JULY 2021

WATER MANAGEMENT

AT FUKUSHIMA DAIICHI

Ten Years of Continuous Progress While Facing Challenges in the Aftermath of the March 2011 Accident.

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Introduction

OUR PROGRESS AND CHALLENGES

MEETING THE CHALLENGE OF WATER MANAGEMENT

In the aftermath of the Great East Japan Earthquake and Tsunami, and the accident that resulted at Fukushima Daiichi NPS (1F), the management of contaminated water on the siteimmediately emerged as a major challenge.

For the management, maintaining control of the complex flow of water at Fukushima Daiichiwas understood to be of vital importance. Of paramount importance were the public health and safety impacts, as well as the emotional and psychological impact of public anxiety.
Three objectives were great concerns: (1) contribute to reduction of the effective dose at the site boundary to 1mSv/year or less, (2) contribute to reduction of the radiation exposure of workers at 1F, and (3) limit the amount of contaminated water flowing into the Pacific Ocean.

More important than these three objectives, there was psychological and economic impor- tance in restoring public confidence in fish and other products from Japan and from the Fukushima area. In particular, it was important to give confidence to farmers and fishermen that they would continue to have a livelihood, and to assure other countries that the Pacific Ocean and its marine life would be protected. To do so, TEPCO needed to demonstrate its ca-pability and determination to undertake the complex long-term decommissioning of the site.

During the immediate post-accident phase, many steps were taken to capture and contain contaminated water. The urgency required innovation and TEPCO engineers hadto improvise. Building basements were converted into holding tanks, waterproofing was carried out in many places, silt fences were installed, temporary tanks quickly constructed,and hundreds of other engineering projects were performed under tremendous stress and terrible working conditions. As time went by, and as working conditions improved, these early efforts evolved into more elaborate, durable and sophisticated solutions, including such water treatment projects as Cesium removal to reduce radiation levels; the development of a sophisticated ALPS (advanced liquid processing system) to remove most nuclides from the water; and the frozen-soil wall to limit the flow of groundwater into contamination zones. As a result, most contaminated water was successfully contained andis now in the process of being further treated in preparation for its eventual disposal.

The purpose of this report is to present a comprehensive overall picture of this many faceted water-management effort, with a sufficient degree of detail yet informative to thenon-technical person.

DEVELOPMENT OF THE WATER MANAGEMENT STRATEGY

Developing an overall approach to water management required addressing the different ways in which water enters the site, moves through it, and drains from it. As it moves through the site, it can contact a variety of sources of contamination, including among the most significant: resolidified fuel debris in reactors, 1, 2, and 3; contaminated standing water inside the buildings and elsewhere on the site; contaminated surfaces (including roofs); and contaminated soil.

Among the most significant challenges in addressing this problem were:

- In the effort to cool the reactors during the loss of electricity at 1F at the time of the accident, cooling water was poured into the reactor buildings. This created contaminatedwater outside the closed loop usually used for reactor cooling. Most of it remained in thereactor building basements, but there was concern it would escape through penetration points at the basement of the buildings and eventually reach the sea.
- So it is important to prevent contaminated water from flowing out of the buildings. The level of the contaminated water inside the buildings is controlled to be lower than thatof groundwater outside (water level difference between inside and outside) to prevent a leakage out of the buildings. However, this measure causes groundwater outside to flowinto the buildings with the lower water level, which generates contaminated water.
- In addition, the explosions at Units 1, 3, and 4 left the building roofs open to the ele- ments, allowing rainwater to directly enter the buildings and mix with the contaminatedwater already inside. This inflow water results in larger volumes of contaminated water which has to be stored, processed, and eventually disposed of.

Three-Pronged Strategy to Address the Challenge

Although different words have been used to describe each of these elements overtime, they have been described as:

1 **REMOVE**, where possible, the sources of contamination.

2 **REDIRECT** water away from contacting sources of contamination.

3 **RETAIN** water safely on the site to prevent leakage into the environmentthat could have an adverse impact.

Eventually, as the result of thousands of hours of planning, innovation, and hard work, water management at 1F achieved important goals.

Early on, TEPCO adopted a three-pronged strategy to address the challenge (see sidebar on page 2). Each strategy faced significant technological and logistical hurdles. Removing nuclides required the development of multi-staged innovative systems to remove radio- active contaminants on a prioritized risk basis. First, gamma-producing Cesium had to be removed, and for that the Kurion and SARRY systems were developed. Then the water was sent to desalination process to recycle back for the water's reinjection into the reactors for cooling purposes, and the other excess water was stored and then the Strontium and othernuclides needed removal. For those purposes ALPS was created.

Keeping water away from sources of contamination has also required multiple approaches,including pumping groundwater from wells to divert it from entering 1F buildings.

As TEPCO and its contractors worked to make progress in each of these areas, there weresuccesses and challenges. Working conditions were difficult, and workers were in many instances attempting to do things that had never been done before, such as construct a frozen soil wall (often referred to as an "ice wall," and officially referred to as the "landside impermeable wall" to distinguish it from the steel "seaside impermeable wall" construct- ed adjacent to the port) to form a waterproof underground perimeter around the Units 1 through 4.

Eventually, as the result of thousands of hours of planning, innovation, and hard work, water management at 1F achieved important goals: reduction of the dose, mainly directand skyshine radiation coming from water storage tanks, at the site boundary (for which water management was a contributing, but not the sole, factor), and reduction of the volume of newly contaminated water. This helped create a safer environment for decommissioning work.

Now, the greatest challenge to the sustainability of the water management program is the finite amount of space in which to store the ALPS treated water, etc. In April 2021, after many months of working with, and receiving input from, all interested parties, the government announced its plan for the ultimate disposition of stored ALPS treated water through a controlled and monitored discharge into the sea. This review incorporates that decision in its review of the entire arc of water management efforts from 2011 to thepresent day.

Overview

WATER MANAGEMENT TODAY AT FUKUSHIMA DAIICHI

A VISUAL ILLUSTRATION OF THE WATER MANAGEMENT SITE

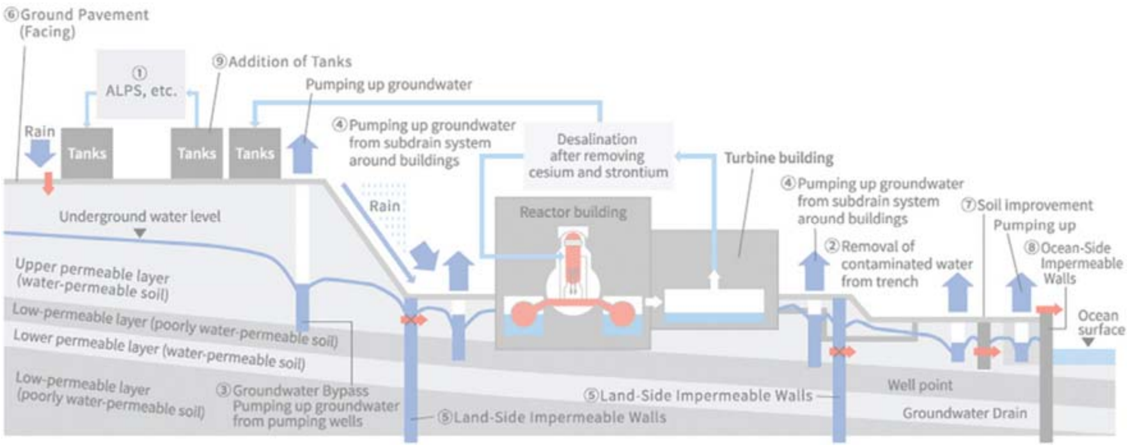
The following two schematics present an overall view of the water management approach at Fukushima Daiichi today.

The first graphic (Schematic 1) represents a cross-section of the site, showing how it slopes down to the sea and how water is intercepted, confined, treated, and stored in various ways.

