

ARTICLE

# Changes in radiation protection measures after the Fukushima Daiichi nuclear accident: evaluation of meeting minutes of the Nuclear Regulation Authority, Japan

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**Abstract** – Since the Fukushima accident, there has been an increasing discussion on post-accident radiation protection as well as nuclear regulation and management. This study assessed the general content of discussions during the chronic phases after the accident, and analyzed the changes over the years in discussion on radiation protection measures related to the accident by focusing on the meeting minutes of the Nuclear Regulation Authority, Japan from 2012 to 2018 using the method of text mining. The analysis revealed that while the authority's main focus was on regulation and management regarding the safety of nuclear power plants, in addition to emergency measures for the future (especially in matters such as evacuation), discussions were also held on radiation protection measures for residents and workers and risk communication in the period following the accident. The authority was observed to have dynamically tackled the issues that were regarded as most urgent after the accident and gradually shifted its focus to mid- to long-term issues. In the aftermath of a nuclear accident, it is important for the authorities responsible for nuclear regulation to deepen their knowledge of social measures such as evacuation, return of residents, and risk communication, and strengthen cooperation with experts from other fields.

**Keywords:** accident / nuclear / countermeasure / risk communication

## 1 Introduction

The accident at Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant (FDNPP) in March 2011 caused devastating damage to Fukushima Prefecture and its people. As measures, such as body surface screenings and control on food and water, were carried out soon after the accident, radiation exposure has been fortunately limited, and it is estimated that the next generation will not be affected and there will not be a discernible increase in cancer incidences among the local people (United Nations Scientific Committee on the Effects of Atomic Radiation, 2014, 2017). After the accident, in addition to reducing the level of radiation in areas outside the evacuation zone and carrying out decontamination to support the return of affected people (Yasutaka and Naito, 2016), various radiation protection measures such as the treatment of contaminated water around the power plant and efforts towards its decommissioning (Ministry of the

Environment, 2019) were also taken. Moreover, as anxiety over exposure to radiation persisted, measures to curb reputational damage were regarded as important (Ohto *et al.*, 2017). To discuss these measures and obtain support on social measures, risk communication involving various stakeholders such as healthcare professionals, experts, national and local governments, non-profit organizations (NPOs), and residents was conducted (Murakami *et al.*, 2017b; Schneider *et al.*, 2019). Furthermore, based on the lessons learned from the accident, matters such as emergency evacuations during a nuclear accident and safety management of nuclear power plants are now more widely discussed both within and outside Japan (Thomas, 2017).

As mentioned above, a wide range of radiation protection measures were implemented after the accident. It is important to analyze how these measures were discussed and carried out over time to share the lessons learned from the accident on a global level in order to prepare for future disasters.

As for the methods to analyze these measures, in addition to narrative summaries by experts and international organizations in this field (Lochard, 2016), a method involving text

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mining of documents published by organizations and committees involved in decision-making was found to be effective. Although after the accident, many case studies assessed the inclination of people's interests by text analysis of newspapers and social media (Abe, 2015; Kanda *et al.*, 2014; Lansdall-Welfare *et al.*, 2014), there were hardly any case studies where organizations and committees involved in decision-making were text-mined.

Therefore, in this study, we focused our attention on the meeting minutes of the Nuclear Regulation Authority, Japan from 2012 to 2018. The goal of the Nuclear Regulation Authority, formerly the Nuclear Safety Commission, is to “absorb and learn lessons from the FDNPP accident of March 11, 2011 so that such nuclear accidents should never be allowed to happen again; restore public trust, in Japan and abroad, in the country's nuclear regulation organizations; and rebuild the nuclear safety system and management by placing the highest priority on public safety and a genuine safety culture” (Nuclear Regulation Authority, 2020). Its mission is “to protect the general public and the environment through rigorous and reliable regulations of nuclear activities”, and the five guiding principles for its activities are: independent decision-making, effective actions, open and transparent organization, improvement and commitment, and swift emergency response. Its policies cover nuclear regulation, radioisotope regulation, nuclear security measures, safeguards, efforts for FDNPP, radiation protection, nuclear disaster prevention, radiation monitoring, and safety research. The committee meets weekly as a general rule, and all its minutes except those with security concerns are published. The authority, from a position of neutrality, focuses on assessing the status of various nuclear power plants and does not necessarily aim to exclusively discuss events related only to the FDNPP accident. However, it is also true that the authority discussed measures taken after the accident and how they can be developed for the future based on lessons learned.

