

ORIGINAL ARTICLE

Extracting information content on radiation risks from the receiver perspective: Examining Fukushima residents 10 years after the Fukushima nuclear reactor accident

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Abstract

The purpose of this study was to clarify how more useful information could be provided to Fukushima Prefecture residents (below, information “receivers”), who are still anxious about radiation risks 10 years after the Fukushima Nuclear Reactor accident. Using the mental model approach, mental models on radiation risks were developed for experts and receivers, with Fukushima residents being the expected readers. The degree of anxiety among receivers about radiation immediately after the accident was compared with their current degree of anxiety, and they were divided into two groups (those with reduced anxiety and those with unchanged anxiety) to create mental models. By comparing the three models, it was found that the receivers generally understand the effects of radiation on health, the environmental dosages, their relationship with the human body, and decontamination methods and effectiveness. It was also observed that they are uninformed about the properties of radioactive substances, effective doses, and expulsion of ingested radioactive substances. There were no major differences between the two receiver models, suggesting that the content and extent of knowledge regarding radiation risks are not directly linked to current anxiety. However, the group with reduced anxiety had a greater level of basic radiation knowledge, suggesting that after the accident, they sought out or recalled more of the knowledge provided.

KEYWORDS

Fukushima, mental model, nuclear reactor accident, radiation risk

1 | RESEARCH BACKGROUND AND OBJECTIVES

1.1 | An overview of the TEPCO Fukushima No. 1 Nuclear Reactor accident and its consequences

Set off by the Great East Japan Earthquake and subsequent tsunami that occurred on March 11, 2011, the Tokyo Electric Power Company Holdings, Inc. (below, TEPCO) Fukushima No. 1 Nuclear Reactor experienced an extremely serious accident (below, Fukushima nuclear accident), ranked at Level 7 on the International Nuclear and Radiological Event

Scale (INES) 8 (National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, 2012). As a result of this accident, radioactive materials equivalent to about 1/6 of the Chernobyl disaster in terms of iodine were released, and about 150,000 residents were evacuated under government evacuation orders (according to the Fukushima prefectural government, 164,865 people were evacuated in May 2012). As of 2021, radiation levels had decreased to less than 1/20 of what they were immediately after the accident, but by December 2022, 28,000 people had been evacuated in and out of Fukushima Prefecture (Reconstruction Agency, 2023).

Multiple surveys have revealed that the accident increased Fukushima residents' risk perception and anxiety about the

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health effects of radiation (Kono et al., 2022, Murakami et al., 2018; Takebayashi et al., 2017).

In this context, the Fukushima prefectural government began holding lectures on radiation risks from March 20, 2011, onward (Fukushima Minpo News, March 19, 2011, morning edition). The headline of an article reporting on the two lectures was “Don’t overreact to radiation risks,” with a clear statement that “there is no effect on the health of the citizens at all” (Fukushima Minpo News, March 21, 2011, morning edition). Subsequently, in response to the recommendation of the Coordinating Council for Countermeasures for Health Concerns of Nuclear Disaster Victims (Committee Coordinating Measures on Health Concerns of Nuclear Disaster Victims, 2012), the Ministry of the Environment (MoE) developed the “Action Plan on Measures on Health Concerns of Nuclear Disaster Victims” (MoE, 2012) because victims’ concerns had not been sufficiently resolved. From February 2014, a “policy package on communicating radiation risks toward return” was developed, with policies aimed at resolving anxiety and encouraging evacuees to return (MoE, 2014). In 2021, a project was launched to “create a place that empowers citizens to read and understand information on the health effects of radiation and the ability to make judgments without being misled by rumors” (MoE, 2021). The project aims to provide scientifically accurate information with the numerical goal of “reducing the percentage of people who believe that Fukushima residents are at risk of health effects impacting the next generation due to current radiation exposure from 40% (as measured in 2020) to 20%” by FY2025.

In other words, immediately after the accident, the Japanese government’s approach was to inform the inhabitants of Fukushima Prefecture about radiation risks and to reduce concerns about health effects. In line with this policy, many of the various information provision activities carried out to date have focused on providing accurate information more quickly in an easy-to-understand manner and across a variety of media in order to reduce excessively heightened concerns and correct misunderstandings (Kono et al., 2020). According to Kikkawa (2012), “since the 3/11 disaster, risk communication has become a hot topic. However, most of the effort applied in this regard has been misdirected,” identifying experts’ attitudes toward and misunderstandings of risk communication as the root of the information provision problem. In particular, the expression “worrying the right way” implies a “deficiency model,” in which people disagree about risks because they lack appropriate scientific knowledge.

Many people are still concerned about the effects of radiation on Fukushima Prefecture residents. For example, in a public opinion poll (telephone survey) conducted on an ongoing basis by Asahi Shimbun and Fukushima Broadcasting Corporation since 2011, asking Fukushima Prefecture residents about their concerns regarding “the effects of radioactive materials on themselves and their families,” 64% of respondents (16% to a great extent + 48% to some extent) felt anxious about effects of radiation on their health in the 2021 survey (Asahi Shimbun Digital, 2021). After peaking at 91% in 2011, the percentage of such anxiety has been declining, although it has stayed approximately flat at around

60% since 2019 (Asahi Shimbun Digital, 2019, 2021), indicating that the level of anxiety among prefectural residents has stopped declining. Sato and Lyamzina (2018) also found from a case study that the limitations and new challenges of radiation accident recovery efforts cause people to be concerned about radiation exposure, suggesting that concerns about radiation do not necessarily decay linearly over time.

