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Examples of practical activities related to public understanding of radiation risk following the Fukushima nuclear accident

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Abstract – After the Fukushima nuclear accident in Japan, a number of practical activities related to public understanding (PU) of radiation risks were implemented inside and outside Fukushima Prefecture. The various noteworthy approaches and strategies behind those practical activities have not been organized and made explicit thus far. In this study, we have organized the noteworthy practical activities related to PU of radiation risks following the Fukushima nuclear accident, and discussed them mainly from the standpoints of communication strategies and approaches. As several examples demonstrate, efforts to contextualize and localize radiation risk in various forms were observed during post-accident recovery in Fukushima, and these efforts were confirmed, through actual experiences, to be an important component of effective PU activities of radiation risks. Community-based or citizen science approaches, such as having affected residents or citizens to measure radioactivity, have contributed to the PU of radiological situations, but some challenges, such as ethical aspects and the handling of uncertainty, have also been revealed. In the era of information and communications technology, a number of citizens, experts, and agencies have made social media a popular platform for disseminating radiation risk messages to the public and have demonstrated that social media can play an important role in providing radiological risk information. The knowledge and lessons learned from the practical activities discussed in this study can be useful in enhancing PU of risks not only radiation but also other stressors such as toxic chemicals, preparing future disasters and supporting risk communication plans during recovery periods after disasters.

Keywords: risk communication / Fukushima nuclear accident / radiological protection / public understanding

1 Introduction

After the Fukushima nuclear accident in Japan, a number of practical activities related to public understanding (PU) of radiation risks were implemented inside and outside Fukushima prefecture. Although the large amount of information provided to people does not appear to have significantly improved PU of radiation risks, the quality of the information may have only accelerated the bifurcation of the public debate because of different ideas and opinions expressed by radiation experts *via* the news media (Science Council of Japan, 2014). The experience with PU of Genetically Modified Organisms (GMO) and Bovine Spongiform Encephalopathy (BSE) issues in UK has led to a shift from a "deficit model" style of communication to two-way communication between the public and scientific communities. In the immediate aftermath of the Fukushima nuclear accident, many radiation risk communication practices were a form of the "deficit model" communication style; as time passed, interactive or collaborative two-way styles of communication have appeared (Horikoshi *et al.*, 2019). A number of interactive practical activities, including pragmatic researches related to PU of radiation risk, gradually emerged after the Fukushima nuclear accident. Innovative or unique forms of practical PU activities, such as the social networking service (SNS) and citizen science

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approaches, were also realized. Amidst growing anxiety about radiation risks in the wake of the accident, citizen scientists in Japan and abroad voluntarily collected information on radiation exposure and disseminated it to the public using SNS and other means, apart from official information sources (Brown *et al.*, 2016). Citizen science is the practice of public participation and collaboration in scientific activities, such as the collection and analysis of empirical data. In recent years, the use of advanced information technology such as smartphones and GPS receivers has become more popular in collecting scientific data, especially in Europe and the United States. This is emblematic of the nature of PU activity in the era of information and communication technology (ICT). Co-expertise processes (Lochard *et al.*, 2020) and community-based approaches were also observed in affected areas of Fukushima. Many activities related to PU of radiation risks implemented in Japan are not well organized or documented in the literature, are sometimes documented only in Japanese, or are inconspicuous, making it impossible to refer to them even if they could contribute to important lessons regarding the PU of radiation risks in the future.

Horikoshi *et al.* (2019) examined approximately 500 pragmatic researches and activities related to radiation risk reduction and communication after the Fukushima accident using cross tabulation, text mining, and correspondence analysis. They evaluated the contributions of academia/experts and revealed that the main practical activities changed over time and that the activities differed by area. Murakami *et al.* (2017) reviewed medical professionals' risk communication activities in Fukushima Prefecture from the prefectural level to the individual level and found that the activities generally started with communication about radiation risks, mainly through group-based discussions, but gradually shifted to face-to-face communications to address comprehensive health risks to individuals and their well being. They observed that the purpose of these activities shifted from "promoting scientific understanding" to "supporting the decision-making of residents (Engagement)". Yamaguchi *et al.* (2018) reviewed risk communication guidelines and public health activities regarding radiation risk communication after the Fukushima disaster and concluded that successful practices are those that are helpful to the local community, supported by the local community, and observable in the local community, and that are supported by strategic approaches with a team organized by many experts in local areas, including local risk communicators.

