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# TEPCO WATER CRISIS
## Greenpeace Germany Briefing

Fukushima Daiichi nuclear plant, 16 October 2018. © Christian Aslund / Greenpeace

**"A very likely problem at Fukushima is that the accident conditions have fractioned the release components entirely differently to a 'routine' radioactive waste stream and, moreover, the seawater and brine content and clays and sands, etc., picked up in the accident debris taken into the clean up processing beyond, making the processing of contaminated water immense in complexity and scale." Dr John Large, Consulting Engineer, 22 June 2018.**[2]

1 Senior Nuclear Specialist, Greenpeace Germany (Tokyo)
2 Briefing note to Shaun Burnie, June 2018.

## Executive Summary

The challenges facing Tokyo Electric Power Company (TEPCO) in relation to the management of highly contaminated water at the Fukushima Daiichi nuclear plant are both enormous and unique. The past eight years have seen a series of phases in the water crisis at the plant, during which there has been a relentless increase in radioactive contaminated water at the site. As of 13th December 2018, the amount of contaminated water at the Fukushima Daiichi plant (units 1-4) was 1.11 million m3 /tons (cubic meters).[3] The majority of this, 988,000 m3 / tons, is processed water held in storage tanks, a volume that increases between 2-4,000 m3 / tons per week.[4] Without 'solving' the water crisis, TEPCO's already unrealistic plans for the molten reactor fuel at the site, are further undermined.

The decision taken by TEPCO more than fifty years ago to lower by 25 meters the proposed Fukushima Daiichi site sealed the fate of the nuclear plant, including a decades long battle with groundwater migration. Post 2011, the decision led directly to the vast accumulation of contaminated groundwater. While the installation of sub drains and pumping wells by TEPCO has led to a reduction of the amount of groundwater entering the reactor building, it is still estimated by TEPCO to be in the range of 150 m3 / tons each day.[5] A figure that escalates as a result of heavy rain, particularly during typhoons. In regards to TEPCO's ice wall, in 2014 at the start of its construction around the entire reactor site,[6] TEPCO claimed that the barrier would remain operational for six years, providing "time to drain and clean the contaminated water from the buildings and make them watertight. The goal is to achieve this by 2020, by which time TEPCO plans to stop all the water flowing into the buildings at the Daiichi site."[7] It was never credible for TEPCO to make these claims and it will not meet its 2020 target, if ever.

All through the water crisis major questions have been raised over decisions taken by TEPCO. These have included doubts over the effectiveness of efforts to reduce groundwater entering the site, the processing of water to remove radioactive materials, and consideration of plans to discharge water into the Pacific.

More than seven years after the start of the nuclear disaster, TEPCO finally admitted in September 2018 that water processing, including its ALPS system, had failed to reduce levels of radioactivity to levels below the regulatory limit permissible for ocean discharge. On 28th September 2018, TEPCO admitted that of the 890,000 m3 / tons of water treated by the ALPS system and stored in tanks, about 750,000 m3 / tons contain higher concentrations of radioactive materials than levels permitted by the safety regulations for release into the ocean.[8] In 65,000 m3 / tons of treated water, the levels of strontium 90 are more than 100 times the safety standards, according to TEPCO. The levels are as high as 20,000 times the standards in some

3 TEPCO, "Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (382th Release)" 10 December 2018, see https://www7.tepco.co.jp/wp-content/uploads/handouts_181210_02-e.pdf
4 Ibid.
5 Ibid.
6 TEPCO, "Fukushima Daiichi NPS Prompt Report Construction Of Water-Blocking Ice Wall Starts At Fukushima", 3 June 2014, see https://www4.tepco.co.jp/en/press/corp-com/release/2014/1237060_5892.html
7 TEPCO, "Questions on the "Land-side Impermeable Wall (Frozen Soil Wall)", 2014, see https://www4.tepco.co.jp/en/decommision/planaction/qa_ice_wall-e.html
8 Asahi Shimbun, "Editorial: TEPCO bungles it again in dealing with Fukushima tainted water", 9 October 2018, see http://www.asahi.com/ajw/articles/AJ201810090025.html

tanks. These admissions by TEPCO contrasts with their earlier claims for ALPS, which would reduce radioactivity levels “to lower than the permissible level for discharge.”[9]

The disclosures have raised more questions than answers. What is clear however is that plans to dispose of more than a 1 million tons of water by pumping into the Pacific Ocean cannot move forward. These plans, supported by the Japanese government agency tasked with overseeing contaminated water, as well as the International Atomic Energy Agency (IAEA), are now in disarray, with justified local opposition against discharge stronger than ever.

This analysis attempts to provide an explanation as to how the water crisis has evolved, why the processing technology has failed to meet the claims of TEPCO, and questions why technical options to remove radioactive tritium, proposed to the Japanese government, were not developed.

The analysis concludes that the failure of processing technology to perform as claimed and remove radionuclides as repeatedly stated, was known by TEPCO from the earliest operations. Public disclosure of the real levels of contamination would have set back TEPCO’s and METI’s apparent  objective which was to solve the enormous water crisis by discharge to the Pacific Ocean. Events have however not worked out as planned.

TEPCO, the Nuclear Regulation Authority and the Japanese government have failed to learn the lessons of past mistakes made by their predecessors. Decisions based on short term financial interests led to a triple reactor meltdown, the contamination of thousands of square kilometers of Japan and the Pacific Ocean, and the evacuation of 165,000 Fukushima citizens, tens of thousand of whom remain internally displaced. Over the past years, alternatives to managing the highly contaminated water have received little real scrutiny, and potentially viable options have been effectively ignored and not developed. The water crisis that exists at the plant is, like the nuclear disaster of March 2011 itself, is entirely man-made.

The Government and TEPCO had set a target of 2020 as a timeframe for solving the water crisis at Fukushima Daiichi nuclear plant. That was never credible. Even the re-processing of all contaminated water will take an estimated 5-6 years, with remaining questions over its efficacy. Volumes of contaminated water will continue to increase in the coming years.

The only viable ‘solution’ is the long term storage in steel tanks over the medium and even long term, with parallel development of processing technology, is the only viable option.

The government and TEPCO need an urgent reassessment of the options for managing contaminated water. Paramount in any future decision making should be the protection of the interests of the those in the front line  - the communities and fishing industries of Fukushima’s Pacific coast. Their views have already been made clear in the past years, including at inadequate public meetings held during 2018. Tetsu Nozaki, chair of the Fukushima Prefectural Federation of Fisheries Cooperative Associations, in August 2018, emphasized that releasing the water into the sea would deal a “devastating blow” to the prefecture’s fisheries industry.[10] Ignoring such views is not an option and neither is discharge to the Pacific Ocean.

Eight years after the start of the Fukushima Daiichi nuclear disaster, the crisis has no end point. TEPCO and the government need to stop misleading the public over the scale of the challenges,

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9 Atomic Energy Society Japan, “Treatment of contaminated water stored in Fukushima Dai-ichi Nuclear Power Plant”, Division of Water Chemistry, Fusion Engineering Division, 10 September 2013, see http://www.aesj.or.jp/jikocho/Treatmentofcontaminatedwater.pdf

10 Kazumasa Sugimura and Chikako Kawahara “Residents blast water-discharge method at Fukushima plant” 31 August 2018, see http://www.asahi.com/ajw/articles/AJ201808310042.html

and to focus on the priority issues of devising a system for the long term management of nuclear waste, including over 1 million 3m / tons of highly contaminated water.

## Introduction

The challenges facing TEPCO in relation to the management of highly contaminated water are both enormous and unique. The past eight years since March 2011 have seen a series of phases in the water crisis at the plant, during which there has been a relentless increase in radioactive contaminated water at the site.

As of 13th December 2018, the amount of contaminated water at the Fukushima Daiichi plant (units 1-4) was 1.11 million m3 /tons (cubic meters).[11] The majority of this, 988,000 m3 / tons, is processed water held in storage tanks, a volume that increases between 2-4,000 m3 / tons per week.[12] With no solution on the horizon for this vast water volume, how did TEPCO find itself in this crisis which directly impacts on future prospects for the site. Without 'solving' the water crisis, TEPCO's already unrealistic plans for the molten reactor fuel at the site, are further undermined.

## TEPCO Decision Making Fifty Years Ago: Sealed Fate of Fukushima Daiichi Plant

Fateful decisions taken more than fifty years ago by TEPCO, effectively sealed the fate of Japan's largest power company and determined that for the remainder of the 21st century and beyond the company (and Japan) will be dealing with its catastrophic legacy.

