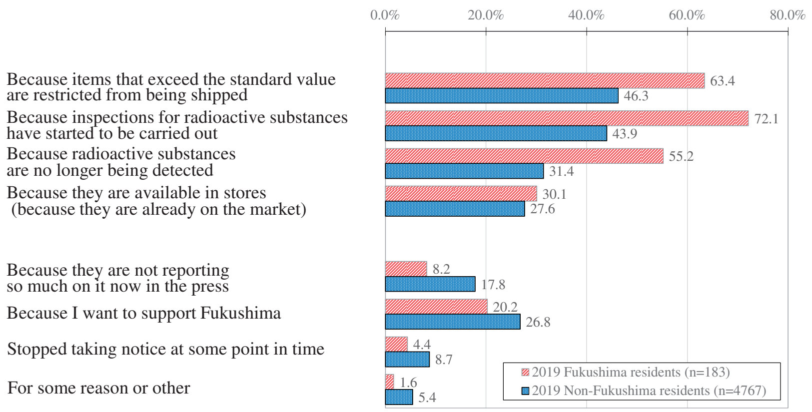


Fig. 2. Reasons why concerns have eased.

and of an equal number by each age group (20s, 30s, 40s, 50s, and 60s). Fukushima Prefecture was assigned a quota of 300 responses, while the remaining 46 prefectures were assigned a quota of 200 responses each. A total of 9,500 responses were collected, implemented in March 2019. For reference, survey results from 2013 to 2017 in Fig. 1 are from surveys carried out in the past using the same method. Surveys were carried out in 2013 (all prefectures, $n = 14{,}091$), 2014 (Tohoku + Tokyo, Nagoya, and Osaka, $n = 1779$), 2015 (Tohoku + major cities, $n = 3839$), and 2017 (all prefectures, $n = 9489$).

The number of people who refuse to eat food produced in Fukushima Prefecture has been decreasing year by year. This is especially true in Fukushima residents.

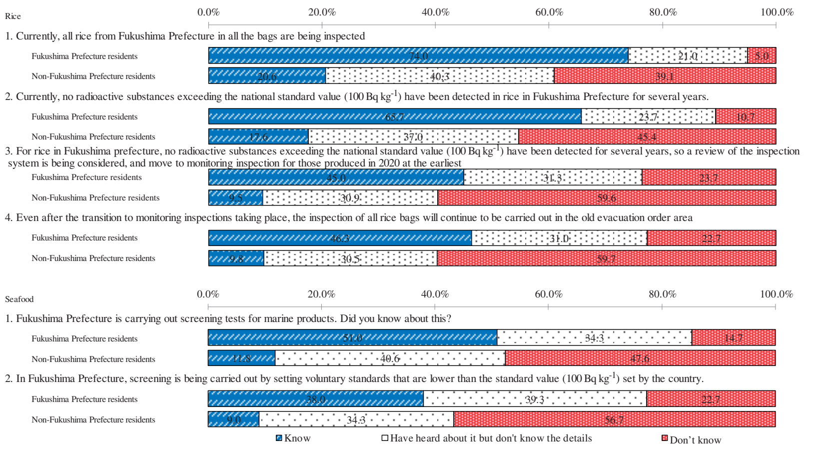


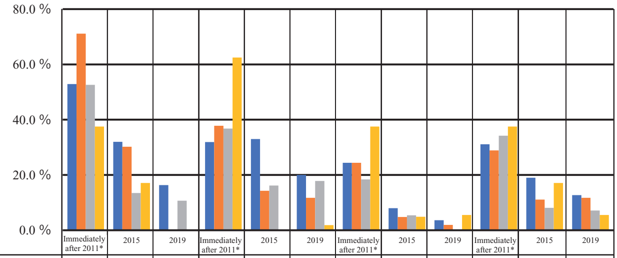
Fig. 3. Rate of awareness of the inspection system.

Anxiety has eased because the inspection system has been implemented consistently, there have been no problems with the inspection results, and shipping restrictions are in place; this finding has been common to all surveys since 2014. The response rate for each reasons for decreased anxiety was greater for Fukushima residents. For Fukushima residents, there is evidence that the number of people rejecting Fukushima products has decreased, but for non-Fukushima residents, there is no clear reason why the number of people rejecting Fukushima products has decreased. With the passage of time, people's memories of the Fukushima nuclear accident have faded, and the number of people who reject it has somehow decreased. (Fig. 2). In Fukushima Prefecture, a large amount of information on the inspection system and inspection results is available, which may explain why the proportion of Fukushima residents who refuse to consume products from Fukushima Prefecture is decreasing.

Furthermore, 95% of residents of Fukushima Prefecture reported that they were aware that all rice bags are tested, if one includes those who said that they had 'heard about it'. Many residents of Fukushima Prefecture are aware of the transition to monitoring inspections, rice inspection results, continuation in the old evacuation order areas, screening inspections for marine products, etc., but these are also recognised by people who do not live in Fukushima Prefecture (Fig. 3). The inspection system and inspection results are less well known outside Fukushima Prefecture, and therefore have less effect on reducing the sense of concern outside Fukushima Prefecture.

3. SURVEY ON DISTRIBUTOR AWARENESS OF FOODS PRODUCED IN FUKUSHIMA PREFECTURE

The results of the survey targeting distributors are presented below. From the corporate data of Tokyo Commerce and Industry 250 in the order of sales ranking from: (1) wholesale trade in Fukushima Prefecture; (2) retail trade in Fukushima



	Immediately after 2011*	2015	2019	Immediately after 2011*	2015	2019	Immediately after 2011*	2015	2019	Immediately after 2011*	2015	2019
Wholesale trade in Fukushima prefecture	**52.9 %**	**32.0 %**	**16.4 %**	**31.9 %**	**33.0 %**	**20.0 %**	**24.4 %**	**8.0 %**	**3.6 %**	**31.1 %**	**19.0 %**	**12.7 %**
Retail trade in Fukushima prefecture,	**71.1 %**	**30.2 %**		**37.8 %**	**14.3 %**	**11.8 %**	**24.4 %**	**4.8 %**	**2.0 %**	**28.9 %**	**11.1 %**	**11.8 %**
Wholesale trade in Japan (excluding Fukushima prefecture)	**52.6 %**	**13.5 %**	**10.7 %**	**36.8 %**	**16.2 %**	**17.9 %**	**18.4 %**	**5.4 %**		**34.2 %**	**8.1 %**	**7.1 %**
Retail trade in Japan (excluding Fukushima prefecture)	**37.5 %**	**17.1 %**		**62.5 %**		**1.9 %**	**37.5 %**	**4.9 %**	**5.6 %**	**37.5 %**	**17.1 %**	**5.6 %**
	There are still direct requests, demands and claims from business partners not to handle products in the disaster area			**It seems that there is a tendency for business partners to request or demand that products from Fukushima prefecture should not be handled**			**There are still direct requests, demands and complaints from consumers not to handle products from the disaster area**			**It seems that there is a tendency for consumers to request or demand that products from Fukushima prefecture should not be handled**		

Fig. 4. Are there currently any requests or demands not to handle products from the disaster area and Fukushima Prefecture? *The figures immediately after 2011 are based on the results from the 2015 survey.

	There were direct requests and demands from consumers.	Supermarkets / Comprehensive supermarket	Online supermarkets / Online shopping	Department stores / Specialty store	Convenience store	Hotel	Restaurants	Food manufacturer	Trading companies	Delivery companies	Wholesale company	Contract food service
Immediately after 2011*												
Wholesalein Fukushima prefecture (N=100)	51.1 %	42.2 %	6.7 %	13.3 %	–	15.6 %	26.7 %	15.6 %	8.9 %	6.7 %	26.7 %	55.6 %
Retail in Fukushima prefecture (N=63)	57.9 %	10.5 %	7.9 %	2.6 %	5.3 %	–	5.3 %	2.6 %	–	5.3 %	2.6 %	21.1 %
Wholesalein places other than Fukushima prefecture (N=37)	62.5 %	75.0 %	12.5 %	12.5 %	–	12.5 %	37.5 %	–	–	12.5 %	12.5 %	62.5 %
Retail in places other than Fukushima prefecture (N=41)	51.9 %	7.4 %	–	–	–	–	–	7.4 %	–	3.7 %	3.7 %	–
2015												
Wholesalein Fukushima prefecture (N=100)	25.0 %	23.0 %	7.0 %	5.0 %	1.0 %	6.0 %	10.0 %	7.0 %	2.0 %	4.0 %	16.0 %	29.0 %
Retail in Fukushima prefecture (N=63)	36.5 %	3.2 %	3.2 %	1.6 %	1.6 %	1.6 %	4.8 %	1.6 %	1.6 %	3.2 %	3.2 %	15.9 %
Wholesalein places other than Fukushima prefecture (N=37)	16.2 %	16.2 %	2.7 %	5.4 %	2.7 %	5.4 %	8.1 %	2.7 %	–	2.7 %	–	16.2 %
Retail in places other than Fukushima prefecture (N=41)	17.1 %	4.9 %	–	–	–	–	–	–	–	2.4 %	2.4 %	–
2019												
Wholesalein Fukushima prefecture (N=55)	9.1 %	16.4 %	1.8 %	3.6 %	–	5.5 %	9.1 %	3.6 %	–	12.7 %	10.9 %	20.0 %
Retail in Fukushima prefecture (N=51)	9.8 %	2.0 %	–	2.0 %	–	–	2.0 %	–	–	–	2.0 %	9.8 %
Wholesalein places other than Fukushima prefecture (N=28)	3.6 %	21.4 %	3.6 %	3.6 %	3.6 %	–	14.3 %	7.1 %	–	3.6 %	3.6 %	14.3 %
Retail in places other than Fukushima prefecture (N=54)	7.4 %	1.9 %	–	1.9 %	–	–	–	1.9 %	–	–	1.9 %	–

* The figures immediately after 2011 are based on the survey results from the 2015 survey

Table 1. Business partner fields with requests not to handle products from the disaster area and Fukushima Prefecture.

Prefecture; (3) wholesale trade in Japan (excluding Fukushima Prefecture); and (4) retail trade in Japan (excluding Fukushima Prefecture), a total of 1000 cases were extracted. The survey period was from 18 March to 20 April 2015, with 241 valid responses (response rate 24.1%), and from 20 March to 20 April 2019 with 188 valid responses (response rate 18.8%).

Although the percentage of direct requests from consumers has decreased, there are still some requests and demands from supermarkets, general merchandise stores, and school lunch providers that ask that products from Fukushima Prefecture not be handled (Table 1). Although the percentage of distributors who 'experience direct requests, demands and claims' that they do not handle products from Fukushima Prefecture is decreasing, a certain percentage of distributors still 'feel the tendency for such requests and demands' (Fig. 4). While the number of requests and complaints to avoid products from Fukushima Prefecture is decreasing, many distributors are convinced that consumers remain uneasy. There is a tendency for consumer trends to be forcefully ‘surmised’.

4. CONCLUSIONS

Ten years have passed since the accident at Fukushima Daiichi nuclear power plant, and radioactive substances contained in agricultural products and marine products are now below detectable levels. Amidst this, the testing stance is changing from one that guarantees safety to one that guarantees relief. In addition, testing is reducing due to financial reasons.

The proportion of Fukushima residents who refuse to consume products from Fukushima Prefecture has been decreasing because they have a high recognition rate of the inspection system and results. But the number of non-Fukushima residents who refuse has not been significantly decreasing because they have a low recognition rate of the inspection system and results.

Radiation inspection system has been ongoing since the accident, but it has either been changed or downsized in the past few years. Now that the current inspection results are no longer available, it is not sufficient to simply use the past approach where people have understood the safety of the products from the inspection data. It is necessary to reconsider how to promote safety, for example, by making sure that people have a new understanding of the past trends in the data on radiation levels contained in the past and radiation effects.

In addition, although the number of consumer requests and complaints related to food from Fukushima Prefecture have decreased since immediately after the accident, many distributors still think that consumers are anxious. There is a tendency for consumer trends to be forcefully ‘surmised’. Distributor awareness remains a reason why the market ranking of rice and beef has not recovered.

While consumers’ resistance to food produced in Fukushima Prefecture has diminished, there is a decreasing demand for food for commercial use and in restaurants due to the coronavirus pandemic. Full-scale restoration of distribution routes is becoming indispensable. Based on this change, there is a need to consider measures such as direct delivery to consumers using online sales, development of related processed products, measures to expand further sales channels, etc., instead of simply repeating sales promotion events and commercials.

Over the last 10 years, it has become clear that the amount of radiation in food produced in Fukushima Prefecture has decreased, and that there have been various changes to agricultural products and marine products. With respect to radioactive contamination, inspection systems have moved on to the next stage. However, there is still no way to solve the problems caused by human minds, such as measures against rumours.

What is clear is that knowledge about the inspection system and dissemination of the test results is effective in reducing the proportion of people who refuse to consume food produced in Fukushima Prefecture. There is a need to disseminate information, both domestically and internationally, based on 10 years of inspection efforts and achievements, and to seek ways to provide information that do not rely on inspections.

NOTES

(1) It is clear from the statistical analysis of the survey of residents of Fukushima Prefecture that the inspection system and inspection results have a strong influence on purchase intention of produce from Fukushima Prefecture. For details, see Sekiya (2016a).

(2) See Sekiya (2019) for treated water issues and Isotope News No. 77 (under construction) for overseas reputational damage.

(3) See Note (1). Sekiya (2016) showed that the awareness of test results and test systems is linked to a reduction in anxiety.

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Synthesis of the JHPS International Symposium on Tritiated Water

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Abstract–As the decommissioning of Fukushima Daiichi nuclear power plant (NPP) progresses, the issue of how to deal with tritiated water has been attracting attention, both domestically and internationally. This article summarises the live discussion at the International Symposium on Tritiated Water, which was held by the Japan Health Physics Society (JHPS) in June 2020. Two issues – the scientific safety of tritiated water and social consensus building – were covered in the live discussion. The importance of further disclosure and dissemination of information based on steady monitoring was highlighted. It was also pointed out that scientific knowledge and scientific research data are merely the bottom line to achieve social consensus. Through the discussions, it was recognised that the role of JHPS is not only to look at the technical issues of safety, but also to look at social issues from the point of view of radiation protection, and to support the solution of these issues.

Keywords: Tritiated water; Fukushima Daiichi nuclear power plant; ALPS; Discharge into the sea

1. INTRODUCTION

As the decommissioning of Fukushima Daiichi nuclear power plant (NPP) progresses, the issue of how to deal with tritiated water has been attracting attention, both domestically and internationally. Water becomes contaminated when it touches the damaged reactors and debris. Advanced Liquid Processing System

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

(ALPS)-treated water refers to water that has been purified in several purification facilities, including the ALPS. Most nuclides (e.g. ^{137}Cs, ^{90}Sr) are removed from contaminated water during this process, except for tritium (TEPCO, 2014; METI, 2020a). Approximately 170 m^3 of ALPS-treated water is generated and stored in tanks every day. The tanks storing ALPS-treated water are expected to be full by the summer of 2022. The Subcommittee on Handling of ALPS-treated Water, established by the Ministry of Economy, Trade, and Industry, concluded its report on 10 February 2020 (METI, 2020b). The report identified two feasible options – discharge into the sea and vapour release – as practical options for handling ALPS-treated water. Experience with conventional reactors, ease of handling, and monitoring methods make discharge into the sea more reliable than vapour release. The Japanese Government will decide the basic policy in the near future. Under these circumstances, local fishermen and residents living along the coast as well as near Fukushima Daiichi NPP have raised concerns about the discharge of water containing radioactive materials into the sea, which may have health effects and cause further 'reputational damage' to fisheries and tourism.

The accident at Fukushima Daiichi NPP had major impacts on radiation protection. One of the roles of Japan Health Physics Society (JHPS) is to contribute to post-accident recovery through various academic activities. In line with this, JHPS held a live online symposium entitled 'International Symposium: How do we Find the Solution to Radiological Protection of Tritium Water? International and Societal Perspectives on Radiation Protection' on 29 June 2020 (Kawaguchi et al., 2020). The symposium was comprised of two parts. In Part I, lectures were given by four speakers: Dr Ichiro Yamaguchi (National Institute of Public Health, Japan), Dr Shu-Jun Chang (Institute of Nuclear Energy Research, Taiwan), Prof. Ik Jae Chung (Seoul National University of Science and Technology, South Korea), and Mr Riken Komatsu (community activist and writer living in Iwaki City, Japan). In addition, a pre-recorded interview with Mr Motofumi Kikuchi (fisherman from Soma Haragama Fishing Port) was shared with speakers and participants. In Part II, following a talk by Ms Ryoko Ando (NPO Fukushima Dialogue/Ethos in Fukushima, Iwaki City, Japan), a live discussion was held between the four speakers in Part I and Ms Ando, facilitated by the author (H. Yoshida). Two issues – the scientific safety of tritiated water and social consensus building – were discussed. This paper summarises the interview with Mr Kikuchi and the live discussion.

2. SYNTHESIS OF THE JHPS SYMPOSIUM

2.1. Summary of the interview with Mr Kikuchi

Soma Haragama Fishing Port is located in the northern part of Hamadori, Fukushima Prefecture, and is a port on the Pacific coast. After graduating from college, Mr Kikuchi returned to Soma Haragama and became a fisherman to follow in the footsteps of his deceased father. Following the accident at Fukushima Daiichi NPP, fishing operations were voluntarily suspended, and trial fishing subsequently commenced. During that time, Mr Kikuchi began developing and selling processed marine products, aiming to restore the pride as fishermen and the culture of Soma-Hama. He sells fish meatballs made from black sleeper at events and trade fairs inside and outside Fukushima Prefecture. In 2015, he and his fellow local fishermen issued *Soma Taberu Tsushin*, an information magazine, with a food gift, and he was appointed Co-Editor-in-Chief (Soma Taberu Tsushin, 2016). Mr Kikuchi continues to play a leadership role, particularly among young fishermen, actively promoting the development of processed marine products and organising tours for tourists.

The summary of the interview with Mr Kikuchi, interviewed by H. Yoshida, is as follows: The majority of the public do not understand the safety of tritium, and as a fisherman, I am very concerned about rumour-based reputational damage. I feel that the safety of the product has not been communicated to the public by the Government and others. The fishermen are doing their best. It would be humane that the side that polluted the fishermen's workplace should stand by and support the fishermen. This is not only a problem for the fishermen, not just for Fukushima or the region. We fishermen want other people to think of it as their own problem, not someone else's. In fishing, the harder you work, the more you get paid. I have always felt that this is the true joy of fishing. However, the fishery has been on trial operation since the accident at Fukushima Daiichi NPP. Compensation will not solve any problems. I hope the Government work hard to restore the culture and the appeal of our job as fishermen. I would like to see the Government support the restoration of brand value, processed products, and the creation of an industry that makes use of local resources.

2.2. Summary of the live discussion

Opinions were expressed on the following questions – 'How exactly can we gain trust in the scientific safety of tritiated water domestically and internationally? What should be done and by whom? What is expected to be improved by it?'

The problem is credibility, and what the experts can do is answer the questions (Dr Yamaguchi). The issue of tritiated water is about safety, and meeting the standards ensures safety. The differences between the Taiwanese and Japanese standards, risk assessment, and especially the realistic impact on the marine environment should be assessed and the information should be disclosed to Taiwan (Dr Chang). 'How safe is safe enough?' is always a challenge. Scientific knowledge and scientific research data are important, but this is merely the bottom line. Emphasising zero risk (safety) does not offer any possibilities. It is necessary to make a space for discussion through negotiations. It should start with very specific negotiations, for example, economic incentives, and the rhetoric for social consensus is required. Consideration of acceptable and unacceptable matters is the first step, and moving to concrete considerations, such as what is necessary and what can be provided, is the next step. It is necessary to negotiate incrementally, rather than explaining that there is no risk. Much of the information is disseminated by the mass media and has a significant impact on public decision-making. It is important for scientists to explain scientific information in a way that the public can understand (Dr Chung). Scientists should solemnly and firmly publish information based on the data. However, most consumers do not understand or act on the scientific findings about tritium. Sometimes it is because someone told them it is safe. Cooperation of scientists and senders of information is important so that senders of information, including the media, can disseminate information based on understanding of the characteristics and effects of tritium. In some cases, scientists lose persuasiveness when they explain things in a simple and understandable way. Therefore, scientists need communicators who can explain scientific data in a way that is easy to understand and connect with the public, but in reality, such communicators are lacking. It is also necessary for scientists to create a relationship with somebody with whom they can entrust the dissemination of information to some degree (Mr Komatsu). Speaking only in the case of tritiated water, it should be noted that the senders of primary information are not trustworthy. The information disclosed and distributed by Tokyo Electric Power Company Holdings (TEPCO) sometimes resulted in corrections to published data after errors were pointed out from outside, or required information was disclosed after indication from outside. This happened when I sent out the information from TEPCO on a social networking service (after I had confirmed it), so my own reputation was damaged as well. The Government takes a position that TEPCO is responsible, so there is nowhere to disseminate information responsibly and reliably. In a situation where primary information is unreliable, a system of monitoring by a third-party organisation is necessary, but this has not been done to date. In a situation where the information is not reliable, it does not make sense to say that the general public's scientific perception is wrong (Ms Ando).

After the accident at Fukushima Daiichi NPP, important decisions have been made in a variety of situations. In many cases, the decisions have been made in very difficult and complex situations. These decisions have been based on scientific evidence, but they have not been made on scientific grounds alone. Also, the consensus in these decisions was not always built well in advance, and some people were, and still are, left outside of these decisions in many ways. Based on these situations, the second question – 'How to build a social consensus on handling of tritiated water, or what exactly is needed in order to build a consensus' – was discussed.

The root of the distrust is that people think various investigations are insufficient. It is necessary to explain that they are being investigated properly. With regard to the option to continue storing the ALPS-treated water on site, it is important to consider the human rights of a few people (who may be affected by it). It is necessary to consider the issues from multiple perspectives (Dr Yamaguchi). The Japanese Government needs to establish a critical decision-making network. A key decision-making network needs to explain why, where, how, what, and when to implement their decisions. The Japanese Government needs to explain why they need to discharge tritiated water into the sea, and explain in detail how they will do it, but this has not been done to date. What and when should also be clarified. How the discharge of tritiated water into the sea will affect Taiwan's marine environment is a matter of concern, so the information should be provided to Taiwan (Dr Chang). One of the important keywords is 'consensus building', and the bottom line is acceptability and trust. Residents of Fukushima do not trust the Japanese Government or other people, and they believe that the Government is pursuing its own interests rather than the interests of the residents of Fukushima. Even if the residents of Fukushima believe that the Japanese Government is doing its best scientifically, the Government does not gain more trust because it is difficult for the residents to understand everything. In the negotiations of give and take, there is a need to let each other know that no infringement on each other's interests, from the Government to local residents and from local residents to the Government. Similar social issues are being discussed in South Korea over the construction of NPPs. It is necessary for the parties concerned to build mutual trust in a realistic way (Dr Chung). More than 9 years have passed since the accident at Fukushima Daiichi NPP. The number of people interested in the accident is decreasing, even in local areas, and a small communication channel is being lost. Some people say they do not trust people from the Japanese Government or TEPCO, but they do trust local assembly members. However, as there is no place to talk with these local representatives, and only a limited number of people talk about tritium and decommissioning, the deviation between those who are interested in the issues and the general public (with no interest in the issues) becomes large. Rather than simply disseminating information through the media, it is important for people to exchange information and opinions at the place where the things really happen. Disclosing traces of full discussions on various proposals, such as large tank storage and underground storage, will build trust; however, such information is not conveyed. We should create a place for discussion in the local community, even if it takes time (Mr Komatsu). Any conclusions decided by someone else without stakeholder involvement are unacceptable. Before presenting conclusions, we need to have a place for discussion and take our time, going through the process little by little (Ms Ando).

3. CONCLUSION

In order to gain trust on the scientific safety of tritiated water, there is a need for further disclosure and dissemination of the information, both domestically and internationally, based on steady monitoring. Key to this is whether the senders of primary information are trustworthy. Safety is a matter of trust. It is important that experts play their role with honesty and integrity. However, scientific knowledge and scientific research data are merely the bottom line. It is necessary for the parties concerned to build trust in a realistic way. The majority of members of the public do not understand the safety of tritium. Scientists need communicators who can explain scientific data in a way that is easy to understand and connect with the public. Any conclusions decided by someone else without stakeholder involvement are unacceptable. It is necessary to create a place for discussion in the local community, even if it takes time. Mr Kikuchi, a fisherman, stated that this is not only a problem for the fishermen, not just for Fukushima or the region. The issue of tritiated water should not be trivialised to a regional problem.

Throughout the discussions, it was reaffirmed that JHPS, a professional group of radiation protection experts, should further consider what to do and what we can do. In this case, it is necessary to think of the problem as one's own, not someone else's, and to have an attitude of empathy rather than sympathy. It was also recognised that the role of JHPS is to look at not only the technical issues of safety, but also the social issues from the point of view of radiation protection, and to support the solution of these issues.

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Supporting societal and economic dynamics of recovery: lessons from Chernobyl and Fukushima

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Abstract–Beyond the consideration of radiological aspects, the rehabilitation of living and working conditions after a large nuclear accident is a complex process in which all dimensions of individual and community life are involved and interconnected. Responsibles of socio-economic entities are facing various difficulties/challenges, including the implementation of protective actions for ensuring the protection of employees, the continuity of production of good-quality products in affected areas, and restoring the confidence of consumers. For affected local communities, the deployment of a socio-economic programme is essential to enable a sustainable future while recognising that a return to the pre-accident situation is generally not achievable. In this context, supporting the societal and economic dynamics of the recovery process requires the adoption of specific governance mechanisms respecting a series of ethical and social values, as highlighted by lessons from the post-accident management of the Chernobyl and Fukshima accidents at Chernobyl and Fukushima Daiichi nuclear power plants.

Keywords: Living conditions; Ethical values; Local community; Sustainable development; Co-expertise; Stakeholder involvement

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

1. INTRODUCTION

The rehabilitation of living and working conditions in affected areas after a nuclear accident is characterised by a double challenge: to provide adequate protection for the people and the environment; and to maintain and support the dynamic of socio-economic activities. Feedback from Chernobyl and Fukushima has shown the importance of direct involvement of affected people and local communities through adoption of the co-expertise process fostering cooperation between local residents and experts. In addition, it highlighted the need to adopt governance mechanisms respecting ethical and social values. After indicating the main lessons and challenges associated with the living conditions for residents following a nuclear accident, this article highlights the key features of the co-expertise process and the governance mechanisms for supporting socio-economic activities during the recovery process.

2. LESSONS FROM EXPERIENCE

After a nuclear accident, people are very confused and do not know where to turn. They no longer trust the authorities and experts, and gradually lose control of their daily life. There is a threat to their dignity. Although people expect to return to the previous situation as soon as possible, lessons from the post-accident management of the accidents in Chernobyl and Fukushima accidents show that this is not possible. Total removal of radioactivity from contaminated areas is not feasible; whatever efforts are made, there is always residual contamination, especially in forests. In addition, many human and societal consequences are irreversible and the destabilisation of communities leads to ruptures and complex dilemmas. The socio-economic dynamics in the affected areas face new constraints. The demography of local communities is modified considerably as a consequence of the evacuations (voluntary or compulsory), with a tendency for young people to leave. Local production from agriculture and fishing, and also from industry as well as leisure and tourist activities, suffer from a degraded image. Finally, the use of the environment is severely restricted due to residual contamination.

In such a context, radiological protection, although essential to protect people (those who have stayed and those who return or settle for the first time), is not able to ensure socio-economic development. Experience has shown that the implementation of radiological standards is not sufficient to restore people's confidence in the recovery process, and that without the active involvement of all stakeholders, it is difficult to create a favourable dynamic.

A major stake in the recovery process is, therefore, on one hand, to put radiological protection at the service of improving living and working conditions in the affected areas and on the other hand to promote socio-economic development taking into account the radiological context. In this perspective, the aim is to contribute to the protection of people and the environment, and to maintain vigilance for ensuring a sustainable future for the local population.

Experience that followed the accidents in Chernobyl and Fukushima accidents has shown that the driving force behind the recovery process lies in respecting the individual choices of those affected and the contribution of local communities, while keeping in mind that none of the stakeholders and none of the decision-making levels (local, regional, national) alone can solve the challenges facing the affected regions.

3. THE CO-EXPERTISE PROCESS

The process of co-expertise – short for cooperation between experts and stakeholders – applied to post-nuclear accident situations emerged in the late 1990s as part of the ETHOS project implemented in villages in Belarus affected by the Chernobyl accident (Lochard, 2013). Based on the direct involvement of affected people to characterise their personal radiological situation and that of their community, the objective of the project was to reduce the exposure of the villagers and to improve their quality of life with support from experts and authorities. The co-expertise process has been refined through its implementation in communities affected by the Fukushima accident (Takamura et al., 2018; Lochard et al., 2020; Yasutaka et al., 2020).

Fig. 1 presents the main steps of the co-expertise process, as well as its methodological foundations. Dialogue, measurements, and local projects are the three pillars of this process (ICRP, 2020).

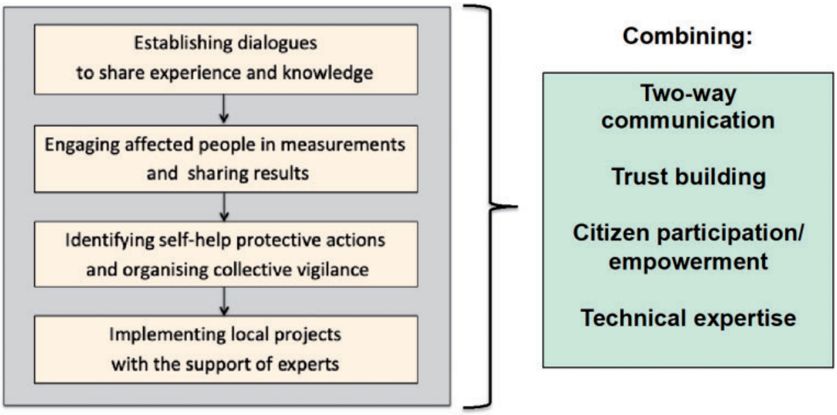

Fig. 1. The co-expertise process in radiological protection.

3.1. The role of dialogue

Dialogue enables those concerned to ask questions to experts by to share their concerns, challenges, and expectations with them; and to gradually familiarise themselves with the basic concepts of radiological protection. At the same time, it allows experts to take ownership of the radiological, societal, environmental and economic factors characterising the local situation. Beyond allowing expression of the plurality of points of view, it is an effective way to question ready-made representations, false ideas, incantatory speeches, and unrealistic positions, and also to identify the values shared by local communities. Listening and empathy are the qualities required for the experts involved.

3.2. The role of measurements

Measuring ambient radioactivity and human exposure is a way of making the invisible and frightening radioactivity visible, to gradually give everyone the keys to understand where, when, and how she/he is exposed and thus to understand the reality of the radiological situation. Whether it is those who have decided to stay, those who wish to return, or those who wish to visit or to settle in the affected areas, all need to understand the reality they are facing, or will face, in order to make informed decisions. Experience has shown that sharing the results of measurements to discuss and compare individual situations is a powerful way to identify possible individual or collective actions to improve the protection of those affected.

3.3. The role of local projects

Beyond their practical objectives (protecting individuals and the community, improving living and working conditions, etc.), local projects are a way for affected persons to recovery the sense of personal fulfilment that were stopped after the accident and look again positively at the future. To implement these local projects effectively, cooperation with the competent authorities, public and private organisations, experts, and professionals is essential. Support for local projects requires the establishment of appropriate decision-making mechanisms to ensure the legitimacy, transparency, and equity of their implementation.

4. THE GOVERNANCE OF SOCIO-ECONOMIC ACTIVITIES

The rehabilitation of decent and sustainable living and working conditions in affected areas must necessarily be based on a 'long-term vision of their development' co-negotiated between all the stakeholders: national, regional, and local authorities; experts, scientists, professionals, and, of course, the people directly affected by the accident (Baudé et al., 2016). The challenge is to articulate the redeployment of social and economic activities damaged by the accident, the emergence of new and innovative activities in line with the local context, and support for local projects led by individuals and/or local communities, which must also aim to constantly improve the radiological situation.

The technical and administrative management of economic development is essential and must be carried out in accordance with the ethical values structuring radiological protection (ICRP, 2018):

- Beneficence and non-maleficence – the primary objective of radiological protection is to contribute to the protection of people and the environment, and to ensure their 'well-being'. In the context of a post-accident situation, the emphasis is also placed on the quality of living together.
- Prudence – due to scientific uncertainties and public concerns, there is a duty to promote health surveillance and to ensure vigilance against potential effects that may occur in the future.
- Justice – support for all those affected by the accident must be organised, and it is necessary to ensure a fair balance in the allocation of human and financial resources devoted to these support actions.
- Dignity – the empowerment of the people and communities concerned is essential to ensure a sustainable recovery process, and is crucial to enable them to regain their autonomy.

The decision-making process concerning economic and social development, such as decisions relating to the implementation of protective actions, should be open to all stakeholders (inclusiveness), with honesty and openness (transparency), and with all the explanations concerning their justification (accountability). This implies a specific approach to expertise in which scientists, experts, and professionals not only make decisions but put themselves at the service of local stakeholders in order to facilitate the development of their capacity to assess and manage their own situation and that of affected areas (Schneider et al., 2019). It also involves monitoring and evaluating local projects with all stakeholders (co-assessment of the situation and issues) in order to adapt strategies and policies as the recovery process evolves.

Past experience has shown that the communities involved in co-expertise experiences are eager to develop local projects in the fields of radiological protection, social activities, economic development, education, memory, and culture. In the process of recovery, memory not only plays a role in commemoration but also serves as a living reminder to raise awareness, maintain vigilance, transmit experience, and thus contribute to build the future.

Capitalising on the accumulated experience and making it accessible to all affected people, as well as sharing it internationally, is a moral duty. In this perspective, the involvement of the education system (schools and universities) is an essential means of sharing the experience with the next generation.

5. CONCLUSIONS

Management of the recovery process must be linked to the 'long-term vision of the territory', taking into account the health, social, environmental, economic, cultural, and memorial dimensions. The objective is to restore individual well-being and the quality of community life in affected areas where people are allowed to reside. This implies the development of a sustainable socio-economic framework articulating the redeployment of infrastructures and socio-economic activities including innovative projects, the support of local projects initiated by individuals and local communities, and the dissemination and transmission of the experience gained in managing the situation. Some experiences of communities affected by the Chernobyl and Fukushima accidents have shown that, to be successful, the recovery process must rely on governance mechanisms securing an open dialogue between all stakeholders in which experts are at the service of the affected people. It also requires the empowerment of individuals and local communities to decide together the values and principles for a common future. This cannot be achieved without the support of the authorities and without respect for individual autonomy.

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Radiation doses of workers engaged in decontamination of the environment

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Abstract–After the accident at Fukushima Daiichi nuclear power plant on 11 March 2011, radioactive materials were released into the atmosphere resulting in environmental contamination. Following the implementation of environmental decontamination efforts, the Radiation Dose Registration Centre of the Radiation Effects Association established the radiation dose registration system for decontamination and related workers to consolidate and prevent the loss of radiation records. This article presents statistics on the radiation doses of decontamination and related workers using official records. Since approximately 10 years have passed since the accident in Fukushima, the types of work conducted in the affected restricted areas have changed over time. Therefore, changes in radiation dose for each type of work and comparisons with nuclear workers are presented.

Keywords: Decontamination worker; Radiation dose registration; Dose statistics; Recovery work

1. INTRODUCTION

After the accident at Fukushima Daiichi nuclear power plant on 11 March 2011, the Government of Japan promulgated the 'Ordinance on the Prevention of Ionizing Radiation Hazard at Work to Decontaminate Soil and Wastes Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake and Related Works' (the Ordinance) on 22 December 2011 (Ordinance, 2011). Enforcement of the Ordinance began on 1 January 2012. The Government of Japan also enacted the

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'Guideline on the Prevention of Radiation Hazard of Workers Engaged in Decontamination and Related Works' (the Guideline) on 22 December 2011, the same day as it promulgated the Ordinance (MHLW, 2011).

Following the establishment of this regulatory framework, environmental decontamination was initiated in two affected areas: the special decontamination area (SDA) and the intensive contamination survey area (ICSA). The SDA corresponded to places with substantial environmental contamination of radioactive materials, and the Government of Japan was responsible for decontamination. The ICSA corresponded to places with an ambient dose rate exceeding 0.23 μSv h^{-1}, and the governor of the local government or the mayor of the local municipality was responsible for decontamination.

This article presents statistics on the radiation doses of decontamination and related workers using official records.

2. RADIATION DOSE REGISTRATION SYSTEM FOR DECONTAMINATION AND RELATED WORKS

2.1. Establishment of the radiation dose registration system

After decontamination and related works began in the areas affected by the accident at Fukushima Daiichi nuclear power plant, concerns were expressed regarding implementation of these decontamination works following enforcement of the Ordinance. Specifically, employers' lack of means to verify each worker's past radiation dose if workers did not report their past radiation dose accurately themselves was highlighted as a concern. Furthermore, the possibility that radiation dose records could be scattered or lost after contractors terminated their business if these records were not properly organised and registered was flagged as a concern.

