NUCLEAR WASTE

Opening the floodgates at Fukushima

Tritium is not the only radioisotope of concern for stored contaminated water

By Ken O. Buesseler

In the time since Japan’s triple earthquake, tsunami, and nuclear disaster in 2011, much has improved in the ocean offshore from the Fukushima Daiichi Nuclear Power Plant (FDNPP). Concentrations of cesium isotopes, some of the most abundant and long-lived contaminants released, are hundreds of thousands of times lower than at their peak in April 2011. Since mid-2015, none of the fish caught nearby exceeded Japan’s strict limit for cesium of 100 Bq/kg (1, 2). Yet, enormous challenges remain in decommissioning the reactors and clean-up on land. Small, and sometimes unexpected, sources of contaminants still continue to enter the ocean to this day (3). Two of the biggest unresolved issues are what to do with the more than 1000 tanks at the site that contain contaminated water and the impact of releasing more than 1 million tons of this water into the ocean.

The tank water is a combination of recovered groundwater and deliberately injected cooling waters, both of which became contaminated when interacting with the highly radioactive nuclear reactor cores. From the first months after the earthquake and tsunami, these waters were contained in tanks to prevent further radioisotope releases and remediated by using several systems, most notably the Advanced Liquid Processing System (ALPS). ALPS was designed to efficiently remove more than 62 different contaminants and has been used to remediate more than 50% of the tank water. However, ALPS cannot remove all contaminants, and the total amount of tritium contained in the tanks also matters, which is reported to be around 1 PBq (PBq = 10^15 Bq) (4). That total is far less than the 8000 PBq of tritium still remaining from global atmospheric nuclear testing in the 1960s or the 2000 PBq from natural interactions between cosmicogenic particles and nitrogen that form tritium in the atmosphere. In addition, all nuclear power facilities emit tritium that, depending on plant design, can be several PBq per year, or even higher, as in the case of nuclear fuel reprocessing plans such as at Cap de La Hague (5).

However, this story is not only about tritium but what else is in the tanks. It was not until mid-2018 when TEPCO, the operator at FDNPP, released data detailing the amounts of more dangerous isotopes, such

Release limits and risk

Different isotopes pose different environmental and health challenges.

<table>
<thead>
<tr>
<th>ISO T E</th>
<th>MAX RELEASE (BQ/LITER)</th>
<th>FOOD LIMIT (BQ/KG)</th>
<th>HALF-LIFE (YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>³H</td>
<td>60,000</td>
<td>10,000</td>
<td>12.35</td>
</tr>
<tr>
<td>²⁴C</td>
<td>2000</td>
<td>10,000</td>
<td>5730</td>
</tr>
<tr>
<td>⁹⁰T C</td>
<td>1000</td>
<td>10,000</td>
<td>211,000</td>
</tr>
<tr>
<td>¹³²Sb</td>
<td>800</td>
<td>1000</td>
<td>2.77</td>
</tr>
<tr>
<td>⁶⁰Co</td>
<td>200</td>
<td>1000</td>
<td>5.27</td>
</tr>
<tr>
<td>¹⁰⁹Ru</td>
<td>100</td>
<td>100</td>
<td>1.01</td>
</tr>
<tr>
<td>¹⁳⁷Cs</td>
<td>90</td>
<td>100</td>
<td>30.0</td>
</tr>
<tr>
<td>¹³⁴Cs</td>
<td>60</td>
<td>100</td>
<td>2.06</td>
</tr>
<tr>
<td>⁹⁰Sr</td>
<td>30</td>
<td>100</td>
<td>29.1</td>
</tr>
<tr>
<td>²³⁵U</td>
<td>9</td>
<td>100</td>
<td>160,000,000</td>
</tr>
</tbody>
</table>

¹Maximum levels allowed in Japan for waters released from nuclear reactor operations. ²Limits allowed for food safety (CODEX standard based upon adult consumer and annual consumption limit). ³Half-life is a physical property indicating the time it takes for 50% of an isotope to decay. A shorter value means a quicker loss.