The purpose of this study was to reveal the transition in the discussions—in the period that follows a major nuclear disaster—on radiation protection as well as regulation and management of nuclear power plants by a committee consisting of experts on nuclear regulations in the country concerned. Specifically, a text mining technique was first used to make an overall assessment of the discussions at the Nuclear Regulatory Authority meetings during the chronic phases following the accident. Then, the transitions in the authority's discussions over the years on radiation protection measures related to the accident such as evacuation, return of residents, radiation exposure, decontamination, decommissioning, reputational damage, and risk communication were analyzed. We hypothesized that the appearance ratios of these words secularly changed over times in accordance with the authority's discussions.

## 2 Methods

### 2.1 Collection of text data for analysis

The text data used in the analysis is an aggregation of the minutes of the Nuclear Safety Commission meetings from January 5, 2012 to September 18, 2012 (Web Archiving Project, 2020) and Nuclear Regulation Authority meetings

from September 19, 2012 to September 26, 2018 (Nuclear Regulation Authority, 2020). Hereinafter, the aggregated minutes will be referred to as the Nuclear Regulation Authority meeting minutes.

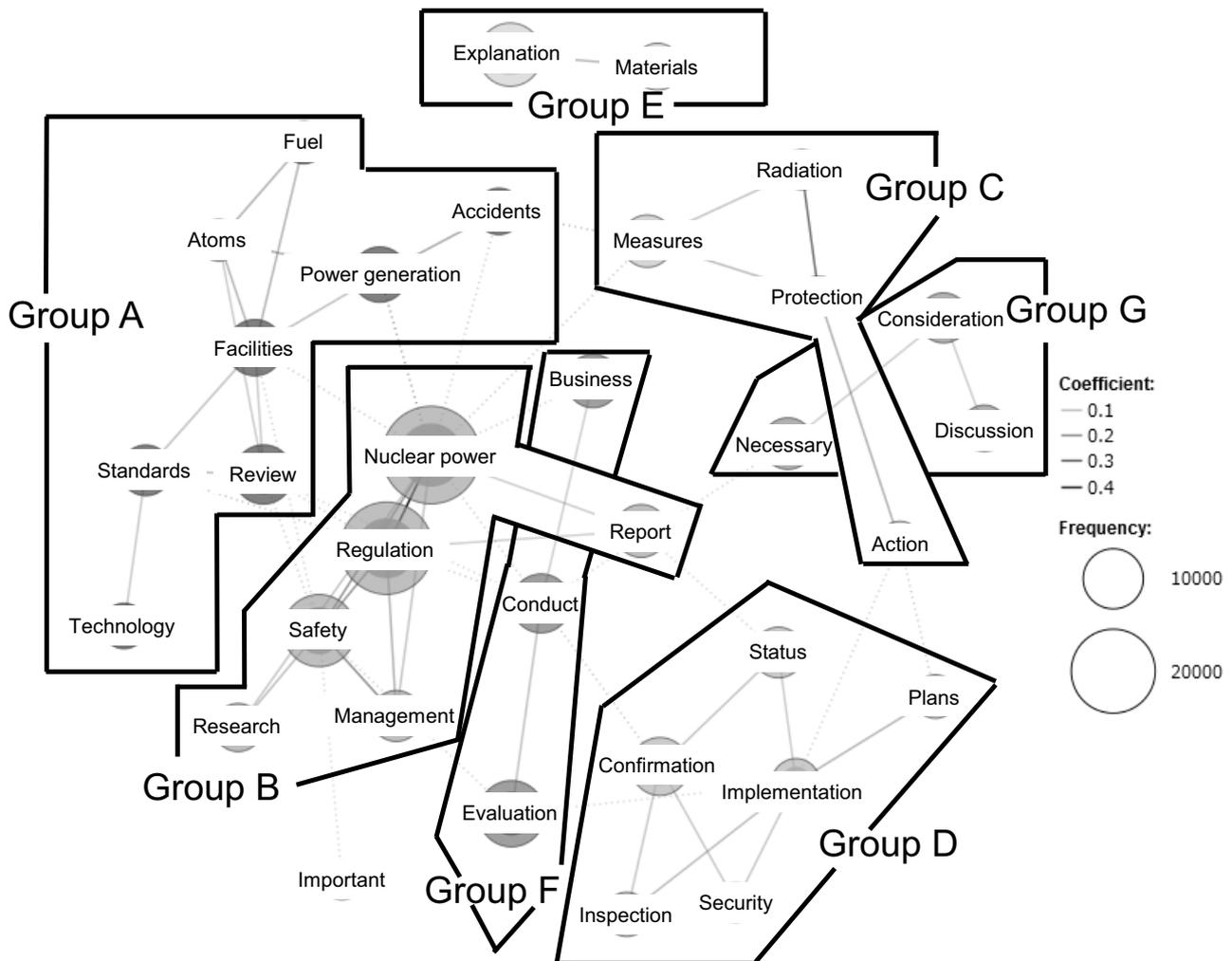
### 2.2 Extraction of the words to be analyzed