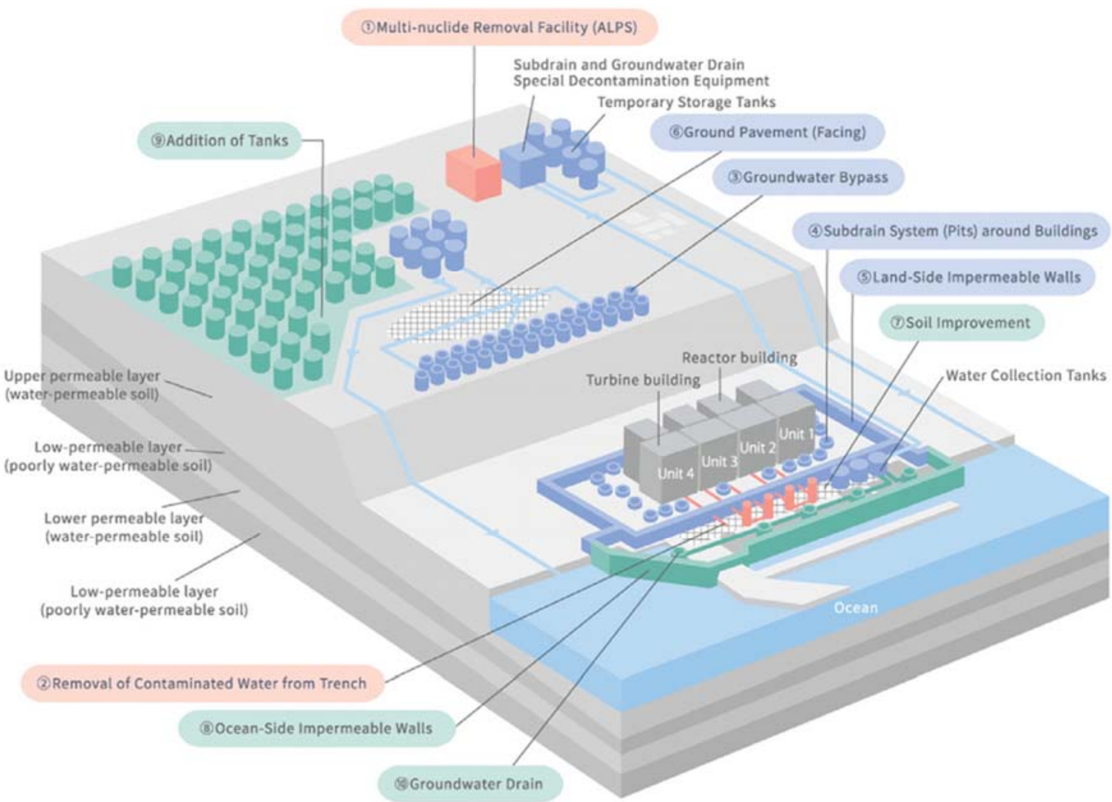
The many different strategies illustrated demonstrate the major progress that has been made. It is the result of innovation, research, and the work of many thousands of individu-als both at the site and at many other locations in Japan and in other countries.

The second graphic (Schematic 2) presents a view of 1F from above, and color-codes various approaches to water management: orange indicates “Remove,” blue represents “Redirect,” and green represents “Retain.”

SCHEMATIC 1 • Cross-Section of the Water Management Site



SCHEMATIC 2 • Aerial View of the Water Management Site



WATER MILESTONES

2011–2012

- Construction of flanged tank farm to hold excess processed water (from groundwater and other leakages) · March 2011–March 2013 Removal of vegetation begins · March 2011

Blockage of direct turbine building (T/B) overflow into the sea completed forUnit 2 · April 2011 and Unit 3 · March 2011

Addition of Cs retention silt screens installed in the port · August 2011

Control of basement water levels to ensure ground water in leakage · June 2011

Kurion Cs removal starts · June 2011

SARRY Cs removal starts · August 2011 •

2013

- ALPS begins operation · March 2013

Start of shotcrete covering of site soil areas to minimize general rainwater infiltration into ground water · Summer 2013 •

2014

Groundwater bypass wells begin operation · April 2014

Reroute of the drainage channels, “B” and “C” into the port · July 2014 Construction of secondary catch basins around tank farms to retain possible tankleakage completed · August 2014

Additional ALPS begins operation · September 2014

High Performance ALPS begins operation · October 2014

Kurion and SARRY systems modified to remove Sr in addition to Cs · December 2014

2015

- Welded tank replacement program accelerates

Removal of trench water by pumping and filling with special concrete completedfor Unit 2 (June 2015) for Unit 3 (July 2015) and for Unit 4 (December 2015) •

- Closure of the seaside impermeable wall · August 2015

Refurbished subdrain system begins operation, with ground water sampling and drain system at 2.5m level and ground water processing system to remove Cs and Sr ·September 2015

Impermeable seaside wall completed · October 2015

2016–2018

Radiation dose at the site boundary reduced below 1mSv per year · March 2016

Reroute of the drainage channels, “K” into the port · March 2016

Lowering of reactor building (R/B) and T/B basement water levels to reduceleakage and flooding begins with Unit 1 T/B · March 2017

Landside impermeable wall (ice wall) fully activates · September 2018 •

2019–2020

- Repair to water proof rooftops of the T/B to minimize rainwater infiltration into highly contaminated surface and adding to water inventories completed · August 2020

Secondary treatment performance confirmation tests for the treated water to be re-purifiedbegins September 2020

3

Strategy

INDIVIDUAL ELEMENTS OF THE APPROACH TO WATER MANAGEMENT

One way to think about the various aspects of water management is this: we try to keep water from becoming contaminated at all. If it does become contaminated, and we removenuclides to the extent possible and store it safely.

DIVERSION OF RUNOFF AND GROUNDWATER

Groundwater Bypass Wells, Pumping Up Water

To divert some groundwater away from areas where it could become contaminated, groundwater bypass wells were dug on the high ground to the west (the mountain side)of Fukushima Daiichi buildings. This enables some groundwater to be pumped up and redirected to the sea before it approaches the buildings. The pumped-up groundwater is stored for a predetermined time and water quality analysis is regularly conducted
by TEPCO and third party organizations. The TEPCO's upper limits of radioactive concentrations are more stringent than the ones set by the Reactor Regulation and the WHO guideline for drinking-water quality. TEPCO discharges the pumped up groundwaterinto the sea only after confirming that the radioactive concentrations of the water do notsurpass the upper limits.

Subdrains

Additionally, subdrain wells that were installed when the buildings were constructed, and whose original purpose was to pump up groundwater to protect the buildings' founda-tions, have now become part of the water management system. Prior to the accident, the groundwater was safe to simply discharge into the sea without checking. Now, the groundwater pumped up from the subdrains may have some extremely low levels of contamination caused by rainwater contacting surface soils that may contain low levelsof contamination remaining from the accident. Therefore, it is now processed to remove radionuclides (other than tritium) to very low agreed-upon standards. TEPCO and third party organizations will make sure that the water meets the stringent water quality stan-dards equivalent to the ones set for the groundwater bypass operations.

This process controls and reduces the level of the natural groundwater table so that the water levels in the building basements can always be maintained at a lower level (to en- sure no out-leakage of contaminated water). Thus the amount of groundwater flowing into the buildings can be carefully reduced to minimize the amount of contaminated water to be processed, stored, and disposed of.

Paving of Surfaces

Prior to the March 2011 accident, much of the surface area of the 1F site was in a natural state — indeed, much of it was forest. Since that time, most of the trees had to be cut down because they had become contaminated, and also to make room for storage tanks and other decommissioning activities. It was also important to harden the surface so that rainwater would neither penetrate into the ground nor become contaminated. Therefore, an extensive project to pave the surfaces at 1F has been undertaken to keep rainwater separate from contaminated surfaces to allow direct discharge to the sea.

While this led to an increase runoff of storm water, this water was directed into drainage channels where it can be appropriately managed. In addition, some older drainage chan- nels were redirected within the port so that water would not run directly into the open sea.Now, all drainage channels lead to the area within the port, and their radiation levels are monitored continuously.

Seaside Impermeable Wall

In an area at the edge of the port — that is, to the sea side of the reactor buildings — a wallwas constructed to block the flow of potentially contaminated groundwater into the sea.The wall, with a length of approximately 780 meters, was completed and put into service in October 2015. The wall consists of approximately 600 steel pipes embedded approxi- mately 30 meters into the earth. Water that builds up behind the wall is pumped up from underground drains, analyzed, treated if necessary and, provided it meets the established standards, discharged into the port area.

