What Can Radiation Protection Experts Contribute to the Issue of the Treated Water Stored in the Damaged Fukushima Daiichi Nuclear Power Plant?

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Decommissioning efforts are underway at the reactor where the accident occurred, namely the damaged Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Plant (FDNPP). However, a large amount of groundwater flowing into the site has become contaminated with radioactive substances and is stored in tanks on site, which has hampered the decommissioning work. Although the inflow of groundwater has been greatly reduced through measures such as the construction of frost walls, approximately 170 m$^3$ of water treated by the Advanced Liquid Processing System (ALPS) is being stored in tanks, each day. The tanks used to store this treated water are expected to become full by around the summer of 2022. It is not easy to get people to understand the efforts of all concerned parties, and providing clear information to these concerned parties is also a challenge. Questions have also been raised regarding whether other alternatives have been fully explored in the ALPS subcommittee. Some people have commented that the answers to the questions raised regarding the biological effects of tritium transmutation are inadequate. Some suspect that the answers are too detailed and incomprehensible, and that the respondents may be manipulating the public with some malicious intent. In any case, each possible plan presents both advantages and disadvantages, depending on the people who are involved. That makes it an ethical and vexing issue that can sway decisions, as perspectives change. While the environmental release plan is scientifically safe, it may represent a painful alternative. On the other hand, a more careful and imaginative approach to the idea of continued storage in tanks or other forms of storage may reveal some troublesome hidden disadvantages. Under these circumstances, experts must be prepared to answer people’s questions in a comprehensive and robust manner.

Keywords: Fukushima Nuclear Power Plant, Groundwater, Decommissioning, Tritium, Risk Communication

Introduction

Decommissioning efforts are underway at the reactors where the accident occurred, namely the damaged Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Plant (FDNPP) shown in online [1, 2]. However, a large amount of groundwater flowing into the site has become contaminated with radioactive substances and is stored in tanks on site, which has hampered the decommissioning work.

In order to solve this problem, the government convened an expert committee and asked for assistance from the international community to present the proposed solutions to the public and solicit opinions. The public’s interest was so high that the dead-
line for public comment was extended three times. The Japanese government’s efforts are presented in Figs. 1–3.

Local councils in Fukushima Prefecture also voted to oppose or deal cautiously with the release of treated water to the ocean, in response to a petition from residents. According to NHK [3], Aizu-sakashita, Ishikawa, Kanayama, Shinchi, Namie, Nishigo, and Miharu are against discharge to the sea. While Iitate, Iwaki, Kawamata, Nihon-matsu, and Yagawa have not declared that they are against discharge to the sea, they are insisting that we should be cautious. Only Koriyama rejected the petition that requested the expression of an objection to discharge to the sea. However, on June 30, 2020, they changed their position to also be against discharge to the sea.

In this context, the International Symposium, “How do we find the solution to radiological protection of tritium water?” of the Japan Health Physics Society was held on June 29, 2020 as a Webinar [4]. This paper discusses what radiation protection professionals should contribute to this issue, based on the discussions at the symposium.

During my presentation, I asked experts to contribute to my part by answering the typical questions asked by concerned people. I also asked non-experts to contribute by using a chat box to respond to displayed answers from experts. We received a large amount of feedback from the audience. There were several demands to share the presentation materials at this symposium, so that they are made open to the public [4]. However, these materials would not be easy to find for a foreign visitor. If the linked page shows an error message, you need to select English and try again.

At this symposium, opinions were not coordinated amongst the panelists prior to the symposium by avoiding pre-workshop discussions. This approach was taken in order to eliminate unintended manipulations of speech. Instead, the symposium was undertaken “on the fly.”

This presentation was dedicated to all of the persons who have been contributing to this difficult issue.

**Concerns regarding the Radiation Safety of Fishery Products**

The TEPCO’s FDNPP is located on the coast, and released...
1) Will the ALPS Treated Water be released to the environment as is?

No. In the case of releasing the ALPS treated water to the environment, the ALPS treated water will be re-purified and diluted to meet the regulatory standards for discharge.

Current Status of ALPS treated water (Dec 2019)

<table>
<thead>
<tr>
<th>Volume</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>300,000 m³</td>
<td>300,000 m³ (28%)</td>
</tr>
<tr>
<td>780,700 m³</td>
<td>780,700 m³ (72%)</td>
</tr>
</tbody>
</table>

What is ‘regulatory standards for discharge’?