TEPCO made a cost cutting decision in the mid-1960's to lower the level of the proposed nuclear plant site to near sea level. The decision was based on a financial assessment that operating sea water pumps for reactor cooling at sea level would be far less costly than having to pump sea water up to reactors located 35 meters above sea level.[13] The geology at the location of the plant, lying as it does on an alluvial terrace, meant that this decision would inevitably lead to a major groundwater challenge, then escalating to a crisis following the start of the Fukushima Daiichi nuclear accident.[14] In the late 1960's, and prior to the start of reactor construction TEPCO lowered the base of the site from 35 meters above sea level, to 10 meters.[15] Worse still, the Fukushima Daiichi basement facilities, including for the turbine buildings where the emergency diesel generators were installed, were located a further 14 meters below the site. As a direct consequence of lowering the site of the Fukushima Daiichi reactors, 850 m3 / tons of groundwater per day flowed on to and under the reactor units 1–4, prior to the March 2011 disaster. The decision was determined by seeking to reduce marginal costs, which have today

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11 TEPCO, "Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (382th Release)" 10 December 2018, see https://www7.tepco.co.jp/wp-content/uploads/handouts_181210_02-e.pdf

12 Ibid.

13 Reiji Yoshida And Takahiro Fukada "Fukushima plant site originally was a hill safe from tsunami", Japan Times, 13 June 2011, see https://www.japantimes.co.jp/news/2011/07/13/national/fukushima-plant-site-originally-was-a-hill-safe-from-tsunami/#.W95gLXozaAw

14 The terrace lies within the Hamadori belt, a stretch of Quaternary deposits limited by the Abukuma Granites to the West, and the Pacific Ocean to the East. The geology comprises a sequence of Cainozoic marine and fluvial sediments directly recharged by rain infiltration, as described in Yamamoto T. The rate of fluvial incision during the Late Quaternary period in the Abukuma Mountains, northeast Japan, deduced from tephrochronology. Isl. Arc. 2005;14:199–212. doi: 10.1111/j.1440-1738.2005.00464.x, and cited in International Journal of Environmental Research and Public Health, "Managing Groundwater Radioactive Contamination at the Daiichi Nuclear Plant" Atsunao Marui and Adrian H. Gallardo, 2015 Jul; 12(7): 8498–8503, see https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4515732/

15 Opcit. Reiji Yoshida And Takahiro Fukada 13 June 2011.

created a nuclear crisis that has effectively bankrupted the company,[16] and which threaten to spiral to tens if not hundreds of billions of dollars over the coming decades and beyond.[17]

To control water in flow to the reactor site during the decades of operation prior to 2011, TEPCO installed a series of sub-drains to reduce the groundwater levels around the buildings and to arrest the inflow of groundwater into the buildings. However, the sub-drains and pumping equipment were damaged by the 2011 tsunami and ceased to operate.

Every day for nearly eight years, TEPCO has been pumping water into the nuclear reactors to cool the molten fuel that has deposited at the bottom and under the Reactor Pressure Vessels (RPV) of Fukushima-Daiichi units 1-3. Without this cooling water the temperature of the molten fuel or corium would increase, particularly in the first years following the meltdown, potentially leading to additional chemical reactions. If TEPCO had failed to cool the corium the resulting chemical reactions would have generated even larger levels of non-condensable gases (mostly CO and CO2). In turn, the high non-condensable gas pressure would subject what is an already weakened primary containment to pressurization and failure in the interim term, thus resulting in greater uncontrolled radiological releases to the atmospheric environment.[18]

As a result of the 2011 nuclear disaster, and desperate efforts to cool the reactors, as much as 70,000 m3 / tons of highly contaminated water accumulated in the reactor buildings of units 1-4. By December 2018, the total estimated water remaining in the reactor and turbine buildings was 27,780 m3 / tons.[19]

It is the combination of water required for cooling and ground water migration that has led to the vast volume of contaminated water. The water becomes radioactive through the release of radionuclides that are in the molten fuel – or corium. In particular fission or activation products, which includes cesium, cobalt, strontium, antimony, and tritium, are readily dispersible in water.[20]

As of 15th May 2011, TEPCO was injecting as much as 720 m3 / tons of fresh water a day into the three reactors at Fukushima Daiichi.[21] By 1 June 2011 513 m3 / tons was being injected.[22] As the molten fuel has cooled, TEPCO has been able to reduce the amount of daily water injection to 225 m3 / tons as of 13th December 2018.[23] However, in the intervening years, the cumulative amount of water processed at the plant is a staggering 2.1 million m3 / tons as of 13th December 2018.[24]

16 Hajime Matsukubo, "Commentary: Why wasn't TEPCO bankrupted?" Citizens Nuclear Information Center, CNIC, 4 June 2018, see http://www.cnic.jp/english/?p=4128

17 Japan Center for Economic Research, "Accident Cleanup Costs May Rise to 50-70 Trillion Yen - It's Time to Examine legal liquidation of TEPCO - Higher Transparency is Needed for the Reasons to Maintaining Nuclear Power", Tatsuo Kobayashi, Principal Economist, Professor Tatsujiro Suzuki, Specially Appointed Fellow (Director of Nagasaki University Research Center for Nuclear Weapons Abolition), Kazumasa Iwata, JCER President, see http://www.jcer.or.jp/eng/research/policy.html

18 For an early description of the Fukushima Daiichi accident see, John Large, "Incidents, Developing Situation And Possible Eventual Outcome At The Fukushima Dai-Ichi Nuclear Power Plants", 11 April 2011, Greenpeace Germany, see https://www.greenpeace.de/sites/www.greenpeace.de/files/Large_Report_R3196-A1_10_April_2011-3_0.pdf

19 Opcit. TEPCO, 10 December 2018

20 IRSN, "Aftermath of the Fukushima Daiichi nuclear accident of March 2011 - Situation update in March 2016", March 2016, see https://www.irsn.fr/EN/publications/thematic-safety/fukushima/fukushima-2016/Documents/IRSN-Fukushima-in-2016.pdf

21 TEPCO, "Plant Status of Fukushima Daiichi Nuclear Power Plant", 15 May 2011, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-04-001-001-09-handouts_110515_01-e.pdf

22 TEPCO, "Plant Status of Fukushima Daiichi Nuclear Power Plant", 1 June 2011, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-04-001-001-09-handouts_110601_01-e.pdf

23 Opcit. TEPCO, 10 December 29 2018.

24 Opcit. TEPCO, 10 December 2018.

As of December 2018 cooling water is still injected into the Reactor Pressure Vessels (RPV) of units 1-3, which then flows to the Primary Containment Vessel (PCV), then the water leaks from PCV to the torus room in the basement floor of the reactor building.[25]

With the high volume of groundwater flowing into and through the nuclear site, a challenge for TEPCO was to prevent migration of the highly contaminated water in the reactor buildings from further release into the environment. TEPCO's efforts center on controlling the water level of the stagnant water in the reactor buildings, maintaining it lower than that of the groundwater around the buildings which allows groundwater to flow into the building (in-leak), while osmotic pressure is supposed to prevent the outflow of the radioactive materials.

## Controlling and Reducing Groundwater Contamination

The water crisis was and remains a direct threat to radioactive contamination of the Pacific Ocean. Estimates were made on the rate of contamination migration in the groundwater depending on the radionuclides, as they interact more or less strongly with the geology of the sandstone layers at the site. Tritium (3H), does not interact with sandstone, and travels at a groundwater velocity of 1 m/day in order of magnitude). Strontium travels slower (1 m/month in order of magnitude) and cesium is even slower (a few cm/day or less).[26] In addition to other measures, TEPCO constructed a "sea-side impermeable wall" between the reactors and the port between April and December 2013. Nearly 900 meters long and buried about 35 meters deep, the wall is made of 594 steel pipes piled underground.[27] It's purpose was to control the flow in the shallow and deep aquifers downstream from the site. In 2014, the space between the wall and the bank was backfilled and five pumping wells ("pits") were drilled and then tested in August and October 2015 ("groundwater drains"). The closing of the wall was completed in October 2015 after the commissioning of the pumping, treatment and release device for the groundwater arriving upstream of the wall was announced. However, the rise of the groundwater behind this wall, now closed, led to a distortion of the impermeable barrier in November 2015. TEPCO then carried out strengthening work and increased the pumping to counteract this phenomenon.[28]

Measures taken to reduce the volume of groundwater entering the site, and reactor buildings, centered on the installation of new sub drains and pumping wells, as well as the frozen barrier or 'ice wall'.

## Sub drains

The sub drain system installed by TEPCO is a series of wells installed near the reactor and turbine buildings, with pumping of the well water beginning in September 3, 2015.[29] The Groundwater Bypass System is a series of pumped wells located above the plant on the top of

25 Nuclear Damage Compensation and Decommissioning Facilitation Corporation, "Technical Strategic Plan 2018 for the Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc." October 2, 2018, see http://www.dd.ndf.go.jp/en/strategic-plan/book/20181109_SP2018eFT.pdf

26 IRSN, "Fukushima Daiichi nuclear accident - Groundwater under the site Situation in January 2016", March 2016, see https://www.irsn.fr/EN/publications/thematic-safety/fukushima/fukushima-2016/Documents/14-IRSN_Fukushima-2016_Safety-Groundwater_201603.pdf

27 TEPCO, "Sea-side Impermeable Wall", https://www7.tepco.co.jp/responsibility/decommissioning/action/w_management/sea_side-e.html

28 Ibid.

29 TEPCO, "Groundwater Pump-up by Subdrain System and Groundwater Drain", see https://www7.tepco.co.jp/responsibility/decommissioning/action/w_management/subdrain-e.html; and TEPCO, "Summary of Decommissioning and Contaminated Water Management", 26 January 2017, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-03-001-d170126_01-e.pdf

the hill.[30] Water from both the new sub-drains and wells, see TEPCO diagram below, is "treated" for radioactive contamination then released into the nuclear plant port areas, and there-after, the Pacific.

This pumped-up groundwater was then processed and released from 14th September, 2015; as of 25th September, 2018, a total of 602,904 m3 / tons had been discharged, after "TEPCO and a third-party organization had confirmed that its quality met operational targets."[31]

The installation of sub drains and pumping wells led to a reduction of the amount of groundwater entering the reactor building, estimated by TEPCO to be under 150 m3 / tons each day.[32]

## Ice Wall

**"Our assessment is that the ice wall has been effective...We now believe we have a system in place to manage the water level."** Naohiro Masuda, TEPCO chief decommissioning officer.[33]

As with many of TEPCO's statements, it does not reflect the reality at Fukushima Daiichi.

