Provisional Translation

Radiological Environmental Impact Assessment Report Regarding the Discharge of ALPS Treated Water into the Sea

(Construction stage / Revised version)

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Tokyo Electric Power Company Holdings, Inc.

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Executive summary

This report compiles the results of the assessment of the radiological impacts on humans and the environment resulting from the discharge of the water treated by the Advanced Liquid Processing System (“ALPS”) Multi-Nuclide Removal Facility (hereinafter “ALPS treated water”) from the Fukushima Daiichi Nuclear Power Station (hereinafter “FDNPS”) into the sea in accordance with the standards and guidelines established by internationally recognized organizations such as International Atomic Energy Agency (hereinafter “IAEA”) and International Commission on Radiological Protection (hereinafter “ICRP”).

This report first describes how contaminated water has been generated, managed, treated, and stored as a result of the accident of FDNPS following the Great East Japan Earthquake in 2011, and what efforts are ongoing to ensure public and environmental safety (Chapter 1).

Next, the report describes how several proposals for handling of ALPS treated water were discussed among experts for more than six years since the potential risk associated with the storage of contaminated water became apparent in 2013 (Chapter 2). The report goes on to discuss the objectives (Chapter 3) and concept (Chapter 4) of this radiological environmental impact assessment in line with the proposed Basic Policy for the treatment, dilution and controlled and monitored discharge of ALPS treated water. Chapter 5 discusses the quality and characteristics of ALPS treated water, etc., the planned method of discharge, and the overview of the discharge facility.

Subsequent chapters 6 and 7 describe the assessment of the radiological environmental impacts on humans and marine plants and animals. Each chapter details the concepts of source term, modeling of diffusion and transfer in seawater, exposure pathways, and establishment of representative persons and reference animals and plants, which align with international standards for radiological environmental impact assessment. The results of the sea diffusion simulation conducted indicate that the concentration of radioactive materials exceeds the background level only within a few kilometers of sea area around the FDNPS because the discharged ALPS treated water is quickly advected and diffused by tidal currents, etc. (Details can be found in “the Summary of Evaluation” and Chapter 6-1-3.(1) “Diffusion simulation result”).

The results of the assessment of the radiological environmental impacts obtained by in-house and external experts based on the above-mentioned reasonable and conservative assumptions indicate that (1) in the case of discharge of ALPS treated water from the seabed approximately 1km offshore from the FDNPS, the foreseeable radiological impact on the people who are most likely to be affected in the vicinity of the discharge point is minimal, specifically, the exposure level is assessed to be approximately 1/500,000 to 1/30,000 of Japanese safety standard set according to the international guidelines; (2) the exposure level on plants and animals inhabiting the 10km x 10km sea area around the FDNPS is only about 1/30,000,000 to 1/1,000,000 of the lower limit of the exposure range proposed by ICRP as the threshold at and below which reference marine biota is not expected to suffer deleterious effects from exposure (derived consideration reference level); and (3) the impact on areas far from the discharge point (transboundary impact) was evaluated to be undetectably low. This indicates that advanced water treatment by ALPS and the discharge plan to effectively use the period of time required for decommissioning will restrain the impacts on humans and the marine ecosystem, and the impacts will be well within Japan’s regulatory standard in accordance with the internationally established safety guidelines.

Chapter 8 describes the considerations related to uncertainties in the assessments described above. It concludes that considering uncertainties does not impair the conservatism of the assessment.

Chapter 9 describes the monitoring plan to be implemented in conjunction with the discharge of ALPS treated water into the sea. This includes an enhanced and expanded monitoring plan that includes increased sampling points, target of measurement and frequency. This monitoring plan beyond the comprehensive monitoring plan that has been ongoing since the 2011 Earthquake is regarded as appropriate based on the results of the radiological environmental impact assessment conducted up to Chapter 7.

In preparing this report, TEPCO has invited external experts from domestic institutes and universities to review and provide comments in the three fields of human radiation protection, environmental protection, and ocean diffusion calculation.

In November 2021, TEPCO published a design stage radiological impact assessment report (a previous iteration of this report, containing assessments based on the information available at the design stage of the plan for discharging diluted, ALPS treated water into the sea). In April 2022, the report was reviewed and revised based on the progress of TEPCO’s study, opinions received through the public comment survey, review by a Task Force of the IAEA, and discussions with the Japanese Nuclear Regulation Authority. In November 2022, in light of these discussions and the advancement to the construction stage, TEPCO published the updated radiological environmental impact assessment report with revised source term. This report was further revised based on second review by the Task Force of the IAEA and re-discussions with the Japanese Nuclear Regulation Authority after November 2022.

Before discharging ALPS treated water, TEPCO will analyze the radionuclides contained in the ALPS treated water which is pre-diluted and publish the results. In addition, during the initial period of discharge into the sea, TEPCO will also contemporaneously publish monitoring data relating to the conditions of mixing and dilution prior to the discharge into the sea. Moreover, for discharge into the sea, the plan is to start the discharge with a small amount of discharge, while monitoring the impact on the surrounding environment, etc. In the unlikely event of a malfunction of the dilution facility due to trouble, power failure, or other reasons, or if abnormal value is detected by the enhanced monitoring regime implemented after the start of discharge, TEPCO will immediately stop discharging until it is confirmed that the conditions have been established for safe discharge and will make every effort to ensure the safety of human and marine plants and animals.

Even after the commencement of discharge, TEPCO plans to further review the assessment and revise this report as necessary to reflect the progress of studies on implementation, opinions from various sectors, and the knowledge obtained through cross-checks by third-party assessments. If necessary, TEPCO will also reflect them in the discharge plan.

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Overview of the assessment

As a basis for the radiological environmental impact assessment contained herein, TEPCO conducted two categories of dose assessments of the expected exposure and impact of the planned discharge of diluted ALPS treated water. The first dose assessment examined exposure and impact to human health and safety. This study (excluding potential exposure[1]) was planned and implemented in accordance with the specific procedures prescribed by the IAEA safety standard document GSG-9 “Regulatory Control of Radioactive Discharges to the Environment” [1] (hereinafter called “GSG-9”) and the IAEA safety standard document GSG-10 “Prospective Radiological Environmental Impact Assessment for Facilities and Activities” [2] (hereinafter called “GSG-10”). Although GSG-9 does not require the assessment of the potential exposure, TEPCO also assessed potential exposure in accordance with GSG-10. The second dose assessment examined impact on the environment, i.e. biota, in accordance with the guideline of GSG-10. The result of these assessments finds that advanced water treatment by ALPS and the discharge plan that effectively utilizes the decade-long decommissioning period will restrain the impact of discharge of ALPS treated water into the sea on humans and marine plants and animals, and will keep within the domestic safety standard determined in accordance with the internationally established safety guidelines.
In compiling this report, in-house experts with knowledge on the radiological environmental impact assessments were selected and assigned, and external experts were invited as members to submit their opinions in three fields of human radiation protection, environmental protection, and marine diffusion calculation.
In this report, the studies conducted by the government on handling of ALPS treated water and enhancement and expansion of future monitoring are also taken into account.

Assessment of radioactive nuclides and diffusion

TEPCO has conducted multiple assessments of diffusion patterns and exposure pathways of ALPS treated water after once discharged. Initial assessments in design stage included a broad source term of 64 nuclides that include 62 nuclides, which were selected to be removed by ALPS from stagnant water in buildings as of December 2011 following the 2011 Earthquake, carbon-14 (C-14) and tritium (H-3). Stagnant water pumped up from buildings on the premise of FDNPS was treated by water treatment facilities such as ALPS and stored in tanks. Composition of radioactive nuclides in each tank group[2] or each tank differs depending on the composition and concentrations of radioactive nuclides in stagnant water

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[1] Potential exposure: Exposure caused by possible events in operation or events or possible events sequences including accidents of radiation sources or failures and operation mistakes of equipment. It was considered for the future.

[2] Multiple tank groups used in connection. Usually, 1 tank group consists of about 8 to 10 tanks.

before the treatment, and lifetime of each adsorbent at the time of treatment in water treatment facilities. The compositions in three distinct tank groups, in which measurement and assessment of concentrations of 62 nuclides subject to removal by ALPS, tritium (H-3) and carbon-14 (C-14) were completed, were selected as the compositions for these assessments.

In this revised report of the construction stage, in light of reviews by a Task Force of the IAEA and discussions with the Japanese Nuclear Regulation Authority, TEPCO updated the assessment based on less broad but more realistic source term of 30 nuclides (including tritium). These nuclides were selected to confirm that nuclides which are not present in ALPS treated water but significantly present or may be present in the stagnant water or strontium removed water (i.e., water before ALPS treatment) in the ALPS treated water satisfy the discharge criteria (see 6-1-2(1) for details). Prior to discharge and dilution of ALPS treated water into the sea, the water will be sampled, and 29 nuclides other than tritium in the sampled water will be measured and assessed to ensure that the concentrations of these nuclides are less than regulatory concentration limits. At the same time, other nuclides subject to removal by ALPS will be measured and assessed voluntarily (see Attachment I “Rationale behind the selection of nuclides measured and assessed for discharge of ALPS treated water into the sea”, for the rationale behind the procedure of selection of 30 nuclides (including tritium) to be measured and assessed before discharge of ALPS treated water into the sea by estimating the amount of radioactive materials in the stagnant).

According to the Japanese regulatory standard based on the internationally recognized guidelines specified by ICRP [3] , it is stipulated that that the sum of the ratios of concentrations to the regulatory concentration limits[3], which are the regulatory standards, (hereinafter called “the sum of the ratios to regulatory concentrations limits”[4]) should be less than 1 after dilution with seawater at the discharging point. However, TEPCO have decided to minimize the amount of radioactive materials discharged into the environment as much as possible by appropriately treating nuclides other than tritium using water treatment facilities including ALPS, and confirming the sum of the ratios to regulatory concentrations limits less than 1 before dilution. In other words, we will not only confirm that the results of the individual assessments of radioactive nuclides such as cesium 137 (Cs-137) and iodine 129 (I-129) are below the regulatory standards, but also manage to ensure never to exceed the regulatory

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[3] The regulatory concentration limit is the standard of discharge of radioactive waste into the sea set for each radioactive nuclide in “Pronouncement which set the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials.” If a person drinks 2L of water equivalent to the regulatory concentration limit every day all their life (for 70 years in the case of an adult), the annual exposure dose will be 1 mSv/year.

[4] Sum of the ratios to the regulatory concentration limits, which are legal concentration limits specified for each nuclide in the case that multiple radioactive materials, are contained. If multiple radioactive materials are contained, the sum of the ratio to the concentrations to the regulatory concentration limit specified for each nuclide by laws must be less than 1.

standards even when the overall effect of the overlapping effects of all those multiple radionuclides is taken into account.

Tritium is an isotope of hydrogen. In most cases, it exists as the molecule, which is one of the two hydrogen atoms in normal water molecule (H_2O) replaced by one tritium atom (HTO in chemical formula). The tritium concentration in the water stored in the tanks exceeds 60,000 Becquerel[5] (Bq)/L, which is the regulatory standard value (regulatory concentration limit), even after treatment by ALPS, etc., and tritium is almost impossible to remove, so the water will be diluted until it meets the regulatory standard. In addition to strict compliance with regulatory standards to protect the public, the government required TEPCO to ensure that the tritium concentration of ALPS treated water at the point of discharge does not exceed 1,500Bq/L[6], which is significantly lower compared to the level of regulatory concentration limit, in order to dispel any concerns of consumers and others and to control reputational effects to the maximum extent possible. In “TEPCO Holdings’ Action in Response to Government’s Policy on the Handling of the ALPS Treated Water from the Fukushima Daiichi Nuclear Power Station” (hereinafter called “TEPCO’s Action in response to Government’s Policy,”) we stipulated that we will keep the tritium concentration in the discharged water less than 1,500Bq/L and set the upper limit of the annual discharge amount 22 TBq[7] (2.2E+13Bq)[8]. To keep the tritium concentration in the discharged water less than 1,500Bq/L, the ALPS treated water will be diluted with seawater at least 100 times or more (at most 1,400 times or more considering the maximum measured tritium concentration of approximately 2.16 million Bq/L in the water stored in the tanks measured so far) before discharge.