As Kikkawa (2012) pointed out, past information provision activities by the national government and the MoE were focused on providing scientifically accurate information to fill the knowledge gap among Fukushima residents and may have thus overlooked the residents’ information needs and concerns. Consequently, although much information was provided by experts, prefectural residents did not receive it, which may be linked to their lack of understanding of radiation risks or a reduction in anxiety.

1.2 | Study objectives

The purpose of this study is to clarify the information content that receivers are seeking and to resolve the above-mentioned mismatch between the information conveyed by experts and the information sought by receivers in order to help Fukushima residents understand their own situation and support their self-determination regarding their own risks in accordance with their own knowledge and anxiety levels regarding radiation health risks.

From the Fukushima nuclear power plant accident to the present, because of the active provision of information by the national and prefectural governments, TEPCO, and researchers in related specialized fields, almost all scientific facts on radiation health effects have been made public, and numerous resources with easy-to-understand expressions and diagrams have been prepared for non-specialists. However, such information were prepared based on expert knowledge structures with the intention of changing behavior, such as alleviating anxiety and promoting evacuee return, and those information might not have been accepted because they did not match the structure of knowledge and understanding of the people of Fukushima Prefecture.

Therefore, the purpose of this study is to gain knowledge for developing information materials that enable understanding of individual situations and decision-making processes based on receivers’ knowledge and cognitive structures. For this purpose, this study uses the mental model approach (Morgan et al., 2002) to clarify the differences in the knowledge and cognitive structures (mental models) of experts and Fukushima residents. The results will be used to clarify what was not sufficiently conveyed to recipients in existing information materials and what receivers are currently seeking.

1.3 | Mental model approach

The mental model approach is a five-step method proposed by Morgan et al. (2002) to create and retest risk messages in a way that is faithful to the science of risk and communication.

A mental model is a body of information and framework that a person uses to understand the world. According to Morgan et al., for risk communication to be authoritative, it must reflect the understanding of experts. Therefore, the first step in this methodology is to create a diagram summarizing the relevant expert knowledge. This diagram is called an “expert model,” but the information contained in it should not be from the mind of a single expert, but rather a combination of knowledge from multiple disciplines relevant to the risk problem. Then a mental model of the information receiver is created for the relevant risk issue in the second and third steps. In the fourth step, a risk message is created based on a comparison of the expert model and the receiver model, and the prototyped message is evaluated in the last step.

This approach has been used to develop and improve materials for risk communication and has been studied, for example, on the subject of infectious disease (Fischhoff & Downs, 1997; Morgan et al., 2002), radiation waste risks (Skarlatidou et al., 2012), and responses to nuclear emergencies (Zelevnik et al., 2020).

This approach emphasizes clarifying the information content that should be provided based on the receivers’ mental model. The experts’ mental model is a reference source of scientific knowledge that corresponds to the information sought by the receivers. It is not a method for finding the information content that should be provided so that the receivers’ mental model approximates the experts’ model.

2 | MATERIALS AND METHODS

This section describes a method for creating mental models of experts and receivers using the mental model approach.

2.1 | Experts’ mental model

Morgan et al. (2002) proposed several types of methods to create mental model. For example, Bostrom et al. (1992) used the assembly method to make an influence diagram of radon exposure at home. The diagram was developed primarily by engineers with expertise in nuclear and environmental issues, in consultation with authors and external reviewers. The scenario method describes the influence diagram as a causal chain of event in which something happens, something else happens, and eventually someone gets hurt. The influence diagram for the risk posed by a nuclear energy source on spacecraft was drawn along the lines of a scenario initiated by various possible breakdowns. It was primarily developed by an engineer with aerospace systems backgrounds, and a simplified version was reproduced (Maharik & Fischhoff, 1993a). In some cases, the model is created by a person with expertise in the subject risk, whereas in other cases, the expert is created based on interviews with experts in related fields (Skarlatidou et al., 2012; Zelevnik et al., 2020).

In this study, we created the influence diagram based on interviews with several experts, and it follows two routes from the source of the risk to the reconstruction of the

area: one route related to radioactive materials in the living environment and the other route related to human health effects.

When extracting the areas of expertise for interviews toward the creation of the experts’ mental model, we interviewed experts with experience in holding safety and security forums in Fukushima Prefecture as members of the Nuclear Safety Investigative Advisory of the Atomic Energy Society of Japan and organizing countermeasures and proposals for the Fukushima Nuclear Reactor accident as vice-president of the Japan Health Physics Society. Then we discussed the matter among research project members and selected eight interview participants in the five fields of radioactive substance radiation sources, environmental dynamics, dosage evaluation, exposure doses, cancer/non-cancer status, and decontamination.

The interviews with the eight experts were conducted between October 2020 and January 2021 and took about 90 min each.

As coders, we organized the scientific knowledge from the speech transcripts and asked the interviewed experts themselves to confirm the content and verify the documentation made public by the MoE and the government. Then, we categorized experts’ knowledge into the following nine fields: radiation sources, radiation measurement, effective doses, health effects, health checks/treatment, environmental dynamics, environmental effects, decontamination, and policy. Finally, an influence diagram was created by incorporating all the knowledge into the scenario described above. The procedure for developing expert mental models, which serve as the basis for designing mental model interviews of receivers, is reported in detail by Kosugi et al. (2021) and Kuwagaki et al. (2021).

An overview is shown in Figure 1.

2.2 | Receivers’ mental model

2.2.1 | Mental model interviews

In the mental model approach, the receiver model is created using the experts’ mental model as the underlying framework. Therefore, it is necessary to determine the receivers’ knowledge and understanding of significant knowledge categories in the experts’ models. Thus, mental model interviews are conducted in the form of open-ended questions with the aim of getting the subjects to talk about what type of knowledge they have and how they understand the health effects of radiation (Kosugi et al., 2022).