On 3rd June 2014 construction began on the 1500 meter ice barrier around the entire reactor site.[34] The cost of construction and installation was 34.5 billion yen (US$292 million), with annual operating costs estimated to be 1 billion yen (US$9.5 million).[35] The system involves installing 1571 pipes to a depth of 30 meters, with liquid coolant in each pipe cooled and circulated to under minus 30 degrees centigrade, with the aim of freezing the ground immediately around the pipes forming a frozen barrier. The principal contractor for the ice wall was the Kajima Corporation. The aim was to reduce groundwater contamination from around 320 m3 / tons per day as of June 2014 to zero.[36] At the same time TEPCO reported that the ice wall would reduce the accumulation of contaminated groundwater to between 30-50 m3 / tons.[37] At the time of construction, TEPCO claimed that the facility would remain operational for six years, providing "time to drain and clean the contaminated water from the buildings and make them watertight. The goal is to achieve this by 2020, by which time TEPCO plans to stop all the water flowing into the buildings at the Daiichi site."[38]

It was never credible for TEPCO to make these claims – including for the reason that the underground pipes had to be buried in a way that would avoid underground reactor pipe work, meaning that the wall was always going to be incomplete.

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30 TEPCO, "Groundwater Bypass System", see https://www7.tepco.co.jp/responsibility/decommissioning/action/w_management/bypass-e.html

31 TEPCO, "Summary of Decommissioning and Contaminated Water Management", 27 September 2018, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-03-001-d180927_01-e.pdf

32 Ibid.

33 Aaron Sheldrick and Malcolm Foster, "Tepco's 'ice wall' fails to freeze Fukushima's toxic water buildup", Reuters, 8 March 2018, see https://www.reuters.com/article/us-japan-disaster-nuclear-icewall/tepcos-ice-wall-fails-to-freeze-fukushimas-toxic-water-buildup-idUSKCN1GK0SY

34 TEPCO, "Fukushima Daiichi NPS Prompt Report Construction Of Water-Blocking Ice Wall Starts At Fukushima", 3 June 2014, see https://www4.tepco.co.jp/en/press/corp-com/release/2014/1237060_5892.html

35 Mari Yamguchi, "Experts: Fukushima must do more to reduce radioactive water (Update)" Associated Press, 7 March 2018, see https://phys.org/news/2018-03-fukushima-ice-wall-partly-radioactive.html

36 TEPCO, "Measure of reduction of groundwater inflow into buildings of Units 1 to 4 using Land-sideImpermeable Wall ("Ice Wall") July 3, 2014, see https://www4.tepco.co.jp/en/nu/fukushima-np/handouts/2014/images/handouts_140703_04-e.pdf

37 Ibid and Kazuaki Nagata "Fukushima No. 1's never-ending battle with radioactive water", Japan Times,11 March 2015, see https://www.japantimes.co.jp/news/2015/03/11/national/fukushima-1s-never-ending-battle-radioactive-water/#.W96hQXozbOQ

38 TEPCO, "Questions on the "Land-side Impermeable Wall (Frozen Soil Wall)", 2014, see https://www4.tepco.co.jp/en/decommision/planaction/qa_ice_wall-e.html

In December 2016, the Nuclear Regulation Authority (NRA) described the ice wall as having "limited, if any effects," and that it should be relegated to a secondary role in reducing contaminated groundwater.[39] The NRA urged TEPCO to tackle the groundwater problem primarily with pumps, not the ice wall.

The water volume numbers expose the failure of the ice wall to perform as claimed by TEPCO. The combination of sub-drains, pumping wells and ice wall, has led to a reduction of groundwater entering the reactor building site. In the period December 2015-February 2016, the amount was on average 520 m3/day; whereas two years later, between December 2017 and February 2018 it was on average 141 m3/day.[40]

However, due to the high rainfall during typhoon season, ground water levels entering the site can surge. For example, groundwater levels rapidly increased in October 2017 during Typhoon Lan[41], with a daily average in the month of 310 m3/ tons – close to the 400 m3 / tons that entered the reactor sites basements prior to the installation of sub-drains, pumping wells and the ice wall.[42] In the last week of October 2017, as Typhoon Lan hit the Tohoku region, a peak of 880 m3 / tons a day was entering the reactor buildings basements.[43] Equally, during dry months, the ground water migration is lower, with 83 m3 / tons a day entering the buildings during January 2018.

Even leaving aside the surge in ground water due to typhoons and heavy rain, the ineffectiveness of the ice wall is highlighted by the fact that the installation of sub drains and pumping wells already reduced the flow of groundwater into the reactor site to 150 tons / m3 per day, prior to the installation and operation of the ice wall. In the three months to February 2018, with near full operation of the ice wall, the rate of groundwater migration into the site was 140 tons / m3 per day – a reduction of 10 m3 / tons per day – which may or may not be due to the ice wall.

There are no prospects that TEPCO's current technology will reduce on going ground water contamination to zero as claimed by TEPCO in 2014. TEPCO is thus faced with the prospect of a relentless build up in contaminated water at the site over coming years.

## Water Processing

In an effort to maintain reactor cooling function and reduce build up in contaminated water, since 2011 TEPCO have installed a range of water processing systems.

In the early weeks following the start of the accident, TEPCO workers, in an effort to create a closed cooling water system for the reactor cores using decontaminated water, used domestic technologies as well as those supplied by the United States and France. The water injection/ treatment system was installed to address the problems triggered by contaminated water leaking from holes, cracks or other breaches in the reactor containment vessels and filling reactor

39 The Asahi Shimbun 'NRA: Ice wall effects 'limited' at Fukushima nuclear plant", 27 December 2016, see http://www.asahi.com/ajw/articles/AJ201612270056.html

40 Opcit. Sheldrick, 8 March 2018.

41 Kyodo, "Seven dead as Typhoon Lan lashes Japan", Japan Times, 23 October 2017, see "https://www.japantimes.co.jp/news/2017/10/23/national/powerful-typhoon-lan-lashes-tokyo-snarling-morning-commute-least-two-dead/#.W-ov2HozbOQ

42 Asahi Shimbun, "Fukushima 'ice wall' linchpin not living up to high hopes" 26 November 2017, see http://www.asahi.com/ajw/articles/AJ201711260031.html

43 Opcit. Sheldrick, March 2018.

buildings, turbine buildings and outside trenches. TEPCO started full operation of the water treatment system on 17th June 2011 and began the circulation cooling system ten days later.[44] Both suffered setbacks, including repeated leaks that brought the operation to a halt until they were sealed. Prior to the operation of the closed system, TEPCO had pumped in fresh water from a nearby reservoir to cool reactor cores, but by 2nd July 2011 it was doing so with only decontaminated water.

The water treatment system had processed 13,610 tons of contaminated water as of the first week of July 2011. By January 2012 it was estimated that as much as 250,000 tons of water was required to cool down the reactors, when injection of water at the rate of around half-a-million liters a day was required to keep the reactors at cold shutdown. In addition, the cost of the decontamination system developed by Areva (Paris, France) and Kurion (CA, US) was then estimated to rise to US$660 million.[45]

The first decontamination system at Fukushima was supplied by French state nuclear company Areva and nuclear-remediation company Kurion, based in California. Kurion's filters, which contain a zeolite mineral which is an extremely porous aluminosilicate that loosely binds metal ions. Through a combination of adsorption and ion exchange, the filters were designed to trap the radioactive elements strontium-90, cesium-134 and cesium-137, reducing their concentration in the water by up to a thousand times. After Kurion processing, the second stage using Areva's process, took over, passing into a series of tanks, mixing with reagents such as nickel ferro-cyanide and barium sulphate, along with polymers and sand. The dissolved radioactive metals formed precipitates and colloids, which were trapped as a radioactive sludge, allowing the water to be desalinated and fed back into the reactors.

## ALPS

Multiple facilities including a Multi-nuclide Removal Facility (Advanced Liquid Processing System ALPS) are used to treat the contaminated water accumulated in Fukushima Daiichi Nuclear Power Station. The ALPS facility has undergone a number of modifications since it first began operation in September 2013, with an improved ALPS and then a High Performance ALPS operating by late 2014.[46]

TEPCO started construction of ALPS in June 2011 and completed it in October 2012. Trial runs commenced in March 2013, and full capacity was achieved in 2014. According to the IAEA, the current system is designed to process approximately 750 m3 of contaminated water per day. A second ALPS system, with the same capacity, was installed in September 2014.[47] An improved system with a capacity of 500 m3/d started operation in October 2014. The IAEA international peer review recommended that TEPCO continue, and even accelerate, its efforts to improve the performance and enhance the capacity of ALPS, "given its importance for management of the water that continues to be generated on-site."[48]

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44 Japan Times, "Water treatment, cooling systems finally working", Kazuaki Nagata, July 8 2011, see https://www.japantimes.co.jp/news/2011/07/08/national/water-treatment-cooling-systems-finally-working/#.W9fxA3ozbOQ

45 "Absorption of Radionuclides from the Fukushima Nuclear Accident by a Novel Algal Strain." PLOS ONE 9(4): e95903, see https://doi.org/10.1371/journal.pone.0095903

46 TEPCO, "Multi□nuclide Removal Equipment ("ALPS") (Existing/ Improved/ High□performance", see http://www.tepco.co.jp/en/decommision/planaction/images/141021_01.pdf

47 IAEA, "Mission Report IAEA International Peer Review Mission On Mid-And-Long-Term Roadmap Towards The Decommissioning Of Tepco's Fukushima Daiichi Nuclear Power Station Units 1-4 (Third Mission)", Tokyo and Fukushima Prefecture, Japan, 9 – 17 February 2015 see https://www.iaea.org/sites/default/files/missionreport130515.pdf

