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Radiological protection challenges facing business activities affected by a nuclear accident: some lessons from the management of the accident at the Fukushima-Daiichi Nuclear Power Plant

T. Schneider[1,*], J. Lochard[2], M. Maître[1], N. Ban[3], P. Croüail[1], E. Gallego[4], T. Homma[3], M. Kai[5], J.-F. Lecomte[6] and N. Takamura[2]

[1] Nuclear Protection Evaluation Centre (CEPN), 28 rue de la Redoute, 92260 Fontenay-aux-Roses, France.
[2] Nagasaki University, Nagasaki, Japan.
[3] Nuclear Regulation Authority, Tokyo, Japan.
[4] Universidad Politénica de Madrid, Madrid, Spain.
[5] Oita University of Nursing and Health Science, Oita, Japan.
[6] Institute for Radiological Protection and Nuclear Safety (IRSN), Fontenay-aux-Roses, France.

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Abstract – Lessons from the Fukushima-Daiichi nuclear power plant accident emphasize the difficulties for restoring the socio-economic activities in the affected areas. Among them, a series of radioligical protection challenges were noted, in particular concerning the protection of employees, the securing of the production and the guarantee provided to consumers of the radiological monitoring of products to restore their confidence. Based on case studies reporting the experience of employers deploying their activities in affected areas, an analysis of these radiological protection challenges has been performed. Characterizing the radiological situation was not always straightforward for the managers. With the help of radiological protection experts, protective actions have been identified and specific efforts have been devoted to provide information to employees and their families helping them to make their own judgement about the radiological situation. Respecting the decisions of employees and developing a radiological protection culture among them have proved to be efficient for restoring the business activities. Continuing or restoring the production not always manageable. It requires to develop dedicated radiological monitoring processes to ensure the radiological protection of workers and the quality of the production. Re-establishing the link with the consumers and organising the vigilance on the long-term were necessary for companies to maintain their production or develop new ones. Deploying a socio-economic programme for ensuring the community resilience in affected areas requires the adoption of governance mechanisms respecting ethical values to ensure the overall objective of protecting people and the environment against the risks of ionizing radiation and contributing to provide decent living and working conditions to the affected communities. It is of primary importance to rely on the involvement of local communities in the elaboration and deployment of the socio-economic activities with due considerations for ensuring the integrity of the communities, and respecting their choices.

Keywords: nuclear accident / Fukushima / business activities / resilience / local communities / ethical values

1 Introduction

The socio-economic impacts of the unprecedented nuclear power plant (NPP) accident in Fukushima-Daiichi, combined with an earthquake and a tsunami, generated enormous economic direct losses estimated at 211 billion USD the first year after the accident (Kajitani *et al.*, 2013), but also during the following years due to the long-term management of the recovery process. The dispersion of radioactive materials in the environment led the national authorities to implement various actions to protect people and the environment, including the evacuation of areas located in the surrounding of the Fukushima-Daiichi nuclear power plant, food restrictions, decontamination activities as well as social and financial support to the affected people (Bachev and Ito, 2014; MOE, 2020). In total, more than 146,000 inhabitants from 12 different municipalities had to evacuate, leaving behind their homes, farms and work (Croüail *et al.*, 2020). The consequences on the socio-economic activities of the

*Corresponding author: thierry.schneider@cepn.asso.fr

Fukushima Prefecture lasted for several years and some consequences can still be observed today. The reduction of availability of labour and also the number of potential customers in affected areas have penalized most businesses. In addition, the impacts of the accident on the reputation of Fukushima Prefecture products such as beef, peach, rice, and sake have led to a drop of 10 to 20% of the selling prices of local products (Zhang *et al.*, 2019; Maître *et al.*, 2020). The tourism industry has also been strongly impacted, with an observed reduction in the number of visitors to the Fukushima area estimated at around 40% in the year following the Fukushima-Daiichi NPP accident (Fukushima Prefecture, 2019) and it took 7 years for the number of tourists to return to the level observed before the accident.

In this context, the managers of business activities have faced and are still facing several radiological protection challenges. Based on a series of case studies of the management of business activities in Fukushima Prefecture, this article aims to highlight in the first part some of these main challenges. The second part is devoted to the analysis of two important radiological protection issues:

– the information of employees and their families on the radiological situation and the implementation of protective actions in the business sector;
– the development of quality assurance process for restoring the image of the products from the contaminated areas.

The third part discusses the governance issues for maintaining and restoring business activities following a nuclear accident, including the associated ethical considerations.

2 Methodology and materials

2.1 Methodology

Drawing on the lessons from the management of the Fukushima-Daiichi NPP accident, the International Commission on Radiological Protection (ICRP) has updated its recommendations on the protection of people and the environment in the event of a large nuclear accident (ICRP, 2020). As part of the preparation of this update, several investigations have been devoted to identify the relevant recommendations to better accompany the business activities in the implementation of the radiological protection system. For this purpose, a qualitative research has been performed based on three approaches:

– the identification of local experiences (case studies) dealing with business activities in the Fukushima Prefecture following the nuclear accident on the basis of testimonies presented during workshops, or reported by the local or national Japanese newspapers;
– a literature review on the impacts of the accident on the business activities, including scientific journals, reports in the newspapers, and reports published by Japanese national and regional public organisations;
– a series of semi-structured interviews carried out with various Japanese business stakeholders.

In addition, relevant material has been collected in the context of the dialogue initiative undertaken by the ICRP with the inhabitants of the Fukushima Prefecture since 2011 (Kotoba Dialogues in Fukushima, 2015; ICRP, 2016; Lochard *et al.*, 2019) as well as during the joint OECD-NEA and Japanese Nuclear Regulation Authority (NRA) workshop on "Preparedness for Post-Accident recovery: lessons from Experience", held in Tokyo in February 2020 (NEA, 2021). The results of the above investigations have also been shared and discussed with the ICRP members of the task group in charge of the update of the recommendations.

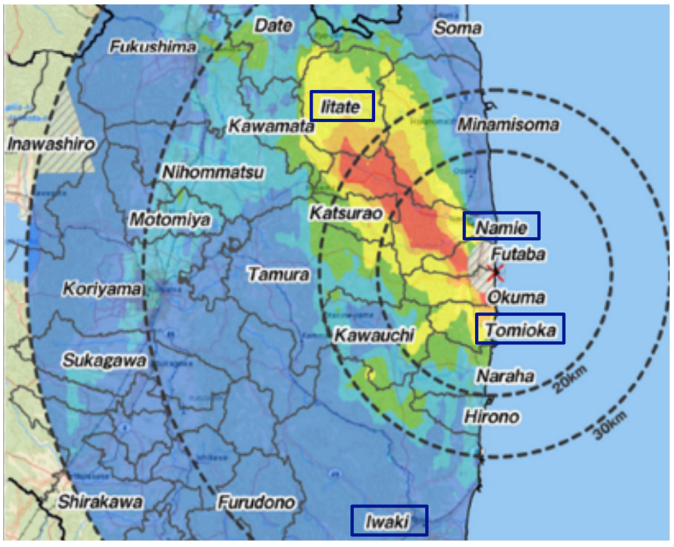

Fig. 1. Map of the area around Fukushima-Daiichi NPP (indicated by the red X), showing the trace of contamination and the location of the case studies.