The concentration of nuclides other than tritium in the ALPS treated water is already below the regulatory standard even before the dilution. The concentration will be further reduced by dilution with seawater. Therefore, the sum of the ratios to regulatory concentrations limits of nuclides other than tritium in discharged water after seawater dilution is less than 0.01, and the impact of radiation will be further reduced (for details, see 5-2).

The diffusion calculation for the discharged water into the sea area was executed by the high resolution model of the sea area near the FDNPS, based on the model [4] whose reproducibility had been verified by the reproduction calculation of the cesium concentration in the seawater after the accident of the FDNPS (for details, see 6-1-2.(2)). For the assessment, only the radiation amount per unit time of tritium released (flow rate and

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[5] Unit indicating the amount of radiation. Becquerel is the number of nuclei whose radioactive nuclide changes into another one by radioactive disintegration in one second.

[6] It is set to the same value as the operation target value of the discharge concentration of the groundwater bypass and subdrain, through which water has been discharged. This value has been described in “Implementation plan III 3.2.1 Management of radioactive waste, etc.” and permitted by the Nuclear Regulation Authority.
The tritium concentration of 1,500Bq/L is 1/40 of the regulatory concentration limit of 60,000Bq/L and about 1/7 of 10,000Bq/L, which is the WHO Guidelines for Drinking Water Quality.

[7] Target discharge control value of the FDNPS before the accident.

[8] E+XX means the XXth power of 10. 2.2E+13 indicates 2.2×10^{13}.

concentration are not considered) is used in the diffusion calculations. Therefore, the effect of dilution, which further reduces exposure, is not considered in this highly conservative assessment.

In this assessment, the concentration of radioactive materials in seawater does not take into account the decrease in dissolved concentration through absorbance of radionuclides to seabed and other materials. On the other hand, the concentration of radionuclides in fish, shellfish and seabed sediment assumed to be in equilibrium with the concentration in seawater after the adsorption, etc. (no further adsorption occurs). Also it is assessed using concentration coefficient and concentration ratio including the impact to the food chain. In reality, it takes a long period of time for radionuclides in seawater, fish and shellfish and seabed sediment to reach an equilibrium, however by using conservative assumptions mentioned above, this model verifies that there is no further increase in exposure to humans, fish and shellfish even if the discharge continues for a long time. This assessment actually verified the impact for a year of discharge of ALPS treated water, and it can also verify accumulation of radioactive materials in the environment for long term discharge (For details, see 4.(3)).

Human exposure pathways

In the setting of exposure pathways, they are roughly divided into external exposures and internal exposures. In line with previous practice, etc.[9], external exposures were assessed assuming the following five pathways: (1) external exposure from the sea surface, (2) external exposure from ship hulls, (3) external exposure under water during swimming, etc., (4) external exposure from beach sands, and (5) external exposure from fishing nets. Internal exposure was assessed assuming the following three pathways: (6) internal exposure from ingestion of seawater, (7) internal exposure from inhalation of seawater spray, and (8) internal exposure from ingestion of seafood (for details, see 6-1-2.(3)).

The exposure pathway to humans is set with an assumption of a representative person in vicinity of the discharge point who are considered most affected. For the living habits and characteristics of the representative person for some exposure pathways should be used the highest group (e.g. 95 percentile value) from some lifestyle data distribution, etc. However, in considering the current situation around FDNPS, we have instead assumed the representative persons are engaged in fishing for 120 days a year (2,880 hours), of which they work near fishing nets for 80 days (1,920 hours), stay on the seashore for 500 hours, and swim for 96 hours, according to “Dose Assessment to the General Public in the Safety Review of Commercial Light Water Reactor Facilities” [5]. Following the preconditions, the ingestion amount of seafood was investigated for two cases based on the ingestion amount

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[9] Handbook for Determining Environmental Impacts of Decommissioning Work, etc. For details, see Chapter 6.

data from “National Health and Nutrition Survey in Japan in 2019” [6] for each of (1) person who ingest an average amount of seafood and (2) person who ingest more seafood than average (one fifth of the amount of an adult for an infant, and half of the amount of an adult for child under school age) (for details, see 6-1-2.(4)).

The result of the assessments was compared with the dose limit[10] of 1mSv/year for the general public, and the dose constraint[11] of 0.05 mSv/year established by the Nuclear Regulation Authority, and the sum of internal and external exposure was below both the public dose limit and the dose constraint in all cases[12]. The dose limit of 1 mSv/year is the internationally recognized standard of public exposure (for details, see 6-1-3).

In addition, the potential exposure assessment based on the IAEA safety standard[13], which was also conducted, assumed that (1) in case of leakage from the piping, a piping rupture occurs near the ocean and all the ALPS Treated Water about 10,000 m^3 in one group of tanks at the facility for measurement and confirmation of water is discharged from north breakwater into the ocean for 20 days without being diluted, as well as (2) the case of massive leakage from tanks, all three groups of tanks for measurement and confirmation are damaged simultaneously due to great earthquake, etc. and of 30,000 m^3 of ALPS treated water is discharged into the sea in a single day. In this case, the migration pathways and exposure pathways of this case will be the same as for normal exposure excluding for the discharge location near the north breakwater. The exposure time of leakage from piping is conservatively set to about one month (27 days), and about one week (8 days) in the case of massive earthquake. As a result, even in such cases, the effective dose of potential exposure was significantly smaller compared to the standard of the accident assessment shown in the IAEA safety standard[13] (for details, see 6-2).

Impact on marine plants and animals

As the assessment of environmental protection, we also assessed the protection of plants and animals during normal operation of the facility for discharging ALPS treated water according to the procedure shown in Annex I of the IAEA safety standard[13]. As the composition of nuclides in ALPS treated water used in the assessment, three cases based on the measured values were adopted in the same way as the human exposure assessment.

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[10] Dose limit: Effective dose or equivalent dose to a person which must not be exceeded in the planned exposure situation (GSR Part 3).

[11] Dose constraint: Predictive value of individual dose related to radiation sources used as a parameter for the optimization of protection and safety at the radiation source in planned exposure situation. It is useful as the boundary for setting of the range of options in optimization. For public exposure, this is a value related to the radiation source established or approved by the government or regulatory body considering the dose from planned handling of all radiation sources under control (GSR Part 3).

[12] The dose limit is the limit for the total of the exposure amount of an individual from all related acts subject to the regulations. The dose constraint is used as the limit value of the dose from a specific radiation source related to a planned act.

[13] GSG-10

As the plants and animals to be assessed, the standard flatfish (left-eyed and right-eyed flounders), the standard crabs (Ovalipes punctatus and Portunus trituberculatus) and the standard brown seaweeds (sargassum and Eisenia bicyclis) were selected from the list of standard animals and plants[14] indicated in the guidelines of the ICRP. The dose was assessed using the method shown by ICRP and the dose rate in the habitat of the standard animals and plants was compared with the derived consideration reference level (DCRL)[15]. As a result, all dose rates in the habitats of the standard animals and plants are much less than the lower limit value of the derived consideration reference level (for details, see Chapter 7).

As an additional precaution, the evaluation results of environmental impact from the factors other than radioactive materials from the ALPS treated water reveal that there is no severe pollution or no serious and hazardous changes to the environment (for details, see Reference D “Assessment result of environmental impacts including other elements than radiation related to discharge of ALPS treated water”).

Changes in response to new information and the result of monitoring

The assessment described in this report was originally conducted based on the information available in November 2021 during the design stage of the plan for discharge into the sea. Subsequently, in April 2022, it was revised based on the assessment reflecting the comments received from the public, comments pointed out by the Nuclear Regulation Authority, the findings of review by the Task Force of the IAEA, etc. In November 2022, in light of the progress of construction work, the previous review by the Task Force of the IAEA, and discussions with the Nuclear Regulation Authority, TEPCO selected the nuclides to be measured and assessed for the discharge of ALPS treated water into the sea, reviewed source terms, and revised the assessment as that of the construction stage. This report is partially revised based on the subsequent discussions in the second review by the Task Force of the IAEA and with the Nuclear Regulation Authority.

Before discharging ALPS treated water, TEPCO will analyze the radionuclides contained in the ALPS treated water which is pre-diluted and publish the results. In addition, during the initial period of discharge into the sea, TEPCO will also contemporaneously publish monitoring data relating to the conditions of mixing and dilution prior to the discharge into the sea. Moreover, for discharge into the sea, the plan is to start the discharge with a small amount of discharge, while monitoring the impact on the surrounding environment, etc. In the unlikely event of a malfunction of the dilution facility due to trouble, power failure, or other reasons, or if any abnormal value is detected by the enhanced monitoring regime

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[14] Standard animals and plants: Specific types of animals and plants assumed in order to associate radiation exposure from the environment with the dose and impact.

[15] Derived consideration reference level (DCRL): Range of the dose rates within a range of one digit specified for each species advocated by ICRP. Dose rate level at which the impact has to be considered if is exceeded.

implemented after the start of discharge, TEPCO will immediately stop discharging until it is confirmed that the conditions have been established for safe discharge and will make every effort to ensure the safety of human and marine plants and animals.

This report concludes that the result of the assessment according to internationally recognized documents shows that exposure from radioactive materials contained in ALPS treated water discharged from the FDNPS is significantly lower than the dose limit, the dose constraint and the derived consideration reference level.

Even after the commencement of discharge, TEPCO plans to further review the assessment and revise this report as necessary to reflect the progress of studies on implementation, opinions from various sectors, and the knowledge obtained through cross-checks by third-party assessments. If necessary, TEPCO will also reflect them in the discharge plan.

1. Background

At the FDNPS, which experienced an unprecedented accident in the event of the Great East Japan Earthquake in 2011, it has been continued to inject cooling water into the reactor in order to cool the damaged reactor and nuclear fuel since the accident. The injected water comes into contact with so-called fuel debris, which is fuel overheated, damaged, and molten in the event of the accident, and then solidified together with surrounding structures, passes through the reactor pressure vessel and reactor containment vessel damaged by the accident, and finally got stagnant on the lowest floor of the reactor building as building stagnant water (hereinafter called “stagnant water”). According to the previous investigation, it has turned out that stagnant water contains damaged fuel and structures of reactor core due to the damage in the event of the accident, or a high volume of water-derived radioactive materials, which are reactor coolants. From the viewpoint of prevention of diffusion of radioactive materials into the environment, it is especially necessary to prevent leakage of stagnant water outside the building.

On the other hand, seawater entered the basement floor of the building due to the tsunami, which was the direct cause of the accident, and then became stagnant water. In addition, rainwater has been entering the building through the ceiling damaged due to debris scattered by the hydrogen explosion of the reactor buildings that occurred in Units 1, 3, and 4 in the event of the accident. Moreover, the underground water level around the building is kept a little higher than the stagnant water level to prevent leakage of stagnant water mentioned above, which cause a little amount of groundwater to enter the building. It is considered that all of such water is mixed with the cooling water mentioned above and becomes new contaminated water.

