Summary of Information and Data Gathered at Meetings and the Expert Panel's Views of the Scientific Status of the Planned Release of Radioactively Contaminated Cooling Water from the Fukushima Nuclear Power Plant Disaster

10 August 2022
Corrected 2022-11-23 (to correspond to the memorandum sent to the Pacific Islands Forum on 2022-08-11)

Prepared by the Expert Panel

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This memorandum is to summarize what the Expert Panel has learned so far from

- three meetings with the Japanese Government and the Tokyo Electric Power Company (TEPCO) –The IAEA had an observer in one of them;
- the data on tank radionuclide contents provided by TEPCO; and
- the briefing by the IAEA Director General to the Pacific Islands Forum (PIF)meeting on 6 July 2022 and the discussion that followed; some members of the Expert Panel were observers of that meeting.

This memorandum also serves to summarize our conclusions and views about the scientific state of the proposed discharges and our recommendations as scientific experts, without any implication as to what positions may or may not be taken by the Forum or any of its members. We have believed for some time that a decision to proceed with construction of the discharge infrastructure was premature at best and that it should be postponed. But, given that Japan's Nuclear Regulation Authority has authorized construction of the discharge pipeline (though not yet the discharge), we believe it is our scientific and ethical responsibility to set down our analysis, conclusions, and recommendations as clearly and forthrightly as possible.

Executive Summary

Our main conclusions are as follows:

1. TEPCO's knowledge of the source term – that is the specific radionuclide contents of the tanks – is seriously deficient. Only a fraction of the tanks have been sampled and, in almost all cases, only nine of 64 total radionuclides are sampled in the data that has been shared with PIF.

2. TEPCO's measurement protocol is statistically deficient and biased; the results are very likely unrepresentative of the contents of the tanks. The protocol does not even appear to be designed to provide a statistically reliable estimate of the radionuclide content of the tanks.
3. TEPCO's assumptions about the 55 radionuclides that have only rarely been measured and are left out of the routine measurement protocol are not a good scientific basis for planning ALPS treatment and eventual dilution and discharge.
4. We are surprised and dismayed that the IAEA has not insisted that measurements be taken in a manner that are statistically representative of the tanks' contents. In our view, this is a minimal basis for pre-operational planning that should have been established prior to construction authorization.
5. Sludges and inhomogeneous distribution of wastes in the early tanks have been inadequately considered and may present operational complications that should have been resolved prior to construction authorization.
6. Given the complex and large nature of the task, the amount of ALPS testing that has been done is inadequate.
7. The considerations of ecological impact and bioconcentration are seriously deficient and do not provide a sound basis for estimating impact. In the case of tritium, the drinking water model used for estimating organically bound tritium is wrong since it does not apply to ocean ecosystems and the associated biota.
8. Among other problems, the sum of ratios method for determining safety is deficient and insufficient since it does not consider that some radionuclides like strontium-90 could be reconcentrated in ocean ecosystems by several orders of magnitude. Monitoring after discharge assuming safety will not prevent problems and subsequent harm, but only document their occurrence.
9. The assumption that "dilution is the solution to pollution" is scientifically outdated and ecologically inappropriate. That is even more so in the case of the proposed discharges, which will inflict substantial reputational damage to fisheries in Japan, and beyond. The proposed action poses transgenerational and transboundary issues that deserve to be much more seriously considered; specifically, they require that ecosystem and reputational harm and transboundary harm be avoided if possible. That requires a wider and more in-depth exploration of options than has occurred.
10. We are dismayed that the IAEA does not seem to have exercised the due amount of pre-operational scientific diligence; rather it has postponed that to the stage immediately preceding discharge – far too late in the process, in our view.
11. Based on our scientific understanding of the matter, we make the following recommendations:
    a. Construction of the pipeline should be indefinitely postponed.
    b. Previously considered options should be revisited from the point of view of preventing intergenerational, transboundary, and reputational harm, particularly to the fishing industry within Japan and the Pacific Ocean region generally.
    c. We recognize that there is no risk-free option. But the risks could be greatly reduced. We propose three options that could reduce risks by *orders of magnitude* and could also prevent most of the intergenerational, transboundary, and reputational harm. The first option does not exclude pursuit of the other two:

i. Processing the waste in ALPS and storing the wastes with mainly tritium in tanks that are far more secure to allow tritium to decay.
ii. Bioremediation in which animals (e.g., bivalves) plants and fungi would concentrate radionuclides into solid form making them more secure from a transboundary contamination point of view.
iii. Treatment in ALPS and use of the treated water to make concrete with low human contact potential, shielding tritium beta particles from the environment.

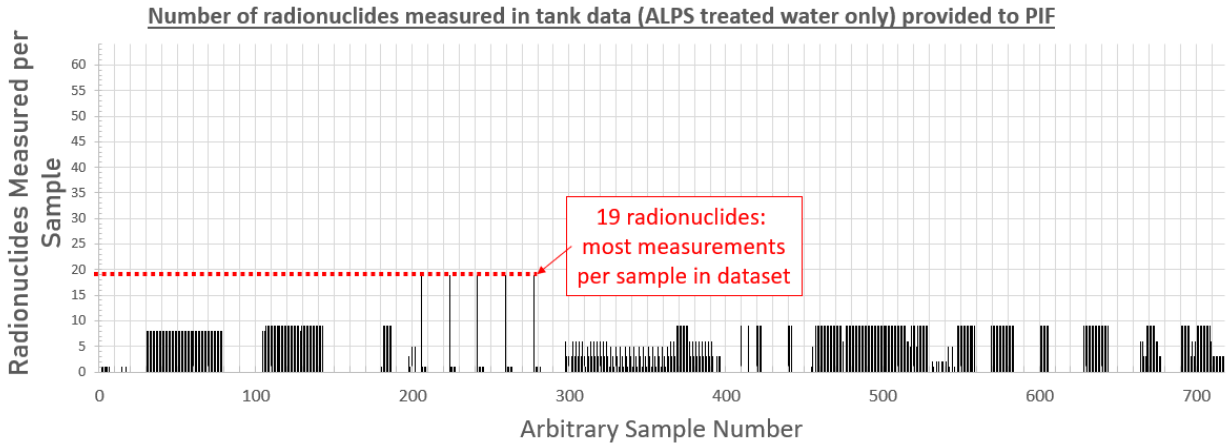
I. Status of our scientific understanding

i. Measurements

Some of our initial questions related to representativeness of the measurements in relation to the radionuclide contents of the tanks, including the measurement protocol and the homogeneity (or lack thereof) of the tank contents remain unanswered. We also have questions about the application of the "sum or ratios" method to determine safety in an oceanic ecosystem.

The information provided by Japan and TEPCO about tank contents and the measurements is as follows:

a. **Number of radionuclides measured in data provided to PIF**: Tank measurements have focused on only seven out of 62 radionuclides (i.e., radionuclides other than tritium and carbon-14); these seven are strontium-90 (Sr-90), cesium-134 (Cs-134), cesium-137 (Cs-137), iodine-129 (I-129), ruthenium-106 (Ru-106), antimony-125 (Sb-125), and cobalt 60 (Co-60). Very few measurements of other radionuclides have been made. The following chart was compiled by one of the Expert Panel members (Dr. Dalnoki-Veress) from data provided to the Expert Panel. It shows how rarely more than seven radionuclides are measured and even then the number remains at a fraction of the total. The maximum number measured in this set was 19 (out of 64 total, including tritium and carbon-14); in almost all cases only seven or nine radionuclides were measured.