The case studies selected for this analysis involve companies from different business sectors located in the Fukushima Prefecture, both within and outside the evacuated areas (see Fig. 1). In total 6 case studies have been selected for this analysis (see Tab. 1).

2.2 Case study No. 1: A manufacturing company in Iitate, continuing its activity in an evacuated area

In the village of Iitate, a factory manufacturing prototypes and moulds for electronic material, maintained its activities during the period of evacuation of the village (from April 22, 2011 to March 31, 2017) thanks to the will and the strong commitment of the president of the company and the mayor of the village. This was also made possible with the consent of the employees and their empowerment.

In fact, in 1984, the president of the Kikuchi Manufacturing company decided to establish a factory in his home village in Iitate. The challenge was to open a high-level technology factory in a depopulated area. In March 11, 2011, the plant was not affected by the earthquake and, being located about 40 km from Fukushima-Daiichi NPP, was able to maintain its activities as it was outside the zone concerned by evacuation orders. Due to the information provided on the radioactive contamination in the Fukushima Prefecture, the president of the company allowed his employees who wanted to continue to work to take a temporary break to face the situation.

However, a few weeks later, on April 22, the entire village of Iitate was designated as Deliberate Evacuation Area

Table 1. Selected case studies.

Case study No. 1: A manufacturing company in Iitate, continuing its activity in an evacuated area
In the village of Iitate, a plant manufacturing prototypes and moulds for electronic material, was able to continue its activities even during the period of evacuation of the village (from April, 2011 to March, 2017). This decision was made by the plant manager in consultation with the employees themselves, and with the support of the mayor of Iitate who wanted to maintain business activities in the village.

Case study No. 2: An international company located in Iwaki, at the border of the evacuated zone
Although located in Iwaki city, more than 40 km from the Fukushima-Daiichi NPP, an international company specializing in the manufacture of car navigation systems suffered from the consequences of the nuclear accident. Activities at the plant were stopped in the first days following the accident, and restarted 2 weeks after. The company implemented various protective actions addressing radiological protection issues for the employees, their families, and for the consumers with the help of experts from the Nagasaki University.

Case study No. 3: A quarry located in Namie, contaminated during the emergency phase
In the Namie town, for areas located outside 20 km northwest of the Fukushima-Daiichi NPP, the evacuation order was late and came into effect on April 22, 2011. Therefore, from March 14 to April 22, 2011, the activity of the quarry has continued, operated without any radiological control. Following measurements of materials coming from this quarry, restrictions have been established in a later phase to avoid dissemination of contaminated crushed stones.

Case study No. 4: A commercial store installed in Tomioka in an evacuated area
In July 2016, a businessman from Tomioka resumed his activities with the opening of a grocery store in the city, while the evacuation order was still in effect in the zone. In this context, the radiological management of his employees has been a challenging issue.

Case study No. 5: Forestry and timber industry
More than 44% of the forests from the Fukushima Prefecture were severely contaminated. While decontamination was limited, some forest activities have been restricted as well as the shipment of non-timber forest products. For the timber industry, specific radiological criteria were set up.

Case study No. 6: Tourism sector
The tourism sector was particularly affected by the Fukushima-Daiichi NPP accident. To overcome this situation, the Fukushima region launched various information and communication campaigns. As a result, in 2018, the number of tourists visiting the Fukushima Prefecture has returned to the same level as before 2011.

following measurements which revealed a high level of radioactive contamination. The president of the company, the mayor of Iitate and also the employees were convinced that the village could not survive without a place to work. As the increase in radiation level did not affect the products themselves (electronic devices), negotiations with the government resulted in the authorization to continue the operation of the factory.

The president of the company, who managed it from the head office in Tokyo, testified that at the time of the accident he made direct contact with the employees and that his priority was to ensure their safety. In this perspective, he questioned all employees to find out whether or not they wished to continue working at the factory (Reconstruction Agency, 2013). During his testimony he also stated that he could not use the words "evacuate" or "stay" because both options were irresponsible in his eyes. He also said he trusted his employees. Some young employees resigned, but the Iitate factory was able to keep operating (Fukushima Minyu, 2016). In total, about 40 of the 250 employees decided to quit their jobs due to the evacuation order and concerns about radiation (Reconstruction Agency, 2013).

The Cabinet Office Team of the Government in charge of assisting the lives of disaster victims allowed the company to continue its operation under the condition that the maximum additional individual effective dose would not exceed 20 $mSv.y^{-1}$, excluding natural exposure. Measures were taken to reduce exposure to radiation and limit outdoor work as much as possible. Therefore, employees who wished to continue working in the factory were allowed to work 5 days a week and 10 hours a day. Due to the evacuation order, they were not allowed to live in the village of Iitate and they had to commute from their temporary houses located outside the village, sometimes with travelling time of more than one hour (Public Information Journal of Iitate, 2012; Sakumi *et al.*, 2016).

Investments were made to install air showers at the front of the plant, to create a shoe washing room and set up specific rules for the entrance into the plant. Decision was also made to measure the radiation levels in the factory premises every day in order to inform the employees of the quality of their working environment (Reconstruction Agency, 2013). The employees of the factory have also been involved in various academic studies aiming to assess their global health (external exposure, medical check-up, mental health...). Concerning external exposure, some employees of the factory as well as employees from the other companies operating in the village participated on a voluntary basis in a study conducted by the University of Tokyo and wore glass dosimeters from January to December 2013. The results showed that for this period the annual external effective dose including natural background was less than 2 mSv for 70% of the workers. The maximum annual effective dose reached 3.6 mSv for a worker having outdoor activities (Sakumi *et al.*, 2016). A study conducted by the Fukushima Medical University (FMU) with the Iitate factory and other companies located in the evacuated areas showed that the general health of workers could be deteriorated by overtime work and commuting-time, decreased physical activity and sleeping time (Orui *et al.*, 2018). It is worth mentioning that following this study schedules of employees were adapted to ensure a well-balanced work and domestic life (Reconstruction Agency, 2013).

In order to preserve the quality of the production the company decided, prior to the national government's decontamination programme, to decontaminate its own premises to avoid contamination of the production line (Reconstruction Agency, 2013). The only contamination detected was due to the transport of packages, stored outside the plant at the time of the accident. Therefore, the company decided to replace all packages and to implement a certification attesting the absence of contamination for the products.

It should be mentioned that some customers were concerned about the possible radiological contamination of the products. The manager of the company engaged a dialogue with these customers and emphasized the established certification process. This gradually made customers' worries disappear (Reconstruction Agency, 2013).

2.3 Case study No. 2: An international company located in Iwaki, at the border of the evacuated zone

Although located outside the zone concerned by evacuation orders and more than 40 km from the Fukushima-Daiichi NPP, an international company of Iwaki city specialized in the manufacture of car navigation systems suffered from the consequences of the nuclear accident. The activities of the factory ceased in the first days following the accident and did not resume until 2 weeks later. About ten employees decided to leave the company between April and September 2011 in order to avoid exposure to radiation. Around thirty additional resignations were recorded until March 2014 (Yoshioka, 2020). While the majority of employees decided to continue working at the factory, many of them nevertheless expressed concerns about the lack of information regarding the presence of radioactivity in their environment (Orita *et al.*, 2014; Takeda *et al.*, 2016). This led the company to implement various actions to provide answers to employees' questions and to help them to make their own judgement on the radiological situation.