Selecting participants

In this study, Fukushima residents are defined as the receivers of information. Currently, many of those who evacuated from the prefecture or to other places in the prefecture after the Fukushima nuclear accident (including voluntary evacuation) have returned to their homes and are going about their daily lives. Ten years have passed since the Fukushima nuclear accident, and differences likely exist in the degree

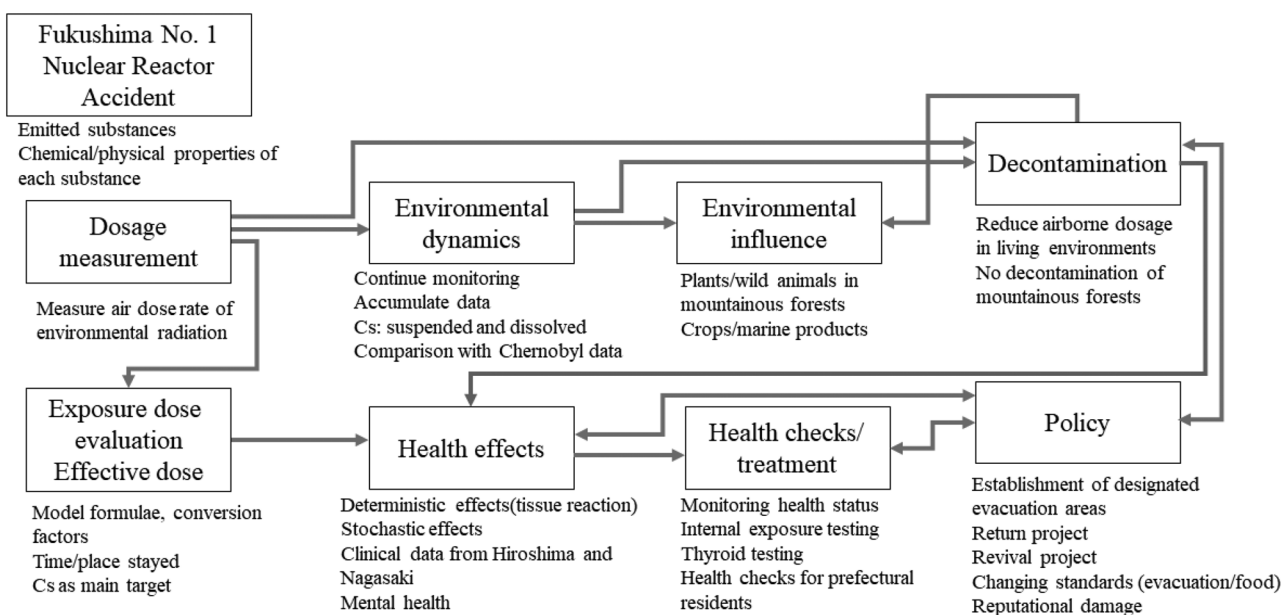


FIGURE 1 Overview of experts' mental models. Each box indicates a knowledge category. *Source:* Created by the authors from Kosugi et al. (2021).

of interest and anxiety and the amount of knowledge among residents. For example, there may be those who are highly concerned and anxious about radiation risk, as well as those who are unconcerned about radiation risk in their daily lives. According to Maharik and Fischhoff (1993b), mental model interviews yield new concepts up to about 10–15 cases, but almost no new concepts are obtained after 20–30 cases. Therefore, in this study, the number of participants was set at 47 to include both highly anxious and less anxious individuals, and a questionnaire was administered before the interview to inquire about their anxiety surrounding radiation effects so that the data could be divided according to the level of anxiety after the interview.

Overview of the semi-structured interviews

In the mental model interview, the following eight questions were always asked to all participants based on the framework of the expert mental model while being mindful to allow participants to freely discuss their knowledge and experience of radiation risk from the day of the earthquake to the present: (1) radioactive materials released due to the accident; (2) health effects of radiation; (3) thyroid checkups; (4) radiation effects other than human health; (5) decontamination; (6) radiation standards; (7) other radiation accidents; and (8) local reconstruction. The interviewer first asked about participants' experiences on the day of the disaster on March 11, 2011 (the day of the earthquake), how they gathered information on the day, and how they and their families reacted. When the participants mentioned knowledge, the interviewer asked further questions about that knowledge, such as "When and from what source did you learn about this?"

Of the authors, two acted as interviewer and transcriber, whereas the third simply observed. Interviews lasted approximately 90 min. The interview period was July–December

2021. Because of COVID-19 precautions, 43 online interviews and 4 in-person interviews were conducted.

Of the 47 participants, 26 were respondents for a polling company, and 21 were informed about the study by collaborating researchers. On the day of the earthquake, participants lived in the following areas: Hamadori (14), Nakadori (24), Aizu (8), and outside Fukushima (1). There were 24 men and 23 women. The age ranges of participants were as follows: 20s (10), 30s (12), 40s (10), 50s (6), and 60s (9). The mean age was 42.2 years.

Ethical considerations

The interviews were designed in accordance with the ethical regulations of Shizuoka University, with which the authors are affiliated. The president's approval was received via the Shizuoka University Institutional Review Board. All authors directly involved with the interviews completed e-APRIN's "Ethics Training on Research Involving Human Participants" in advance.

Organizing interview data

The interview utterance data content was subjected to text analysis based on the following process. The 10 participants who answered "Very much" for both "Current anxiety about the effects of radiation" and "Anxiety as a result of the accident" were classified as having ongoing anxiety. The remaining 37 participants responded that they currently had "some" (17), "not much" (17), or "none at all" (3) anxiety, with 23 reporting "very much" at the time of the earthquake, implying that the anxiety of these 37 participants had reduced over time, and they were thus classified as having reduced anxiety.