Currently, by multilayered countermeasures[16], we manage to prevent leakage of contaminated water out of the building and also reduce the daily generated amount from about 540 m^3 (as of May 2014) to about 130 m^3 (as of 2021), and we are aiming to further reduce the daily generated amount to less than 100 m^3 by 2025. The contaminated water which will be generated in future must be treated in the same way and discharged appropriately.

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[16] Examples of multilayered countermeasures:
- a To reduce the generated amount of contaminated water, contaminated water pumped and purified by the cesium adsorption device and desalinated by the reverse osmosis membrane device is reused as cooling water used to cool the nuclear fuel damaged by the accident.
- b In addition, the amount of groundwater entering the building is controlled. Specifically, the groundwater level near the building is kept low by pumping groundwater from uplands and the area adjacent to the building, installing land-side impermeable walls (frozen soil walls) around the building, etc.
- c To prevent leakage of contaminated water generated in the building to outside the system, the contaminated water level in the building is kept a little lower than the groundwater level outside the building by pumping contaminated water in the building.
- d Pumped contaminated water is stored in tanks installed on uplands after treatment by water treatment facilities which consist of the cesium adsorption device, ALPS, etc., in order to prevent contamination and reduce the dose.

Contaminated water is purified by the cesium adsorption equipments[17] and ALPS, which can remove 62 nuclides, and stored in tanks on the site. ALPS treatment makes the sum of the ratios to regulatory concentrations limits of 29 nuclides other than tritium less than 1 (water in which the sum of the ratios to regulatory concentrations limits of nuclides other than tritium is less than 1 is called “ALPS treated water.” Water in which the sum of the ratios to regulatory concentrations limits is not less than 1 even after treatment is called “treated water to be purified.” “ALPS treated water” and “treated water to be purified” are collectively called “ALPS treated water, etc.”) (See Reference A “Site boundary dose assessment of Fukushima Daiichi Nuclear Power Station and the regulatory concentration limit in the Japanese laws”). As of December 2022, there are 1,066 tanks that store strontium treated water (water before ALPS treatment)[18] and ALPS treated water, etc., and the stored amount is about 1.32 million m^3, while the capacity is about 1.37 million m^3. Although it is necessary to carefully examine the effect of the measures to control the generation of contaminated water and prediction of the amount of contaminated water generated, the planned capacity is expected to reach after the summer of 2023.

As shown in “Mid- to Long-Term Roadmap towards Decommissioning of the Fukushima Daiichi Nuclear Power Station” [7] revised by the government at the ministerial meeting on decommissioning and contaminated water measures (current “the ministerial meeting on decommissioning, contaminated water and treated water measures”) in December, 2019, decommissioning at the FDNPS is a continuous risk reduction activity to protect people and the environment from risks associated with radioactive materials manifested by the accident. In the long-term process toward decommissioning of the FDNPS for several decades, it is necessary to deal with the issues with greater radiation risks such as extraction of fuel debris and securing temporary storage locations of spent fuel, and it is essential to steadily reduce total risks from medium- to long-term viewpoints in order to appropriately deal with these issues.

The requirement to reduce the overall risks with the view of medium- to long-term views is the same in handling the contaminated water problem. So far, we have been steadily reducing the risks to the dose of less than 1 mSv/year, which is the dose limit for general public recommended by the ICRP in Publication 60 issued in 1990, for additional exposure dose associated with decommissioning on the site boundary by controlling the amount of contaminated water generated containing large amount of radioactive materials through so-called multi-layered countermeasures, and by removing radioactive materials contained in contaminated water through water treatment facilities including ALPS. In order to safely and steadily proceed with the decades-long decommissioning, storing ALPS treated water, etc. for long time is not practical (for details, see Reference B “Timeline of consideration of each

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[17] Equipments to purify contaminated water by adsorbing cesium and strontium.

[18] Water with most of the cesium and strontium removed before purification by ALPS.

disposal method of ALPS treated water”), and it is necessary to continue to steadily reduce overall risk at the FDNPS by removing as much radioactive material as possible using water treatment facilities including ALPS, implementing discharge in a safe manner minimizing to the fullest extent possible impacts on humans and plants and animals, and appropriately storing spent fuels in temporary storage in dry cask to be installed in the future.

2. Consideration of handling of ALPS treated water

The details are as described in Reference B “Timeline of consideration of each disposal method of ALPS treated water,” the method of handling of contaminated water and ALPS treated water, etc., has been discussed for several years initially with the Ministerial Conference of Contaminated Water, Treated Water and Decommissioning issues, the government, the IAEA, municipal administrations, local residents and experts. In 2013, the government established the Tritiated Water Task Force under the Committee on Countermeasures for Contaminated Water Treatment, with participation of nine members of experts from the fields such as nuclear, environmental science, radiology, radiation biology, fish chemistry in addition to members from Nuclear Regulation Authority and related ministries. The Task Force conducted technical studies on the five disposal methods (geosphere injection, discharge into the sea, vapor release, hydrogen release, and underground burial), which were proposed based on the scientific knowledge on tritium and the preceding cases [8][19]. In addition, since 2016, the Sub-committee on Handling of ALPS Treated Water has been established with 13 members of experts from the fields of such as nuclear, geological engineering, sociology, environmental science, agriculture, radiation biology, radiation science, fish chemistry as well as members from related ministries, to conduct a comprehensive deliberations, including social viewpoints such as reputation damage based on the results of the Tritiated Water Task Force [9]. The Sub-committee on Handling ALPS Treated Water compiled the report in February 2020, in which it examined five disposal methods from various perspective, including monitoring feasibility. The Sub-committee then stated that the methods of geosphere injection, hydrogen release and underground burial have many issues as realistic option in terms of regulatory, technology and time schedule, while the methods of the discharge into the sea and the vapor release are considered as more realistic options. The conclusion was that in comparison to the vapor release, the method of the water discharge into the sea has already established regarding the amount of release. Furthermore, the ease of handling of discharge facilities and the way of monitoring should be conducted. In accordance with these reasons, the Sub-committee also pointed out the limited room for expansion of tanks for long-term storage and the increased risk of leakage due to natural disasters and deterioration, and concluded that discharge of ALPS treated water into the sea ensure the steady implementation.

In addition, the Government of Japan has hosted the decommissioning review missions by the IAEA five times from 2013 to 2021 and has incorporated their opinions into considerations. The decommissioning review missions by the IAEA have pointed out the importance of the disposal plan for ALPS treated water. In the IAEA’s report in 2015, IAEA assessed that storage in tanks was “at best a temporary measure while a more sustainable

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[19] Discussion on continuation of tank storage was included.

solution was needed[20].” Subsequently, in the IAEA’s report in 2019, it was stated that “a decision on the disposition path for the stored ALPS treated water containing tritium and other radionuclides, after further treatment as needed, must be taken urgently[21].”

In addition, in the report of the IAEA following-up review for the progress decommissioning of FDNPS in 2020, also assessed the technical aspects of the report of the Sub-committee, as being "based on a sufficiently comprehensive analysis and sound scientific and technical basis[22].”

Moreover, after the report was compiled in the Sub-committee on the Handling of ALPS Treated Water, the government held the Meeting to hear the Opinions of Related Parties on the Handling of ALPS Treated Water and widely solicited for opinions including those in writing. As a result, among the submitted opinions, some expressed concerns about the impact of discharge of ALPS treated water into the sea on the surrounding environment, etc. Based on these considerations and opinions, the government announced the Basic Policy to handling ALPS treated water into the sea upon securing the safety as “Basic Policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings’ Fukushima Daiichi Nuclear Power Station” (April 13, 2021, the Ministerial Conference of Contaminated Water, Treated Water and Decommissioning, hereinafter called “Basic Policy”) [10].

Considering the Basic Policy, on April 16th of the same year, we announced “TEPCO’s Action in response to Government’s Policy” [11] which include the following approach:

- Regarding the discharge of the ALPS treated water into the sea, we will ensure the safety of the public, surrounding environment as well as agricultural, forestry and fishery products through compliance with safety standards based on relevant laws and legislations. We will take further measures based on international standards and practices to confirm the safety of the water to be discharged.
    - To ensure the safety of the public and surrounding environment, we will surely comply with regulatory standards and relevant laws for concentration of tritium and other radioactive materials in the water to be discharged, which are set based on international recognized methods (e.g. International Commission on Radiological Protection (ICRP) publication).
    - With regard to the radiological impact of the discharge on the humans and the environment under the condition indicated in the Basic Policy and international recognized method, we will assess its safety and publish the results prior to starting

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[20] 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, issued 13 May, 2015, p. 13, https://www.iaea.org/sites/default/files/missionreport130515.pdf

[21] 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, issued 31 January, 2019, p. 8, https://www.iaea.org/sites/default/files/19/01/missionreport-310119.pdf

[22] Review Report IAEA Follow-up Review of Progress Made on Management of ALPS Treated Water and the Report of the Subcommittee on Handling of ALPS treated water at TEPCO's Fukushima Daiichi Nuclear Power Station, issued 2 April, 2020, p. 6, https://www.meti.go.jp/press/2020/04/20200402002/20200402002-2.pdf

the necessary procedure for approval by Nuclear Regulation Authority. Additionally, we will receive reviews the Task Force of the IAEA and others. (The original report was issued in November 2021. We will publish the results including this revision and continue to receive reviews by experts of the IAEA, etc. after the start of water discharge.)

3. Objectives of the assessment

The objective of this Radiological Environmental Impact Assessment is as follows.

Objective 1: Evaluate the impact of radiation on humans and the environment in the case of our disposal of ALPS treated water by the internationally recognized method (IAEA safety standard and ICRP recommendation).

Objective 2: Announce the result of the assessment inside and outside Japan and consider the method to minimize the risks associated with disposal by making revisions, etc., as needed considering opinions from related parties.

4. Concept of assessment

This report was drafted assuming a dose assessment of the representative person by planned discharge shown in GSG-9, but the specific assessment method was based on GSG-10 and we also assessed potential exposure and environmental protection, which is not required in GSG-9.
The following shows the concepts of the assumptions in the assessment and the evaluation method.

(1) Dose constraints

The Japanese nuclear regulation system does not specifically set any dose constraints[23] and instead sets a target dose value of 0.05 mSv/year for the general public outside the surrounding monitoring area of light water reactor for power generation in normal operation.
On February 16, 2022, the Nuclear Regulation Authority issued the “Concept and Assessment Guidelines for Verifications in the Radiological Impact Assessment,” which says that “it must be verified that the estimated result of the representative person is small when compared to the fluctuation range of the annual radiation dose in humans in the region are exposed to through their living habits, etc., that is less than 50 μSv/year. The value of 50 μSv/year is the target dose for commercial light water reactors in normal operation, which corresponds to the dose constraint set in the IAEA Safety Standards [12].” In accordance with the Nuclear Regulation Authority’s view, TEPCO determined to treat the target dose value of 50μSv/year = 0.05mSv/year as corresponding to the dose constraint value (GSG-9 Fig.3) in the IAEA safety standards.