The Radiation Dose Registration Centre (RADREC) of the Radiation Effects Association has been operating a centralised radiation dose registration system for nuclear workers since 1977 (Asano and Ito, 2019). This system uses a database and radiation passbook which records past dose and health examination results for each worker. In order to address concerns with contamination of sites following the Fukushima accident, a radiation dose registration system for decontamination and related workers was initiated in November 2013, referencing the preceding nuclear worker system. In March 2015, RADREC started operating a database system for the dose records of decontamination and related workers.

In conjunction with the use of a radiation passbook, the RADREC database allows primary contractors to record radiation dose and verify the past dose of each worker.

2.2. Registration categories

The radiation dose registration system comprises two categories for contractors joining the registration system, depending on their work content and area.

Category I represents decontamination work which occurs inside the SDA, as well as the handling of specified waste. Category I requires contractors to use the radiation passbook, record radiation dose quarterly, and register radiation dose and health records after completing their work. Enquiries about workers' past dose records must be addressed. These requirements assume that related work takes place at higher radiation dose rates, and they are similar to the corresponding requirements for workers in radiation-controlled areas in nuclear facilities.

Category II represents work which occurs in the ICSA. Contractors under Category II only need to register radiation dose and health records after completing their work, because radiation dose rates in the ICSA are lower than the corresponding rates in the SDA.

2.3. Registering records with the database

Designated institutions can issue radiation passbooks to Category I workers. When these passbooks are issued, a central registration number (personal ID) is obtained. Radiation passbooks and personal IDs are commonly used in both decontamination and nuclear facilities in order to manage radiation dose for both types of project.

Contractors joining the registration system can access the RADREC database and register the title of their work project and their quarterly radiation dose. They can also enquire about workers' past dose records. If a decontamination worker has performed nuclear work, the radiation dose they have incurred at nuclear facilities can be verified using the RADREC database, which cross-references the decontamination and nuclear databases.

3. RADIATION DOSE STATISTICS FOR DECONTAMINATION AND RELATED WORKERS

3.1. Changes in the radiation dose to workers

As of 1 November 2020, approximately 120 primary contractors for 750 recovery projects joined the RADREC registration framework, and registered project titles for decontamination and related work or the handling of specified waste. The database includes the radiation dose records of approximately 100,000 workers.

Using the database's periodically registered records, radiation dose statistics are provided in Fig. 1. Even if subcontracted workers participated in multiple projects in a given year, their radiation dose records are aggregated in the database using each worker's central registration number.

The number of decontamination workers increased from 2012 to 2015, and then decreased from 2015 to 2018 because operations across the whole decontamination area had terminated by March 2017.

The highest recorded dose ranged from 6.7 to 13.9 mSv year^{-1}, but no workers received an annual dose >20 mSv. The average dose ranged from 0.3 to 0.7 mSv year^{-1}. In 2019, more than 90% of workers were exposed to <1 mSv year^{-1}.

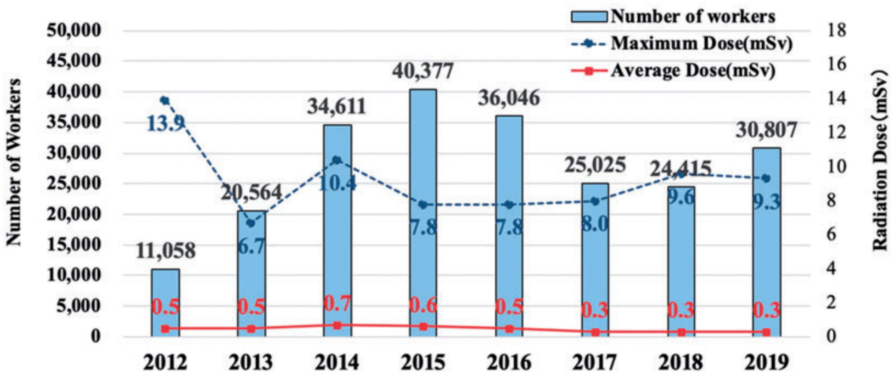

Fig. 1. Changes in radiation dose to decontamination workers.

3.2. Changing types of work in the special decontamination area

In the early stages after the accident at Fukushima Daiichi nuclear power plant, decontamination works began in the SDA and ICSA. However, 10 years have passed since the accident, and decontamination works in the whole area had terminated by March 2017. Since then, the types of recovery work and activities have changed at these sites. Construction and operation of the Interim Storage Facility and construction of the Specified Reconstruction and Revitalisation Base have become substantial. The works related to the Specified Reconstruction and Revitalisation Base particularly involve activities in the higher-dose-rate 'difficult-to-return zone', where decontamination and related works have not yet been implemented (MOE, 2020). This section discusses radiation dose by type of work since the accident.

3.2.1. Work type categories

To clarify the work in progress in the SDA, work types are divided into the following five categories, based on the titles of the work projects registered in the RADREC database.

- 'Decontamination': whole-area decontamination, land restoration at temporary storage sites, and demolition of houses in the SDA.
- 'Waste disposal': handling of specified waste of <100,000 Bq kg^{-1}, minimising waste volumes, and incineration facilities.

- ‘Interim storage’: construction of soil separation and storage facilities, transportation of soil and waste from temporary storage facilities to the Interim Storage Facility, and processing and storage of soil and waste.
- ‘Reconstruction/revitalisation’: construction of a Specified Reconstruction and Revitalisation Base, demolition of houses, and decontamination in six municipalities (Futaba, Okuma, Namie, Tomioka, Iitate, and Katsurao).
- ‘Others’: radiation monitoring and management support for construction, consultants, and road construction.

3.2.2. Worker numbers for each type of work

Changes in the number of workers for each work type are provided in Fig. 2. Workers engaged in multiple projects are counted for each project; therefore, total worker numbers do not correspond to the data presented in Fig. 1.

Decontamination workers were dominant from 2012 to 2016. The number of workers at the Interim Storage Facility accounted for approximately 2% of all workers in 2015, and accounted for approximately half of all workers in 2019.

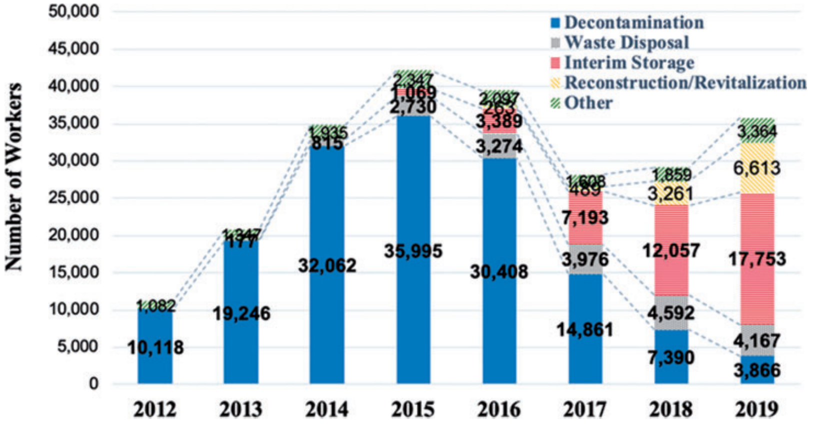

Fig. 2. Worker numbers for each type of work.

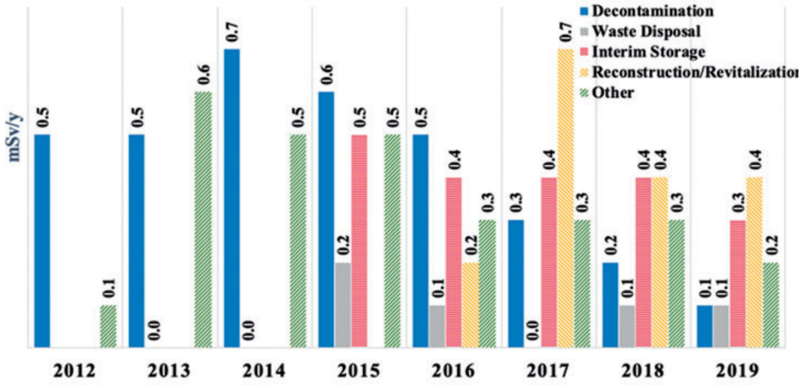

Fig. 3. Average dose for each type of work.

3.2.3. Average dose for each type of work

Average doses for each type of work are provided in Fig. 3. The average dose for decontamination of the whole area from 2012 to 2016 ranged between 0.5 and 0.7 mSv year^{-1}. After termination of decontamination works in the whole area, average dose decreased to 0.1 mSv year^{-1} in 2019. Average dose at the Interim Storage Facility was 0.3–0.5 mSv year^{-1}. Before operation of the Interim Storage Facility, workers had been exposed to higher doses because of decontamination efforts and the demolition of housing prior to land development at the scheduled site.

The average dose at the Specified Reconstruction and Revitalisation Base was 0.7 mSv year^{-1} in 2017 because projects were implemented in the ‘difficult-to-return zone’, where contamination remained significant.

The average dose pertaining to waste handling was lower because this work includes handling waste of $<$100,000 Bq kg^{-1} and is mainly implemented outside the SDA.

3.2.4. Maximum dose for each type of work

Maximum doses for each type of work are provided in Fig. 4. The maximum dose for decontamination workers was 13.9 mSv year^{-1} in 2012, which included radiation doses resulting from the Pilot Project of Japan Atomic Energy Agency, of which some work was implemented in the ‘difficult-to-return zone’.

The maximum dose between 2012 and 2014 was due to decontamination work. Since 2015, maximum doses occurred during work at the Interim Storage Facility, especially amongst project managers, who tended to remain longer at each site. No workers received an annual dose $>$20 mSv.

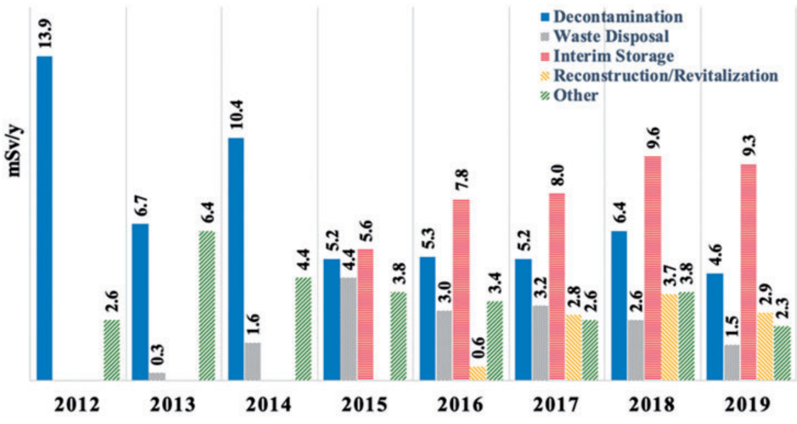

Fig. 4. Maximum dose for each type of work.

3.3. Comparing radiation doses between decontamination workers and nuclear workers

A statistical comparison between decontamination workers and nuclear workers in 2019 and fiscal year 2019 is provided in Table 1. Compared with nuclear workers, worker numbers and doses were lower amongst decontamination workers.

Table 1. Comparing radiation doses between decontamination workers and nuclear workers.

	Decontamination workers (January–December 2019)	Nuclear workers (April 2019–March 2020)
Number of workers	30,807	63,638
Average dose (mSv)	0.3	0.6
Maximum dose (mSv)	9.3	19.6
Collective dose (man-mSv)	10,103	36,174

4. CONCLUSIONS

The radiation dose registry system for decontamination and related workers has been operating successfully. Statistical comparisons with nuclear workers are also available.

Although decontamination efforts in the whole area had terminated by the end of 2017, construction and operation of the Interim Storage Facility and construction of the Specified Reconstruction and Revitalisation Base remain in progress. Since approximately 10 years have passed since the accident at Fukushima Daiichi nuclear power plant, the types of work in the affected areas have changed over time. Considerations of radiation protection measures are important, depending on recovery phase.

After the nuclear accident, the recovery process within the affected restricted area may continue to change over the long term. The preparation of careful and prudent radiation protection measures is required throughout the recovery process.

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Health management and care following the Fukushima nuclear power plant accident: overview of Fukushima Health Management Survey

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Abstract–Following the accident at Fukushima Daiichi nuclear power plant, Fukushima Prefecture is conducting the Fukushima Health Management Survey, which has been contracted out to Fukushima Medical University. The purpose of this survey is to investigate the exposure doses and health conditions of the residents of Fukushima Prefecture in order to prevent, diagnose, and treat diseases at an early stage, and to maintain and improve the health of residents in the future.

This survey consists of a basic survey to estimate external exposure doses and detailed surveys to investigate health conditions. The detailed surveys comprise: (i) thyroid ultrasound examination; (ii) comprehensive health check; (iii) mental health and lifestyle survey; and (iv) pregnancy and birth survey.

In the basic survey, the external exposure dose was estimated for >466,000 people during the first 4 months after the accident; it was estimated to be <5 mSv for 99.8% of residents.

The thyroid ultrasound examination included four rounds of echo examinations covering approximately 380,000 children aged <18 years at the time of the accident in each round. The first, second, third, and fourth examinations identified 116, 71, 31, and 21 children with thyroid cancer/suspected cancer, respectively. The Fukushima Prefectural Oversight Committee analysed the results from the first and second examinations, and evaluated that 'the detected increased rate is unlikely to be the impact of radiation'. However, the Oversight

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Committee is deliberating the future direction of thyroid examination, taking into consideration the advantages and disadvantages of the examination as well as ethical viewpoints.

In the comprehensive health check, approximately 210,000 people in the evacuation area were examined, and increased rates of lifestyle-related diseases [e.g. obesity, hypertension, diabetes, and dyslipidaemia (low high-density-lipoprotein cholesterol)] were confirmed. In the mental health and lifestyle survey, approximately 210,000 people, including residents in the evacuation area, were examined. A deterioration in general mental health was found for the period immediately after the accident across a wide range of age groups, and although recovery was seen over the years, the rate of mental health issues remains above the national average. The pregnancy and birth survey revealed that the pre-term birth rate, low-birthweight rate, and rate of congenital anomalies did not differ from the national average.

The purpose of Fukushima Health Management Survey is not only to collect data on the health of the residents of Fukushima Prefecture, but to provide direct support to residents regarding the health issues clarified by the survey. Moreover, various initiatives are being implemented in cooperation with various local government authorities with the aim of maintaining and promoting the health of the residents.

Keywords: Fukushima nuclear accident; Fukushima Health Management Survey; Radiation effects; Thyroid cancer; Exposure dose

1. INTRODUCTION

The accident at Fukushima Daiichi nuclear power plant, triggered by the Great East Japan Earthquake, occurred on 11 March 2011. Large amounts of radioactive substances were released into the environment, and there is concern about the impact on the health of the residents. High dose rates have been recorded in air in Soso District, Iwaki City, Fukushima City, Iitate Village, and other areas in Fukushima Prefecture. The evacuation alert area has expanded over time from the initial 3-km area to a 20-km area. In addition, certain regions outside the 20-km area were designated by the Japanese Government as deliberate evacuation areas (where there is a risk of annual exposure $\geq$20 mSv) and evacuation-prepared areas (to be evacuated in case of emergency). As a result, >113,000 residents were forced to evacuate. Fukushima Prefecture started the Fukushima Health Management Survey in 2011 with the aim of monitoring the health of residents for a long period of time, and maintaining and improving their health in the future. This survey is being conducted by Fukushima Medical University Radiation Medical Science Centre for the Fukushima Health Management Survey.

2. OVERVIEW OF FUKUSHIMA HEALTH MANAGEMENT SURVEY

The Fukushima Health Management Survey includes a basic survey which aims to estimate the external exposure dose of residents, and detailed surveys to address different health conditions (Yasumura et al., 2012; Kamiya, 2018; Fukushima, 2020a). There are four detailed surveys and tests comprising: (i) thyroid ultrasound examination; (ii) comprehensive health check; (iii) mental health and lifestyle survey; and (iv) pregnancy and birth survey.

2.1. Basic survey

In a radiation accident, it is extremely important to estimate the individual exposure dose of the inhabitants in order to evaluate the health effects of radiation exposure and to manage health. Therefore, in the basic survey, the effective dose of external exposure for the 4 months immediately after the accident was estimated for the entire prefectural population of approximately 2,050,000 people (Fukushima, 2020a,c). The external exposure dose estimation system, developed by the National Institutes for Quantum and Radiological Science and Technology, was used to estimate the external exposure dose of each individual. This method uses a combination of information on the behaviour of residents for 4 months immediately after the nuclear accident and a dose rate map created from temporal radiation monitoring information of the area, etc. (Nagataki et al., 2013; Ishikawa and Tanaka, 2015; Kamiya et al., 2016).

The basic survey clarified the estimated values for effective external exposure dose for >466,000 people over the 4 months immediately after the accident. The external exposure dose to the inhabitants was <5 mSv for 99.8% of the residents and <2 mSv for 93.8% of the residents. The maximum value was 25 mSv, the mean value was 0.8 mSv, and the median value was 0.6 mSv (Fukushima, 2020c). The Fukushima Health Management Survey Oversight Committee evaluated that it was unlikely that exposure in this dose range would have a significant detectable impact on health (Fukushima, 2020c).

2.2. Detailed survey: thyroid ultrasound examination

2.2.1. Methods of thyroid ultrasound examination, results, and analysis

In the thyroid ultrasound examination, approximately 370,000–380,000 prefectural residents aged <18 years at the time of the accident were examined, mainly by ultrasonography (Suzuki et al., 2016a).

In total, 116, 71, 31, and 21 children with thyroid cancer or suspected cancer were identified in the first, second, third, and fourth rounds of the thyroid ultrasound examination, respectively (Suzuki, 2016; Suzuki et al., 2016b; Fukushima, 2020d). It follows from these results that the prevalence of thyroid cancer calculated from the first examination was approximately 30 times higher compared with prevalence rates that had been reported previously (Katanoda et al., 2016).

On the other hand, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported the exposure dose of the thyroid gland as follows. The average thyroid doses following the accident in Chernobyl were 1100, 440, and 330 mGy in Belarus, Russia, and Ukraine, respectively (UNSCEAR, 2011). The highest thyroid dose following the accident in Fukushima was found in 1-year-old children, and was 47–

83 mGy (UNSCEAR, 2014, 2015). Therefore, the thyroid dose from the accident in Fukushima was lower than that from the accident in Chernobyl. Ohira et al. analysed the dose–response relationship between the thyroid dose estimated by UNSCEAR and the corrected odds ratio for the detection of thyroid cancer in each region, and found no increase with dose (Fukushima, 2020d; Ohira, 2020).

The age distribution of the detected childhood thyroid cancers differed between Fukushima and Chernobyl. In Chernobyl, thyroid cancer was frequently observed in children aged 0–4 years 5–8 years after the accident (1990–1993); in Fukushima, thyroid cancer has not been detected in this age group 7 years after the accident (Tronko et al., 2014; Fukushima, 2020a,d).

2.2.2. Evaluation of the thyroid ultrasound examination results and the future

Fukushima is not the only place where thyroid ultrasound examinations have led to the discovery of many cases of thyroid cancer. In South Korea, a 15-fold increase in the incidence of thyroid cancer was observed in 2011 compared with 1993, which was before ultrasound examination for thyroid cancer commenced (Ahn et al., 2014). This increase in incidence is presumed to be due to the sensitivity of ultrasound examinations. A similar trend has also been observed in the USA, Europe, and other parts of the world where ultrasound examinations are performed.

Based on the evidence mentioned above, the Fukushima Oversight Committee evaluated that the rate of thyroid cancer found in the first and second examinations was unlikely to be an effect of radiation exposure from the accident in Fukushima (Fukushima, 2016, 2020a,d). However, this is not the final conclusion, and there is a need to continue with careful and unprejudiced analysis of the examination results.

It is important that thyroid ultrasound examinations are only performed in individuals who have given their consent after understanding the advantages and disadvantages of the procedure. For this reason, on-site briefings for parents and lessons for students are held as part of the thyroid ultrasound examination, where the characteristics of thyroid cancer and the advantages and disadvantages of the thyroid ultrasound examination are explained in an easy-to-understand manner. At the same time, information is transmitted via the web and explanation leaflets for the thyroid examination. The future direction of the thyroid ultrasound examination is being discussed by the Oversight Committee and countermeasures will be taken according to the results of the review.

2.3. Detailed surveys: comprehensive health check, mental health and lifestyle survey, and pregnancy and birth survey

2.3.1. Comprehensive health check

The comprehensive health check targeted approximately 210,000 residents of the evacuation area (Fukushima, 2020a). This examination revealed an increase in obesity, hypertension, diabetes, dyslipidaemia (low high-density lipoprotein cholesterol), chronic kidney disease, liver dysfunction, and polycythaemia, indicating that evacuation-related lifestyle changes following the Great East Japan Earthquake can be considered as risk factors for these diseases (Sakai et al., 2014; Satoh et al., 2015, 2016a,b; Ohira et al., 2016a,b; Takahashi et al., 2017). The results made it apparent that changes in living environment, lifestyle, and eating habits, as well as changes in the local community due to long-term evacuation had a strong impact on the health status of residents. It is possible that the risk of lifestyle-related diseases will continue to increase among evacuees as their evacuation lifestyle becomes long term, and thus health management is becoming an important topic (Hashimoto et al., 2017).

2.3.2. Mental health and lifestyle survey

Approximately 210,000 residents in the evaluation area are in the scope of this survey (Fukushima, 2020a). As part of this survey, residents who are considered to be in need are provided with care and support via telephone or printed documents (Oe et al., 2016a,b; Maeda and Oe, 2017; Fukushima, 2020c).

A Kessler 6 scale (K-6) evaluation was conducted on overall mental health, including anxiety, among evacuees aged ≥16 years. Those with a score ≥13 points in the K-6 evaluation were considered to be in need of support. According to the K-6 score, the proportion of Japan's general population in need of mental health support is 3.0%. The current survey showed a value of 14.6% among evacuees in 2011, but a decrease over time was observed, and a value of 5.7% was reported in 2018 (Fukushima, 2020c). However, even in 2018, approximately 7 years after the accident, the value remains approximately double that of the general population of Japan, indicating that the general mental health condition of evacuees had not fully recovered at this time. On the other hand, traumatic reactions in those aged ≥16 years were evaluated by the PTSD checklist (PCL) survey, and emotions and problematic behaviour in children were evaluated by the Strength and Difficulties Questionnaire (SDQ) survey. The percentage of residents who were evaluated as needing assistance in both surveys was high in the year immediately after the accident at Fukushima, but decreased over time. The proportion of children in need of assistance according to the SDQ survey is now almost the same as the national average.

With respect to attitudes towards radiation risk, in 2011, immediately after the accident, approximately 60% of the residents stated a belief that radiation exposure from the accident in Fukushima may have some impact on the next generation. Although this has decreased since then, in 2018, approximately one-third of residents still believed that there may be some impact on the next generation (Fukushima, 2020c). Major challenges remain in risk communication and radiation literacy.

2.3.3. Pregnancy and birth survey

Between 145,000 and 160,000 pregnant women in Fukushima Prefecture are surveyed each year. Most of these women have been issued a mother and child health handbook. The survey investigates the physical and mental health of women, takes measures to reduce anxiety, and provides necessary care (Fukushima, 2020a). The survey clarifies that the pre-term birth rate, low-birthweight rate, and congenital anomaly rate did not differ in the period from 2011 to 2018 between women in Fukushima Prefecture and the national average (Fujimori et al., 2014; Fukushima, 2020b). However, it was revealed that the rate of postpartum depression among new mothers was high in Fukushima. This survey provides scientific evidence on pregnancy- and childbirth-related health issues in Fukushima, and is also a source of information against reputational damage.

3. CONCLUSION

Radiation disasters have a strong and shocking impact on multiple aspects of public life, such as health, society, and the environment. The effects on health are not only linked directly with the exposure dose, but are also strongly affected by sudden changes in the living environment. This is particularly valid in the case of evacuation. Therefore, when considering the health effects of nuclear accidents, it is necessary to deliberate not only the exposure dose but also various other factors that affect health. In such a situation, the Fukushima Health Management Survey plays an important role in monitoring, maintaining, and improving the health status of residents.

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Health issues today in affected areas near Fukushima Daiichi nuclear power plant

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Abstract–Due to vigorous efforts to decontaminate the environment following the accident at Fukushima Daiichi nuclear power plant, the size of the difficult-to-return zone has reduced significantly and people have started returning to their homes. As the population has increased, medical needs have ensued. A marked increase in traffic as well as decontamination and reconstruction projects has led to an increase in the number of road traffic and occupational accidents. Acceleration of population aging has resulted in an increased number of elderly residents with multiple medical problems. Uncontrolled/untreated medical problems among middle-aged to older workers have made them susceptible to deterioration of health conditions. Insufficient social support for elderly people living alone has resulted in delayed access to medical care. Early intervention and the prevention of health deterioration are instrumental. When responding to medical needs, proactive approaches, including home visits for elderly patients and health promotion, have been implemented. Human resource development is crucial to ensure the sustainability of these activities.

Keywords: Health issues; Medical services; Nuclear accidents; Recovery

1. BACKGROUND

Since the accident at Fukushima Daiichi nuclear power plant (NPP), vigorous efforts have been made to decontaminate the environment. The size of the difficult-to-return zone has reduced significantly and people have started returning to their homes.

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

Soon after the accident, 12 municipalities, including eight towns and villages in Futaba region, were ordered to evacuate. In total, 98,000 people were evacuated. In 2014, the Japanese Government started lifting the evacuation order for Kawauchi Village, and this was extended gradually to other municipalities. In 2019, the evacuation order was lifted for the first time in part of Okuma Town, the municipality where Fukushima Daiichi NPP is located. Currently, 22,000 people live in areas where the evacuation order has been lifted. The difficult-to-return zone has now reduced to one-third of its size in 2011, representing 2.7% of Fukushima Prefecture.

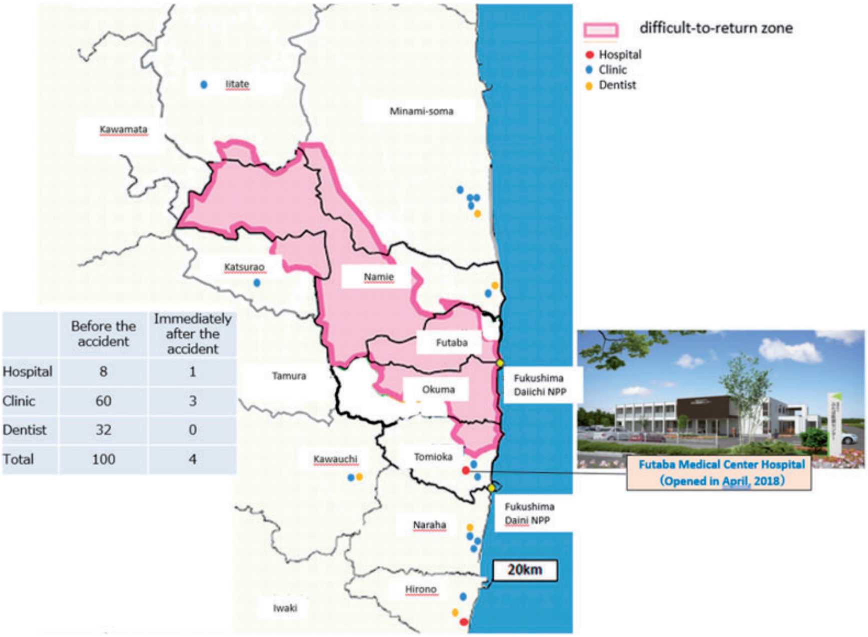
As the population living in areas where the evacuation order was lifted has increased, medical needs have ensued. For example, the number of calls to the emergency medical services (EMS) in Futaba region has been increasing by 10% every year for the last 6 years (Fukushima Prefecture, 2019). The main reasons for EMS calls are acute illnesses. However, there has been a marked increase in traffic, as well as decontamination and reconstruction projects, and the proportion of injuries caused by road traffic and occupational accidents is much higher in these areas than national data. Also, interhospital transfer is more common than the national average. This reflects a shortage of medical resources in areas where the evacuation order was lifted. Until Futaba Medical Centre (FMC) was established, there was no emergency hospital in this region.

2. DEVELOPMENT OF MEDICAL SERVICE SYSTEMS IN FUTABA REGION

Before the accident at Fukushima Daiichi NPP, there were 100 medical facilities in Futaba region (Fig. 1). After the accident, all medical facilities within 20 km of the NPP were forced to close, and only four medical facilities around the evacuation zone continued or recommenced medical practice soon after the accident. Since some of the evacuation orders have been lifted and people have started returning to their homes, medical needs have grown. Several outpatient clinics have re-opened; however, medical practice in the area is difficult due to a shortage of medical staff, the financial burden, and uncertainty about the future.

Acceleration of population aging has resulted in an increase in the number of elderly residents with multiple medical problems requiring careful medical attention. Uncontrolled/untreated medical problems among middle-aged to older workers have made them susceptible to deterioration of health conditions, requiring emergency and more intensive treatment. Insufficient social support for elderly people living alone has resulted in delayed access to medical care.

To respond to increasing emergency medical needs in Futaba region, Fukushima Prefectural Government established an emergency hospital – FMC – in Tomioka Town in 2018. FMC is located 8 km south-west of Fukushima Daiichi NPP. The main role of FMC is to provide emergency medical care and disaster responses, including radiological emergency responses. Although it is a small hospital with 30 beds, it operates 24 h per day, 7 days per week, 365 days per year to meet local



	Before the accident	Immediately after the accident
Hospital	8	1
Clinic	60	3
Dentist	32	0
Total	100	4

Fig. 1. Medical facilities in areas where the evacuation order has been lifted (as of 1 April 2020).

emergency needs. Also, it is expected to provide home care and contribute to comprehensive community care following the return of elderly people with physical disabilities to the area. Health promotion efforts are required for residents with multiple medical problems and workers with health risks such as diabetes and hypertension. In order to achieve these goals, good collaboration is needed with other medical facilities, healthcare providers, and local municipalities inside and outside the region. In particular, good cooperation with Fukushima Medical University is prerequisite to ensure the quality of care and continuity of projects.

Over the last 2 years, FMC has responded to 60% of emergency medical needs in Futaba region (Miyagawa and Tanigawa, 2020). The number of emergency room (ER) visits increased by 50% in 2019 compared with the previous year. Regarding the areas of residence of patients, Naraha, Tomioka, and Hirono account for more than half of patients, reflecting the populations of these municipalities and their proximity to FMC. Patients from outside Futaba region or Fukushima Prefecture account for 35% of ER visits. These patients have mainly suffered injuries due to road traffic or occupational accidents. Two peaks have been observed in the age distribution of patients: 50–59 years and >80 years. Injury is the most common reason for visiting the ER, followed by respiratory problems. The younger group generally visit the ER with injuries, and the older group generally present with respiratory problems. Regarding admitted patients, those aged >80 years account for 60% of admissions. Similar to diagnoses in the ER, the two main reasons for admission are injury and respiratory problems. Most injuries requiring admission are fractures related to osteoporosis, and the majority of respiratory problems are due to pneumonia. Osteoporosis and pneumonia are very common medical problems among elderly people. Patients with major trauma, acute myocardial infarction, or acute stroke require advanced medical intervention, and are generally transferred to designated medical facilities such as level 1 trauma centres or stroke centres outside the region, such as in Iwaki or Minamisoma.

Health issues are not limited to medical problems. More than 40% of residents are aged >65 years and most of them have chronic illnesses. Early intervention and the prevention of health deterioration are instrumental. There is a need to undertake more home visits for elderly patients. There is also a need for health promotion in collaboration with local municipalities, such as holding educational seminars for residents and comprehensive community care events. The key concept is a proactive approach. In order to address family and community issues, it is imperative to get involved in comprehensive community care, which is organised by the municipal government and social welfare liaison. Last but not least, development of human resources is crucial to implement the abovementioned activities. Close collaboration with academic institutions, organisations, and municipalities is needed.

3. ISSUES AND CHALLENGES

Evacuation orders have been lifted and people are returning. However, 80% of former residents have not yet returned. What do they think?

In Tomioka and Namie Town, where the evacuation order has been lifted for 3 years, those who have already returned or wish to return account for only 16–18% of the population (Reconstruction Agency, 2019). Approximately half of the residents have decided not to return. In Okuma and Futaba Town, where the evacuation order was lifted most recently, only approximately 10% of former residents want to return and 60% have decided not to return. Most former residents have re-established their lives in the evacuation site. The longer the evacuation order is in place, the fewer people want to return. It has been reported that concerns about consuming locally sourced food and tap water in Tomioka were significantly more prevalent among those who were undecided about returning and those who had decided not to return compared with residents who had returned to their homes in Tomioka (Orita et al., 2020). The proportion of residents who felt that cancer would occur due to radiation exposure and that genetic effects would arise in the next generation due to living in Tomioka was significantly higher among those who decided not to return and those who were undecided about returning. Studies have indicated that the perception of risk of radiation exposure was closely associated with the intent to return home. Given their well-being and re-established lives in the evacuation site, it would not be unreasonable to say that returning is one of the options, not the only option.

There are two challenges here: universality and rarity. Firstly, before the nuclear accident, Futaba region had been suffering from an aging population, depopulation, and a shortage of medical resources. The accident at Fukushima Daiichi NPP underscored those issues. However, in Japan, these issues are not unique to Futaba region, and the accident clearly highlighted medical and public health issues that exist elsewhere in the country. The other challenge is rarity; trying to rebuild a sustainable community where all residents were once evacuated after a major nuclear accident is unprecedented. These experiences provide a basis for future planning following a major nuclear accident.

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SAGE ICRP

Activities to support individual dosimetry of children in Kawamata Town

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Abstract–Kawamata Town in Date District, Fukushima Prefecture is located more than 30 km north-west of Fukushima Daiichi nuclear power plant, but on 22 April 2011, part of the Yamakiya District of Kawamata Town was designated as a planned evacuation area. The exposure of children was a concern in Kawamata Town. Based on the proposal of Kindai University, Kawamata Town Board of Education took the initiative to measure individual radiation doses with an integrated dosimeter (glass badge) for all kindergarten children, nursery school children, elementary school students, and junior high school students in the town. These measurements were continued for nearly 3 years from June 2011 until the end of March 2014. The total number of measurements was approximately 16,800 across 11-cycle measurement, with 3 months' accumulation taken as one-cycle measurement. Kindai University provided financial support for the glass badge measurement service, and cooperated in the analysis of measured values and the development of advice based on the results. The main body implementing the measurements was Kawamata Town Board of Education, and the data obtained belong to Kawamata Town. When measurements were starting to be taken, schools got involved in the collection and distribution of dosimeters after explanations were provided to principals and school nurses who were in charge of risk communication. Thanks to the efforts of the schools, the recovery rate exceeded 90%, increasing the reliability of the measurements. It was clear who needed the information – the children and their parents. Kawamata Town Board of Education summarised the cumulative dose results for each measurement and notified parents via personal reports. These were sent to parents with advice on measurement results prepared by Kindai University, and care was taken to ensure that people could understand the measured results. Further briefing sessions were held as appropriate. At the briefing sessions, at the request of Kawamata Town Board of Education, the faculty

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members of Kindai University explained the measurement results from a professional point of view, and a professor from the Faculty of Medicine provided individual health consultations. Kawamata Town took the lead in using specialists to gain peace of mind, and this was key to the project's success. The situation was managed by taking measurements by dosimetry, and asking experts to interpret the data and provide advice to help reassure the residents.

Keywords: Nuclear accident; Support for reconstruction; Glass badges; Experts; Exposure of children

1. INTRODUCTION

The All Kindai Kawamata Town Reconstruction Assistance Project was a cross-faculty project launched by Kindai University to support the early reconstruction of Kawamata Town in Date District, Fukushima Prefecture by making full use of its research capabilities as a comprehensive university with 14 faculties and 48 departments. Reconstruction support measures proposed by Kindai University faculty members were split into groups for: (i) agriculture/industry/town development promotion; (ii) decontamination promotion; (iii) mental health and physical care; and (iv) radiation/radioactivity measurement. These support measures started in earnest on 31 May 2013, incorporating the intentions of the residents of Kawamata Town. Support is provided while incorporating the opinions of residents in terms of 'reconstruction support', such as revitalisation of the local agricultural industry and the development of education and culture, and 'regeneration support' following the accident, such as decontamination research and health management.

2. KINDAI UNIVERSITY'S RECOVERY SUPPORT IN KAWAMATA TOWN

The radioactive materials released by the accident at Fukushima Daiichi nuclear power plant were distributed over a wide area covering eastern Japan. Kindai University is a comprehensive university based in western Japan, and its main campus is located approximately 570 km south-west of Fukushima Daiichi nuclear power plant. In late March 2011, Kindai University Atomic Energy Research Institute (AERI) opened a telephone consultation hotline (three lines) regarding the health effects of radiation with the cooperation of 44 nuclear personnel (including retirees) in the Kansai region, and efforts were made to alleviate anxieties by providing consultations with residents and providing information on radiation and the situation as it stood. This was held for 10 days from 24 March 2011, and 705 enquiries were handled.