For both groups, the utterance data focused on knowledge ((1) information obtained directly or indirectly from texts or

experts; (2) information obtained from direct experience or heard from others' direct experience: Both types include scientifically inaccurate content), which was organized using the nine knowledge categories from the experts' mental model (radiation sources, radiation measurement, effective doses, health effects, health checks/treatments, environmental dynamics, environmental effects, decontamination, and policy). However, when there was no relevant knowledge category, utterances on similar categories were collected to create new ones. In addition, scientifically inaccurate knowledge and misunderstandings were retained and classified. Furthermore, experts in Japan differentiate between the terms radioactive substance, radioactivity, and radiation, whereas many laypeople simply use *Hoshano* (the term sounds as same as radioactivity) for all three, without distinguishing substances based on their ability to emit radiation or their dosage. Here participants' utterances such as "exposure to *hoshano*" or "contamination by *hoshano*" were applied as is (i.e., using the term *hoshano*) to the mental models.

To extract the most diversified knowledge that could be incorporated in the receivers' mental models without missing anything, three coders performed initial categorizations, which they confirmed with one another and made corrections when utterances were categorized into knowledge categories. The content was placed in the same positions as in the experts' mental model, yielding two types of tentative receivers' models. These were compared to the experts' model, with the differences organized as shown in Table 1. Because there were many similarities between the tentative receivers' models for the group with reduced anxiety and the group with continued anxiety, differences and similarities between these groups were both included.

2.3 | Confirming the generalizability of the receiver population

2.3.1 | Survey design

Based on the differences among the three mental models shown in Table 1, 50 knowledge items were extracted, focusing on receivers' anxiety and concerns, matters of interest such as health effects and countermeasures, and content required to understand health risks on radiation and countermeasures, such as the properties of radioactive substances and environmental dynamics. During the extraction, emphasis was placed on differences between experts and receivers and between the two receiver groups in terms of their knowledge of radiation risks and countermeasures, as well as knowledge that is likely to become a factor in anxiety about health effects. The receivers' knowledge included scientifically inaccurate content, which was left "as is" to determine whether it formed part of the receiving population's mental model.

To determine the extent to which these 50 knowledge items were shared among Fukushima Prefecture residents (who were the assumed readers), an online questionnaire

survey was conducted. The survey did not ask whether scientific knowledge was correct but asked how much the participants agree with various popular images of radiation and radioactivity and used a 4-point scale ("strongly disagree," "somewhat disagree," "somewhat agree," and "strongly agree") to rate the 50 knowledge items. Posing questions with binary correct/incorrect response options may cause bias, such as participants checking the correct answer before responding.

In addition to the knowledge items, the questionnaire included questions about participants' residence at the time of the accident and at the time of the survey, participants' years of residence, individual attributes of family members, and anxiety about radiation effects at the time of the disaster and at the time of the survey; it was composed based on the Fukushima Radiation Stress Scale, which is used in ongoing resident health surveys by Fukushima Prefecture (Kawakami, 2014).

Presidential approval was received from the president of Shizuoka University for conducting this questionnaire survey.

2.3.2 | Overview of survey implementation

The survey was conducted in August and September 2022, targeting individuals aged 20–70 years who were living in Fukushima at the time of the accident. Of the 900 respondents, 34 who had "no interest at all in radiation" both immediately after the accident and now were thought not to have relevant mental models and were excluded, leaving 866 analysis targets. Regarding respondents' attributes, 54.4% were male and 45.6% female; 14.8% were in their 20s, 18.7% in their 30s, 23.6% in their 40s, 22.2% in their 50s, and 20.8% in their 60s. Residence locations at the time of the accident were 33.4% in Hamadori, 49.7% in Nakadori, and 17.0% in Aizu.

Analysis target data: Excluding those who responded "None (none at all + not much)" regarding anxiety at the time of the accident, those whose anxiety had decreased between then and now (389 people) were the group with reduced anxiety, whereas those whose anxiety had not changed (including changes from "somewhat" to "a lot") (323 people) were the group with continued anxiety.

3 | RESULTS

3.1 | Results of the questionnaire survey: confirming generalizability

The percentages of participants (both the continued and reduced anxiety groups) who agreed with the knowledge content of the 50 items are shown in Table 2 (total of "strongly agree" and "somewhat agree"). The six items with high agreement percentages in both groups were as follows: "There are various types of radioactive substances," "There are radioactive substances originally in the natural world that

TABLE 1 Comparisons of knowledge between experts and receivers.