A series of lectures on radioactivity and its potential effects on health was organized until the fall of 2011, with the assistance of experts from Nagasaki University. Following these conferences, private consultations with health professionals having an expertise in radiological protection were offered to the employees and their families so that they could express their concerns and questions about radioactivity and receive the appropriate information. The factory nurse was trained by Nagasaki University to resume and continue private consultations with employees and their families, as well as to ensure their long-term health follow-up. At the same time, ambient dose rate measurements were made using dosimeters installed in the plant.

The results of these measurements as well as those of the contamination of the food served in the canteens were continuously displayed in the factory hall and on the company intranet (Yoshioka, 2020). Since 2012, the company in partnership with Nagasaki University also proposed access to whole body counting (WBC) measurements for the employees and their families. The 2012 and 2013 WBC campaigns showed that the estimated annual effective dose corresponding to the internal contamination measurements was between 0.01–0.06 mSv for the first screening and between 0.01–0.02 mSv for the second screening (Orita *et al.*, 2014). The WBC campaigns continued until 2017 with no case of internal contamination exceeding the detection limit. Then, it was decided, by mutual agreement with the employees, to stop the WBC campaigns (NEA, 2021).

Following the accident, the number of overseas customers dropped drastically. Concerned about the reluctance of the market, the company's international administrative board was faced with the decision of whether to maintain or not the production in Iwaki City. This raised a significant concern for the local authorities threatened by the possible impact on the business activity of the City. After an analysis of the situation the company finally decided to implement various initiatives to rehabilitate its brand image. Many business trips abroad were organized to meet with the former customers and address their concerns regarding the radiological quality of the company's products. At the same time, a certification proving the product safety was established in October 2012 by an authoritative third-party organization well established in Germany (TUV Rheinland) (Yoshioka, 2020). This certification ended in October 2016 and was not renewed due to the disappearance of customer fears (NEA, 2021).

2.4 Case study No. 3: A quarry located in Namie, contaminated during the emergency phase

The evacuation of some areas of Namie town, located 20 km or more from the Fukushima-Daiichi NPP, was delayed as it was classified as a deliberate evacuation area. The evacuation order came into effect on April 22, 2011. Therefore, from March 14 to April 22, 2011, all the business activities of that part of Namie town continued, including the activity of a quarry. The latter mined and shipped during the period between 2,000 and 5,750 tons of crushed stones mainly intended for use in the production of concrete. No radiological control of the production was implemented (IRSN, 2017).

In December 2011, the municipality of Nihonmatsu, located about 70 km west of the Fukushima-Daiichi NPP, informed the Ministry of Environment (MOE) (MOE, 2018) that radiation levels of 1.24 $\mu Sv.h^{-1}$ have been detected in a brand new building, built between April to July 2011. This level exceeded by about 50% the radiation levels measured outdoors and residents were therefore advised to move elsewhere (Japan Property Central, 2012). An investigation carried out by the public authorities showed that the building had been constructed with concrete made from contaminated crushed stones from the Namie quarry. Further investigations revealed that the contaminated aggregates extracted from the quarry had been supplied to more than 1,000 construction sites, including buildings, agricultural irrigation canals, roads, a school, a golf course and a municipal swimming pool (The Japan Times, 2012; Kitsutaka *et al.*, 2014; IRSN, 2017).

In March 2012, the Japanese Ministry of Economy, Trade and Industry decided to set specific criteria for the radiological control of crushed stones and aggregates coming from all quarries located in the affected areas. The criterion for the shipment of those materials has been set at 100 $Bq.kg^{-1}$ of radiocaesium. For construction projects dedicated to public use, however, a maximum surface dose rate of 0.23 $\mu Sv.h^{-1}$ has been set (Japan Health Physics Society, 2014; IRSN, 2017).

2.5 Case study No. 4: A commercial store installed in Tomioka in an evacuated area

A businessman from Tomioka, whose company provided food for the canteen at the Fukushima-Daiichi NPP before the accident, decided to open a grocery store to help create jobs in his home town. It is interesting to note that even though the evacuation order was still in effect, in the 'Evacuation-prepared area in case of emergency' some activities were allowed, including businesses involved in recovery and reconstruction work, and businesses targeting temporary returnees. In this context, this grocery store (small supermarket), including a cafeteria, opened in July 2016. The first customers were mainly workers engaged in the decommissioning of the NPP and in environmental decontamination in the surrounding municipalities. As a result, during weekdays, 98% of the grocery store consumers are workers, but footfall drops by about 40 to 50% on weekends (Sankei Biz Journal, 2016).

The manager of the grocery store, in charge of 10 employees, admitted that in addition to having difficulties to make his business profitable, he also suffers from the lack of information on the radiological situation, and on how to inform and protect his employees (Croüail *et al.*, 2020).

The manager also underlined during interviews the difficulty of starting a new business activity in a contaminated area because of the responsibility to ensure the safety of the employees with regard to the radioactivity. He testified that he had received technical and financial supports from the municipal trade and industry committee to start his activity but that he had sorely lacked support on radiological protection issues. On his own initiative, he obtained the license for Type-III radiation protection supervisor. This helped him to understand radioactivity and its effects, and thus to better manage the radiological protection of his staff thereafter (Rainbow NTT Journal, 2018).

However, when the grocery store opened, he had difficulties finding employees willing to work in a contaminated area (IEEI, 2020). The employees expressed worries about radioactivity and he even received remarks from people such as: "*Are you really going to make these employees work in a dangerous place?*" (Rainbow NTT Journal, 2018). By discussing with his employees and by showing them the results of his own dosimeter (given by the municipality as a resident of Tomioka), he gradually convinced them about the safety of their working environment (Uniform-net Journal, 2020).

It should also be noted that the distribution of personal dosimeters (D-Shuttle®) organized by the municipality of Tomioka is only dedicated to the residents and does not concern people working in the municipality. As most of the grocery store's employees were from outside Tomioka, they were not given individual monitoring devices, which would have helped them learn about their exposure and thus be able to make their own judgements about the radiological environment of their working place.

The manager of the grocery store has been heavily involved in the process of revitalizing the town of Tomioka village. He said: "*By driving around the evacuation area since May 2013, I started to see the situation objectively and I became tired of being a victim.*" Having in mind different projects for the city he mentioned: "*I would also like to work on things that would serve to revitalize the entire town of Tomioka*." (IEEI, 2020).

2.6 Case study No. 5: Forestry and timber industry

Almost 70% of the Fukushima Prefecture is covered with forests, with a large associated production of timber, firewood and charcoal, cultivated mushrooms, etc, as well as traditional practices dear to local communities, in particular forest walks and collecting mushrooms and wild berries (Orita *et al.*, 2017). However, following the Fukushima-Daiichi NPP accident, it was estimated that more than 44% of the forest from the Fukushima Prefecture was "severely contaminated", with contamination level in the range of 10–30 $kBq.m^{-2}$ of ^{137}Cs (Yoshihara *et al.*, 2014; Saito *et al.*, 2019). Since decontamination of forest areas can be extremely costly, generate huge amounts of waste and also induce significant impact on the ecosystem without a significant reduction in exposure (Bird and Braxton Little, 2013), authorities have chosen not to carry out major decontamination actions. In this context, some forest activities have been restricted by the government, starting with mushroom cultivation, charcoal production, and leisure activities such as mushroom and wild vegetables picking, hunting, etc. However, it should be noted that logging for industry has not been prohibited within the affected areas, except for the evacuation areas.