However, the Basic Policy of the Government of Japan limits the annual total amount of tritium contained in ALPS treated water allowed to be discharged into the sea as below the operational target value of 22 TBq/year (2.2E+13Bq/year): the annual discharge limit of the FDNPS before the accident. The Basic Policy imposes this standard in view of various factors, such as the risk optimization of the whole of decommissioning process, the effect of natural decay of radioactive materials expected during land storage of ALPS treated water, the leakage risk and occupational exposure during long-term storage, the plan to complete disposal of ALPS treated water before the completion of decommissioning, and the policy to address the concerns of stakeholders. As shown in “TEPCO’s Action in response to Government’s Policy” (April 2021) above, we set the annual discharge amount of tritium to 22 TBq/year (2.2E+13Bq/year) as an evaluation condition of this report and assessed the radiological environmental impact.
The relationship between the dose constraint and the annual discharge amount of tritium of 22 TBq/year (2.2E+13Bq/year) is discussed in 6-1-3. The results of the optimization of protection and safety for dose constraint value are shown in Reference G.

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[23] See footnote No.12.

(2) Tritium

A part of tritiated water (HTO) is converted to organically bound tritium (OBT) by plants and animals, etc., in the environment.
The following shows the effective dose factor in the case of ingestion of tritium [13].

Tritiated water	1.8E-11 Sv/Bq
OBT	4.2E-11 Sv/Bq

The effective dose factor of tritiated water reflects conversion of a part of tritium to OBT in the body after a human ingests tritium. As shown in Table II-9-1 and II-9-2 in chapter II-6 “Water quality other than radioactive materials” of Attachment II “Properties of ALPS treated water, etc.,” the ALPS treated water to be discharged contains almost no organic matter and almost the whole of it is considered to be tritiated water when discharged, so the case of directly drinking seawater or inhaling seawater spray is assessed by the effective dose factor of tritiated water.
On the other hand, as with humans, a part of tritiated water is converted to OBT when ingested by plants and animals. If OBT is ingested directly through seafood, etc., the effective dose factor of OBT is applied, so for the ingestion of seafood, the effective dose factor is used after correction assuming that 10% of tritium ingested is OBT. Specifically, we used adult: 2.0E-11Sv/Bq, child under school age: 3.5E-11Sv/Bq, and infant: 7.0E-11Sv/Bq as the corrected effective dose coefficient of tritium for the exposure assessment of ingestion of seafood. The calculation of expected exposure remained within dose limit and dose constraint corresponding to target dose value at nuclear power plants for each of these representative persons shown in Table 6-1-3(3).
The above mentioned dose assessments are based on highly conservative assumptions.
In reality, we have detected no OBT in fish extensively monitored in the sea are near the FDNPS nor did we detect any bioaccumulation of tritium compared with the tritium concentration in the seawater in the surrounding area. In addition, there is a general understanding that no evidence for biological concentration of OBT from HTO has been found in international studies [14][24].

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[24] For example, “Tritium and the environment,” which was issued by Institute for Radiological Protection and Nuclear Safety in France in 2012 [14] says “To date, no phenomenon of tritium bioaccumulation has been observed in marine organisms on the French Channel coast. This observation leads to the conclusion that discharge from nuclear industry, led by the spent fuel processing plant in La Hague, are overwhelmingly in the form of HTO.”

However, there is uncertainty about the transfer of OBT in the environment. The impact of uncertainty on the OBT fraction is discussed in Chapter 8 “Discussion about the uncertainty of the assessment,” and summarized in Attachment III “Impact of the organically bound tritium in the exposure assessment of tritium.”

(3) Assessment of migration and accumulation of nuclides other than tritium

Our study assumes that nuclides other than tritium will be advected and diffused while dissolved in the seawater. Unlike tritium, a part of other discharged nuclides is assumed to be adsorbed to suspended particles in the seawater, seabed sediment, hulls, beach sand, and fishing nets, or advected or concentrated in marine organisms depending on the chemical forms of radioactive materials, etc., so the disposition in the environment is assumed not to be the same as that of tritium. As for this trend, when an element has a higher distribution factor to seabed sediment, etc., or biological concentration factor, the increase in concentration of such elements in the soil and in organisms is expected to be higher. In contrast, the concentration of these elements in seawater is expected to decrease due to the migration from the seawater to the soil and organisms.

However, ALPS treated water to be discharged is purified by coagulating sedimentation, adsorption, filtration, etc., and contains almost no impurities, so even if it is adsorbed to suspended particles, it will be unlikely that a lot of sediment is generated, and only a limited amount of seawater directly contacts the seabed sediment, etc., which means that initially the amount of radioactive materials adsorbed to seabed sediment is much smaller than the total amount of discharged radioactive materials. From the viewpoint of model simplification, the expected decrease in the concentration in the seawater caused by adsorption to the seabed sediment was not considered in our diffusion models.

However, to address the possible impact of absorption and advection, our models have been made so that such differences in the disposition in the environment need not be considered, by assuming that adsorption has proceeded until the concentration in the seawater reaches the equilibrium state as for adsorption to seabed sediment, etc., and biological concentration, which proceeds in the long term in reality, and setting both of them conservatively.

Figure 4-1 shows accumulation of radioactive materials in the sea. Radioactive materials contained in the ALPS treated water spread with advection and diffusion by tidal currents after discharge into the sea. At this point, some radioactive materials are adsorbed by suspended particles in the seawater and seabed sediment in actual seawater.

Therefore, the concentration of radioactive materials in seawater decreases not only through advection and diffusion but also through adsorption on suspended particles and seabed sediment. On the other hand, the concentration of the radioactive materials in seabed sediment increases because of accumulation of radioactive materials adsorbed by suspended particles and seabed sediment. Tendency of adsorption from seawater to suspended particles and seabed sediment is determined by the coefficient called distribution factor. When the concentration of radioactive materials in seawater is constant, the concentration in seabed sediment increases initially due to adsorption, but the adsorption does not proceed further with the equilibrium state (a state in which adsorption and deposition are balanced) after continuous increase of the concentration due to long term accumulation. Thus, immediately after the discharge begins, the decrease of the concentration of radioactive materials in seawater (dissolved concentration) is large due to adsorption on suspended particles and seabed sediment. As the accumulation in seabed sediment proceeds, the adsorption on seabed sediment decreases and the decrease of the concentration of radioactive materials in seawater (dissolved concentration) becomes smaller.

The time to reach equilibrium actually varies with the discharge amount and the type of radioactive material, but the model in this report assumes that the equilibrium state has been reached immediately after the discharge. In other words, excluding the decrease of the concentration of radioactive materials in seawater (dissolved concentration) due to the adsorption on suspended particles and the seabed sediment, the concentration in seafood is assessed from the concentration in seawater after long term discharge, while at the same time the external exposure from seabed sediment is assessed from the concentration in those after long term accumulation.

Some nuclides among radionuclides to be measured and assessed decay into other radionuclides (progeny nuclides). Among progeny nuclides, when the half-lives are shorter than those of parent nuclides, such as Sr-90/Y-90, such progeny nuclides do not accumulate. While progeny nuclides which have longer half-lives than their parent nuclides can be accumulated, all measurement results of gross alpha in tank groups have shown no detected status. In addition, the assessment is performed with the conservative assumption that more than one alpha nuclides are included with the value of concentration of gross alpha measurement result (the detection limit value).

From the gross alpha measurement result, on the assumption that Pu-241 is contained with higher concentration than its progeny nuclide Am-241, the concentration of Am-241 can accumulate nearly two times as high as present concentration. However, exposure from Am-241 is only small proportion and therefore the impact to exposure assessment result caused by accumulation of Am-241 is deemed small.

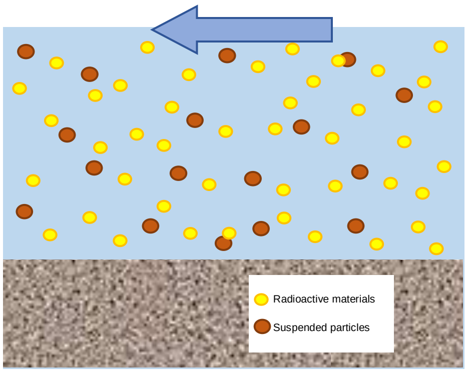
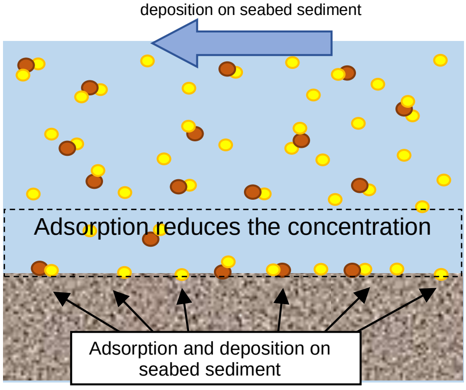
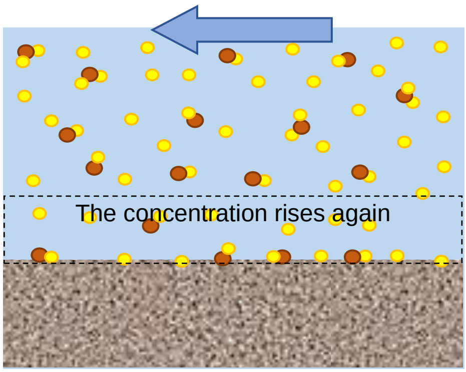
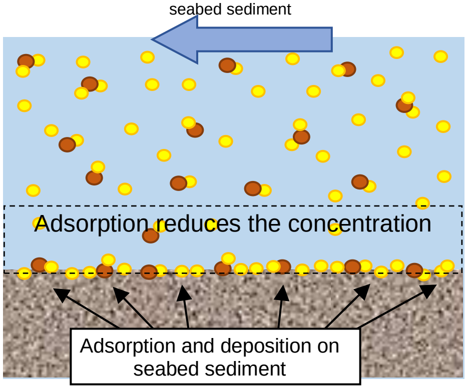
For advection and diffusion in the sea, we also verified that annual variation was small, by simulated calculation of seven years.

Therefore, following is the summary of this assessment.

- For dose pathways relating to seawater, we have assumed that the concentration in seawater is not depleted by transfer to the seabed sediments, irrespective of expected

migration to seabed sediments and organisms, and that it stays at the same level throughout the discharge period.
- For dose pathways relating to the seabed sediments, we have assumed that there is dynamic equilibrium between seawater and seabed sediments from one year even though in reality equilibrium is not be expected to occur for a number of years.

We have calculated the highest exposure dose that would occur during discharge period assuming that such discharges will be consistent and continuous. We have assessed full accumulation of radioactive materials including C-14 and I-129, described in other sections, in the environment due to long-term discharge as many decades later. Thus, the peak dose value is considered not higher than the value in this assessment. Figure 4-2 shows projected exposure (dose commitment) by accumulation of radioactive materials in the environment, which the IAEA showed in its first report on its February 2022 Review Mission on the Safety Aspects of Handling of ALPS Treated Water at Fukushima Daiichi Nuclear Power Station as well as this report’s exposure assessment. As mentioned above, the assessment in this report assumes that the equilibrium state for accumulation in sea sediment based on the distribution factor is immediately achieved – which is not expected in reality to occur for years after the commencement of discharges. Accordingly, the model used is sufficiently conservative with respect to advection and dispersion for radioactive materials, and no changes are required in light of the revised source term.