Experts' mental model	Receivers' mental model (tentative)	
	Group with continued anxiety	Group with reduced anxiety
Source	• Iodine blocks the thyroid • Cesium takes centuries to disappear • <i>Hoshano</i> is emitted until the reactor is completely decommissioned • <i>Hoshano</i> and radioactive substances that affect the human body • Has a half-life (<i>Hoshano</i> in general) • <i>Hoshano</i> accumulates in the thyroid • Adsorbs to soil and then to clothes, hands, or the body in case of contact with soil • Enters water (tap water, pond water)	• Cesium stays around residential area • The half-life of iodine is very short • Cesium has varying half-lives
Health effects	• Children are more likely to be affected • Children are more likely to be affected by radioactivity • Exposed to <i>hoshano</i> due to microwave ovens, x-rays, and CT scans • <i>Hoshano</i> accumulates within the body • Once a certain amount is absorbed into the body, the rest spreads throughout the body • Causes cancer • Causes childhood thyroid cancer • Damages genes/DNA • Harmful to the body • Effects may appear 10 or 20 years later • High dosages above the limits are fatal	• Children are more likely to get cancer • The effects on parents will be passed down to their children • Sperm are affected and conception is more difficult
Environmental dynamics/Overall countermeasures	• <i>Hoshano</i> enters even with the windows closed • <i>Hoshano</i> permeates your body if exposed to it • It also permeates the Earth • Particles cling to the ground and are concentrated • <i>Hoshano</i> in food is swallowed • Even if the soil removed for decontamination is bagged, the <i>Hoshano</i> passes through • Many abnormalities and deformities in animals • There is <i>hoshano</i> in the natural world • Emitted radioactive substances dispersed in the wind • Hot spots are everywhere, regardless of the distance from the reactor • Mountains have high dosage • Mushrooms and wild herbs have high dosages • There are places that have not been decontaminated such as mountainous forests and dams • For decontamination, scrape off the soil, replace it, and wash it with water • Reference values imply safe standards, that separates safe and dangerous conditions • [Countermeasures] Implement total dose testing and all-bag testing of rice • [Countermeasures] No shipping if the reference limit is exceeded. Anything in the market is okay • [Countermeasures] Do not go to high-dosage areas or stay there for a long time • [Countermeasures] <i>Hoshano</i> levels decrease after decontamination	• High dosage in drain spouts and gutters • Many radioactive substances falling into forests • Anything falling on soil is difficult to remove • Permeates underground • The government established various reference values after the earthquake • [Countermeasures] Do not eat mushrooms or wild herbs every day • [Countermeasures] Peel vegetables thoroughly and do not eat the dirty parts • [Countermeasures] Eat fermented foods (good for one's metabolism) • [Countermeasures] Stew boar meat and vegetables thoroughly and wash them off to remove almost all <i>Hoshano</i>

are unrelated to the accident,” “We are exposed to radiation from outer space, the ground, and food in our daily lives,” “Rain gutters and other pools of water have high dosages,” “Radiation will not fall to zero even if the house and garden are decontaminated,” and “Radioactive substances emitted

during the accident dispersed in the wind.” All of these items had agreement percentages over 80%. The former three items are basic knowledge on radioactive substances, whereas the latter are knowledge gleaned from lived experience after the accident.

TABLE 2 Responses to knowledge items on the online questionnaire (showing the percentages of participants in the two receiver groups who agree to the questionnaire items).

	Group with reduced anxiety	Group with continued anxiety
1 Figures measured at a monitoring post signify the amount of radiation received in 1 h in that area	78.7	76.7
2 There are various types of radioactive substances	86.7	81.4
3 Cesium can seldom be removed once it adheres to soil	58.8	73.7
4 The iodine emitted in the accident remains in the environment	66.1	79.2
5 Radioactive substances have varying half-lives	80.8	78.9
6 Radioactive substances attached to a building roof can be washed away with water	64.8	68.1
7 Rain gutters and other pools of water have high dosages	80.5	80.2
8 Radioactive substances/radioactivity will dissolve in water	48.3	68.1
9 Radiation will not fall to zero even if the house and garden are decontaminated	87.4	82.1
10 Radioactive substances emitted in the accident disperse in the wind	87.2	80.5
11 Radioactive substances emitted in the accident will take centuries to fall to be completely eliminated	83.5	78.9
12 Radioactive substances originally in the natural world are unrelated to the accident	90.0	82.4
13 Radioactive substances in mountains and forests move to human living environments through rain and wind	72.0	75.8
14 Radioactive substances are still slightly leaking from the Fukushima No. 1 Nuclear Reactor	70.7	81.4
15 We are exposed to radiation from space, the ground, and food in our daily lives	87.9	81.5
16 The radiation received by people in the Fukushima Prefecture (outside the areas where return is difficult) is about the same as that received by people in other areas	66.6	63.5
17 Testing of the radioactive substances/radioactivity ingested through food, etc., is still ongoing	73.3	72.2
18 Radioactive substances in soil attach to or are absorbed by crops, exposing the people who eat them to radioactivity	70.7	75.6
19 Radioactive substances/radioactivity falling to earth eventually permeate the ground	62.0	69.0
20 Reference values for foods that are safe to eat and places that are safe to live imply that anything under that value is safe	72.5	65.3
21 We are exposed to radiation due to x-rays and CT scans	89.2	79.9
22 Radiation levels in mushrooms, wild herbs, and river fish are sometimes still high	77.9	79.9
23 Nuclear reactors in Japan and overseas expel tritium into the sea	71.5	77.7
24 If heavy water is expelled into the sea, it causes economic losses in the fishing industry due to reputational damage	79.7	77.4
25 The water in dams and ponds still contains radioactive substances/radioactivity	71.0	81.4
26 Most radioactive substances emitted by the accident persist in mountains and forests	78.7	79.9
27 Of the radioactive substances emitted by the accident, iodine has a short half-life, reaching negligible levels a year later	50.9	62.8
28 Iodine is likely to accumulate in the thyroid	82.6	79.6
29 Children are more likely to be affected by radiation than adults	81.0	79.3
30 The effects of radiation on parents will not be passed down to their children	46.5	55.7
31 Radioactive substances/radioactivity in the body continue to accumulate there	62.0	74.9
32 The health impact of minimal doses of radiation has not been scientifically clarified	78.7	74.0
33 The health impact of minimal doses of radiation is extremely minimal and cannot be scientifically confirmed	75.8	70.6
34 The probability of dying of cancer due to minimal doses of radiation is too low to be scientifically confirmed	74.3	66.5
35 The increase in thyroid cancer after the accident is unrelated to exposure	37.5	56.0
36 In the Fukushima Prefecture, there are currently no radioactive substances or radioactivity entering the body through food (purchased in stores, etc.)	76.3	65.1
37 In the Fukushima Prefecture, there is currently no need to worry about environmental radiation	61.9	58.6
38 After the accident, deformities and various abnormalities have appeared in animals and plants in the evacuated areas and mountains	52.7	75.2