Using the text data analysis tool KH Coder version 2 and 3 (ChaSen was used as the morphological analysis engine) (Higuchi, 2016a, Higuchi, 2016b), words (nouns, verbs formed by adding “*suru*” to a noun, adjectival nouns, proper nouns, names of organizations, names of places, tags [words specified for forced extraction], and verbs) were extracted for analysis from the text data. General terms that should not be used (“administration,” “please,” “other,” “thanks,” “so much,” “thank you,” “today,” “this time,” “this case,” “opinion,” “next,” “agenda,” “Inc.,” “accompany,” “committee member,” “*Heisei*” (Japanese era name), “extend,” “related,” “earlier,” “inform,” “1,” “one,” “2,” “two,” “3,” “three,” “furthermore,” “else,” “now,” “say,” “reckon,” “think,” “attachment,” “very,” “look,” “view,” “page,” “deputy,” “year,” “form,” and “Co., Ltd.,” “President”) were specified.

Through a preliminary extraction operation assessing the most frequently used words, the top 40 words were confirmed to be the general terms—1: “nuclear power”, 2: “regulation”, 3: “safety”, 4: “evaluation”, 5: “explanation”, 6: “review”, 7: “conduct”, 8: “confirmation”, 9: “facilities”, 10: “power generation”, 11: “business”, 12: “report”, 13: “measures”, 14: “necessary”, 15: “management”, 16: “standards”, 17 “status”, 18: “consideration”, 19: “correspondence”, 20: “research”, 21: “implementation”, 22: “materials”, 23: “accidents”, 24: “write”, 25: “discussion”, 26: “technology”, 27: “inspection”, 28: “plans”, 29: “fuel”, 30: “action”, 31: “atoms”, 32: “relationship”, 33: “radiation”, 34: “important”, 35: “security”, 36: “contents”, 37: “protection”, 38: “be based on”, 39: “advance”, and 40: “substance”. We also confirmed “radiation” and “protection” as the top 33 and top 37 words.

Therefore, by first performing the co-occurrence network analysis, similar terms that had a high appearance ratio were grouped together. For the groupings, words that appeared at least 4000 times were used. “Protection” was included in this analysis, because the number of the appearance was 4001. The co-occurrence network uses a network diagram to show the connections between words based on the Jaccard's coefficient. These words are connected with lines based on the combination of words that co-occur in their appearance patterns in texts. In this study, words that had relatively strong connections were automatically detected and grouped using subgraph detection (modularity).

The following target terms related to radiation protection measures after the FDNPP accident were then forcibly extracted, based on the purpose of this study: “nuclear accident”, “evacuation”, “return”, “decontamination”, “temporary storage site”, “interim storage”, “contaminated water”, “decommissioning”, “exposure”, “internal”, “external”, “cancer”, “carcinogenesis”, “thyroid”, “risk”, “communication”, “*risu komi*” (abbreviation of risk communication in Japanese), “dialogue”, “reputation”, “peace of mind”, and “anxiety”. In addition, a coding file was created by combining the following target terms: “internal exposure” (‘internal’ and ‘exposure’),



**Fig. 1.** Co-occurrence network of terms with more than 4000 appearances. The area of the circle is proportional to the number of appearances, and the thickness of the line is proportional to the strength of the relationship between terms. Coefficient: Jaccard's coefficient. Solid lines between terms represent the same groups, whereas the dotted lines represent the different groups.