This led the authorities to restrict the shipment of non-timber forest products. For the shipment of timber products, the authorities set up specific radiological criteria such as: 40 $Bq.kg^{-1}$ dry for firewood and wood pellets; 280 $Bq.kg^{-1}$ dry for coal; and 300 $Bq.kg^{-1}$ for wood pellets with bark (IRSN, 2017).

In addition, the Ministry of Health, Labour and Welfare established specific guidelines for managing radiological protection of workers engaged in activities within areas exceeding 2.5 $\mu Sv.h^{-1}$ (MHLW, 2012; The Manichi, 2015). Guidebooks on radiological protection issues dedicated to foresters were also prepared. Although studies have shown that in some affected areas the estimated annual dose of foresters was not greater than that of farmers, builders or employees working also in these areas (Orita *et al.*, 2017), in 2015, this sector was still 40% down from what it was before the accident (Greenpeace, 2016).

2.7 Case study No. 6: Tourism sector

The tourism sector was particularly affected by the Fukushima-Daiichi NPP accident. Although Japan has always been perceived as a safe travel destination, this perception changed after the accident as potential tourists were worried about possible radiation exposure from consuming contaminated food or breathing contaminated air (Chew and Jahari, 2014). As a result, in the year following the accident, the number of national and international visitors and school visits to the Fukushima Prefecture decreased respectively by more than 40% and 80% (Fukushima Prefecture, 2019). To overcome this situation, tour packages, hotel rates, and airline tickets were significantly reduced (Chew and Jahari, 2014). The region also launched various information and communication campaigns detailing the radiological state of the

environment, the progress of the decontamination work, as well as the radiological quality of local food products. The flagship products of the region (e.g., sake, peaches, etc.) were the subject of national advertising featuring personalities such as the Emperor or the Prime Minister (Maître *et al.*, 2020). The objective of organizing the Tokyo Olympic Games, initially planned for July 2020, was also a driving force to restore the image of the Fukushima region, since some events were supposed to be organized within the Prefecture (e.g., Olympic Torch Relay in J-village, etc.). As a result, in 2018, the number of tourists visiting Fukushima Prefecture returned to the same level as before 2011.

3 Radiological protection challenges faced by the local socio-economic actors following the Fukushima-Daiichi NPP accident

The analysis of the case studies reported above highlights two major radiological protection issues that business activities had to face to maintain or develop following the Fukushima-Daiichi NPP accident:

- the protection of employees and their families against radiation, and;
- the implementation of a radiological quality assurance process for the products and at the same time actions to restore the image of the products.

3.1 Preservation of the business activity and protection of employees

In the territories affected by the Fukushima-Daiichi NPP accident, business activities were considerably impacted either because they were located within the evacuation perimeters, or because it was impossible to maintain the production chains due to the lack of workforce and customers. The first challenge for plant managers was to evaluate whether or not to maintain the production in place. In this perspective, access to relevant information on the radiological situation was crucial to be sure to make a decision guaranteeing both the protection of the employees and the good radiological quality of the products (see Sect. 3.2). The case studies highlight the difficulties that employers have encountered in accessing relevant information and also in obtaining the support of radiological protection experts who were in position to help them to characterize and assess the radiological situation (see the case of the plants located in Iwaki or in Iitate). In addition, the radiological criteria intended to help decision makers have not always been fully effective, whether it is their absence, as was the case in particular for Namie's quarry, or the taking into account of the specific situation of the companies.

Depending on the type of business, the conditions for preserving production or even introducing new ones are significantly different and the radiological situation is only one factor among others. For some factories, decontamination has to be implemented prior to restart the production and allowing employees to return. In the following years, the gradual lifting of evacuation orders also allowed some companies to resume their activities in their hometown even though in February 2020 only 30% of the companies present before the accident were listed in 12 municipalities for which the evacuation order was lifted (Nii, 2020).

In contaminated areas where business activities are authorised to be developed, employers engage their responsibility vis-à-vis the exposure situation of their staff. The case studies show that although employees in most workplaces have not been classified as "radiation exposed workers" authorities have developed specific guidelines for ensuring the radiological protection of workers, and employers have put in place a dedicated information and organization to ensure the protection of their employees and provide them with decent working conditions (MHLW, 2012).

Therefore, in such areas, radiological protection of employees for business activities is essentially based on applying guidelines provided by authorities and information provided by the employers, together with the implementation of a programme to measure radiation in the workplace and to monitor individual exposures in order to identify the best options for maintaining doses as low as reasonably achievable. This monitoring is mainly focused on the external dose rate inside and around the plant, but it can also concern the monitoring of food provided at the canteen and the whole body counting to give information to the employees on their internal dose, associated with their life in the contaminated areas. Such a programme is only effective if it is accompanied by a dialogue with employees to listen to their concerns and involve them directly in the decision-making process concerning protection choices. This involvement also contributes to the development of a practical radiological protection culture among staff which is useful both in the workplace and outside. To characterize the radiological situation in the workplace, it is necessary to have access to measurement devices and individual dosimeters as well as guidance on their use. Finally, it should be noted that all of these actions involve technical investments which represent an additional cost which is sometimes not marginal for the company. In this perspective, national and local authorities should provide technical and financial support to the affected businesses.

Particular attention has to be paid to the well-being of employees and to mutual trust between employees and the manager to overcome the difficulties encountered following the accident. This is based on the voluntary commitment of employees to work in affected areas ensuring that socio-economic support is sufficiently developed to allow them to choose to stay or leave the affected area. In addition, their access to meaningful information and the means to make their own judgement on the radiological situation should be guaranteed. For this, taking care not only of the employees but also of their family has proved to be effective as for example in the case of the plant located in Iwaki.

The concerns of employees on the possible future effects of radiation on health have been observed in the various case studies. The involvement of health professionals in supporting employees and their families as well as the organization of a health surveillance programme are essential to respond to these concerns and also to contribute to ensure their well-being. In addition to the potential health effects of radiation, changes in the working and living conditions of the employees such as increased transport times, change in eating habits, restriction of physical activities, etc, call for the development of health surveillance in the perspective of a multidisciplinary approach (Sawano *et al.*, 2020; Schneider *et al.*, 2020).

3.2 Implementation of a radiological quality assurance process for the products and restoration of their image

Managers of businesses located in the affected territories have all encountered difficulties in ensuring the radiological quality of their products before placing them on the market. They had to organize a quality assurance and surveillance system for monitoring the products as well as providing the market with transparent information on their radiological quality. They also had to adapt this system to the specific situation: the solutions adopted range from good quality assurance practices directly developed by companies to formal certification provided by an authoritative third-party organization. In this perspective, the role of the Fukushima Technical Support Centre (High Tech Plaza in Iwaki and Koriyama) should be noted. This centre carried out radiological measurements for industrial products affected by radiation or subjected to harmful rumours. It also provided quality certifications on various industrial productions in the first months following the Fukushima-Daiichi NPP accident (Fukushima Prefectural Government, 2011).