Accumulation process in seabed sediment, etc. in actual phenomena		If discharge into the sea starts, advection and diffusion of radioactive materials discharged from the discharge outlet supplies radioactive materials, which increases the concentration in the seawater.
	Supply of radioactive materials by advection and diffusion => Adsorption to suspended particles and adsorption and deposition on seabed sediment 	Some of the supplied radioactive materials are adsorbed to seabed sediment, suspended particles, etc. As a result, the radioactive material concentration in the seawater drops and the radioactive material concentrations in seabed sediment, suspended particles, etc., rises and reaches the equilibrium states depending on the distribution factors of each nuclide.
	Supply of radioactive materials by advection and diffusion => Rise in the concentration 	Then, more radioactive materials are discharged and the radioactive material concentration in the seawater rises.
	Supply of radioactive materials by advection and diffusion => Rise in the concentration => Adsorption and deposition on seabed sediment 	Some of the radioactive materials are adsorbed near seabed sediment, suspended particles, etc., the concentration in the seawater side drops, and the concentrations in seabed sediment and suspended particles rises and reaches equilibrium. Long-term repetition of this process raises the radioactive material concentrations in seabed sediment, suspended particles, etc., as well as the radioactive material concentration in the seawater, which reaches the equilibrium state.

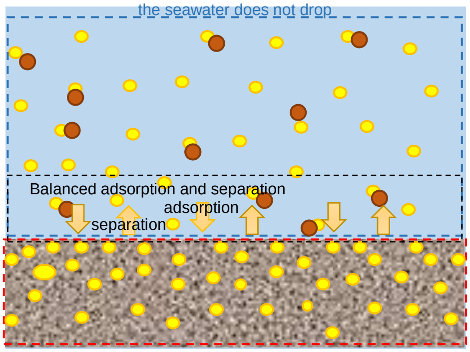
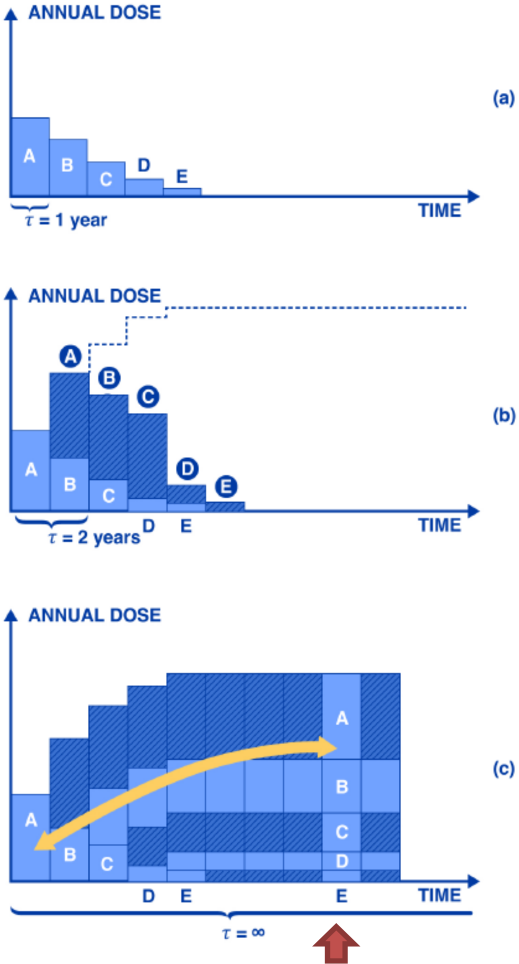
Model of this report	It is assumed that adsorption occurs but the concentration in the seawater does not drop  It is assumed that adsorption on seabed sediment, etc., which instantaneously reaches the concentration at which there is no room for further adsorption (=equilibrium state) occurs	The assessment assumes that radioactive materials are accumulated immediately to the equilibrium state of concentration in seabed sediment based on the concentration in the seawater. On the other hand, it is assumed that the concentration in the seawater does not to decrease even in the event of adsorption in seabed sediment, etc. This simulates the state that the seawater, seabed sediment, etc., reaches the equilibrium states (balance of adsorption and desorption) due to long-term continuation of discharge and no more adsorption occurs.

Figure 4-1 Actual accumulation process in seabed sediment, etc., and model in this report (image)



This report assessed the conditions under which radioactive materials accumulated.

Figure 4-2 Image of future exposure (dose commitment) by accumulation of radioactive materials in the environment [15] **and exposure assessment in this report.**

(4) Carbon 14 (C-14)

Carbon 14, whose half-life is as long as 5,700 years, is circulated and distributed globally in the atmosphere, terrestrial biosphere, hydrosphere and geosphere with stable carbon isotopes. According to Table 4 in Annex B of the 2008 report on sources, effects and risks of ionizing radiation to the General Assembly of the "United Nations Scientific Committee on the Effects of Atomic Radiation" (hereinafter called "UNSCEAR2008 Report") [16], C-14 is identified to be generated 1.4E+15Bq (1.4PBq) annually in the atmosphere by cosmic ray.

In addition, according to Table 13 in Annex B of the 2016 Report on sources, effects and risks of ionizing radiation to the United Nations Scientific Committee on the Effects of Atomic Radiation (hereinafter called "UNSCEAR2016 Report") [17]and European Commission Radioactive Discharges Database [18], radioactive discharges from the reprocessing facilities have been made in the form of gas and liquid more than 1E+12Bq respectively every year. On the other hand, the yearly radioactive discharge of C-14 from ALPS treated water will be less than 1E+10Bq and this is small amount compared to those, therefore its impact to global scale can be ignored and only the dose assessment for the representative person was performed.

(5) Iodine 129 (I-129)

Since Iodine 129 has a very long half-life of 16 million years, there is a possibility to distribute globally over the very long term in case it is discharged to the sea. However, there are high quantities of stable isotopes of iodine contained in seawater, and the discharged I-129 is migrated, whilst it is isotopically diluted by those stable iodine isotopes.

According to Table 13 in Annex B of UNSCEAR 2016 report and European Commission Radioactive Discharges Database, more than 1E+12Bq of I-129 in liquid form was annually discharged from the reprocessing facilities. In regard to the discharge of ALPS treated water, only the dose assessment for the representative person was conducted since annual discharge of I-129 is expected approximately 1E+08Bq and the impact in a global scale is negligible.

5. Properties of ALPS treated water, etc. and discharge method

5-1. Properties of ALPS treated water, etc.

As of December, 2022, ALPS treated water, etc., of about 1.32 million m^3 currently stored in tanks is water purified by ALPS (excluding strontium treated water), which is designed to be able to remove 62 nuclides excluding tritium and C-14 among the radioactive nuclides contained in contaminated water. Contaminated water newly generated during the period of discharge into the sea has to be treated appropriately by ALPS, etc., in the same manner and discharged into the sea. The rationale behind the selection of 62 nuclides subject to removal by ALPS is shown in Reference F “Rationale behind the selection of nuclides subject to removal by ALPS” and the mechanism to remove radioactive materials from contaminated water is shown in Attachment II “Properties of ALPS treated water, etc.”

ALPS can purify 62 radioactive materials other than tritium and C-14 up to less than 1 of sum of the ratios to regulatory concentrations limits, but about 70% of ALPS treated water (based on the breakdown of the tank groups fully filled with water by September 30, 2022) is so-called “treated water to be purified,” which contains more radioactive materials other than tritium than the standard applicable to discharge into the environment (sum of the ratios to regulatory concentrations limits of less than 1) due to the treatment before performance improvement in the early stage of the treatment plan, priority on the treatment amount for reduction of additional exposure dose on the site boundary, etc. Such treated water to be purified, which is yet to be purified sufficiently, is surely purified until the sum of the ratios to regulatory concentrations limits of radioactive materials other than tritium becomes less than 1 before discharge (secondary treatment) and then discharged as ALPS treated water. Table 5-1-1 shows the regulatory concentration limit of tritium, C-14, and 62 nuclides subject to removal by ALPS.

As for the secondary treatment by ALPS, we conducted a secondary treatment performance verification test for a total of 2,000 m^3 of two tank groups since September 2020 and verified that the sum of the ratios to regulatory concentrations limits of nuclides excluding tritium in each tank group can be reduced to less than 1 [19]. The water quality of ALPS treated water, etc., including the result of the secondary treatment performance verification test, is shown in Attachment II “Properties of ALPS treated water, etc.” For assessments in design stage, a total of 64 nuclides which consist of 62 nuclides subject to removal by ALPS, tritium and C-14 were assessed as target nuclides for dose assessment.

On the other hand, to select the 62 nuclides to be removed by ALPS, it is assumed that some nuclides are now sufficiently decayed to have sufficiently small abundances since for these 62 nuclides the inventory data set of one year after the accident at FDNPS, was used for the assessment.

In light of the above, TEPCO conducted thorough studies to select the target nuclides for ALPS treated water discharge into the sea and newly selected 29 nuclides were newly selected as nuclides to be measured and assessed (Table5-1-2). This report assesses 30 nuclides including tritium, as target nuclides for dose assessment.

Table 5-1-1 Regulatory concentration limits of 62 nuclides subject to removal by ALPS, tritium, and C-14

	Target nuclides (physical half-life)	Regulatory concentration limit (Bq/L)		Target nuclides (physical half-life)	Regulatory concentration limit (Bq/L)
1	H-3 (about 12 years)	6.0E+04	33	Te-129m (about 34 days)	3.0E+02
2	C-14 (about 5700 years)	2.0E+03	34	I-129 (about 16 million years)	9.0E+00
3	Mn-54 (about 310 days)	1.0E+03	35	Cs-134 (about 2.1 years)	6.0E+01
4	Fe-59 (about 44 days)	4.0E+02	36	Cs-135 (about 2.3 million years)	6.0E+02
5	Co-58 (about 71 days)	1.0E+03	37	Cs-136 (about 13 days)	3.0E+02
6	Co-60 (about 5.3 years)	2.0E+02	38	Cs-137 (about 30 years)	9.0E+01
7	Ni-63 (about 100 years)	6.0E+03	39	Ba-137m (about 2.6 minutes)	8.0E+05
8	Zn-65 (about 240 days)	2.0E+02	40	Ba-140 (about 13 days)	3.0E+02
9	Rb-86 (about 19 days)	3.0E+02	41	Ce-141 (about 33 days)	1.0E+03
10	Sr-89 (about 51 days)	3.0E+02	42	Ce-144 (about 280 days)	2.0E+02
11	Sr-90 (about 29 years)	3.0E+01	43	Pr-144 (about 17 minutes)	2.0E+04
12	Y-90 (about 64 hours)	3.0E+02	44	Pr-144m (about 7.2 minutes)	4.0E+04
13	Y-91 (about 59 days)	3.0E+02	45	Pm-146 (about 5.5 years)	9.0E+02
14	Nb-95 (about 35 days)	1.0E+03	46	Pm-147 (about 2.6 years)	3.0E+03
15	Tc-99 (about 210,000 years)	1.0E+03	47	Pm-148 (about 5.4 days)	3.0E+02
16	Ru-103 (about 39 days)	1.0E+03	48	Pm-148m (about 41 days)	5.0E+02
17	Ru-106 (about 370 days)	1.0E+02	49	Sm-151 (about 90 years)	8.0E+03
18	Rh-103m (about 56 minutes)	2.0E+05	50	Eu-152 (about 14 years)	6.0E+02
19	Rh-106 (about 30 seconds)	3.0E+05	51	Eu-154 (about 8.6 years)	4.0E+02
20	Ag-110m (about 250 days)	3.0E+02	52	Eu-155 (about 4.8 years)	3.0E+03
21	Cd-113m (about 14 years)	4.0E+01	53	Gd-153 (about 240 days)	3.0E+03
22	Cd-115m (about 45 days)	3.0E+02	54	Tb-160 (about 72 days)	5.0E+02
23	Sn-119m (about 290 days)	2.0E+03	55	Pu-238 (about 88 years)	4.0E+00
24	Sn-123 (about 130 days)	4.0E+02	56	Pu-239 (about 24,000 years)	4.0E+00
25	Sn-126 (about 230,000 years)	2.0E+02	57	Pu-240 (about 6600 years)	4.0E+00
26	Sb-124 (about 60 days)	3.0E+02	58	Pu-241 (about 14 years)	2.0E+02
27	Sb-125 (about 2.8 years)	8.0E+02	59	Am-241 (about 430 years)	5.0E+00
28	Te-123m (about 120 days)	6.0E+02	60	Am-242m (about 140 years)	5.0E+00
29	Te-125m (about 57 days)	9.0E+02	61	Am-243 (about 7400 years)	5.0E+00
30	Te-127 (about 9.4 hours)	5.0E+03	62	Cm-242 (about 160 days)	6.0E+01
31	Te-127m (about 110 days)	3.0E+02	63	Cm-243 (about 29 years)	6.0E+00
32	Te-129 (about 70 minutes)	1.0E+04	64	Cm-244 (about 18 years)	7.0E+00