48 Ibid.

On 27 May, 2015, the treatment of all highly contaminated water (RO-concentrated salt water) which contained strontium, except residual water in the bottom of the storage tanks, was completed. By 2015, ALPS was processing approximately 1,260 tons/day. This compares with projections of 1,960 tons/day in 2014. TEPCO planned to increase this amount "by remodeling the devices and revising the operation flow to raise performance."[49]

Desperate for positive news on the Fukushima Daiichi disaster, TEPCO, along with the IAEA from the early operation of ALPS have promoted the technology and that removal of hazardous radionuclides had been successful. The IAEA report of 2015, stated that,

"Initial results from tests using contaminated sea water and outlet water from the cesium removal process have demonstrated that 62 radionuclides can be removed to achieve levels that satisfy the regulatory limits for discharge."[50]

The effectiveness of TEPCO's water processing technology in reducing the concentration of radionuclides to permitted levels for future discharge has been questioned since the early years of it operation.[51] As explained below, TEPCO and the Japanese government were fully aware that the processing of contaminated water was not functioning as they publicly claimed. In September 2013, the Nuclear Emergency Response Headquarters, noted that, countermeasures required to control the increasing volume of contaminated water included, "accelerating decontamination of water by fixing the malfunction of the multi-nuclide removal equipment (ALPS)".[52]

In 2015, TEPCO briefings disclosed that further decontamination of strontium processed water would be required.[53] Stating that "In order to further lower risk, the water which has had strontium removed through the use of non-ALPS facilities will be re-treated through the ALPS facility" and that "Water which was treated through ALPS during the period in the past when the facility was not performing optimally will also be re-treated through the ALPS facility." Concluding that "As part of the final review of the water discharge, further decontamination of treated water other than the above will be considered."

As of September 2018, the strontium by cesium-absorption apparatus KURION and SARRY, the secondary cesium absorption apparatus, a total of approximately 482,000 m³ had been treated, according to TEPCO.[54]

## Failure of Fukushima Water Processing

The scale of the radioactive water challenge at Fukushima Daiichi is unique. But it has taken TEPCO more than seven years to correct its earlier claims that its water processing technology was working as stated. On 28th September 2018, TEPCO admitted that of the 890,000 m3 / tons of water treated by the ALPS system and stored in tanks, about 750,000 m3 / tons contain higher

49 TEPCO, "Update on the completion of contaminated water treatment" January 23, 2015 Tokyo Electric Power Company, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-03-002-001-handouts_150123_02-e.pdf
50 Opcit. IAEA, 9 – 17 February 2015.
51 See comments of Ming Zhang in June 2011 in Nature, "Fukushima deep in hot water", Geoff Brumfiel and David Cyranoski, 7 June 2011, https://www.nature.com/news/2011/110607/full/474135a.html, WM2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA Lessons Learned from the Fukushima Daiichi Nuclear Accident – A Discussion from a Neutral Point of View – 14384 Ming Zhang, Geological Survey of Japan, AIST
52 Opcit. Nuclear Emergency Response Headquarters, 3 September 2013.
53 TEPCO, "Regarding contaminated water purification" March 16 2015, Tokyo Electric Power Company, see https://www7.tepco.co.jp/wp-content/uploads/hd03-02-03-002-001-handouts_150316_02-e.pdf
54 Opcit. TEPCO, 27 September 2018.

concentrations of radioactive materials than levels permitted by the safety regulations for release into the ocean.[55] In 65,000 m3 / tons of treated water, the levels of strontium 90 are more than 100 times the safety standards, according to TEPCO. The levels are as high as 20,000 times the standards in some tanks.

The disclosures confirm suspicions that have existed over recent years that TEPCO was not being transparent in providing accurate results of the processing Decontamination Factors (DF) which determines the efficiency of removal of radionuclides at the, processing technology at Fukushima Daiichi.[56]

In June 2018, consulting engineer, John Large reviewed for Greenpeace Japan some of the public data provided by TEPCO. The company has published vast reams of data since 2011, but it is almost impossible for independent verification as to the accuracy of the information. His initial analysis concluded that there were significant questions over the accuracy of TEPCO's information, including the near consistent reference in TEPCO 2016 data sheets that reported that after processing the concentration of cesium-137 was 30Bq/l, "a level which remarkably is spot on the discharge limit to the marine environment."[57]

How was it that TEPCO, which knew there were wide variations in the DF of processing systems, including ALPS, published data that did not reflect reality ?

There are many questions as to how this failure has occurred and why it took TEPCO seven years to admit something they have known for at least five years.

As of 20th November 2018, the Japanese government has failed to explain why TEPCO did not report in a transparent manner the failure of this processing technology over the last years. The government has also yet to explain whether these disclosures effectively removes the option to discharge the processed water into the Pacific Ocean.

More immediate is how did processing fail to meet the stated efficiency claimed by TEPCO and what are the implications?

## Decontamination Factors

After the Kurion and Sarry treatment of water, TEPCO reported in 2013 that the Cs-137 content of water was 20,000 Bq/g. According to TEPCO in 2013, the Decontamination Factor (DF) set for ALPS was 600,000 which would reduce radioactivity levels "to lower than the permissible level for discharge."[58] Elsewhere it has been reported that ALPS had a much higher DF, ranging to as high as 8.3 million for cesium and 165 million for strontium – reaching non-detectable levels.[59]

The ALPS radionuclide targets 62 radionuclides, include Cesium-137 (Cs-137), Strontium-90 (Sr-90), Cobalt-60 (Co-60), Carbon-14 (C-14) and Iodine-129 (I-129) five of the most significant radionuclides present in the contaminated water. They have a range of half lives, from 29 years

55 Asahi Shimbun, "EDITORIAL: TEPCO bungles it again in dealing with Fukushima tainted water", 9 October 2018, see http://www.asahi.com/ajw/articles/AJ201810090025.html

56 Julian Ryall, "Japan plans to flush Fukushima water 'containing radioactive material above permitted levels' into the ocean", 16 October 2018, Daily Telegraph, see https://www.telegraph.co.uk/news/2018/10/16/japan-plans-flush-fukushima-water-containing-radioactive-material/

57 John Large, "Preliminary analysis of TEPCO processed water data sheets", June 21st 2018, Large&Associates, London for Shaun Burnie, Greenpeace Germany.

58 Atomic Energy Society Japan, "Treatment of contaminated water stored in Fukushima Dai-ichi Nuclear Power Plant", Division of Water Chemistry, Fusion Engineering Division, 10 September 2013, see http://www.aesj.or.jp/jikocho/Treatmentofcontaminatedwater.pdf

59 Fortum, "Highly selective ion exchange materials: CsTreat, SrTreat and CoTreat", Jussi-Matti MäkiProduct Manager, NURES, BORES, see https://www.fortum.com/products-and-services/power-plant-services/nuclear-services/nuclear-waste-management/nures/highly

for Sr-90, through to 15.7 million years for I-129. ALPS is an ion exchange process, (ion exchange targets charged atoms or particles).[60] Ion exchange is a well established technology with a wide range of applications across industry. In terms of its use in the nuclear industry, it has largely been developed to reduce radioactive levels from water in nuclear reprocessing plants, as well as select nuclear reactors.

The ion exchange system uses resins or polymer as a medium in the form of an insoluble matrix (or support structure) normally in the form of small (0.25–0.5mm radius) micro beads. These are fabricated from an organic polymer substrate. The beads are typically porous, providing a large surface area on and inside them. The trapping of ions occurs along with the accompanying release of other ions, and thus the process is called ion exchange. Fortum, a Finnish company, is a major supplier of the titanium oxide micro beads ion exchange, used in ALPS and sold under the proprietary ion exchange material name of Nures®, which includes materials for strontium, cesium and cobalt removal.[61] There are two precipitation phases at the ALPS pretreatment facility and after these 14 ion exchange vessels plus 2 ion exchange towers as an Absorption Tower.[62] Ion exchange materials are used in vessels with 1 m3 net volume. The system includes three parallel lines, A, B and C line, each with a nominal capacity of 250 m3/h. Two operational lines operate to reduce the amount of highly active water stored in the tanks at the site.

According to Fortum, and citing TEPCO, the original cesium content of the contaminated water prior to cesium removal Kurion and Sarry was reported as about 5E+6 Bq/cm3, and it was reduced by the cesium removal system to such a level that in RO reject it is about 3E+3 Bq/cm3. The concentration of Sr-90 (half-life about 29 years) in RO reject is about 1.6E+4 Bq/cm3 and Sr-89 (half-life about 51 days) late 2011 about 1.1E+4 Bq/cm3.[63]

ALPS started its operation with the first line on 30th March 2013 and by 29th October 2013 a total of 25,888 m3 / tons were treated, which according to TEPCO, were at a non-detectable level.[64] During that seven month period the ion exchange beds were not changed.[65]

## Early Results of ALPS

In the first reporting of ALPS performance in 2014, TEPCO reported favorable results. According to a sample of the radionuclide content of processed water, “Co-60, Ru-106, Sb-125, Te-125m and I-129 were detected at comparatively high levels”, while Sr-90, “was reduced to 1/100 millionth - 1/billionth” of the original contaminated water input.[66] However, in relation to the target limit for discharge, TEPCO reported that levels of Sr-90, Cobalt-60 and Cs-137 were all below, while I-129 remained above the limit.