Kawamata Town is located more than 30 km north-west of Fukushima Daiichi nuclear power plant. The population was 15,352 in May 2011. This is not the town where the nuclear power plant is located, nor is it adjacent to this town. From March 2011, evacuees from Namie Town, living within 20 km of Fukushima Daiichi nuclear power plant, were being accepted in Kawamata Town. On 22 April 2011, the Japanese Government decided to set an area >20 km from Fukushima Daiichi nuclear power plant with an estimated cumulative dose of >20 mSv by 11 March 2012 as the planned evacuation area. As such, Yamakiya District, which is part of Kawamata Town, was designated as part of the planned evacuation area. Approximately 8% of the residents of Kawamata Town lived in the Yamakiya District. In early April 2011, information was indirectly received that the Mayor of Kawamata Town was looking for someone who could give advice on radiation protection. Hence, as there are researchers specialising in nuclear power and radiation at Kindai University AERI, which has an educational reactor with a thermal output of 1 W, contact was made with Kawamata Town and the town was visited on 30 April 2011. An investigation was started into the pollution situation by measuring the air dose rate, examining the effect of reducing the dose rate by removing surface soil, and collecting environmental samples in collaboration with the town. The purpose of the investigation was to understand the actual situation, and collect data that would contribute to the proposal of countermeasures. From May to June 2011, AERI received questions from the town and undertook sample measurements as requested. Most of the questions and requests were related to schools, and a detailed survey of outdoor pools was undertaken, including recommendations on how to remove surface soil in the schoolyard, advice regarding the need to wear masks, and recommendations on the safety of opening classroom windows. For agricultural land, radioactivity levels of vegetables in vegetable gardens, water in ponds, sunflowers, and paddy fields were measured and data were provided. In this way, as radiation experts, Kindai University and Kawamata Town built a relationship of trust while receiving consultations on the interpretation of data on radiation in the town and proposals for countermeasures against radiation.

On 21 June 2011, Kindai University was commissioned by Kawamata Town as an 'earthquake reconstruction advisor'. Kindai University has provided reconstruction assistance for the Great East Japan Earthquake with funds of approximately 200 million yen from faculty and staff. Part of this was used for support activities in Kawamata Town. Since radioactive substances that are widely distributed in the environment cause radiation exposure, it was thought necessary to have a means to measure radiation, so radiation measuring instruments were donated. In addition to the glass badges described later, 50 pocket dosimeters, four portable radiation measuring instruments, two in-vehicle dose rate recording systems with GPS function, and five air radiation dose rate electric display systems were provided. Air radiation dose rate electric display systems were installed at the entrances of five kindergartens and nursery schools, and the parents of the attending children gained some relief from seeing the dose rate decreasing each day. Lecturers were provided and various lectures were held. At Kindai University Higashi-Osaka campus, an exhibition of Kawamata Town produce was held alongside university events to promote the support activities.

The following four points were kept in mind regarding reconstruction support: (i) support should be implemented in consultation with the town and in response to requests; (ii) build a strong trusting relationship between Kindai University and Kawamata Town; (iii) all the data obtained belong to the town, and presentations are made jointly with the town; and (iv) support is given in order for Kawamata Town to become a model district for reconstruction, to lead ultimately to broad reconstruction of Fukushima Prefecture.

3. INDIVIDUAL DOSIMETRY OF CHILDREN USING GLASS BADGES

In May 2011, during consultations in Kawamata Town about radiation countermeasures, concerns were raised about the exposure of children. In response, Kindai University proposed individual dosimetry using glass badges. These dosimeters can easily measure the dose received by an individual. It is possible to estimate the dose from the air dose rate and present and explain the level, but as the individual dose varies depending on the behaviour of the individual, it is better to measure the dose to each individual. Even if there is no impact on health, it is important to know the current status of each individual. A measurement service provided by Chiyoda Technol Corporation was used for personal dosimetry using glass badges. Kindai University provided financial support for measurements, and helped to analyse the values measured and create advice based on the results at the request of the town. Kawamata Town Board of Education took the lead in distributing and collecting glass badges and organising measurement data. The first measurements were taken in June 2011 for approximately 1700 children from one nursery school, four kindergartens, six elementary schools, two junior high schools, students, and teachers for all children from nursery schools to junior high schools in the town. Glass badges were sent to each school and distributed to every child in every class. Each school undertook collections. After wearing the glass badges for 3 months, one cumulative dose was obtained to make one cycle. This measurement was taken continuously for approximately 3 years until the end of March 2014, and the total number of measurements in the 11-cycle measurement was approximately 16,800. As of June 2011, this was the first project in Japan to measure the daily exposure dose of residents for every individual. Subsequently, measurements using glass badges started to be taken in other areas.

The cumulative dose for 3 months was taken as one measured value. The minimum dose unit is 0.1 mSv. For the natural background dose, the dose before the accident (annual dose 0.54 mSv) in Oarai-machi, Ibaraki Prefecture, where the glass badge measurement service facility is located, was adopted, converted into days, and then subtracted uniformly from the measured value. By subtracting it uniformly, it becomes easier to revise the measured dose at a later date. A histogram of the dose in the first cycle is shown in Fig. 1. As shown in Fig. 1, the maximum value was 2.0 mSv, the average value was 0.39 mSv, and the dose ranged widely. The dose decreased with each round of measurements, and in the final (11th) cycle, the maximum value was 0.3 mSv, the average value was 0.08 mSv, and the distribution was narrow with a mode of 0.1 mSv. The maximum dose for 1 year from June 2011 was

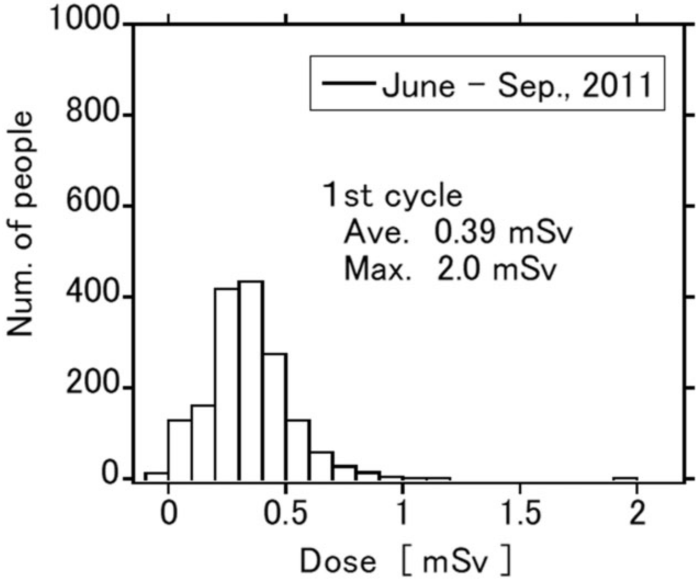

Fig. 1. Dose histogram (June–September 2011).

3.6 mSv and the average was 1.14 mSv, and it became clear that the dose was not at a level of concern for human impact. Fig. 2 shows the change in dose over time. The vertical axis shows the dose converted over 90 days. The maximum and minimum of the average values for each school are also shown. The dose decreased over time. Fig. 2 also shows the decreasing curve for 'cases without decontamination' estimated by the physical attenuation of radioactive caesium, starting with the first dose. The measured values are below this curve, which is considered to be indicative of the effect of topsoil runoff and decontamination due to rain.

It was thought that measuring external exposure dose with glass badges in a radiation field where radioactive caesium was widely distributed on the ground surface following the accident at Fukushima Daiichi nuclear power plant might not be an appropriate dose evaluation. In contrast, a joint study between the Japan Atomic Energy Agency and the National Institute of Radiological Sciences demonstrated that the results of external exposure dose measurements using individual dosimeters can be evaluated with almost no underestimation of the effective dose (JAEA, NIRS, 2015). Moreover, for small children, the dose is higher than for adults, even in the same radiation field. The following results have been reported. As for the conversion coefficient from the peripheral dose equivalent to the individual dose equivalent, a value of 0.7 is appropriate for adults, whereas the value is 0.8 for those aged 3 to 18 years. (NIRS, JAEA 2015). This also makes it apparent that measuring the individual dose of children is of great significance. As described above, although measurements were implemented as it was thought that it would be useful to have an

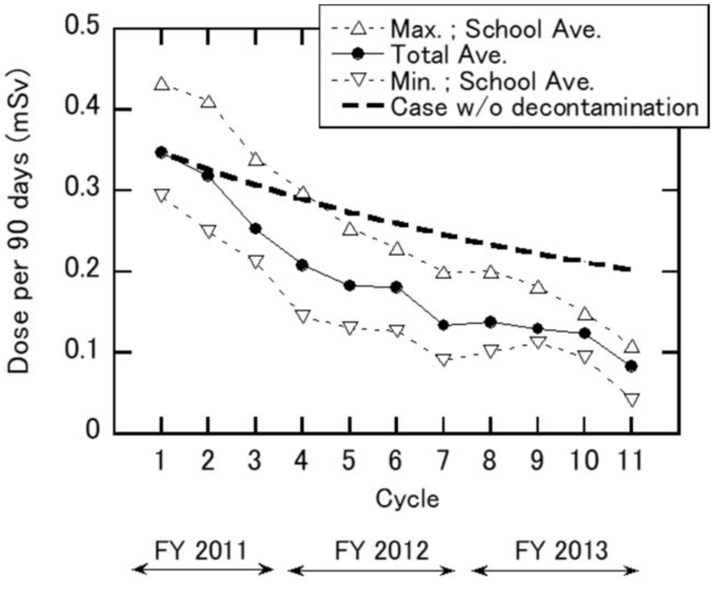

Fig. 2. Changes in dose over time.

approximation of the dose level for each child, it was, in fact, possible to provide a value close to the effective dose for each individual.

4. CONCLUSION: FACTORS FOR SUCCESS

Due to the impact of the accident at Fukushima Daiichi nuclear power plant, radiation exposure was no longer 'somebody else's issue'. Faced with this, the residents of Kawamata Town wanted information from experts and wanted to gain knowledge about radiation in order to gain peace of mind. To live a life with peace of mind in a radiation-exposed environment, it is necessary to clarify the exposure dose by taking measurements. This article reports dosimetry of children using glass badges. The main reason for the success of this task was that Kawamata Town took the lead in using experts to gain reassurance. The situation was managed using dosimetry, and asking experts to interpret the data and provide advice; the advice obtained helped the residents to gain peace of mind. The main measuring party was Kawamata Town Board of Education, and data were obtained for each individual and for the town. The main intentions were clear, namely that 'materials should be measured to give reassurance', and 'the meaning of the values, not just the values, should be conveyed'. When measurements commenced, schools got involved in the collection and distribution of glass badges after explanations were provided to principals and school nurses in charge of risk communication. Thanks to the efforts of the schools, the recovery rate was 90% or more each time, and the reliability of the measurements was high. Information was communicated between the board of education, the principal, the class teacher, and the parents. Each communicator communicated in a state where the content was convinced at each level. As a result, the dose to children could be determined, which led to peace of mind. It was clear that the target of the information was the children and their parents. Consideration was given so that the measurement results could be understood. Kawamata Town Board of Education summarised the cumulative dose results for each cycle and notified the parents with a personal report; this was sent out with advice on measurement results prepared by Kindai University. Measurements were not just taken and left, but briefing sessions were held on the measurement results as appropriate. At the same time, individual sessions on health were held to try and ease concerns. The first briefing session was held on 13 November 2011, and the sixth and final briefing session was held on 23 March 2014. There was a 3-year summary report on 6 July 2014.

Measurements with glass badges provided peace of mind to all parents with children. As collections were made by the schools, the collection rate exceeded 90% each time due to the schools' efforts. This enabled the situation for the entire town to be determined as measurements were not only taken for those who wished to be measured. As a result, the measurements were highly reliable, which led to great comfort.

ACKNOWLEDGEMENTS

The authors wish to thank Mayor Furukawa and other people in the town hall, especially Deputy Director of Education Nakae and Superintendent of Education Kanda who played strong parts as promoters. The huge efforts of the school staff and Kawamata Town Board of Education have led to completion of the measurements.

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Support activities in Namie Town, Fukushima undertaken by Hirosaki University

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Abstract–Several radiation monitoring research projects are underway on dose assessment, biological analysis, and risk communication under an agreement with Namie Town. Indoor radon and thoron progeny concentrations have been measured using passive-type monitors to estimate internal doses due to inhalation. In addition, airborne radiocaesium concentrations at five points in Namie Town have been analysed using a high-purity germanium detector to estimate internal doses for comparison with radon. External radiation doses from natural and artificial radionuclides have also been estimated using an in-situ gamma-ray spectrometer. Other support activities are mentioned briefly in this article,

Keywords: Support activity; Namie Town; Dose assessment; Environmental monitoring; Radiation effect

1. INTRODUCTION

Hirosaki University and Namie Town in Fukushima reached an agreement on cooperation for recovery in September 2011. Three support plans were proposed, as follows: (i) recovery of Namie Town (e.g. decontamination and promotion of renewable energy); (ii) security and safety of residents (e.g. health consultation and

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environmental radiation monitoring on demand); and (iii) accumulation of scientific findings (Tokonami et al., 2015). Since then, numerous support activities have been undertaken. Evacuees were allowed to return to their homes in Namie Town from March 2017. As of November 2020, 1500 residents had returned, representing 7% of Namie Town's total original population (Ogura et al., 2021). A new research project was commenced on dose estimation for residents of Namie Town. This project proposed a comparable measure of radiation risk with doses derived from natural radiation sources. This article will give an overview of the project on dose assessment as well as other support activities conducted by the Institute of Radiation Emergency Medicine, Hirosaki University.

2. CHARACTERISTICS OF NAMIE TOWN

In 2011, the Japanese Government designated a 'special decontamination area', where measures were implemented for the decontamination of soil, etc. This area includes three zones, as shown in Fig. 1. The difficult-to-return zone is areas where the annual cumulative dose estimated from the ambient dose rate has not fallen below 20 mSv, even 6 years after the accident. Areas where the annual cumulative

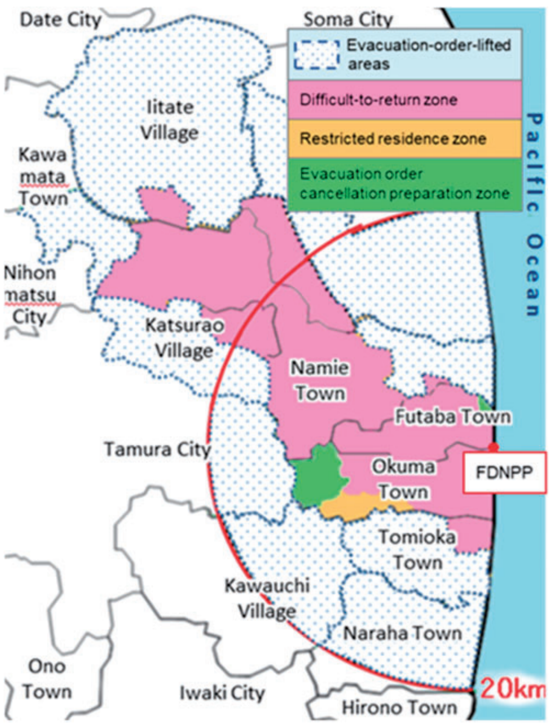

Fig. 1. Map of Namie Town and surrounding area (Fukushima Revitalization Station, 2021).

effective dose estimated from the ambient equivalent dose rate exceeded 20 mSv but $<$ 50 mSv as of March 2012 was designated the 'restricted residence zone'. Areas where the annual cumulative dose was confirmed to be $\leq$20 mSv were designated as 'evacuation-order-lifted areas'.

3. SUPPORT ACTIVITIES IN NAMIE TOWN

3.1. Dose estimation for residents in Namie Town

Concentrations of radon and thoron progeny were measured using passive-type monitors (Fig. 2) in 93 houses to evaluate the inhalation dose for residents (Ploykrathok et al., 2021; Thamaborn et al., 2021). Measurements were taken during the period from August 2017 to November 2019. Measurements were taken over four 3-month periods (October–December, January–March, April–June, and July–September) in each dwelling to cover a whole year. Radon concentrations varied from 6 to 242 Bq m^{-3}, and the median values in each period were 32, 28, 27, and 31 Bq m^{-3}, respectively. Thoron progeny concentrations (equilibrium equivalent thoron concentration) varied from 0.1 to 20 Bq m^{-3}, and the median values in each period were 0.7, 0.7, 0.8, and 0.8 Bq m^{-3}, respectively. The annual average indoor concentrations of radon and thoron progeny were evaluated as 31 and 0.7 Bq m^{-3}, respectively.

Annual effective doses due to inhalation of radon and thoron progeny were estimated in accordance with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2010). The residents of Namie Town completed a questionnaire on estimated indoor and outdoor occupancy factors, and these values were found to be 0.83 and 0.17, respectively. Annual effective doses from radon and thoron progeny were estimated to vary from 0.6 to 2.3 mSv

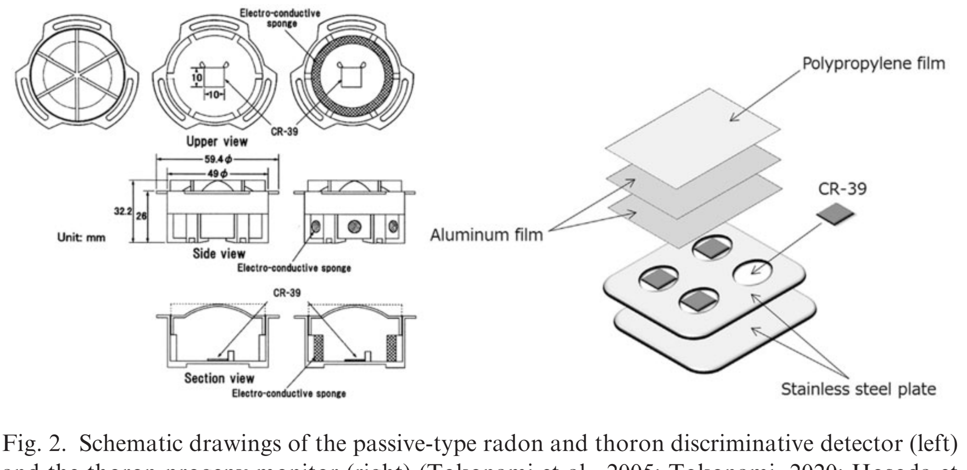

Fig. 2. Schematic drawings of the passive-type radon and thoron discriminative detector (left) and the thoron progeny monitor (right) (Tokonami et al., 2005; Tokonami, 2020; Hosoda et al., 2017).

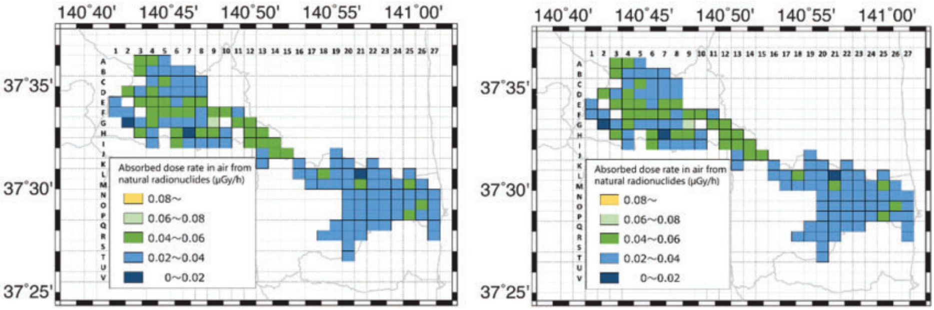

Fig. 3. Map of absorbed dose rate in air from natural radionuclides (left) and artificial radionuclides (right) (Ogura et al., in press).

and from 0.1 to 3.4 mSv, respectively. The total annual effective dose due to radon and thoron varied from 0.7 to 5.5 mSv, with a median value of 1.4 mSv.

In addition, airborne radiocaesium was measured using a high-purity germanium detector at five sampling points in Namie Town from August 2017 to September 2019 (Hegedüs et al., 2020a,b). The maximum activity concentration of ^{137}Cs of 1.28 ± 0.09 mBq m^{-3} was observed on 23 August 2017, and subsequently the value decreased towards the detection limit. The annual effective dose due to inhalation of airborne ^{137}Cs was estimated to be $<$83 nSv for all age groups at the maximum observed activity concentration. The estimated inhalation dose was found to be much smaller than the inhalation dose from radon and thoron progeny, which are natural components.

To estimate external doses from natural and artificial components, measurements of gamma-ray pulse-height distribution were taken using a 3×3-inch NaI(Tl) scintillation spectrometer at the 130 accessible points that divide Namie Town into a mesh of 1 km $\times$ 1 km (Ogura et al., in press). Fig. 3 shows the dose rate maps of natural and artificial components (Ogura et al., in press). The median and range of absorbed dose rates in air from artificial radionuclides were evaluated as 133 and 67–511 nGy h^{-1}, respectively, in the evacuation order cancellation zone, and 1306 and 892–2081 nGy h^{-1}, respectively, in the difficult-to-return zone. These values were corrected to 1 April 2020 based on the analysis of radiation monitoring data obtained from 103 monitoring posts in Namie Town. The median annual effective doses due to external exposures from natural and artificial radionuclides were estimated to be 0.19 and 0.40 mSv, respectively, in the evacuation order cancellation zone, and 0.25 and 3.9 mSv, respectively, in the difficult-to-return zone.

3.2. Other support activities

Following the accident at Fukushima Daiichi nuclear power plant, many types of radionuclides as well as radiocaesium were released into the environment. Assessment of these other radionuclides was important to ensure safety and identify

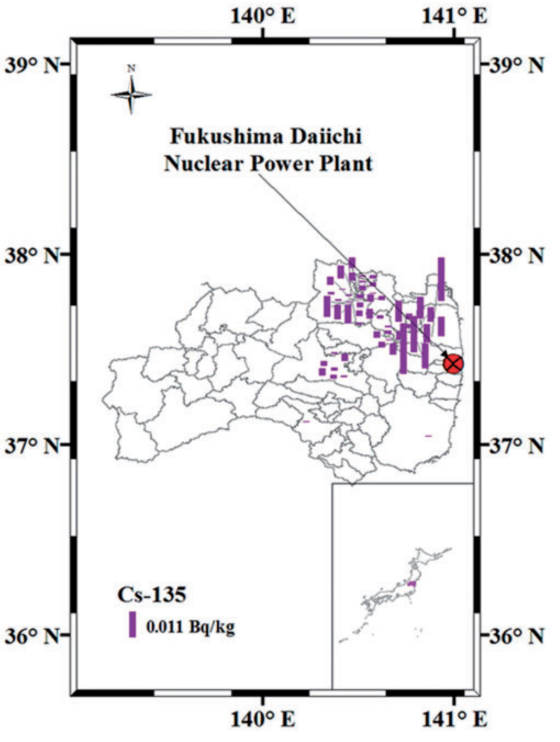

Fig. 4. ^{135}Cs distribution in soil before the accident at Fukushima Daiichi nuclear power plant (Yang et al., 2016).


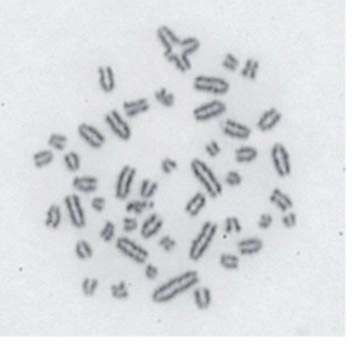

Fig. 5. *Apodemus speciosus* collected in Namie, Fukushima (left) and metaphase spread with chromosome aberration (right).

the sources of contamination. A new analytical method was developed for radionuclides that are difficult to analyse, such as ^{90}Sr, ^{129}I, ^{236}U, and ^{135}Cs, using solid phase extraction and mass spectrometric techniques (Yang et al., 2016, 2018, 2019a,b; Tazoe et al., 2018). Novel methods were applied to environmental samples collected in Namie Town and the coastal areas in Fukushima Prefecture to assess the impact of the accident.

Regarding the biological effects of radioactive substances released into the environment due to the accident at Fukushima Daiichi nuclear power plant, analyses were undertaken of chromosomal translocation in peripheral blood lymphocytes obtained from evacuees aged <18 years, radiation effect surveys on wild mice living in the contaminated area (Fig. 5, Fujishima et al., in press), and transition of deposition of radioactive substances in the reproductive organs of free-roaming cats. These results were reported to the local government of Namie Town for risk communication and utilisation with residents.

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On the role of experts: experiences from 35 years of Chernobyl consequences in Norway

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Abstract–The fallout from the 1986 Chernobyl accident caused dramatic and long-lasting consequences for parts of food production in Norway, and the indigenous Sámi reindeer-herding lifestyle and culture in central Norway was particularly threatened. Banning food production – or condemning food – was considered unacceptable in a long-term perspective, and huge efforts were made to develop mitigating options. Some of these are still in place, 35 years after the accident. This article describes some of the long-term efforts made by Norwegian authorities to attempt to alleviate the consequences for the reindeer herders. Every accident and crisis is unique, and this is true for the experiences in Norway. However, some of the experiences in Norway are likely to have universal value.

Keywords: Sámi reindeer herder; Radiocaesium; Remediation; Whole-body monitoring

1. INTRODUCTION

The 1986 Chernobyl accident had significant consequences for Norway with high levels of contamination and long-lasting challenges in animal husbandry (cattle, sheep, goats, and semi-domestic reindeer) utilising unimproved forest and mountain pastures for grazing (Tveten et al., 1998; Liland and Skuterud, 2013). There were major consequences for producers in many areas, particularly the indigenous Sámi reindeer herders in central Norway. This article will therefore focus on experiences from work related to the Sámi reindeer herders. It should be mentioned that the

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situation was not unique to Norway, and that Sámis across the border in Sweden experienced similar consequences (e.g. Beach, 1990).

When talking about the roles of professionals and experts in a large crisis such as the Chernobyl accident, it may be useful to draw parallels with the coronavirus disease 2019 pandemic. From the start, the experts played important roles in assessing risk and suggesting solutions, while the politicians made the decisions trying to balance costs and benefits. Also, from the start, members of the public may have had strong opinions, and as restrictions last, many citizens may wish to influence and adjust their own situations, with experts continuously being important sources of advice. This article will illustrate that there are some commonalities with the Chernobyl experience.

The author has had a central position in Chernobyl consequence management in Norway since the mid-1990s, and a short summary of experiences will be biased by his views. The reader is referred to Liland and Skuterud (2013) and Skuterud et al. (2016) for more details and perspectives.

2. RESPONSES AND MITIGATING ACTIONS

When the Chernobyl accident happened in 1986, Norway had no operational nuclear emergency preparedness. It took weeks to gain overviews of the affected areas, and there was much uncertainty about the consequences. However, the vulnerability of reindeer herding to radioactive contamination was known from the time of nuclear weapons testing, and a monitoring programme of Sámi reindeer herders in northern Norway was still ongoing. It was quickly realised that reindeer husbandry could be particularly affected by the fallout from Chernobyl. In July 1986, high radiocaesium levels in samples led to national news headlines such as: ‘Lichens may be contaminated for decades. Reindeer husbandry is threatened’. A permissible level of 600 Bq kg^{-1} for radiocaesium in basic foodstuffs was established in June 1986, and the contamination levels in reindeer resulted in a ban on reindeer meat from central and southern Norway in autumn and winter 1986.

Further increases in radiocaesium levels in reindeer meat in autumn 1986 led the Norwegian health authorities to raise the permissible level for marketed reindeer meat to 6000 Bq kg^{-1} to reduce the challenges for the herders as producers. A part of the argument given in the press release announcing the change was: ‘A maintained intervention level of 600 Bq kg^{-1} will [...] result in production for condemnation and uneasiness among reindeer herders in the coming years. A despondent atmosphere, apathy and defection of young people will come forward in reindeer husbandry and the Sámi community [...]. If the limit is not raised, these problems will last for many years and can thereby threaten the Sámi lifestyle and culture, irrespective of monetary compensation’. From a radiation protection point of view, the increase was justified by low consumption of reindeer meat by the average consumer in Norway (approximately 0.6 kg $year^{-1}$) and corresponding negligible radiation doses. However, the reindeer herders themselves were recommended not to eat meat with high radiocaesium levels, but to refer to the limit for basic foodstuffs of

600 Bq kg^{-1} as reindeer meat was a dietary staple for them. The authorities offered less-contaminated reindeer meat as a substitute for their own produce. The health authorities also distributed dietary advice with recommendations on how much could be consumed depending on radiocaesium levels, and advice on cooking and preparation methods to reduce radiocaesium levels of the consumed product. Later, compensation for an 'alternative diet' was established so that economic constraints should not be a reason for consumption of contaminated meat.

Restrictions on land use and grazing, or continued bans and condemnation of foods, were not seen as acceptable in Norway after the accident, and huge efforts were made for several years to develop countermeasures for animal husbandry. The efforts involved scientists, the authorities, and animal owners – often in cooperation – with important practical input from the animal owners. Most of the measures were much more cost-effective than condemning foods (Tveten et al., 1998).

3. SOCIOCULTURAL BACKGROUND

An official Norwegian report in 1986 concluded that the Chernobyl accident caused a general information crisis where the authorities lost trust and credibility due to cases of erroneous information etc. For many of the indigenous Sámi reindeer herders, this added to an already sceptical and tense relationship with the state due to a history of assimilation policies and programmes aiming to increase productivity in reindeer husbandry, and reduce the number of herders (Stephens, 1994).

The Chernobyl fallout created a dramatic change for the reindeer herders. Over a few days in spring 1986, their diet changed from being one of the healthiest and most sustainable to one of the most radioactive. From having a lifestyle where they were the masters with their local know-how and experience – and had reindeer husbandry and the culture as 'boundary maintenance' vis-à-vis the rest of society – they suddenly became dependent on the authorities and scientists (Stephens, 1994). Some were afraid that the Norwegian Government would use the Chernobyl fallout as an opportunity for rationalisation, and there was deep concern whether the state would continue to provide monetary compensation if it would take 20–30 years before contamination levels decreased (Stephens, 1994). The herders realised that they could not 'surrender' to the experts and the authorities (Paine, 1992). They therefore started searching for solutions (e.g. experiments with clean feeding during winter 1986/87, although some scientists warned about animal welfare issues and losses of 10–20% of the animals) (Paine, 1992). By 1988, much experience on countermeasures had been gained, and a memorandum was sent to the Norwegian Government demanding that 'individual solutions be accepted' (Paine, 1992).

The clean reindeer meat offered by the authorities in the first years after the Chernobyl accident solved an ingestion dose challenge but was not very popular (Stephens, 1994). It also deprived the herders of the other parts of the reindeers' bodies (blood, organs, antlers, hooves, etc.) which they used in preparation of traditional meals or handicrafts. Furthermore, as the culture is based on learning through participation in traditional activities and own experience, parents feared that those customs would disappear, together with related words in their language. The various remedial actions (clean feeding, live monitoring of reindeer, whole-body monitoring etc.) together successfully averted the long-term catastrophe for reindeer herding culture that was feared initially, but increased the dependence of the Sámi reindeer herders on scientists and state subsidies (Stephens, 1994).

4. WHOLE-BODY MONITORING – ALSO AN ARENA FOR COMMUNICATION

In response to the consequences of the Chernobyl accident, the whole-body monitoring programme was extended to the South Sámi areas in central Norway. The aim was primarily to survey ingestion doses and time trends in internal radiocaesium levels, but also included dietary surveys and interviews about the reindeer herders' efforts to reduce their radiocaesium intake. Together with monitoring of radiocaesium in foodstuffs, the results of the whole-body monitoring could thus also be used to estimate the effects of their efforts to reduce doses (Fig. 1).

During the first years, the monitoring campaigns were carried out annually. However, as radiocaesium levels in reindeer and people decreased – and the scientific, technical, and practical challenges with remediation in reindeer herding were gradually solved – there was less contact between herders and experts. The author's first encounter with the reindeer herders was during the monitoring campaign in 1996 – 3 years after the previous campaign. The herders' frustrations about abandonment, lack of communication, and continuous concerns about health effects made a strong impression.

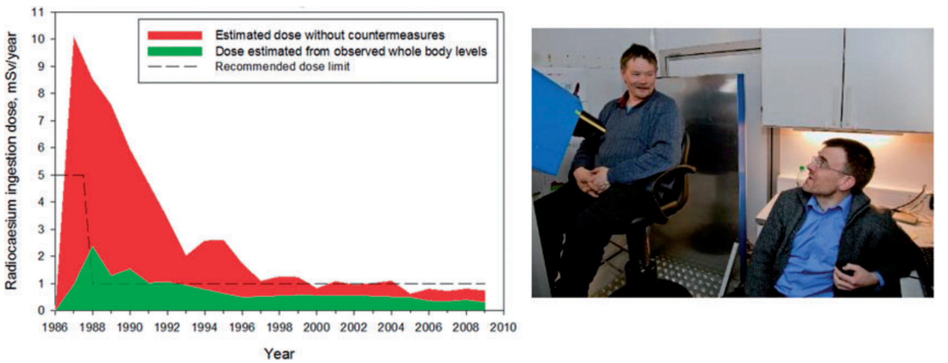

Fig. 1. Left: Ingestion doses to Sámi reindeer herders in the Snåsa region. The green area shows doses estimated from observed whole-body levels, while the red area shows the estimated doses if no countermeasures had been implemented [adapted from Skuterud and Thørring (2012)]. Right: A reindeer herder (left) being monitored in the Norwegian Radiation and Nuclear Safety Authority's mobile laboratory (the author to the right). © Geir Tønset, Adresseavisen.

Invitations to participate in the whole-body monitoring programme have been distributed to all registered herders in the affected areas, and the monitoring takes place at central locations in the Sámi areas. There is no strict schedule; participants meet at their own convenience and are offered a light meal while queuing for the measurement or talking to friends, colleagues, or the experts. It is important to note that the monitoring has not just been a 'technical' happening resulting in a measurement result. The measurement allows time for communication with each individual (e.g. comparisons with previous year's results and on their efforts to limit the radiocaesium intake). It is believed that this time for personal communication is important for the participants. Also, it is felt that a relatively comfortable measurement geometry (Fig. 1) facilitates conversation better than many more advanced measurement devices. Conversation topics and questions range widely (e.g. from understanding of risks related to measured levels, to questions on contamination in the environment and restrictions). Therefore, having a team of personnel with wide competence has been an advantage. The team must also be prepared to handle questions outside the responsibility of the Norwegian Radiation and Nuclear Safety Authority (DSA), as the public cannot be expected to know which topic belongs to which authority.

5. HEALTH CONCERNS

The permissible levels in foods; the monitoring, control, and countermeasures in reindeer husbandry; and the whole-body monitoring of people all refer to radiation doses and potential health effects. It is therefore natural that reindeer herders have concerns about health effects of the fallout. In 1990 and 2006, they sent letters to the Ministry of Health demanding more information and comprehensive health monitoring. The issue was also raised at a stakeholder meeting in 2008: 'Why hasn't there been a follow-up of health issues for the Sámi population after Chernobyl?' 'Where are the results? We are being researched on but learn nothing about the possible health effects' (Oughton et al., 2008). These quotes partly refer to the whole-body monitoring campaigns and the fact that they do not answer their most basic question: 'What risk does the radiocaesium in my body pose to my health?' Early studies of potential effects gave equivocal results (e.g. Reitan et al., 1998). Further studies have been discussed among the authorities with involvement of Sámi representatives. None have been initiated as the doses are lower than those expected to induce health effects, and because of reservations against more studies with equivocal results; these might well increase the reindeer herders' notions of being 'guinea pigs' in the large 'Chernobyl experiment'.

Despite some critical voices as demonstrated above, DSA has continued the monitoring campaigns, partly because they are appreciated as arenas for communication. Some more in-depth interviews with reindeer herders about their risk perception in 2016 indicated that the monitoring programme was seen as a positive measure, even among those interviewees who did not participate in the programme (Svenningsen, 2016). The interviews by Svenningsen documented how the herders' situations have changed over three decades. Gradually, they achieved positive response expectations due to increased knowledge, and perception of control and influence over the contamination and risks. In 2016, the herders had little focus on health risks and radioactivity (Svenningsen, 2016).

6. THE ROLE OF EXPERTS

As mentioned in the Introduction, during and after crises, professionals and experts have obvious roles in risk assessment and in developing and suggesting options for remediation. Much out of necessity, the consequences of the Chernobyl accident in Norway initiated extensive cooperation between scientists, the authorities, and affected people in solving the challenges. It was also obvious – from an early stage, as illustrated in this article – that the citizens also wanted to be involved when the consequences affected their daily lives. The experts' contributions to developing a suite of actions, such that the herders could select what was appropriate for them, have been important for their coping. People are different, and have different preferences and attitudes, including towards experts; hoping for consensus is often futile.