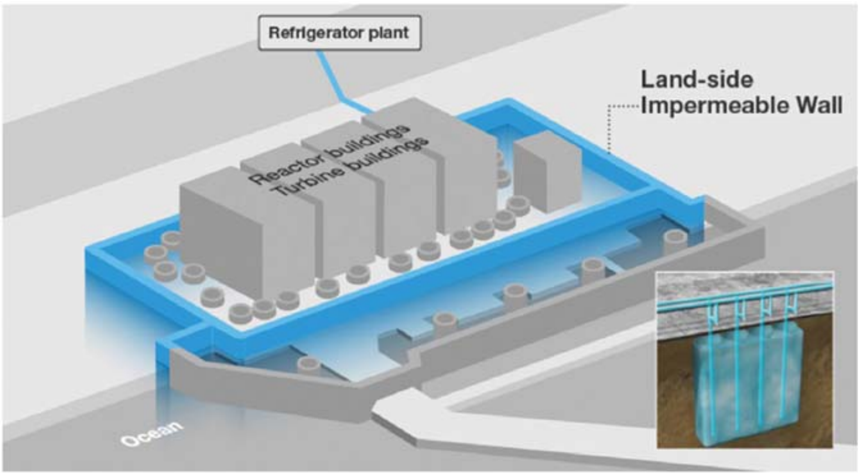
Landside Impermeable Wall

A great deal of attention was given to the development and construction of the frozen soil wall, often referred to as the "ice wall," which forms a perimeter around the four crippled re-actor units, intended to work in conjunction with the subdrain system to control the groundwater levels adjacent to the highly contaminated building basements. This allows reductionof groundwater from intruding into the buildings where it could become significantly more contaminated, and to prevent that contaminated water from flowing out of the buildings toward the sea.

Construction of the wall received the attention because of its innovative application. The concept, which uses frozen soil as a substitute for a physical wall, was chosen as a way to overcome the difficulty of building a watertight barrier around the many pipes and othersubterranean fixtures that surround the four reactor buildings. The technology involved had been used in other contexts, such as a temporary way to stabilize the ground for tunnel construction and to prevent water intrusion, but never for a project intended to lastas long or on so large a scale. Despite its complexities it has been a success in controlling water levels.

Schematic 3, below, offers an illustration of the frozen-soil wall, officially referred to as the "landside impermeable wall" in contradistinction to the seaside impermeable wall adjacentto the port.

SCHEMATIC 3 • Frozen-soil Wall (Landside Impermeable Wall)



After being constructed and activated in phases, the frozen-soil wall was fully activated in September 2018. It has so far been shown to be effective in redirecting groundwater flow- ing from the mountain side around the contaminated buildings so it can flow to the sea.

Since the wall's completion in September 2018, it has reduced inflow of groundwater and rainwater into buildings by 100 cubic meters (from 190 to 90 cubic meters) per day whencompared with the period before the wall was in place. Its existence will allow the flooded building basements to eventually be drained and dried, removing that potential for con- tamination of additional water that enters the basements.

▸ For more information on the development of the frozen-soil wall, go to https://www.tepco.co.jp/en/decommision/planaction/landwardwall/index-e.html

Repair of Damaged Roofs of Buildings

In order to prevent rainwater from flowing into the buildings, damaged roofs, caused by explosions and by debris falling back down on them during the accident, are being repairedto minimize additional generation of contaminated water.

Along with the ice wall and subdrain systems, the aim is to reduce contaminated water generation to about 150 and 100 or less cubic meters per day by the end of 2020 and 2025, respectively. Contaminated water left in the buildings is being processed according to plan. All the contaminated water left in the buildings, other than reactor buildings where fuel debris is being cooled (along with the process main building and the high-temperatureincineration building), was treated by the end of 2020.

REMOVAL AND TREATMENT OF CONTAMINATED WATER

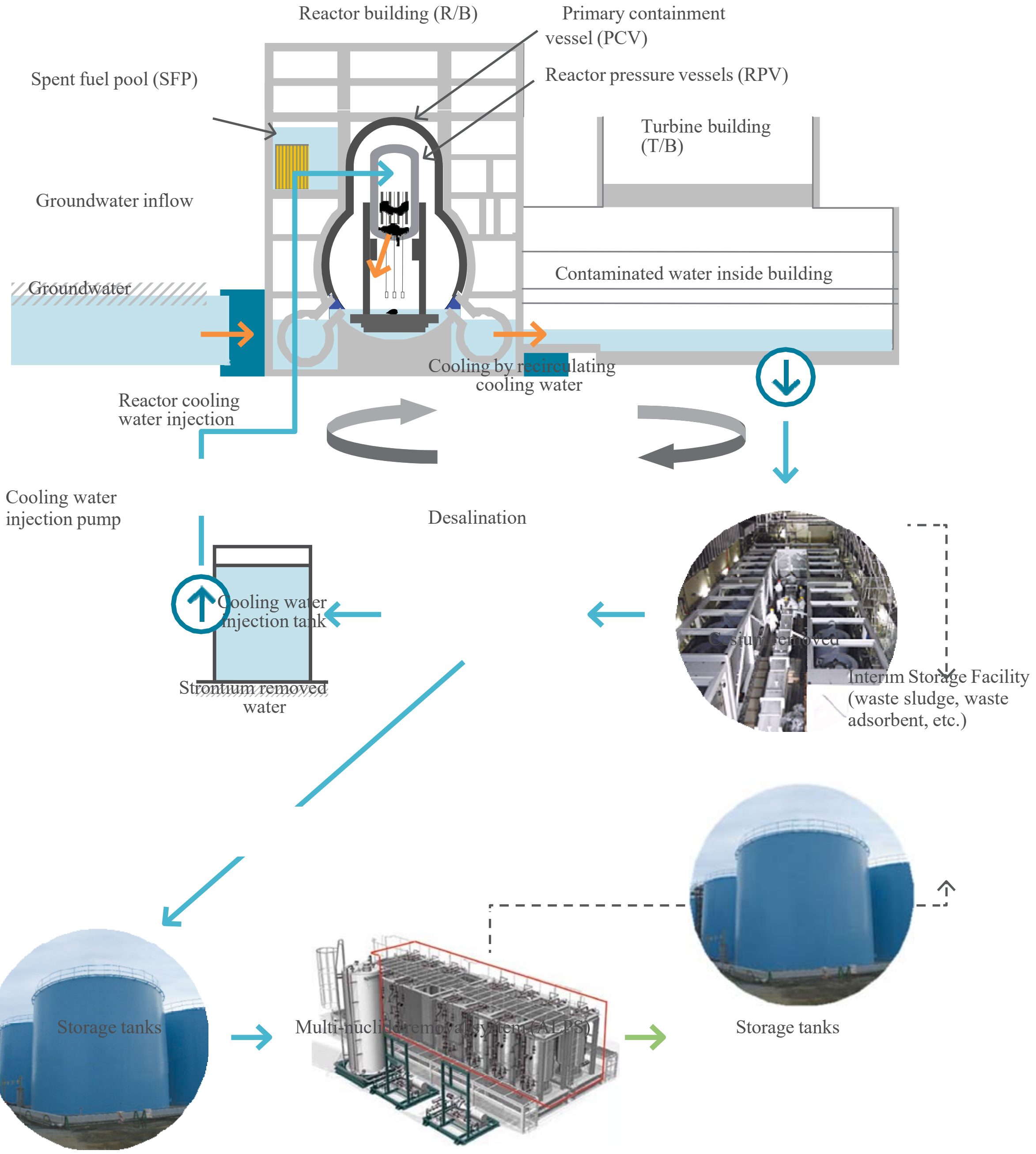
For water that could not be diverted, the strategy is to remove as many sources of contam-ination as possible, and to treat and safely store (or contain) the water that did become contaminated. That included water that was standing in the site immediately after the accident (such as in the trenches near the port and in the basements of buildings) as well as water that would enter the site afterward via rainwater or groundwater. This section of the report addresses the removal and treatment of the water, and the following section addresses its safe storage.