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60 For a simple explanation of ion exchange see, “The Basics of Ion Exchange and Water Chemistry-Part I”, **C.F. “Chubb” Michaud CWS-VI, available at http://www.wcponline.com/2007/02/26/basics-ion-exchange-water-chemistry-part/**

61 Fortum, “Fortum to supply more ion exchange materials for purification of radioactive liquids in Fukushima, Japan”, 22 September 2015, see http://globenewswire.com/news-release/2015/09/22/769907/0/en/Fortum-to-supply-more-ion-exchange-materials-for-purification-of-radioactive-liquids-in-Fukushima-Japan.html

62 Fortum Power and Heat, “Cesium and Strontium Removal with Highly Selective Ion Exchange Media in Fukushima and Cesium Removal with Less Selective Media”, Esko Tusa Fortum Power and Heat, Finland, WM2014 Conference, 2-6 March, 2014, Phoenix, Arizona, U.S, see http://archive.wmsym.org/2014/papers/14018.pdf

63 Ibid.

64 TEPCO, “Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (123rd Release), 30 October, 2013 Tokyo Electric Power Company, see https://www4.tepco.co.jp/en/press/corp-com/release/betu13_e/images/131030e0201.pdf

65 Opcit. Fortum March 2014.

66 TEPCO, “Status of Contaminated Water Treatment and Tritium at Fukushima Daiichi Nuclear Power Station” Noboru Ishizawa Project Planning Department Fukushima Daiichi Decontamination and Decommissioning Engineering Company Tokyo Electric Power Company, Inc., 2014, see https://fukushima.jaea.go.jp/english/outline/pdf1410/4a-1_Ishizawa.pdf

Since the reporting of the early sample analysis there has been little public disclosure explaining the results of further ALPS operation. Official results for 2017, compiled by Citizens Nuclear Information Center in Tokyo (CNIC), report that for the radionuclides Sr-90 and I-129 the maximum values were 4.7 and 6.8 times above the notification target discharge level.[67] The C-60 levels were 50 times below the notification target level.

| | total-β | H-3 | Sr-90 | I-129 | Ru-106 | Sb-125 | Co-60 | Tc-99 | Ni-63 |
|---|---|---|---|---|---|---|---|---|---|
| Maximum value in ALPS-treated water (FY 2017) | 454 | 1593000 | 141 | 62 | 93 | 5 | 4 | 59 | 3 |
| Notification concentration in effluent | — | 600000 | 30 | 9 | 100 | 800 | 200 | 1000 | 6000 |

These reported maximum levels from 2017 do not however match the disclosures made by TEPCO in September 2018, where maximum Sr-90 levels for example were up to 20,000 times the notification target discharge level. It has not been explained by TEPCO why such disparity exists.

## ALPS Failure - Potential Factors

There are multiple factors that could have reduced the Decontamination Factor of the ALPS system and therefore led to the failure of TEPCO to reduce the radionuclide content to below discharge limits. As of January 2019, TEPCO has not provided detailed technical analysis on the reasons for underperformance of ALPS. Below we identify some potential factors, but until TEPCO discloses full details a comprehensive understanding remains unknown to the public.

* **Water Chemistry -** The water chemistry was not optimal, reducing the ion exchange efficiency. The ALPS system, like any chemical process is affected by the PH level. According to Fortum, the micro-beads operated at a range of PH levels – with a PH of between 4-8 for its CoTreat, with an optimal range of PH 5-7; for its SrTreat the PH level required is >7, and optimal >10. For its CsTreat there is a wider margin with PH levels from 1-13. If TEPCO failed to closely monitor the PH water balance in the ALPS process, the efficiency of both strontium and cobalt treatment could have been affected, reducing the DF factors considerably. The contaminated water processed at ALPS is not consistent in its content, with wide variations in concentrations of both radionuclides and other materials, one factor requiring constant water chemistry monitoring and variation.

* **Flow rate and filter replacement -** linked to the efficiency of ion exchange is the operating flow rate of water through ALPS. While this on one level is basic water management, the operating conditions, and complexity of the water challenge at Fukushima Daiichi presents major challenges. One reason for the failure of the processing technology to remove significant radionuclides such as Sr-90 may in fact have been due to TEPCO's efforts to increase processing volume. The IAEA noted in 2015 that while successful, the volume of water being processed did not meet the design throughput of the ALPS and other technologies. "Whilst acknowledging TEPCO's efforts to reduce the risk of storing large volumes of highly radioactive

67 Nobuko Tanimura, "The Fukushima Daiichi Nuclear Accident: Current State of Contaminated Water Treatment Issues and Citizens' Reactions", Citizens Nuclear Information Center (CNIC), October 2018, see http://www.cnic.jp/english/?p=4219

water by removing strontium and other radionuclides as quickly as possible, the IAEA team believes waste minimization should also be an important consideration in such efforts."[68]

The IAEA team in 2015 noted that the actual operating capacity of the three ALPS systems had been only 1200 tons / m3 per day as compared to their full design capacity of 2000 tons / m3 per day. Discussions during the IAEA mission, "indicated that this shortfall may be related to the complexity of the treatment flow sheets and the use of newly developed selective sorbents being industrially deployed for the first time. There is, for example, a need for frequent cleaning or replacement of the cross flow filters in the first two ALPS systems, resulting in significant downtime."[69] The IAEA also highlighted that, "Lower than expected service life of strontium sorbent in the high performance ALPS system is another example. Obviously, fine-tuning operating conditions and achieving performance targets for these systems is taking more time than initially estimated."[70] Yet the IAEA continued to report that progress on decontamination of water was proceeding as planned, including to reach a level of concentration that would be below discharge limits.

In early testing of ALPS, it was found that if the absorbing materials/ cross flow filters were replaced after 20 days of operation, the concentration of radionuclides was below the notification target level. However, more frequent replacement led to lower water processing rates due to higher outage for the plant. As reported by Nobuko Tanimura in 2018 for Citizens Nuclear Information Center (CNIC), a decision was taken to operate ALPS at a rate that would lower the Decontamination Factor, leading to a less efficient processing.[71] The decision was due to the rapid build up of contaminated water, including resulting higher radiation dose rates at the Fukushima Daiichi plant boundary.

In deciding to increase flow rate while increasing the time between replacement of ion exchange materials, TEPCO may also have been acting in part on the advice of the IAEA to speed up the process – the consequence of which led to the failure to remove the quantity of radionuclides, including Sr-90, as claimed by TEPCO (and the IAEA) during the past five years – and now admitted by TEPCO. Ironically, by calling on TEPCO to increase water processing rates, (leading to TEPCO to replace clogged contaminated filters less than required), the IAEA has played a role in setting back perhaps for ever, the plans to discharge the water into the Pacific – something the IAEA has recommended during the past years.

*** Salinity -** It has been confirmed that water salinity has a greater impact on strontium sorption than for cobalt.[72] The results can be partly explained by the concentration of competing ions present in seawater. From the earliest weeks of the proposed water processing experts in Japan expressed reservations about the decontamination process due to salinity. Kenji Takeshita, a specialist in water treatment at the Tokyo Institute of Technology, stated in 2011 that although a zeolite filtration system worked at the Three Mile Island nuclear reactor (which suffered a partial core meltdown in 1979, the water pumped through it was fresh. "This time the water is full of

68 IAEA, "Mission Report IAEA International Peer Review Mission On Mid-And-Long-Term Roadmap Towards The Decommissioning Of Tepco's Fukushima Daiichi Nuclear Power Station Units 1-4 (Third Mission)", Tokyo and Fukushima Prefecture, Japan, 9 – 17 February 2015 see https://www.iaea.org/sites/default/files/missionreport130515.pdf
69 Ibid.
70 Ibid.

71 Nobuko Tanimura, The Fukushima Daiichi Nuclear Accident: Current State of Contaminated Water Treatment Issues and Citizens' Reactions, CNIC, October 2, 2018, see http://www.cnic.jp/english/?p=4219
72 Handley-Sidhu, S. et al. "Influence of pH, competing ions, and salinity on the sorption of strontium and cobalt onto biogenic hydroxyapatite. Sci. Rep. 6, 23361; doi: 10.1038/srep23361 (2016), see https://www.nature.com/articles/srep23361

salt... The chemical similarity between sodium and cesium ions may make the zeolite extraction process far less efficient."[73]

In addition to the above, fluctuations in water temperature, increase in turbidity (which can block plug/foul ion exchange units) and other factors have most likely contributed to the under-performance of the ALPS. TEPCO set a DF of 600,000 for the ALPS, but with all of the above factors its clear that there has been wide variation in the efficiency of ion exchange operations. One of the principal suppliers, Fortum clearly states that its technology has a large range of DF – see table below.

**Decontamination Factor of Fortum Supplied Ion Exchange Materials[74]**

| Radionuclide | Cesium Treatment | Cobalt Treatment | Strontium Treatment |
|---|---|---|---|
| Decontamination Factor | 1000-10,000 (highest achieved 8 million) | 10-2000 | 200-2000 (highest achieved 165 million |

TEPCO was clearly aware of the wide range of DF's at ALPS, yet continued to report consistent levels of radionuclides (other than tritium) below the regulatory limit. Something has clearly gone wrong with TEPCOs reporting of water processing at Fukushima Daiichi.