The duration of the contamination problems has required long-term follow-up of affected people. Norwegian authorities have decided to offer whole-body monitoring as long as radiocaesium in reindeer meat is an issue; there is still an elevated permissible level of $3000\,Bq\,kg^{-1}$ for reindeer meat, and reindeer are routinely live monitored prior to slaughter. Considering the experts' roles in establishing the restrictions, it seems obvious that they should also contribute to managing the concerns they can cause. Furthermore, in a situation with long-lasting contamination, there will also be a continuous need for communication with newcomers and new generations of herders. The coronavirus disease 2019 pandemic is just one of the cases lately that have demonstrated the importance of providing science-based information; the potential for alternative voices on the consequences of radioactive fallout is huge.

Despite the initial challenges in 1986 related to trust and culture etc., the continued efforts by herders, scientists, and the authorities; joint experiences from applying different measures; and possibilities for communication have helped the affected population build competence on how to manage their personal contamination situation. And as the cooperation continues, we all maintain the competence we have gained – and acquire more.

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The role of experts in the development of recovery handbooks: UK and European experience

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Abstract–The importance of involving experts in the development of strategies for managing areas contaminated as a result of a nuclear accident is now well recognised. Following the Chernobyl accident in 1986, the initial focus, quite understandably, was on the technical aspects of reducing doses to the affected population. Subsequently, work carried out in the UK and elsewhere in Europe looked at the broader impacts of protective actions on agriculture, the environment, and society. From 1997, a group of experts from academia, government, and non-government organisations met regularly in the UK to debate these issues. One of the outputs included the first version of the UK Recovery Handbook for Radiation Incidents in 2005. Based on the success of the UK group, a European network of experts was established, leading to the development of European handbooks in 2009. The UK handbooks are living documents that are updated regularly with substantive input from experts.

Keywords: Recovery handbooks; Protective actions; Experts

1. INTRODUCTION

Recovery handbooks are tools to assist in the development of strategies for managing contaminated food production systems, inhabited areas, and drinking water supplies following a radiation emergency. The handbooks have been developed in conjunction with a wide range of experts, stakeholders, and end users. Depending on the prevailing circumstances, there are many potential protective actions (previously

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called ‘countermeasures’) that can be applied. Consequently, decision makers need guidance on how to select options according to: radionuclide(s) released, chemical forms, levels, and spread of deposition; time of year; land use in affected areas; timescales for preparing and implementing protective actions; legislative, physical, and societal constraints; and overall acceptability. It is impossible to have one generic strategy for all emergency scenarios.

There are three handbooks (food production systems, inhabited areas, and drinking water supplies), each of which is divided into several sections providing supporting scientific and technical information; an analysis of the factors influencing recovery; compendia of comprehensive, state-of-the-art datasheets for approximately 100 protective actions; and guidance on planning in advance for recovery. There is also a decision-aiding framework to select and combine protective actions, and several worked examples for illustrative radiation emergency scenarios.

The audience for the recovery handbooks is wide ranging and can include central government and agencies, national and local authorities, radiation protection experts, remediation contractors, agriculture and food industry, and drinking water providers. In terms of application, the handbooks have several functions. In the preparation phase, they can be used to engage stakeholders; to develop local, regional, and national plans; and to identify gaps in recovery capability. In the post-emergency phase, they can be used to aid decision-making. Finally, the handbooks can also be used during recovery exercises and for training and familiarisation purposes.

2. INVOLVEMENT OF EXPERTS IN HANDBOOK DEVELOPMENT

Recovery handbooks were first published in the UK in 2005 (HPA, 2005). This was almost 20 years after the Chernobyl accident. The intervening period represents the time taken for experts to fully understand the behaviour of radionuclides in different environments, and how this knowledge could be applied to prevent or reduce radionuclide transfer to the population. Over the years, the types of experts involved in handbook development have broadened from those with primarily scientific and technical backgrounds to those involved in applied fields including policy, planning, and stakeholder engagement. The contribution made by experts is further elaborated below, based on the timeline shown in Table 1.

2.1. European experts: 1990–1999

During the period 1990–1999, the European Commission supported numerous research projects throughout Europe under its 3rd and 4th Framework Programmes. These projects involved scientific and technical experts from research organisations, radiation protection institutes, and academia. Their work provided data and information on mechanisms of radionuclide transfer to the population through, for example: physicochemical properties of soils; bioavailability of

Table 1. Timeline for the involvement of different experts in handbook development.

Timeline	Type of expert involvement
1990–1999	EC 3rd and 4th Framework Programmes; EC–CIS ECP/JSP
1993–2009	UK 'Applicability' study; UK expert group established. UK recovery handbooks published in 2005 (v1) and 2008/9 (v2/3)
2000–2009	EC 5th and 6th Framework Programmes (FARMING, STRATEGY, EURANOS). European recovery handbooks published in 2008/9 (v1/2)
2011–2016	UK recovery handbook published in 2015 (v4); UK recovery capability study
2020–2022	Major update to UK recovery handbook (v5)

EC-CIS ECP/JSP, European Commission–Commonwealth of Independent States Experimental/Joint Studies Projects.

radionuclides in plants and animals; radio-ecological modelling; effectiveness of agricultural countermeasures; and decontamination options for inhabited areas. The results of these projects and other targeted studies with experts from the Commonwealth of Independent States (Russia, Belarus, and Ukraine) were published in numerous reports and peer-reviewed papers (e.g. European Commission, 1996; Sinnaeve et al., 1996). This provided a solid foundation for the handbooks.

2.2. UK experts: 1993–2009

UK scientists took the relevant outputs from the EC 3rd and 4th Framework Programmes to investigate the applicability to the UK of recovery strategies used elsewhere in the Commonwealth of Independent States and Europe (Nisbet, 1995). This involved broadening the types of experts consulted (e.g. economists, policy directors, farm managers), as well as the topics considered (e.g. resource availability, cost, and acceptability of the protective actions). The study concluded that the use of expert judgement to gauge the practicability of protective actions was useful, but also highlighted considerable divergence of opinion. Establishment of an expert working group was recommended as part of UK contingency planning. The new group, called the 'Agriculture and Food Countermeasures Working Group' (AFCWG), was set up in 1997 by the National Radiological Protection Board and Ministry of Agriculture (Nisbet and Mondon, 2001). Membership included a wide range of experts from government (e.g. central, regional, local; devolved administrations) and non-government organisations (e.g. retail, food processors, farming unions, consumer groups, environmentalists, academics). The aim of the expert group was four-fold: to encourage communication between experts; to disseminate relevant information; to debate practicability of protective actions for planning purposes; and to provide expert input during a radiation emergency. The group remained active until 2009. It provided a role model for the establishment of similar expert groups in Europe, as well as providing vital input to the first three versions of the UK Recovery Handbook for Radiation Incidents.

2.3. European experts: 2000–2009

The European Commission's 5th and 6th Framework Programmes supported the FARMING (Nisbet et al., 2005), STRATEGY (Howard et al., 2005), and EURANOS (Raskob et al., 2010) projects. These played a key role in the development of recovery handbooks at the European level. These projects broadened the focus from agriculture and food to inhabited areas, drinking water supplies, and forests. A range of approaches were used to engage with the experts, including international and national working groups (initially through the FARMING network), scenario-focused workshops, and exercises. This led to the compilation of compendia of protective actions through the STRATEGY project, and opportunities to brainstorm the structure and content of generic European handbooks through the FARMING and EURANOS projects. These handbooks were published in 2009 (Brown et al., 2009; Nisbet et al., 2009a,b). Customised versions of the handbooks were subsequently produced in Scandinavia, Spain, Ireland, and Slovakia. Experts from multiple disciplines were engaged during the period 2000–2009 (e.g. radiation protection specialists, agriculturalists, foresters, veterinarians, radio-ecologists, doctors, environmentalists, journalists, engineers, hydrologists, economists, emergency planners, farming union representatives, consumers, computer scientists, meteorologists, and physicists).

2.4. UK experts: 2011–2016

The Fukushima accident in 2011 led to a period of reflection in the UK where many areas of emergency planning, response, and recovery were stress tested using input from a wide range of independent experts. Recovery capability (i.e. capability for monitoring, data and information collection and exchange, dose assessment, remediation, waste management, and stakeholder engagement) was one such area that was assessed by Public Health England. Findings from this study have subsequently led to a new and ongoing programme of work being co-ordinated by the UK Nuclear and Radiological Emergencies–Recovery Working Group (NRE-RWG). Priorities include a major update to the UK Recovery Handbook for Radiation Incidents, development of a waste management plan, and elaboration of models for the future provision of remediation capability, as well as monitoring, sampling, and analytical capability.

During the period 2011–2016, the UK Recovery Handbook for Chemical and Biological Incidents was published for the first time (Wyke et al., 2012; Pottage et al., 2015) based on the radiation counterpart with input from experts in chemical and biological hazards. There was also an opportunity to carry out a minor update to the fourth version of the UK Recovery Handbook for Radiation Incidents (Nisbet et al., 2015), incorporating some of the learning from remediation work after Fukushima.

3. MAJOR UPDATE TO UK RECOVERY HANDBOOK: 2020–2022

The last major update to the UK handbook was in 2009. Since then, there have been changes to international and national legislation relating to nuclear emergencies. Recovery guidance has also been updated (e.g. ICRP, 2020), and lessons have been learned not only from Fukushima but from other non-radiological events including Novichok poisoning in the UK and the worldwide coronavirus pandemic. NRE-RWG is supporting a new project, initiated in 2020 by Public Health England, to completely overhaul the UK Recovery Handbook for Radiation Incidents. PHE is working closely with, and is reliant on, experts in other government departments and agencies, as well as the private sector and local authorities. The experts span areas such as food, agriculture, environment, drinking water supply and quality, nuclear operation and decommissioning, remediation technologies, recovery policy, legislation, and regulation. NRE-RWG is providing access to other experts and potential end users who will peer review all aspects of handbook development.

Key features of the updated handbook include: expanding the scope to encompass a much wider range of scenarios; additional worked examples; a wider range of building structures, surfaces, materials, and food products; new frameworks for recovery planning and waste management; new information on protective actions and their effectiveness; revised datasheet template and content; and a simplified decision-aiding framework. Redundant material has also been identified and will be removed.

4. CONCLUSIONS

Experts have played a crucial role in the development of recovery handbooks over the last 30 years. European research projects carried out in the 1990s by scientific and technical experts led to a comprehensive understanding of the behaviour of radionuclides in the environment, and showed how protective actions (countermeasures) could be used to prevent or reduce exposure of the population. Subsequent UK studies engaged with a broader range of experts and looked beyond the radioecological effectiveness of protective actions to provide a better appreciation of their practicability. Working with expert groups such as AFCWG provided a sound basis for development of the first version of the UK Recovery Handbook for Radiation Incidents. Further multi-disciplinary European projects carried out over the period 2000–2009 established networks of expert groups with responsibility for further developing recovery handbooks for Europe. Recovery handbooks are living documents that need to be updated periodically to remain state-of-the-art. Consequently, a major update to the UK handbook was initiated in 2020 in collaboration with experts from a wide range of backgrounds.

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How to overcome the difficulty of talking about the experience of a nuclear disaster

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Abstract–At the ICRP International Conference on Recovery After Nuclear Accidents Session 3.4 Forum on the Transmission of Experience held in December 2020, a panel discussion took place on the topic, 'How to overcome the difficulty to talk about the experience of nuclear accidents?'. The facilitator was Ryoko Ando (NPO Fukushima Dialogue) and the following six people participated as panelists: Atsushi Chiba (teacher at Fukushima Prefectural Asaka High School), Yoshiko Aoki (NPO Group of Storytellers About 311 in Tomioka), Miku Endo (Great East Japan Earthquake and Nuclear Disaster Memorial Museum), Kenji Shiga (former Director of Hiroshima Peace Memorial Museum), Thierry Schneider (Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire), and Noboru Takamura (Director of Great East Japan Earthquake and Nuclear Disaster Memorial Museum, Nagasaki University).

Keywords: Hiroshima; Nuclear disaster; Fukushima; Chernobyl; Disaster records

1. INTRODUCTION

At Session 3.4 Forum on the Transmission of Experience in the ICRP International Conference on Recovery after Nuclear Accidents held in December 2020, a panel discussion took place on the topic of 'How to overcome the difficulty to talk about the experience of nuclear accidents'. Six panellists participated: Atsushi Chiba (teacher at Fukushima Prefectural Asaka High School), Yoshiko Aoki (NPO Group of Storytellers About 311 in Tomioka), Miku Endo (Great East Japan

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Earthquake and Nuclear Disaster Memorial Museum), Kenji Shiga (former Director of Hiroshima Peace Memorial Museum), Thierry Schneider (Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire), and Noboru Takamura (Director of Great East Japan Earthquake and Nuclear Disaster Memorial Museum, Nagasaki University). With the development of nuclear technology starting in the 20th century, humans have had to face nuclear disasters which have never been experienced before. To date, there is no common understanding on how to understand such disasters, and discussions raise their own unique difficulties. This article report on the discussion of the panellists, who have faced three different nuclear disasters in Hiroshima, Chernobyl, and Fukushima, about what makes it difficult to talk and how to overcome this.

1.1. Hiroshima Peace Memorial Museum

The collection of materials at Hiroshima Peace Memorial Museum was started by Shogo Nagaoka, who taught at the Department of Geology and Mineralogy, Hiroshima University of Literature and Science. Two days after the atomic bomb was dropped on 6 August 1945, Nagaoka entered Hiroshima City, where Hiroshima University of Literature and Science was located. Having noticed the changes caused by the heat rays of the granite in the city, he started collecting materials related to the atomic bombing. Although this had been a personal collection of bomb-related materials, in 1948, after retiring from Hiroshima University of Literature and Science, Nagaoka was hired by Hiroshima City Hall as a specialist in conducting material surveys, and the materials that he owned at that time became the property of Hiroshima City. In 1949, the Atomic Bomb Reference Material Display Room was established based on these materials. In 1955, Hiroshima Peace Memorial Museum opened, and Nagaoka became the first Director. The exhibition at that time included exhibits related to the peaceful use of nuclear energy, as well as materials from the atomic bombings. In 1975, a large-scale renovation was carried out, the contents of the exhibition were renewed, and the exhibition on the peaceful use of nuclear energy was removed. In 1991, a second major renovation was carried out, and in 2019, a third large-scale renovation was carried out.

1.2. Belarus Bragin Museum

In the Bragin district of Belarus, the Bragin Museum, which conveys memories of the Chernobyl accident, was renovated as part of the European Union's Chernobyl disaster area support project CORE programme, which was carried out from 2004 to 2008. The exhibition was divided into four sections after the refurbishment: exhibition of works by painters from the 30-km exclusion zone; exhibition of items from the 30-km exclusion zone; memorial to the young firefighters of Bragin who were victims of the accident; and a special exhibition, 'The Lost Land'. 'The Lost Land' was the result of collaborative work between adult volunteers, artists, and professional curators, consisting of six groups in the Bragin district. Volunteers had the opportunity to talk about what they had witnessed and experienced in the process of preparing for the exhibition, and were able to express not only their hardships but also the beauty of their hometown and their desire to continue living there. The exhibits are things collected by a volunteer group of residents. In this process, the residents came up with a common language, and that became a new way to talk about the accident and the circumstances that had been experienced. It also became the procedure to reconnect the past and present of the disaster area that had been disconnected by the accident.

1.3. The Great East Japan Earthquake and Nuclear Disaster Memorial Museum

The Great East Japan Earthquake and Nuclear Disaster Memorial Museum aims to record and disseminate memories of the Great East Japan Earthquake and the nuclear disaster, and the subsequent reconstruction process. This museum was constructed and opened in Futaba-machi, Fukushima Prefecture – the area affected by the nuclear disaster – in September 2019. There are three basic concepts: (i) records and lessons learned from nuclear disasters and reconstruction – 'passing on to the future and sharing with the world'; (ii) 'disaster prevention/mitigation' that makes use of the experiences and lessons learned from nuclear disasters that are unique to Fukushima; and (iii) collaboration with people who care about Fukushima to 'contribute to the acceleration of reconstruction' by revitalising local communities, culture, and traditions, and developing human resources that will be responsible for reconstruction in collaboration with local communities and organisations. The exhibition consists of six booths, and the contents of the exhibition are organised in chronological order starting from the time of the accident. In the hall, it is also possible to hear the testimonies of those who experienced the earthquake (storytellers).

2. PANEL DISCUSSIONS

The panel discussion proceeded by asking the panellists two questions prepared by the facilitator. A summary of the panellists' responses to the questions is given below.

2.1. Have you ever felt that it was difficult to talk about your experience of the nuclear disaster? If so, when did you feel that way? Moreover, why do you think that was the case?

As a teacher in Fukushima Prefecture, Chiba is engaged in activities such as radiation education for students and study tour in disaster areas. From the results of a questionnaire conducted by Chiba for high school students inside and outside Fukushima Prefecture in 2019, it was inferred that the overall knowledge of radiation was poor and that the culture of 'learning' radiation itself was not fostered. In respect of understanding of the earthquake, knowledge about the scale of the earthquake itself has not been passed on to the next generation, such as not knowing the results of rice radioactivity tests in Fukushima Prefecture, and mistaking that the area where evacuation orders were issued represented 50% of Fukushima Prefecture. Immediately after the accident in 2011, difficulties associated with talking about a nuclear disaster were too delicate to handle in class, and there was a great deal of trouble because no data and teaching materials had been prepared. Nowadays, all the data are available and teaching materials have been prepared, so issues can be dealt with. According to Chiba, there are three points of difficulty for students to talk about nuclear disasters:

(i) They lack underlying knowledge. Today's high school students experienced the earthquake when they were in elementary and junior high school, so there is little information about their experiences at that time, and adults are not able to convey it well.
(ii) It is difficult to talk about due to the seriousness of the experience. At Asaka High School in Koriyama City, some students have returned after evacuating, while others have moved to Koriyama from the evacuation areas, and it seems that it is difficult for students who have different experiences to talk to each other. On the other hand, the importance of the experience of the disaster is recognised, and many opinions are put forward when there is time for discussions after lessons relating to the disaster.
(iii) The lessons learned from the disaster, including among adults, have not been summarised. Although the current situation in Fukushima Prefecture is still complex, it may be difficult to talk about because it has not been summarised in an easy-to-understand format.

Aoki, who has been working to tell the story of the earthquake and nuclear disaster in Tomioka-Town since 2013, finds it difficult to talk about because the damage caused by the nuclear disaster is not visible. Even within Fukushima Prefecture, the status of the disaster has not been shared, and there is concern that there is prejudice about Futaba-Region, which became the disaster site. It is very difficult to explain the damage to the nuclear disaster areas in Fukushima Prefecture compared with the areas physically damaged by the tsunami, such as Miyagi and Iwate. Nuclear disasters are more terrifying than the health risks of radiation, which are often described by medical professionals and physicists, as they gradually uproot people's lives due to changes in social conditions, such as the inability to live for a long period of time, but it is difficult for that to be understood.

Endo, who has been working at the Great East Japan Earthquake and Nuclear Disaster Memorial Museum since April 2019, was a third-year elementary school student living in Iwaki City at the time of the earthquake. After evacuating for approximately 2 weeks, she returned home. She chose Futaba Mirai Gakuen High School as her high school which was established in Hirono-town, Futaba-Region, and decided to learn about nuclear disasters as part of her studies. She took a job at the Great East Japan Earthquake and Nuclear Disaster Memorial Museum as she was keenly aware of the heavy responsibility, and at the same time, there was conflict regarding whether she would be able to work as a staff member as she was not a direct victim of the nuclear disaster. At the Great East Japan Earthquake and Nuclear Disaster Memorial Museum, she heard many people's stories and learnt a lot looking through various documents. However, there is always conflict about whether she can speak with little knowledge. Furthermore, there are more opportunities for interviews and although it may be difficult to remember the time of nuclear accident evacuation, she also believes that it is important to talk about her own experience.

Shiga, the former Director of Hiroshima Peace Memorial Museum, responded by mentioning the experience of the atomic bombing in Hiroshima. There are testimonies that people did not wish to discuss their own experiences straight after the bombing. 'Storytellers' started to appear after a certain point in time, but there may have been some barriers to overcome or time that had to pass first. Currently, the storytelling of the experience is mainly conducted for students on school trips, but while he has a great deal of anxiety about how much the experiences have been conveyed. In Hiroshima although there is an overflowing number of experiences of the atomic bombing being conveyed, there is concern that the communication has become one-way. This means that a 'common language' to talk with each other has not been formed, and there is concern that some people may be blocking their ears in the flood of one-way narratives. The cause of the difficulty in talking is that the atomic bomb disaster was so huge that the narrator gives up, and feels that the listener is not a party. It seems that a nuclear disaster may create a 'gap' between those who did and did not experience it.

Schneider, who has experience in supporting Belarus after the Chernobyl accident, talked about two difficulties from the perspective of supporting the reconstruction of both Fukushima and Chernobyl after the accident. The first difficulty was the sense of distance between experts and residents which he had felt when he visited the disaster-stricken areas of Belarus in the 1990s. To overcome that distance, experts had to take things one step at a time, and feel the importance of listening to the residents' voices. While a scientific point of view is also important, it is the recovery of normal daily life that is important for the residents. A strategic approach that fits radiation protection to reality by making use of scientific knowledge is important. Another difficulty was communicating the experience in the disaster area within a community of radiation protection professionals. Two panellists living in Fukushima mentioned that their lives had changed significantly, but despite the fact that everything started from that point, it is actually often difficult to communicate what is happening in day-to-day life within the professional world. Currently, importance is placed on the involvement of stakeholders in radiation protection, and it is important to look at the reality while listening to the words of local people when passing on memories.

Takamura talked about his experience as the Director of the Great East Japan Earthquake and Nuclear Disaster Memorial Museum and as an expert on radiation exposure and health effects, having been involved in communication with residents immediately after the accident at Fukushima Daiichi nuclear power plant. The main cause of difficulty in explaining is the fact that radioactivity cannot be perceived by the five senses. Although it was possible to confirm numerical values easily as long as measuring instruments were available, no one initially explained the meaning of the numerical values. It seems that this may have caused major confusion. In the time that has passed since the accident, more and more machines have become available and more people have taken measurements, but even then, as experts, he has tried to explain the meaning of these values.

2.2. Having heard the others, what do you think is needed to get over the difficulty of speaking about it?

Chiba pointed out the importance of overcoming the 'gap' that was seen in the first round of answers. There are three points of importance. The first point is education. It is important to first broaden understanding within Fukushima Prefecture, such as visiting the affected areas, removing prejudice, and learning about efforts for reconstruction. That will spread throughout the Prefecture. Currently, momentum for on-site visiting in Fukushima Prefecture slow. The second point is to understand and talk about not only radiation but also the Great East Japan Earthquake and the entire nuclear disaster. Students have much they want to talk about, and the opportunity to talk is important. The third point is for adults to know about it. Should we not take the opportunity of the Great East Japan Earthquake and Nuclear Disaster Memorial Museum to create a 'practical radiological protection culture'?

Aoki explained that imagination was more important than anything in order to overcome difficulty of talking about the experience of a nuclear disaster. It would be good to use imagination to learn that what happened in Fukushima Prefecture and Futaba Region is not something local that happened in a single region, but is something that could occur anywhere in the world. Tomioka-town must rebuild a city in the future with a population that has declined sharply since the disaster. Aoki wants to increase the number of people who think of it as their own task to as many as possible, and feels that this belief is necessary to overcome the difficulty of talking.

Endo said that the need to improve knowledge is important. She thinks that listening to individual episodes is one such method. At the Great East Japan Earthquake and Nuclear Disaster Memorial Museum, the storyteller's experiences tell us what people were thinking about at the time of the disaster. It is also possible to get a real-time view of Fukushima Prefecture as it heads toward reconstruction. By knowing these things, the difficulty of talking will perhaps gradually disappear by accumulating learning about the earthquake disaster as if it is happening to yourself.

Shiga said that the 'imagination' that Aoki pointed out earlier is also an important keyword in the exhibition at Hiroshima Peace Memorial Museum. In order to stir the imagination, the exhibit was changed to be one that asked questions, but 'gaps' had to be overcome. At Hiroshima Peace Memorial Museum, storytellers talk about their bombing experiences. This museum mainly targets elementary to junior high school students on school excursions. Hearing about the atomic bomb experiences of the same generation brings a unique atmosphere to the students. It is as if they have found a common language. Another point was that mentioning a victim's name had a great impression on the students' reactions. The damage caused by the atomic bomb is often talked about in numbers. Growing up in Hiroshima, we visit the museum and listen to the experience of being bombed many times. One student who listened to Shiga thought it was the same story again. But halfway through, she said, she changed her mind. What was mentioned at that time was the episode of an 18-year-old first-born woman who died after giving birth to a boy while suffering severe burns on the night of 6 August 1945. The midwife who helped with the birth was also severely burned by the bombing. Shiga talked while showing the actual tools used for the childbirth with the midwife's name on them. When the student saw it, she said that although she had thought it was distant history, a story of the past, she realised that there was a person with that name who had given birth to a child. Perhaps the student became aware of the existence of one individual once she saw her name, and could come to feel that it was an event that had happened to a human being.

For Schneider, it has been 10 years since the Fukushima accident and now it is time to pass down memories. Objectivity is important for this, but this is not just by talking about the past but also by heading into the future. To that end, it is important to build a collaborative relationship, and that will also encourage dialogue, both about science and about daily life. It is also important to draw lessons for the next disaster.

Takamura pointed out the importance of learning from the past for the future. Shouldn't we ask again what we learned from the Chernobyl accident that preceded the Fukushima accident? It is important to enhance education, learn from the past, and incorporate what has been learned as knowledge.

3. CONCLUSION

In this discussion, it was testified that there would be many 'gaps' in a nuclear disaster. The 'gap' appears as a risk perception gap for radioactivity between experts and the general public immediately after the accident. Over time, as well as the recognition of risk of radioactivity, new 'gaps' are created in multiple layers, such as parties and non-parties, generations, and within the expert community. This is largely caused due to the fact that nuclear disasters are extremely rare, so few people have the same experience, and it is not easy to imagine. At the same time, because the damage is so great or invisible that it is often expressed as a statistical value, and that it is difficult to actually feel it. In particular, considering the fact that there is a gap between experts who have actually experienced the disaster and those who have not, even in the professional community, it seems that the main reason for the gap is not a matter of knowledge but rather the experience of the disaster or the lack of experience in the disaster area. Furthermore, this gap still exists between individuals who experienced the atomic bombings in Hiroshima and those who did not, suggesting that this gap will not disappear naturally over time.

In order to eliminate this gap, it is very important to 'collaborate' and share experience. As experience/non-experience is an important factor, putting it simply, sharing experience is the most effective way to eliminate the gap. If that is not possible, it is important to discuss the experience continuously in words and find a 'common language'. On the other hand, verbal communication has naturally its limits. Imagination is the most important factor to convey and understand what we have not experienced, and also empathy is essential to make your imagination work. This is because we can only empathise with what we can imagine.

Here, it is very interesting that Shiga pointed out that the 'proper name' of a victim was the major driving force that evoked empathy for the atomic bombing experience in Hiroshima. The 'proper name' highlighted that it was not an unspecified number of anonymous people who suffered from the atomic bomb, but many each individuals who could not be irreplaceable. By focusing on the story of an individual who actually lived there, the historical event that was only vaguely perceived by the recipients of the information can be realised as a living event that they can relate to themselves. Furthermore, the irreplaceableness of individual life and existence can be shown through a victim's name. Simply put, it is a matter of course that there was an irreplaceable life there, but this can be rephrased as finding the universal value of 'human dignity'. Finding universal value in the individual event of a proper name made it possible to take on an unknown event as an experience that one can relate to oneself. It can be said that this is the core of passing on and sharing experiences. I would like to conclude this paper by pointing out that what was clarified in this discussion was the importance of finding universal value in handing down experiences.

As a resident and a counsellor

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Abstract–At the time of the accident at Fukushima Daiichi nuclear power plant in 2011, I was living in Iwaki City with my two children and my husband. With our home damaged by the tsunami and the deteriorating status following the situation at the nuclear power plant, we spent 2 years as evacuees before returning to Iwaki City. Subsequently, I decided to work as a radiation counsellor in the Suetsugi district of Iwaki City. I would like to describe my experience of taking measurements and helping to communicate with the residents while respecting the lives of local people.

Keywords: Suetsugi; Nuclear accident; Ethos in Fukushima; Fukushima; Radiation protection

1. FROM THE EARTHQUAKE UNTIL MY RETURN TO IWAKI CITY

The Great East Japan Earthquake on 11 March 2011 also caused a tsunami. We were at the mercy of damage caused by the earthquake, the tsunami, the nuclear accident, and the rapid succession of sudden changes.

1.1. Accident and evacuation

At the time of the earthquake on 11 March 2011, I was living with my husband, our 2-year-old son, and our 10-month-old daughter at our home in Yotsukura-machi, Iwaki City. Our home, which was a few hundred metres from the sea, was

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

hit by the tsunami, so we evacuated to a nearby hillside shelter for 5 days. Subsequently, we learnt about the accident at Fukushima Daiichi nuclear power plant, and although no evacuation orders had been issued around our home, as the children were young, we decided to leave the city voluntarily. At first, we relied on an acquaintance and evacuated to Koriyama City, Fukushima Prefecture for approximately 2 months. We next evacuated to Sendai, Miyagi Prefecture where I was born and raised, and lived there for approximately 2 years with my children. During the evacuation, I had many discussions with my family. In order to establish a proper foundation to life in Iwaki City, we decided to return before the children started at elementary school.

1.2. Nowadays: life during evacuation, learning about radiation

My husband stayed in Iwaki City for his job. This meant that we had to live apart as a family. Life during the voluntary evacuation with my children alone was a similar life to that of a single mother, and in addition to being the most difficult time to raise children, I didn't know how to assess the danger of radiation, which led me to think of it as more dangerous. As a result, I became emotionally trapped and became harsh towards my children. Realising this, I started to study so that I would not have a negative influence on my children. I focused on looking at data that did not appeal to my emotions. As well as checking the daily data on radiation levels that were reported in newspapers and on the television, I measured the radiation levels in our own living space using a Geiger-Muller counter. After understanding the situation, I compared previous nuclear accidents with the accident in Fukushima, and gradually eased the restrictions on activities that I had previously self-imposed on myself and my family.

2. ACTIVITIES AS A COUNSELLOR IN SUETSUGI

2.1. How I became a radiation counsellor in Suetsugi district

Shortly after returning to Iwaki City, Ryoko Ando of Ethos in Fukushima, who was already engaged in radiation measurement activities in Suetsugi, invited me to join and I agreed (Ando, 2016a,b). I was involved in the Suetsugi project as a radiation a counsellor from January 2015 when the project received financial support from Iwaki City until March 2017. After that, from April 2017 to March 2020, the project was supported by Fukushima Medical University as part of its research project (Ando, 2018). When I was searching for answers myself during the evacuation, there were times when I felt very lonely. As such, I thought that the activities in Suetsugi might help to turn the place into somewhere that local residents could face their own concerns and feelings about radiation at their own pace and come to terms with them, and I felt that I might be able to help in that respect.

2.2. Work as a counsellor

2.2.1. External exposure measurement

Our activities included taking measurements of individual doses using an integrated personal D-shuttle dosimeter, which measured external exposure, and holding briefing sessions to explain the analysis of the results and graphs to the residents (Chiyoda Technol, 2020). Makoto Miyazaki of Fukushima Medical University was asked to analyse the data and explain it as an expert (Miyazaki, 2017). Dr. Miyazaki did not always come to Suetsugi, so I gave detailed explanations to the residents myself, and acted as a communication link whereby I would contact Dr. Miyazaki when queries were raised.

Dr. Miyazaki drew a line indicating the background level in the lower area of the graph of personal doses and a line indicating an additional 1 mSv of exposure over 1 year at the top, and explained to the residents in a visual way that their personal dose was virtually always in the gap in between (Fig.1). Explaining the link between individual lives and personal doses was easily understood by the residents when looking at a graph, without the need for difficult technical terms.

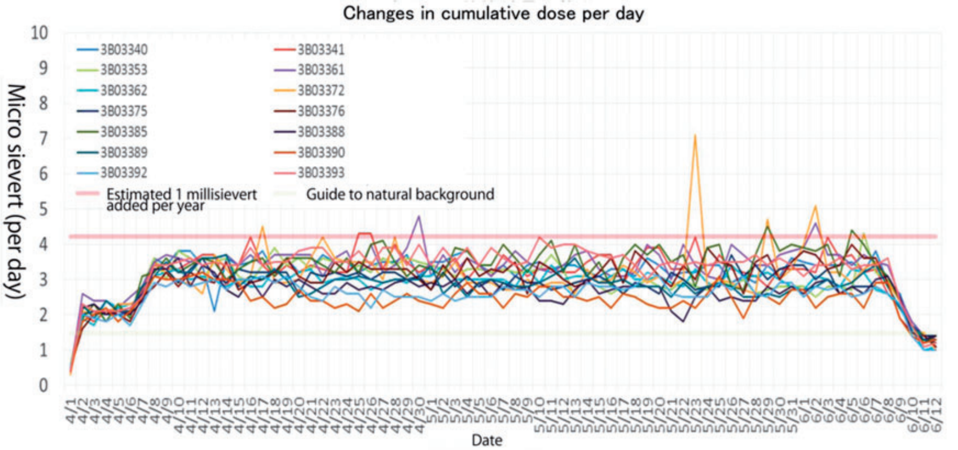


Fig. 1. Results of external exposure measured using 15 individual cumulative D-shuttle dosimeters (Chiyoda Technol) in the Suetsugi district from April to May 2014 (created by Makoto Miyazaki, Fukushima Medical University).

2.2.2. Food measurement

My main role was to manage radiation measurements of foodstuffs at a meeting place in Suetsugi district. I explained the results of the food measurements. I was careful to do two things: to let the residents know that the results were measured in

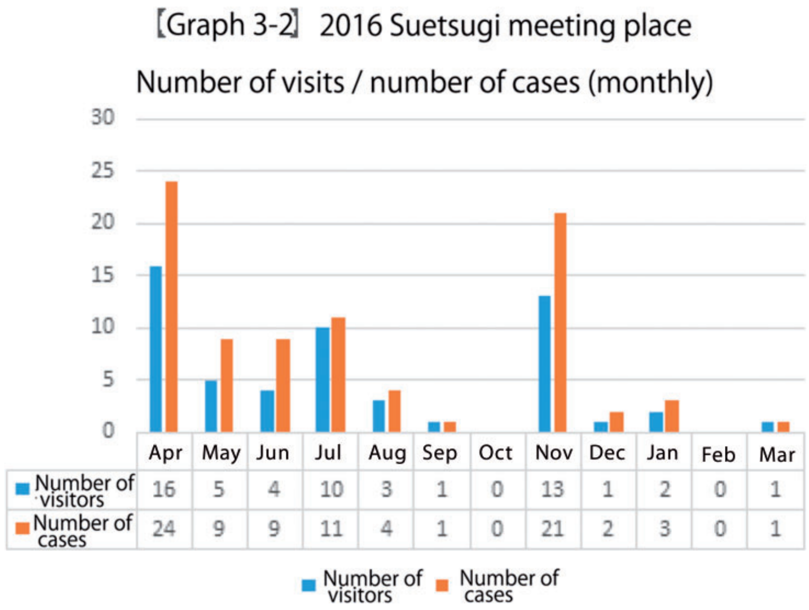
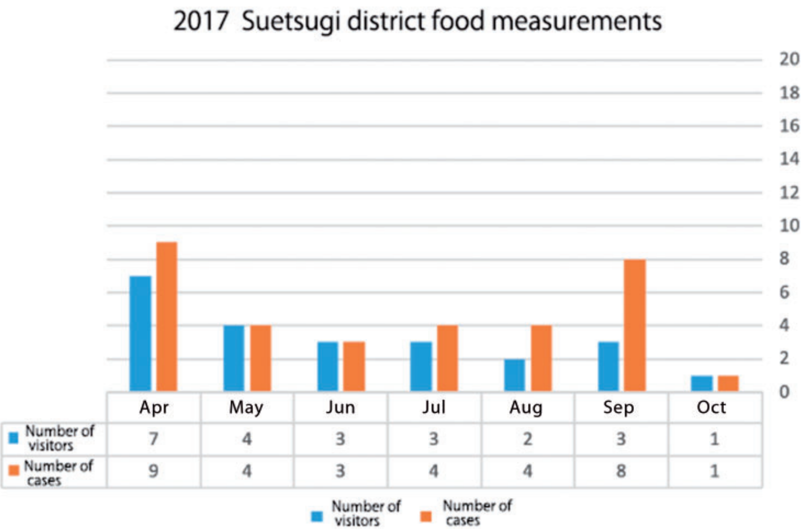


Fig. 2. Number of people visiting for measurement and number of food items measured in Suetsugi district in fiscal year 2016.

radioactivity per kg, and to encourage them, through conversation, to have a concrete picture of the amount they would actually consume in their own diets.