Japan’s regulatory standards for discharge is set in compliance with the international standards known as publications of International Commission for Radiological Protection (ICRP), keeping public radiation dose less than 1mSv/year.

For example, if the water contained only tritium among the radionuclides, Japan’s regulatory standards allow discharge of water with 60,000 Bq per liter of tritium concentration.

In any case, all ALPS treated water will be diluted in the case of discharge to the environment.

Fig. 2. Will the Advanced Liquid Processing System (ALPS) treated water be released to the environment as is? (https://www.mofa.go.jp/press/release/press4e_002789.html).

The impact of the radiation to human health as a result of the discharge is considerably small.

Graph: Comparison of radiation impacts between the releases of entire amount of the ALPS treated water disposed of in one year and natural radiation

<table>
<thead>
<tr>
<th>Vapor Release</th>
<th>Discharge into the sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0012 mSv/year</td>
<td>0.00081 mSv/year</td>
</tr>
<tr>
<td>Natural exposure</td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Even if the entire amount of the ALPS treated water stored in the tanks were to be disposed of in one year, the impact would be no more than 1/1,000 of the exposure impact of natural radiation (2.1 mSv/year) in Japan. *Based on a UNSCEAR-specified method.

3) How has the GOJ been providing information to the International Community?

The GOJ has repeatedly been explaining the situation of the FDNPS to the international community on various occasions:

- Briefing sessions have been held 105 times for all the Diplomatic Missions in Tokyo (DMT).
- Monthly Report on the discharge record and monitoring results
- Technical briefings on the occasions of international conventions
- Reports on the decommissioning progress and the surrounding environment
- Related information is available on the METI website: (https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/index.html)

CONCLUSIONS

- Significant progress has been made to move FDNPS from an emergency situation to a stabilized situation.
  - The Report made by the ALPS Subcommittee outlines the potentially available options: 1) discharge into the sea and 2) vapor release. The IAEA’s Review Report concluded that the two options selected are technically feasible.
- The Government of Japan (GOJ) will decide its basic policy on the handling of ALPS treated water.
- Japan appreciates the IAEA’s Review Report of April 2020 and continues to count on the IAEA’s assessments.
- The GOJ will continue to inform the international community of the situation of the FDNPS in a courteous and transparent manner.
- The GOJ stands ready to explain our stances in response to any unfounded claim.

Fig. 3. How has the Government of Japan (GOJ) been providing information to the international community? (https://www.mofa.go.jp/press/release/press4e_002789.html).
large amounts of radioactive material into the ocean directly after the accident, including 3.5 PBq of $^{137}$Cs. Further, more radioactive material has since migrated to the ocean via atmospheric deposition, including 7.6 PBq of $^{137}$Cs [5]. In addition, radioactive material continues to be released into the ocean through rivers, such as 23 TBq of $^{137}$Cs during the period from March 11, 2011 to December 31, 2017 [6].

This release has raised concerns regarding the radiation safety of seafood, and cautious, large-scale efforts have been made to verify the safety of the fish, while promoting unique test operations show in “Results of the monitoring of radio-activity level in fisheries products” managed by Ministry of Agriculture, Forestry and Fisheries, as of July 29, 2020 [7]. Fortunately, concentrations of radioactive cesium in seawater off of TEPCO FDNPP decreased drastically within a few years after the accident, and remain low and stable shown in “Status of water environment around the TEPCO’s Fukushima Daiichi Nuclear Power Station and the impact to marine fish” provided by Fisheries Agency of Japan [8]. Furthermore, with the exception of those specified in the area where the test operations were conducted, all fish were confirmed to be safe by April 1, 2019, and consumers are now enjoying the seafood that was landed during the test operations.

**Current Status of Stored Treated Water at TEPCO FDNPP**

Although the inflow of groundwater has been greatly reduced through measures such as the construction of frost walls, approximately 170 m$^3$ of water treated by the Advanced Liquid Processing System (ALPS) is being stored in tanks, each day. The tanks used to store this treated water are expected to become full by around the summer of 2022. Therefore, the time to arrive at solutions is limited. With the exception of tritium, ALPS is capable of removing most of the radionuclides from contaminated water.