## Failure To Investigate Alternatives To Discharge and Disposal

"It is the only feasible method." Toyoshi Fuketa, Chair of the Nuclear Regulation Authority, on the discharge of contaminated water to the Pacific Ocean.[75]

Prior to the disclosures by TEPCO in October 2018 of the failure of its water processing to reduce radionuclide content to below discharge limits, there was a momentum building for a decision to be made for the discharge of the contaminated water to the Pacific Ocean. The emphasis of TEPCO and the Japanese government in recent years has been solving the water problem through disposal, with discharge to the Pacific the clearly preferred option. In 2013-2016, the Tritiated Water Task Force conducted technical evaluations of disposal methods. It considered five options,[76]

* geosphere injection (no pre-treatment/ post-dilution/ post-separation);

* offshore release (post-dilution/ post-separation)

* vapor release (no pre-treatment/ post-dilution/ post-separation)

* hydrogen release (no pre-treatment/ post-separation)

* underground burial (no pre-treatment)

73 Nature, "Fukushima deep in hot water: Rising levels of radioactive liquid hamper clean-up effort", 7 June 2011, see https://www.nature.com/news/2011/110607/full/474135a.html

74 Fortum, "Highly selective ion exchange materials: CsTreat, SrTreat and CoTreat", Jussi-Matti MäkiProduct Manager, NURES, BORES, see https://www.fortum.com/products-and-services/power-plant-services/nuclear-services/nuclear-waste-management/nures/highly

75 Asahi Shimbun, "Residents blast water-discharge method at Fukushima plant", 31 August 2018, see http://www.asahi.com/ajw/articles/AJ201808310042.html

76 METI, "Tritiated Water Task Force Report", June 2016 Tritiated Water Task Force" June 2016, see http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20160915_01a.pdf; and CNIC, "The Fukushima Daiichi Nuclear Accident: Current State of Contaminated Water Treatment Issues and Citizens' Reactions", 2 October 2018, see http://www.cnic.jp/english/?p=4219

Of the above options, the preferred option is direct disposal to the Pacific. The Task Force concluded that "sea discharge would cost 3.4 billion yen (US$30 million) and take seven years and four months to complete. It concluded that this was cheapest and quickest of the five methods."[77]

However, the scope of the options finally considered by the Task Force, fails to explain the other alternatives to discharge/disposal that TEPCO and the Japanese government agencies were made aware of, but chose to disregard.  In fact those options were originally considered in the first years following 2011, and included the processing of water to separate tritium.

The Committee on Countermeasures for Contaminated Water Treatment (hereafter, the Committee), and which operated under the guidance of METI's International Research Institute for Nuclear Decommissioning (IRID), reported in 2013 that it had received proposals from industry both domestically and worldwide on options for removing radioactive tritium.[78] The review concluded that, "Although there are many proposals about tritium separation technologies, there is no innovative proposal that will significantly improve the separation performance of the Combined Electrolysis Catalytic Exchange (CECE) process which is, from past knowledge and experience, the most promising system."[79] A final decision was taken on 19th April 2016 by the Committee that concluded that none of the tritium removal technologies could be applied at the Fukushima Daiichi site.[80]

Major criteria that was applied appear to center on the financial implications and the potential to scale up the technology to be able to process the volume of water at the Fukushima Daiichi plant. In evaluating the proposals, IRID stated that, "Although many proposals were submitted, there was no proposal that showed an immediate applicability to Fukushima Daiichi nuclear power plant", and confirmed, "that tritium could be separated theoretically, but there is no practical separation technology on an industrial scale. Accordingly, a controlled environmental release is said to be the best way to treat low-tritium-concentration water."[81]

However, the conclusion that no technology exists that could meet the tritium water challenge at the Fukushima Daiichi plant is contradicted by several of the contractors which submitted evidence to the Committee in 2014-16.

One of the proposed technologies for tritium removal was from Kurion, the U.S. company which had already supplied technology for water processing. Kurion presented its report to the Committee  that it could scale up its technology and significantly reduce the tritium content of the contaminated water. As the company's chief technical office explained in 2015, "the Kurion's system, could remove the tritium from 800,000 cubic meters of water so that only about a cubic meter of the radioactive material remained."[82] The estimated timeframe was five to eight years, and cost estimates of about US$1 billion to set up, plus several hundred million dollars a year to operate. The company constructed a test facility in Houston Texas to demonstrate the applicability of its technology at Fukushima Daiichi.

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77 Ibid.

78 Committee on Countermeasures for Contaminated Water Treatment "Technology Information Form 2", see http://irid.or.jp/cw/public/group/form2_301-350.pdf

79 Ibid.

80 METI, "Committee on Countermeasures for Contaminated Water Treatment", 19th April 2016, 14th meeting, see http://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/tritium_tusk/pdf/160419_07.pdf (in Japanese)

81 International Research Institute for Nuclear Decommissioning (IRID), "Previous Discussions on the Management for Tritiated Water", 3 June, 2014 Ministry of Economy, Trade and Industry Agency for Natural Resources and Energy (Cabinet Office, Management Office of the Team for Decommissioning and Contaminated Water Countermeasures), see https://www.mri.co.jp/english/news/2014060212E.pdf

82 Kurion technical officer, Gaetan Bonhomme, cited in Los Angeles Times, "4 years after Fukushima, Japan considers restarting nuclear facilities", 30 March 2015, see http://www.latimes.com/world/asia/la-fg-japan-nuclear-20150330-story.html

Its Modular Detritiation System (MDSTM), according to Kurion, meets the criteria for removing tritium with a DF of 1000, and being capable of "processing several dozen cubic meters per day to several hundred cubic meters per day in a cost effective manner."[83] While the processing does not remove all tritium, (it reports that the level is well below the 6x104 Bq/l release limit) Kurion made clear that with the significant reduction in volume of tritiated water, "the tritium can be concentrated in a very small volume for stabilization (e.g. concrete) for disposal as low level waste."[84]

Several other companies made proposals to the Committee on how tritiated water could be processed,[85] as well as the U.S. Department of Energy (DOE). In the case of the latter, the DOE due to its historical nuclear program has a long history with managing tritium, and not a positive one. Due to the nuclear waste legacy, the U.S. is confronted with enormous challenges at its nuclear production sites, including with tritium. One consequence is that more analysis has been conducted by the U.S. DOE on how to manage tritium waste than in any other country. One 2015 assessment from the Pacific Northwest National Laboratory (PPNL), and available for consideration by Japanese authorities, is technology that utilizes graphene oxide laminar membranes (GOx) for the separation of low-concentration (10-3-10 µCi/g) tritiated water.[86] As PPNL reports, the average end product removes 60 percent of the initial tritium, with the potential to scale up to remove 99 percent.

There are little if any detailed analysis in the public domain that explains the thinking of the Japanese authorities to not consider more thoroughly the options for tritium removal.

## Costs Of Tritium Removal

"Some people will say that's expensive, but compared to what? I'd be very interested to talk to someone who says you should release this water, and discuss the costs of that...How would you do it? What would be the impact? And how would you compensate people who might be affected. Gaetan Bonhomme , Kurion chief technical officer.[87]

The cost estimates for the technology proposed by PPNL is of course significant, with a range of US$60-US$180 per liter.[88] This includes combined annual energy operating costs and capitalization of the facility over 10 years. This compares with costs for CECE, the technology that received the most positive view from the Committee, of between US$2 – US$20 per liter.

If applied to the Fukushima Daiichi water, processing 1 million m3 / tons of contaminated water, and based on estimates would range from US$2-US$20 billion for CECE technology; and US$50-US$180 billion for graphene oxide technology developed by the DOE.

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83 Kurion, "Kurion Modular Detritiation System (MDSTM)", Committee on Countermeasures for Contaminated Water Treatment 2014.

84 Ibid.

85 IRID "Summary of major responses to the RFI (classified into items and categories) [Topic 2 Treatment of contaminated water", 2014, see http://irid.or.jp/cw/wp-content/uploads/2013/11/RFI_Result1118_1_21.pdf

86 U.S.DOE, "Separation of Tritiated Water Using Graphene Oxide Membrane" Prepared for U.S. Department of Energy Fuel Cycle Research and Development Material Recovery and Waste Form Development CampaignGJ Sevigny, RK Motkuri, DW Gotthold, LS Fifield Pacific Northwest National Laboratory AP Frost, W Bratton Kurion June 2015 FCRD- MRWFD-2015-000773 PNNL-24411, see https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24411.pdf

87 Opcit. Los Angeles Times, March 2015.

88 Ibid.

The reality is that the Fukushima Daiichi disaster is going to cost hundreds of billions of dollars over the coming years. As of FY2017 the cost of the disaster was ¥7,033.3 trillion (US$64.21 billion).[89] Government 2016 estimates are that total costs will be ¥21.5 trillion (US$193 billion); however this is considered a significant underestimate. The Japan Institute for Economic Research (JIER) in 2017 estimated that total costs for 'decommissioning', decontamination and compensation of the Fukushima could range between ¥50-70 trillion (US$449-628 billion),[90] and with enormous uncertainties. If confirmed over the coming years it will be the most expensive industrial accident in history, with even greater implications for the people and energy future of Japan.

Of course, there is no certainty that any of these water processing technologies would perform as claimed – and as we have seen from TEPCO, it is right to be skeptical. The history of the nuclear industry is littered with examples of claims of performance not matching reality.

However, given the scale of the water challenge at Fukushima Daiichi, and the timeframe for how long the crisis at the plant will require managing – which is certainly not the 30-40 years claimed by TEPCO, but many more decades and most likely well into next century, the priority must be to properly assess and apply all appropriate technologies to reduce the hazards at the site and to minimize off site environmental and human health impacts. This, however, is not how the Japanese government and TEPCO have acted, with direct discharge to the Pacific effectively considered the cheapest and quickest option.

