

Minimizing Harm: the concrete option for solving the accumulation of radioactively contaminated water at the Fukushima Daiichi Nuclear Power Plant site

A paper prepared by the Independent Expert Panel to the Pacific Islands Forum

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Abstract: The Tokyo Electric Power Company (TEPCO) proposes to treat 1.3 million cubic meters of accumulated, radioactively contaminated water to greatly reduce concentrations of all radionuclides other than tritium and carbon-14 by using the Advanced Liquid Processing System (ALPS). It proposed to dilute the resultant water so that the tritium concentration would be 1,500 Bq/liter, which is one-seventh drinking water guideline of the World Health Organization for that radionuclide. Japan's Nuclear Regulation Authority and the IAEA have been evaluating the health and environmental impact questions with the presumption that TEPCO's plan could comply with IAEA guidelines and Japan's regulations. However, a presumption that TEPCO's plan would comply in principle with all guidelines does not appear to include the transboundary implications of IAEA's guidance in its General Safety Guide No. 8 (GSG-8) that requires that benefits outweigh the harms for individuals and societies. The Expert Panel of scientists appointed by the Pacific Islands Forum have recommended an option that would avoid transboundary impacts, in conformity with GSG-8. That option is to treat the water in the ALPS system as now proposed by TEPCO and then to use it to make concrete with little potential for human contact, such as the concrete being used on the Fukushima Daiichi site and/or tsunami barriers for coastal protection. This Expert Panel paper is focused on the concrete option; it should be seen in the context of the broader issues with the TEPCO plan that were covered in an overall assessment made by the Expert Panel in August 2022.¹

Over 1.3 million metric tons of radioactively contaminated water are stored in about 1,000 tanks at the Fukushima Daiichi Nuclear Power Plant Site (hereafter "Fukushima"). The water contains dozens of radionuclides, much of it in high concentrations thousands of times higher than present drinking water standards. These radionuclides include cesium-137, which emits penetrating gamma radiation, and strontium-90, which emits strong beta radiation and concentrates in the bone. The predominant radionuclide, in terms of quantity of radioactivity is tritium – a radioactive isotope of hydrogen; it is in the form of tritiated water, HTO, in which an atom of ordinary hydrogen in water has been replaced by radioactive tritium.

The Tokyo Electric Power Company, (TEPCO) which owns the power plant, has proposed that the water in the tanks be treated through its Advanced Liquid Processing System (ALPS) to greatly reduce the concentrations of all radionuclides except tritium and carbon-14, the latter being present in relatively small amounts. This ALPS-treated radioactive water would then be diluted to reduce tritium concentrations to below the Japanese regulatory standards and released into the Pacific Ocean over a period of roughly thirty years about 1 kilometer off the East Coast of Japan. The dilution factors needed

¹ Expert Panel to the Pacific Islands Forum, "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," 11 August 2022

would depend on the batch of water since tritium concentrations in tanks are from about 100 times to over 1000 times TEPCO's target concentration of 1,500 Bq/L. TEPCO has stated that the dilution factor will be over 100 times but has not provided a more precise estimate of the overall average expected dilution factor.

Since contaminated water is still being generated, this ocean dumping – that is what it would be called if the water were put in a barrel and thrown overboard – of radioactive water would continue for 30 years (possibly more).² The water would still contain some strontium-90 and other radionuclides with attendant risks of uptake associated with seafloor sediments at the outfall point, trophic transfer, bioconcentration and propagation through oceanic ecosystems. Besides the radioactivity exposure, which TEPCO estimates will be well below 1 millisievert per year, the dumping would also create reputational damage to the fishing and tourist industries, not only in Japan but across other countries in the Pacific region. In this paper, we explore a specific alternative that would greatly mitigate or avoid numerous environmental, legal and reputational problems. Specifically, we propose that TEPCO:

- Treat the water with the ALPS system, as now proposed, independently confirming concentration levels in every tank;
- Use this water without dilution to make concrete for useful applications that have little potential for public contact.

Treating the water with the ALPS system to the degree now proposed would leave only very small quantities of radionuclides like strontium-90, cobalt-60 and cesium-137, if the ALPS system works smoothly or if the waste is treated multiple times, both contingencies having been mentioned by TEPCO and the IAEA in the context of the TEPCO plan. In effect, the first step in our proposal is the same as that proposed by TEPCO, except that we advocate better testing of the ALPS system in advance and over time to ensure that it is working effectively and continues to do so.