b. **Assumption about the sum of ratios of radionuclides not measured**: For the rest of the radionuclides, the sum of the ratios of the concentrations (which are not measured) to

the regulatory limit is always assumed to be 0.3. This assumption is maintained independent of the measured concentrations of the seven radionuclides or the sum of the ratios of these seven with their respective regulatory limits. For instance, the sum of ratios for the seven could be less than one, one, 10, or 100; yet the same assumption about the other 55 radionuclides would be maintained. In effect, TEPCO is assuming that these radionuclides are always at concentrations that would have the same impact independently of the impacted indicated by the measurements of the seven radionuclides. During the meeting on 15/16 June 2022 TEPCO agreed that it would be reasonable to assume that the sum of ratios for the 55 changed when the measured concentrations of the seven radionuclides changed. Using 0.3 as the sum of ratios for the unmeasured 55 radionuclides is scientifically unsupported and likely not a sound basis for planning ALPS processing and discharges. TEPCO said it has not varied the ratio for these 55 radionuclides because the primary aim of the measurements is to control external radiation at the site boundary. The objective in that regard is that it stays below the 1 mSv/year limit.

c. **Sampling time and procedure**: Samples are taken only once for each set of tanks from the last batch of ALPS treated water before the tank set is full. A single 30-liter sample is taken, which is inadequate for understanding true content and concentrations.
d. **Sludges in the tanks filled in the early years**: The presence of sludges in the tanks that received water in the years immediately after the accident was confirmed. These early years extended to 2013 and 2014. The sludges were not sampled then and have not been sampled since that time. The plan is to remove the water above the 30-cm mark in the tanks and leave the rest, including the interstitial water in the sludges and the sludges themselves to be dealt with as part of tank decommissioning. It is unclear if any sludge depth is greater than 30 cm; that has not yet been discussed.

ii. Expert Panel conclusions regarding measurements and measurement protocol

a. **TEPCO's primary aim in measurements**: The primary aim is not related to readiness for the discharges, such as assessment of the adequacy of ALPS capacity; rather TEPCO has stated that it is to maintain the site boundary external dose to less than 1 mSv/year. This is not a scientifically suitable basis to plan for treatment or discharge of the radioactive wastewater.
b. **Unrepresentative measurement protocol**: The measurement protocol practically ensures that the radionuclide concentrations measured in the samples are unrepresentative of the contents of the tanks. There is sample bias as to the time of sampling and the manner of sampling. Sample radionuclide concentrations are expected to vary a great deal (as indicated for instance by large cesium-137/strontium-90 ratio variations). Taking one sample consistently from the last batch of water ensures sample bias rather than sample representativeness; even the direction of the bias cannot be determined, given this measurement protocol. The impact of this bias on the assessment of the source term cannot be determined because there is no set of random samples against which the biased measurements can be compared.
c. **Scientifically incorrect use of sum of ratios**: It is scientifically incorrect to use a sum of ratios of 0.3 for 55 non-measured radionuclides independently of the results of the measurements of the concentrations of the seven measured radionuclides. A

representative relationship of the 55 to the seven should have been established based on random sampling and ratios assigned accordingly.