Cesium and Strontium filtering equipment (Kurion and SARRY)

Prior to the development of ALPS (see below), the Kurion (named for its manufacturer) and SARRY (Simplified Active Water Retrieve and Recovery System, manufactured by Toshiba) systems were developed. The two systems were originally designed to remove significant levels of Cesium, and began operation in June and August of 2011, respectively. Then, in order to meet the goal of reducing the radiation dose at the site boundary, the systems were adapted to also remove Strontium. This was accomplished by adding other adsorbents to the treatment process.

SCHEMATIC 4 • Reactor Cooling Status: Cooling by RecirculatingCooling Water

Reactors are maintained in a low temperature stable state through continuous coolingwhich recirculates cooling water and injects it into the reactors



A key element to the success of water managementat Fukushima Daiichi has been the development ofthe Advanced Liquid Processing Systems (ALPS),which can remove 62 different types of nuclides from water to trace levels.

The two systems continue to operate as a pretreatment to ALPS to remove most of the highly radioactive Cesium isotope. Water is first treated in the Kurion/SARRY systems, thensalt is removed in reverse osmosis units, to create water pure enough to recycle back into the reactors for cooling purposes. The excess water is then transferred to ALPS to remove most of the other nuclides except tritium. The need to remove salt stems largely from the saltwater left behind in the buildings by the tsunami, and chloride in the groundwater.

Removal of Water from the Trenches

Highly contaminated stagnant water in the sea-side trenches (Units 2 to 4), which are tunnels connecting seaside facilities and turbine buildings containing seawater pipes andcables, had been removed to prevent them from leaking and the trenches were filled in andsealed with a special concrete by the end of 2015.

ALPS

A key element to the success of water management at Fukushima Daiichi has been the development of the Advanced Liquid Processing Systems (ALPS), which can remove 62 different types of nuclides from water to meet the legally required standards, the main exception being tritium. Development of the system was accomplished in partnership with Toshiba, Hitachi-GE, and the U.S.-based company Energy Solutions.

The objective in developing ALPS was to remove nuclides from the water that had accumulated in storage tanks since the accident (all of which had already been throughthe Kurion/SARRY process to remove gross Cesium, and was being stored in tanks).

As it was a completely new technology that required a significant amount of testing, the introduction of ALPS took place in stages and was not without its challenges. High-integritycontainers (HIC) had to be used to store the waste products generated from the filtrationsystem, early filters and other components had to be modified to withstand the high levels of radiation to which they were subjected, and corrosion was an early problem that had to be overcome.

But through perseverance, the system became operational in 2013, and has gone through three evolutionary stages: Initial ALPS, Additional ALPS, and High-Performance ALPS, the last of which was developed with about $150 million in funding from the Japanese govern- ment and was constructed primarily by Hitachi-GE. The storage of water before treatmentby ALPS, some of which only had Cesium removed, had contributed to an increase the effective dose at the site boundary to 9.76 mSv/year, greatly exceeding the goal of 1mSv/ year (as of the end of FY 2013).[1]

The purification of contaminated water through the combination of the ALPS, Kurion, and SARRY systems have been a major contribution to achieving the goal of reducing theeffective dose at the site boundary to below 1 mSv/year by the end of FY2015.

Although the dose goal had been met, the specific goals for reducing concentrations of each nuclide were not met in every case due to the faster ALPS processing rates. Radiationdose reduction for site personnel and the site boundary was a higher risk reduction priority. Thus ALPS was operated at a less replacement frequency of adsorbents to reduce radiation doses as quickly as practicable in a safe manner.

By November 2018, all the Cesium-Strontium removed water that was being stored in flanged tanks (which were somewhat leak-prone — see the section on storage, below) hadbeen treated, with a high priority both because of that water's level of contamination and also because of the problems associated with the flanged (as opposed to welded) tanks.

About 70% of the ALPS treated water, etc. stored in tanks contains radionuclides other than tritium at the concentration which exceeds legally required standards. Secondarytreatment will be carried out to satisfy the legally required standards for discharge other than tritium, and the amount of radioactive materials including carbon-14 will be reducedas much as possible.

▸ For more information on stored water, go to TEPCO Treated Water Portal
https://www4.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

1 On April 13, 2021, the Government of Japan announced its decision regarding the disposition of treated water being stored at Fukushima Daiichi NPS. Because the policy of discharge into the sea will require some of the treated water to undergo further treatment before it can be discharged, the Government and TEPCO have agreed that the phrase "ALPS treated water" will henceforth be used only to refer to water that has been treated by ALPS *and* meets the stringent standards for discharge. Because this report is primarily concerned with events and activities that took place prior to the adoption of that definition, and because it refers to government and other documents that were issued prior to the adoption of the new definition and which use the phrase "ALPS treated water" more broadly,
this report uses the phrase "ALPS treated water" in the same manner as those documents: to mean water that has been treated at least once by the ALPS system, regardless of whether it may require secondary treatment prior to discharge into the sea.

Removal of Stagnant Water from the Basements of the Buildings

In the reactor building and turbine buildings, stagnant water is a source of contamina- tion. To remove this potential source of contamination, removal of stagnant water from the buildings will be carried out step by step in order to prevent it from leaking. It is also important to ensure that water levels in the basements remain below groundwater levels outside the foundations, so that water from inside the buildings does not flow out as groundwater levels are lowered by the effects of the subdrain, the landside impermeablewall, and paving of the site's surfaces.

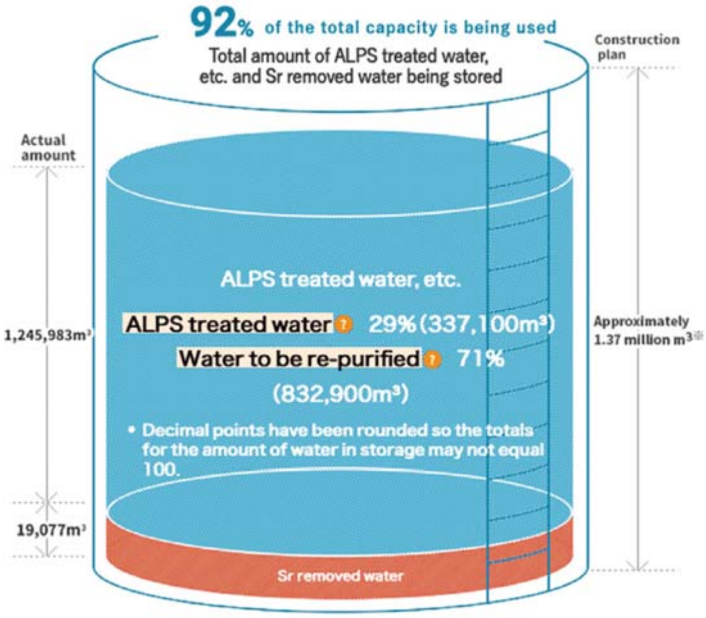
Through those efforts, removal and treatment of stagnant water from the buildings (ex- cluding the reactor buildings of Units 1-3, the process main building (PMB) and the high temperature incinerator building (HTI)), was completed by the end of 2020. For the PMBand HTI, the completion of stagnant water removal and treatment is being preceded by dose mitigation for high-dose zeolite sandbags, which had been placed in the basement floor to absorb Cesium from the water. (The process main building was used in con- nection with solid radioactive waste management prior to the accident.) The amount of stagnant water in the reactor buildings will be reduced to around half of current levels byFY2022–2024.

STORAGE AND CONTAINMENT

ALPS treated water, etc. is being stored in tanks on site. Initially after the accident, tanks had to be built quickly and they were assembled from prefabricated sections fastened together. These "flanged" tanks proved problematic and have now been almost entirely replaced with more durable welded tanks, significantly reducing leakage risks. A very limited number of flanged tanks remain in use for storage of water with very low levels ofradioactivity, such as ground water pumped up from the bypass wells.

In line with a tank construction plan, total tank capacity for ALPS treated water, etc. and strontium removed water was increased to approximately 1.37 million cubic meters by the end of 2020. However, the amount stored in tanks is expected to reach the capacity aroundNovember 2022.