“external exposure” (‘external’ and ‘exposure’), and “communication” (‘communication,’ ‘*risu komi,*’ or ‘dialogue’). The other target terms and “exposure” were also used as the codes without any combination. In these words, “radiation” and “protection” were not included, because these words were general terms as described above.

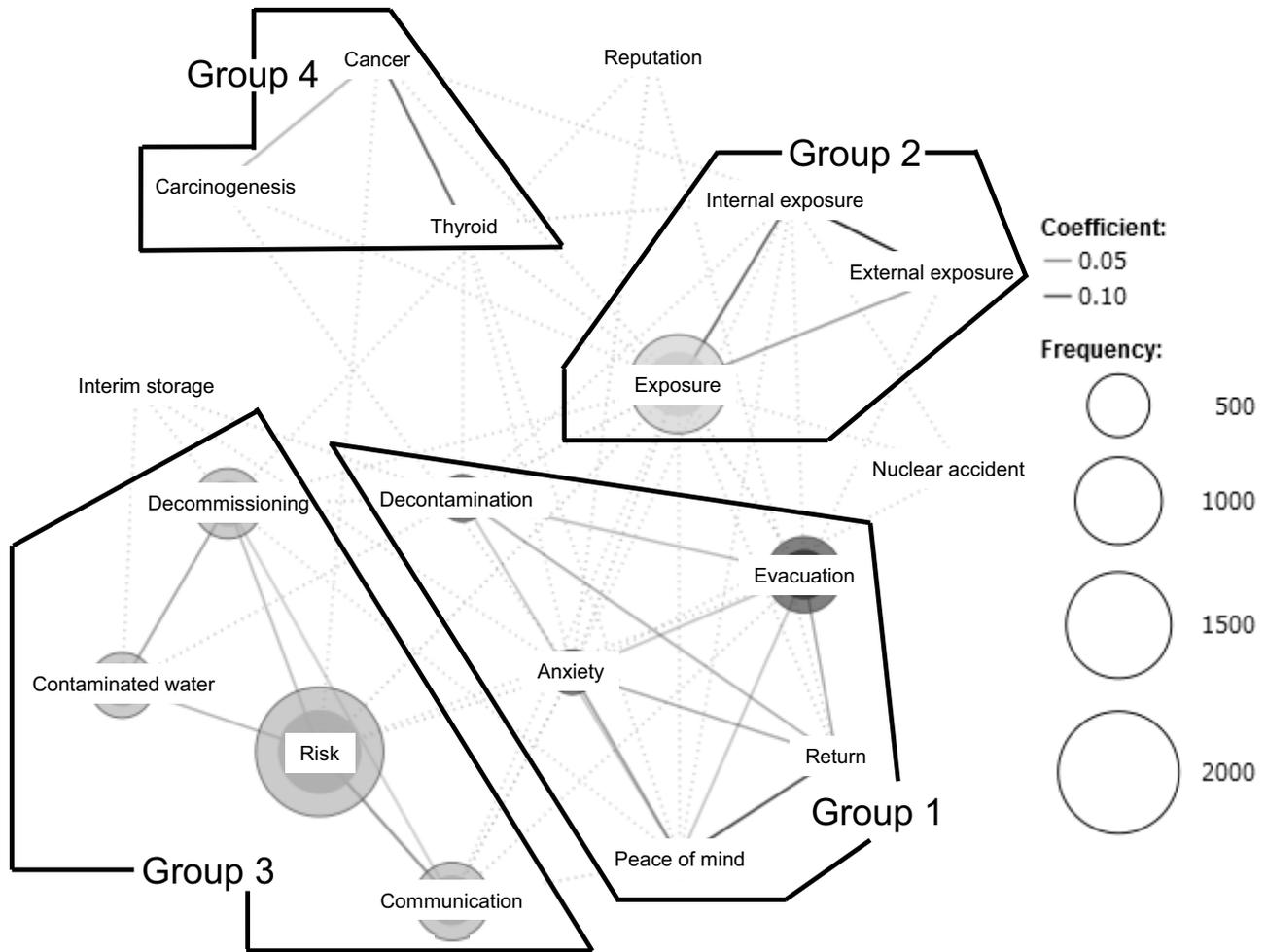
The total number of extracted words, number of different words, and number of sentences in the text data was 1 185 304, 12 951, and 158 079, respectively. In order to observe the similarities and changes in the appearance pattern of each target term, the appearance ratio of that term (number of sentences that include the target term in proportion to the total number of sentences) was calculated for each year, using a sentence as the coding unit. We then performed a Chi-square test to investigate differences in the appearance ratio among years. Furthermore, by performing co-occurrence network analysis, groupings were made based on the similarity between terms. In addition, in order to analyze the context in which target terms with a high appearance ratio were used, the top three extracted words with the strongest relationships were identified based on the Jaccard's coefficient. Moreover, the