The Fukushima experience has shown the importance of organizing communication and dialogue with consumers and stakeholders to ensure and restore confidence in the quality of products. To this end, the role of the practical radiological protection culture is crucial to address the radiological situation. Business leaders should favour direct contact with consumers for the organisation of the quality assurance process by engaging them in the dissemination of information and good practices. The dissemination of information through the media and, in particular, access to the results of measurements of the products is one of the key components for restoring consumer confidence (Maître *et al.*, 2020). In addition, the dissemination of practical information on the radiological characterisation of the environment in the affected areas, as for example the results of environmental monitoring, helps to restore the confidence of tourists and provides them specific knowledge to make their own judgement about the radiological situation (Chew and Jahari, 2014).

Although the business activities were obliged, already prior to the Fukushima-Daiichi NPP accident, to establish a business continuity plan to deal with possible unexpected events, feedback experience showed that at the time of the accident, business owners were not sufficiently prepared to put in place a suitable process ensuring the radiological quality of their production. In addition, guidelines for business activities including radiological criteria were not available. The case studies have shown the importance for companies in the event of an accident to be able to react quickly to guarantee the radiological quality of their products and the future of their business activity. They also underlined the need to introduce flexibility in the implementation of the process to adapt it progressively according to the evolution of knowledge on the radiological situation, the general protection framework put in place by the authorities, and the expectations of the consumers. Finally, as underlined by Lee and Kubota (2016), the cooperation between neighbouring companies is also crucial to favour the restoration of business activities in affected areas.

4 Governance and ethical issues for maintaining and restoring business activities following a nuclear accident

4.1 Framework for restoring socio-economic development of local communities

Following a nuclear accident, the main challenge for the recovery process is to restore the socio-economic development to support local communities in the affected areas where the radiological conditions have been deemed by the authorities to be sufficiently secured to allow people to reside and work (Lee and Kubota, 2016). In this perspective, cooperation between local, regional and national authorities aims to develop and adopt a common project for local communities to ensure their future including the different facets of sustainable development (WCED, 1987; Hammer and Pivo, 2017). In practice, such a common project relies notably on the selection of areas in which to re-establish production and to organise support for the establishment and maintenance of agricultural, industrial and commercial activities.

In the Hamadori region, and more broadly in the Fukushima Prefecture, future socio-economic development relies heavily on the Fukushima Innovation Coast Framework, which combines financial support and incentives for the development of a series of innovative projects. The "Fukushima Innovation Coast Framework" (FICF) was established in January 2014 by the national government and the Fukushima Prefecture with the aim of promoting research and development in the field of robotics, decommissioning, energy, environment, etc. in the Hamadori region along the Pacific coast, most affected by the nuclear accident, but also by the earthquake and the tsunami (FICF, 2018).

The amended Act on Special Measures for Fukushima Reconstruction and Revitalization was enacted in May 2017, including the establishment of a council at ministerial level.

In July 2017, Fukushima Prefecture established a foundation called: "Fukushima Innovation Coast Framework Promotion Organisation" (FIPO, 2020) to implement support measures including grants to small and medium-sized enterprises, investment incentives for companies, as well as temporary industrial or commercial premises made also available on a free basis to individual enterprises (Zhang *et al.*, 2019).

By focusing on innovation, this framework aims to rebuild the region's industrial base and, in addition, to encourage the return of evacuees to their places of residence, as well as the establishment of new residents in the region with the hope of promoting the rebirth of an attractive and dynamic society.

The spirit of this framework was emphasized in the interview with Isao Kikuchi, President of Kikuchi Manufacturing (Fukushima Minyu, 2016):

"*The robot industry is called the fourth industry, and growth is expected in the future... We have a plan to build a 'university complex' in Minamisoma with university researchers who have various research themes. We have already connected 10 universities in the robotics field... Fukushima Prefecture was devastated by the disaster, but it is precisely because of the current environment that we can take on the*

challenge. We need to join forces with the big common goal of "Fukushima's recovery". We believe that the university complex will help the Japanese robotics industry grow."

Among the various projects under development, it is worth mentioning:

- the establishment of a test area for robots and drones (Fukushima Hamadori Robot demonstration zone);
- the establishment of a hydrogen production unit in Namie, using renewable energies and aimed at contributing to the objective of the Fukushima Prefecture of reaching 100% renewable energies by 2040;
- the establishment of a Japan Atomic Energy Agency (JAEA) research centre for the development of technologies for the decommissioning of the Fukushima-Daiichi nuclear power plant.

The objective of the framework is to create industrial clusters, to foster human resources, and to increase the number of visitors in the region. In other words, it is to contribute to the resilience of the affected communities and to develop a sustainable socio-economic project for the region. Particular attention has been devoted to the governance of this socio-economic development, steered by a council at the ministerial level and mobilizing public organisations and private companies (Nii, 2020). The overall goal of the Innovation Coast Framework is "to become a symbol of hope and to be a pioneer in using innovation to solve social issues" for the Hamadori region (Hope Tourism, 2020).

Resilience is generally defined in the literature as the return to an "equilibrium" after an event (Norris *et al.*, 2008; Paton, 2009). However, the experience of the Chernobyl and Fukushima post-accidental situations reveals that the return to the ante-situation is generally not achievable in itself. Complete removal of radioactivity from contaminated areas is not feasible and whatever efforts are made, there is always residual contamination, especially in forest areas (Takada *et al.*, 2020). In addition, many human and societal consequences are irreversible and the destabilization of communities leads to ruptures and complex dilemmas. To cope with this situation as Norris points out in his article, resilience has to be seen as a "process" rather than a "result" and has to refer to "adaptability" rather than "stability". From this perspective, community resilience after a disturbance is described as: *"a process linking a set of networked adaptive capacities to a positive trajectory of functioning and adaptation in constituent populations"* whose final results aim at the well-being of individuals and communities (Norris *et al.*, 2008).

Therefore, following a nuclear accident, it is crucial to achieve a sufficient level of community resilience for socio-economic activities in order to ensure sustainable development in the future. The main challenge is to engage communities in a process of rehabilitating decent and sustainable living and working conditions (Lochard, 2013). This process relies on a "long-term vision of the socio-economic development of the territory" co-negotiated between all the concerned actors: national, regional and local authorities, experts, scientists, professionals and of course the people directly affected by the accident (Baudé, 2016). To this end, it is essential to maintain the "integrity" or "cohesion" of the communities, which has generally been greatly disturbed by the consequences of the accident. This "long-term vision" should be renegotiated periodically according to the evolution of the local situation and to take into account the emergence of new expectations of the local population. The challenge is to articulate the revival of social and business activities damaged by the accident, the emergence of new and innovative activities in line with the local context and support for local projects carried out by individuals and/or local communities, which should also aim to improve the radiological situation.

As the cohesion of the local/regional communities has been significantly affected by the consequences of the accident, it is necessary to promote a common project to support the socio-economic development in a harmonized and fair dynamic. In this context, as Norris emphasizes, the main objectives of the community resilience process are to reduce risks and resource inequities, involve the local people in mitigating the consequences, create organisational links between all actors as well as stimulate and maintain social supports. Such a process requires relying on reliable sources of information but also on flexible decision-making skills with the participation of the affected citizens (Norris *et al.*, 2008; ICRP, 2021).