Regarding the mass balance of tritium, there is nearly a balance between daily decay and daily addition. According to recent data, the decay components are larger than the daily influent. The amount of tritium in the stored tanks is $8.6 \times 10^{14}$ Bq, as of October 31, 2019 [9], so that the amount of tritium water is 16 g. As the total volume of stored water was 1,226,379 m$^3$ as of August 20, 2020, the average concentration of tritium in the stored water is estimated to be roughly 1 MBq/L. However, decay appears to be predominant when rough calculations are carried out with the latest data.

The total amount of tritium at the damaged TEPCO’s FDNPP is estimated to be $3.4 \times 10^{15}$ Bq as of March 2011 [10]. Of this amount, $5 \times 14^{14}$ Bq has already spilled into the ocean.

On the other hand, if the transfer of tritium from debris increases in the future, it may exceed the decay. However, the balance is determined by the flow amount from debris, since the major component of tritium would still remain in the debris. Before the accident, the planned maximum emission of tritium was $2.2 \times 10^{11}$ Bq/yr at the TEPCO’s FDNPP. Thus, $3.5 \times 10^{12}$ years would be required, if the pre-accident planned release rate were applied. On the other hand, the planned maximum emission of tritium into the ocean is $1.8 \times 10^{10}$ Bq/yr at the reprocessing plant in Aomori, Japan. Therefore, the proposed emission rate mentioned below is between actual past emissions from TEPCO’s FDNPP and the future plan of the reprocessing plant.

**Proposed Plans by the Subcommittee on Handling of the ALPS Treated Water**

The ALPS subcommittee was established in November 2016 as a subcommittee of the Contaminated Water Treatment Committee organized by the Agency for Natural Resources and Energy to discuss the technical issues presented in the report of the Tritiated Water Task Force (issued in June 2016) to help the government decide on countermeasures regarding treated water. The subcommittee on handling of the ALPS treated water (ALPS subcommittee) has identified two realistic options: discharge to the sea and vapor release [9]. In the case of releasing the ALPS treated water to the environment, the treated water will be re-purified and diluted to meet the regulatory standards for discharge. The impact of the radiation on human health as a result of the discharge is being assessed.

Regarding the amount of tritium, it is often compared with tritium that is already in the environment, while sometimes mentioning past fallout. Even if it is a planned emission from a nuclear facility, people may have different perceptions of risk, which reflects the situation of the nuclear facility, such as whether or not it is damaged. Risk perception is subjective in that it depends on imparted feelings of trust. Furthermore, risk perception is also subjective in that it is based on credibility, so that professionals need to be honest in order to earn credibility.

Application of the exposure situation is very important for radiation protection. Which exposure situation should be
applied for this situation, such as a planned exposure situation or existing exposure situation? How should we think about the justification of radiation protection, as the International Commission on Radiological Protection (ICRP) recommended?

Among the three principles of radiation protection, justification is presented first. The other two are optimization and dose limits. Originally, “justification” refers to “the justification of practice”; that is, the benefits of radiation use should outweigh the disadvantages. Then, since the 2007 ICRP Recommendations, it also includes the justification of protection not limiting practice. The justification of protection principle is applied to all three exposure situations. The International Atomic Energy Agency (IAEA) General Safety Requirements Part 3 [11] describes this in a more limited way, and states that measures should be taken in the existing exposure situation, so that the disadvantages of taking measures are not too great.

When considering a comparison of the benefits and disadvantages of nuclear power generation, meaning that one should consider not only “planned exposure situations,” but also large-scale nuclear accidents, one will come to the conclusion that various factors need to be taken into account in making social decisions. While the legal framework for compensation will also be important in the event of an accident, this factor is beyond the scope of the ICRP.

Considering the “existing exposure situations in emergency and post-accident situations,” the application of the justification of practice will not be easy. This means that not only “practice,” but also the legitimacy of “protection” would be questioned. While it may be logical within the virtual theory of trade-offs, it would conflict with the argument of human rights for restoration from tort, and could be perceived as being too utilitarian, ignoring basic human rights without adequate compensation.

In order to reduce the radiation risk, it is necessary to reduce the radiation dose. The optimization of trade-offs is based on utilitarianism. The cost-effectiveness analysis used in utilitarianism is based on the compensation principle, and if the compensation principle is not functional, utilitarianism will fail. Therefore, it is also necessary to consider the ethics of this utilitarianism. What do you think about the scope of application of justification in radiation management for the existing exposure situation after an accident?

What Are the Concerns about the ALPS Treated Water?