original texts of the minutes were reviewed in order to find out how those target terms were typically used.

### 3 Results

Figure 1 shows a co-occurrence network of the terms that appeared at least 4000 times. Frequent terms were categorized into co-occurrence group A (review, facilities, standards, fuel, atoms, power generation, accidents, technology); group B (nuclear power, regulation, safety, management, research, report); group C (measures, radiation, protection, action); group D (inspection, implementation, plans, status, confirmation, security); group E (explanation, materials); group F (evaluation, conduct, business); and group G (necessary, consideration, discussion). “Important” did not form a co-occurrence group. In particular, “radiation” and “protection” showed the strongest co-occurrence (Jaccard's coefficient = 0.25).

Figure 2 shows the co-occurrence network of the target terms. Each target term was classified into the following four co-occurrence groups: group 1 (evacuation, return, peace of mind, anxiety, decontamination); group 2 (exposure, internal



**Fig. 2.** Co-occurrence network of target terms. The area of the circle is proportional to the number of appearances, and the thickness of the line is proportional to the strength of the relationship between terms. Coefficient: Jaccard’s coefficient. Solid lines between terms represent the same groups, whereas the dotted lines represent the different groups.

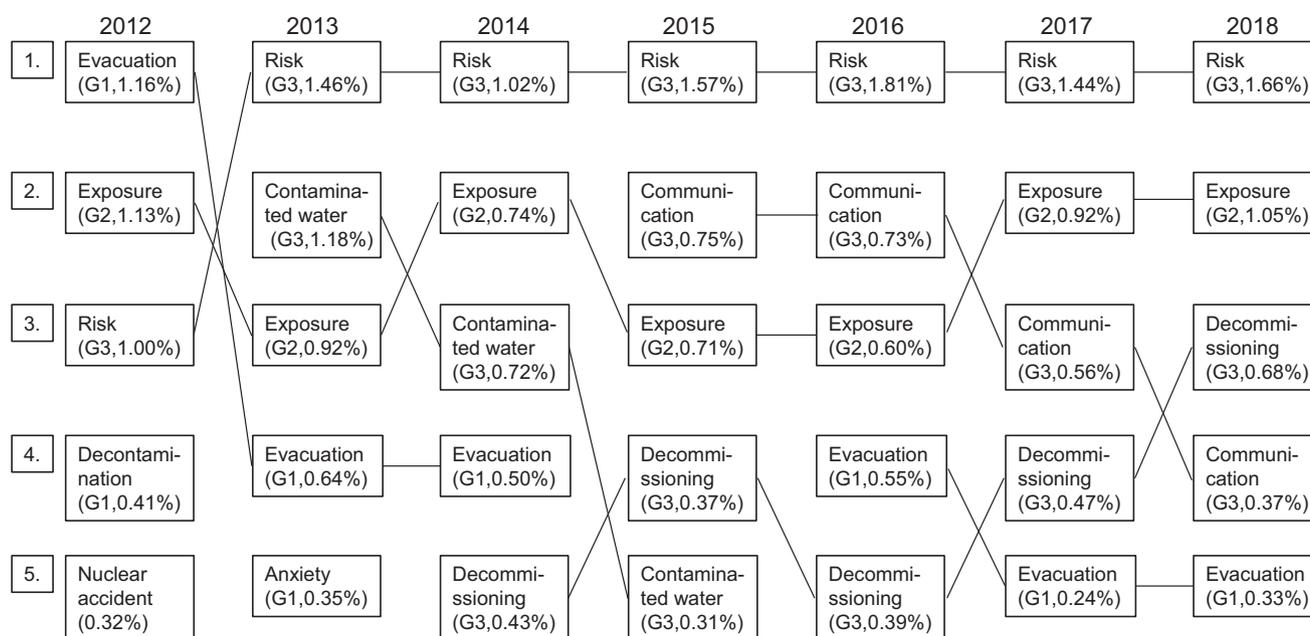
exposure, external exposure); group 3 (risk, communication, decommissioning, contaminated water); group 4 (thyroid, cancer, carcinogenesis). “Reputation”, “nuclear accident”, and “interim storage” did not form a co-occurrence group. “Temporary storage site” is not shown as it had a low appearance ratio and co-occurrence with other terms, and did not form a co-occurrence group.