(Continues)

TABLE 2 (Continued)

	Group with reduced anxiety	Group with continued anxiety
39 Radiation is capable of damaging genes	83.1	78.0
40 The human body can repair damaged genes	65.3	68.7
41 Even if radioactive substances enter the body, they will be excreted metabolically	50.7	60.7
42 Because children have a highly active metabolism, they are more likely than adults to excrete radioactive substances	43.2	53.3
43 A high radiation dosage delivered all at once is fatal	88.2	79.6
44 If you do not eat mushrooms or wild herbs every day, there are no health effects from radiation	53.8	62.2
45 Stewing boar meat and vegetables thoroughly and washing them will eliminate almost all the radiation	28.8	53.6
46 Many crops and marine products from the Fukushima Prefecture are still being tested	84.3	75.2
47 Foods that exceed radiation testing limits are not allowed on the market	83.5	77.7
48 The standards for shipping foods specify radiation levels that will not have a negative health effect even if eaten every day	84.4	73.6
49 Standard values are determined for various targets, including decontamination, evacuation, food, and health	82.4	67.4
50 Radioactive iodine was detected in tap water after the accident	55.2	68.8

In terms of the amount of knowledge, the group with reduced anxiety had more knowledge items with high agreement percentages. Eleven items had agreement greater than 80% only in the group with reduced anxiety, including “We are exposed to radiation through X-rays and CT scans as well,” “A high radiation dosage all at once is fatal,” “The standards for shipping foods specify radiation levels that will not have health effects even if eaten every day,” and “Many of the crops and marine products from Fukushima Prefecture are still being tested.” These items included basic knowledge on radiation and knowledge on the risk management of Fukushima food products. Elsewhere, the two items for which only the group with continued anxiety had agreement over 80% were “Radioactive substances are still slightly leaking from the Fukushima No. 1 Nuclear Reactor” and “The water in dams and ponds still contains radioactive substances/radioactivity,” indicating that more people in this group believed that radioactive substances remained in their vicinity.

In addition, both groups had low agreement percentages for items on health effects, particularly effects on children, such as “The effects of radiation on parents will not be passed down to their children,” “The increase in thyroid cancer after the accident is unrelated to exposure,” “Even if radioactive substances enter the body, they will be excreted metabolically,” and “Because children have highly active metabolisms, they are more likely than adults to excrete radioactive substances.” This indicates that this information was not known by the receivers.

The results for all 50 items indicate that the group with reduced anxiety tended to have a higher rate of awareness and knowledge than the group with continued anxiety, but the difference was not large enough to say that one group had it and the other group did not. This suggests that anxiety is not defined by the presence or absence of specific knowledge.

3.2 | Confirming the receivers’ mental models

Based on the tentative receivers’ mental models created based on the knowledge common to the groups with continued and reduced anxiety gained through receiver interviews and shown in Table 1, the four items shown in Table 2 with agreement under 60% were deleted (“30. The effects of radiation on parents will not be passed down to their children,” “35. The increase in thyroid cancer after the accident is unrelated to exposure,” “42. Because children have highly active metabolisms, they are more likely than adults to excrete radioactive substances,” and “45. Stewing boar meat and vegetables thoroughly and washing them will eliminate almost all the radiation”). These items were considered not to be shared among the receiver population, and the receivers’ mental models were confirmed. Table 2 shows the receivers’ mental models aggregating items common to the two groups.

3.3 | Comparing the mental models

3.3.1 | Comparing experts and receivers

When comparing the experts’ mental model (Figure 1) and the receivers’ mental model (Figure 2), the greatest difference was that the latter did not contain the knowledge category “Exposure dose evaluation: Effective dose.” Except for this point, the knowledge categories were mostly shared, indicating that receivers also had basic knowledge of the causal flow of radiation risks. Specifically, the experts and receivers had a general understanding of how the “radioactivity” emitted by the accident entered human life spaces and the mechanisms by which it affected the human body and nature. The listed