1. Biological Accumulation of Organically Bound Tritium

For internal dose estimation, radiation dose conversion factors are important. The dose conversion factors for tritium vary depending on the chemical form of tritium, and the dose conversion factors for organically bound tritium (OBT) are roughly 2.7 times higher than those for tritiated water [12].

In the case of releases of tritium-substituted organic compounds to the environment, the measured tritium concentration was 105 Bq/kg (dry weight) as OBT in flounder (Platichthys flesus), and the “apparent” concentration factor was 3,700 for fish [13]. The conditions are very different such as the chemical form in which tritium is released into the environment is very different, and the comparison as it stands is not appropriate; however, because the study is largely unknown to the public, the number of people who are concerned is limited, and it is difficult to develop a social discussion on this issue, so the concerns of those who are concerned remain unaddressed. Regarding the concentration factor, it is thought to be the radioactive material concentration ratio between fish and seawater. However, when taking OBT as something like food, the “apparent” concentration factor will be increased.

With this added in, it is shown that OBTs accumulate in the environment [14]. This story is a little bit complicated, however this makes a few people who concern radiation shudder. Furthermore, the longer biological half-life of non-exchangeable OBT (NxOBT) that binds to the carbon skeleton of organic matter and does not readily exchange also represents a serious threat for these people. Therefore, experts have to provide an explanation regarding this “apparent” concentration factor in plain language, as well as how we consider the dynamics of tritium in our environment.

Regarding the safety assessment of tritium in the environment, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report explicitly mentions the risks of NxOBT [15].

In this regard, the fear of DNA damage due to element conversion is also common among people who are particularly concerned about tritium. The risk of DNA damage due to elemental conversion is also addressed in the report of the ALPS subcommittee. This effect would also be able to be quantitatively evaluated.
2. Measurement of Tritium

Although this policy is now under review, over 10 million samples of brown rice have been measured for radioactivity concentration every year, up to fiscal year 2019. As of April 2020, the Ministry of Health, Labour and Welfare is providing data on the concentration of radioactive substances in food products in nearly 2.6 million samples obtained since March 2011. In addition, each municipality is also conducting a huge number of food tests. However, the number of measurements of tritium in food is limited.

For this reason, Iwaki Citizens’ Radiation Measurement Center has been measuring tritium in environmental samples [16]. Although they have been asking TEPCO various questions, communication has failed and trust has not been established. On the other hand, they are deeply grateful for the technical support from the Japan Chemical Analysis Center.

OBT is also measured at the Tarachine civic measuring station, which is located in Iwaki city, Fukushima. Currently, the minimum detection limit is 1.1 Bq/kg-dry [17]. For free water tritium, their detection limit is 1.98 for a roughly 2 Bq/L water sample [18], so that the daily monitoring of TEPCO has a smaller detection limit. In consideration of the safety of workers engaged in work, Tarachine keeps the detection limit of $^{90}$Sr at roughly 0.6–0.8 mBq/L. In addition, they are working to obtain an electrolytic concentrator to further reduce the detection limit.

3. Radionuclides Other than Tritium

Although the contaminated water contained radionuclides other than tritium, the performance of the ALPS was not fully achieved due to constraints imposed by the severe conditions at the damaged site, and nuclides such as $^{99}$Tc, $^{106}$Ru, and $^{129}$I were not below the expected regulatory concentrations at several measurements.

Although TEPCO published the detailed raw data honestly on its website, as information that can be found very easily (via only a few simple clicks) [19], it was criticized as being very difficult to find and understand (several puzzling clicks are required), and misinterpreted as being hidden. This misinterpretation is not the fault of the residents. Without adequate consideration, people will be forced into such misapprehensions, as a result of nonfunctional communication.

Regarding the total amount of these radionuclides in the tanks, it is not easy to get an accurate view of the whole picture. The abundance of each radionuclide in each reactor is estimated for safety evaluations, and is disclosed to the public. Due to the large number of tanks, there are limitations to obtaining a more accurate evaluation.

Issues We Should Solve Regarding the ALPS Treated Water

The following three issues were presented in this symposium.

1) Why do experts believe that releasing treated water after additional treatment and dilution is scientifically safe, despite that fact that harmful substances will be released into our precious ocean?

2) What kinds of criticism are there for this assessment?

What kinds of concerns are there regarding examinations of alternative methods?