Although the above-mentioned studies provided valuable insights into the activities related to PU of radiation risk, few studies have reviewed the practical PU activities of radiation risk implemented after the accident or attempted to make them knowledgeable or to discuss lessons learned in order to prepare for future nuclear accidents. Various approaches and strategies underlie the activities related to PU of radiation risks conducted after the accident, but these have not been well organized or made explicit thus far. In the current paper, we have organized the noteworthy activities related to PU of radiation risks implemented after the accident and discussed them mainly from the standpoint of communication strategies and approaches.

2 Methods

Examples of practical activities related to PU of radiation risk after the Fukushima accident were collected from the database (about 500 in total) created in Horikoshi *et al.* (2019), as well as from academic papers, government reports, websites, and books. The database from Horikoshi *et al.* (2019) covered practical activities reported between 2011 and March 2017. The first author first selected candidate examples for analysis, and then, based on discussions among co-authors, determined which examples to analyze. We selected those that featured either two-way communications among stakeholders or an innovative or unique means of communication. Each extracted example was systematically organized using an information organization sheet. Each example was analyzed and discussed from the perspective of communication approaches and strategies, and an attempt was made to identify characteristics and lessons learned that could be used as a reference for future activities to improve PU of radiation risk.

3 Results

3.1 Overview of selected practical activities related to PU of radiation risk

Examples of the practical activities covered in this analysis are shown in Table 1. Twenty-one examples were extracted and categorized into five categories: community-based approach (CBA; seven examples), researcher (including academic institution)-driven approach (RDA; two examples), dialogue and meeting (DM; two examples), citizen science approach (CSA; two examples), and innovative or unique communication strategies and approaches (IUCSA; eight examples). The characteristics of the examples in each category are described below. Although categorization is not a common practice, it is organized according to these categories for convenience. There are also examples of practical activities that include elements of more than one category.

In the present paper, CBA is defined as an approach in which affected communities are actively engaged in planning, monitoring, and evaluating the radiological situation of the local environment with the help of experts. In the selected examples, the community or local residents play a central role in understanding radiological situations in their local environments. The process of measuring and interpreting their own radiation levels in their environment by themselves, sometimes with the help of experts, is a hallmark of these examples. Although radioactivity measurement is a necessary component in the selected PU activities, the ultimate objectives of the activities addressed here were to determine whether it was possible to live safely, reclaim daily life, or start agricultural activities in affected areas, or whether further measures were needed. In addition, some activities introduced here have been recognized as good examples of a co-expertise process in the aftermath of the accident (Schneider *et al.*, 2019; Lochard *et al.*, 2020).

RDA is defined as an approach in which PU activities related to radiation risk are driven mainly by institutional and academic researchers. There are many examples of such

Table 1. Examples of practical activities related to PU of radiation risk implemented in Fukushima.

Category * -ID	Name	Organizers /participants	Beneficiaries	Purpose	Main activities	Key features	Period	Ref.
CBA-1	Radiation measurements in Suetsugi Community, Iwaki	Local residents and experts	Local residents	To understand the possibilities of resuming agricultural activities in the community	Measuring ambient dose rates and radiocesium concentrations in soil and food in order to understand the local radiological situation; also, the whole-body measurement of residents.	Co-expertise process, leadership presence	2011–	Lochard *et al.*, 2020; Endo, 2016; Schneider *et al.*, 2019; Ando, 2015
CBA-2	Radiation measurement in Okubo-Yosouchi community, Iitate village	Local residents and experts	Local residents	To assess the status of radiation and revitalize communities and agriculture	Measuring ambient dose rates and radiocesium concentrations in soil to understand the local radiological situation	Co-expertise process, leadership presence	2013–2016	Moritomo, 2016; Ishii *et al.*, 2017
CBA-3	The Iwaki Oceanographic Research Team Umi-Labo	Local residents and experts	Local residents	To understand the current situation of the Iwaki sea	Catching and cooking fish, and measuring radiocesium in fish to understand the marine radiological situation offshore of the Fukushima Daiichi Nuclear Accident Site	Citizen-led activity, learning by doing	2013–	Komatsu, 2018; Igarashi, 2018
CBA-4	Radiation measurements and interactive learning program, “Yamakiya School”	Local residents and experts	Local residents	To strengthen the local community, to deal with the lack of local resources, and to encourage local agriculture	Measuring ambient dose rates and radiocesium concentrations in local food and experiential learning	Co-expertise process, learning by doing, leadership presence	2017–	Yasutaka *et al.*, 2020
CBA-5	“Resurrection of Fukushima”	NPO, managed by volunteers and farmers, experts	Villagers of Iitate	To rebuild lives and reconstruct agricultural-centered industries on Iitate village	Measuring radiation and analyzing radioactivity; developing decontamination technologies, pilot projects for the revitalization of agriculture, pilot projects for the creation of new industries; care for the victims *e.g.*, health care for the residents, disclosure of the information gathered in the area to the rest of the world	Co-expertise process	2011–	Kanno *et al.*, 2014