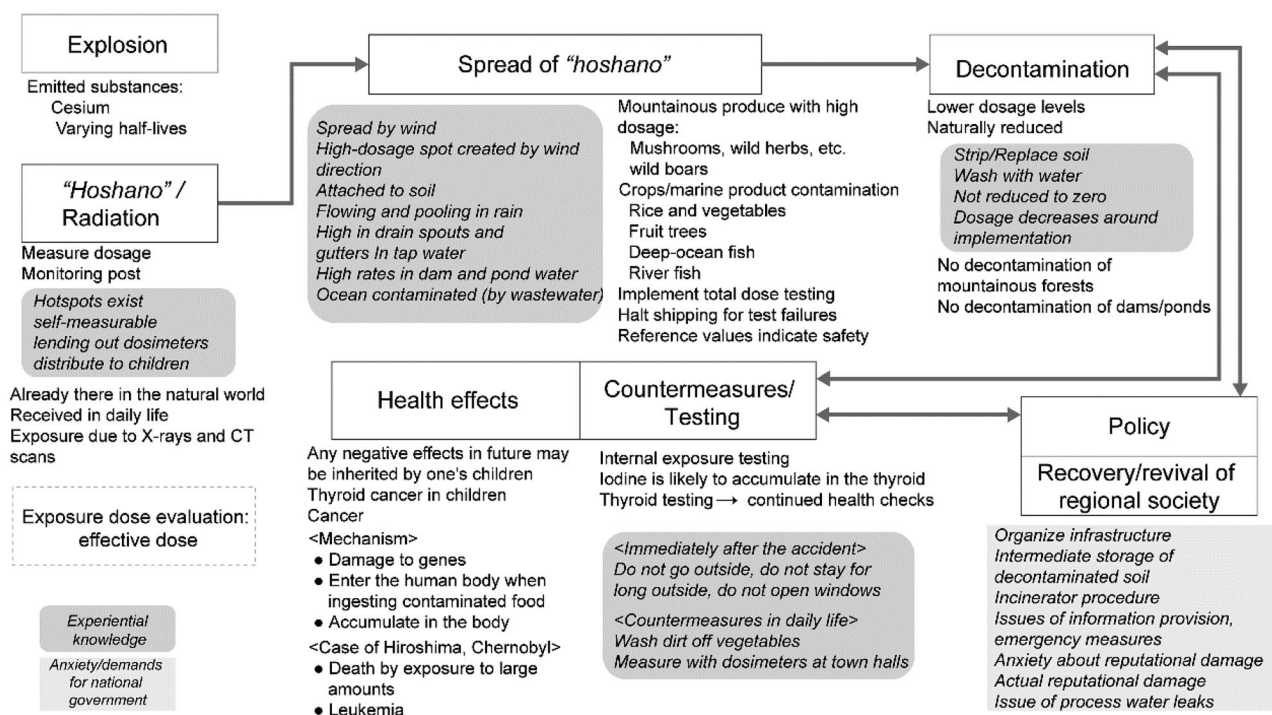


FIGURE 2 Receivers' mental models. Common models for group with reduced anxiety and group with continued anxiety. *Source:* Created by the authors from Kuwagaki et al. (2022).

health effects included the effects of radiation on the body (on organs) and specific cases such as childhood thyroid cancer.

Although the experts considered behavior and countermeasures based on the chemico-physical properties of the emitted substances, the receivers had no knowledge of individual substances and mistook them for *hoshano* (radioactivity). In addition, although the experts had knowledge structures that closely connected exposure doses and health effects, the category of exposure doses did not exist in the receivers' mental models, and they believed that even tiny amounts of "radioactivity" would damage the body. Based on their knowledge of past nuclear reactor accidents and the atomic bomb, the receivers imagined hair loss and leukemia as health effects; they were aware that high doses were required for fatalities, but they had no idea how high a dose that entailed. Besides this, only the receivers' mental models included specific knowledge based largely on their own experience and being directly informed (experiential knowledge) about how to deal with radioactivity diffused into the environment, such as decontamination of homes, schools, parks, and public facilities, dosage measurement of houses and regions, food testing, and health checks.

3.3.2 | Comparing the receivers' group with reduced anxiety and the group with continuing anxiety

The knowledge categories and their content were largely shared by the mental models of the two receiver groups,

implying that the reasons and triggers for high current anxiety or reduced anxiety may not necessarily depend on knowledge or its lack. Both groups were aware that mountainous forests, rivers, and dams were not decontaminated, that mushrooms and wild herbs had high radiation dosages, that radioactive substances existed in the natural world in addition to those emitted by the accident, and that exposure also occurred because of medical care such as x-rays. They believed that all the crops sold on the market had been tested, suggesting that Fukushima residents are surviving by avoiding high-dosage locations and avoiding or reducing their intake of high-dosage foods such as mushrooms and wild herbs.

However, the details of the mental models differed between the groups with reduced anxiety and those with ongoing anxiety. The reduced anxiety group tended to have relatively more knowledge. Although the ongoing anxiety group shared experiential knowledge on food selection and cooking, the group with continued anxiety was characterized by a lack of sufficient knowledge on the excretion of ingested radioactive substances and measures that individuals can implement personally.

4 | DISCUSSION

4.1 | Information content proposal based on receivers' mental models

Individual knowledge content in each knowledge category differed significantly in the accuracy and level of detail

TABLE 3 Responses to anxiety items on the questionnaire (showing the percentages of participants in the two receiver groups who agree to the questionnaire items).

	Group with reduced anxiety	Group with continued anxiety
1 I am worried about becoming seriously ill in the future due to radiation effects	39.8	73.4
2 Every time I get sick, I worry that it is due to radiation	20.6	63.5
3 I am worried that radiation effects will be genetically passed on to my children, grandchildren, and so on	42.7	75.6
4 I feel very anxious or uncomfortable seeing news about nuclear reactor accidents	63.0	82.4
5 I have been discriminated against by others (treated unfairly) due to having lived in Fukushima	37.6	63.8
6 I avoid telling people about being (or having been) a Fukushima resident	19.0	59.7
7 I have argued and been in conflict with my family about radiation's effects on health	23.6	57.6
8 I am anxious that although this accident has been resolved, another nuclear reactor abnormality will happen in future	71.9	82.7

between expert and receiver mental models. As previously stated, the receivers use the term *hoshano* without distinguishing radioactive substances or radiation, being only aware of “cesium” among the radioactive substances emitted from the Fukushima No. 1 Reactor and “thyroid cancer” as a health effect due to ongoing testing conducted by national and local governments. Although health effects are a subject of concern and anxiety following the accident, little is known about the mechanisms through which they occur. There is also little knowledge of the processes that link health effects to the relationship between the substances released by the nuclear accident and their quantities, which are directly related to health effects in the experts’ mental models. In other words, although the receivers are most concerned about health effects, they have little information about the effects themselves, about the factors that cause them, about the processes that lead to them, and about the connections between them. Therefore, it is thought that explaining the causal flow of the expert mental model in reverse order, focusing on the health effects that are of greatest concern to the receiver and what effects occur, why, and under what conditions, would be in line with the receiver’s interests and help them understand the information. For example, the causal flow could be presented as follows: “health effects such as thyroid and other cancers” → “derived from serious cell and genetic damage due to radiation” → “what dosage conditions lead to this damage” → “how long one would need to spend in which locations in Fukushima Prefecture,” and so on. In terms of the content when explaining health effects, receivers should be given information on the distinction between radiation and radioactivity, which are now referred to collectively as “radioactivity,” the specifics of possible health effects (e.g., Items 30, 31, and 32 in Table 3), and the relationship between exposure and health effects (e.g., Items 39, 40, and 41 in Table 3). Some of these items contain insufficient content or misunderstandings for decision-making or risk identification and thus require supplemental or more appropriate information.