Over the years, the number of people bringing in food consistently all through the year has decreased. On the other hand, the number of people bringing in seasonal fruits and vegetables did not decrease noticeably. (Figs 2 and 3) I personally felt that many people wanted to keep a record of the produce that they were familiar with or had an emotional attachment to, and this impressed me a lot. For example, mandarin oranges, astringent persimmons for drying, and other fruits that can only be picked at certain times of the year. I feel that the reason why they want to measure the food is because that food is very much connected to their sense of fulfillment in life. By checking the radiation levels of food, it seemed to me that they were not only learning about radiation levels and safety, but also reaffirming the value of their own lives. I am sure there were various reasons why the residents wanted to measure the radiation levels of various foodstuffs, and I felt that I could understand the various thoughts of these people. For example, in a household that was harvesting mandarin oranges, there were people who had been looking forward to sending them to other families living far away, as they did every year. They had decided to refrain from doing so after the nuclear accident, but were pleased that they 'could confidently feed them to their little grandchildren' when they discovered that there were no issues. Someone who had been worried about radiation at the beginning but who was chatting brightly after taking measurements left an impression on me.



	Apr	May	Jun	Jul	Aug	Sep	Oct
Number of visitors	7	4	3	3	2	3	1
Number of cases	9	4	3	4	4	8	1

Fig. 3. Number of people visiting for measurement and number of food items measured in Suetsugi district in 2017.

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すえつぎだより

編集
安東量子
鈴木伴栄
門馬麻衣子

広島大学の院生が今年も来ました

8月28・29日、放射線災害からの復興を担う国際的に活躍できる人材を育成するために設けられた、「広島大学大学院フェニックスリーダー育成プログラム」の学生と指導教官らが末続を訪れ視察を行いました。

28日、震災と原発事故以降の放射線防護に関する末続独自の取り組みを、当事業の安東量子、福島大学宮崎真先生そして高木宏区長が説明を行い、学生からの質疑応答の時間が設けられました。午後には、いわき市除染対策課の職員の案内で除染廃棄物の仮置き場を見学、高木区長の案内で津波被災跡地を訪問。完成なった海岸堤防や河川堤防の復興状況の様子を見学しました。

翌29日には、末続集会所で食品測定の実演を見学したほか、末続住民との対話集会も行われました。

末続駅で高木区長の説明に聞き入っています

この「フェニックスリーダー育成プログラム」は、海外、発展途上国からの留学生も多く在籍しています。末続の方からは、「海外に福島の本当の状況を伝えてほしい」との声も出て、学生たちは「自分の国でも伝えていきたい」と応じていました。

後日、広島大学の教員からは、視察を終えてから、学生の学習意欲が目に見えて変わった、驚くほどの前向きになったと聞きました。ご協力いただいた皆さま、ありがとうございました。

お昼ご飯を食べながら学生さんとの対話。

1

Issued 20 December 2017 Vol.9

Suetsugi-dayori

Editors Ryoko Ando Tomoe Suzuki Maiko Momma

Hiroshima University graduate students came again this year.

On 28 / 29 August, students and academic advisors of the "Hiroshima University Graduate School Phoenix Leader Development Program", which was established to develop human resources who are able to play an active role internationally in respect of recovery from radiation disasters, visited and came to observe Suetsugi.

On the 28th, Ryoko Ando, Professor Makoto Miyazaki of Fukushima University, and Mayor Hiroshi Takagi explained their unique efforts regarding radiation protection after the earthquake and the nuclear accident, and there was a time for questions and answers from the students. In the afternoon, we visited the temporary storage site for decontamination waste under the guidance of the staff of the Iwaki City Decontamination Countermeasures Division and visited the tsunami-stricken area under the guidance of Mayor Takagi. The reconstruction status of the completed coastal levees and river levees were observed.

The following day, on the 29th, a demonstration of food measurement was observed at the Suetsugi meeting place and a dialogue was held with the Suetsugi residents.

This "Phoenix Leader Development Program" enrolls many international students from overseas and developing countries. Some people of Suetsugi said that they "wanted the true state of Fukushima to be conveyed to those overseas" to which the students responded, "we also want to tell people of our own country".

Later on, the faculty members of Hiroshima University noted that the students' motivation to learn changed visibly after the inspection and that they became amazingly positive.

Thank you very much to everyone who helped.

Listening avidly to Takagi district mayor's explanation at Suetsugi station

【photo】 Chatting with students during lunch.

Fig. 4. *Suetsugi-dayori* December 2017 edition. Left: Original Japanese version. Right: English translation.

2.2.3. Publishing *Suetsugi-dayori*

Also, a newsletter, *Suetsugi-dayori,* was produced once every 3 months (Fig.4). *Suetsugi-dayori* included the measured radiation results, enabling the results to be shared between all residents of the district. By doing this, even people who could not come to hear Dr. Miyazaki's explain were able to understand the situation, and even if they did not come to the foodstuff measurement themselves, they were able to understand the radiation situation of local foods.

Although there have been changes in activities such as individual dose measurements, with the use of D-shuttle dosimeters stopping as time passed, food measurements and publication of *Suetsugi-dayori* continued for approximately 5 years.

I wrote many interview articles for *Suetsugi-dayori*. I would talk to one person every month for approximately 2 h on average. I felt that everyone had a clear memory of what happened at the time of the accident, even after time had passed. When normal life returned, I was able to listen to stories of life based on Suetsugi community, experiences and a view of life.

Residents also expressed the loneliness of large families living apart due to the evacuation and the fact that there were fewer children from Suetsugi. On the other hand, I heard that even in such a situation, they were encouraged to see the young generation in the area working hard to cope with the radiation. We heard from people of all ages about their experiences of how they have recovered in their own way from the nuclear accident they suddenly encountered in the middle of their lives.

3. WHAT I LEARNT AND WANT TO CONVEY REGARDING ACTIVITIES AS A COUNSELLOR

3.1. Meaning of measurement, attitude as a counsellor

What's important in measurement is not just giving the results. Through conversations, I became aware of why the measurements were wanted and what the foods meant to people. Eating habits are directly linked to an individual's life and that of their family, and have a major influence on quality of life. To regain control of one's diet through measurement is equivalent to rebuilding one's life in the face of the reality of radioactive contamination. Their attachment to food means their attachment to life, and listening to their feelings through measurement was the most crucial aspect of the measurement.

I continued to be involved in measurements without being nervous. I thought that if I tried too hard to get people to understand radiation, it would put unnecessary pressure on the people who came, and they would not feel able to voice any small doubts. I personally thought I would spend 10 years taking measurements. I think this was probably the main reason why I was accepted by the district. I myself relaxed and asked the seniors in my own life to talk about child-rearing and housework, and I worked to create a relaxed atmosphere where people felt comfortable to chat. I believe this is why measurements were continued for years without resistance from local people.

Furthermore, in the latter years, the residents started to provide topics and essay articles for publication in the newsletter. It felt like people were looking forward to each issue of *Suetsugi-dayori*.

3.2. Characteristics of the activities in Suetsugi

I believe that what characterised our actions in Suetsugi was maintenance of the stance that the residents were the central focus. Residents' wishes were valued, and external supporters such as ourselves did not push their opinions aside. Moreover, we were careful not to trample on the lives and relationships of local people. Experts acted as experts and counsellors acted as counsellors to assist if there were enquiries from the residents, and we tried to think 'together' about the measurements (Lochard et al., 2020).

There was no need for counsellors to explain radiation using technical terms when residents were unclear about something. I think that explaining that you do not understand something if you do not understand it, and following this up properly after consultation with an expert is the best way to gain the trust of residents.

Supporters are merely outsiders. I think the most important thing is for outsiders to earn the trust of residents in order to support the community (Ethos in Fukushima, 2020). Those of us involved as supporters in the community continued to work diligently, fulfilling our respective responsibilities. I think this helped to build trust and made it possible for us to work for a long time.

4. CONCLUSIONS

It is almost 10 years since the earthquake and accident at Fukushima Daiichi nuclear power plant. The progress in Suetsugi district over these 10 years has been summarised in videos and papers. These papers and videos give a clear picture of what radioactivity, experts and measurements look like from the residents' point of view. I would like all the experts to take a look too. Our activities have been carried out over a long period of time with major efforts from local people and many volunteer supporters, including Dr. Miyazaki, Mr. Jacques Lochard. Please see papers for details on how and what went on (Ando 2016a,b, 2018; Lochard et al. 2020; Ethos in Fukushima 2020).

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Lessons from the Fukushima Daiichi nuclear power plant accident –from a research perspective

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Abstract–Since the accident at Fukushima Daiichi nuclear power plant, there has been a focus on the impact of low-dose radiation exposure due to nuclear disasters and radiology on human bodies. In order to study very low levels of impact on the human body from low-dose radiation exposure, a system with high detection sensitivity is needed. Until now, the most well-established biological radiation effect detection system in the field of emergency radiation medicine has been chromosomal analysis. However, chromosomal analysis requires advanced skills, and it is necessary to perform chromosomal analysis of a large number of cells in order to detect slight effects on the human body due to low-dose radiation exposure. Therefore, in order to study the effects of low-dose radiation exposure on the human body, it is necessary to develop high-throughput chromosome analysis technology. We have established the PNA-FISH method, which is a fluorescence in-situ hybridisation method using a PNA probe, as a high-throughput chromosome analysis technique. Using this method, the detection of dicentrics and ring chromosomes has become very efficient. Using this technology, chromosomal analysis was performed on peripheral blood before and after computed tomography (CT) examination of patients at Hiroshima University Hospital, and it was possible to detect chromosomal abnormalities due to low-dose radiation exposure in the CT examination. Furthermore, it was shown that there may be individual differences in the increase in chromosomal abnormalities due to low-dose radiation exposure, suggesting the need to build a next-generation medical radiation exposure management system based on individual differences in radiation sensitivity. If techniques such as chromosomal analysis, which have been used for biological dose evaluation in emergency radiation medicine, can be used for general radiology, such as radiodiagnosis and treatment, that will be a

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contribution to radiology from an unprecedented angle. This article will discuss the clinical application of new biological dose evaluation methods that have been developed in the field of emergency radiation medicine.

Keywords: ICRP; Nuclear accident; Reconstruction; Fukushima; Radiation protection

1. RADIATION DISASTERS AND MEDICAL/BIOLOGICAL RESEARCH

Among the atomic bomb survivors, leukaemia developed 5 years after the exposure, and various malignant tumours followed. Extensive epidemiological studies of the atomic bomb survivors have shown that carcinogenic risk is correlated with radiation dose. In the Chernobyl accident, children were seen to develop thyroid cancer due to ingestion of radioactive iodine, which has led to subsequent molecular biological studies of thyroid cancer. In the nuclear accident at Tokaimura, a small fuel preparation plant operated by Japan Nuclear Fuel Conversion Co., some victims were exposed to extremely high radiation exposure, and the importance of radiation dose evaluation by chromosome analysis and treatment using regenerative medicine in emergency exposure medicine was recognised. In the accident at Fukushima Daiichi nuclear power plant, operated by Tokyo Electric Power Company Holdings, thyroid cancer was identified by ultrasound screening.

1.1. Atomic bomb

Regarding the health effects on the survivors of the atomic bombing in 1945, a large-scale epidemiological survey of survivors undertaken by Atomic Bomb Casualty Commission (ABCC) and the Radiation Effects Research Foundation has led to elucidation of the relationship between radiation exposure and diseases such as malignant tumours (Kamiya et al., 2015). On the other hand, chromosome analysis, which became possible in the 1960s, has been established as a method for biological dose evaluation of the impact of radiation, such as dicentric analysis (Fig. 1). Furthermore, in a study on the pathogenic mechanism of leukaemia and malignant solid tumours found in the atomic bomb survivors, genetic abnormalities in leukaemia and cancer using molecular biological techniques were identified based on the identification of disease-specific chromosomal abnormalities in leukaemia, and this discovery led to the development of molecular-targeted medicine (John et al., 2004).

1.2. Chernobyl nuclear accident

In the 1986 Chernobyl accident, workers exposed to very high doses of radiation were treated with bone marrow transplants. Bone marrow transplantation was a medical treatment that had just been developed at that time, and the importance

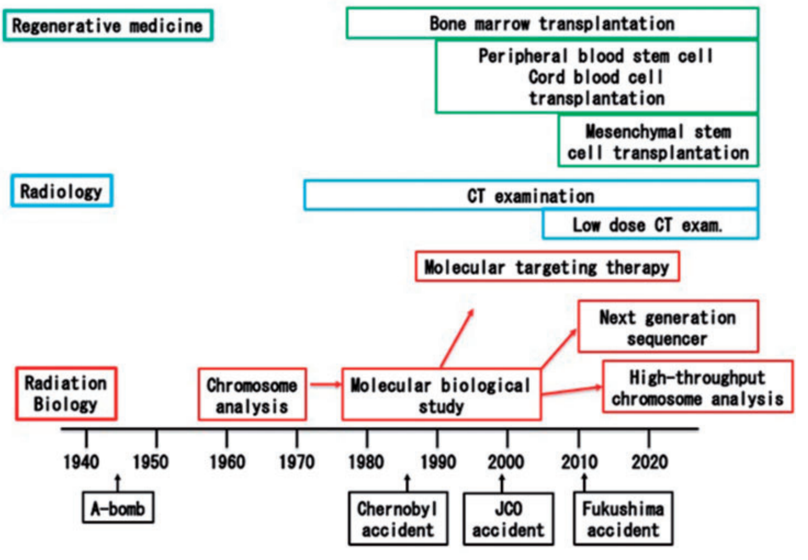

Fig. 1. Radiation disasters and development of medical and biological research. CT, computed tomography; JCO, Japan Nuclear Fuel Conversion Co.

of regenerative medicine was suggested for subsequent treatment of those who were highly exposed. The development of childhood thyroid cancer has become a problem in the general population. Subsequently, advances in molecular biological research on thyroid cancer have led to genetic analyses of patients with thyroid cancer among the victims of the Chernobyl accident, and progress has been made in the elucidation of specific gene mutations (Efanov et al., 2018).

1.3. Tokaimura nuclear accident

In the Tokaimura nuclear accident in 1999, three people were very seriously exposed to radiation and two people were killed. In addition, 667 members of the public were exposed. Regenerative medicine such as peripheral blood stem cell transplantation and cord blood stem cell transplantation was adopted for the treatment of exposed victims, but unfortunately this did not save lives (Fig. 1). However, the experience of this accident re-affirms the importance of biological evaluation of radiation exposure dose by analysis of peripheral blood lymphocyte count and chromosomal aberration frequency, and application of regenerative medicine for the victims of emergency radiation exposure (Hayata et al., 2001).

1.4. Fukushima Daiichi nuclear power plant accident

In the 2011 accident at Fukushima Daiichi nuclear power plant, there were no cases of serious exposure to radiation. Regarding thyroid exposure of general inhabitants, the local countermeasures headquarters measured radioactive iodine in approximately 1000 residents of areas such as Iitate Village, but there were no cases of suspected high-level exposure. The same result was found in the exposure dose estimation of the Fukushima Prefectural Health Survey. However, the thyroid examination of the Fukushima Prefectural Health Survey has identified paediatric cases of thyroid cancer, and debate exists regarding whether this is due to radioactive iodine or overdiagnosis of latent cancer by the examination (Ohtsuru et al., 2019). For this reason, the general public is showing increasing interest in low-dose exposure, including medical radiation exposure. In addition to medical and biological research, such as epidemiological research, the fields of Science, technology and society (STS), the research of the social impact of science and communication between scientists and citizens, are attracting attention to solve these problems.

2. RESEARCH ON THE IMPACT OF RADIATION IN MEDICAL AND BIOLOGICAL RESEARCH

2.1. Research on the impact of radiation and leukaemia/cancer research

In the field of basic biology, functional analysis of genome-repair-related proteins encoded by genes such as RAD51 has been performed since the 1990s by genetic analysis using yeast and *Escherichia coli*. Since the latter half of the 1990s, research on the mechanism of human DNA repair has made remarkable progress centred on genetic analysis of hereditary diseases (i.e. reverse genetics research), and many human DNA repair-related factors such as ATM in ataxia telangiectasia and MRE11 and NBS1 in related diseases have been discovered. Research on the mechanism of human DNA repair led to the discovery of BRCA1 and BRCA2, which are factors involved in the control of homologous recombination repair of DNA double-strand breaks involved in the development of breast cancer and ovarian cancer. It has also made great contributions to the development of cancer research (McKinnon and Caldecott, 2007).

On the other hand, the Giemsa staining method established in the 1960s has made it possible to identify the breakpoint of chromosome translocations, which led to the discovery of disease-specific chromosomal abnormalities in leukaemia such as Philadelphia chromosome (9:22 translocation) shown specifically in the chromosomal abnormalities of the atomic bomb survivors and patients with chronic myelogenous leukaemia. After that, from the latter half of the 1980s, progress in molecular biological research on chromosomal translocation breakpoints in leukaemia has clarified that the 9:22 translocation of chronic myelogenous leukaemia forms the fusion gene of ABL and BCR, and that the 15:17 translocation, the disease-specific chromosomal aberration of promyelocytic leukaemia, led to fusion of the retinoic acid receptor and PML gene. Disease-specific chromosomal abnormalities have been shown to be very useful in predicting disease prognosis, as well as improving the accuracy of leukaemia diagnosis. Moreover, these findings have led to the development of molecular targeted therapy, such as Imatinib, a specific inhibitor of ABL kinase, for chronic myelocytic leukemia, and all-trans-retinoic acid for acute promyelocytic leukemia. The success of molecular-targeted therapies for leukaemia has led to the development of molecular-targeted therapies for many cancers (Fig. 1) (John et al., 2004).

In cancer research, the advent of next-generation sequencers has enabled genomics, the comprehensive analysis of genomic information. Furthermore, regarding protein analysis, proteomics (i.e. comprehensive protein analysis) has become possible due to recent progress in protein production technology and mass spectrometers. Using the enormous amount of biological information obtained by these new technologies, such as artificial intelligence, we are reaching an age where new and previously unconsidered findings can be obtained. For example, in myelodysplastic syndrome, which is often seen in the atomic bomb survivors, comprehensive analysis of gene mutations has shown abnormalities in gene groups related to splicing (Yoshida et al., 2011). This type of data-driven study will be promoted in the field of radiation research alongside hypothesis-driven research, which has represented the mainstream until now.

2.2. Research on non-cancer diseases and impact of radiation

With regard to the relationship between radiation effects and non-cancer diseases, the effects of radiation exposure on nerve tissues such as atomic bomb microcephaly and the onset of neurological diseases are known; however, the details are not yet fully understood. In ataxia-telangiectasia caused by ATM dysfunction, neuropathy such as progressive ataxia and cerebellar ataxia has been confirmed, and it is known that a gene mutation of DNA double-strand break repair factor MRE11 also causes ataxia-telangiopathy (McKinnon and Caldecott, 2007). Studies have shown that DNA damage and its repair are important for the normal development of nerve tissue, but the details remain unknown. The mechanism of neuropathy due to exposure to radiation remains to be clarified.

It has also been clarified that cerebrovascular impairment, or vascular disorders, occur in the atomic bomb survivors (Shimizu et al., 2010). The relationship between radiation and myocardial damage has attracted attention as ischaemic heart disease has been shown to occur following radiation therapy for breast cancer in the left breast (Darby et al., 2013). On the other hand, in cardiovascular diseases, the involvement of DNA double-strand breaks and their repair mechanism in myocardial regeneration after arteriosclerosis and myocardial infarction has been suggested (Uryga et al., 2016). Elucidation of the relationship between angiopathy and radiation injury, which can cause various diseases, is likely to provide important knowledge not only for understanding the occurrence of diseases, but also for the development of treatment methods. It has also received attention from the perspective of radiation emergency medicine.

2.3. Medical application of biological dose evaluation methods

With technological innovations in engineering such as image analysis technology and the development of high-precision irradiation systems in recent years, radiology

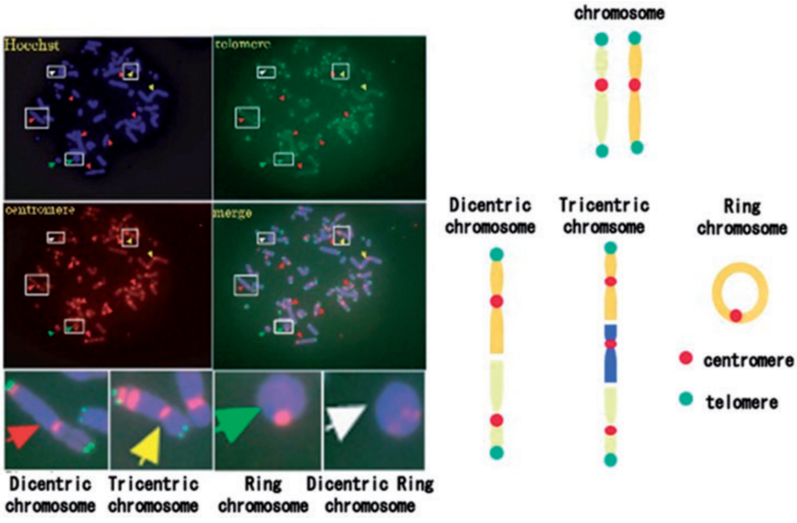

Fig. 2. Detection of chromosomal abnormalities using the PNA-FISH method. By culturing human peripheral blood lymphocytes for 48 h and then staining centromeres and telomeres by fluorescence in-situ hybridization using a PNA probe, it becomes easy to detect chromosomal abnormalities such as dicentric chromosomes and ring chromosomes. Modified from Shi et al. (2012). © 2021 Radiation Research Society.

– such as radiological diagnosis and radiation therapy – has made remarkable progress. On the other hand, collaboration between radiology and research on radiation effects, especially in the biological field, has not progressed very much to date.

In emergency radiation medicine, analysis of chromosomal abnormalities in lymphocytes has been established as a biological dose evaluation method. This method analyses chromosomes by collecting peripheral blood from an exposed victim, and separating and culturing lymphocytes to obtain cells in the mitotic phase. Chromosome analysis techniques established to date can evaluate exposure dose with high accuracy, but advanced training is required to identify chromosomal abnormalities. Microscopic images are visually analysed, and this places a great physical and mental burden on the technicians. Therefore, we have developed the PNA-FISH method which facilitates the detection of chromosomal abnormalities by colouring the centromeres and telomeres of chromosomes using fluorescence in-situ hybridization with a PNA probe (Fig. 2) (Shi et al., 2012).

By performing high-throughput chromosomal analysis of 1000 cells or more using this method, it is possible to detect a small number of chromosomal abnormalities such as dicentrics and ring chromosomes formed by low-dose radiation. Using this technology, chromosomal analysis of peripheral blood lymphocytes was performed on patients who underwent normal-dose chest computed tomography (CT) examination, and it was possible to detect an increase in chromosomal abnormalities (Fig. 3) (Shi et al., 2018).

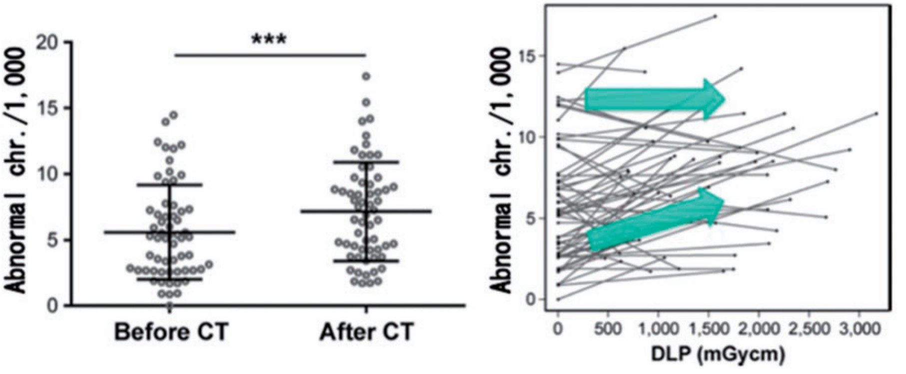

Fig. 3. Chromosome analysis by standard-dose computed tomography (CT) examination using the PNA-FISH method. Left: as a result of analysing the chromosomal abnormalities of peripheral blood lymphocytes before and after CT examination by PNA-FISH in 60 cases of non-cancer disease, the number of chromosomal abnormalities increased significantly following CT examination. Right: in cases where there were only a few chromosomal abnormalities (dose length product (DLP) = 0) before CT examination, the increase in chromosomal abnormalities by CT examination was more remarkable than in cases where there were numerous chromosomal abnormalities before CT examination. Modified from Shi et al. (2018). © 2021 Radiation Research Society.

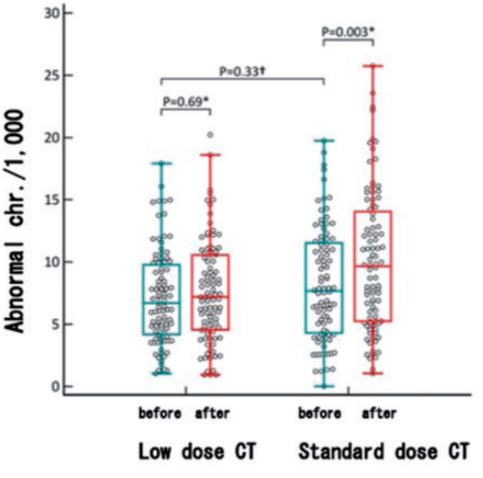

Fig. 4. Comparison of exposure effects of standard-dose and low-dose computed tomography (CT) examinations. The number of chromosomal aberrations in peripheral blood lymphocytes was compared using the PNA-FISH method before and after standard-dose and low-dose CT tests. Standard-dose CT (spectral detector CT) showed a significant increase in the number of chromosomal abnormalities, but low-dose CT did not show a significant increase in the number of chromosomal abnormalities. Modified from Sakane et al. (2020).

On the other hand, low-dose CT examinations used in lung cancer screening tests, which have recently been shown to reduce lung cancer mortality by approximately 20%, did not show a clear increase in chromosomal abnormalities, even with the PNA-FISH method. The validity of lung cancer screening tests by low-dose CT examination is biologically supported by these findings (Fig. 4) (Sakane et al., 2020).

In the future, using high-throughput chromosomal automatic analysis and biological markers developed in radiation effects research, it is anticipated that next-generation radiology will include the development of safe radiological diagnostic technology and methods to predict the side effects and effects of radiotherapy.

3. CONCLUSIONS

In medical and biological science, the importance of research using mathematical life science approaches, or understanding essential life phenomena by constructing models to interpret data is increasing. Originally, radiation research was established by the fusion of biology and physics, and this has evolved using mathematical life science approaches by proposing models based on the observation of radiation-induced cell death, cell proliferation, and chromosomal abnormalities. Therefore, radiation research could be a good model of modern life science.

One of the characteristics of radiation research is that it has a great deal of contact with society. In particular, valuable experience has been gained from the accident at Fukushima Daiichi nuclear power plant regarding risk communication in the event of a radiation disaster. Careful analysis of such valuable experiences is very important to enable scientists and medical professionals to respond appropriately, not only to radiation disasters but also to other disasters including emerging infectious disease pandemics such as coronavirus disease 2019.

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From a policy perspective: what is at stake?

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Abstract–What is at stake? It was one of the most frequently asked questions in a series of fora with concerned parties on the rehabilitation of living conditions in the aftermath of the accident at Fukushima Daiichi nuclear power plant. It was obvious that radioactive contamination was the source of the problem, and people were at a loss over how to cope with the situation. Various measures were taken under such circumstances, including detailed radiation monitoring, a decontamination programme to reduce the level of radiation in the living environment, and activities related to communication about radiation risk. Nevertheless, this question was asked repeatedly. Measures against radiation exposure were certainly necessary, but it is a reality that they were not enough to solve the difficulties experienced by people in the affected areas. This article presents the author's personal view of the underlying reasons for this, and discusses the way to facilitate recovery after a nuclear accident.

Keywords: Nuclear accident; Disruption of life; Recovery; Transdisciplinary approach; Three-layered help model

1. FUNDAMENTAL QUESTION

In November 2011, the International Commission on Radiological Protection (ICRP) initiated a forum on the rehabilitation of living conditions after the accident at Fukushima Daiichi nuclear power plant. It developed into a series of meetings – the ICRP Dialogue – in which a variety of concerned parties shared experiences and exchanged views to address challenges in affected communities (Lochard et al., 2019). One question was asked frequently at the meetings: 'what is at stake?'

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For experts in radiological protection, this question may sound somewhat strange. It was obvious that the source of the problem was radioactive contamination. Various protective measures were taken against it, including detailed radiation monitoring, a decontamination programme to reduce the level of radiation in the living environment, and activities related to communication about radiation risk (Shimura et al., 2015). Nevertheless, the same question was asked repeatedly. This reality prompts us to rethink our view about the situation faced by the people of Fukushima.

In the case of a nuclear emergency, residents living near the site could be exposed to high doses of radiation. Preventing/mitigating adverse radiation effects is the main focus of the emergency response (IAEA, 2015). Immediate actions such as evacuation are taken depending on the situation. Following the immediate response, restrictions may be imposed on people's lives to prevent inadvertent exposure, but these restrictive measures are accepted in the interests of safety. In this way, safety, especially radiation safety, is emphasised in the emergency response. However, even if society as a whole agrees on this scheme, the implications of safety are probably different between experts and the public.

Nuclear/radiation experts play a central role in planning and implementing the emergency response. For these experts, ensuring safety is a top priority, and they do their best to keep radiation doses reasonably low. On the other hand, for the public, being safe is an implicit assumption to have a normal life. In ordinary times, they take it for granted to be safe and do not pay particular attention to their safety. If they need to change their way of life for the sake of safety, this will have a huge impact.

After the accident at Fukushima Daiichi nuclear power plant, life changed for people living in the affected areas. Changes in the living environment brought various difficulties, such as health concerns, family issues, stigmatisation, and community severance. All these problems stemmed from consideration of radiation safety. There is no doubt that the root cause was radioactive contamination, but people's lives were hugely disrupted by focusing on radiation exposure and protective measures against it. Under such circumstances, people were at a loss about what to do. Many issues came together and they lost their perspective. That is why the same question was asked repeatedly: 'what is at stake?'

2. WHAT 'RECOVERY' MEANS

If this view is correct, what is recovery for the affected people? To answer this question, we need to know what issues arise after a nuclear accident. In the case of the accident at Fukushima Daiichi nuclear power plant, people from affected areas have suffered from various problems, including changes in their living environment, concerns about their children's health, and difficulties related to nursing care for the elderly. In addition to these personal and family issues, people who were ordered to relocate experienced division of their community and loss of connection with others. Some of them were depressed and lost motivation for life. Broadly speaking, what was common and easy to achieve in normal times suddenly became something special and difficult to achieve.

In a post-accident situation, new problems arise, and existing problems accelerate or reignite. For example, sales of farm produce from Fukushima reduced after the accident, and farmers have suffered from harmful rumours ever since. This is a new problem brought about by the accident. At the same time, the accident appears to have accelerated an existing problem – a decrease in the farming population in the area. From this perspective, it is not difficult to imagine various pending issues erupting all of a sudden in the wake of an accident. However, no two are the same. What matters will vary between communities, families, and individuals. As such, specific measures for recovery need to be considered on a case-by-case basis.

Having said that, there will be common features. These may resemble what we are currently experiencing in the midst of the coronavirus disease 2019 pandemic. Our daily lives have changed considerably since the beginning of the pandemic. It is not just a matter of public health, but striking a balance between infection control measures and social activities.

The situation following a nuclear accident may be basically the same. The core of the problem is disturbance of the balance of life. Life consists of many activities and materials necessary for each activity. We keep balance between them almost unconsciously as it is routine practice. However, when affected by an external force that is strong enough to disturb the balance, we get upset and struggle to find a new point of equilibrium.

If that is the case, recovery needs to restore the balance of disrupted life at all levels in the affected area. This is not as easy as it sounds. Just imagine you are a farmer, ordered to relocate, and have nothing to do in a small makeshift house. In this case, it is not just restoring the balance, but starting life all over again. That is why recovery takes time, and why elderly people tend to be left behind. There will be no true recovery without resolving inner struggles, and we cannot specify an end date for this reason.

3. FACILITATING RECOVERY

3.1. Transdisciplinary approach

The question is, how will society be able to facilitate recovery? Nuclear accidents and subsequent responses disrupt life in many ways. A wide range of measures will be necessary and, as already stated, specific measures for recovery need to be considered on a case-by-case basis. On the other hand, addressing the respective issues separately may not be effective. An issue-by-issue approach will lead to a sort of sectionalism, and all problems are linked to one another in each individual, family, and community. It is desirable to involve various stakeholders and utilise their knowledge and skills to address the difficult situation as a whole.

On this point, radiological protection is a multi-disciplinary field that involves a range of disciplines, such as epidemiology, physics, engineering, economics, and sociology, to assess and control radiation exposure (Fig. 1a). Still, we have to

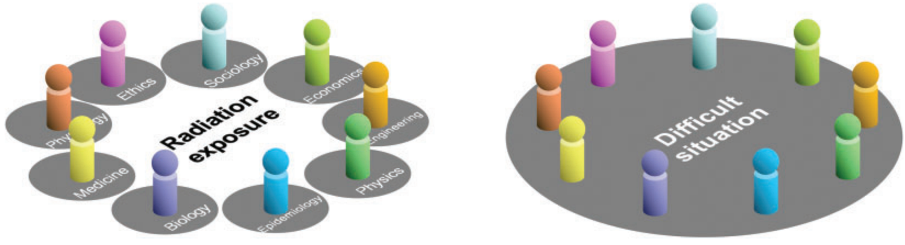

Fig. 1. Comparison of a multi-disciplinary approach (a) and a transdisciplinary approach (b).

admit that related experts were not necessarily helpful to the people of Fukushima. This may be because individual experts stayed within the domain of their own specialties, and the scope was too limited to address the complex nature of the post-accident situation. What is required is a transdisciplinary approach that eliminates barriers among disciplines. Rather than subdividing problems to fit in the existing framework, available knowledge and skills of stakeholders should be mobilised to tackle the difficult situation (Fig. 1b).

The so-called 'co-expertise process' may be regarded as a simple form of the transdisciplinary approach. It is a process of co-operation between experts, professionals, and local stakeholders that aims to share local knowledge and scientific expertise for the purpose of assessing and better understanding the radiological situation, developing protective actions, and improving living and working conditions (ICRP, 2020). It should be emphasised that people are not recipients of support, but actively involve themselves as stakeholders on an equal footing. Active involvement is key because it may help people get a better grip on the situation and adjust their way of living on their own. In fact, true recovery is nothing less than regaining control of one's life, and it can only be achieved by an individual's own will. Our question should be how to better support those people who are struggling.

3.2. Three-layered help model

Living in a country which is prone to natural disasters, the Japanese often refer to the three-layered help model in the context of disaster preparedness. The three layers are public help, mutual help, and self-help, and correspond to efforts at the levels of society, community, and individual (Fig. 2). This model could be useful to find a direction of systematic support for recovery after a nuclear accident.

Public help is necessary to prepare the environment for recovery. Typically, public help is programmes directed by the government or relevant authorities, such as large-area radiation monitoring and the development of necessary infrastructures.

As described above, ultimate recovery, in the sense of regaining control of each individual's life, rests with self-help. However, at the same time, it is important to remember that self-help does not mean surviving on one's own. The passage of time is different from person to person, particularly after a significant event such as a

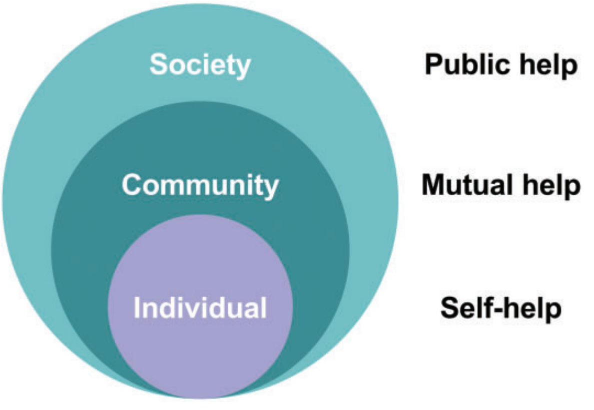

Fig. 2. Concept of three-layered help model. Public help is efforts at society level. Mutual help and self-help are efforts at community level and individual level, respectively.

nuclear accident. Some people can adapt to the new normal fairly quickly, while others do not. Any individual should not be abandoned on the pretext of self-help.

In this regard, mutual help is important to keep individuals from being isolated. It provides eyes to watch over those who need longer to recover. Mutual help also has more active function. In a community whose members live in the same environment and have a similar lifestyle, people are likely to share common problems. If their efforts to address these problems develop into some form of collaborative activity, it will provide a platform for co-expertise. In any case, mutual help is a vital component in ensuring the flexibility and sustainability of efforts for recovery. Considering its importance, supporting communities behind the scenes should be positioned as part of public help.