* The half-lives are indicated 2-digit accuracy using ICRP Publication 107 “Nuclear Decay Data for Dosimetric Calculations” [20]

Table5-1-2 Tritium and nuclides to be measured and assessed for discharge of ALPS treated water into the sea

	Target nuclides（Physical half life）	Regulatory concentration limit（Bq/L）
1	H-3（approx.12Years）	6.0E+04
2	C-14（approx.5700Years）	2.0E+03
3	Mn-54（approx.310Days）	1.0E+03
4	Fe-55（approx.2.7Years）	2.0E+03
5	Co-60（approx.5.3Years）	2.0E+02
6	Ni-63（approx.100Years）	6.0E+03
7	Se-79（approx.300,000Years）	2.0E+02
8	Sr-90（approx.29Years）	3.0E+01
9	Y-90（approx.64 Hours）	3.0E+02
10	Tc-99（approx.210,000Years）	1.0E+03
11	Ru-106（approx.370Days）	1.0E+02
12	Sb-125（approx.2.8Years）	8.0E+02
13	Te-125m（approx.57 Days）	9.0E+02
14	I-129（approx.16M Years）	9.0E+00
15	Cs-134（approx.2.1Years）	6.0E+01
16	Cs-137（approx.30Years）	9.0E+01
17	Ce-144（approx.280Days）	2.0E+02
18	Pm-147（approx.2.6Years）	3.0E+03
19	Sm-151（approx.90Years）	8.0E+03
20	Eu-154（approx.8.6Years）	4.0E+02
21	Eu-155（approx.4.8Years）	3.0E+03
22	U-234（approx.250,000Years）	2.0E+01
23	U-238（approx.4.5B Years）	2.0E+01
24	Np-237(approx.2.1MYears)	9.0E+00
25	Pu-238（approx.88Years）	4.0E+00
26	Pu-239（approx.24000Years）	4.0E+00
27	Pu-240（approx.6600Years）	4.0E+00
28	Pu-241（approx.14Years）	2.0E+02
29	Am-241（approx.430Years）	5.0E+00
30	Cm-244（approx.18Years）	7.0E+00

※Half-life shows in 2 significant digits referring to ICRP Publication 107 “Nuclear Decay Data for Dosimetry Calculations” [20]

5-2. Discharge method

The following shows the policy on the method of discharge into the sea following “TEPCO’s Action in response to Government’s Policy.”

- The design and operation of the facilities necessary for discharge into the sea will comply with laws and get the necessary permissions from the Nuclear Regulation Authority.
- The amount of radioactive materials excluding tritium in treated water will be reduced by repeating secondary treatment prior to the discharge until the concentration before dilution surely falls below the regulatory standard value related to safety (until the sum of the ratios to regulatory concentrations limits of nuclides other than tritium becomes less than 1). We will not discharge treated water of which sum of the ratios to regulatory concentrations limits of radioactive materials excluding tritium before dilution is not less than 1.
- Before dilution and discharge, we will measure and assess the concentration of the radioactive materials in ALPS treated water (29 nuclides to be measured and assessed and tritium) and announce the results of the measurement and assessment every time, as well as perform third-party measurement, assessment, announcement, etc., and announce the results. Nuclides that are not included as the nuclides to be measured and assessed among nuclides subject to removal by ALPS (62 nuclides) will be measured and the results will be announced, as well.
- After that, tritium, which is difficult to exclude, is diluted with a massive amount of seawater (to be determined depending on the tritium concentration in the treated water to be discharged; about 100 to 1,400 times or more) before discharge, in order to meet the standard of the safety regulations of the government (regulatory concentration limit) set to reduce the impact on the environment immediately after discharge (at site boundary), dispel concerns of consumers, etc., as much as possible, and minimize reputation damage. Thanks to this, the sum of the ratios to regulatory concentrations limits of radioactive materials other than tritium becomes less than 0.01. Besides, in actual operation, two sea water transfer pumps are enough to dilute the ALPS treated water to be discharged by setting the concentration limit of tritium before dilution below 1 million Bq/L.
- The tritium concentration of discharged water will be sufficiently lower than 60,000Bq/L, which is the standard of the safety standards of the government (regulatory concentration limit), and 10,000Bq/L, which is the WHO Guidelines for Drinking Water Quality: specifically, less than 1,500Bq/L as with the operation target of the currently applied discharge concentration of the groundwater bypass, subdrain, etc.
- Discharge into the sea will be started carefully with a small amount. The soundness of facilities, the transfer procedure of ALPS treated water, measurement process of the concentration of radioactive materials, assessment of dilution of tritium in discharged water, the state of diffusion into the sea, etc., will be verified.

- If the transfer facility or dilution facility does not function as planned due to malfunction, power failure, etc., we will stop the discharge immediately. If any abnormal value is detected in sea area monitoring, we will stop discharge and investigate the state. When resuming discharge, confirm the safety of discharge.
- The upper limit of the annual discharge amount of tritium, which cannot be removed by ALPS, will be 22 TBq (2.2E+13Bq) per year, which is the discharge control value of the FDNPS before the accident, for the time being. Moreover, we will minimize the discharge amount as well as secure the site for facilities necessary for decommissioning by preferentially discharging water with a low tritium concentration and waiting for natural decay based on the half-life for water with a high concentration. Attachment IV “Analysis on the period of discharge of ALPS treated water” shows the simulation result related to discharge of ALPS treated water assuming that discharge will be started in FY 2023 and completed in FY 2051.

Table 5-2-1 shows the specific items to be implemented as shown in “TEPCO’s Action in response to Government’s Policy.”

Table 5-2-1 Specific items to be implemented

Secondary treatment of treated water to be purified	• The amount of radioactive materials excluding tritium in treated water to be purified to be discharged into the environment is reduced by secondary treatment by ALPS, etc., to ensure that radioactive materials other than tritium surely falls below the regulatory standard value related to safety (until the sum of the ratios to regulatory concentrations limits of nuclides other than tritium becomes less than 1).
Analysis of ALPS treated water	• Before dilution and discharge, we will announce the measurement and assessment results of the concentration of radioactive materials of tritium, 29 nuclides to be measured and assessed and nuclides subject to removal by ALPS that are out of above every time, as well as perform third-party measurement, assessment, announcement, etc.
Dilution and discharge (including emergency actions)	• Tritium, which is difficult to remove, is diluted with a sufficient amount of seawater (100 or more times) before discharge so that the concentration will be sufficiently lower than the regulatory concentration limit. Thanks to this, the sum of the ratios to regulatory concentrations limits of nuclides other than tritium in discharged water becomes less than 0.01. - The tritium concentration will be the same as the operation target of the discharge concentration of the groundwater bypass, subdrain, etc. (less than 1,500Bq/L). • The upper limit of the annual discharge amount of tritium will be 22 TBq (2.2E+13Bq) per year, which is the discharge control value at FDNPS before the accident, for the time being. The annual discharge amount of tritium is reviewed as needed based on the progress of decommissioning. • If the transfer facility or dilution facility does not function as planned due to a failure, outage, etc., stop the discharge immediately. • If any abnormal value is detected in sea area monitoring, stop discharge and investigate the state. When resuming discharge, confirm the safety of discharge.
Sea area monitoring	• Sea area monitoring is started according to the plan enhanced since about one year before the scheduled date to start discharge. • Monitoring of seawater, fish, and seaweeds are enhanced. - Tritium is intensively measured and assessed in addition to the past measurement and assessment focusing on Cs-137. - The measurement sample continued to be seawater but the sampled amount of fish and seaweeds are increased. • The radioactivity measurement result at the time of discharge is announced. - Third-party analysis, announcement, etc., are considered.

5-3. Facilities for discharge

“TEPCO’s Action in response to Government’s Policy” shows a conceptual diagram of the facilities for discharging into the sea (Figure 5-3-1). Subsequent to that, the design of the facilities was concretized, and thereafter finalized through the IAEA review and NRA review meetings. The assessment was performed reflecting the status of consideration of the facilities for discharge shown below. The optimization of facility capacity is summarized in Reference G "Upper Limits of Annual Release Amounts of Each Nuclide Based on Dose Constraints and Optimization Evaluation Results”.

For more details on the discharge facilities, see “Application for amendments in the Implementation Plan for Fukushima Daiichi Nuclear Power Station as Specified Nuclear Facility [21].”

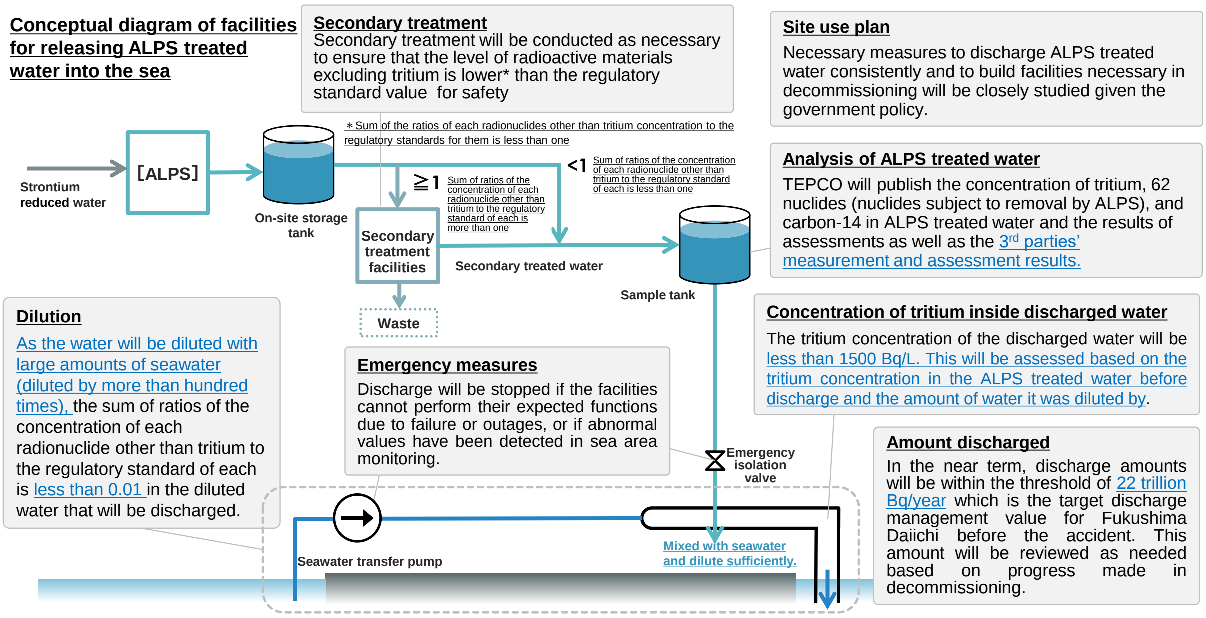
5-3-1. Overview of the facilities for discharge

The facilities for discharge into the sea mainly consist of “the measurement/confirmation facility” to verify the radioactive material concentration of ALPS treated water before dilution, “the dilution facility” which consists of seawater transfer piping and discharge vertical shaft (upper-stream storage) including the seawater transfer pump and seawater pipe header to pump and discharge seawater for dilution, “the transfer facility” which consists of the treated water transfer pump and treated water transfer piping and valves to transfer ALPS treated water from the measurement/confirmation facility to the seawater piping, and “the discharge facility (related facility)” which consists of the discharge tunnel and discharge outlet.