Figure 3 shows the changes of top five words over the years in the ranking of the appearance ratio of the target terms. It also shows each term’s co-occurrence group and its appearance ratio. “Risk” and “exposure” had a high appearance ratio irrespective of the year. “Evacuation” in 2012, “contaminated water” from 2013–2014, “communication” from 2015–2017, and “decommissioning” in 2018 ranked among the top three. The appearance ratio of the target terms showed significant differences among years except “temporal storage site”, “internal storage”, “cancer”, and “carcinogenesis” ( $P < 0.05$ ).

Table 1 shows the changes over the years in the extracted words that have strong relationships with terms having a high appearance ratio. Regarding “risk”, “reduction” consistently appeared as a term with a strong relationship irrespective of the year. However, while “risk” had a stronger relationship with

“evaluation” and “goal” in 2012, a change over the years was observed whereby its relationship with “probability” and “map” became stronger from 2014. While reviewing the original texts of the meeting minutes to see how “risk” was typically used, it was found to have been used in 2012 as follows: “With regard to the reduction of radiation risk, for Tokyo Electric Power Company, the entire property has been covered by a large amount of contaminated water since the earthquake, due to the tsunami and hydrogen explosion.” In contrast, it was used in the following context in 2018: “As for the FDNPP, discussion on the revision of the risk map (roadmap to reduce mid-term risks) is ongoing; with regard to this, the efforts for the FDNPP have shifted from a period where the focus was directed at responding to risks as threats emerged to a period with a heavier focus on planning...”.

Regarding “exposure”, “medical care” and “dose” appeared as terms with strong relationships irrespective of the year; however, depending on the year, it was observed to have a strong relationship with words including “existing”, “health”, “emergency”, “public”, and “internal”. Typical phrases in the original texts of the minutes included, “Based on the lessons learned from the Tokyo Electric Power FDNPP



**Fig. 3.** Changes of top five words over the years in the ranking of the appearance ratio of the target terms. The number in parenthesis shows the appearance ratio. G: co-occurrence group.

**Table 1.** List of extracted words with a strong relationship with the target terms (the top three in terms of the Jaccard’s coefficient are listed).

Target items	Ranking	2012	2013	2014	2015	2016	2017	2018
Risk	1	Reduction	Reduction	Reduction	Reduction	Reduction	Reduction	Map
	2	Evaluation	Goal	Probability	Probability	Communication	Probability	Reduction
	3	Goal	Activity	Fukushima	Map	Map	Utilization	Probability
Exposure	1	Medical care	Dose	Dose	Medical care	Dose	Dose	Medical care
	2	Existing	Health	Work	Dose	Medical care	Medical care	Dose
	3	Dose	Individual	Emergency	Limit	Public	Internal	Center
Evacuation	1	Area	Lift	Shelter	Leave the area	Residents	Residents	Lift
	2	Residents	Orders	Indoor	Shelter	Shelter	Shelter	Residents
	3	Lift	Residents	Residents	Prevention	Indoor	Indoor	Area
Contaminated water	1	Removal	Leak	Concentration	Tank	Removal	Battle	Careful attention
	2	Cesium	Concentration	Sea water	Concentration	Tank	Compensation	Battle
	3	Tank	Tank	Tank	Removal	Turbine	Ask	Pay
Communication	1	Stake	Interest	Everyone	Region	Risk	Region	Region
	2	Holder	Operation	Visit	Bidirectional	Region	Everyone	People
	3	Peace of mind	Tool	Region	Activity	Activity	Visit	Field
Decommissioning	1	Fuel debris	Promotion	Company	Direct	Work	Compensation	Fukushima
	2	Process	Meeting	Waste	Waste	Fukushima	Fukushima	Team
	3	Direct	Process	Contaminated water	Fukushima	Direct	Reconstruction	Waste

accident, we are developing new proposals for: monitoring in times of emergency, a medical care system for exposure in times of emergency, the prophylactic use of stable iodine tablets, and screening in terms of medical care for exposure” in 2012, and “these are the Nuclear Emergency Core Hospitals, that is, the core hospitals of local governments in the current medical care systems for radiation exposure; and these are their business continuity plans (BCP) as well as the survey of external reviews” in 2018.