4.2 Respecting ethical values

The case studies presented above revealed that beyond the technical considerations concerning the implementation of radiological protection actions, the consideration of ethical values, in particular respect for the dignity of the affected persons, was also a dimension taken into account by business managers for ensuring the preservation and revival of their business activities.

In this perspective, it is useful to examine the set of core ethical values underpinning the radiological protection system provided by the International Commission on Radiological Protection in its Publication 138 and to appreciate their meaningfulness and contribution for accompanying the socio-economic development and ensuring the well-being of local communities (ICRP, 2018). Table 2 presents the core and procedural ethical values underpinning the radiological protection system.

The ethical values identified by ICRP are well suited to fostering the process of socio-economic recovery in a post-accident situation. This is highlighted in the following discussion:

- beneficence/non-maleficence: from a radiological protection point of view, the primary objective of the framework for recovery is to contribute to protect people and the environment and to ensure the "well-being"/"wellness" of affected individuals (Oughton, 2016). Therefore, it is essential to ensure that the socio-economic development is clearly articulated with these objectives and not only driven by economic considerations. The decision-making process put in place for the socio-economic development should take due considerations of the impacts and contributions that decisions may have on living and working conditions, life expectancy, mental health and well-being and livelihoods of the affected people. Environmental protection and more globally the quality of the environment have also to be considered in this process.

Table 2. ICRP ethical values (ICRP, 2018).

Core ethical values underpinning the system of radiological protection			
Beneficence/Non-maleficence	**Prudence**	**Justice**	**Dignity**
To promote or do good/to avoid doing harm	To make informed and carefully considered choices without the full knowledge of the scope and consequences of an action	The upholding of what is right, equitable, and fair	The value and respect that every person has and deserves regardless of her/his age, sex, health, social condition, ethnic origin, religion, etc.
Procedural values			
Accountability	**Transparency**	**Inclusiveness**	
The obligation of individuals or organisations who are in charge of decision making to answer for their actions to all those who are likely to be affected, including reporting on their activities, accepting responsibility, and accounting for actions taken and the consequences, if necessary	Accessibility of information about the deliberations and decisions concerning potential or on-going activities, and the honesty with which this information is transmitted	Ensuring that all those concerned are given the opportunity to participate in discussions, deliberations, and decision-making concerning situations that affect them	

– prudence: the adoption of a socio-economic project for the recovery process should necessarily be accompanied by measures dedicated to the organization of vigilance on health issues. Health, and in particular that of children, is indeed the main concern of the affected populations (Maître *et al.*, 2021) and this concern is reinforced by the uncertainty associated with the effects of ionizing radiation at low doses. The potential effects of radiation on the ecosystem and the biodiversity should also be taken into account when monitoring the evolution of the environment. The organization of long-term health and environmental monitoring is one of the essential pillars of sustainable development.
– justice: the deployment of the socio-economic support should be organized with the aim of ensuring equitable and fair contribution to the protection and well-being of the different affected communities, and the different categories of stakeholders. In this perspective, it is essential to put in place governance mechanisms—including representatives of the different stakeholders at local/regional and national levels—in order to identify the main priorities to achieve this goal. In addition, during the implementation of the socio-economic programme, it is necessary to regularly evaluate whether its implementation ensures a good and fair balance in the allocation of human and financial resources and to identify whether additional efforts should be granted for certain local communities. In practice, individuals and local communities are affected differently by the residual contamination, their exposures depending on their habits, their environment and their socio-economic situation. Furthermore, the benefits and drawbacks of implementing protective actions are not always distributed evenly among the people concerned. In this context, special attention should be paid to the protection of vulnerable groups and future generations.
– dignity and autonomy: the post-accident situations of Chernobyl and Fukushima emphasized the imperative need to restore and preserve the dignity of the affected people and communities in the recovery process (Lochard, 2016). In this perspective, the establishment of a socio-economic programme should first be based on the voluntary commitment of individuals and communities to live and/or work in the affected areas. Therefore, for the implementation of this programme, it is necessary to ensure that resources (human, technical, financial...) are available to preserve this autonomy. The socio-economic programme should therefore include specific measures to support citizens' initiatives aimed at regaining control on their daily life, where experts are at the service of the people concerned (co-expertise processes, self-help protective actions, local projects..). This requires the support of the authorities and the respect of individual autonomy.

Regarding the procedural values put forward by the ICRP, they apply to the practical implementation of the recovery process. Emphasis should first be placed on access to information for affected people and communities in order to guarantee the transparency of decision-making processes, as well as the modalities of implementation of actions related to economic development, in particular those concerning radiological protection. It is also necessary to ensure an open dialogue with all stakeholders (employee, employers, economic actors, local/regional/national authorities, experts...) in order to promote their active participation in the implementation of protective actions and those aimed at rehabilitating decent living and working conditions. Finally, decision-makers should responsibly engage in procedures that allow affected communities to assess the relevance and sustainability of the socio-economic development process with respect to radiological protection and the rehabilitation of living conditions. In this perspective, all stakeholders are accountable for developing a vision for the future of the affected territories and a strategy for transmitting the acquired experience.

5 Conclusion: considerations on preparedness

The analysis of the different case studies clearly shows that following a nuclear accident, those responsible for socio-economic activities face various challenges related to radiological protection issues for which they are generally not well prepared. These challenges range from the implementation of protective actions to ensure the protection of employees and the continuity of the production with good quality products in affected areas, to the restoration of consumer confidence. In addition, experience also highlighted

that the deployment of a socio-economic programme in the affected areas, defined with the local communities with the aim to enhance their resilience, requires the adoption of governance mechanisms respecting a series of ethical values to ensure the overall objective of protecting people and the environment against the harmful effects of exposure to ionizing radiation and of contributing to the well-being of individuals.

In view of these considerations, a better integration of radiological protection issues in the context of the preparedness framework for recovery and a strengthening of cooperation between the different stakeholders could significantly improve community resilience and strengthen the quality of the recovery process. This is in line with the objectives of the Sendai Framework for Disaster Risk Reduction 2015–2030 adopted at the 3rd UN World Conference on Disaster Risk Reduction held in Sendai, Japan, on March 18, 2015 (UNDRR, 2015). This framework is focused on preventing new risks, reducing existing risks and strengthening resilience. Governance is clearly emphasized in Priority 2 which states: "*strengthening disaster risk governance for prevention, mitigation, preparedness, response, recovery, and rehabilitation is therefore necessary and fosters collaboration and partnership across mechanisms and institutions for the implementation of instruments relevant to disaster risk reduction and sustainable development*" (UNDRR, 2015).

From this perspective, for business activities located in the vicinity of nuclear installations, the emphasis should be on the integration of the nuclear risk, alongside with natural and technological risks, in the preparation of business continuity plans (Maruya, 2013; Hatton *et al.*, 2016). To this end, a dialogue between socio-economic and local stakeholders should be established as part of preparedness plans for recovery, to identify the specific challenges for the resumption of socio-economic activities in the areas that would be affected by an accident. An analysis of the vulnerabilities and challenges to ensure the radiological protection of people and the environment should also be performed and discussed with all concerned stakeholders taking into account ethical considerations to ensure an equitable and sustainable resilience of the socio-economic activities.