It is necessary to explain the risks of radiation health effects and how to manage them. Previous studies have shown that

informing people about how to manage risks reduces their risk perception and anxiety. There is insufficient awareness regarding the excretion of ingested radioactive substances, the role played by metabolism, or measures to reduce radioactive substances in food such as boiling and discarding the water (Table 2). Measures available to individuals are anticipated to become important content in risk communication. For example, because Fukushima Prefecture used thyroid testing, receivers who are anxious about thyroid cancer may be encouraged to take action if the test procedures and data obtained thus far are made available to them. Receivers are also aware of the installation of monitoring posts, individually purchased or municipally lent portable dosimeters, and the dosages near their own homes and in other regions because of mass media reporting on measurement values; this knowledge leads them to take individual measures such as avoiding or minimizing time spent in high-dosage areas. Although content such as this has been made available to some extent, the importance of this information implies that its provision should continue in the future.

4.2 | Remaining challenges and topics for future research

Many of the utterances obtained during the mental model interviews did not fit into the knowledge category of the experts’ mental models and did not reflect the mental model focused on scientific knowledge. In particular, there were a certain number of receivers who still had great concerns based on rumors and misinformation, and this was more common in the group with continuing anxiety.

Responses to anxiety-related items in the questionnaire survey to confirm the generalizability of the results are shown in Table 3. In comparison to the group with reduced anxiety, the group with continuing anxiety was more likely to agree with items such as “I am worried that radiation effects will be genetically passed on to my children, grandchildren, and so on” (continued anxiety group 75.6%, reduced anxiety group 42.7%), “I am worried about becoming seriously ill in the

future due to radiation effects” (likewise 73.4% and 39.8%), and “Every time I get sick, I worry that it is due to radiation” (63.5% and 20.6%). This shows a deep-rooted anxiety about health effects in the group with continuing anxiety. Likewise, agreement percentages in the continued anxiety group were high for “I feel very anxious or uncomfortable seeing news about nuclear reactor accidents” (82.4%, 63.0%) and “I avoid telling people about being (or having been) a Fukushima resident” (59.7%, 19.0%), suggesting that the reactor accident remains a psychological stressor. In addition, even the reduced anxiety group had over 70% agreement for “I am anxious that although this accident has been resolved, another nuclear reactor abnormality will happen in future” (82.7%, 71.9%). These anxieties are unlikely to be entirely dispelled by acquiring scientific knowledge (Tsuchiya et al., 2022). Discussions on future risk communication must include not only the knowledge indicated by the comparison of mental models but also the creation of information with consideration for the psychological factors and needs expressed here.

Based on the characteristics of the mental model approach and on the fact that receivers have a certain amount of knowledge, the receivers of information in this study are people who live in Fukushima and who can be assumed to already have a significant amount of information on the effects of radiation and the Fukushima No. 1 Reactor accident. Therefore, it is difficult to apply this information to those who have little knowledge of radiation risk or who are unaware of the circumstances of the accident and the current situation in Fukushima Prefecture.

Within the mental model interviews, multiple utterances mentioned that information about risk management should be provided not only to Fukushima residents but also to people throughout Japan. In the future, it will be necessary to provide information to people outside Fukushima. There are several projects that can play an important role in supporting the understanding of radiation risks among people outside Fukushima regarding the current status of Fukushima, including the release of treated water from the Fukushima reactor into the sea or the movement of decontaminated soil to other prefectures. Because the points derived from this study can only contribute to a limited extent, further research is needed to examine information content and media that are suitable for people outside Fukushima.

5 | CONCLUSION

In this study, a mental model approach was used to obtain knowledge on how to convey information to people in an easy-to-understand manner. The context is that about half of the residents of the prefecture still feel anxiety about radiation effects 10 years after the Fukushima nuclear power plant accident. The comparison of mental models showed that experts and receivers of information generally agreed on the knowledge categories that radioactive materials emitted by the Fukushima nuclear power plant accident could spread to people’s residential areas and cause health effects and that the

national and local governments would take measures, such as decontamination and inspection of agricultural products, to ensure safe living areas and reduce the health effects. The results showed that experts and receivers generally agreed on the knowledge categories related to reducing health effects and creating safe living areas. However, there were significant differences in the accuracy and detail of individual knowledge in each category, and the knowledge present in the mental models of the receivers was fragmented, with little connection between categories or knowledge. It was also found that although the receivers were most concerned about health effects, they had little knowledge about health effects, about the causative radionuclides and exposures, and about the mechanisms that cause adverse effects. The results indicate that information is required on the processes that cause adverse effects, the relationship with exposure, and measures to reduce exposure, focusing on specific diseases and symptoms of health effects that the receivers are most concerned about. It was also suggested that in contrast to the expert mental model, which leads from the characteristics of radioactive materials to human health effects, it is easier for the receivers to understand explanations in the order from health effects to radiation exposure.

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