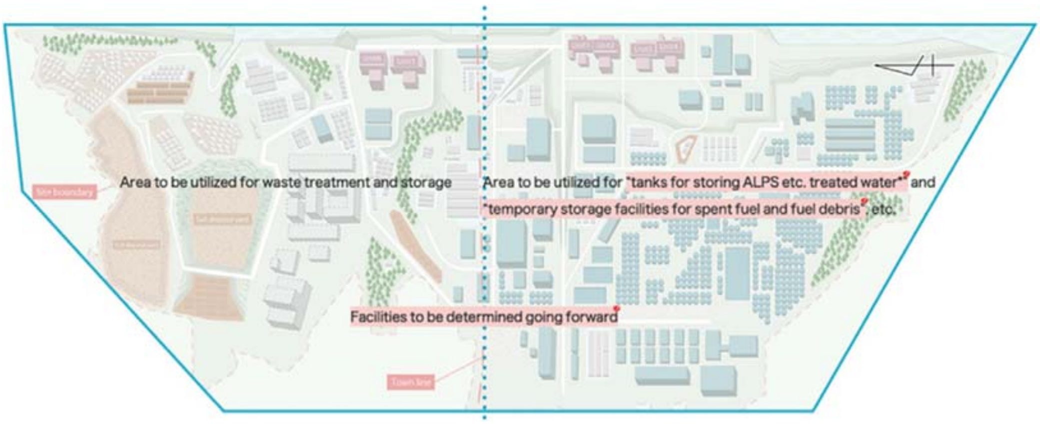
SCHEMATIC 5 • Onsite Storage Tank Water Capacity



As of June 17, 2021

SCHEMATIC 6 • Limitations on Storage Capacity

The illustration shows how the limits of the site's capacity are being reached, and how space isallocated for future storage of not only water but also solid waste, spent fuel and fuel debris.



Storage and Disposition

LONG-TERM CHALLENGES AND OPPORTUNITIES

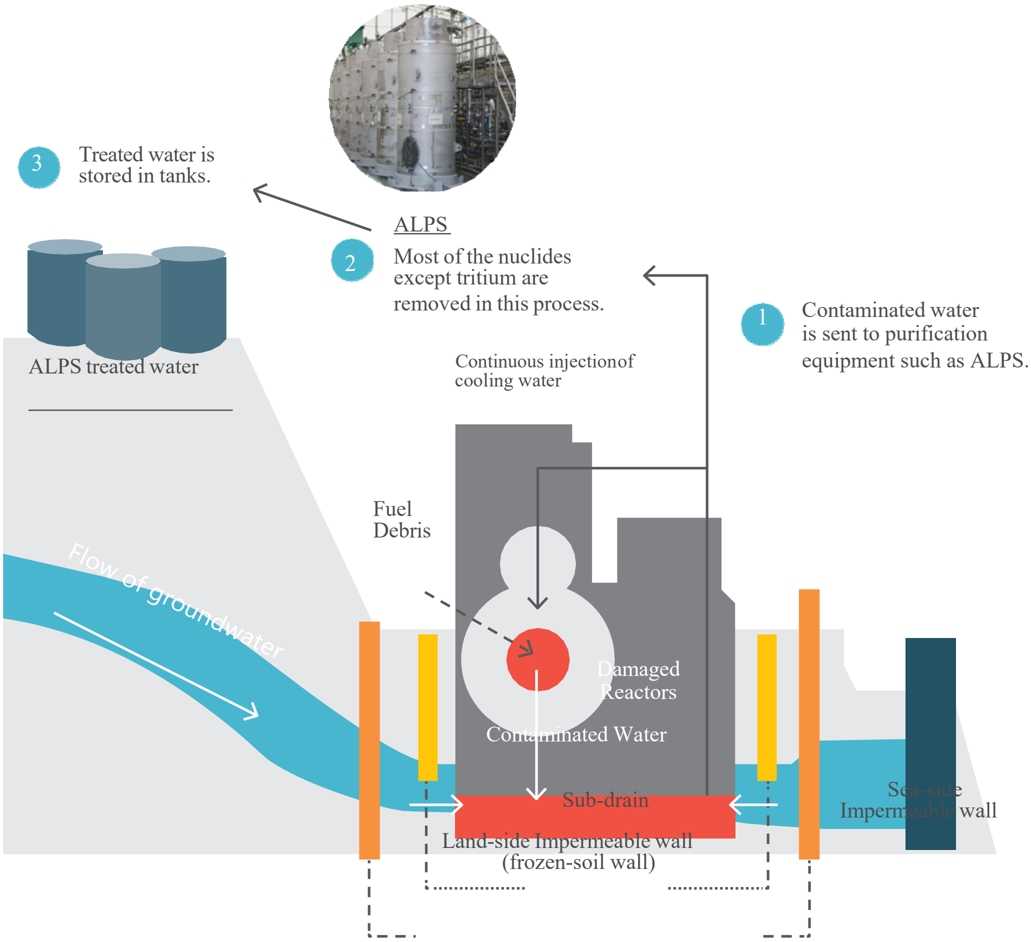
CHALLENGES

As we can see from the preceding sections of this report, the water management challenge since the accident in 2011 has required a wide spectrum of approaches, along with the development of innovative technologies. It is not finished, and indeed the challenge will remain for decades until decontamination and decommissioning ofthe site is fully completed.

Perhaps ironically, a measure of the success of the effort to contain, treat, and safely store water at 1F is the number of tanks that now occupy so much of the facility. But, the amount of space available for storage is finite.

This section of our report summarizes the discussion surrounding the disposal of stored ALPS treated water, starting with a brief description of tritium, discussing the alternatives that were considered for disposal, all disposition options considered including the one selected, and summarizing the steps that TEPCO will take — regardless of which method is used — to safeguard the environment, solicit input frominterested individuals and groups, communicate with the public, and help maintain public acceptance of agricultural and marine products from the Fukushima area.

SCHEMATIC 7 • Simplified Water Flow Diagram at 1F

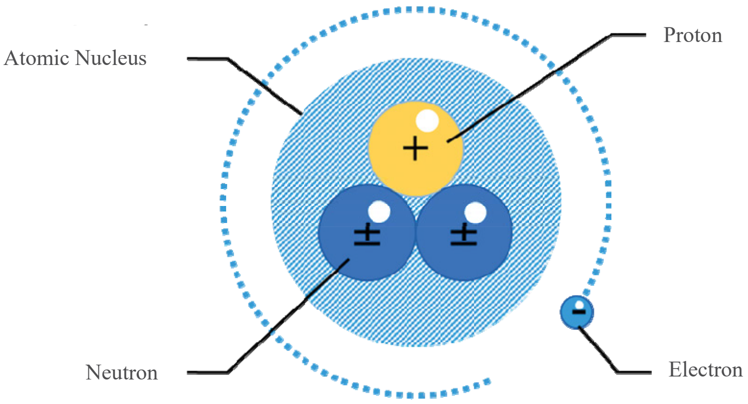


Tritium

The essence of the issue is this: the ALPS treated water contains some tritiated water — that is H_2O with an isotope of hydrogen whose nucleus contains one proton and two neutrons, contrasted with ordinary hydrogen's sole proton. This triple nucleus is what givesit the name "tritium."

Most of the naturally created tritium on Earth comes from cosmic ray interactions high inthe Earth's atmosphere. Anything that contains water will also contain tritium, including the human body and everything we eat. Tritium is also a common feature of nuclear power plant effluent, and there is a long history of handling and disposing of it safely. However, TEPCO recognizes that there is public concern about introducing additional tritium into theenvironment from the ALPS treated water at Fukushima Daiichi, as well as possible trace amounts of other nuclides.

SCHEMATIC 8 • Tritium is a Relative of Hydrogen



Facts About Tritium

What is tritium?

As noted above, tritium is a variant of hydrogen, which in turn is one of the twoelements of water. This water is referred to as "tritiated water."

Does tritium exist naturally?

Yes. It is produced mainly due to reactions in the upper atmosphere between atmo-spheric nitrogen and oxygen atoms and high-energy cosmic rays. Almost all of it becomes tritiated water and falls to earth as precipitation.