Table 1. (continued).

Category -ID	* Name	Organizers /participants	Beneficiaries	Purpose	Main activities	Key features	Period	Ref.
CBA-6	"D-Shuttle" Project by Fukushima High School	High school students	Local students, academic community	To understand the current situation in Fukushima and tell the world about Fukushima	Led by high-school students, measuring individual external doses by D-shuttle inside and outside Fukushima	Student-led activity	2014–2016	Hara *et al.*, 2015; Adachi *et al.*, 2015
CBA-7	"Roundtable meeting for Kashiwan Products for the Kashiwan People"	Local farmers and consumers, experts	Local farmers and consumers	To build trust to sell and consume local agricultural products	Measuring local agricultural products by local stakeholders, deciding "measurement methods" and "standards" by themselves	Public engagement, leadership presence	2011–2012	Igarashi, 2012
RDA-1	Collaborative pragmatic research led by researchers	Academic researchers with help of local people	Scientific community and authorities	To obtain empirical evidence in order to understand realistic radiological conditions of the affected areas	Measuring radiation levels in the affected areas in Fukushima with help of local residents and local authorities	Community-based research, public engagement, building trust	2011–	Naito *et al.*, 2016, 2017; Yoshida-Ohuchi *et al.*, 2016, 2020
RDA-2	Initiatives driven by academic institutions (*e.g.*, Nagasaki University)	Universities	Local community and scientific community	To provide scientific support for the residents' return to the former evacuation areas and for reconstruction	Measuring radiation levels in local environments and conducting individual consulting on radiation exposure and health by a public health nurse who stayed in the area for a long period	Co-expertise process	2011–	Takamura *et al.*, 2018
DM-1	ICRP/Fukushima Dialogue	ICRP, local volunteers, NPO "Fukushima Dialogue"	Local residents, general public, international radiation protection experts	To help recovery after the Fukushima Daiichi accident by giving local people a forum to share experiences, and an opportunity to work together with experts from Japan and beyond	Conducting dialogue meetings, site visits for participants, and ICRP to understand the challenges faced by local residents, to learn from this experience, and to reflect it in revised ICRP recommendations for recovery after major nuclear accidents	Authority-led risk communication	2011–	Ando, 2016; Lochard *et al.*, 2019
DM-2	"Yorozu" health consultation project	FMU	Iitate villagers	To reduce anxiety about radiation and health	Medical professionals, including volunteers, go to each municipality to provide one-on-one health consultations for residents. The consultation is not limited to radiation	Application of proven dialogue methodology (IDPA methodology)	2011–	Murakami *et al.*, 2017

Table 1. (continued).