“Evacuation” had a strong relationship with “area”, “residents” and “lift” from 2012–2013, followed by “shelter” and “indoors” from 2014–2017. In 2018, it again showed a strong relationship with the terms similar to 2012. As for original texts, in 2012, the term “evacuation” was used in contexts such as: “As the decontamination activities are in full swing and consideration of the revision of the evacuation areas is starting, we think that it is time to re-examine radiation dose monitoring, such as coming up with a plan for radiation dose

monitoring that appropriately reflects the changes in the situation”; in 2016 as: “With regard to the emergency response, various means of evacuation methods—such as overland routes, sea routes, and taking shelter indoors—were specified in advance, but the most crucial part of decision-making concerns the evacuation method that combines overland routes and sea routes, taking into account situations in which roads are blocked due to an earthquake”; and in 2018 as: “To summarize the measurement results of the real-time radiation dose measurement system, in terms of the average radiation dose from the past year in areas outside of municipalities that still have evacuation orders and those that have evacuation orders lifted, including even the northern part of the prefecture that has the highest level, the dose is within the national standard radiation dose from before the accident”.

“Contaminated water” had strong relationships with different terms over the years. In 2013 and 2014, when “contaminated water” appeared frequently, it was observed to have a strong relationship with terms such as “concentration” and “tank”. In the original text from 2013, the term was used in contexts such as: “The red line is one that carries underground stagnant water, and this is a line of high concentration of contaminated water.”

While there was also a change in the terms that “communication” had a relationship with over the years, it was found to have a consistently strong relationship with “region” from 2014. A representative phrase from the original text in 2016 when the term had a high ratio of appearance is: “So far, we have been working on communication activities, but, in view of the fact that they tend to be one-way explanations and involve many technical terms despite our efforts, we would like to continue to inculcate the concept of risk communication among our employees in order to gain the trust of local communities.”

“Decommissioning” also had the tendency of changing the terms it had strong relationships with over the years. In 2018, when “decommissioning” had a high appearance ratio, it had a strong relationship with “Fukushima”, “team”, and “waste”. In the original text, the term was used in contexts such as: “There are phenomena where radiation is emitted from metal waste, and it is usually thought that this process takes 1000 years or 10 000 years: scientifically, this is not expected to happen in an extremely short time, such as one year; our Decommissioning and Other Waste Management Team is discussing what kind of forecast we should come up with for matters of this type.”

## 4 Discussion

To examine nuclear regulation and management, as well as radiation protection measures after the FDNPP accident, this study focused on the meeting minutes of the Nuclear Regulation Authority and analyzed the changes in various measures over the years using the method of text mining.

The analysis of the co-occurrence network of terms with a high appearance ratio revealed that the terms can be categorized into six co-occurrence groups (group A–G). Co-occurrence group B in particular had a high appearance ratio, confirming that the main role of the Nuclear Regulation Authority is regulation and management with regard to the safety of nuclear power plants. The assessment criteria for

nuclear facilities and fuel (co-occurrence group A), measures and radiation protection (group C), and future plans and inspection for security (group D) were also confirmed to have been discussed. Further, the strong occurrence of “radiation” and “protection” was confirmed.

As a result of analyzing the co-occurrence network of the target terms, it was confirmed that terms with strong relationships form rational networks. For example, evacuation, return, and decontamination (co-occurrence group 1); decommissioning and contaminated water (group 3); and thyroid and cancer (group 4). “Communication” showed strong relationships with decommissioning and contaminated water (co-occurrence group 3), suggesting that the Nuclear Regulation Authority discussed risk communication in terms of decommissioning and contaminated water. “Anxiety” and “peace of mind” constitute the same co-occurrence group with evacuation, return, and decontamination (group 1). It can be attributed to the fact that “peace of mind” was regarded as an important factor in supporting “decontamination” (Murakami *et al.*, 2017a) and people’s “return” (Miyazaki *et al.*, 2016).