Is tritium ever useful?

Tritium has been used in industrial and commercial applications for many decadesto enable such devices as watches and exit signs to be seen in the dark.

Why can't it be removed like all the other nuclides?

Tritium is not a substance that has been added to or dissolved in water. Rather,is simply a type of hydrogen that is part of the water molecule itself. Although recently, researchers have made progress in treating small amounts of tritiated water to remove some amounts of tritium, the Subcommittee report noted that "notechnologies have been judged as being close to practical use at the Fukushima Daiichi NPS."

Is tritium harmful to humans or to the environment?

Tritium contained in water molecules has relatively low impacts on health, comparedto other radioactive materials. The impact of the tritium per Becquerel is less than three hundredth of that of potassium 40, which is a natural nuclide and exists in the human body. As reflected in international and Japanese standards, tritium's impact on human health is about 1/700th of that of Cesium 137, and experiments with mice showed that even when they drink highly concentrated tritium water — far higher concentrations than would ever be discharged into the sea — they did not show elevated levels of cancer.[2]

Is tritium already in the environment?

Yes. The amount of tritium in precipitated water (rain and snow) in Japan is estimatedto be about 223 TBq per year. In addition, tritium is generated in nuclear power plantsand nuclear facilities in and outside Japan as a result of their operations. Most of the tritium produced in these plants is confined to the nuclear reactors, while some is removed from the reactors during maintenance activities such as fuel replacement, and is discharged into the sea, river, lake, and atmosphere in accordance with their country's regulations. The five-year average discharge (before March 2011) from all nuclear power plants in Japan total was 380 TBq/y. Other nuclear facilities, often release more amounts of tritium.

2 "ALPS treated water (Measures for Decommissioning of Fukushima Daiichi Nuclear Power Station)," Ministry ofEconomy, Trade and Industry, Government of Japan, November 2020, p. 17. https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/alpsqa202011.pdf

Remaining Nuclides Other Than Tritium

As of December 31, 2020, about 70 percent of the ALPS treated water, etc. stored in tankscontains radionuclides other than tritium at the concentration that exceeds the legally required standards for discharge. The reasons for this go back to the limitations of early water purification system operations.

For this reason, the subcommittee decided, and TEPCO has agreed, that this water shouldundergo secondary purification to remove these nuclides, thereby enabling the remaining treated water to satisfy the legally required standards for discharge. In its March 2020 response to the Subcommittee, TEPCO said the following.

- After the ALPS treatment of the Strontium-removed water, which has a higher risk as compared to other treated water to be re-purified stored, the adsorbents will be replaced, and a secondary treatment using ALPS will be conducted on a trial basis (in FY2020).
  - About 2,000 m^3 of water with high-concentration (sum of ratios of legally required concentrations of 100 times or above) will be treated, and the secondary treatment performance will be verified.
  - Thereafter, further secondary treatment will be continued while preparing for regular contaminated water treatment and installing receiving tanks.
- Further secondary treatment prior to the start of discharge requires careful study of securing empty tanks, making arrangements for laying pipes and worker exposure andleakage risks involved in decontamination of receiving tanks for re-use.[3]

Both the Subcommittee and TEPCO recognized the importance of this extra step not only to environmental protection but also to preserving public confidence in, and the reputationof, the safety of the Fukushima region and the products it produces.

The secondary treatment performance confirmation tests was carried out in Septemberand October of 2020. The results showed that removal of radionuclides other than tritium satisfy the legally required standards. Although carbon-14 is excluded from the targeted radionuclides and has a sufficiently low concentration, it is conservatively included amongthe legally required standards.

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3 TEPCO Draft Study Responding to the Subcommittee Report on Handling ALPS Treated Water (March 2020), at p. 10. https://www.tepco.co.jp/en/decommission/progress/watertreatment/images/200324.pdf

TABLE 1 • Results of Re-purification Performance Test Sum of ratios of legally required concentrations for nuclides targeted for removal (62 nuclides) + Carbon-14

Group	Before	After
J1-C group	2,406	0.35
J1-G group	387	0.22

▸ For the results of the tests on water treated with multi-nuclide removal equipment, go to https://www.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

Limitations on Storage

Why, some have asked, given the impracticability of removing tritium, can the water not be stored indefinitely? The need to dispose of the water is intrinsically connected to the lim- itations on continued storage. The short answer is that space for on-site storage is running out, off-site storage is extremely problematic, and long-term storage poses risks of its own. This section of our report explores those issues.

As noted earlier in this report, tank construction was increased to a total capacity of about 1.37 million cubic meters by the end of 2020. The tanks are expected to be full around November 2022, and additional space for installing more tanks than currently planned is constrained by the need to use that space for other decommissioning activities.

Transfer to offsite storage was also found impractical, as it would require legally compliant transfer facilities and the approval of municipalities on transfer routes, as well as approval for the new storage site itself. Pipelines to additional sites pose their own complications, as would the use of vehicles or ships to transfer the water for offsite storage. Moreover, the need to dilute the water for shipment would dramatically increase the volume to be trans- ferred and (unless the water were re-concentrated) to be stored, thereby further increasing the need for storage facilities.

In light of these constraints, the only option to continue storage in tanks is to store the ALPS treated water, etc. and strontium removed water on-site using standard tanks in a more efficient arrangement on the ground. Opportunities to do so are extremely limited given the already dense arrangement of the tanks, the need to use other parts of the site for other purposes, and the need to continue various decontamination and decommissioning operations.

OPPORTUNITIES

Various Methods Considered for Disposal

Over the past several years, virtually all possible options have been studied by a special independent subcommittee of experts. Basically, five different methods were consideredfor disposal of the stored ALPS treated water:

- Geosphere injection
- Discharge into the sea
- Vapor release
- Hydrogen release
- Underground burial

Three of these methods were called "unprecedented" by the subcommittee. For geosphere injection, appropriate ground would need to be sought and no monitoring methods have been established. For hydrogen release, new technologies would be needed for pretreatmentand other complications include the potential for a hydrogen explosion. And for underground burial, the problems of vapor release associated with heating and solidification, together withthe challenge of finding an appropriate place for disposal, were considered too daunting.

Thus, the Subcommittee narrowed the options down to the two for which there is practical precedent: evaporation release and discharge into the sea. It acknowledged that both pose challenges of their own, including social concern. Both were studied further, and details on the pros and cons of each approach were discussed in detail inReport of the Subcommittee on Handling of the ALPS treated Water (February 2020),and TEPCO Draft Study Responding to the Subcommittee Report on Handling ALPS Treated Water (March 2020).

Controlled and Monitored Discharge Into the Sea

As noted earlier, tritium is commonly found in nuclear reactors and is disposed of in a carefully regulated and controlled manner. Each nuclear power site worldwide and in Japandischarges effluent containing tritium of tens of billions Becquerels to one hundred trillion Becquerels in a year into the world's oceans, lakes and rivers.

The amount of tritium discharged globally from fuel processing facilities alone is 10,000 TBq or more a year — far more than the entire amount stored at Fukushima Daiichi, whichwould be discharged in diluted form over a span of many years.