4. CONCLUSIONS

Recovery after a nuclear accident means nothing other than restoration of the balance of life which has been disturbed by the accident and protective measures against radiation exposure. In some cases, it is almost like starting life over, which is a difficult challenge and may take a long time. Public help plays a role in improving the environment needed for recovery, but ultimately, recovery rests with self-help, in the sense of each individual regaining control of their life. Mutual help plays a crucial part in the process of recovery, and due consideration should be given to how society can support communities over the long term.

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Dialogue as therapy: the role of the expert in the ICRP Dialogues

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Abstract–Science communication is commonly framed as a battle with ignorance and the field of radiological protection is not exempt from this tendency. By correcting deficits in the public's understanding of science, the expert is often imagined to be able to convince the public of its objective safety ('anzen'), thereby inspiring a sense of calm ('anshin'). In the wake of the 2011 Fukushima Daiichi disaster, however, the International Commission on Radiological Protection has sought to break with this tradition by organising a series of participatory seminars in which experts engage those affected by the disaster as equals. Drawing on ethnographic fieldwork, this article suggests that the Dialogue seminars can be best understood using the metaphor of therapy; using it to describe the premise, form, and objectives of the Dialogues with a view to identifying good practice for future radiological protection scenarios.

Keywords: Citizen; Dialogue; Deliberation; Radiation protection; Therapy

1. INTRODUCTION

What is the role of the expert in responding to a nuclear disaster? Two roles are often offered in answer: the expert might act as an advisor to the state, thereby informing policy; or she/he might act as a science communicator, educating the public on the science of radiological protection. Both roles are premised on a linear transmission of knowledge from the expert to the audience. Implicitly, the

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expert has much to teach but little to learn. What then to make of the seminars staged by the International Commission on Radiological Protection (ICRP) in Fukushima? For in the ICRP Dialogues (2011–2016) and Fukushima Dialogues (2016–2018), ICRP members said relatively little, allotting more time to listening to local stakeholders. This article examines how these Dialogues sought to reconfigure the role of the expert. Drawing on participant observation, interviews, and textual analysis, I argue that, in these seminars, ICRP members adopted a role akin to a therapist: one who listens to their client's concerns and provides factual context, but refrains from offering judgement on what the client should or should not do.[1]

2. FROM SCIENCE COMMUNICATION TO DIALOGUE

Science communication has traditionally been premised on a one-way flow of information from rational experts to an emotional public. This model of science communication remains influential in the response to the Fukushima Daiichi disaster. By correcting deficits in the public's understanding of science, experts have been imagined as able to convince the public of its objective safety ('*anzen*'), thereby inspiring a sense of calm ('*anshin*'). In so doing, the expert is able to both promote public (mental) health and restore the fortunes of the affected territory, encouraging both the return of its citizens and the consumption of its produce. These assumptions are particularly plain in efforts to frame science communication as a battle against 'radiophobia': excessive and irrational fear of radiation.

Both the notion of radiophobia and the deficit model of public understanding are objects of extensive critique (see, for example, Wynne, 1992; Girard and Dubreuil, 1996).[2] Though it is beyond the remit of this article to retrace the contours of this debate, it is worth noting that parallel critiques of radiophobia have been made in both critical and technical literatures and that the Dialogues – as well as antecedent projects in Belarus[3] (Dubreuil et al., 1999; Ando, 2016; Lochard, 2017a) – have consciously built upon the latter (Takahashi, 2020). Core organisers of the Dialogues (including Jacques Lochard) also contributed to the International Chernobyl Project: an IAEA assessment 'of the guidance given by Soviet authorities to persons living in radiologically contaminated areas', which explicitly condemned the discourse of radiophobia:

> *If the stressor is a real threat, it is dishonest to pretend otherwise or to imply that an anxious response is in some way abnormal... While it may have suffered in translation, the*

[1]This paper condenses and updates claims made in my thesis, 'The Improvised Expert' (Takahashi, 2020, pp. 121–145). Relevant pages are provided throughout.
[2]For further discussion, see Takahashi (2020, pp. 85–88)
[3]Namely, the ETHOS and CORE programmes.

> *use of the term 'radiophobia' by scientific experts in the USSR illustrates this problem. In a spirited exchange at the IAEA Scientific Meeting in 1988... it was argued that the use of this diagnostic term, at any rate in western Europe and the USA, implies a fear reaction to a stimulus that is normally regarded as wholly benign. Few would place Chernobyl in this category* (IAEA, 1991).

Both this report of the International Chernobyl Project and its 1996 successor – published to coincide with the 10th anniversary of Chernobyl (IAEA, 1996) – estimate the biological effects of exposure to be relatively modest, while emphasising that 'dismay has been universal and anxiety widespread' and poses a risk to public health (IAEA, 1991). However, the authors remain at pains to emphasise that anxiety is 'understandable' in such circumstances and should not be interpreted as abnormal or irrational (IAEA, 1996). Rather than reducing anxiety to a symptom of ignorance, to be fixed through science communication, the reports call for a 'campaign of therapeutic advice on stress management' – thereby establishing the 'management of emotions' as a vital aspect of radiological protection. It is within this 'therapeutic' tradition that the Dialogues fall.

3. THE DIALOGUE FORMAT

The metaphor of therapy is also useful in describing the format of the Dialogues.[4] ICRP Vice-Chair Jacques Lochard has stressed that the Dialogues were not organised around a model per se, but an ethos, directly inspired by the ETHOS project in Belarus and distilled into three guiding maxims: (1) the role of the expert is to 'work with the people, not for them'; (2) the seminars should be 'a suitcase without a handle, belonging only to those who participate'; and (3) 'the path is built as you walk, by walking'. Where these aphorisms aim to distil the guiding spirit of seminars, the metaphor of therapy seeks to accomplish a more prosaic task – that of describing ICRP's practices. Any observer would notice that the Dialogues were predominantly organised around two types of session. Each seminar has featured presentations delivered by both lay and expert participants. These have been described as a 'warm-up' for a second type of session, namely structured dialogues in which stakeholders sit in a semi-circle and take it in turns to share. This format is redolent of group therapy. The microphone makes its way around the semi-circle twice, giving each participant an opportunity to reflect on what their peers have said before the discussion is opened to the floor. No interruptions are permitted, and criticism of other participants is strongly discouraged. Engaging with notable reserve, ICRP members act only as facilitators. They do not join the circle and fastidiously avoid offering any explicit judgements, even when they are solicited. 'We really try not to tell people what to do even when we're asked, "is it safe for me to do this and that?"', Clement stated. 'We don't answer "yes" or "no"... because it's not our role to tell

[4]For further discussion, see Takahashi (2020, pp. 134–140).

people what to do'.[5] Implicit in this code of conduct is an assumption that Fukushima residents are experts on their own lives. In a similar vein to non-directive therapists who insist that 'it is the client who knows what hurts, what directions to go, what problems are crucial' (Rogers, 1961), members of ICRP have aspired to let their interlocutors steer their interactions on the basis that when experts 'make up the questions we think people want us to answer... it doesn't really work because we usually don't get it right'. Though this was not a self-conscious emulation of therapeutic practice, Lochard notes that the comparison is apt:

> *What is important is to put words to what they [the participants] are feeling, what they are living. I think this is a process. I like your term, therapy. Somehow, it's like psychoanalysis. You don't give advice to people. You organise a mechanism where, in fact, people just speak, and the psychoanalyst is just listening. Don't speak anything, just listening. You have a mechanism. You lay out the bed and ok... I think, in a way, there is something a bit like this in the Dialogue. The purpose is not to say, "you should do this. You should do that". "This is what ICRP is thinking" "These are the recommendations". We are listening.*[6]

4. WHAT DOES DIALOGUE DO?

Listening to those affected by the nuclear disaster has an obvious value for ICRP.[7] By the ICRP's own account, the perspectives offered by local residents have powerfully informed both Task Group 94's work on *Publication 138* (ICRP, 2018) and Task Group 93's efforts to update the ICRP's earlier recommendations on responses to large nuclear disasters (Lochard, 2017b; ICRP, 2020). The organisers were keen to stress, however, that the Dialogues were not primarily convened for the benefit of ICRP. 'First, we're human beings and wanted to help in some way', Clement noted. 'We knew we had some expertise or knowledge or experience that might help. That was key, on a personal or human level'.[8] The dialogue process, Lochard agreed, was driven 'first' (and implicitly, foremost) by a quotidian desire to 'empower' local participants, helping them to 'regain control of their daily lives' (see also: Lochard et al 2019).[9]

How was this empowerment achieved? The seminars certainly offered an opportunity for local participants to learn about radiological protection from both ICRP and one another. Yet accounts of the Dialogues consistently tie empowerment to the act of being heard. Many emphasised the value of being able to express fear, anxiety, and pain – instinctively reaching for the language of therapy. Having observed a

[5]Clement, interviewed September 2018.
[6]Lochard, interviewed August 2017.
[7]For further discussion, see Takahashi (2020, pp. 141–144).
[8]Clement, interviewed September 2018.
[9]Lochard, interviewed August 2017.

seminar for the first time on 7 and 8 July 2017, Board Director of Institut de Radioprotection et de Sûreté Nucleaire Dominique le Guludec remarked that the seminar reminded her of her own time as a medical practitioner:

> *I used to be a doctor. I used to work in a hospital. I know that half the cure is the communication between patient and doctor. Why is it so important? Because, for the patient, expressing his pain – his difficulties – is very helpful*... (le Guludec, 2017).

A physician by training, le Guludec's point of comparison is to the hospital bed, not the psychiatrist's couch. Nonetheless, a focus on the catharsis of self-expression has long been a feature of therapeutic practice and is a common motif in accounts of the Dialogues. The KOTOBA web documentary, for example, speaks of how actors 'release' their 'restrained fear and frustration' through vocalisation (KOTOBA, 2016) – suggesting that by expressing negative emotions in a 'neutral territory',[10] one is able to purge or purify them. In discussing the therapeutic function of the Dialogues, Clement emphasised that he was not qualified in psychology or psychiatry: 'I'm not a therapist. I'm not a medical doctor. I don't know these things'.[11] Nonetheless, he affirmed that 'letting people say their piece is really important... That is [a] huge for many people, and that is therapy'.[12] One frequent participant went further in asserting the value of cathartic expression, suggesting that 'at times, th[e] process [of dialogue]... uncovered people's emotions that had been buried intentionally and rationally to move forwards' (Ban, 2016). In celebrating the exposure of 'intentionally' repressed emotions as a boon – rather than portraying this as a potentially traumatic experience – Ban tacitly ascribes to the Dialogue process the function of exorcising negative emotions through open expression.

5. CONCLUSION

The metaphor of therapy helps to distinguish the Dialogues from science communication efforts aimed at combatting radiophobia. It is clear that ICRP did not organise its seminars in the hope of persuading residents to return to Fukushima. Indeed, the organisers remain explicitly agnostic on the question of safety. Instead, the Dialogues aim to help participants feel able to make choices. 'We're not trying to convince people that it's ok to live with radiation', Clement stated, 'We're trying to help people share their experiences... so they can decide'. Lochard was no less emphatic. Whether participants made decisions that were 'in line, or not' with his own appraisal of the situation was 'not the issue', he insisted:

> *What is important is that they regain some confidence and that they start to move and to say – to think – 'this is not something that is out of my understanding. I can understand'.*[13]

[10]Clement, interviewed September 2018.
[11]Clement, interviewed September 2018.
[12]Clement, interviewed September 2018.
[13]Lochard, interviewed August 2017.

This call for action over inaction, decision over indecision, and active choices over passive ones is coupled with an ambivalence toward the content of these decisions. It is the paralysis of confusion, not a reticence to live in Fukushima, that is constructed as the problem to be overcome. To become 'empowered' in this context is to pass from one state of experience to another. As one frequent participant noted, the societal norm when facing a technical problem is to have 'productive discussions' based on 'what can be seen and what can be heard' (Ban, 2016). However 'ICRP focused on what is unseen and unheard' on 'people's feelings and determination' – understanding that '[i]t is the 'unseen' that inspires people to action' (ibid.). Such work does not diminish the challenges of evacuating or living with radiation. Participants are still forced to make 'wrenching decisions' in conditions that are not of their choosing. As in therapy, the Dialogues aim to 'empower' participants principally in the sense of making them feel able to face these decisions.

The organisation of the Dialogues has garnered considerable attention, and some suggest that it could mark the beginning of a 'participatory turn' in responses to nuclear disasters. If this is true, the challenge for future programmes will be to build on the experience of ICRP to go beyond therapy. Where the Dialogues offered catharsis, participatory forums can also offer mechanisms for collective decision-making or political advocacy. In short, they can offer different modes of 'empowerment' to participants, including ones more directly concerned with the exercise of (political) power.[14] In fostering formats which take the lay expertise of affected residents seriously, one should also examine the wealth of participatory practices that have been championed outside the nuclear domain. For this reason, dialogue between different expert communities remains crucial. Continued engagement between experts in radiological protection and science and technology studies, in particular, promises to bear fruit at a time when ICRP is continuing to develop notions of scientists and local residents acting as 'co-experts' in developing 'practical radiological protection cultures' (ICRP, 2020).

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Involvement of stakeholders during the preparedness phase of post-accident situation management

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Abstract–The Steering Committee for Post-accident Management Preparedness (CODIRPA) was commissioned by the French Government in 2005 with the aim of establishing the main principles to be set up for population protection and recovery in the long term. From the beginning, one of the main principles was the pluralistic nature of the working groups (WGs), including scientific and technical experts, representatives from state departments, nuclear operators, and representatives of civil society (i.e. stakeholders). Stakeholders were mainly associated with the various WGs of CODIRPA. In order to foster the involvement of stakeholders from civil society in the works of CODIRPA, a new organisation was implemented with two WGs: one mainly composed of technical experts for tackling technical issues, and one for evaluating the proposals made by the experts from the stakeholders' point of view. This article presents the results of this new strategy.

Keywords: Preparedness; Post-accident management; Stakeholder involvement

1. INTRODUCTION

The Steering Committee for Post-accident Management Preparedness (CODIRPA) was created in 2005 under the leadership of the French Nuclear Safety Authority (ASN). The aim of CODIRPA was to develop a comprehensive strategy for the management of population protection and the resilience of affected

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territories against the consequences of a major nuclear accident. For this purpose, working groups (WGs) were created on specific topics (e.g. medical and psychological support, consumption of locally produced foods, evaluation of radiological contamination of the environment, remediation actions and waste management) based on lessons learnt from the accidents in Chernobyl and Fukushima. In this approach, the following basic guiding principles (ASN, 2012) were used:

- Anticipation: the issues at stake in post-nuclear accident management need to be taken into account from as early as the end of the emergency phase.
- Justification: actions, especially those aimed at protecting the population, must be warranted, meaning that the expected benefits must exceed the risks and drawbacks inherent in their implementation.
- Optimisation: population exposure to ionising radiations must be kept to a level as low as reasonably achievable, taking economic and societal factors into account.
- Shared construction and transparency: post-accident management must involve the population, elected officials, business community, and social stakeholders.

Lessons learnt from previous radiation accidents (Lochard et al., 2020) demonstrate that the fourth principle is essential to attain the main objectives of post-accident management (i.e. protecting the population from harmful effects of radiation, providing support to affected populations, and sustaining the resilience of the affected territories from economic and social viewpoints). In order to cope with this fourth principle, the pluralistic nature of CODIRPA was promoted from the beginning through the inclusion of representatives of scientific and technical expert institutes, governmental departments, nuclear operators, and civil society [e.g. members of non-governmental organisations and members of local information committees (LICs)]. These LICs exist for each nuclear plant (NP) and involve local stakeholders living in the urgent protective action zone, as defined by the International Atomic Energy Agency (IAEA, 2015). As such, the main recommendations issued by CODIRPA (ASN, 2012) included the views and opinions of stakeholders from civil society.

Nevertheless, the participation of stakeholders was limited to attending the meetings of the various WGs and providing advice on the management options discussed, which represents fairly limited involvement. Thus, CODIRPA decided to implement a WG on ways to foster the involvement of stakeholders in evolution of the post-accident management strategy. The so-called 'stakeholder involvement' WG (SI-WG) proposed several actions, one of which is presented in this article. Moreover, the principles of this action were extended to other WGs and a specific example is discussed below.

2. HEALTHCARE PROFESSIONAL WORKING GROUP

A key group of people who may serve as facilitators between the authorities and experts and the affected population are healthcare professionals (Kawashima et al., 2020; Ozaki et al., 2020). As such, the SI-WG proposed to create a document intended for medical care professionals with two objectives: to provide answers to questions that patients could ask their healthcare professionals, and to provide answers to the healthcare professionals' own questions.

To achieve this, the healthcare professional WG (HCP-WG) was set up, with two subgroups:

- A group of healthcare professionals living in the vicinity of an NP located in the centre of France, close to the city of Poitiers. This 'local' group included hospital practitioners, family doctors, emergency doctors, pharmacists, veterinarians, and nurses. A representative of the expert group (see below) and a representative of ASN were also included in the local group to coordinate the work between the two groups.
- The expert group was composed of experts in radiation protection, medical care, and post-accident management; representatives of ASN; and representatives of ANCCLI, the national association of LICs.

The work started with acculturation of the local group to the post-accident situation with a simulation of the consequences of a nuclear accident at the nearest NP. The local group was then in charge of generating a list of questions that they could be asked by their patients in a post-accident situation, and their own questions. A list of 201 questions on various subjects was developed, such as generalities about radioactivity, irradiation, and contamination (one question); health care (86 questions); daily and social life (69 questions); professional life (16 questions); the environment (four questions); and management of the emergency phase (27 questions), including two supplementary questions that arose later on. All of the questions were practical in nature, such as 'what are the precautions to be taken when receiving a potentially contaminated patient?' or 'will the public services remain open?' Even surprising questions were taken into account, such as 'will my pet be evacuated with me?' or 'do I have to cut my hair if I'm contaminated?' The questions were transferred to the expert group for answering. Experts from specific domains (e.g. thyroid pathology specialists) were asked for help in writing some answers. During the course of this process, the need for additional factsheets to go deeper into some specific subjects was underlined by the local group. A list of 25 subjects was established and transmitted to the expert group. The resulting document (80 pages, including numerous illustrations) was then submitted to the local group for approval. In particular, the local group was asked if the final document was sufficiently clear, complete, and understandable (i.e. met their expectations). This step is currently underway. A synthesis of their comments will be made, and the document will be amended and published. The whole process is depicted in Fig. 1.

Although the final document is not yet published, this action is judged as very positive by both the stakeholders who participated in the process and the SI-WG. As a result, CODIRPA is intending to publish this document in several formats, including publication on a website with a search engine in order to find answers associated

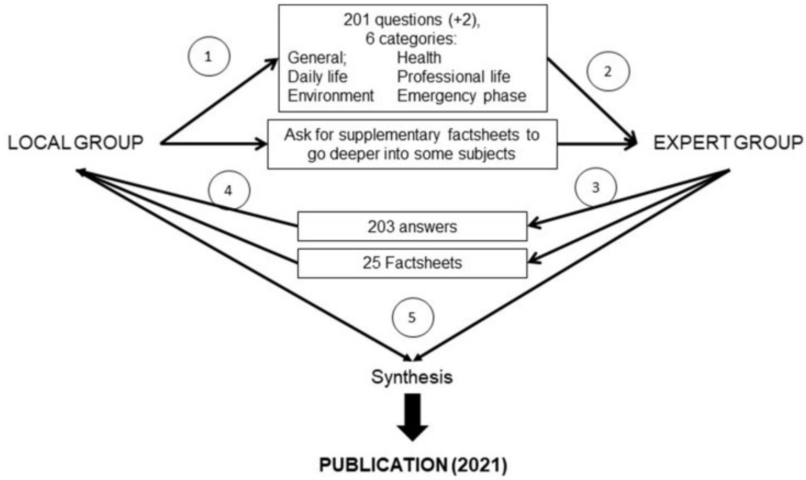

Fig. 1. Process used for creation of a document intended for healthcare professionals working in or close to the urgent protective action zone. (1) Generation of questions and factsheets; (2 and 3) preparation of answers and factsheets; (4) review of the complete document; and (5) synthesis and publication.

with keywords, a printable document, and a pocket memo for hospital practitioners. Moreover, in a plenary session, CODIRPA decided to foster the involvement of stakeholders, especially stakeholders in the vicinity of NPs, in all WGs.

3. CITIZEN PANELS IN THE LOCAL FOODSTUFF CONSUMPTION WORKING GROUP

In the first step, ways to reach the objective of fostering the involvement of stakeholders was debated in CODIRPA, who proposed to test a new way of working with local stakeholders (i.e. people who are potentially affected by a nuclear accident). The general principle (Fig. 2) is to test the proposals made by a technical WG (in charge of developing protective measures on the basis of technical and radiation protection elements) with a panel of citizens living in the vicinity of an NP, including representatives of the local LIC, to gain their advice on whether the protective measures are understandable, and whether the protective measures will be acceptable for the population. The advice of the panel will be presented to the main WG, gathering the technical WG and representatives of the panel and the LIC. The main WG will subsequently issue a final report including a synthesis of the panel's advice and final recommendations on protective measures to be implemented. The final report will be submitted to a plenary session of CODIRPA, before issuing recommendations for new protective measures to the French Government.

In order to evaluate the feasibility, interest, and potential pitfalls of this new scheme, the decision was made to apply these principles to a specific WG in

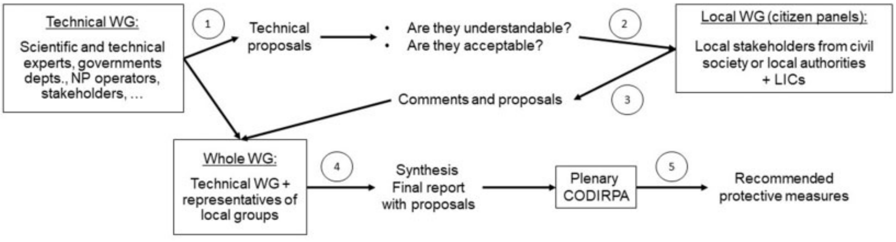

Fig. 2. Schematic representation of the general principles for working with stakeholders with five different steps. (1) A technical working group (WG) proposes protective measures. (2) Submission of proposals to a local WG. (3) Comments and proposals of the local WG are presented to the whole WG. (4) Final report with proposed protective measures taking into account the comments of the local WG submitted to a plenary session of the Steering Committee for Post-accident Management Preparedness (CODIRPA). (5) Recommended protective measures proposed to the French Government. NP, nuclear plant; LIC, local information committee.

charge of delineating protective measures against internal contamination from locally produced foodstuffs. In fact, a main exposure pathway in the long term in a post-accident situation is exposure through ingestion of locally produced foodstuffs, even 35 years after the Chernobyl accident (Bertho et al., 2019). Thus, a central protective measure is the restriction of consumption of locally produced foodstuffs in an area defined by estimates of radiation exposure (technical criteria). These technical criteria could be, for instance, an effective dose due to ingestion or a level of radioactive contamination in locally produced foodstuffs. Both of these options have advantages. However, such a protective measure should be understood and accepted by the local population, especially those living a self-sufficient lifestyle, as the consumption of products from kitchen gardens, hunting, fishing, and forest gathering (e.g. mushrooms, wild berries) might be forbidden.

For that purpose, the main WG asked for the collaboration of four LICs located in four different regions of France, representing four different agricultural practices and eating patterns: North shore (fish products and seafood), Rhone valley (fruits and vineyards), South west (fruits, vegetables, and poultry), and Loire basin (vegetables and vineyards). The LICs are in charge of gathering local citizens (approximately 20 citizens per region), as representative as possible of the diversity of the local population, and representatives of local authorities (mayors and representatives of local administration). These panels are currently under construction. The next step will be to set up face-to-face meetings during which a phase of acculturation to a nuclear accident situation will be made, including a scenario for contextualising the post-accident management situation. Thereafter, the different options will be presented and an open discussion will take place. The local LIC will be in charge of preparing a synthesis of the discussions and proposals made by the citizens, which will need to be approved by all the participants. These proposals will subsequently be presented to the main WG. A final report will be issued, taking into account the proposals of the citizen panels.

This action is in development; however, the LICs are very positive about this approach. Moreover, some key points appear to be essential for the success of this new approach. The first point is setting up face-to-face meetings with citizens and a limited number of experts so that each citizen can express their concerns and opinions in an open-minded frame. The second point is the diversity of citizens joining the panels, in order to have a picture of the local population and eating patterns. The third point relies on confidence among the citizens that their opinions will be taken into account. For that purpose, it is important that the synthesis of the panel discussion is approved by each participant. It is also important that the final report of the main WG includes the comments of panels, and that the panels receive a feed back about their proposals.

If successful, this method will be applied to other subjects, such as waste management and citizen measurements. In addition, meeting citizens living in the vicinity of an NP regarding a specific subject of interest in their daily lives is a way to improve the safety culture among these populations. Moreover, in the worst case of a nuclear accident, these knowledgeable citizens may help the local population to acquire good practices of radiological protection when living in a contaminated territory. The SI-WG will continue its work with the aim of making proposals to answer two new questions – how to promote a safety culture among populations in the vicinity of an NP in the preparedness phase, and how to involve local stakeholders in the management of a real post-accident situation. The present process of local stakeholder consultation with the help of the local LIC is a first step, but other means are needed to improve these two key points.

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Feedback assessment from the audience as part of health literacy training for health professionals: a case from Fukushima after the nuclear accident

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Abstract–Following the accident at Fukushima Daiichi nuclear power plant in 2011, a series of health literacy training workshops for local health workers was developed and implemented. This study aimed to analyse who among the intended audience gained the greatest benefit from the training. Nine health workers attended a workshop consisting of classroom training and a follow-up feedback assessment of materials they created in the workshop. The materials were assessed by a total of 131 intended readers. Using Sakai's tool, those items asking readers to rate the accessibility of written information were used to compare the materials before and after revision. The total score for Sakai's measure showed a significant improvement, and the elderly and those without regular doctor visits were more likely to notice improvements after revision. Such health literacy training could serve as a model programme to prevent inequity in access to health information in the face of a regional health crisis.

Keywords: Health literacy; Fukushima nuclear accident; Education; Public health nurses; Feedback

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1. INTRODUCTION

Improving health literacy skills helps people to understand and use health information for health promotion. Raising awareness of health literacy and offering skills training to health professionals helps to improve their communication with their clients (Nutbeam et al., 2018). Scientific evidence linking these two wings of health literacy interventions to improve health literacy within community populations and to offer skills training among health professionals is needed, but this is scarce, and the fundamental question regarding whether health literacy training among health professionals would help to improve access to health information remains unanswered.

Immediately after the accident at Fukushima Daiichi nuclear power plant in 2011, local healthcare professionals faced extreme difficulties with communicating the health risks of the region-wide radiation contamination. As one of the measures to solve this risk communication issue, the lead author worked with colleagues in Japan and the USA to develop, implement, and evaluate a series of health literacy training workshops for public health nurses (Goto et al., 2015). The training was adapted from Rudd's 'Eliminating Barriers – Increasing Access Workshop' (Rudd, 2010), which was designed to help health professionals to understand and fill the gap between professional and public knowledge.

Aiming at wider implementation, the original training (Goto et al., 2015, 2018) was made more concise. Comparison of the original and shorter version revealed that the increase in participants' knowledge was comparable, although practical application seemed much less in the shorter versions (Machida et al., 2019). Therefore, the authors upgraded the concise version by requiring participants to assess feedback from the intended audience on written materials that they had revised. This study aggregated the data from feedback assessment training of workshop participants, primarily to see if the accessibility of the materials they created improved after revisions made during the workshop, and secondly to explore who among the intended audience gained the most benefit from the improved materials.

2. METHODS

2.1. Workshop content and participants

Firstly, as shown in Table 1, participants learned basic skills to assess and improve written health information in a classroom setting. As a follow-up activity, they used their acquired skills to revise their own health information materials under the supervision of instructors. Secondly, each participant conducted a small-scale survey asking members of the intended audience to rate the accessibility of the material before and after revision. The participants analysed the collected data and reported back to the instructors about their learning through the feedback assessment.

In the present study, three workshops targeting municipality, university, and hospital staff were implemented in 2017 and 2018. These were much smaller in size than previously reported workshops (Goto et al., 2015, 2018) because they were

Table 1. Content of the health literacy training programme (1-day version) in Fukushima.

In-class session (2 h) →	Follow-up (approximately 1 month)
1. Ice-breaking activity 2. Lecture • General background of health literacy and numeracy • Instructions to use material assessment tools • Techniques to improve text, graphics, and risk presentation 3. Exercise • Assessment and revision of an assigned written health material 4. Training evaluation	1. Revision of own material with on-line instruction by instructors 2. Evaluation survey among intended audience to compare materials before and after revision 3. Self-assessment of the survey results and submission of a report to instructors 4. Feedback on the report by instructors

conducted as a pilot study including the feedback assessment component in the training. Five public health nurses attended the municipality workshop; all revised their materials and two succeeded in conducting the feedback assessment. Three participants (two nutritionists and a nurse) attended the university workshop and two feedback assessment reports were returned (the two nutritionists worked as a pair). Individual training was conducted for one doctor, who was from a hospital located outside Fukushima Prefecture but visited Fukushima frequently to implement parenting support activities.

2.2. Feedback assessment items

Basic characteristics of respondents, including sex, age, employment status, whether they attended regular doctor visits, and health literacy level, were collected. Health literacy level was assessed using Tokuda's one-question instrument (Tokuda et al., 2009). Regarding the main outcome of accessibility of written materials, Sakai's list of key points to improve Japanese text (Sakai, 2011) was modified and used as a guideline in the training to adapt the original English workshop into Japanese. There were 13 assessment items: Chinese characters (two items); length of sentences and paragraphs (two items); supplementary explanation of terms in parentheses (two items); professional terms (four items); writing style; content; and reading time. Of note, a lower score indicates better accessibility.

2.3. Statistical analysis

Change in the total score for Sakai's measure before and after revision was examined using Wilcoxon matched-pairs signed-rank test. Regarding analysis of factors associated with improvement of the total score for Sakai's measure, Chi-squared test was used for univariate analysis and a binominal logistic regression model was used for multi-variate analysis by entering factors that were significant in the univariate analyses. All statistical analyses were conducted using STATA Version 14.0 (Stata Corp, College Station, TX, USA).

2.4. Ethical consideration

The protocol of this study was reviewed and approved by the Ethics Committee of Fukushima Medical University (No. 29116).

3. RESULTS

Five reports with data from feedback assessment surveys were collected from three nurses, one pair of nutritionists, and one doctor. They developed leaflets on health check-ups, cancer screening, prevention of osteoporosis, healthy life expectancy, and support for children with disabilities. The total number of survey respondents, who were the intended audience of the participants' written materials, was 131.

The total score for Sakai's measure decreased significantly from 6 (range 0–13) to 0 (range 0–13) ($P < 0.001$), indicating better accessibility. When examining at subscale level, the proportion of those who reported improvement was lower for 'supplementary explanation of terms' and 'content'.

Regarding the characteristics of respondents in the feedback assessment surveys (Table 2), the elderly [adjusted odds ratio (aOR) 1.56] and those who did not have regular doctor visits (aOR 80.18) were more likely to report improvement in Sakai's measure.

In the reports that training participants submitted with their feedback assessment data, they wrote about recognising the importance of altering material content in accordance with the aim of providing information, and the characteristics of the intended audience. One nurse wrote, 'it is important to make it a routine to have difficult parts reviewed by the intended audience and revise based on their comments'.

4. DISCUSSION

A clear improvement was observed in the accessibility of written health information following health literacy training. Technically, supplementary explanations in parentheses, and, more intrinsically, conveying the main message clearly requires careful attention when developing materials. Incorporating the feedback assessment survey into the training served two purposes: evaluation of the revised materials by the intended audience; and the provision of training for participants to help recognise the importance of obtaining feedback from the intended audience, as described in their submitted reports. One of the teaching tools in this training programme is the translated version of the US Centres for Disease Control and Prevention's clear communication index. This tool assesses the accessibility of both text and numerical

Table 2. Feedback assessment results and respondents' characteristics.

Characteristics	n*	Change in total score† n (%) Not improved	Improved	Univariate analysis‡ P-value	Multi-variate analysis§ aOR (95% CI)	P-value
Sex						–
Women	116	23 (20)	93 (80)	0.29	–	
Men	13	1 (8)	12 (92)			
Age (years)						
10–59	74	19 (26)	55 (74)	0.02	1.00	
60–79	56	5 (9)	51 (91)		1.56 (1.18–2.08)	<0.01
Employment						
Yes	26	9 (35)	17 (65)	0.02	1.00	0.12
No	97	14 (14)	83 (86)		2.51 (0.79–7.96)	
Regular doctor visit						
Yes	75	23 (31)	52 (69)	<0.001	1.00	<0.001
No	52	1 (2)	51 (98)		80.18 (8.08–796.13)	
Health literacy level¶						–
Adequate	79	10 (13)	69 (87)	0.35		
Low	42	8 (19)	34 (81)			

aOR, adjusted odds ratio; CI, confidence interval.
*Some items did not add up to the total number (n=131) due to missing data.
†A total of 13 items was calculated for the assessment of materials before and after revision. The 'after' score was subtracted from the 'before' score. Minus digits and zero were considered as 'not improved' and plus digits were considered as 'improved'.
‡Chi-squared test was used.
§Logistic regression model was used. Outcome variable was 1 = 'improved' and 0 = 'not improved' as defined in †.
¶Health literacy level was assessed using Tokuda's one-question instrument. Subjects were asked about their confidence in completing a medical form; those who felt confident were classified as 'adequate health literacy' and those who did not feel confident were classified as 'low health literacy'.

information. Prior to scoring, the index asks users to identify the characteristics of the intended audience in addition to the aims of the information provided. This message was well conveyed in the study workshop, and the recent training evaluation reported that participating nurses had more positive attitudes towards feedback from community members compared with non-participants (Yumiya et al., 2000).

This study found that feedback assessment respondents who were elderly and did not have regular doctor visits were more likely to notice improvement in the materials. One nationwide survey in Japan reported that the elderly were less confident about seeking health information (Ishikawa et al., 2012). Their vulnerability to access information could be enhanced by advancing technology. Another national survey among the elderly in the USA found a negative loop between low health literacy and use of the internet; elderly people with low health literacy tend not to use the internet to obtain health information and are left behind in the digital information age (Levy et al., 2014). This does not only affect elderly people; as Protheroe et al. (2009) wrote, 'a person can be literate within a familiar environment and context, but functionally illiterate when required to comprehend and respond to unfamiliar vocabulary and concepts in an unfamiliar environment'. Healthcare settings are unfamiliar environments for many, and universal precaution is key to promoting health literacy at health organisations (Brega et al., 2015). This training programme showed that one way of reaching out to populations at risk of not receiving health information is to train health professionals to have a health literacy perspective and skills.

This study had two main limitations. First, results from the analysis regarding who gained the greatest benefit from the improved materials need to be interpreted cautiously. It is not conclusive whether the materials assessed among the non-elderly were less improved or whether the elderly actually gained greater benefit from the revision. Second, a conventional one-question item was used to assess the health literacy level of respondents in the feedback assessment. Use of a more precise measure may have resulted in a significant association with health literacy level rather than age and familiarity with health services.

Almost a decade has passed since the accident at Fukushima Daiichi nuclear power plant. Since then, the authors have developed, implemented, continuously evaluated, and upgraded their health literacy training. The training programme is expanding to integrate the workshop into medical and nursing education (Murakami and Goto, 2019) and on-the-job training for various health professionals within and outside Fukushima. Such training could serve as a model programme to prevent inequity in access to health information in the face of a health crisis.

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Comparison of thyroid doses to the public from radioiodine following the Chernobyl and Fukushima accidents

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Abstract–Estimates of thyroid doses to the public from radioiodine intake following the accidents at Chernobyl and Fukushima Daiichi nuclear power plants are compared. The basis for thyroid dose estimates after the Chernobyl accident was a large set of measurements of ^{131}I thyroidal content for approximately 400,000 residents in Belarus, Ukraine, and Russia. Due to a lack of direct thyroid measurements after the Fukushima accident (just over 1000 residents were measured), thyroid doses were estimated based on ecological models and are therefore associated with much higher uncertainty than those based on direct thyroid measurements. Thyroid dose estimates for evacuees were up to 50,000 mGy for Chernobyl and up to approximately 100 mGy for Fukushima. This large difference in thyroid dose to the public is mainly due to the different dominant pathways of radioiodine intake: ingestion of fresh, locally produced cows' milk (Chernobyl) and inhalation of contaminated air (Fukushima).

Keywords: Chernobyl accident; Fukushima accident; Thyroid dose; Radioiodine; Public

1. INTRODUCTION

The accidents at Chernobyl and Fukushima Daiichi nuclear power plants are the most serious to have occurred in the nuclear industry. Numerous thorough studies have been undertaken regarding the health effects in the population exposed to

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radioactive releases after the Chernobyl accident. As a result of these studies, the scientific community has agreed that the sharp increase in the number of cases of thyroid cancer among those individuals exposed in childhood in the severely contaminated areas could be attributed to the Chernobyl accident. Additionally, it has been concluded that 'there has been no persuasive evidence of any other health effects in the general population that can be attributable to radiation exposure' (UNSCEAR, 2011).