Category -ID	* Name	Organizers /participants	Beneficiaries	Purpose	Main activities	Key features	Period	Ref.
CSA-1	Safe Cast	NPO, international volunteers	General Public	To create useful, accessible, and granular environmental data (*e.g.*, environmental radiation)	Measuring radiation and posting the data online	Citizen science	2011–	Brown *et al.*, 2016
CSA-2	Minna-no (everyone's) Data Site (Collective Database of Citizens' Radioactivity Measuring Labs)	NPO, local laboratories	General public	To integrate all of the radioactivity measurement data into a common platform and disseminate them to the public	Collecting and publicizing radioactivity measurement data from the participating measurement laboratories, to improve the knowledge and measuring techniques of the participating measurement laboratories, to carry out our own analysis and survey research based on the collected data, to publish opinions based on the results of our survey research with the aim of influencing countermeasures and resolving problems related to radioactive contamination	Citizen science	2013–	Citizens' Radiation Data Map of Japan Project Team, 2018
ICSA-1	"Questions and Answers about Radiation in Daily Life"	Japanese Health Physics Society	General public	To provide the right information on radiation to concerned citizens	Answering radiation-related questions from the public and publicizing Q&As on the website	Academic society-led activity, easy-to-understand format, Q&A format	2011–2012	Ogino, 2012; Kono *et al.*, 2020
ICSA-2	"Radiation Quartet"	National Institute of Public Health	General public	To understand radiation while playing cards	Developing educational tool	Innovative approach, educational tool	2014	Horiguchi, 2013
ICSA-3	"Nasubi no Gimon" ("Nasubi Asks Questions")	MOE	General public	To share correct information that eliminates misconceptions about situations in Fukushima	Nasubi, a Japanese comedian from Fukushima Prefecture, asked experts various questions regarding radiological conditions in Fukushima and publicized easy-to-understand messages in cartoons	A comic book, website and movies	2014–	MOE, 2014
ICSA-4	"Kawaraban Michishirube" A public relations magazine about radiation	Iitate village and academic institutions	Villagers	To provide information about radiation and health, mainly for evacuated villagers	Writing articles and publicizing them in public relations magazine "Kawaraban Michishirube"	Stakeholder involvement, easy-to-read public relations magazine,	2012–2016	Iitate village, 2012

Table 1. (continued).

Category -ID	* Name	Organizers /participants	Beneficiaries	Purpose	Main activities	Key features	Period	Ref.
	and health for Intate villagers					contextualization and localization		
ICSA-5	"Information Booklet for Returnees"	Experts, MOE	Local experts	A communication tool between local experts and residents, to help local experts build trust with local people by providing them with needed information	NA	Contextualization and localization, collaboration with local people through local experts, co-expertise process	2017–2018	Kuroda, 2020
ISCA-6	Dr. Tsubokura's radiation classroom	Local newspaper	Local public	To provide information on radiation	A local doctor writes a series of columns in the local newspaper focusing on the topic of radiation.	Information dissemination by local newspaper, short columns and familiar topics	2015–	Fukushima Minyu, 2015
ISCA-7	Active E-learning of ICRP111 on Twitter	Twitter users	Twitter users	To gain information and lessons from ICRP Publication 111.	A Fukushima-based Twitter user played the role of a teacher and explained ICRP111 on twitter in a series of posts. Friend users, including is a radiation expert, asked questions as "students" and discussed it. The activity was later published as an e-book	Effective use of SNS, virtual communication	2012	@J_Tphoto and @buvery, 2012
ISCA-8	Communications on decontamination of Date City	Date City officers	Local residents	To gain an understanding and consensus among the residents for decontamination works and to determine temporary storage sites	Using plastic beads to visualize invisible radiocesium in the environment and the effect of decontamination on reducing radiation exposure	Leadership presence, innovative communication	2011–	Date City, 2014

initiatives conducted by researchers in cooperation with residents, such as (Naito *et al.*, 2016, 2017; Yoshida-Ohuchi *et al.*, 2016, 2020). Researchers from outside Fukushima, with the cooperation of local residents, measured personal or air doses of radioactivity in living environments such as houses, and explained the results to the residents. Some universities set up satellite offices in the evacuation municipalities and conducted risk communication for residents. In the village of Kawauchi and the town of Tomioka, the Nagasaki University has been involved in communication with residents by stationing specialists in the satellite offices to build a sense of trust with them (Takamura *et al.*, 2018). The cases selected here were distinctive in that not only were the results of individual measurements fed back to the participants or local community, but the results were summarized in academic papers and often utilized as reference materials in municipal and government decision-making processes.