d. **Highly questionable data**: There are a number of anomalous and questionable data points and measurements in the dataset provided to PIF by TEPCO. For instance, the stated limit for tellurium-127 (Te-127) is 5,000 Bq/L. But four different Te-127 measurements are listed as being less than (i.e. with the symbol "<") in the hundreds of thousands *to tens of billions of Bq/L*. The highest number is almost 18 million times the official limit, but no statement can be made about its ratio since the measurement indicates it is less than 18 million times the limit. Te-127 is a beta emitter that emits beta particles in the hundreds of kilo-electron volt energy range and so should be easily detectable at these concentrations. We are puzzled that there is detectable Te-127 at all since its half-life is only 9.4 hours. Any Te-127 present at the time of the accident should have decayed away well before the time of the 2019 measurement. The reported Te-127 data, if real, raises a serious question. Are there intermittent criticalities occurring in the molten cores? If not, the Te-127 values indicate that TEPCO's measurement and data quality control procedures are poor. In either case, we believe that it is urgent that TEPCO and the IAEA urgently address this issue.
e. **Uncertainty regarding total radioactivity and direction of measurement bias**: Overall, the state of knowledge of the actual content of radionuclides in the tanks as to total radioactivity for each radionuclide as well as their concentrations is highly uncertain, since it is based on biased sampling. Given that, it is difficult to see how a program of ALPS treatment can be designed that will ensure sufficient ALPS capacity and preclude the need for repeated ALPS treatment before discharge.
f. **Vague and unsatisfactory basis for planning**: As it is, TEPCO's statement that the dilution required will be more than one hundred is far too vague and an unsatisfactory basis for planning. One of us (Dr. Buesseler) had already pointed out in November 2021 that dilution of tritium at the highest reported concentrations would have to be 1,700 times to reach the target 1,500 becquerels/liter (Bq/L) upper limit. Statistically valid knowledge of tank radionuclide contents of all radionuclides is required for sound planning of treatment and discharge and the development of an initially reliable schedule by which time the entire discharge process will be completed. We recognize there are uncertainties in regard to future quantities of cooling water and radionuclide concentrations in them. But that is more reason to have firm grip on what is now in the tanks.
g. **Too limited testing of ALPS**: The testing of the ALPS system has been very limited to date; its representativeness for indicating whether it could successfully treat the large volumes of water whose radionuclide content is not well-established remains open to question.
h. **Inadequate pre-operational preparation and de facto premature IAEA endorsement of discharges as the preferred approach**: The IAEA has indicated that repeated ALPS treatment would be done if required. That was implied by the statement that the discharge is not in compliance with the protocol would be viewed as non-compliant. He explicitly stated that his main concern was not what is in the tanks now but what is the situation after ALPS treatment – that is, just prior to discharge. In effect, the IAEA has endorsed the discharge plan without adequate knowledge of the radionuclide content of the tanks or of the ability of the ALPS system to handle the actual radionuclide load in an

operationally efficient manner. We believe that pre-operational preparation should include much better knowledge of the source term.

i. **Inadequate knowledge of waste inhomogeneities**: Pre-operational readiness also requires much better knowledge of the inhomogeneities of waste in the tanks filled in the early years. Specifically, the water above the sludge layers should be of special pre-operational concern.
j. **Questions about ability of ALPS to handle waste load**: We are concerned that IAEA did not indicate whether and how it has considered the ability of the ALPS system to handle the volume, concentration and variety of wastes that are present in the tanks or any contingencies in that regard (other than the implication of repeated ALPS treatment).
k. **Failure of IAEA to ask for representative waste sampling**: The IAEA told the Forum on 6 July 2022 that it is there to provide "authoritative" opinions to Japan and that Japan is the decision-maker. We are surprised and disappointed that the IAEA did not use its scientific authority to ask for statistically representative sampling that would enable a reliable knowledge of the source term; nor did it advise Japan that such knowledge should be available prior to the NRA's authorization of construction. We continue to hold that it is not a sound scientific course to authorize construction prior to representative sampling of the tanks' contents and a reliable estimate of the source term of each radionuclide of concern.
l. **Inappropriate and premature authorization of construction**: Authorizing construction to prepare for discharge before doing the necessary sampling to establish tank contents of all radionuclides is not good pre-operational practice. The source term needs to be established much better than it has been. The ability of the ALPS system to handle the varied contents of the tanks – including early tanks with particulate loads and sludges that may be stirred up as the tanks are being emptied – has not been satisfactorily established.
m. **Scientifically and ecologically unsound postponement of full and proper sampling**: Waiting until the time of discharge to do full and proper sampling is not a sound procedure either from a scientific or ecological point of view. Operational difficulties, the need to repeat ALPS treatment many times, and/or the need to greatly increase dilution may all present difficult hurdles. Having excluded all alternatives, the pressure to discharge into the oceans by increasing dilution as a way of solving problems is likely to be great. This may, among other things, greatly stretch out the time over which the discharges occur. By continuing to expend financial resources on this, so far, unsound plan, the Japanese government will be committed to pursuing a plan that may have greater negative financial, environmental and human health consequences.