TABLE 2 • Results of Assessment of Tritiated Water Task Force

METHOD OF DISPOSAL

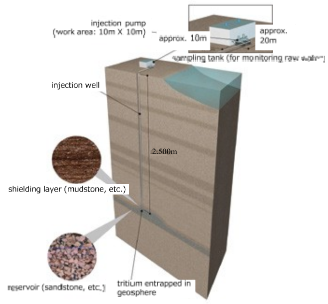
1 Example of Geosphere Injection

Technical Feasibility

- If proper stratum is not found, commencement of handling will be delayed.
- There is no monitoring method established

Regulatory Feasibility

It is necessary to formulate new regulations and standards related to disposal concentration



2 Example of Discharge to the Sea

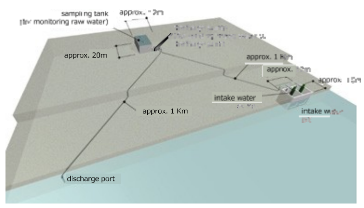
Technical Feasibility

(Examples)

- Existing Nuclear facilities' liquid radioactive waste discharge to the sea

Regulatory Feasibility

Feasible



3 Example of Vapor Release

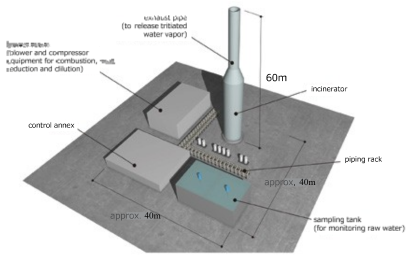
Technical Feasibility

(Example) TMI-2

- Water volume: 8,700 m^3
- Tritium volume: 24 tri. Bq.
  Tritium conc.: 2.8mil. Bq/L
- Total period: 2.8 years

Regulatory Feasibility

Feasible



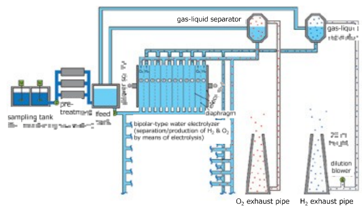
4 Example of Hydrogen Release

Technical Feasibility

To handle the ALPS treated water, R&D for pre-treatment and scale expansion might be needed.

Regulatory Feasibility

Feasible



5 Example of Underground Burial

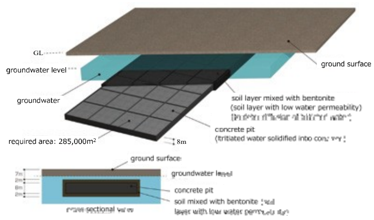
Technical Feasibility

(Examples)

- Concrete pit disposal site
- Shut-off disposal site

Regulatory Feasibility

New standards might be needed.



TEPCO has provided assurance that disposal would be halted immediately if any abnormality is detected.

For Japan, the three year average of the tritium emission records before March 2011 is about 18 to 83 TBq/year for a power station with pressurized-water reactors; about 0.0316to 1.9 TBq/year for a power station with boiling-water reactors; and about 360 TBq/year for all nuclear power stations in Japan. As a result, the concentration in the surroundingsea area ranges between below the detectable limit and 1,100 Bq/L. The processing facility in Japan is licensed to discharge a maximum of 18,000 TBq a year, and the actual
discharge in FY2007 was 1,300 TBq, while changes in the concentration in the surroundingsea area range between below the detectable limit and 1.3 Bq/L.

Groundwater pumped up from the subdrains and groundwater drain also contains a combination of background and plant-related tritium at a level sufficiently below legally required standards for discharge. The operational target concentration for this release is less than 1,500 Bq/L for tritium, which is one-fortieth the legally required standard for
discharge. In March 2020, TEPCO said it would observe the same standard for discharge ofdiluted ALPS treated water into the sea. This standard is significantly more stringent than the World Health Organization's guideline for drinking water, which permits 10,000 Bq/L.

TEPCO has provided assurance that discharge would be halted immediately if any abnormality is detected, and independent monitoring of water quality — already beingundertaken both inside and outside the 1F port area, is expected to be enhanced by an increase in frequency and the number of sampling points, with results published
promptly. In addition, Japan's Nuclear Regulation Authority has said it will be providing careful oversight to ensure safety and environmental protection.

According to the Subcommittee, discharge into the sea has both advantages and disadvan-tages when compared with vapor release:

- Advantages
  - As noted earlier, there is considerable experience with this method, and it can be donewithin the range of preceding practices in Japan and elsewhere.
  - Reliable implementation based on experience.
  - Available monitoring methods.
  - Known and simpler facility configuration, with institutional knowledge.
  - Easier to forecast effects of dilution and diffusion in the sea than in the atmosphere.
- Disadvantage
  - Its potential to cause reputational damage to fishery and tourism in Fukushimaprefecture and surrounding regions.

Control and Monitored Vapor Release

This method would dispose of the water into the atmosphere as vapor. Following secondary treatment, the water would be boiled and the resulting vapor diluted with air before being released. As with discharge into the sea, the process would be halted for any abnormalities, and it would be carefully monitored. The tritium contained in vapor evaporates naturally from the spent fuel pools and others are discharged to theatmosphere through ventilation.

The advantages to this approach include its use in the normal functioning reactors at time of ventilation, and the fact that some precipitated salts and nuclides would remain behind as dried residue. However, that residue would be radioactive waste for which disposal would be required. Vapor release was used after the Three Mile Island accident, though on a smaller scale than would be required at Fukushima Daiichi NPS. It has never been used ata similar scale in Japan.

Disadvantages of vapor release include:

- It is difficult to forecast the vapor's diffusion in the atmosphere, making monitoringmore challenging.
- Variation caused by wind direction and velocity, and by precipitation, are expected tobe greater than with discharge into the sea.
- The diffusion of the vapor over land is expected to influence a wider range of industriesthan discharge into the sea.

Of course, a combination of both methods could be used, but it would result in the expense and management challenges of two different types of disposal facilities, in addition to com- bining both the advantages and disadvantages of each method.

THE SELECTED APPROACH: CONTROLLED AND MONITORED DISCHARGE INTO THE SEA

After an extensive process of weighing the merits of each method, and extensive consultation with scientific experts, affected parties, local communities, the general public, and other governments, on April 13, 2021 Japan's government announced it hadselected discharge into the sea as the preferred method for ultimate disposition of the ALPS treated water.

The government of Japan announced on April 13 its basic policy decision regarding the disposition of the ALPS treated water that is currently being stored at Fukushima Daiichi. The announcement was followed shortly by an official statement from TEPCO. On April 16,TEPCO provided more detailed information on how it plans to move forward.

Government Basic Policy

The decision was the culmination of six years of discussion among the Tritiated Water Task Force and the Subcommittee on Handling of ALPS Treated Water, which included input from affected communities, experts, and others. During that time, various approaches wereconsidered. The construction of more and/or larger tanks would not solve the long-term problem of accumulating amounts of water, and there is inadequate space for additional tanks at the site. Offsite storage also posed logistical and regulatory issues, many of them relating to the transportation of the water over distances.

After those alternatives were considered, two methods remained under consideration:discharge into the sea and vapor release (evaporation). But vapor release ultimately wasalso found to have too many disadvantages:

- Forecasting diffusion and monitoring impact in the atmosphere would be far moredifficult than discharge into the sea
- Variation caused by wind direction and velocity, and precipitation, is far greater than withdischarge into the sea.
- Diffusion of the vapor over land would likely affect a wider range of industries, activitiesthan would discharge into the sea.

Ultimately, discharge of the stored water, after further treatment (where needed) and dilution was found to be the optimal alternative based on considerable experience and having been done within the range of preceding practices, available monitoring methods, and simpler facility configuration and institutional knowledge. The government's policy quoted the International Atomic Energy Agency in noting that controlled discharges into the sea are "routinely used by operating nuclear power plants and fuel cycle facilities in Japan and worldwide."

The government emphasized that before the overall policy can be implemented, TEPCO must obtain the necessary regulatory approval and conduct the discharge operations subject to the Nuclear Regulatory Authority's regulations as well as with the provisions ofthe Reactors Regulation Act.

The policy anticipates that TEPCO will start discharging water into the sea in approximatelytwo years. The water to be discharged will be treated in the ALPS system and "purified until the level of radioactive materials other than tritium satisfies the legally required standards for safety." Because tritium itself (a form of hydrogen) cannot be removed from the water, the water will be diluted more than 100x so that tritium concentrations are the same as theoperational targets for the water currently being pumped from the 1F subdrains and dis- charged into the sea. The scientific consensus is that when diluted, tritium poses very low risks to human health or the environment. This dilution, the policy notes, will also further dilute any trace amounts of other nuclides remaining in the water.

The policy obligates TEPCO to monitor developments in technology to separate tritium prior to discharge, and it requires TEPCO to conduct the entire process in accordance withthe principle of keeping radioactivity "as low as reasonably achievable," known as ALARA.

- Open call for "Technology to separate Tritium from Water Treated with Multi-Nuclide Removal Equipment (ALPS)", go to https://www.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

Reputational and Economic Protections for Fukushima

The plan includes extensive economic protections for Fukushima. Those steps include stringent standards for the discharged water, requirements for reporting and transparencyof data, and independent monitoring and advisory groups. Extended and enhanced monitoring of water quality, specifically for tritium, will be carried out at fishing grounds, swimming beaches, and other locations.