According to estimates of the atmospheric releases from the two accidents, the quantities of radioactive isotopes of iodine and caesium released in Fukushima were assessed to be approximately an order of magnitude lower than those released in Chernobyl (UNSCEAR, 2011, 2014). Nevertheless, based on the Chernobyl experience, there is understandable concern about possible health effects in the population due to thyroid exposure to radioiodine following the Fukushima accident. This article compares the levels of thyroid exposure in the population following the Chernobyl and Fukushima accidents.

2. THYROID EXPOSURE PATHWAYS

In general, there are four exposure pathways contributing to the thyroid dose of members of the public: (i) internal exposure from inhalation and ingestion of ^{131}I; (ii) internal exposure from inhalation and ingestion of short-lived radioiodines (^{132}I, ^{133}I, and ^{135}I) and of short-lived radiotelluriums (^{131m}Te and ^{132}Te); (iii) external exposure from radionuclides in the radioactive cloud and radionuclides deposited on the ground and other surfaces; and (iv) internal exposure from incorporated long-lived radionuclides such as ^{134}Cs and ^{137}Cs due to inhalation and ingestion. The comparative contribution of each of these pathways to the thyroid dose of an individual varies according to the specific circumstances of exposure (residence history, dietary habits, etc.). However, the main factor affecting the contribution of the above-mentioned pathways is whether ingestion or inhalation dominates ^{131}I intake. Table 1 provides typical contributions of various pathways to thyroid doses for the public living in contaminated areas after the Chernobyl and Fukushima accidents. These have been estimated on the basis of several publications (Gavrilin et al., 2004; Minenko et al., 2006; UNSCEAR, 2011, 2014; IAEA, 2015a). Of particular interest is internal exposure to the thyroid from radioiodines.

Table 1. Typical contributions of various pathways to thyroid doses for the public living in contaminated areas after the Chernobyl and Fukushima accidents.

Exposure pathway	Chernobyl	Fukushima
Internal exposure from ^{131}I	>90%	40–50%
Internal exposure from short-lived radioiodines	1–4%	5–20%
External exposure	1–2%	40–50%
Internal exposure from $^{134}Cs + ^{137}Cs$	~1%	~1%

Table 2. Distribution of estimated thyroid doses in residents (children up to 3 years of age and adults) from contaminated areas in Belarus, based on direct thyroid measurements (Savkin and Shinkarev, 2007).

		Thyroid dose (Gy)		
Area	Age group	<0.3	0.3–2.5	>2.5
Villages from three southern raions of Gomel oblast evacuated before 5 May 1986	0–3 years	5.6%	39.8%	54.6%
	Adults	32.5%	60.0%	7.5%
Villages from three southern raions of Gomel oblast not evacuated before 5 May 1986	0–3 years	14.5%	55.8%	29.8%
	Adults	65.3%	33.7%	0.9%
Villages in contaminated territories of Mogilev oblast	0–3 years	61.1%	37.1%	1.9%
	Adults	94.0%	6.0%	0.02%

3. EXPOSURE TO THE PUBLIC AFTER THE CHERNOBYL ACCIDENT

The most reliable estimate (i.e. associated with the lowest possible uncertainty) of thyroid dose for a member of the public is based on in-vivo monitoring of the ^{131}I thyroidal content of that person. In May–June 1986, large-scale monitoring was conducted in the three most contaminated countries: Belarus, the Russian Federation, and Ukraine. By the end of June 1986, measurements of ^{131}I in the thyroid had been conducted on more than 400,000 people, including more than 200,000 in Belarus, 45,000 in the Russian Federation, and approximately 150,000 in Ukraine (Uyba et al., 2018; ICRP, 2020). Consumption of fresh milk from cows grazing on contaminated pastures was the main pathway of radioiodine intake for the majority of residents after the Chernobyl accident. This arose because of delays in notifying the public after the accident and a delay in the application of urgent countermeasures. The daily rate of consumption of fresh milk was not found to vary much with age. However, thyroid mass increases with age from birth to adulthood by a factor of approximately 10. Therefore, while the thyroidal uptake of iodine from the diet does not depend upon age, the average thyroid dose for infants is approximately 10 times that for adults. This contributed to large thyroid doses, especially in children living in rural areas in the vicinity of the damaged reactor.

For example, approximately 55% of children aged <3 years from evacuated villages and approximately 30% of children aged <3 years from non-evacuated villages of the three southern raions[1] (Bragin, Khoiniki, and Narovlya) of Gomel oblast[2] of Belarus received thyroid doses >2.5 Gy (Savkin and Shinkarev, 2007) (Table 2). In comparison, only a small proportion of young children (approximately 2%)

[1]A raion is a political unit approximately equivalent to a county in the USA.
[2]An oblast is a political unit approximately equivalent to a state in the USA.

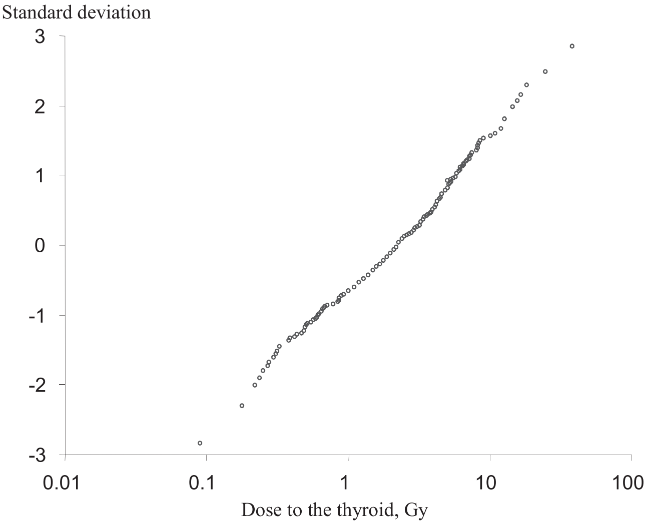

Fig. 1. Lognormal distribution of individual thyroid doses derived from direct thyroid measurements for children up to 17 years of age from the evacuated village of Pogonnoe in Khoiniki raion of Gomel oblast.

from villages located further away (approximately 200 km from the Chernobyl nuclear power plant) in Mogilev oblast received thyroid doses >2.5 Gy.

As a rule, the distribution of individual thyroid doses estimated on the basis of direct thyroid measurements can be described satisfactorily with a lognormal function. This distribution can then be applied to individuals in an area with similar exposure conditions. An example of a lognormal distribution of thyroid doses derived from direct thyroid measurements for 226 children up to 17 years of age from the evacuated village of Pogonnoe in Khoiniki raion of Gomel oblast is presented in Fig. 1. The geometric mean of that distribution was estimated to be 2.1 Gy with a standard deviation of 3.1 (Uyba et al., 2018). The highest estimates of thyroid doses to children derived from direct thyroid measurements were found to be as high as 50 Gy (Shinkarev et al., 2008).

A typical contribution of short-lived radioiodines to the thyroid dose for the public in contaminated areas was estimated to be a few percent of the contribution from ^{131}I. Of the short-lived radioiodines, ^{133}I and ^{132}I (due to the intake of ^{132}Te and its radioactive decay to ^{132}I in the body) made the greatest contribution in terms of internal dose to the thyroid (Gavrilin et al., 2004).

4. EXPOSURE TO THE PUBLIC AFTER THE FUKUSHIMA ACCIDENT

After the Fukushima accident, in-vivo monitoring of the ^{131}I content in the thyroid was conducted for just over 1000 residents in March–April 2011 (UNSCEAR, 2014; IAEA, 2015a). Due to the small number, the measurements were only used to test a radio-ecological model of thyroid dose reconstruction. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report, the settlement-average thyroid absorbed dose estimates in the first year after the accident for evacuated residents from Fukushima Prefecture were in the range of 0.007–0.035 Gy for adults and 0.015–0.083 Gy for infants aged 1 year. For residents from settlements in Fukushima Prefecture and six neighbouring prefectures that were not evacuated, the thyroid absorbed dose estimates were in the range of 0.001–0.017 Gy for adults and 0.003–0.052 Gy for infants aged 1 year (UNSCEAR, 2014). However, due to the small number of direct thyroid measurements, the UNSCEAR estimates were based on an assumption that a substantial contribution to the thyroid dose was from ingestion of ^{131}I, which resulted in overestimation of the thyroid doses for the public.

An analysis of direct thyroid measurements conducted on 26–30 March 2011 for 1080 children from three settlements – Iwaki City, Kawamata Town, and Iitate Village – showed that inhalation of ^{131}I was the dominant pathway, rather than ingestion (IAEA, 2015b). According to the International Atomic Energy Agency (IAEA) estimates, the geometric means of the distribution of individual thyroid equivalent doses[3] for children aged 0–15 years, derived from direct thyroid measurements, were 3.2 mSv for 134 children of Iwaki City, 2.2 mSv for 647 children of Kawamata Town, and 6.0 mSv for 299 children of Iitate Village (IAEA, 2015b). According to another re-assessment of internal thyroid doses to those children, all dose estimates were $<$30 mSv (Kim et al., 2020). The prevalence of the inhalation pathway for ^{131}I for the measured children was a result of early notification of the public and application of urgent countermeasures following the Fukushima accident. In this way, the ingestion of ^{131}I in contaminated drinking water and foods was avoided for the majority of residents. Where inhalation is the dominant pathway, the average thyroid dose to adults from ^{131}I is less than that to infants from the same settlement by a factor of approximately 2 (compared with a factor of 10 when ingestion of cows' milk dominates), which reflects an increase in breathing rate with age by a factor of approximately 5 from infant to adult. A typical contribution of short-lived radioiodines to the thyroid dose for the residents who lived in areas where the main fallout occurred on 15 March 2011, and who did not consume contaminated drinking water and food, is estimated to be within 15% of the dose to the thyroid from ^{131}I. The contribution of short-lived radioiodines to the thyroid dose for the residents who lived in areas where the main fallout occurred on 12 March 2011 may have been as high as 30–40%. Among the short-lived radioiodines, the main contributors to the thyroid dose were ^{133}I and ^{132}I through the intake of ^{132}Te (Shinkarev et al., 2015).

[3]Thyroid equivalent dose expressed in millisieverts is numerically equal to thyroid absorbed dose expressed in milligrays.

5. CONCLUSION

Consumption of cows' milk contaminated with ^{131}I, for which prompt countermeasures were lacking, was the dominant pathway of radioiodine intake for the public following the Chernobyl accident, and this resulted in high thyroid doses (up to 50,000 mGy). Conversely, timely notification of the public and urgent application of countermeasures following the Fukushima accident enabled ingestion of ^{131}I from contaminated drinking water and food to be avoided for the majority of residents. The dominant pathway for those residents was inhalation of ^{131}I in contaminated air. This resulted in much lower thyroid doses (up to just over 100 mGy).

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Development of computer simulator 'Kawauchi Legends' as disaster response medical training software: overcoming the COVID-19 pandemic

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Abstract–Medical disaster response training is provided for international students in Kawauchi Village to share the lessons learnt from the accident at Fukushima Daiichi nuclear power plant. At present, this is difficult due to the coronavirus disease 2019 (COVID-19) pandemic. The purpose of this article is to report the development of hands-on medical training software on a topic that does not require in-person attendance. The 'Kawauchi Legends' disaster simulator was developed as a useful tool to teach the medical response to various disasters, and this was applied in a 3-day webinar in October 2020. Fourteen students participated in the webinar and successfully learnt medical management, manipulating their avatars in the virtual environment. This software can be an effective substitute for in-person disaster training without physical involvement. Such innovative teaching methods mean that lessons from the Fukushima accident can continue to be shared, even in the COVID-19 pandemic situation.

Keywords: Fukushima Daiichi nuclear power plant accident; Kawauchi Legends; Disaster simulation software; Medical training; COVID-19

1. BACKGROUND

One of the important missions for responders to the accident at Fukushima Daiichi nuclear power plant is to share the lessons learnt. As part of this, a disaster response training seminar is run in Kawauchi Village, Fukushima Prefecture for both domestic

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and international students regarding uncertain hazards following the accident. However, face-to-face training has become difficult recently due to the coronavirus disease 2019 (COVID-19) pandemic (Fig. 1).

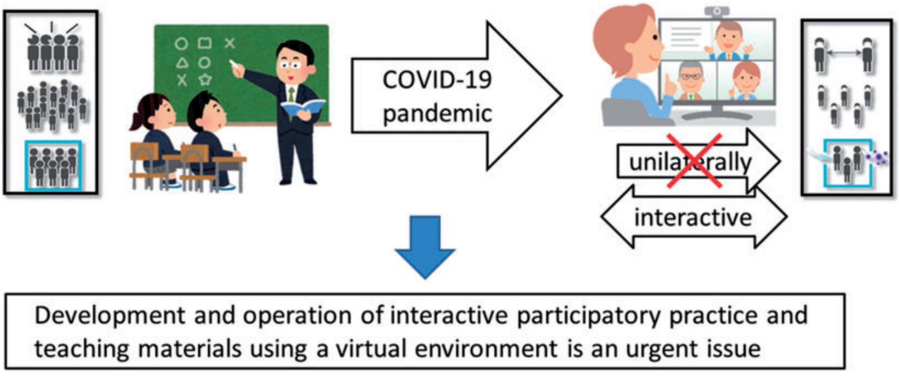


Fig. 1. Changes in practice and training environment due to the coronavirus disease 2019 (COVID-19) pandemic.

2. OBJECTIVE

The purpose of this project is to develop tools for a practical medical response to uncertain hazards when in-person presence is not possible, and to continue sharing lessons learnt from the Fukushima accident with the next generations.

3. METHODS

3.1. Concept of software development

The disaster simulator ‘Kawauchi Legends’ was developed for practical medical training. The simulator concept was created by the Department of Radiation Disaster Medicine of Fukushima Medical University and the Kawauchi Branch of the Futaba Fire Department, and the software was produced by Mark-on Ltd. The software concept and development overview is shown in Fig. 2.

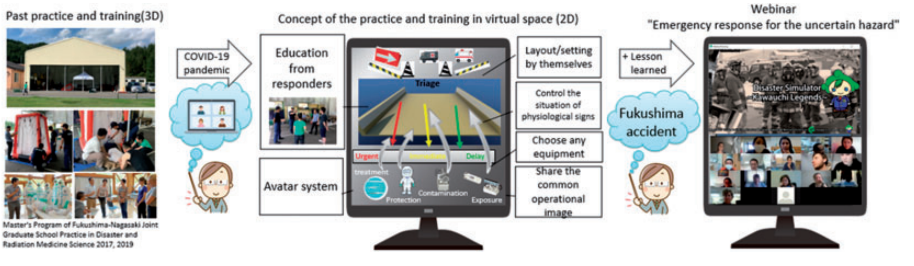


Fig. 2. Development of the practical medical training online simulator.

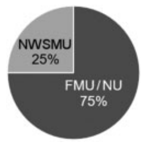
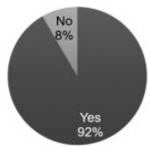
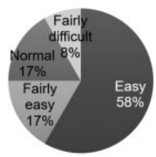
3.2. Webinar

After development and testing of the 'Kawauchi Legends' simulator, the international webinar 'Emergency response for uncertain hazards' was organised via a Zoom video conference hosted by Fukushima Medical University on 19–21 October 2020.

3.3. Questionnaire survey

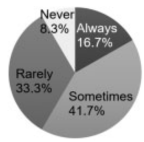
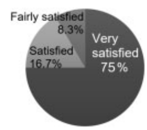
After the webinar, a web-based questionnaire survey was applied, consisting mainly of questions using four- or five-point Likert scales to estimate the application of the software in training (Table 1). Before the questionnaire survey, the concept of the survey was explained, and the participants gave their informed consent.

Table 1. Results of the questionnaire survey.

	Question	Distribution
1	Please choose your university (FMU/NU, NWSMU)	
2	Did you participate in this training using the simulation software? (yes/no*)	
3	Was it easy to download the simulation software? (easy/fairly easy/normal/fairly difficult/difficult)	
4	Was the operation of the simulation software easy? (easy/fairly easy/normal/fairly difficult/difficult)	
5	Did you enjoy the training using the simulation software? (very enjoyable/enjoyable/not enjoyable/not enjoyable at all)	

(continued on next page)

Table 1. *(continued)*

	Question	Distribution
6	Do you think that practical training using the simulation software can replace by classroom exercises? (always/sometimes/rarely/never)	
7	Do you think that practical training using the simulation software can replace practical exercises? (always/sometimes/rarely/never)	
8	How satisfied are you with the lectures using the simulation software? (very satisfied/satisfied/fairly satisfied/not satisfied/not satisfied at all)	
9	If you have any thoughts on the lectures using the simulation software, please answer.	Listed below[†]

FMU, Fukushima Medical University; NU, Nagasaki University; NWSMU, North Western State Medical University.
[*]No, as attending from tablet/smartphone.
[†]Answers to Question 9, 'If you have any thoughts on the lectures using the simulation software, please answer':

- I think the software requires some further development. It would be great to add some features. For example, possibilities to talk to the patient, adding some sounds like crying 'help'. Sometimes the dose rate was different in the same point using different equipment. Problems of transporting the patient with all transporting equipment. It would be very interactive if we receive an injury if doing something wrong. For example, went to site with chemicals without the protective gear and starting vomiting, etc.
- It is a really smart idea to use simulation software at the time of COVID-19. I think this practical training is very interactive at the time of online learning.
- The ability to use this software in a medical facility in each department facility.
- I had played with simulation game software called 'Combat Medic' decades ago, and I found it easy to operate as the movements and controls were almost identical to those of the game. It was also very practical and enjoyable.
- I thought that actually putting on and taking off the protective gear was something that could not be experienced with simulation software. I was reminded again that the parts that you can feel on your skin are not the same you can feel using a computer. But the simulation software was wonderful. It was amazing to be able to feel so close to the participants with the coronavirus disaster.
- It was amazing. It was awesome.
- Overall, it was great!
- Impressions are extremely positive, a desire to repeat or delve into teaching.

4. RESULTS

4.1. Basic function of 'Kawauchi Legends'

The 'Kawauchi Legends' disaster simulator was designed for Windows and Mac OS platforms; currently, tablets and smartphones are not supported. Deploying compressed application files makes the application available. Both Japanese and English interface languages are available. The user can choose from one of four practice scenes using the selection menu: Disaster Site A (a nuclear power plant), Disaster Site B (a dirty bomb), a triage scene, and a medical site. A common operation scene can be shared with up to 20 people at the same time. Appropriate protective gear and equipment (e.g. chest drainage tube, dosimeter, decontamination gear, zone barrier, etc.) can be selected. A teacher (trainer) can set up any type of medical condition in a victim by changing an injured person avatar and data on its vital signs monitor. The user can estimate the physical findings of the victim, set up a triage tag, and move the injured person to an appropriate place already zoned by other users.

Examples of using the software are shown in Fig. 3.

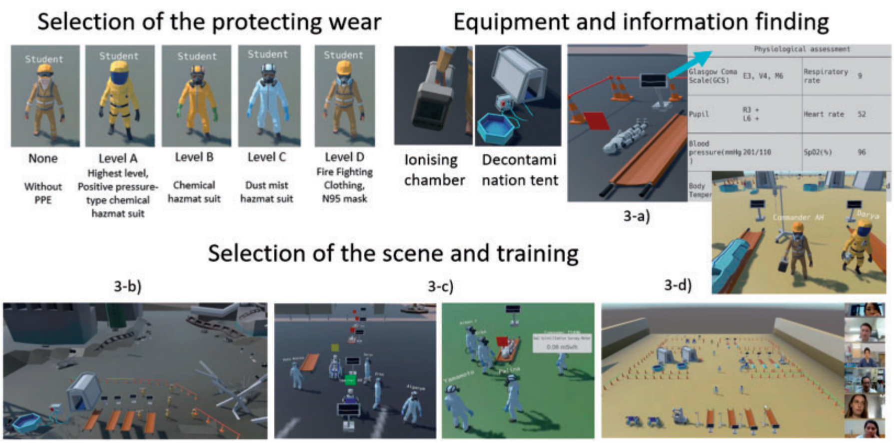


Fig. 3. Basic functions of 'Kawauchi Legends'. (a) The user can estimate physical findings of victims on a vital signs monitor. (b) Rescue training on Disaster Site A (a nuclear power plant). (c) Training on the triage scene. (d) Resuscitation and decontamination on the medical site.

4.2. Results of the questionnaire survey

Fourteen participants (four Japanese and 10 foreign participants; 10 domestic and four international accesses) took part in the webinar. The participants were from Fukushima Medical University and Nagasaki University in Japan, and North Western State Medical University in Saint Petersburg, Russia. Among them, 12 participants (three Japanese and nine foreign participants; nine domestic and three international accesses) completed the questionnaire (Table 1).

5. DISCUSSION AND CONCLUSION

Software was developed to share the disaster response experience of the Fukushima accident. According to the questionnaire results, the 'Kawauchi

Legends' software could not fully replace all the effects of in-person training, but it was found to be a sufficiently effective substitute for the classroom and practical face-to-face exercises. This confirms that even during the COVID-19 pandemic, it is possible to maintain high-quality standards of education through innovative methods.

It was fairly difficult for injured workers to access medical services at the time of the Fukushima accident due to a lack of information, knowledge, and skill about radiation for responders (National Diet of Japan, Fukushima Nuclear Accident Independent Investigation Commission, 2012; Tominaga et al., 2014). This may have been one of the causes of disaster-related deaths, defined as deaths due to the deterioration of underlying medical problems due to poor medical access or illnesses (Hasegawa et al., 2015, 2016). Therefore, education in disaster management plays an important role as a countermeasure to the diverse and lasting effects on society after a large-scale nuclear accident (Ohtsuru et al., 2015).

There is a need to ensure that we can overcome the COVID-19 pandemic by reducing social communication distance through a variety of modern technologies, such as the 'Kawauchi Legends' simulator, while maintaining physical distance.

ACKNOWLEDGEMENTS

The authors wish to thank Professor Noboru Takamura (Nagasaki University), Mr Tomoi Uesugi (Kawauchi Branch of the Futaba Fire Department), Dr Elena Ryzhii (Fukushima Medical University), and Mr Daisuke Kobayashi (Fukushima Medical University) for valuable advice and support.

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Development of an application tool to support returnees in Fukushima

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Abstract–To promote radiation protection and health promotion among returning residents (returnees) in coastal areas of Fukushima, eHealth principles were used to develop a new application tool (app) that can record radiation exposure and health status while providing comprehensive support to returnees. Intended users are returnees and health and welfare workers. After assessing their needs, a flowchart and prototype for operational logic were created using commercially available software tools. Professional developers will focus on improving the user interface and ensuring data security. The finished app will be compatible with mobile telephones and tablets. Utility and ease of use are paramount to serve returnees of all ages effectively.

Keywords: Application tool; Fukushima accident; Health promotion; Returnees; Radiation protection

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

1. INTRODUCTION

Reconstruction after a nuclear accident is a complex process that involves not only radiation protection, but also social and environmental considerations for people returning to affected areas (ICRP, 2020). Indeed, in the case of the accident at Fukushima Daiichi nuclear power plant, residents returning to municipalities near the power plant (returnees) have been actively supported by health and welfare workers in reducing radiation exposure and promoting health (Takamura et al., 2016; Murakami et al., 2017). In addition, the returnees have increased their autonomous decision-making on radiation protection through the practice of citizen science and dialogue seminars with experts (Ando, 2016; Lochard et al., 2019). However, health and welfare workers faced difficulties in providing services due to limited time, human resources, and other logistical and administrative challenges.

Nowadays, digital application (app) tools are ubiquitous, with an emphasis on interactive online communication. The European Union's Nuclear Emergency Situations – Improvement of Medical and Health Surveillance – Stakeholder INvolvement IN Generating Science (SHAMISEN–SINGS) project reported recommendations for app development to share radiation- and health-related information in a timely manner among local stakeholders and affected populations during early- and long-term recovery from a nuclear accident (ISGlobal, 2019). This type of usage of information technology (IT) is being branded as 'eHealth' in the field of health promotion by the World Health Organization (WHO, 2019). Thus, combining radiation protection and health promotion in an app may be a useful adjunct for health and welfare workers who support returnees by connecting information and people. This article reports on the development of a new app to record radiation and health measurements for use in areas affected by the Fukushima accident.

2. METHODS

Details of initial efforts have been reported previously (Ohba et al., 2020). Briefly, the intended users of this tool are returnees and health and welfare workers, among whom a needs assessment was conducted. Based on the results and thorough discussion among team members (which took approximately 2 months), a blueprint of the app content and its modalities was developed.

Next, the first author prepared a mock-up using FileMaker Pro 14.0.6 (Claris International Inc., Santa Clara, CA, USA), which enabled other team members to check the detailed operation logic of the app. Iterative revision and re-checking at this stage took approximately 1 month in total.

The authors collaborated with an IT company in Fukushima Prefecture, experienced in app development for health promotion. This development stage took approximately 3 months.

3. PRODUCTS AND CONCEPT

3.1. Blueprint of the app

The blueprint of the app included two major categories: radiation exposure and health promotion. The radiation exposure items were estimations of internal and external doses, based on geographic location (based on postal code) and records from personal dosimeters, whole-body counters, and food consumption as recorded by users' manual input. As radiation protection depends on the awareness of one's own radiation exposure environment (Fujimura et al., 2017), a protocol was developed to automatically estimate doses and offer precautions in the app. Health promotion items include anthropometry, medical measures, medications, health behaviours, and mental health. Links to related information, automatic responses, and a separate interactive communication function with the research team were also prepared. The authors believe that automatic responses to the user in each of these items is important in order to increase user awareness of radiation protection and health promotion, and to further motivate users to continue using the tool. The link with the author team in this trial will eventually be replaced with links with local services.

Regarding data storage and data sharing: (i) users (returnees or health and welfare workers) record personal information in the app; (ii) the information is stored securely in a cloud system, which is a web server; and (iii) pre-registered health and welfare workers, who are the service providers of returnees joining the pilot, can access recorded information on their own secure computer or tablet in order to provide tailor-made support. This digital information tool provides a continuous flow from data collection, including solicitation of residents' needs, to support and/or care planning among health and welfare workers.

3.2. Reconstruction of the blueprint using a mock-up

Fig. 1 shows an example of the workflow of the prototype app, which provided a platform for validation of functions. Experts in various fields (radiation, medicine, health promotion, risk communication, mental health, and health information) on the research team reviewed the prototype to improve the blueprint, which was subsequently presented to the IT company. This workflow is intended to eliminate discrepancies of understanding between the research team and the IT company. In addition, the mock-up becomes more efficient in terms of development resources because the focus can move to designing usability, including the interface.

3.3. Points of the developing app

Fig. 2 is the app menu screen designed with pictogram icons and large text displays in order to increase usability among the intended users, many of whom are elderly. This arrangement followed the European Union's SHAMISEN-

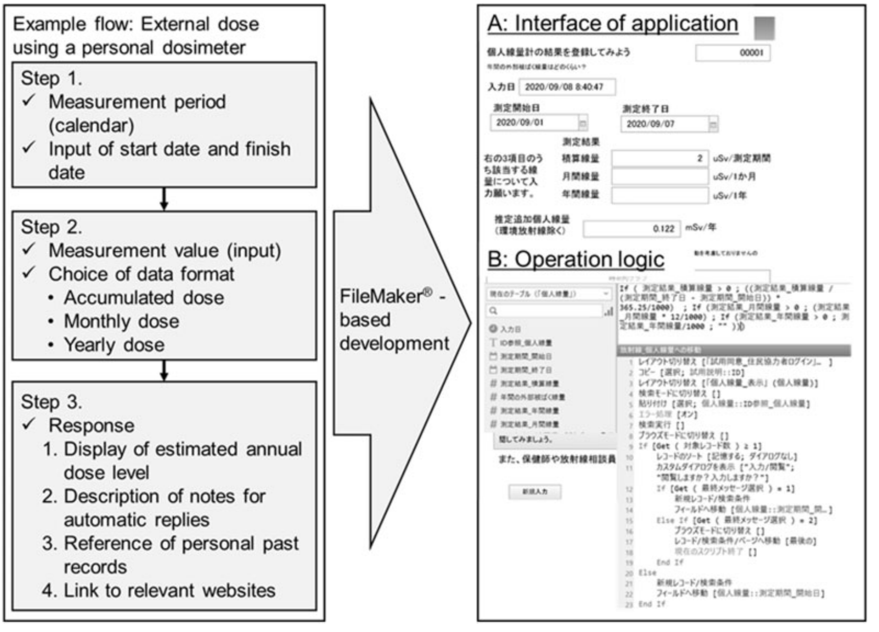

Fig. 1. Pre-development workflow shown by FileMaker.

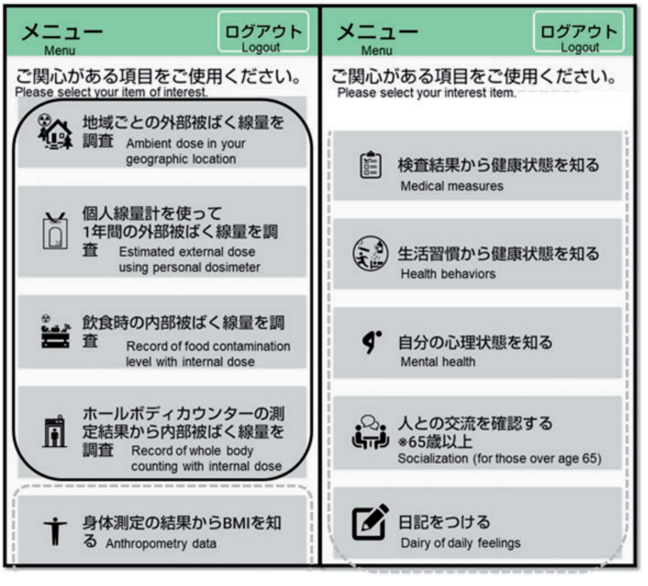

Fig. 2. Tentative menu screens of the app. Items enclosed by a black solid line are radiation records. Those enclosed in grey dotted lines are health records.

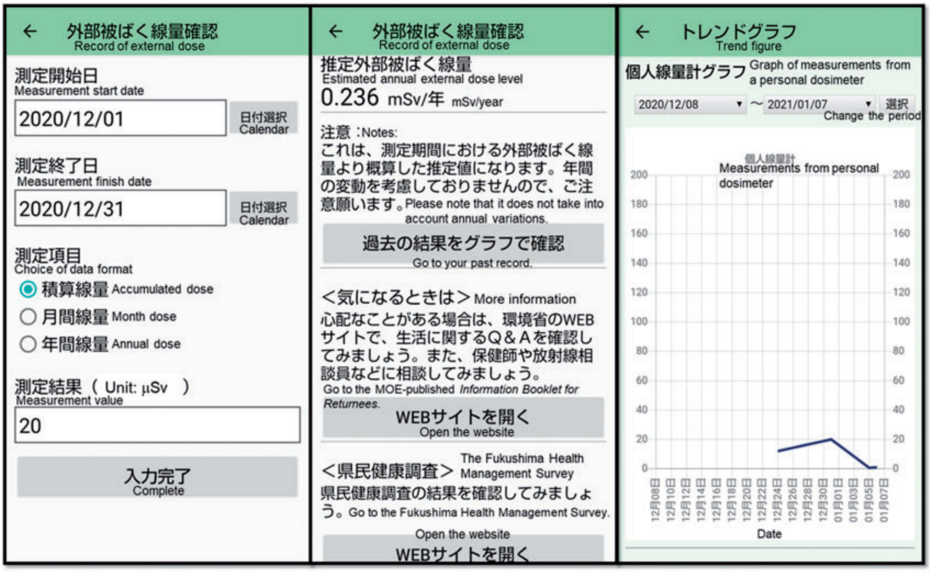

Fig. 3. Tentative screens for recording external dose.

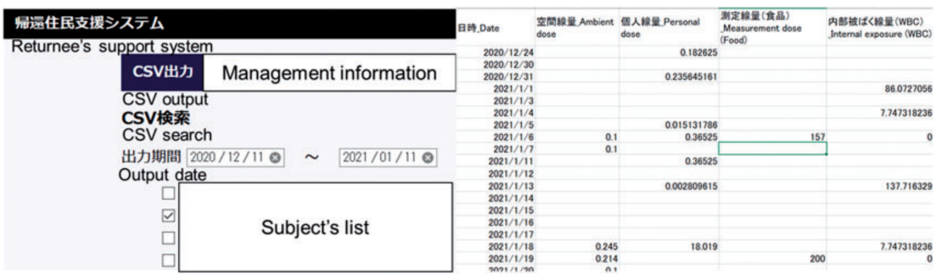

Fig. 4. Data output page on the website for pre-registered service providers (left). Data output of a comma separated value (CSV) file downloaded by the website (right).

SINGS recommendations (ISGlobal, 2019) for app development after a nuclear accident.

Fig. 3 shows subsequent screens after clicking ‘estimated external dose using personal dosimeter’ in Fig. 2. The left screen appears first, followed by the middle and right screens. A history record icon in the middle screen leads to the trend graph in the right screen. The link icon in the middle screen leads to external information from web pages from Japan's Ministry of the Environment, its Information Booklet for Returnees, and Fukushima Health Management Survey reports (Fukushima Prefecture, 2019; Kuroda et al., 2020).

Fig. 4 shows the web screen provided by the cloud server for health and welfare workers to monitor clients' data. Data can be downloaded in a comma separated value file from the webpage. This feature provides data security as personal data are not stored on an individual device. Only pre-registered providers can access the stored data with an ID and password.

4. CONCLUSION

This app provides an awareness-raising opportunity for returnees to adjust their behaviour for radiation protection and health promotion. Health and welfare workers can provide support to returnees using the app's data. This innovation uses technology to connect people: those returning to areas affected by the nuclear accident, and those in health and welfare professions. There are some limitations to acknowledge; for instance, in order to serve elderly and child-rearing returnees effectively, further consideration is warranted for practicality and ease of use. More efforts are needed to serve multiple age groups and ethnic groups in the affected areas. As such, the authors will continue to upgrade their tool by reviewing content and improving usability through pilot tests to be conducted in fiscal year 2021, in collaboration with returnees and local health and welfare workers (Ohba et al., 2020).

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Regulatory approach to management of radioactive waste generated during remediation activities in the Chernobyl contaminated areas

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Abstract–It is known that remediation activities in areas affected by radiological accidents may result in generation of huge volumes of very low-level radioactive waste that can overwhelm national capabilities, and be outside of the existing national regulation requirements for radioactive waste management. This may pose a challenge for adoption of an adequate strategy for remediation waste management and application of regulatory requirements that are commensurate with the waste hazard. The Republic of Belarus faced this problem after the Chernobyl accident when performing remediation activities in the contaminated areas. This article presents the experience of the Republic of Belarus in overcoming the challenges and conflicts that arose in the process of developing a rational strategy for safety management of remediation waste, and its justification and optimisation, bearing in mind the need to adopt advanced regulatory instruments of relevance to the management of this waste.

Keywords: Remediation waste; Regulatory approach; Management strategy

1. INTRODUCTION

As a result of the accident at Chernobyl nuclear power plant (NPP) in 1986, 46,450 km^2 of the territory of the Republic of Belarus was subjected to radioactive contamination, with ^{137}Cs content in soil $>37\,kBq\,m^{-2}$. Decontamination and remediation activities in the affected areas resulted in >400,000 tons of remediation waste (RemW) contaminated with ^{137}Cs and ^{90}Sr in concentrations from 1 to

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10^5 Bq kg^{-1}, which were disposed in 91 'emergency' storage sites (RemWSS). Only seven of the sites were specially built repositories, equipped with waterproof clay and film barriers; most of the other sites were occasional sites (ravines, sand pits, trenches, etc.) which created a potential danger of migration of radionuclides into groundwater.

The Law 'On legal treatment of territories contaminated as a result of the Chernobyl NPP catastrophe' enacted in 1991 differentiated between two types of waste in the contaminated area: waste with activity exceeding the exemption level (radioactive waste) and very low-level radioactive substances with activity that was 10-fold lower. The Law stipulated that the national regulatory authorities (Promatomnadzor and the Ministry of Health) should ensure regulation of the management of waste classified as radioactive, with very low-level radioactive substances being exempted from supervisory control. The strategy established by legislation for management of RemW specified that, in due time, the waste would be sorted and radioactive waste would be relocated into adequately equipped near-surface disposal facilities. The public, environment agencies, state authorities, mass media, and other stakeholders insisted on urgent measures for the relocation of RemW according to the adopted strategy, and in compliance with the regulatory requirements of the time for the management of institutional radioactive waste (SPORO-85). Application of these requirements to management of RemW was completely baseless given the huge volume and other specific features. In reality, RemW of both types had been mixed in the RemWSS, and there was very little possibility of separating them and relocating them separately.

The situation called for elaboration of an innovated regulatory approach and an advanced rational strategy for RemW management/regulation providing reasonable assurance that the RemW operating system would have a sufficient level of safety, and potential exposures of the population would be within the exposure limits given in the National Radiation Safety Standards. An important rationale for rethinking the existing approach was that the radiation impact of the RemWSS on the population had been assessed as insignificant in comparison with the exposure caused by contamination of the areas in which the RemWSS were located.