Looking at the appearance ratio of each target term, those that showed a ratio of at least 0.15% each year are: evacuation, return, decontamination, and anxiety (co-occurrence group 1); exposure and internal exposure (group 2); risk, communication contaminated water, and decommissioning (group 3); and nuclear accident (no group). Words such as evacuation, decontamination, anxiety, return, and communication may, at first glance, seem to have a weak relationship with nuclear regulation and management, which is the main role of Nuclear Regulation Authority in terms of policy; however, these terms suggest that the authority discussed radiation protection measures for local residents and workers and risk communication after the accident, in addition to measures for future emergencies (in particular, evacuation). After a nuclear disaster, it is important for the authorities dealing with nuclear regulation to deepen their knowledge about social measures such as evacuation, return, and risk communication, and cooperate with experts from relevant fields.

We confirmed that the appearance ratio of most target terms significantly changed among years. In particular, this study revealed the changes over the years in the ranking of the appearance ratio of target terms, from “evacuation” in 2012, to “contaminated water” from 2013–2014, “communication” from 2015–2017, and “decommissioning” in 2018. In addition, although the appearance ratios of “risk” and “exposure” were always high irrespective of the year, when analyzing the terms that they had strong relationships with and how those terms were used in the original texts of the minutes, it was confirmed that the terms of “risk” and “exposure” were used differently. In contrast to 2012 when “risk” and “exposure” were used in contexts such as: the risk evaluation for the works around the FDNPP and local residents’ exposure to radiation after the accident or the evaluation and reduction of the risks of exposure in times of emergency in the future when an accident happens, in 2018, the terms were used in contexts such as: the reduction of and plan for the mid-term risks of nuclear power plants. As such, the content of discussion had changed. From 2012–2014, the second to fourth years after the FDNPP accident, discussion included urgent issues such as nuclear safety management in the future based on the lessons learned from the accident, evacuation and radiation dose evaluation

soon after the accident, and treatment of the contaminated water generated around the power plant. However, in 2018, decommissioning and the mid-term approach to and planning for the future of nuclear power plants were discussed. According to the Fukushima prefectural government public opinion survey, about 60% of Fukushima residents cited “efforts toward decommissioning” as information they would like to obtain regarding the earthquake and the FDNPP accident (Fukushima Prefecture, 2020). The increasing discussion at the Nuclear Regulation Authority was observed to be consistent with the information required by the residents.

It is noteworthy that the appearance ratio of “communication” was low in 2012 and 2013, but increased from 2015. In general, it is desirable that risk communication is conducted as soon as possible (Gamhewage, 2014; World Health Organization, 2020). The timing of the increase in discussion on risk communication might seem to be somewhat late. The risk communication conducted immediately after the FDNPP accident (till a year later) largely involved explanation and focused on radiation; gradually, risk communication that involved collaboration and more participation by stakeholders was conducted (Murakami *et al.*, 2017b). Text mining also revealed that community-based risk communication was discussed by the Nuclear Regulation Authority.

There are some limitations of this study. First, this study was based on the Nuclear Regulation Authority meeting minutes and did not cover all the efforts made by the government of Japan regarding radiation protection after the FDNPP accident. The authority was established with the goal of rebuilding nuclear safety system with the safety of the people of the country as its highest priority, and its discussion mainly focuses on nuclear safety. Therefore, this study was unable to adequately evaluate changes over the years in the discussion on various measures such as health measures for issues not limited to addressing just the radiation after the FDNPP accident. Second, the efforts made immediately after the accident were outside the scope of this study as it focuses on the meeting minutes from 2012—a year after the accident—in order to discuss the measures taken during the chronic phases after the accident.

## 5 Conclusion

In this study, a change was observed in how the Nuclear Regulation Authority addressed various issues during the chronic phases after the FDNPP accident. Issues were discussed in a flexible manner by first tackling those that were considered to be the most urgent, before gradually moving on to mid-term issues. The authority started to discuss risk communication intensively from 2015 and highlighted the importance of community-based risk communication.

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*Conflicts of interest.* M.T. has started the research project founded by the Nuclear Regulation Authority since August

2020. M.M. has also joined the research project. This research project is unrelated to the submitted work.

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