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89 TEPCO, "FY2017 Financial Results (April 1, 2017 – March 31, 2018) Tokyo Electric Power Company Holdings, Inc." 26 April 2018, see http://www.tepco.co.jp/en/corpinfo/ir/tool/presen/pdf/180426_1-e.pdf

90 Japan Center for Economic Research, "Accident Cleanup Costs May Rise to 50-70 Trillion Yen - It's Time to Examine legal liquidation of TEPCO - Higher Transparency is Needed for the Reasons to Maintaining Nuclear Power", Tatsuo Kobayashi, Principal Economist, Professor Tatsujiro Suzuki, Specially Appointed Fellow (Director of Nagasaki University Research Center for Nuclear Weapons Abolition), Kazumasa Iwata, JCER President, see http://www.jcer.or.jp/eng/research/policy.html

Fukushima Daiichi nuclear plant, with some of the 1000 highly contaminated water storage tanks located to west of reactor units 1-, 16 October 2018. © Christian Aslund / Greenpeace

## Long Term Tank Storage

"In this request of technical information, there are many opinions and proposals suggesting that comprehensive evaluation on handling of tritiated water should be performed." IRID 2014.[91]

There has been no comprehensive evaluation of managing tritium as recommended by the IRID in 2014. But the reality confronting Japanese authorities and TEPCO is that storage on site remains the only environmentally justifiable and viable option in the coming years (decades). Given the major set backs in plans for release of tritiated water to the Pacific Ocean, and given recent disclosures of failure of processing technology, including ALPS, continuing and improved tank storage, while in parallel investigating effective processing technology, is the only environmentally justified approach. This means that priority must be given to securing sufficient storage capacity over the medium term.

According to the IAEA in November 2018, the projection is that the "current site facility plan regarding tank construction capacity of 1.37 million m3 /tons, the storage of ALPS treated water is expected to reach full capacity within coming three to four years."[92] Clearly, additional storage capacity must be created.

IRID, in considering the storage option in 2014 concluded that, "there were safety issues that needed to be addressed. In order to store condensed tritiated water stably and for a long term after separation, the impact of radiolysis and Helium gas generated by the decay of tritium should be taken into account."[93]

There is no denying the challenge of long term storage of tritium – not least due its chemical properties which mean that over time it can diffuse through metals. According to the U.S. DOE,

91 Opcit. IRID 2014.

92 Preliminary Summary Report IAEA International Peer Review Mission On Mid-And-Long-Term Roadmap Towards The Decommissioning Of Tepco's Fukushima Daiichi Nuclear Power Station Units 1-4 (Fourth Mission) Tokyo And Fukushima Daiichi Nps, Japan, 5-13 November 2018, see https://www.iaea.org/sites/default/files/18/11/missionreport-131118.pdf

93 Opcit. IRID 2014.

“Tritium in the form of tritiated water may be difficult to store for long periods due to its corrosive properties. This corrosiveness is likely due to tritium oxide generating free radicals (OH− ) from radiolytic decomposition of water in addition to extra energy from beta decay impinging on surrounding molecules.”[94]

A key factor is the steel type used for tank construction. The Fukushima Daiichi storage tanks have had multiple failures since 2011.[95] The original flange and horizontal type tanks were found to be inadequate, suffering leaks of contaminated water.[96] TEPCO confirmed that these tanks had a service life of five years.[97] In 2014, Mitsubishi Heavy Industries, Ltd. (MHI) began the supply of vertical tanks made of welded carbon steel to replace the flange tanks.[98]

While the replacement of the flange tanks was essential, it remains unclear what the service life will be for the new tanks. Japanese authorities are aware that carbon steel is not considered appropriate for storing tritiated water. The U.S. DOE reported in 2008 that, "Plain carbon steels and alloy steels cannot be used for tritium service. These steels have high strength and (normally) a body-centered-cubic crystal structure, both of which make the material less ductile and much more susceptible to hydrogen embrittlement."[99]

There are no immediate solutions to the nuclear crisis at the Fukushima Daiichi, and they likely will not emerge any time soon – and therefore priority should be given to long term management (storage) of contaminated water, combined with continuation of processes to remove radionuclides.

In 2014, the IRID confirmed that there was a likelihood of having to store highly contaminated water for a prolonged period. Therefore, it called for “a comprehensive evaluation on handling of tritiated water should be started immediately together with stakeholders, by sharing international knowledge and experience. In the comprehensive evaluation, not only the applicability of separation and the technology of long-term storage of tritiated water, but also risks including natural disasters, and keeping it with the present condition should be taken into consideration.”[100]

There is no evidence that since 2014 TEPCO or those agencies responsible for the management oversight of the Fukushima Daiichi plant have initiated a concerted effort to prepare for long term storage of highly contaminated water. The discharge option has come to dominate the debate – driven principally by lowest financial cost considerations – not considerations of environmental protection or the interests of the communities along the Fukushima Pacific coast.

The fact that TEPCO have now confirmed that their processing technology has not worked as stated, and that levels of radioactivity are not below regulatory limits, inevitably sets back any

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94 DOE, “DOE Handbook Tritium Handling And Safe Storage”, DOE-HDBK-1129-2008 December 2008 U.S. Department of Energy AREA SAFT Washington, D.C. 20585, see https://www.standards.doe.gov/standards-documents/1100/1129-bhdbk-2008/@@images/file. The DOE notes that “:In a severe case, storage of tritiated water recovered from tritium removal systems in liquid form at concentrations as low as a few curies per milliliter has corroded through the weld area of stainless steel vessels after only a few days of exposure.”

95 Yoko Kubota, Yuka Obayashi, "Wrecked Fukushima storage tank leaking highly radioactive water", Reuters, 20 August 2013, see https://www.reuters.com/article/us-japan-fukushima-leak/wrecked-fukushima-storage-tank-leaking-highly-radioactive-water-idUSBRE97J02920130820; BBC, "Japan's Fukushima nuclear plant leaks radioactive water", 20 February 2014, see https://www.bbc.co.uk/news/world-asia-26254140; Mari Yamiguchi, "Fukushima Nuclear Disaster: Water Tanks Flawed, Workers Say", Associated Press, 8 November 2013, see https://weather.com/science/environment/news/fukushima-nuclear-plant-water-tanks-flawed-20131108

96 CNIC, “The Severe Contaminated Water Situation at Fukushima Daiichi Nuclear Power Station”, September/October 2013, see http://www.cnic.jp/english/newsletter/nit156/nit156articles/01_leak2.html

97 TEPCO, “Fukushima Daiichi NPS Prompt Report 2014 Fukushima Daiichi NPS Prompt Report (Jul 24, 2014): Soundness of storage tanks secured at Fukushima Daiichi NPS”, July 2013, see http://www.tepco.co.jp/en/press/corp-com/release/2014/1239559_5892.html

98 MHI, “MHI Starts Shipments of Factory-made Tanks for Storing Contaminated Water at Fukushima Daiichi Nuclear Power Station”, 4 October 2014, News Letter No,1790, see https://www.mhi.com/news/story/1404101790.html

99 Opcit. DOE 2008.

100 Opcit. IRID 2014.

planned discharge to the Pacific. TEPCO over the coming years will have to demonstrate that processing, including ALPS, is capable of reducing levels as originally stated. At the same time, TEPCO and METI agencies have failed to further develop options for tritium removal. The water crisis was entirely predictable, and yet there has been no serious efforts to prepare for the least environmentally hazardous option – long term storage.

This is exactly what was proposed by engineers from the Citizens Commission on Nuclear Energy (CCNE) in 2017, recommending that "ten 100,000-ton large-scale tanks, of the kind currently being used in the national oil reserve base, should be constructed and the tritium water stored for 123 years, when it is expected that the radiation will have decayed to one-thousandth of its current value."[101] Storage beyond this point as waste would most likely be the preferred option. The CCNE proposal was both technologically and economically viable, using well-proven engineering at the current industrial level, and is "the most stable and safe solution of all those proposed."[102]

## Fukushima Contaminated Water Crisis at the United Nations IMO

Since 2011, the Japanese government has made a commitment to the United Nations International Maritime Organization (IMO) parties that it would, "maintain and strengthen ongoing ocean monitoring, investigate and determine the impact of the dispersion of radioactive materials, make every effort to publicize the findings, and study ways to minimize discharge into the ocean."[103] The preferred option to discharge over 1 million m3 / tons of highly contaminated water, clearly does not comply with Japan's international commitment to protection of the marine environment.

In August 2011, the Government of Republic of Korea made a credible case that the events at Fukushima Daiichi, along with other industrial accidents that contaminate large scale marine areas, falls within the scope of the London Convention/Protocol.[104] Additionally Contracting Parties are obliged to lend assistance to control the situation in terms of protection and preservation of the marine environment for the country where the accident originated bearing in mind the general obligations set out by the Article 3 of the Protocol, in particular Article 3.4, which is also customary international law.