Many dialogues and meetings were held to improve PU of radiation risk after the Fukushima accident, such as ICRP Dialogue/Fukushima Dialogue and the activities conducted by Fukushima Medical University. ICRP Dialogue/Fukushima Dialogue was a series of dialogue meetings involving national and international experts and local residents (Lochard *et al.*, 2019). Flexible themes were discussed, depending on the time of year, and were used to build relationships and share awareness of issues. The application of a proven dialogue method, *i.e.* IDPA (Identification, Diagnosis, Prospective, Action proposals) method (EURANOS, 2009), contributed to the sharing of values, the promotion of mutual understanding, and an understanding of the diversity of "interpretations" among residents. In the Yorozu ("general") Health Consultation, one of many risk communication activities initiated by Fukushima Medical University, medical personnel visit municipalities to provide health consultations for local residents (Murakami *et al.*, 2017). Hundreds of volunteer medical personnel from all over Japan participated as consultants. Consultations are held during events such as mass medical checkups in municipalities and are designed to reduce the avoidance of learning about radiation by creating a "face-to-face relationship" through one-on-one communication and not limiting the consultation to the subject of radiation. These examples are unique in that they are designed to be places where participants can share their experiences and thoughts not only about radiation, but also about their present and future life as well as their health concerns regarding living in the affected areas.

Citizen science refers to scientific activities performed by amateur scientists. Following the Fukushima accident, some citizen science groups endeavored to fill data gaps, as citizen group members in Japan measured radioactivity in the environment and communicated the results *via* the Internet (*e.g.*, Brown *et al.*, 2016; Citizens' Radiation Data Map of Japan Project Team, 2018). Citizen science activities addressed here played an important role in improving the PU of radiation by confirming the reliability of radioactivity measurements in the environment by the government and obtaining data in areas the government does not cover.

A number of innovative and unique initiatives were implemented to improve the PU of radiation risk following the Fukushima accident. These include preparing materials that respond to residents' actual concerns, using unique visual effects to explain the current radiological situation and decontamination, communication through games and online information–entertainment learning programs, and using social networking sites such as Twitter for active learning sessions.

4 Discussion (lessons learned)

As summarized above, during the recovery phase after the Fukushima accident, many unique and interesting PU initiatives and practices were implemented inside and outside Fukushima. We believe it is possible to identify several key lessons for improving PU practices for radiological risk and protection, especially in the recovery phase after a nuclear accident. In the following section, we discuss several important tips learned from those examples.

4.1 Contextualization and localization of radiation risk

Contextualizing radiation risks in the context of everyday life could help the public understand radiation risks. A number of risk communication efforts presented in this paper have been undertaken to convey the risks of radiation in the context of local life and needs. For example, community-based monitoring programs working with scientists to measure and understand radiation in the living environment have been implemented elsewhere in the post-accident recovery (Dubreuil *et al.*, 1999) . They include measuring internal and external radiation exposure as well as radiation levels in locally produced foods. Measuring radiation was necessary for local residents to understand the radiological conditions in their living environment as they sought to resume livelihoods and agricultural activities in the affected areas. "Information Booklet for Returnees", published by the Japanese Ministry of Education (MOE), was created for local counsellors to use as a communication tool to address the concerns and needs of returnees (Kuroda, 2020). Questions raised in the booklet were linked with residents' actual concerns of radiation risk in the context of their everyday life. The Yorozu ("general") health consultation project led by FMU started one-to-one health consultations with local residents; the program was run by local government public health nurses in 2012. They set up booths at public health-check venues, listened to people's concerns, responded individually to questions from the nurses, and provided educational material for them (Murakami *et al.*, 2017). Such general health consultations could provide opportunities for local residents to share their local or individual concerns about radiation exposure and other health issues. Local public health nurses played an important role by listening and responding to various health concerns of those living in affected areas. Measurements by a whole-body counter (WBC), which measures internal radiation levels within the body, have been used to communicate risk between medical professionals and local residents in Fukushima (Hayano *et al.*, 2014; Tsubokura *et al.*, 2020). In Minamisoma Municipal General Hospital, a physician explained WBC results to each examinee and offered outpatient counseling to people with >20 Bq/kg of ^{137}Cs to discuss lifestyle choices, with a focus on food selection. Such consultations provide an opportunity for people to understand radiation exposure in their daily lives.

The experiences gained from PU activities after the Fukushima accident demonstrated that the contextualization and localization of radiation risks in the living environment can be effective at improving PU of radiation risks. A similar lesson was learned from Brian Wynne's study of Cumbrian sheep farmers, in which Wynne emphasized "knowledge in context" and illustrated the need for improved, two-way communication between scientists and the involved public during emergency situations (Wynne, 1989). Efforts to contextualize and localize radiation risk in various forms could provide valuable information with which to prepare and implement communication strategies and approaches that help the public understand radiation risk in living environments.