The policy also provides for significant economic and reputational initiatives for the Fukushima region, fishermen, agricultural products, as well as an effort to enhance the public's understanding, control the spread of false rumors, and reach out to othergovernments. Nevertheless, the policy states, "if reputational damage occurs, the Government will require TEPCO to provide rapid compensation in a form that functions asa safety net."

In a statement issued the same day as the Government's policy, TEPCO said it takes the matter "very seriously" and "will strictly comply with all laws and regulations . . . while also thoroughly implementing measures to minimize the adverse impacts on reputation."The company promised prompt and transparent communication both within Japan and internationally.

TEPCO's statement concluded: "As the party responsible for the Fukushima Daiichi Nuclear Power Station Accident, TEPCO will strive to regain trust in our business endeavors, and in accordance with our fundamental principle of 'balancing recovery withdecommissioning,' move steadily forward with the decommissioning of the Fukushima Daiichi Nuclear Power Station, contaminated water and treated water countermeasures,while prioritizing safety."

TEPCO Action Document

On April 16, TEPCO issued its "Action in Response to the Government's Policy on the Handling of ALPS Treated Water." The action document provides additional detail on the design and operation of the facilities to be used in the discharge of ALPS treated water, including secondary treatment facilities to ensure the water has been adequately purified,emergency measures to stop the discharge if necessary for any reason, facilities to dilute the water to the required levels, and mechanisms for analyzing the water.

The document extensively addresses environmental monitoring, including the monitoring of not only water but also fish and seaweed. It also provides for objectivity andtransparency of monitoring activities to be ensured by IAEA, local governments, and an expert committee.

The action document also addresses the component of the government's policy concerning protection for the people of Fukushima from the economic and other impactsof potential reputational damage related to the discharge program. It aims ; to foster understanding through effective international and domestic communication; to promote the distribution and consumption of agricultural, marine, and forestry products of Fukushima; and, if necessary, to provide compensation for reputation-related damage.

Further Resources (in English) Regarding Disposition of theALPS Treated Water:

Government of Japan Basic Policy April 13:

https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/bp_alps.pdf; presentation deck,

https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/202104_bp_breifing.pdf

https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/pr_bpalps.pdf

TEPCO Statement April 13:

https://www.tepco.co.jp/en/hd/newsroom/announcements/archives/2021/20210413_01.html

TEPCO Media Release April 16:

https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210416_01.html

TEPCO April 16 Action Plan:

https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210416e0101.pdf; presentation deck,

https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210416e0102.pdf

Fukushima Daiichi Treated Water Portal:

https://www.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

Implications and Timetable

Implications

The radiation implications of the decision are believed to be minimal. Exposure impact has been studied for discharge into the sea, and if the total amount of the ALPS treated water stored in the tanks were disposed of every year, the impact would be no more than one-hundred thousandth of the exposure impact of natural radiation (2.1 mSv/year). Theseestimates are based on the results of a tritium dispersion simulation.

The area in which tritium exceeds the background level (1Bq/L) will be limited to 2km from Fukushima Daiichi, and even in that area, the concentration (1 to 10Bq/L) is a maximum one-thousandth of the WHO drinking water guideline (10,000 Bq/L).[4]

TEPCO also plans to conduct fish-feeding tests to provide empirical evidence regarding the radioactivity within ALPS treated water as part of environmental monitoring. TEPCO will ask for the cooperation and support of experts and those involved in the fishery industry,and will report on the status and results of testing.

Timetable

Decisions remain to be made with respect to the timing and duration of the process. On theone hand, there is a desire to advance the process steadily, and a recognition that as time passes, the overall volume of water to be stored continues to grow. Delay also increases therisk of leaks caused by natural disaster or other problems. On the other hand, it is import- ant to build public confidence by not appearing to rush the process, and by taking into account the views of all interested parties.

In its April 16 action document, TEPCO is committed to steadily completing the decommissioning of Fukushima Daiichi and to providing a concrete plan based on the Mid-and-Long-Term Roadmap. For the next two years, activities will be focused on preparation for the beginning of discharge, including obtaining the necessary regulatory approvals.

Preventing Reputational Damage

Mindful of the negative impact that the March 2011 accident has had on fisheries and agri- culture, etc. in Fukushima Prefecture and surrounding regions, a great deal of attention is being paid to initiatives designed to prevent, or at least limit, similar reputational harm that might result from public anxiety or misunderstandings about the health and environmentaleffects of the discharge of stored water.

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4 “Basic policy on handling of the ALPS treated water,” Ministry of Economy, Trade and Industry, April 13, 2021, pp. 14–15;see also, TEPCO Holdings’ Action in Response to the Government’s Policy on the Handling of ALPS Treated Water, April 16, 2021, p.9 n.5.

These efforts are still in their developmental stage, and some will depend on the particulardischarge method chosen. In general, they are expected to include the following:

- Technical and Operational
  - Effective public understanding about tritium
  - Recognizing, and emphasizing, the importance of secondary treatment for removal ofnuclides other than tritium prior to discharge
  - Effective monitoring of the process including ability to stop operations if necessary(e.g., standards exceeded, operational malfunction, etc.)
- Commercial
  - Expanding purchases of Fukushima products by TEPCO itself
  - Supporting use of Fukushima products among members companies of "FukushimaOKnet," which was established in November 2014 by 11 companies to promote Fukushima products, tourism, and public education. As of April 2021, it had grownto 159 companies.
  - Promoting Fukushima products in the restaurant industry, retail, and masssales industries.
  - Examining ways to collaborate with people aiming to develop Fukushima's agriculture and fisheries industry
  - Examining ways to add higher value to Fukushima products (branding)
  - Consumer confidence measures, such as Marine Eco-Label, rice inspection.
- Communication with overseas
  - IAEA Director General Rafael Mariano Grossi visited 1F in February 2020. In his statements, he expressed that two options, such as discharge into the sea and vapor release, for discharge of the treated water will be technically feasible and in line with the international practice and also IAEA would be ready to assist in its implementation,for example in radiation monitoring for helping provide reassurance to the public.
  - TEPCO jointly with METI have briefing and 1F site tour to foreign press proving information about progress of decommissioning, including water issues.

Conclusion

A CONTINUING COMMITMENT

As we have seen, the main near-term objectives of the water management effort have been achieved: reduction of the radiation dose, creation of safer and more pleasant working conditions, and protection of the environment. But the challenge of water management will remain with us until the goal of full decommissioning is attained. TEPCO is committed to working steadfastly and safely towards that goal, and to maintaining effective and environmentally sound water management practices throughout that time.

TEPCO is also committed to continuing the extensive efforts it has been making to reach out to the communities surrounding Fukushima Daiichi, as well as other groups and com-munities in Japan and elsewhere, to keep people informed about what is happening and to receive and carefully consider the viewpoints of many different people.

TEPCO wishes to express its appreciation to the thousands of workers and the many contractors and subcontractors who have worked diligently to meet the challenge, as well as the many researchers and innovators whose contributions have been invaluable. We continue to recognize our unique responsibilities after the March 2011 accident, and to remain committed to a safe and thorough decontamination and decommissioning, as well as to the revitalization of Fukushima.

RESOURCES

TEPCO Treated Water Portal
https://www4.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

METI ALPS Portal
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/atw.html

Development of the Frozen-Soil Wall
https://www.tepco.co.jp/en/decommision/planaction/landwardwall/index-e.html

Stored Water
https://www4.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html

Report of the Subcommittee on Handling of the ALPS treatedWater (February 2020)
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20200210_alps.pdf

TEPCO Draft Study Responding to the Subcommittee Reporton Handling ALPS Treated Water (March 2020)
https://www.tepco.co.jp/en/decommission/progress/watertreatment/images/200324.pdf

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https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/bp_alps.pdf; presentation deck,
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/202104_bp_breifing.pdf
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/pr_bpalps.pdf

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TEPCO April 16 Action Plan
https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210416e0101.pdf;presentation deck,
https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210416e0102.pdf