After confirming the water, of which radioactive materials have been removed by ALPS up to a sufficiently law concentration, is so-called “ALPS treated water” (water whose sum of the ratios to regulatory concentrations limits of nuclides other than tritium is verified to be less than 1), and then diluted with a large amount of seawater 100 or more times.

The water to be discharged is received by the measurement/confirmation facility, the radioactive material concentration is homogenized by circulation and stirring, and then it is verified by sampling and analysis that the water is ALPS treated water. The verified water is transferred to the dilution facility by the transfer facility, mixed with a large amount of seawater pumped with the seawater transfer pump through the Unit 5 intake channel by the dilution facility, and drained to the discharge facility after dilution of the tritium concentration up to less than 1,500Bq/L.

The details of each facility are shown in the following pages. Figure 5-3-1 shows the conceptual diagram of the discharge facility. Figure 5-3-2 shows the big picture of the facility for discharge into the sea and related facilities.



Conceptual diagram of facilities for releasing ALPS treated water into the sea

Secondary treatment
Secondary treatment will be conducted as necessary to ensure that the level of radioactive materials excluding tritium is lower* than the regulatory standard value for safety

＊Sum of the ratios of each radionuclides other than tritium concentration to the regulatory standards for them is less than one

Site use plan
Necessary measures to discharge ALPS treated water consistently and to build facilities necessary in decommissioning will be closely studied given the government policy.

Analysis of ALPS treated water
TEPCO will publish the concentration of tritium, 62 nuclides (nuclides subject to removal by ALPS), and carbon-14 in ALPS treated water and the results of assessments as well as the 3rd parties' measurement and assessment results.

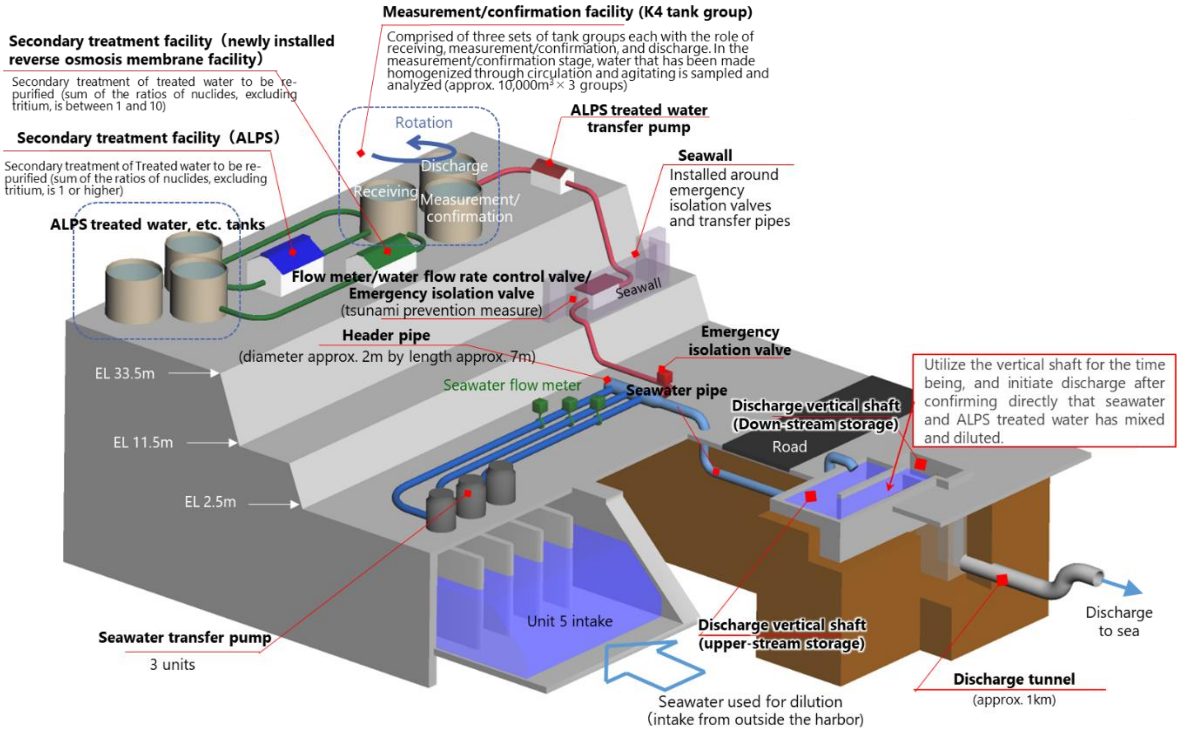
Dilution
As the water will be diluted with large amounts of seawater (diluted by more than hundred times), the sum of the ratios of the concentration of each radionuclide other than tritium to the regulatory standard of each is less than 0.01 in the diluted water that will be discharged.

Emergency measures
Discharge will be stopped if the facilities cannot perform their expected functions due to failure or outages, or if abnormal values have been detected in sea area monitoring.

Concentration of tritium inside discharged water
The tritium concentration of the discharged water will be less than 1500 Bq/L. This will be assessed based on the tritium concentration in the ALPS treated water before discharge and the amount of water it was diluted by.

Amount discharged
In the near term, discharge amounts will be within the threshold of 22 trillion Bq/year which is the target discharge management value for Fukushima Daiichi before the accident. This amount will be reviewed as needed based on progress made in decommissioning.

Figure 5-3-1 Conceptual diagram of facilities for discharging ALPS treated water into the sea



Measurement/confirmation facility (K4 tank group)
Comprised of three sets of tank groups each with the role of receiving, measurement/confirmation, and discharge. In the measurement/confirmation stage, water that has been made homogenized through circulation and agitating is sampled and analyzed (approx. 10,000m³ × 3 groups)

Secondary treatment facility（newly installed reverse osmosis membrane facility）
Secondary treatment of treated water to be re-purified (sum of the ratios of nuclides, excluding tritium, is between 1 and 10)

Secondary treatment facility（ALPS）
Secondary treatment of Treated water to be re-purified (sum of the ratios of nuclides, excluding tritium, is 1 or higher)

Seawall
Installed around emergency isolation valves and transfer pipes

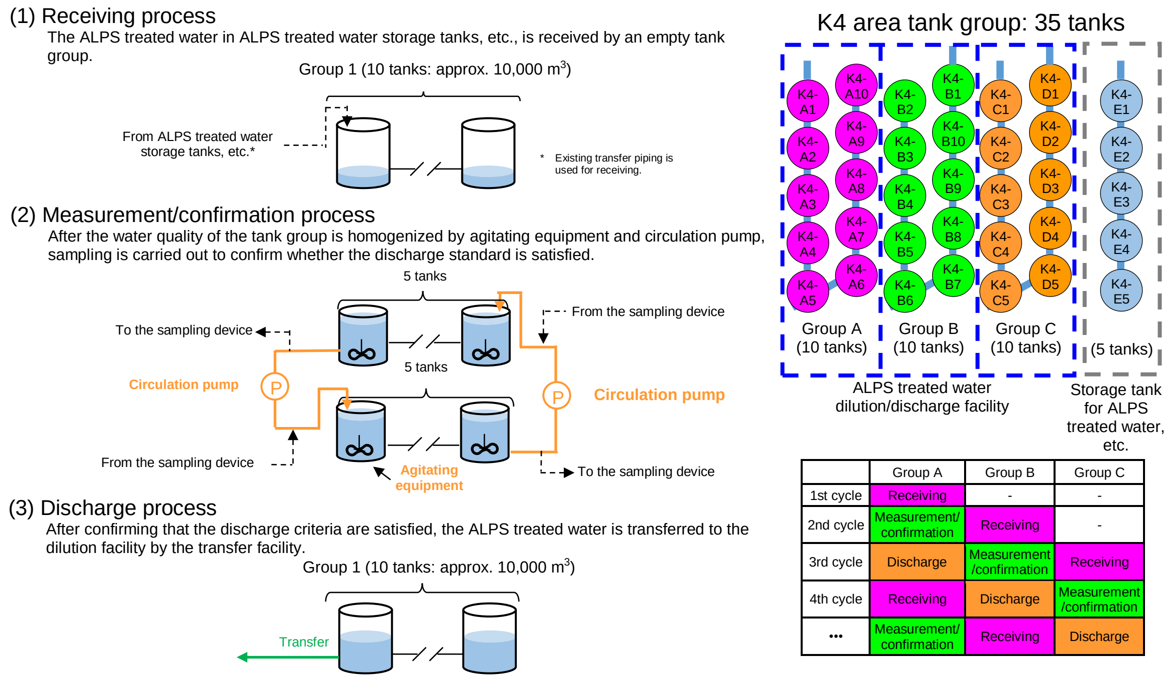
Utilize the vertical shaft for the time being, and initiate discharge after confirming directly that seawater and ALPS treated water has mixed and diluted.

Figure 5-3-2 Overview of facilities for discharging into the sea and related facilities

5-3-2. Measurement/confirmation facility

For the measurement/confirmation facility, we will use 30 out of 35 tanks, each of which has a capacity of 1,000m^3, installed in the K4 tank areas in the center of the site 33.5 m above sea level near ALPS. To sample and analyze homogenized water, use 10 tanks, whose nominal total capacity is about 10,000 m^3, as 1 group, and install total 30 units of a stirring device in each tank and a circulation device with two circulation pumps of which the capacity is 160m^3/h for each pump. In principle, setting aside time more than the required time for two rounds of water flow of measurement/confirmation tank for operation time (this is not an option when enough circulation/agitation is confirmed by examination, even after the service started). Since we have to deal with three purposes, namely receiving, measurement/confirmation, and discharge, set up three tanks groups and operate them on a rotation basis.

Figure 5-3-3 shows the schematic diagram of the measurement/confirmation facility. This figure also outlines the operation of the measurement/confirmation facility.



	Group A	Group B	Group C
1st cycle	Receiving	-	-
2nd cycle	Measurement/ confirmation	Receiving	-
3rd cycle	Discharge	Measurement /confirmation	Receiving
4th cycle	Receiving	Discharge	Measurement /confirmation
•••	Measurement/ confirmation	Receiving	Discharge

Figure 5-3-3 Schematic diagram of measurement/confirmation facilities

In the discharge process, the tritium concentration of ALPS treated water is registered in monitoring/control device, and ALPS treated water transfer flow rate is set within the maximum 500m^3/day (minimum flow rate (annual average) is equal to or greater than the volume of contaminated water generated) so that the tritium concentration contained in the released water is less than 1,500Bq/L which is the upper limit of the operation.

To prevent human error, the tritium concentration confirmed in the process of measurement/confirmation should be mechanically read by a scanner and registered in monitoring/control device.