4.2 Public involvement in radiological protection

After the Fukushima accident, a variety of public-involved studies and monitoring programs were implemented to enhance people's understanding of radiological situations. Public-involved studies or monitoring programs can be broadly divided into two approach types: top-down and bottom-up. In the top-down approach, formal institutions such as research institutions, universities, and NPOs initiate public engagement and citizens collect radiation measurement data for them. On the other hand, the bottom-up approach involves public-initiated or public-driven practices, such as measuring ambient dose rates in the environment or concentrations of radioactive materials such as ^{137}Cs in food items. In the post-accident situation in Fukushima, both the top-down and bottom-up approaches certainly were taken and both played important roles in improving the PU of radiation risks. The involvement of Nagasaki University with Kawauchi village (Takamura *et al.*, 2018), a community-based participatory radiation measurement in Yamakiya (Yasutaka *et al.*, 2020), and individual dose measurements designed by institutional researchers (Naito *et al.*, 2016) can be categorized as examples of the top-down approach. While there have been numerous top-down practices, including examples presented here, the selected examples are unique in that these activities are long lasting and have been adapted to changing circumstances. Although the primary purpose of top-down approaches led by formal institutions or institutional scientists was to obtain scientific knowledge in the affected areas, in some cases the monitoring activities evolved into activities that contributed to solving local problems through close interaction with local residents rather than just acquiring radiation data by researchers (Yasutaka *et al.*, 2020). Community-based radiation measurement studies conducted by the present authors (Naito *et al.*, 2017) in the affected areas in Fukushima met the needs of the local residents and helped them to understand the actual radiological situations in their living environment and their own radiation exposure. The dialogue with the local residents provided a good opportunity for the researchers to learn about residents' needs, and their local knowledge was very helpful in interpreting the measurement data. The proactive involvement of local residents is important in understanding and solving radiological risk problems, as the case of Fukushima confirmed. The measurement of radiation by residents can be a solution to a problem (*e.g.*, relieving anxiety), but it can also be limited to the discovery of a problem (*e.g.*, discovery of a high dose level or the generation of anxiety). Appropriate countermeasures cannot always be presented. When conducting research in collaboration with local residents, it is necessary to pay attention to the possibility that the research results may negatively impact both the local residents and society.

While the cases mentioned above were targeted to local residents in the affected areas of Fukushima, some activities involving the general public at the national and international levels were also noteworthy. Safecast and Minna-no-data-site ("Everyone's Data Site"), which are categorized as citizen science approaches, have been collaborating with the public on collecting and sharing radiation data. Their activities could provide insightful data that can promote PU of radiation exposure in the environment.

4.3 PU of radiation risk in the era of ICT

The growth of information and communication technologies has made social media popular for disseminating radiation risk messages by citizens, experts, and agencies. The Fukushima nuclear accident was the first large-scale nuclear disaster to occur in the era of ICT. After the accident, the results of radiation measurements and monitoring information from various entities were released on websites and *via* SNS. SafeCast and Minna-no-data-site are typical of those cases. A noteworthy initiative was an interactive study group that emerged in virtual space on SNS. The idea was that experts became the commentators and non-experts became the learners, reading and understanding ICRP 111. This two-way learning exchange became a publication (@J_Tphoto and @buvery, 2012). Due to the nature of Twitter, information is provided mainly in one direction, but a virtual community like this one attempted to search for two-way communication on the Internet. The process of scientific data acquisition and dissemination by the public or citizen scientists is expected to become more widespread. The impact on PU of science can be significant. On the other hand, there are various challenges, including ethical issues. Ethical issues related to citizen science should be addressed when projects start and throughout the course of scientific and communication activities.

4.4 The presence of driving forces or mediators in PU activities

For the PU activities implemented after the Fukushima nuclear accident, some individuals have been important driving forces or mediators, such as founders of NGOs, local farmers, local government officials, medical doctors, and scientists. Such personnel were clearly present in examples of CBA-1, CBA-2, CBA-4, and ISCA-8. Some experts have supported the residents' data collection, analysis, and interpretation, and acted as mediators between residents and authorities or residents and experts. Schoolteachers, public health nurses, and administrative ward chairpersons who worked in the affected areas before and after the accident, also have been instrumental in helping the affected residents. An administrative ward chairperson used their traditional community decision-making channel to initiate a community-based radiation monitoring program. The presence of such personnel could help the public understand the radiological situation and their own exposure to radiation, and could help them regain confidence that there is a future for the affected areas in Fukushima. Honda *et al.* (2020), who conducted interviews with ten risk communicators after the accident, suggested that having professional and empirical knowledge founded on professional ethics is an important element that supports and facilitates risk communication works. The presence of driving forces or mediators who consistently conduct their work and activities based on professional ethics and expertise can also help to promote PU activities and build trust among stakeholders.