In practice, further developments will be needed in the future to better analyse the possible contribution of supporting mechanisms aimed at improving the well-being of affected people and to develop decision-making processes supporting the socio-economic recovery of local communities, with due considerations to take into account radiological protection and ethical issues. The training of experts, as well as the development of awareness of local communities to contribute to the development of radiological protection culture within the society, will be also necessary to favour the integration of these issues into the preparation of business continuity plans.

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References

Bachev H, Ito F. 2014. Implications of Fukushima nuclear disaster for Japanese agri-food chains. *Int. J. Food Agric. Econ.* 2(1): 95–120.

Baudé S, *et al.* 2016. Local populations facing long-term consequences of nuclear accidents: lessons learnt from Chernobyl and Fukushima. *Radioprotection* 51(HS2): S155–S158.

Bird WA, Braxton Little J. 2013. A Tale of Two Forests: Addressing Post-nuclear Radiation at Chernobyl and Fukushima. *Environ. Health Perspect.* 121(3): a78–a85.

Chew EYT, Jahari SA. 2014. Destination image as a mediator between perceived risks and revisit intention: A case of post-disaster Japan. *Tour. Manag.* 40: 382–393.

Croüail P, Schneider T, Gariel JC, Tsubokura M, Naito W, Orita M, Takamura N. 2020. Analysis of the modalities of return of populations to the contaminated territories following the accident at the Fukushima power plant. *Radioprotection*. https://doi.org/10.1051/radiopro/2020049.

FICF. 2018. *Fukushima Innovation Coast Framework*. Available from: https://www.meti.go.jp/english/publications/pdf/fukushima_innovation2018.pdf.

FIPO. 2020. *Fukushima Innovation Coast Framework Promotion Organisation*. Available from: https://fipo.or.jp.

Fukushima Minyu. 2016. *Five Years After the Great East Japan Earthquake, Isao Kikuchi, President of Kikuchi Manufacturing, Necessitates the Challenge of Local Companies*. Available from: https://www.minyu-net.com/news/sinsai/sikisya05/FM20160318-058813.php (In Japanese).

Fukushima Prefectural Government. 2011. *Vision for revitalization in Fukushima Prefecture*. Available from: https://www.pref.fukushima.lg.jp/download/1/vision_for_revitalization.pdf.

Fukushima Prefecture. 2019. *Steps for Revitalization in Fukushima*. Available from: https://www.pref.fukushima.lg.jp/uploaded/attachment/372366.pdf.

Greenpeace. 2016. *Radiation Reloaded: Ecological Impacts of the Fukushima Daiichi Nuclear Accident,* 5 years later.

Hammer J, Pivo G. 2017. The triple bottom line and sustainable economic development theory and practice. *Econ. Dev. Q.* 31 (1): 25–36.

Hatton T, Grimshaw E, Vargo J, Seville E. 2016. Lessons from disaster – creating a business continuity plan that really works. *J. Bus. Contin. Emerg. Plan.* 10(1): 84–92.

Hope Tourism. 2020. *Learning with Fukushima*. Available from: https://www.hopetourism.jp/en/.

ICRP. 2016. Proceedings of the International Workshop on the Fukushima Dialogue Initiative. *Ann. ICRP* 45(2S).

ICRP. 2018. Ethical foundations of the system of radiological protection. ICRP Publication 138. *Ann. ICRP* 47(1).

ICRP. 2020. Radiological Protection of People and the Environment in the Event of a Large Nuclear Accident. ICRP Publication 146. *Ann ICRP* 49(4).

ICRP. 2021. Proceedings of the International Conference on Recovery after Nuclear Accidents: Radiological Protection Lessons from Fukushima and Beyond. *Ann. ICRP* 50(S1).

IEEI. 2020. *Interview with a key man on the current situation in Fukushima Prefecture, which was badly damaged by the earthquake and nuclear accident*. Available from: http://ieei.or.jp/2018/01/special201706013/.

IRSN. 2017. *Évaluation dosimétrique de cinq filières de production de biens manufacturés en situation post-accidentelle*. Rapport n° PRP-HOM/SER/2017-00009. Available from: http://logi103.xiti.com/go.click?xts=410711&s2=3&p=Rap-PRP-HOM-SER-2017-00009&clic=T&type=click&url=http://www.irsn.fr/FR/expertise/rapports_expertise/Documents/radioprotection/IRSN_Eval-dosimetrique-biens-manufactures-post-accident_PRP-HOM-SER-2017-00009.pdf.

Japan Health Physics Society (JHPS). 2014. *Issues and Recommendations Associated with Radiation Protection after Fukushima Daiichi Nuclear Power Plant Disaster*. Available from: http://www.jhps.or.jp/upimg/files/2nd_JHPS-issues_and_recommendationsrecom.pdf.

Japan Property Central. 2012. *High radiation levels from concrete in new apartment building*. Available from: https://japanpropertycentral.com/2012/01/high-radiation-levels-from-concrete-in-new-apartment-building/.

Kajitani Y, Chang SE, Tatano H. 2013. Economic Impacts of the 2011 Tohoku-Oki Earthquake and Tsunami. *Earthq. Spectra.* 29: S457–S478.

Kitsutaka Y, Sogo S, Maekawa K, Imamoto K, Nakarai K, Yamada K, Miyazato S. 2014. *Technical Committee on the Containment of Radioactive Contaminants and Safe Use of Concrete Materials*. Japan Concrete Institute, Committee Report JCI-TC 124A.

Kotoba Dialogues in Fukushima. 2015. *The story of four years of dialogue for the rehabilitation of living conditions in the areas contaminated by the Fukushima accident*. Web documentary. Available from: http://www.fukushima-dialogues.com.

Lee M, Kubota A. 2016. Study on the restart of local businesses in the areas affected by the earthquake, tsunami and nuclear power plant disaster – Focus on the secondary and tertiary industries in Odaka Ward (Minami-sōma City), which is in the "zone in preparation for the lifting of the evacuation order". *J. City Plan. Inst. Jpn* 51(3).

Lochard J. 2013. Stakeholder Engagement in Regaining Decent Living Conditions after Chernobyl. In: *Social and Ethical Aspects of Radiation Risk Management, Radioactivity in the Environment, Vol. 9* (D. Oughton, S.O. Hansson, Eds.), pp. 311–331. Elsevier.

Lochard J. 2016. First Thomas S. Tenforde Topical Lecture: The Ethics of Radiological Protection. *Health Phy.* 110(2): 201–210.

Lochard J, Schneider T, Ando R, Niwa O, Clement C, Lecomte JF, Tada JI. 2019. An overview of the dialogue meetings initiated by ICRP in Japan after the Fukushima accident. *Radioprotection* 54 (2): 87–101.

Maître M, Croüail P, Durand V, Lecomte JF, Charron S, Schneider T. 2020. The management of contaminated goods in Japan since the Fukushima accident. *Radioprotection* 55(1): 17–28.