3) The basic framework of this issue. In particular, this issue is not something that should concern only fishermen, but should also involve normal citizens, as well.

Although the title of this international symposium was “How do we find the solution to radiological protection of tritium water?” radiation communication would not also represent a main issue, since it is not an issue of risk assessment. Furthermore, radiological protection would also not be a main issue, since it is not an issue of risk assessment. Many public comments discussed the nature of the political process, as well as social equity, social justice, and reliability.

Kikuchi-san, who was one of the speakers of this session, said that, “If it is really at a safe level, as the government and TEPCO say, I would not be able to oppose it. But I wonder if the information I’ve seen so far is reliable. From the fishermen’s point of view, we can’t trust it.” He also added that he could not accept ocean releases if the current situation does not improve, for reasons other than scientific debate [20].

One young group tweeted that, “We are concerned with the procedure and the manner of political decision-making. This is a problem that is situated before the discussion of whether or not to remove tritium.” We have to say that roughly 70% of the contaminated water contains a certain amount of radioactive substances other than tritium. This is an issue of the reliability of TEPCO. Therefore, we want both transparent information disclosures, and open opportunities for questions and answers with residents to be realized.”

These statements show where the problem lies: the manner of the procedure is being questioned. They are pointing out that it is not actually a matter regarding tritium at all (e.g.,
whether we will remove tritium or not. From the expert side, however, the idea of tritium removal from these huge tanks should be unrealistic, considering the scale.

The real issue concerns reliability and trust. For this reason, what the experts can do is to respond sincerely to various questions received from people. Therefore, it is important to see that these questions are discussed in the open frankly, while asking for support from local risk communicators.

Since this issue has a complex relationship with respect to interests among stakeholders, it is important to share comprehensive examinations, for issues that require multilateral perspectives. Actually, the mayors of the towns of Futaba and Okuma in Futaba County have also expressed concerns to the national government regarding the current above-ground storage, and have asked for a quick solution, contrary to the decision of the councils of the municipalities in Fukushima Prefecture on July 7, 2020, since the tank’s presence on the site is considered to be an impediment to a return to these home towns.

The mayor of Fukushima has expressed his opposition to the release of radioactive substances from Fukushima Prefecture into the ocean, and called for measures to be taken outside the prefecture at the regular press conference held on April 9, 2020 [21]. The municipalities’ associations in Fukushima have also stated that they have argued that the issues should be resolved outside the prefecture, and on August 24, 2020 called for a nationwide discussion. The difference from the stance of the two mayors of the towns of Futaba and Okuma in Futaba County was that they have not asked for this issue to be decided quickly. This phenomenon is similar to the inter-community structure when accepting nuisance facilities.

**Suggested Principle Ideas to Solve These Issues**

(1) The safety of the environmental release of treated water containing tritium has been evaluated from multiple perspectives. It is necessary to continue to confirm its safety through steady monitoring, regardless of which plan is adapted among the possible solutions. Regarding such monitoring, the Government of Japan has established the Comprehensive Monitoring Plan [22] and releases all data [23].

(2) Safety is a matter of trust, which requires professionals to do their part in good faith.

(3) How to transmit relevant data and information while maintaining transparency is important in terms of trust, and collaboration with scientists and communicators is necessary for well-informed social agreement.

(4) There is a need to take into account the interests of those who have difficulties expressing their opinions as minorities in society, in terms of human rights.

**Summary**

It is not easy to get people to understand the efforts of all concerned parties, and providing clear information to these concerned parties is also a challenge. Questions have also been raised regarding whether other alternatives have been fully explored in the ALPS subcommittee. Dr. Nishio commented at a public hearing in Tokyo on Aug. 31, 2018 that the answers to the questions raised regarding the biological effects of tritium transmutation are inadequate. Some residents suspect that the respondents for public comments may be manipulating the public with some malicious intent since although the answers are carefully crafted, they are detailed and not always easy to understand. In any case, each possible plan presents both advantages and disadvantages, depending on the people who are involved. That makes it an ethical and vexing issue that can sway decisions, as perspectives change. While the environmental release plan is scientifically safe, it may represent a painful alternative. On the other hand, a more careful and imaginative approach to the idea of continued storage in tanks or other forms of storage may reveal some troublesome hidden disadvantages. Under these circumstances, experts must be prepared to answer people’s questions in a comprehensive and robust manner.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.

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