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REFERENCES AND NOTES

7. T. V. Nguyen et al., BMC Genomics 17, 796 (2016).

10.1126/science.abd3857
as ruthenium-106, cobalt-60, and strontium-90 (7). The concentrations of these radioactive isotopes are orders of magnitude lower than tritium but highly variable from tank to tank (see the figure). By TEPCO's own assessments, more than 70% of the tanks would need secondary treatment to reduce concentrations below that required by law for their release (7).

However, there are other important factors to consider. These radioactive isotopes behave differently than tritium in the ocean and are more readily incorporated into marine biota or seafloor sediments (see the figure). For example, the biological concentration factors in fish are up to 50,000 higher for carbon-14 than tritium (8). Also, isotopes such as cobalt-60 are up to 300,000 times more likely to end up associated with seafloor sediments (8). As a result, models of the behavior of tritium in the ocean, with tritium's rapid dispersion and dilution, cannot be used to assess the fate of these other potential contaminants.

To assess the consequences of the tank releases, a full accounting after any secondary treatments of what isotopes are left in each tank is needed. This includes the volume, not just for the nine isotopes currently reported but for a larger suite of possible contaminants, such as plutonium. Plutonium may be present in FDNPP cooling waters but was not released in large amounts to the atmosphere in 2011.

The public has been told that there are few options other than ocean discharge. However, given the short half-lives of the isotopes known in the tanks, time would help. With a 12.3-year half-life, in 60 years, 97% of all the tritium would decay, along with several of the other shorter lived isotopes. In those intervening years of cleanup on site, about four times the current volume would be generated. The risk of tank leaks—even if stored in earthquake-resistant tanks, similar to what Japan already does for petroleum or liquefied natural gas—needs to be weighed against the greatly reduced amount of radioactivity after decay. The lack of space, the reason for the urgency in ocean release, could be alleviated if tanks were stored just outside the boundaries of the current FDNPP.

Last, public fears should not be dismissed because these decisions may have negative impacts on local fisheries that are just now rebuilding. Making data available is a good start (9) but not enough. Seafood and ocean monitoring should continue to involve local fishermen, and studies that involve public participation in sampling would be an effective tool to improve public education and build confidence in the results (10).

The current focus on tritium in the wastewater holding tanks ignores the other radioactive isotopes but presents a solvable issue. A solution includes reducing the concentrations of non-tritium contaminants, reporting after secondary treatment independently verifies concentrations for all contaminants in each tank, and reconsidering other storage options. If there is a release, supporting independent ocean study of multiple contaminants in seawater, marine biota, and seafloor sediments should occur before, during, and after. Although the operators have promised some of this, actions will matter more than words. What needs to be added to the discussion is that the non-tritium isotopes in those tanks have vastly different toxicities and fates in the ocean.

### Sorting out what is in the tanks

One legacy of the Fukushima Daiichi nuclear disaster after the 2011 Tohoku-oki earthquake and tsunami is the accumulation of water with a variety of radioisotopes in tanks. Assessing the risk of discharging water from these tanks back into the ocean requires knowing radioisotope amounts and their ability to concentrate in seafloor sediments and biological tissues.

Radioisotope concentration ranges for more than 200 tanks reported on 31 Dec 2019 by TEPCO (9) organized by their effective dose (dose coefficient).

Radioisotopes concentrate to varying degrees in biological systems such as fish (Bq/kg wet weight fish per Bq/kg in seawater) and seafloor sediment (Bq/kg dry weight sediment per Bq/kg in seawater).

![Graph of radioisotope concentrations](image-url)

### REFERENCES AND NOTES

2. Radioactivity levels are measured in becquerels (Bq) per unit volume or mass, with 1 Bq = one decay event per second.
4. International Commission on Radiological Protection (ICRP) publication 119, “Compendium of dose coefficients based upon ICRP publication 60” (ICRP, 2010).
5. TEPCO, Draft study responding to the subcommittee report on handling ALPS treated water, 24 March 2020.

### ACKNOWLEDGMENTS

This work was supported by the Deerbrook Charitable Trust and the Center for Marine and Environmental Radioactivity. Writing assistance by K. Kostel is also appreciated.
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Science 369 (6504), 621-622.
DOI: 10.1126/science.abc1507