II. Safety and ecological aspects

In his November 2021 comments on the TEPCO Environmental Impact Assessment, Dr. Buesseler mentioned that the EIA does not mention organically bound tritium (OBT), an issue we consider of primary importance in terms of its impact. This issue was discussed with TEPCO during our 15/16 June 2022 meeting. At that time, TEPCO informed the Expert Panel that TEPCO will be assuming a 10% OBT ratio as a conservative value, considering that ICRP Publication 56 estimates that 3% of tritium in drinking water would be converted to OBT and that ICRP 134 has an estimate of 6%.

Using a drinking water conversion factor is not scientifically valid for the proposed discharges. The discharge water is not going to be consumed by people; rather it would be diluted with

seawater to 1,500 Bq/L. The parameter of interest therefore is not what happens in the human body when tritiated water is consumed directly, but what happens in oceanic ecosystems. Background concentrations of tritium is seawater are a fraction of a Bq/L; as a result the proposed discharge concentration is thousands of times the natural and nuclear testing background concentration.

Moreover, discharges at this concentration will occur at a single point over many decades, creating a gradient over a significant part of the nearby ocean that marine life will experience. Further, a single fraction for conversion of tritiated water to OBT is unlikely to a satisfactory scientific basis for considering this complex problem that will persist for a century or so. For instance, it is well-known that benthic organisms respond differently to various toxicants than pelagic fish. It should also be noted that tuna with traces of Fukushima related contamination have been found across the Pacific on the shores of the United States.[1]

There are many different geochemical forms of OBT, such as total OBT, exchangeable OBT, non-exchangeable OBT, soluble OBT, insoluble OBT, tritiated organics, and buried tritium, and each may have a different fate in the ocean. A simple classification is required to clarify understanding within the tritium research community. Unlike for tritiated water (HTO), the environmental quantification and behavior of OBT are not well known.[2]

The kinetics of the turnover of tritium between seawater HTO, biota HTO, and OBT is an important consideration not addressed. HTO in two algae and a mollusk was shown to exchange rapidly with seawater HTO. However, the overall tritium turnover between HTO and the whole-organism OBT is a slow process with a tritium biological half-life on the order of months.[3] The generic consideration of OBT provided by ICRP (International Commission on Radiological Protection) may not be appropriate for specific organic forms such as OBT in fish.[4]

We are surprised and dismayed that the IAEA does not appear to have pointed to the inappropriateness of using a drinking water-related parameter for a decades-long discharge of tritium contaminated water into the ocean, even though a scientifically valid Environmental Impact Assessment is required by its protocol.

Bioconcentration is also a special concern for strontium-90, which concentrates in the bone, because of its similar chemistry to calcium. Though its initial concentration is planned to be well

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[1] Daniel J. Madigana, Zofia Baumann, and Nicholas S. Fisher, "Pacific bluefin tuna transport Fukushima-derived radionuclides from Japan to California," *Proceedings of the National Academy of Sciences*, 2012, at https://www.pnas.org/doi/pdf/10.1073/pnas.1204859109

[2] S. B. Kim, N. Baglan, P. A. Davis, "Current understanding of organically bound tritium (OBT) in the environment," *Journal of Environmental Radioactivity*, December 2013 at https://www.sciencedirect.com/science/article/abs/pii/S0265931X13001604

[3] Bruno Fiévet, Julien Pommier, Claire Voiseux, Pascal Bailly du Bois, Philippe Laguionie, Catherine Cossonnet, Luc Solier, "Transfer of tritium released into the marine environment by French nuclear facilities bordering the English Channel," *Environmental Science and Technology*, June 2013 at https://pubmed.ncbi.nlm.nih.gov/23656411/

[4] John Harrison, "Doses and risks from tritiated water and environmental organically bound tritium," *Journal of Radiological Protection*, September 2009 at https://pubmed.ncbi.nlm.nih.gov/19690361/

below the regulatory limit, the potential for reconcentration by many orders of magnitude exists, with a biological half-life in fish on the order of months to years.