4.5 Limitations and challenges

A few limitations worth noting. First, this study does not cover all the PU activities implemented following the Fukushima nuclear accident. For example, there is limited discussion of practical activities for PU related to radiation risk that were implemented by medical professionals. Undocumented resident-driven activities are not covered. We may have eliminated valuable practical activities that include relevant information. However, we are confident that the examples selected, as well as the lessons learned from them, adequately covered the important aspect of PU of radiation risk, since the examples were selected by authors who have been involved in PU activities in Fukushima and discussion in the Task Group on PU activities after the accident in the Japan Health Physics Society. Another limitation is that the identification of good practices was a subjective process from the viewpoints of experts. Evaluations of PU activities from recipients' perspectives are missing. In order to objectively evaluate the effectiveness of practical activities related to PU of radiation risk, it is also necessary to evaluate what risk communication has been effective for residents and what has been helpful from the public's perspective.

One challenge is how to spread the good PU practices of one community to other communities. The purpose of a community-based approach led by local people was to solve problems in one's own community, and these efforts by themselves did not provide much in the way of support or development in other areas. The presence of enthusiastic personnel is an important element of good practice, but not all communities have such personnel. In their absence, it would be important to consider what mechanisms and systems need to be in place. Opportunities such as interregional exchange dialogues could contribute to aid and develop a form of PU that meets the needs of the area.

Another challenge is ensuring the sustainability of budgets and human resources for PU activities. The continuity of practical activities requires a budget. The continuity of such activities to obtain scientific evidence also depends on budgets and human resources. While some activities are sufficient for a successful PU as part of a transitory effort, they often require continuous monitoring. Continuous efforts are also important for building trust between residents and scientists.

5 Conclusion

In this study, we have reviewed the noteworthy activities to improve PU of radiation risks conducted after the Fukushima, Japan, nuclear accident in terms of communication strategies and approaches, and discussed lessons learned and challenges remaining. During the post-accident recovery phase, a wide range of practical activities related to PU of radiation risks were conducted inside and outside Fukushima. We draw several key lessons and challenges for improving PU practices for radiological risk and protection, especially in the recovery phase of a post-nuclear accident. As seen in the various examples, efforts to contextualize and localize radiation risk in various forms were observed during post-accident recovery, and these efforts were confirmed, through actual experiences, to be an important component of effective PU activities of radiation risks. There were several noteworthy examples of community-based or citizen science approaches to radiation risk PU practices implemented in Japan. Experiences with such approaches, such as residents measuring radiation levels, have been proven to contribute to PU of radioactive situations, but some challenges, such as ethical issues and the handling of uncertainty, should be noted. As the Fukushima nuclear accident was the first large-scale nuclear disaster to occur in the era of ICT, a number of citizens, experts, and agencies have made social media a popular way to disseminate radiation risk messages to the public and demonstrated that social media can play important roles in providing radiological risk information. Moreover, the presence of driving forces or mediators who consistently conduct their work and activities based on professional ethics and expertise can also contribute to PU activities and help build trust among stakeholders.

Fitzpatrick-Lewis *et al.* (2010) suggested that risk communication strategies incorporating the needs of local residents with a multifaceted delivery method are most effective at reaching a target audience. While the PU of science is important, it is also important for scientists to understand the public (Fujigaki *et al.*, 2008). Many of the activities brought about by experts after the Fukushima accident were aimed primarily at improving the PU of radiation risk, that is, at providing knowledge to the public. On the other hand, experts themselves considered their interactions with the population and its ethical norms, leading them to turn to activities such as public engagement, which are characterized by activities to support the decision-making of the population (Murakami *et al.*, 2017). The body of knowledge and lessons learned from practical activities introduced and discussed in this study can be useful in enhancing PU of not only radiation but also other disaster situations such as chemical accidents. They can also help us prepare for future disasters and support risk communication plans during recovery periods.

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