The second step is very different. In the TEPCO plan, dumping the water in the Pacific Ocean would lead to varying degrees of bioaccumulation and bioconcentration of different radionuclides including strontium-90, cesium-137, cobalt-60 and tritium, as well as propagation of radioactive exposure through oceanic food webs. These processes would not occur if the water is used to make concrete.

The potential for radiation exposure to the public would also be essentially eliminated. Tritium decays by emitting relatively low-energy beta particles with an average energy of 5.7 kilo-electron volts (range 0 to 18.6 keV). The stopping distance of the tritium beta particles in concrete is only a few microns at most. Essentially no beta particles would exit the concrete. If someone came close to the structure, their clothes would stop any particles that exited. Tritium beta particles can be stopped by a sheet of paper. That is why its principal risks arise when it is inside the body and becomes part of our cells, potentially disrupting their metabolism, among other things. This is a critical difference between putting radioactive treated water into the ocean and making concrete with it.

It is also important to note that water binds chemically with the cement. Thus, even the disintegration of the concrete over the decades, should that occur, will not result in public radiation exposure from

² "Dumping" is the formal term to describe such an activity as evidenced by the title of the 1972 treaty to prevent ocean pollution: "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter".

tritium. The short stopping distance means that tritium's beta particles would still be stopped within the concrete.

The half-life of tritium is 12.3 years. Almost the entire tritium radioactivity (about 97%) in the ALPS-treated water would have decayed away in about 60 years – which may well be the duration of discharges of ALPS treated water given the generation of additional groundwater fed cooling waters until the molten fuel has been removed from the stricken reactors. While TEPCO claims that the water discharges would last for thirty years, it is noteworthy that there is still some residual fuel debris in the Three Mile Island Unit 2 reactor. Its decommissioning is not expected to be complete until 2037, 58 years after the 1979 partial meltdown.³ The accident at Fukushima was much more severe, involving multiple meltdowns, explosions, and reactor vessel damage.

The risk would also be reduced by the much shorter time frame in which the accumulated water could be dealt with if the concrete option is adopted. Japan uses about 40 million tons of cement a year, according to the Japanese Cement Association. Assuming that use patterns are similar to those in the United States, about a third of this may be used for making concrete with low potential for human contact. Some or much of the ALPS treated water could actually be used for concrete needed at the Fukushima Daiichi site – for barrier walls, containers, stabilizing piles of radioactive soil and the like.

At the low end, about 0.4 liters of water are mixed with a kilogram of cement. Thus, the accumulated water could be consumed in just about 8% of the cement used in Japan in a single year. Assuming that a much smaller fraction of concrete were made with it – on the order of 1% or 2% each year – the stored water would be consumed in less than a decade. After that, only the water generated by cooling in real time would be used. Thus, the risks from earthquakes damaging tanks and spilling their contents into the Pacific Ocean, would be much reduced.

We first proposed the concrete option for evaluation by TEPCO in its August 2022 assessment of the TEPCO proposal and the various scientific and technical issues associated with it prepared for the Pacific Islands Forum, made available to TEPCO and other Japanese authorities as well as the International Atomic Energy Agency (IAEA). We noted that this option, among others, *“may have orders of magnitude lower impact than the proposed course”* (italics in the original).⁴ Transboundary impacts would be essentially avoided. Despite that, the option has not been taken seriously, much less officially evaluated.

During the April 13, 2023 meeting with the Expert Panel, TEPCO took the position that it had already considered the concrete option in 2016 and rejected it in favor of ALPS treatment and release of the radioactively contaminated water⁵ into the Pacific Ocean. The Expert Panel has reviewed the TEPCO

³ U.S. Nuclear Regulatory Commission, Three Miles Island Unit 2 – Site Status Summary, at <https://www.nrc.gov/info-finder/decommissioning/power-reactor/three-mile-island-unit-2.html> viewed on 2023-05-16

⁴ Expert Panel paper prepared for the Pacific Islands Forum, August 11, 2022, op cit.

⁵ TEPCO has insisted that the post-treatment water be called “ALPS treated water” without the use of the phrase “radioactively contaminated.” However, it is a simple fact that the water to be released will have radioactive tritium, carbon-14 as well as small amounts of other radionuclides. It is, objectively speaking radioactive water. This scientific fact could, with apologies to Shakespeare's Romeo and Juliet, be stated as: “radioactive water by any other name would be just as radioactive”.

concrete proposal; it is fundamentally different in a number of ways and in its implications for impact on the environment.