The process included detailed assessment of the potential radiological hazard of the RemWSS, which embraced adoption of the hazard assessment criteria and thorough examination of the RemWSS: the state of natural barriers, inventory, potential effect of the RemWSS on the environment, etc.

2. CRITERIA FOR HAZARD ASSESSMENT OF THE REMWSS

The proposed criteria for hazard assessment of the RemWSS were based on the notion that the risks posed by the RemWSS to human health should be consistent with the risks from the contaminated areas where the RemWSS were located. This approach was assumed to be reasonable because the RemWSS were placed in the exclusion zone where radionuclide activity in soil was similar to radionuclide activity in RemW. If essentially the same criteria were applied to the RemWSS and the contaminated areas, the two should be identical with regard to their impacts on human health and the environment.

In accordance with the above-stated notion, the following criteria for hazard assessment of the RemWSS for members of public were adopted:

- the RemWSS should pose a risk to human health consistent with the risk from the contaminated areas in which the RemWSS are located;
- for members of the public beyond the boundary of the exclusive zone where active radiation monitoring is maintained, a limit on effective dose equivalent from all exposure pathways is 1 mSv year^{-1};
- releases of radioactivity from the RemWSS into the environment are as low as reasonably achievable; and
- protection of groundwater and surface water resources complies with the national standards established for radioactivity of water in public drinking water supplies (0.1 mSv year^{-1}).

Applying drinking water standards to protection of groundwater or surface waters near contaminated sites, to the extent reasonably achievable, would help to avoid the need for costly clean-ups of drinking water if affected sources were ever to be used for this purpose.

3. EXAMINATION OF THE REMWSS

3.1. Inventory

The government authorities took the first steps to observe the RemWSS in the 1990s. The survey included detailed field investigation with step-by-step drilling over a profile of waste to take samples of waste and groundwater. This led to the production of comprehensive inventories for each site, with descriptions of the site dimensions, radionuclide capacities, and activity concentrations (see Table 1).

The distribution of radionuclides below the foundations of the RemWSS to a depth of 1.5 m of the natural barriers was studied. Radionuclide activity decreased abruptly with the depth of the layer, and at 1.5-m depth, the content of ^{137}Cs was 18–32 Bq kg^{-1} and the content of ^{90}Sr was 2.5–6.0 Bq kg^{-1}.

3.2. Laboratory studies

The forms of existence of radionuclides in the RemW samples were analysed. The results showed that 80–95% of ^{137}Cs was in a non-exchangeable form. The proportion of ^{90}Sr non-exchangeable forms varied from 32% to 92% depending on the zone of origin of the RemW. The obtained data were used for calculation of the coefficients of mobility of radionuclides in the RemW. The coefficient values for ^{137}Cs were in the range of 0.05–0.21; for ^{90}Sr, the coefficients were 0.12–0.42 in the nearest zone and 1.0–2.4 in the distant zone.

Table 1. Parameters of remediation waste storage sites (RemWSS).

Parameters of RemWSS-2		Parameters of RemWSS-3	
Design area	11,000–19,000 m^2	Total number of sites	82
Design capacity	30,000–55,000 m^3	Total area	731,000 m^2
Waste layer thickness	2.4–3.4 m	Total bulk volume	323,000 m^3
Total activity as of 31.12.99	from $18.5 \cdot 10^{10}$ Bq to $67.3 \cdot 10^{10}$ Bq	Total nuclide activity as of 31.12.99	$<2 \cdot 10^{12}$ Bq
Maximum specific activity of:		Maximum specific activity of:	
^{137}Cs	$(3.7–32) \cdot 10^3$ Bq kg^{-1}	^{137}Cs	10^5 Bq kg^{-1}
^{90}Sr	51–358 Bq kg^{-1}	^{90}Sr	4.8 10^3 Bq kg^{-1}
$^{239,240}Pu$	0.19–0.7 Bq kg^{-1}	$^{239,240}Pu$	48 Bq kg^{-1}

The mobility coefficients and parameters of radionuclide washout due to atmospheric precipitation were applied in the mathematical models developed to predict the migration of radionuclides from the RemWSS.

3.3. Monitoring of groundwater

In 1993–1994, 11 RemWSS were equipped with a system of observation boreholes to control migration of radionuclides from the RemWSS. The 11 RemWSS were selected on account of observing radionuclide behaviour in most typical RemWSS, having the whole spectrum of natural and technological conditions (waste inventory, level of groundwater, thickness of natural barriers) prevalent in all 91 RemWSS.

The approach to the placement of monitoring boreholes, sampling methods, preparation, and measurement of samples made it possible to observe changes in the activity of radionuclides in groundwater with sufficient reliability. For most sites, the water samples from the boreholes located downstream of the groundwater showed a higher radionuclide concentration, which indicated the migration of radionuclides from the RemWSS. However, for all RemWSS examined, the radionuclide concentration in the groundwater did not exceed the permissible levels accepted in the Republic of Belarus for drinking water (10 kBq m^{-3} for ^{137}Cs and 370 Bq m^{-3} for ^{90}Sr).

3.4. Assessment results

A mathematical model was developed to assess whether a RemWSS represented a potential hazard based on the principle of a chamber model and using the examination results. Forecasting estimations of radionuclide migration from the RemWSS showed that migration of ^{137}Cs is limited by the aeration zone, and in the case of a site flooding, it is limited by the region of mixing of radioactive contamination with groundwater directly beneath the site. The ^{90}Sr concentration in the groundwater under the RemWSS could reach values from 0.2 to 75 kBq m^{-3}. The RemWSS impact zone is a distance from 100 to 350 m, within which the ^{90}Sr concentration decreases to the maximum permissible value.

Validation of the assessment results was achieved through comparison of the modelling outputs with the experimental data obtained from regular monitoring of the concentration of radionuclides in groundwater, and comparison with the results of calculations using other mathematical models.

The assessment results showed convincingly that any doses to the public associated with contamination of groundwater by radionuclide migration from the RemWSS were small compared with the doses from all pathways associated with the surrounding contaminated soil.

4. REGULATORY APPROACH

Although it involved unquantifiable uncertainties, demonstration of compliance with the criteria based on the results of detailed RemWSS examination was a key argument in achieving common understanding among stakeholders, including the public and regulators, of the feasibility and necessity of applying an advanced regulatory approach to the management of the RemWSS.

From a regulatory point of view, the waste disposed in the occasional sites of the exclusive Chernobyl zone was allocated to a special waste category, defined as substances with ^{137}Cs activity concentration exceeding 0.96 kBq kg^{-1}, formed as a result of activity to eliminate the consequences of the Chernobyl accident.

A special regulation, titled 'Regulation for the Management of Remediation Waste Resulting from Works on Elimination of Consequences of Chernobyl NPP Catastrophe' (SPOOD-98), was developed with due account of the waste peculiarities: location in a closed access control zone, huge volumes, low concentrations of ^{137}Cs and absence of other radionuclides in notable concentrations, and variability of protection barriers.

The previously adopted strategy to redispose RemW from 'emergency' storage sites into dedicated near-surface facilities was abandoned. SPOOD-98 established mandatory preventive and protective measures that must be taken to maintain sites in a safe condition, and set regulatory requirements for organising technical and radiological control over the RemWSS, including requirements for handling RemW: waste collection, storage, transportation, inventory taking, and radiation protection of personnel.

In terms of engineering arrangement and considering the regulatory requirements, all the RemWSS were classified into one of three categories, each requiring a separate approach towards their maintenance and operating conditions, regulatory control, and selection of management technologies:

- RemWSS-1: engineering structure designed for waste with a specific activity of ^{137}Cs in excess of 96 kBq kg^{-1}, which ensures reliable isolation of waste with the help of concrete engineering protective barriers and hydraulic devices, equipped with a system of permanent monitoring of the impact on the environment. This type of repository should comply with the requirements for near-surface LLW disposal facilities.
- RemWSS-2: engineering structure for near-surface disposal of RemW with specific activity of ^{137}Cs from 0.96 to 96 kBq kg^{-1}, which is equipped with simple clay and film barriers, and systems to monitor the impact on the environment. The summary data of RemWSS-2 are given in Table 1.
- RemWSS-3: storage sites set in abandoned territories during the initial postaccident period, generally with no design and no hydrogeological restrictions taken into account. Depending on the natural location and existence/state of the engineering barriers, they require additional works on engineering arrangement and monitoring of their impacts on the environment. The summary data of RemWSS-3 are given in Table 1.

5. PRINCIPAL LESSONS LEARNT FROM THE REPORTED EXPERIENCE

The principal lessons learnt from the reported experience are as follows.

- Managing RemW that has arisen during remediation activities after a major accident may require a different approach from that used in the country to manage normal planned streams of radioactive waste.
- The success of achieving agreement on establishing a special approach to management of RemW is based primarily on the ability to understand the real hazard of the waste to public health, and the scale of the technical capabilities required to ensure the safety of RemW for the population.
- Agreement on establishing a rational strategy on management of RemWSS may be achieved through logical work with stakeholders, tending to bring the rationale of the decisions taken into line with the regulatory requirements based on the principle of optimisation of radiation protection and the specific features of the RemW.
- A major component of the RemW management strategy is connected to the establishment of regulatory requirements, which should, as far as possible, be based on the existing waste management regulations, but specifically modified to consider the specific factors associated with the prevailing circumstances arising due to the emergency situation.
- Specific factors include the need to set appropriate hazard criteria as well as special monitoring procedures, application of which should result in meeting the established criteria and the ability to demonstrate compliance with them.
- Use of science-based hazard criteria and common understanding among stakeholders of how these criteria have been or can be validated will contribute to the

adoption of a sound and cost-effective RemW management strategy, despite opposition from the public, the media, and other factors.

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Chornobyl exclusion zone: current status and challenges

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Abstract–Comparisons of the large nuclear accidents that occurred at the nuclear power plants in Chornobyl and Fukushima usually focus on the emission of radionuclides, the contamination area, doses to the public and liquidation workers, etc. However, little attention has been paid to various factors that affect decisions regarding the future development of these territories, such as the sociopolitical and economic situation in the countries during the accident and at the present time, the density and structure of the population, climate change, media coverage, and accessibility of information to the public. This article attempts to discuss the above factors, speculates about the paths for future development of both exclusion zones, and suggests the most promising areas for joint research in the future.

Keywords: Chornobyl; Fukushima; Social aspects

1. INTRODUCTION

Browsing 'comparison of Fukushima and Chornobyl', one can find dozens of papers, both scientific and mass media, comparing various aspects of the disasters, including the extent of radionuclide release (Steinhauser et al., 2014; Imanaka et al., 2015), reconstruction of doses, received by professionals who were involved in mitigation and consequences liquidation and the inhabitants of the affected areas (Suto et al., 2013; Hatch and Cardis, 2017; Mori et al., 2017), and analysis of the media coverage of the two disasters (Tomkiv et al., 2016). As the two largest disasters in the

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history of nuclear power, the accidents at the Chornobyl nuclear power plant (ChNPP) and Fukushima Daiichi nuclear power plant (FDNPP) are constantly compared in order to enhance knowledge and skills in disaster preparedness as a whole, and on nuclear safety and security in particular. Radionuclide composition of emissions and the wind rose at the time of the accident, soil types and ecosystem dose rates, and the number of evacuees are the main factors to consider when hypothesising about the future development of the exclusion zones in both Chornobyl and Fukushima. Nevertheless, there are significant differences between the two accidents in terms of the sociopolitical and economic situations in the countries during the accident and at the present time. When comparing these two accidents, it is also important to consider the significant leap in technology made by mankind in the last 25 years. Rather than duplicating the comparisons that have been made previously (Balonov, 2013; Hachiya and Akashi, 2016; Wakeford, 2016; Lucchini et al., 2017), this article will focus on assessing the current state of both radionuclide-contaminated territories, and making an educated guess regarding future development.

Today, 35 years since the accident at ChNPP, discussions about the status of the exclusion zone are ongoing. Although the territory of the exclusion zone was defined as a national reserve area in accordance with the Decree of the President of Ukraine (2016) (Chornobyl Radiation and Ecological Biosphere Reserve, 2016), proposals of returning it to economic use are discussed periodically by the Government of Ukraine. At the same time, the Government of Japan has a clear policy of returning people to the remediated areas of Fukushima Prefecture, gradually lifting the evacuation orders (Kawasaki, 2020; 'Transition of evacuation designated zones 福島県ホームページ', n.d.). Returning to the difficult-to-return zone and the 10-km zone in Chornobyl out of question out with this discussion.

To understand the current situation, it is important to be aware of several factors that affect the attitudes of the societies towards accidents.

- the sociopolitical and economic situations and type of ownership in each country;
- the population density and its dynamics after the accident, as well as the economic load of each territory before the accident; and
- environmental factors, affected by climate change, disaster preparedness, and coping and mitigation strategies of the two societies.

2. SOCIOPOLITICAL AND ECONOMIC SITUATIONS IN EACH COUNTRY

The difference in the sociopolitical systems in each country, the attitude of the population and governments to private property, and the readiness of the authorities to listen to the opinions of voters are some of the main factors that influence decisions on the status of contaminated areas.

- At the time of the accident at ChNPP due to the socio-political system of USSR, residents were not allowed to have land in private property.
- Polesie (north of Ukraine and south of Belarus, respectively) was a swampy, subfertile, and sparsely populated area, traditionally used for forestry.
- The consequences of the Second World War in 1941–1944, and the policies of expropriation, collectivisation, and cosmopolitanism pursued by the USSR resulted in a specific attitude of the population towards private property and distrust of the authorities.
- The destruction and significant reformatting of economic ties due to the collapse of the USSR, the lack of a legal framework for comfortable business, political instability, and open hostilities in the Ukrainian territory resulted in significant restrictions to the budget available for the ChNPP exclusion zone. Today, 35 years since the evacuation and decisions to exclude the territory from economic use, financing the development of this zone and associated research is not on the agenda for modern Ukraine.

All of the above created the preconditions for a specific attitude of Ukrainians towards evacuation, giving residents no legal basis for claims to the territory. The difficult economic situation in the 1990s and the abandonment of the infrastructure in the exclusion zone for more than 30 years since the residents were evacuated means that it has remained in state ownership. Although discussions on returning the exclusion zone to economic use have been ongoing for the past 10 years, the suggestion to transform the territory into the Chornobyl Radiation-Ecological Biosphere Reserve, joined to the Polesie State Radiation-Ecological Reserve (Republic of Belarus) to form a single reserve, seems the most reasonable.

At the same time, Japan, which is relatively isolated from political perturbations overseas due to its island location and ancient monarchical traditions, reached certain stability of the state system.

- Inheritance traditions of land and buildings, and respect for private property, are deeply rooted in Japanese culture, and this determines the uncompromising will for the return of territory to the owners, while significantly limiting the countermeasures available for implementation by the Government of Japan.
- The evacuation zone is located in the most advantageous territory from a geographic and economic point of view, namely the flat coast of the island, and is covered with soil that is optimal for farming. This area is most suitable for construction and, as a consequence, has a developed infrastructure, making an important contribution to the economy of Northern Japan.
- The political system of Japan, which has been stable since the Second World War, has strong traditions of parliamentarism and a collegial government, and this significantly affects the decision makers. Society requires a unified approach to territory decontamination, which narrows the range of measures available for application, violating the choice of radioecologically and economically optimal

measures to, to some extent, extensive and labour-consuming measures that aim to reduce the population's radiophobia.

- The stable economic growth of Japan since the Second World War has allowed the country to fund radiological research, empowering post-accident decontamination processes.

Thus, significant social pressure on territory decontamination decision makers, the high economic congestion of the territory, and the need to obtain permits to work in the radionuclide-contaminated territory from its owners dictate the need for the fastest possible decontamination and return of territories to public use. To date, evacuation orders have been lifted for all zones designated as 'restricted residence zones' and 'evacuation order preparation zones', leaving only the significantly contaminated 'difficult-to-return zone' evaculated. The Government of Japan, together with the Japanese and international scientific communities (Wu et al., 2017; Evrard et al., 2019), are in active discussions about the development of countermeasures to reduce contamination in even the most contaminated areas.

3. POPULATION STRUCTURE

When discussing the future of the territories contaminated by both radiation accidents, it is impossible to ignore the population density of the countries, and, consequently, the need for living space, as well as the type of land use.

The current area of Ukraine is 603,500 km^2, of which 44,000 km^2 (7%) is under temporary occupation (Ministry of Reintegration of the Temporarily Occupied Territories of Ukraine, n.d.). The Ukranian population decreased from 49 million in 2001 to 42 million in 2020 (World Population Prospects – Population Division – United Nations, n.d.), with a density of 72.6 people km^{-2}. The growing role of agriculture in the country's economy, as well as global trends towards urbanisation and population migration from manufacturing to service industries, has led to the concentration of the population in cities. The population density in Northern Ukraine, with its swampy and wooded territory, has always been below the national average; for example, in the regions adjacent to the exclusion zone, the population density ranges from 33.8 people km^{-2} to 51.5 people km^{-2}, with clear negative population dynamics (All-Ukrainian Population Census, n.d.). Thus, even taking into account the efforts to restore the reputation and infrastructure of the exclusion zone, the return of evacuees is not in the scope of sociodemographic trends.

The current area of Japan is 377,900 km^2. The Japanese population decreased from 127 million people in 2001 to 126 million people in 2019, and the national average population density is 333 people km^{-2} (Portal Site of Official Statistics of Japan, n.d.; World Population Prospects – Population Division – United Nations, n.d.). Although the average population density in Fukushima Prefecture is relatively low and amounts to 144 people km^{-2}, the distribution of residents is uneven due to the extremely mountainous terrain. Radionuclide fallout occurred in Futaba, Namie, and Okuma Towns with populations ranging from 6000 to 22,000 people

[Fukushima (Japan): Prefecture, Cities, Towns and Villages – Population Statistics, Charts and Map, n.d.], and also affected two national highways. As such, returning evacuees to their homes and decontaminating the territory is a pressing issue for the national and prefectural governments.

4. CLIMATE CHANGE

Japan's position in the Pacific Ring of Fire (Hinga, 2015), which increases the risk of seismic and volcanic events, and the island location of the country, which leads to seasonal risk of typhoons and high precipitation periods, means that the level of disaster preparedness is high in Japanese society. Japan has well-developed plans for earthquakes and tsunamis (Hasegawa et al., 2018; Katoh et al., 2018), and the population is aware and well trained due to regular disaster preparedness drills. Until 2011, the risk of nuclear disaster had not been considered (Brumfiel, 2013), but the accident at FDNPP caused a significant shift towards nuclear and radiation safety. At the same time, due to the temperature buffering capacity of the Pacific Ocean, the climate change affecting Japan is milder compared with the sharp continental climate of Ukraine. These factors also exist in the evacuation zone of FDNPP. However, the disaster response infrastructure has been restored along with the rest of the infrastructure of the newly populated cities, and therefore the climatic changes of the last decade have had no direct effect on the prospect of returning the evacuation zone of FDNPP to economic use.

The exclusion zone in Chornobyl is located in the middle of Eastern Ukraine, with a sharp continental climate. Historically, swamps in this area were drained (Hostert et al., 2011), resulting in a significant (artificial) ecosystem shift. The exclusion zone is subject to two paradoxically opposite processes. At present, due to limited human and material resources, drainage channels, previously used to ameliorate swamps, are clogged, leading to re-waterlogging of the area. At the same time, due to global climate change, the entire territory of Ukraine, including the exclusion zone, has been subject to droughts in the past 10 years, which, in turn, has provoked dust storms and forest fires (Ager et al., 2019). In addition, due to the location in the interior of the continent, as well as climatic changes that were not predicted, neither the population nor the Government of Ukraine are used to responding quickly to emergencies, which leads to lengthy public debate, delayed response, and a lack of a clear government strategy on risk management or disaster preparedness. Climate change has made a significant contribution to the further development of the exclusion zone, which is further complicated by the prohibition of economic activity in this area as the territory belongs to the nature reserve fund.

The accidents at ChNPP and FDNPP are, without doubt, the largest incidents that have resulted in the release of radionuclides into the environment. Nevertheless, the accidents are strikingly different in terms of the socio-economic situation, humanitarian issues, informational factors, climatic profile, and strategies for future development. The exclusion zone of ChNPP, excluding the 10-km zone contaminated by transuranium elements, has been converted into a biosphere reserve (Chornobyl Radiation and Ecological Biosphere Reserve, 2016) in order to prevent the spread of radionuclides outside the contaminated zone, and also to form a space for the preservation of native flora and fauna. A unique open-air laboratory is under construction in the ChNPP exclusion zone, which will allow the study of short- and long-term radioecological effects in the wild. At the same time, the FDNPP evacuation zone, excluding the difficult-to-return zone, has been decontaminated successfully, and work is underway to restore the infrastructure and return people to the remediated territories. Museums and memorial complexes to honour the victims of the Great East Japan Earthquake are opening in the restored territories, and innovative approaches to clearing the territory; land reclamation; and psychological, medical, and social adaptation of migrants and individuals affected by radiation damage are tested here. Development of the territories affected by the two largest radiation accidents is moving in two opposite directions, allowing professionals who have the opportunity to work in both exclusion zones to study the entire spectrum of the consequences of radiation accidents, and the options for society's response to them. As a result of detailed study of the approaches in both countries, and the cooperation of scientists and decision makers, it will be possible to develop new, improved strategies to respond to radiation accidents, taking into account not only the type of radionuclide contamination and the environmental factors, but also the socio-economic background of the contaminated territory.

At the same time, the views of both countries on the future of the most contaminated areas of the exclusion zones are surprisingly identical. Both Ukraine and Japan unanimously chose these territories as the most suitable to handle high- and low-activity radioactive waste. Japan chose to store bags with radioactive soil, removed from the entire contaminated territory, in the FDNPP exclusion zone, and Ukraine constructed storage facilities for spent nuclear fuel and opened a solid waste reprocessing factory in the ChNPP exclusion zone.

5. CONCLUSIONS

Summarising all of the above, it is important to emphasise the importance of the joint work of international, Japanese, and Ukrainian professionals in radiobiology, radioecology, and modelling of the environmental response to radiation disasters. The joint work of multi-national and multi-disciplinary groups will make it possible to study the migration paths of radionuclides comprehensively in both anthropogenic-affected (Japan) and natural (Ukraine) environments, and will also provide an opportunity to improve countermeasure plans in case of future disasters, taking into account social and humanitarian aspects.

The most promising areas for joint research are:

- the use of robotics for remote assessment of the radiation situation: Japan's wide access to the latest technologies and the possibility of testing them in the ChNPP exclusion zone with minimal administrative obstacles and public outcry;

- conducting sociological research with a single experimental design for both exclusion zones;
- the development of dosimetric monitoring systems and their adaptation to work in conditions of high and low anthropogenic pressure;
- the development of a training programme for specialist-mediators capable of broadcasting the results of radioecological research to the general public; and
- continuing to study the response of ecosystems to radionuclide contamination – conducting research with a general design which will simplify the interpretation of the results.

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Communicating radiation risks to the residents of the Chernobyl-affected areas in Russia: key lessons learned

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Abstract–This article analyses the communication experiences of radiation protection experts at federal/regional and local level. Efforts to justify protective measures were more successful at federal level, while the task of adjusting risk perception among local residents remains unresolved. At the recovery stage (15 years after the accident at Chernobyl nuclear power plant), the main difficulties were associated with the fact that expert knowledge was in conflict with public perception of the risk of low doses and legislative approaches. In these situations, communication success depends directly on an expert's personality. When large areas are affected, the efforts of a few dedicated experts are clearly not sufficient. More systematic approaches (training of doctors, teachers, etc.) require governmental support and experienced personnel. Federal authorities had changed their attitudes by the 15th anniversary of the accident. However, at regional level, this process stretched out for another 15 years. Public perception of large-scale health consequences still persists. Examples and survey results are presented in this article.

Keywords: Chernobyl accident; Recovery; Health risk communication; Public perception of radiation risk; Decision-making

1. RISK PERCEPTION TODAY

Almost 35 years after the accident at Chernobyl nuclear power plant, life in radioactively contaminated areas (RCAs) in Russia have basically returned to

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normal, with the exception of some aspects of social well-being associated with perceived radiation risk. Indeed, in the national ratings of social and economic well-being and quality of life, the four most contaminated regions in Russia are consistently placed in the middle of the list (RIA Novosti, 2019). At the same time, in the eyes of the residents of RCAs, the radiation-induced consequences for their health remain clear. Chernobyl-related payments from the budget are ongoing; both the public and the authorities (both regional and federal) have no doubt that this is compensation for the radiation effects. Residents have long come to terms with the additional risk, but the economic dimension of this issue continues to be relevant for them. Monetary compensation is a permanent measure, and, naturally, the RCA residents want it to remain for the long term. The federal authorities, referring to scientists, say that the radiation doses do not exceed the established standards, and in the overwhelming majority of cases, health consequences are not expected; therefore, compensation seems to be unnecessary. In 2016, the Russian Government announced the completion of federal programmes to help regions affected by the radiation from Chernobyl. However, attempts by the federal authorities to cancel individual payments and benefits stipulated by the law are blocked at regional level.

Perception of the inevitability of serious consequences for health from radiation, regardless of the dose, is characteristic of both the affected people and society as a whole. In 2012, answering the question about the number of deaths from radiation exposure after the accidents at Chernobyl and Fukushima Daiichi nuclear power plants, respondents in 45 regions of Russia extrapolated this perception to people who could be exposed. The gap between the respondents' assessments and the actual statistics was three to four orders of magnitude, and this was essentially independent of the age, education, social status, and place of residence of the respondents (Fig. 1) (Melikhova et al., 2013).

2. THE KEY ROLE OF RISK PERCEPTION IN THE TRANSITION TO RECOVERY

Leading Soviet radiologists and radiation protection specialists (RP experts) faced the problem of a specific public perception of low-dose radiation risk in the late 1980s, when the Government put forward the concept of living safely in the areas with residual radiation contamination developed by the National Commission on Radiation Protection of the USSR (NCRP) for broad public discussion (Ilyin, 1995). The leitmotif of this concept was the removal of restrictions on the mode of life for people living in the zone of strict control, and ensuring that the established level of lifetime dose was not exceeded. From the radiologically acceptable range (≤1 Sv in 70 years), after long discussions, 350 mSv was chosen as an intervention criterion for the critical group of the population (children). Such a level, on the one hand, ensured compliance with the national radiation safety standards; however, on the other hand, it made it possible to ensure a high degree of protection of the population at significantly lower material cost (IBRAE, 2016).

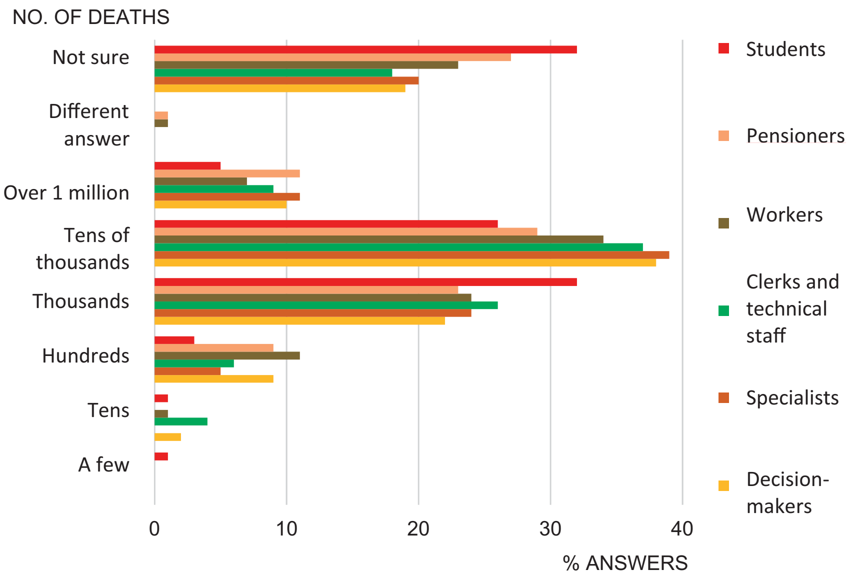

Fig 1. Distribution of respondents' answers to the question 'In 1986 there was an accident at the Chernobyl nuclear power plant. In your opinion, how many people died from radiation exposure as a result of this accident?' Results given as percentage of the total number of respondents. The survey was conducted by the Russian sociological service 'The Public Opinion Foundation' on 26–28 October 2012; 1500 people were interviewed at their place of residence in 44 regions of the Russian Federation.

However, this option for optimising RP did not receive the support of either society or international experts invited by the Soviet Government in 1989 for a comprehensive assessment of the protective measures proposed by domestic scientists, including the '350 mSv' concept. The reasons for criticism were diametrically opposed. Leading foreign scientists assessed the concept as overly conservative. The international Chernobyl project, in which nearly 300 leading experts worldwide participated, including experts from the World Health Organization, the Food and Agriculture Organization, and the International Atomic Energy Agency, lasted for 3 years. During this time, as well as the decisions made, the entire situation in the contaminated areas, including the health status of residents, was assessed. Criticising the '350 mSv' concept, foreign scientists noted excessive conservatism in assessing life-long doses, including account for the doses already received by the population. In their opinion, in the post-Chernobyl situation, the criterion for resettlement could be higher (Ilyin et al., 2016).

On the contrary, Soviet society, including the medical and scientific elite, considered it unfair and inhumane to suggest that people innocent of the accident should take additional health risks by living in contaminated areas, regardless of the small size of the risk. The authors of the '350 mSv' concept were accused of inhumanity, attempts to destroy the gene pool of the nation, etc.

Completely ignoring the findings of the International Chernobyl Project, the Soviet Government sided with the public and supported an alternative concept that followed the public perception of risk. The good intention to broaden social support measures to those who were 'to live with Chernobyl radiation' led to the adoption, in 1991, of a law that drastically increased the area of territories where protective measures were applied. The number of residents affected by these measures increased from 0.5 million to 7 million (Arutyunyan et al., 2016).

3. COMMUNICATION EFFORTS OF RP EXPERTS

3.1. Communication at federal level

Subsequently, the Russian RP experts tried to convey the following arguments to the federal authorities and legislators: (i) radiological consequences of the accident, including medical consequences, are limited; and (ii) establishment of compromise and, in fact, incorrect criteria for classifying areas as 'exposed to radiation' in legislation led to unjustified scaling of non-radiological consequences.

In the conditions of a severe economic crisis, the Russian authorities realised within 2–3 years that it would be impossible to fulfil the social obligations guaranteed by the law in full, and began to listen to the RP experts again. At federal level, more favourable conditions for risk communication emerged. However, to obtain verified and methodologically consistent estimates of the true causes of deterioration in public health indicators, years of observation were required. At the same time, the situation was different at regional level. Counting on funding from the federal budget, the ruling elites of the contaminated territories of 19 regions presented more and more 'evidence' of radiation consequences for the health of the population. The legislative decision to involve medical authorities in the search for radiation consequences, as well as relatively good funding against a backdrop of chronic underfunding of non-Chernobyl research fields, led to a tangible influx of scientists from other fields without special radiological education. As a result, a powerful stream of hasty and methodologically untenable 'evidence' of radiation consequences fell upon the RCA residents and the public (Melikhova et al., 2012).

By the 10th anniversary of the accident, the Russian Government, solving the acute problems of the budget deficit, adopted the dose concept and prepared amendments to the Chernobyl legislation. However, over the same period, the management paradigm had not changed at all: monetary compensation can only be provided for radiation exposure; non-radiation consequences for the population because of the Chernobyl accident are not an issue. It is not surprising that the federal government's attempts to cut payments from the federal budget have repeatedly encountered tough resistance from the population and regional authorities. Government opponents turn the management paradigm to their advantage: if money is provided, there are consequences. The Chernobyl law on social protection is still in force; society is not ready to abandon it.

The continuing status quo in Chernobyl legislation shows the long-term consequences of overtly broad interpretation of the areas that 'suffered' from radiation and their residents. These are political costs (forced continuity of outdated legislation and inability of ‘playing back’ in fear of public protest), economic problems of the areas (Chernobyl status ‘does not attract money’), and permanent reproduction of public ideas about the danger of radiation in general and radiation from Chernobyl in particular.

3.2. Communication with concerned residents and the public

Much effort has been invested in informing concerned residents of RCAs and the public about the scientific position regarding the consequences of the Chernobyl accident through federal and regional media. In the late 1980s and early 1990s, the accident and its consequences were extremely painful topics for the post-Soviet society, and the media was almost completely closed to RP professionals. Over time, journalists have become more willing to lend a voice to scholars challenging public consensus. However, RP experts were only one side in the dialogue and often gave conflicting assessments. No matter how successful their media appearances, they could not change anything.

Public opinion about the scale of the medical consequences of the accident largely originates from the belief that radiation is dangerous at any dose. RP experts cannot say that this is not true, as the linear non-threshold (LNT) hypothesis is the core assumption for radiation safety regulation.

The LNT hypothesis confuses the medical community and regulators, provoking unwarranted hygiene fears, including lowering regulatory levels and looking for evidence of harm to public health in the low-dose range. Stochastic effects have a long latency period, so medical and epidemiological programmes stretch over decades. National experts from different scientific schools interpret the intermediate results obtained in opposing ways. As a result, three decades later, RP professionals cannot give an unambiguous answer about the actual number of victims of the radiation accident (Astafiev, 2016; NMRRC, 2016; Tukov et al., 2020).

RP experts participating in various measurement programmes in contaminated areas were looking for effective ways to influence the perception of radiation hazard by RCA residents. Some lessons of risk communication in a situation where negative expectations about health have already formed, together with mistrust of visiting scientists for collection of experimental material and who do not want to delve into the real problems of the residents, can be summarised as follows.

- First, it is necessary to demonstrate the safety of living in the contaminated areas, and only then convince. Generally, specialists who travelled with their families to the contaminated south-western districts of the Bryansk region, and lived there as rural residents, were able to overcome the mistrust of local authorities and residents, and explain their arguments.
- Radiation risk should be communicated in a context relevant to local communities. It makes no sense to talk to people about the risk and to give scientific arguments if they are worried about other aspects. For example, in the late 1990s,

residents of the south-western districts of the Bryansk region were very sensitive to a possible reduction in Chernobyl benefits. In one of the conversations, this concern was voiced as follows, 'Why are you telling us that we have little radiation? We are ready to eat radiation with a spoon if paid for it'. The dominance of economic interests was also demonstrated in the course of sociological surveys in the autumn of 2003. Answering the question 'What worries you the most today?', residents chose the option 'low standard of living' three times more often than 'radioactive contamination' (ICRIN, 2005).

- The high professional qualifications of an expert must be complemented by a wealth of life experience and personal charisma. To influence people's opinions, an expert must not only be able to answer questions about individual risks in different situations, but must also understand how these people think, what they believe, and how to put their own ideas into the population's belief system with minimal resistance.
- Trust in information is formed through trust in the personality of an expert. The tasks of experts do not usually include immersion in the problems of the local community and individuals; it remains a personal choice. Experience in contaminated areas has confirmed the thesis that empathy and compassion are much more important than the risk information provided (Covello, 2014). Information will not necessarily be perceived, especially the first time, but respect for people's needs will be appreciated.
- It is often difficult for RP experts to admit that not all people are willing to act logically on risk information. The fear of radiation is a normal human reaction. Telling anxious people that there is nothing to be afraid of (i.e. it is stupid to be afraid) is counterproductive. In such situations, one should focus on rational measures to manage individual risks.
- Subjective risk perception is formed under the influence of different and often contradictory information signals coming from different sources. To explain the apparent contradictions, one needs to understand the positions of all interested parties, and put radiation risk into perspective.
- Many years of personal experience of a normal 'life with radiation' does not lead to automatic correction of the subjective perception of radiation risk which has developed under the influence of generally accepted ideas. The task of reformatting generally accepted concepts requires systemic approaches at state level (professional development of doctors, teachers, etc.). At state level, this task is not set as it is much easier to maintain the status quo in the current situation.

4. CONCLUSIONS

To conclude, the perception of radiation risk by society is a complex and still poorly studied social phenomenon that plays a key role in decision-making during the recovery stage. After the accident at Chernobyl nuclear power plant, it was the public perception of risk that led to rejection of the NCRP/International

Commission on Radiological Protection approaches to risk management in the low-dose range. In the conditions of a severe economic crisis, the federal authorities quickly recognised the need to switch to scientifically based dose criteria, but they are still not ready to recognise the responsibility of the state for non-radiation consequences. Therefore, it has not yet been possible to 'play back' and change the Chernobyl legislation.

The absence of changes in the public perception of radiation risk indicates the low efficiency of the communication efforts of the RP community, based on a simplified approach of 'explaining risks in simple language'. One of the main barriers is disagreement between RP professionals regarding the validity and expediency of using the LNT hypothesis in the range of fundamental scientific uncertainty. The significance of a consolidated expert opinion for public perception of risk is clearly underestimated, and there are certain reasons to believe that the issues discussed go far beyond the national boundaries of the Russian Federation.

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