TEPCO's preparation in regard to the complex ecosystem issues that are involved is very inadequate; it does not provide a scientific basis for concluding that ecosystem harm will be minimal. We recognize that much regulation is still based on the idea of "dilution is the solution to pollution." However, the science of protecting the oceans and its ecosystems, including but not only the human beings who depend on the oceans, has moved far beyond that notion.

Ocean dumping of radioactive waste cannot be and should not be justified on the ground that tritiated water is routinely dumped by nuclear power plants and reprocessing operations such as those at La Hague in France or Sellafield in the UK. On the contrary, as scientific experts we believe that the challenge presented by the large volume of liquid radioactive waste with significant tritium contamination is an opportunity to find and implement safer and more sensible options and setting a better precedent to deal with future catastrophes. That could open the door for others to move on from present dumping practices to more ecologically protective ones.

III. Conclusions and scientific recommendations

Even though Japan's Nuclear Regulation Authority has given the go ahead for construction and the IAEA has registered no objection, our considered scientific view is that this decision is very premature and that it lacks a sound scientific basis. Besides the concerns about the inadequacy of sampling and related matters, the ecological considerations have been insufficient and, in the case of tritium OBT, based on scientific guidance from the ICRP that clearly does not apply to the proposed discharges.

Further, in view of the highly problematic tellurium-127 measurements, we recommend that TEPCO and the IAEA urgently take up the issue of measurement and data quality control and the issue of whether intermittent criticalities are occurring in the molten cores.

Finally, we believe that there are alternatives that may be far less damaging that deserve to be considered before further steps, such as pipeline construction, are taken to consolidate a decision to discharge. Some of the alternatives considered, such as longer term-storage for tritium decay, removal of tritium, or evaporation of tritiated water after ALPS treatment need to be more fully considered on a comparative basis for ecosystem impact. There is ample time to consider other options, as there is no urgency to release this cooling water since space for alterative storage exists within and around the Fukushima facility.

The expert panel have also discussed three options that TEPCO does not appear to have considered as yet; their impact may be far lower than the proposed discharges:

- **Safe storage and radioactive decay**: By their own estimates of discharge rates, release will take 40 years, during which time additional waters will be collected extending this time frame by decades. If ALPS-treated water containing tritium were stored in safe, earthquake proof tanks on site or in surrounding areas, 97 percent of the tritium would disappear in about six decades due to radioactive decay, given its 12.3 year half-life. The option of safe storage has not been fully considered.
- **Bioremediation**: Certain animals, plants and fungi can remove radionuclides from water and concentrate them, enabling the resultant waste to be managed along with the much greater amounts of radioactivity in solid wastes (including the cakes from tank sludges).

- **Use of ALPS treated water to make concrete for special applications**: Tank water could be treated as currently planned and the cleaned water, containing mainly tritium, used to make concrete for applications where there would be little human contact (that is in non-building and non-public applications). The volume of water could be consumed in a few years, a far shorter time frame than the proposed discharges. The concrete would shield the tritium beta particles even if it is eventually converted to rubble, by which time most of the tritium would have decayed away.

We recognize there is no perfect or risk-free solution. The waste is here and it poses a difficult problem. We are not advocating the adoption of a specific course at this time other than to delay construction significantly and consider much less damaging alternatives . We have mentioned three alternatives as illustrations of approaches *that may have orders of magnitude lower impact than the proposed course*. We also note that the safe storage option – ALPS treatment followed by more secure storage – does not preclude the other two. They are examples of options that would protect the oceans and address the serious problems of (i) transboundary pollution and (ii) the reputational damage that is all but certain to occur to Japan's fishing industry and the fishing industry in the Pacific region more generally. They deserve to be studied fully and discussed with the Japanese people, including fishing communities, and with the communities in the Pacific region more generally. And they deserve to be studied without the presumption that construction gives that discharge into the Pacific Ocean is the preferred option.

Finally, we wish again to stress that we have written down these observations and conclusions as scientific matters; our recommendations derive from those scientific considerations. They are not meant to represent the views of any other party whatsoever, including the Pacific Islands Forum or any member of the Forum.