The concrete option evaluated by TEPCO in 2016 has the following features:

- It would significantly increase the volume of waste;
- The water in the tanks would not be treated. As a result, the full complement of radionuclides in the tanks would be solidified. As the Expert Panel has repeatedly noted, and as one of our members detailed in an article published in *Science* in 2020, some tanks contain very high concentrations of strontium-90 and cesium-137.⁶
- Failing to treat the water to remove almost all of the radionuclides other than tritium and carbon-14 would make it more risky for workers to make the concrete and for the public over the decades that the concrete might deteriorate. The radiation emanating from the concrete would no longer be essentially completely stopped by the concrete itself.
- The TEPCO option was to bury the concrete either above or below the ground water table. This kind of processing and disposal is called grouting. While there is no exact parallel to the Fukushima Daiichi situation, disposal of radioactive waste with high concentrations of radionuclides in soil by grouting has not had good success in the United States.⁷

We would therefore agree with the TEPCO rejection of the option of mixing untreated tank water with a cementitious material and disposing of it underground. The Expert Panel proposal is fundamentally different and deserves an official assessment by TEPCO on its own merits.

In the months since we proposed the concrete option, we have also examined the matter of the compliance of the TEPCO proposal with IAEA public safety and environmental protection guidelines. TEPCO and the IAEA have claimed that even though Japan's Nuclear Regulation Authority has given the go-ahead to build the tunnel in preparation for the release of the radioactive water, no such release would actually occur until the IAEA guidelines were met. However, it appears that the TEPCO plan would violate certain IAEA guidelines even if its criteria for safety of the water for release were fully met.

Specifically, we have examined IAEA's General Safety Guide No. GSG-8, entitled *Radiation Protection of the Public and the Environment*.⁸ The provisions at issue are also contained in Publication 124 of the International Commission on Radiological Protection.⁹

GSG-8 advises that planned actions that would create radioactive impacts should first of all be justified and, if they are, then they should be optimized. These terms have very explicit meanings in GSG-8. Justification, as per paragraph 2.11, means that the "benefits to individuals and to society" should "outweigh the harm (including radiation detriment)".¹⁰ Countries other than Japan will not experience

⁶ Ken O. Buesseler, "Opening the Floodgates at Fukushima: Tritium is not the only radioisotope of concern for stored contaminated water," *Science*, 2020 <http://science.sciencemag.org/content/369/6504/621>

⁷ Brice Smith, "What the DOE knows and does not know about grout," Institute for Energy and Environmental Research, 2004 at <http://ieer.org/wp/wp-content/uploads/2004/10/grout.pdf>

⁸ IAEA, *Radiation Protection of the Public and the Environment, General Safety Guide NO. 8 (GSG-8)*, International Atomic Energy Agency, 2018 at https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1781_web.pdf

⁹ International Commission on Radiological Protection, *Protection of the Environment Under Different Exposure Situations*, ICRP Publication No. 124, 2014, at http://journals.sagepub.com/doi/pdf/10.1177/ANIB_43_1

¹⁰ GSG-8, 2018, op. cit.

any benefits from the proposed releases of ALPS treated radioactive water. *Given zero benefits, any harm will necessarily outweigh the benefits, even if the harm is small.* It appears to us therefore that, for the societies in the Pacific region, the justification requirement of GSG-8 has not been met.

Neither the first IAEA report, based on its first visit in February 2022,¹¹ nor the most recent (visit of January 2023)¹², refer to GSG-8 or the justification principle in it. Yet, the IAEA itself has explicitly included GSG-8 as one of the “relevant standards for radioactive discharges to apply to this [Fukushima] review.”¹³

The IAEA appears to have endorsed the idea of release of ALPS-treated radioactive water to the Pacific Ocean even before it conducted any missions to Japan specific to the issue. At the announcement of the agreement by the IAEA to review the releases of water in April 2021 – several months before its first mission to Japan, the Director General of the IAEA had expressed a clear, positive opinion on the TEPCO plan saying that it was “both technically feasible and in line with international practice, even though the large amount of water makes it a unique and complex case.”¹⁴ Director General Grossi made no reference to the transboundary aspects of justification. The only justification he offered is that it is common practice done under “strict safety and environmental standards.” In effect, the practices of states with nuclear power plants to impact countries without them via routine discharges of radioactive water to the oceans were used to endorse an admittedly complex and unique TEPCO proposal.¹⁵ The simple fact is that when there is harm to countries that do not dump radioactive wastewater to the oceans, GSG-8 indicates that there is no justification for imposing such harm on them even if it is small.