Maître M, Croüail P, Schneider T, Kuroda Y, Miyasaki M, Tanigawa K, Oughton D, Tomkiv Y, Skuterud L, Liutsko L, Charron S, Olz-Viol C, Kesmeniene A, Ostroumova E. 2021. Living conditions and health status of populations living in territories impacted by nuclear accidents – Some lessons for developing health surveillance programme. *Environ. Int.* 147.

Maruya H. 2013. Proposal for improvement of Business Continuity Management (BCM), based on lessons from the Great East Japan Earthquake. *J. JSCE* 1: 12–21.

MHLW. 2012. *Guidelines on Prevention of Radioactive Hazards for Workers Engaged in Work Under a Designated Dose Rate" (Labour Standards Bureau Notification No. 0615–6, 15 June 2012)*. Available from: https://www.mhlw.go.jp/english/topics/2011eq/workers/dr/dr/pr_120615_a04.pdf.

MOE. 2018. *Environmental Remediation in Japan*. Available from: josen.env.go.jp/en/pdf/progressseet_progress_on_cleanup_efforts.pdf.

MOE. 2020. *Fukushima Innovation Coast Framework*. Available from: https://www.env.go.jp/en/chemi/rhm/basic-info/1st/09-04-04.html.

NEA. 2021. *Preparedness for post-accident recovery process: lessons from experience*. Workshop Summary Report, Tokyo, Japan, 18–19 February 2020, NEA/CRPPH/R(2020)1.

Nii Y. 2020. *How to Restart Affected Businesses "Four-Year Experience by a Public-Private Joint Team". NEA Workshop on "preparedness for post-accident recovery process: lessons from experience"*. Tokyo Japan. February 18–10, 2020. Available from: https://www.oecd-nea.org/download/wpnem/Tokyo2020JointWorkshop/documents/4-3_Tokyo2020Workshop_YasumasaIgarashi.pdf.

Norris F, Stevens S, Pfefferbaum B, Wyche K, Pfefferbaum R. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *Am. J. Community Psychol.* 41: 127–150.

Orita M, Hayashida N, Nukui H, Fukuda N, Kudo T, Matsuda N, Fukushima Y, Takamura N. 2014. Internal Radiation Exposure Dose in Iwaki City, Fukushima Prefecture after the Accident at Fukushima Dai-ichi Nuclear Power Plant. *PLoS One*. https://doi.org/10.1371/journal.pone.0114407.

Orita M, Fukushima Y, Yamashita S, Takamura N. 2017. The Need for Forest Decontamination: For the Recovery of Fukushima. *Radiat. Prot. Dosim.* 175(2): 295–296.

Orui M, Suzuki Y, Goto A, Yasumura S. 2018. Factors associated with maintaining the mental health of employees after the Fukushima Nuclear disaster: findings from companies located in the evacuation area. *Int. J. Environ. Res. Public Health* 15: 53.

Oughton D. 2016. Societal and ethical aspects of the Fukushima accident. *Integr. Environ. Assess. Manag.* 12: 651–653.

Paton D. 2009. Business Continuity during and after Disaster: Building Resilience through Continuity Planning and Management. *ASBM J. Manag.*

Public Information Journal of Iitate. 2012. *Businesses that have reopened or are continuing to operate in the village*. September 24, N° 583. Available from: https://www.vill.iitate.fukushima.jp/uploaded/attachment/3632.jpg (In Japanese).

Rainbow NTT Journal. 2018. *A town that is always ready to welcome those who come back*. Available from: http://rainbow.nttdocomo.co.jp/enterprise/detail/224/.

Reconstruction Agency. 2013. *Business continuity in the region affected by the nuclear disaster at Kikuchi Manufacturing (Iitate Village, Fukushima Prefecture)*. Available from: https://www.reconstruction.go.jp/topics/main-cat4/sub-cat4-1/20130731_casebook_3-10.pdf (In Japanese).

Saito K, Mikami S, Andoh M, Matsuda N, Kinase S, Tsuda S, Sato T, Seki A, Sanada Y, Wainright-Murakami H, Yoshimura K, Takemiya H, Takahashi J, Kato H, Onda Y. 2019. Temporal change in radiological environments on land after the Fukushima Daiichi nuclear plant accident. *J. Radiat. Prot. Res.* 44(4): 128–148.

Sakumi A, Miyagawa R, Tamari Y, Nawa K, Sakura O, Nakagawa K. 2016. External effective radiation dose to workers in the restricted area of the Fukushima Daiichi Nuclear Power Plat during the third

year after the Great East Japan Earthquake. *J. Radiat. Res.* 57(2): 178–181.

Sankei Biz Journal. 2016. *Development of convenience stores and supermarkets to encourage residents to return home*. Available from: https://www.sankeibiz.jp/macro/news/160312/mca1603120500009-n1.htm.

Sawano T, Ozaki A, Tsubokura M. 2020. Review of health risks among decontamination workers after the Fukushima Daiichi Nuclear Power Plant Accident. *Radioprotection* 55(4): 277–282

Schneider T, Oughton D, Cardis E. 2020. Guest editorial: The SHAMISEN project – Applicability or lessons learnt and recommendations for disaster situations. *Environ. Int.* 144: 106000.

Takada M, Yasutaka T, Kanai Y, Kuroda Y. 2020. Factors affecting resumption of forest or satoyama usage by former evacuees following their return after the Fukushima Dai-ichi Nuclear Power Plant accident. *Radioprotection* 55(4): 325–334.

Takeda S, Orita M, Fukushima Y, Kudo T, Takamura N. 2016. Determinants of intention to leave among non-medical employees after a nuclear disaster: a cross-sectional study. *BMJ Open* 6: 0e011930.

The Japan Times. 2012. *Radioactive gravel finds way to school*. Available from: https://www.japantimes.co.jp/news/2012/01/19/national/radioactive-gravel-finds-way-to-school/.

The Manichi. 2015. *Gov't plans not to decontaminate Fukushima forests away from residential areas*. Available from: https://mainichi.jp/english/articles/20151222/p2a/00m/0na/012000c.

UNDRR. 2015. *Sendai Framework for disaster Risk Reduction 2015–2030*. United Nations office for Disaster Risk Reduction. Available from: https://www.undrr.org/.

Uniform-net Journal. 2020. *Voice 57*. Available from: http://www.uniform-net.jp/example/voice-1632.

WCED. 1987. *World Commission on Environment and Development. Our common future*. Oxford: Oxford University Press.

Yoshihara T, Matsumura H, Tsuzaki M, Wakamatsu T, Kobayashi T, Hashida S, Nagaoka T, Goto F. 2014. Changes in radiocesium contamination from Fukushima in foliar parts of 10 common tree species in Japan between 2011 and 2013. *J. Environ. Radioact.* 138: 220–226.

Yoshioka T. 2020. Efforts Toward Erasing Anxiety over Radiation and Regional Recovery by Alpine. In: *NEA Workshop on "preparedness for post-accident recovery process: lessons from experience"*, Tokyo, Japan. Available from: https://www.oecd-nea.org/download/wpnem/Tokyo2020JointWorkshop/documents/4-4_Tokyo2020Workshop_TadashiYoshioka.pdf.

Zhang H, Dolan C, Jing SM, Uyimleshi, Dodd P. 2019. Bounce Forward: Economic Recovery in Post-Disaster Fukushima. *Sustainability* 11: 6736.

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