Most recently, the water crisis at the Fukushima Daiichi nuclear plant was discussed at the November 2018 session of the Contracting Parties to the London Convention & Meeting of Contracting Parties to the London Protocol. In an intervention by Greenpeace International it was stated that the government of Japan, "had made a commitment to maintain and strengthen ongoing ocean monitoring, investigate and determine the impact of the dispersion of radioactive materials, make every effort to publicize the findings, and study ways to minimize discharge into the ocean. Having noted recent reports in Japan that, following failure of treatment systems, permission to dispose of waste waters at sea were under consideration, the observer noted that

101 Nuclear Power Committee Council Special Report 1 "Post-retirement after quarantine storage for over 100 years" November 11, 2017, p.7 see http://www.ccnejapan.com/?p=7900

102 Ibid.

103 *Scientific Group Of The London Convention – 34th Meeting; And Scientific Group Of The London Protocol – 5th Meeting 11 – 15 April 2011 Agenda Item 15, Report Of The Thirty-Fourth Meeting Of The Scientific Group Of The London Convention And The Fifth Meeting Of The Scientific Group Of The London Protocol.*

104 Thirty-Third Consultative Meeting Of Contracting Parties To The London Convention & Sixth Meeting Of Contracting Parties To The London Protocol 17 – 21 October 2011 Agenda item 9 LC 33/9/2 25 August 2011 Matters Related To The Management Of Radioactive Wastes Practical International Assistance after Large Scale Industrial Accidents affecting Marine Areas Beyond National Jurisdiction Submitted by the Republic of Korea.

such reports would raise serious concerns for the protection of the marine environment on both a local and international scale."[105]

Greenpeace International further noted that that it was through international cooperation that the Russian Federation was able to avert disposal at sea of liquid radioactive waste in the 1990s, including assistance at the time from Japan, queried what steps had been taken, or might be taken, to seek or to provide similar international assistance in addressing the problems of liquid radioactive waste arising from the Fukushima disaster."[106]

The delegation of Japan informed the IMO parties, "that no decision had been made on the final treatment of waste water stored at the Fukushima Daiichi Nuclear Power Plant, and that the final treatment was still under consideration, while listening to the opinions of local residents and experts. It was further noted that no matter what the final treatment would be, Japan will ensure that the radioactive level of disposed water including tritium would be lower than the level permitted under regulatory standards."[107]

Japan also reported that TEPCO would carry out a second order treatment for the sake of safety and of security, before disposing of the water, "in order to ensure that the radioactive level of the water would be below the criteria for disposal."[108]

The delegation of the Republic of Korea noted that the issue of radioactive contaminated water potentially being discharged into the sea, "was a major concern for neighboring countries, and welcomed further updates and information sharing from Japan."

As the contaminated water crisis at Fukushima Daiichi has no viable solution for the coming years, it is inevitable that the issue will continue to be raised by member states and NGO's at the IMO and other international forums.

## Conclusion

"I don't believe the technology is available for easy removal of tritium," and that "The amount is not particularly mind-boggling from a global perspective. We can't help discharging water once it has cleared safety levels."[109]

There is no timeframe for when the contaminated water at Fukushima will 'clear' safety levels – that's the nature of radioactivity. There is little evidence that the Japanese government has applied internationally accepted environmental methodology for deciding options for the contaminated water. For example, the principle of Best Practicable Environmental Option (BPEO) first outlined in in the UK in 1976, is defined as "the outcome of a systematic consultative and decision making procedure which emphasizes the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment, as

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105 Fortieth Consultative Meeting Of Contracting Parties To The London Convention & Thirteenth Meeting Of Contracting Parties To The London Protocol 5-9 November 2018 Agenda item 16 Consideration And Adoption Of The Report Draft report of the Fortieth Consultative Meeting and the Thirteenth Meeting of Contracting Parties.
106 Ibid.
107 Ibid.
108 Ibid.
109 "IAEA recommends discharging Fukushima radioactive water to the sea," December 5, 2013, see http://ajw.asahi.com/article/0311disaster/fukushima/AJ201312050043.

a whole, at acceptable cost, in the long term as well as the short term."[110] Emerging out of this approach was the concept of 'Best Available Techniques', which as applied to the nuclear industry means discharging radioactive waste into the environment is not permitted when alternative management techniques are available. Clearly, such an approach needs to be applied at Fukushima Daiichi.

The contaminated water crisis at the Fukushima Daiichi nuclear plant is a consequence of decisions taken more than fifty years ago to lower the site for nuclear plant, failure to act on evidence of a major seismic and tsunami risks to the plant, and of course the events of 11 March 2011 and subsequent decisions. No government or industry confronted by the scale and range of challenges resulting from 2011 would have been able to manage the resulting disaster. However, time after time, TEPCO, and the bodies of the Japanese government, appear to have conspired to make the crisis worse. The disclosures by TEPCO that their processing technology has not performed as they have reported to the people of Japan the past years, is only the latest in long history of mis-reporting and cover ups.[111]

Most significantly, and as a result of the determination of thousands of Fukushima citizens and their dedicated lawyers, three former executives of TEPCO have been charged with professional negligence resulting in death and injury over the accident and being prosecuted in the Tokyo District Court.[112] Accused of failing to act to prevent the nuclear disaster, evidence has been presented in court demonstrating that TEPCO ignored a 2002 government appointed panel seismic assessment that warned of a 20 percent chance of a magnitude 8 occurring in the Japan Trench off the northeastern Japan[113] and also TEPCO's own 2008 technical assessment that predicted a maximum credible tsunami of 15.7 meters could hit the Fukushima Daiichi plant and hence a higher seawall was essential.[114] The failure of TEPCO management to act on evidence of major risks to Fukushima available in 2002 and 2008, was due in large part by considerations of the financial implications. The cost of new sea wall construction, including the temporary shutdown of the reactors, combined with the losses incurred from the shutdown of the seven Kashiwazaki Kariwa reactors, also owned by TEPCO, following the 2008 Chuetsu earthquake,[115] was the deciding factor for TEPCO management,[116] and endorsed by Japanese regulators. The same mindset exists today, framed in the first instance by financial considerations, and the apparent belief that environmental protection and human health risks are not a priority.

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110 NFLA, "Proposed Changes to Sellafield's Environmental Permits, NFLA, Radioactive Waste Policy Briefing Number 74: UK Government consultation on the future regulation of nuclear sites as they reach their 'end' states", Nuclear Free Local Authorities, December 2018, see http://www.nuclearpolicy.info/wp/wp-content/uploads/2019/01/Rad_Waste_Brfg_74_Sellafield_discharges.pdf

111 CNIC, "Revelation of Endless N-damage Cover-ups: the "TEPCO scandal" and the adverse trend of easing inspection standards", November/December 2002, see http://www.cnic.jp/english/newsletter/pdffiles/nit92.pdf; and Greenpeace International, "Japanese nuclear safety scandal uncovered", 30 August 2002, see https://www.greenpeace.org/archive-international/en/news/features/japanese-nuclear-safety-scanda/

112 Jiji, "Court told ex-Tepco Execs were informed barriers could prevent tsunami flooding at Fukushima plant", 28 March 2018, see https://www.japantimes.co.jp/news/2018/02/28/national/court-told-ex-tepco-execs-informed-barriers-prevent-tsunami-flooding-fukushima-plant/#.W-wDgnozaAw

113 Ei Okada and Masanori Makita, "Whether tsunami predictable, damage avoidable focus of TEPCO nuclear disaster trial", 15 October 2018, Mainichi, see https://mainichi.jp/english/articles/20181015/p2a/00m/0na/028000c

114 The Diplomat, "TEPCO Prosecution: A Sign That Japan's Nuclear Industry Is in Free Fall", 4 March 2016, see https://thediplomat.com/2016/03/tepco-prosecution-a-sign-that-japans-nuclear-industry-is-in-free-fall/

115 Greenpeace Japan, "TEPCO'S Atomic Illusion", Shaun Burnie, 23 June 2017, see http://m.greenpeace.org/japan/Global/japan/pdf/TEPCO_briefiing_20170623.pdf

116 Opcit. Ei Okada and Masanori Makita, 15 October 2018. In an affidavit submitted to the court on 5th September 2018, a TEPCO official responsible for tsunami countermeasures at the time explained that "Our business environment was deteriorating because of the Niigata Chuetsu offshore earthquake of 2007 that halted the Kashiwazaki-Kariha nuclear power station, and we wanted to prevent the Fukushima No. 1 plant from stopping by all means. The statement said that the former management once decided to introduce measures to protect against possible tsunami damage but decided to postpone them after finding out that they were more costly than expected, implying that managerial decisions were behind the delay.

As this analysis has sought to demonstrate, the failure of processing technology to perform as claimed and remove radionuclides as repeatedly stated, was known by TEPCO from the earliest operations. Public disclosure of the real levels of contamination would have set back TEPCO's and METI's clear objective which was to solve the enormous water crisis by discharge to the Pacific Ocean. Events have however not worked out as planned.

TEPCO, the NRA and the government have failed to learn the lessons of past mistakes made by their predecessors. Decisions based on short term financial interests led to a triple reactor meltdown, the contamination of thousands of square kilometers of Japan and the Pacific Ocean, and the evacuation of 165,000 Fukushima citizens, tens of thousand of whom remain internally displaced. Over the past years, alternatives to managing the highly contaminated water have received little real scrutiny, and potentially viable options have been effectively ignored and not developed.

The Government and TEPCO had set a target of 2020 as a timeframe for solving the water crisis at Fukushima Daiichi nuclear plant. That was never credible. Even the re-processing of all contaminated water will take an estimated 5-6 years, with remaining questions over its efficacy. Volumes of contaminated water will continue to increase in the coming years. Storage in tanks over the medium and even long term, with parallel development of processing technology, is the only viable option.

The government and TEPCO need an urgent reassessment of the options for managing contaminated water. Paramount in any future decision making should be the protection of the interests of the those in the front line - the communities and fishing industries of Fukushima's Pacific coast. Their views have already been made clear in the past years, including at inadequate public meetings held during 2018. Tetsu Nozaki, chair of the Fukushima Prefectural Federation of Fisheries Cooperative Associations, in August 2018, emphasized that releasing the water into the sea would deal a "devastating blow" to the prefecture's fisheries industry.[117]

Ignoring such views is not an option and neither is discharge to the Pacific Ocean. Eight years after the start of the Fukushima Daiichi nuclear disaster, the crisis has no end point. TEPCO and the government need to stop misleading the public over the scale of the challenges, and to focus on the priority issues of devising a system for the long term storage and management of nuclear waste, including over 1 million tons of highly contaminated water.

117 Kazumasa Sugimura and Chikako Kawahara "Residents blast water-discharge method at Fukushima plant" Asahi Shimbun, 31 August 2018, see http://www.asahi.com/ajw/articles/AJ201808310042.html