Optimization is the next major issue, if actions are justified. GSG-8, ICRP-124, and other official publications provide explicit guidance that keeping radiation exposures “as low as reasonably achievable” is a part of the optimization process.¹⁶ The IAEA has discussed optimization as part of its Task Force evaluations but only in the context of release of radioactive water to the Pacific Ocean.¹⁷ The IAEA has made specific reference to the principle of keeping doses “as low as reasonably achievable” (known by its acronym as the ALARA principle) but only in reference to keeping doses low in the context of the TEPCO plan.

¹¹ IAEA Review of Safety Related Aspects of Handling ALPS-Treated Water at TEPCO’s Fukushima Daiichi Nuclear Power Station -- Report 1: Review Mission to TEPCO and METI (February 2022), IAEA, 2022, p. 35

¹² IAEA Review of Safety Related Aspects of Handling ALPS-Treated Water at TEPCO’s Fukushima Daiichi Nuclear Power Station -- Report 5: Review Mission to NRA (January 2023), IAEA, 2023.

¹³ “Overview of the IAEA”, International Atomic Energy Agency, February 2023, Slide 48.

¹⁴ IAEA video, “Statement by IAEA Director General on Fukushima Water Disposal,” 13 April 2021, at <https://www.iaea.org/newscenter/multimedia/videos/statement-by-iaea-director-general-on-fukushima-water-disposal>

¹⁵ The first IAEA visit on the water issue occurred in September 2021, almost five months after Director General Grossi’s April 2021 statement. See IAEA Press Release, IAEA Team Visits Japan to Begin Implementing Project to Monitor and Review Water Release at Fukushima Daiichi, 6 September 2021 at <https://www.iaea.org/newscenter/pressreleases/iaea-team-visits-japan-to-begin-implementing-project-to-monitor-and-review-water-release-at-fukushima-daiichi>

¹⁶ GSG-8, paragraph 2.16, p. 7 and ICRP 124, p. 20

¹⁷ IAEA Review of Safety Related Aspects of Handling ALPS-Treated Water at TEPCO’s Fukushima Daiichi Nuclear Power Station -- Report 1: Review Mission to TEPCO and METI (February 2022), IAEA, 2022, p. 35

A variety of national and international guidance and regulatory documents provide insight into the interpretation of the phrase “as low as reasonably achievable”. Even if the public doses from the proposed TEPCO action were to be very small, they will be higher than those from our specific concrete-making proposal. Demonstrating that the optimization goal has been achieved requires all reasonable alternatives be examined. For instance, the U.S. Nuclear Regulatory Commission has a poster which explains the ALARA principle as follows:

ALARA is the principle of reducing exposures to radiation when it is reasonable or practical to do so—that is, reducing radiation exposures to As Low As Reasonably Achievable, or ALARA.

- ALARA evaluations usually address two aspects of what actions are reasonable: (1) typical good practices that are done to reduce exposures and (2) *comparison of costs and benefits of alternative actions*.¹⁸

In summary, treating the water and making concrete with low potential for human contact is a feasible and reasonable option that would essentially eliminate transboundary harm, have essentially zero doses; it could reduce earthquake risk by being completed decades before the action proposed by TEPCO. Yet none of the parties – TEPCO, the NRA, or the IAEA – have addressed the comparative costs and benefits or even accepted the need to evaluate this option as part of the optimization process.

In addition while the IAEA and TEPCO have repeatedly stated that they will fulfill their respective roles and ensure the release of ALPS-treated radioactive water to the Pacific Ocean over decades will be “safe” and in conformity with IAEA safety and environmental guides, the term has been construed narrowly, without due consideration of the justification and optimization requirements of GSG-8 in regard to the people and societies in the Pacific region. The fact that other countries with nuclear power have been releasing radioactively contaminated water into the seas without due regard to GSG-8’s transboundary implications for countries without nuclear power cannot negate that fact.

We urge the NRA and the IAEA to include consideration of the transboundary implications of GSG-8 and the comparative implications of the concrete option as outlined here versus the dumping action proposed by TEPCO.

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¹⁸ U.S. Nuclear Regulatory Commission, *Poster Title: ALARA Evaluation*, 16 September 2009, at <https://www.nrc.gov/docs/ML0925/ML092530539.pdf>, italics added.