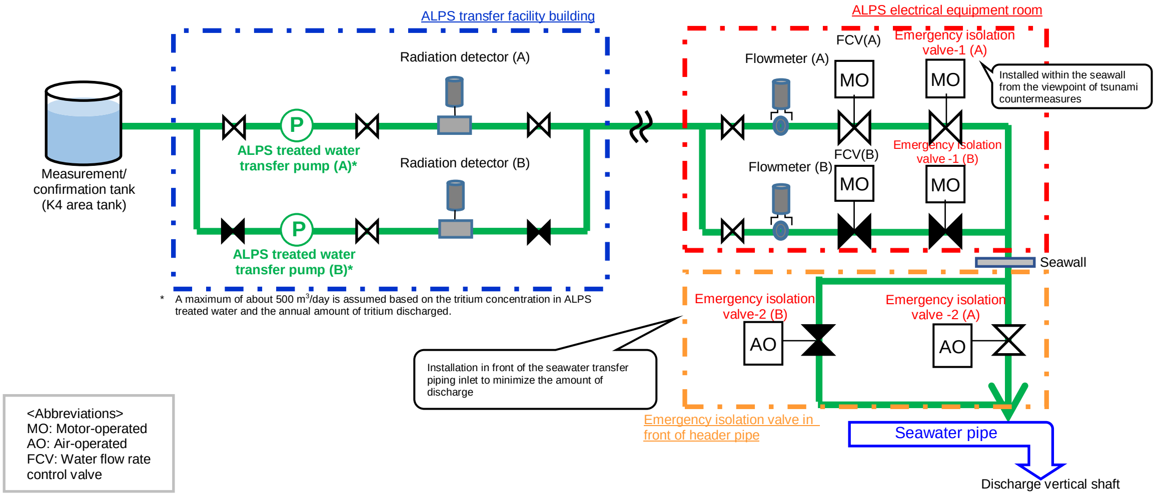
Monitoring/control device automatically calculates ALPS treated water transfer flow rate from the registered tritium concentration and seawater flow rate.

5-3-3. Transfer facility

The transfer facility is mainly composed of ALPS treated water transfer pump and transfer piping, etc.

In the transfer facility, the ALPS treated water transfer pump has a 30m^3/h transfer capacity per unit and consists of two units: an operation unit and a spare unit. The flow rate is operated within the max. 500m^3/day using ALPS treated water flow rate control valve and ALPS treated water flow meter installed downstream. And these pumps are installed in the ALPS transfer facility building near the measurement/confirmation facility to transfer ALPS treated water from the tanks of the measurement/confirmation facility 33.5 m above sea level to the dilution facility. Install a radiation detector (scintillation detectors) to detect gamma rays for emergency isolation in the building in order to prevent water from being discharged without sufficient purification.

In the transfer facility, the transfer piping is installed to connect the measurement/confirmation facility 33.5 m above sea level to the seawater piping 2.5 m above sea level. Install an emergency isolation valve in two points in the transfer piping to enable to stop immediately transfer of ALPS treated water in the event of occurrence of an abnormality. One point is set before the injection part of the seawater piping in order to minimize the discharge amount of ALPS treated water in the event of occurrence of an abnormality. The other point is set in the ALPS electrical equipment room set up inside the seawall to be newly constructed 11.5m above sea level in preparation for cases that the former emergency isolation valve does not work due to water immersion, etc., caused by the expected Japan Trench tsunami. In the same room, a flowmeter to measure the flow rate of ALPS treated water to be transferred to the seawater pipe header and the flow rate adjustment valve to adjust the flow rate as specified and the range of maximum 500m^3/day are installed. Figure 5-3-4 shows the schematic diagram of the transfer facility



* A maximum of about 500 m^3/day is assumed based on the tritium concentration in ALPS treated water and the annual amount of tritium discharged.

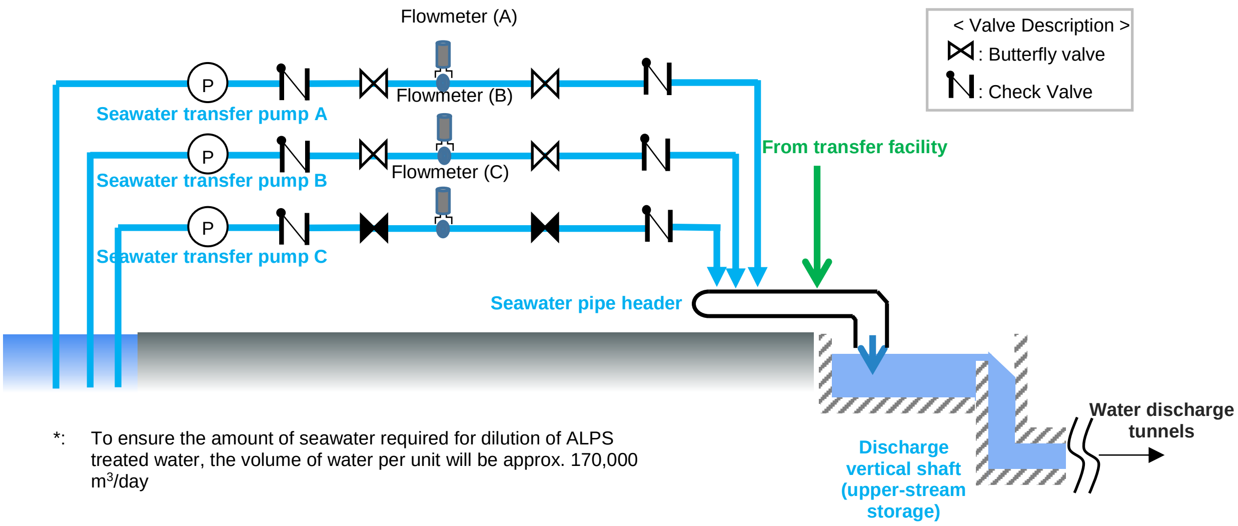
<Abbreviations>
MO: Motor-operated
AO: Air-operated
FCV: Water flow rate control valve

Figure 5-3-4 Schematic diagram of the transfer facility

5-3-4. Dilution facility

The dilution facility consists of a seawater transfer pump, seawater piping (including header), and a discharge shaft (upstream water tank) with the purpose of diluting the ALPS treated water with seawater, transferring it to the discharge shaft (upstream water tank), and discharging it to the discharge facility (related facility). Dilution is done by injecting ALPS treated water into the seawater pipe header and mixing it.

The dilution facility is installed in a location 2.5 m above sea level in the sea side of Units 5/6. A flowmeter is installed in the seawater transfer piping to ensure that the tritium concentration is less than 1,500Bq/L by dilution with a high volume of water (100 or more times). For the seawater transfer pump, the intake channel for the existing Unit 5 circulation water pump is reused. Conservatively, three pumps (one pump out of three is for spare) are installed. The capacity of the seawater transfer pump will be about (7,086 m^3/h per unit), at which the flowrate of the seawater transfer pump can be measured, in order to enable sufficient dilution with seawater. And no flowrate adjustment is performed. Figure 5-3-5 shows the schematic diagram of the dilution facility.



*: To ensure the amount of seawater required for dilution of ALPS treated water, the volume of water per unit will be approx. 170,000 m^3/day

Figure 5-3-5 Schematic diagram of the dilution facility

As mentioned above, because dilution is performed by injecting ALPS treated water into the seawater pipe header and mixing it; the mixing behavior in the seawater piping of ALPS treated water was calculated, the expected dilution effect was assessed, the maximum mass concentration on the cross section of the concentration assessment at the seawater piping outlet of injected water was assessed to be 0.28%, and it was concluded that the water was diluted about 357 times.

5-3-5. Discharge facility (related facility)

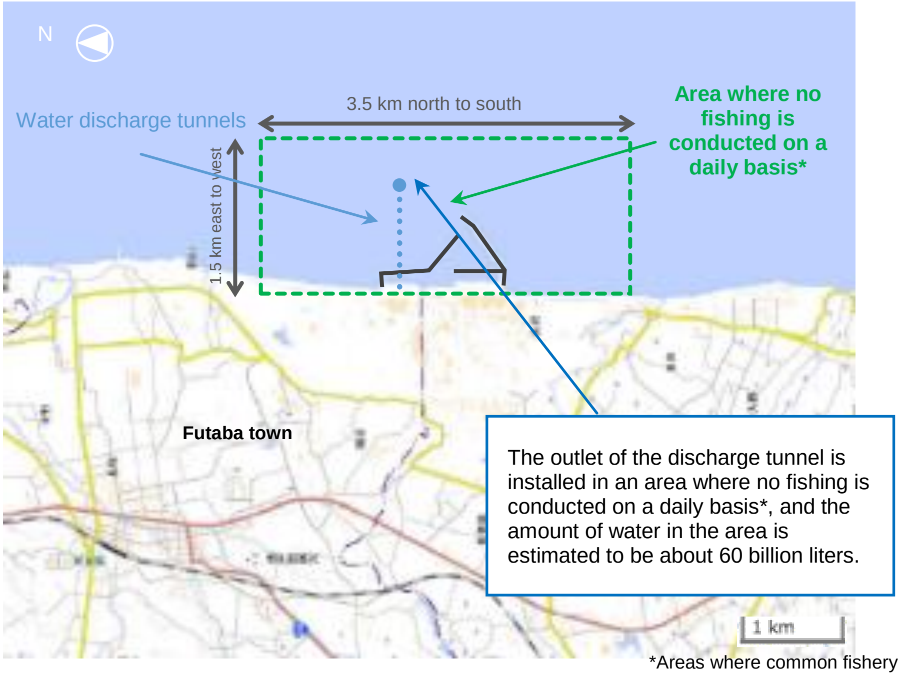
In this discharge of ALPS treated water into the sea, as a result of optimization of the design process, the water diluted and mixed with a large amount of seawater is discharged not through the existing discharge outlet installed on the coast to the north of the northern breakwater, but through the discharge outlet installed on the seabed about 1 km off the coast of the FDNPS (See Figures 5-3-6 to 5-3-7).

The discharge facility consists of the discharge vertical shaft (down-stream storage), discharge tunnel, and discharge outlet, and is designed to transfer water flowing out over the partition wall (weir which separates the upper-stream storage from the down-stream storage) in the discharge vertical shaft to the outlet, which is approximately 1 km away, by making use of the head between water in the discharge vertical shaft (down-stream storage) and the sea surface. The discharge tunnel passes through bedrock to minimize the leakage risk and improve seismic resistance.

This proposal has the following advantages compared with the proposal to use the existing discharge outlet.

- Compared with water intake inside and outside the port using the existing intake and discharge facilities, water inside the port, of which radioactive material concentration is higher than that of water outside the port, is not discharged. To take water outside the port, isolation from the inside of the port is secured with a partition weir in the south side of the Unit 5 intake gate, and a part of the permeation prevention work of the north breakwater of the port is removed. Attachment V “Impacts of intake and discharge of diluted water on outside” shows discussion about the impact of the radioactive material concentration in the port. As a result of the exposure assessment, the assessment results of both water intake inside and outside the port was much smaller than the dose limit and target dose value, but it turned out that the external impact of water intake outside the port is smaller.
- Since discharged water is diffused offshore, seawater is hard to recirculate (hard to be taken again as seawater for dilution).
- The impact on fishing is reduced by setting the position of the discharge outlet within “area where common fishery rights are not set” where fishing is not done on a daily basis.
- As a result of a geological investigation, a stable bedrock is exposed on the seabed, so construction can be performed safely and steadily (See Figure 5-3-8).

Figures 5-3-9 shows the overview of the structure of the discharge vertical shaft (upper-stream storage/down-stream storage) in the water discharge tunnel side. Figure 5-3-10 shows the image of the discharge outlet, which is the discharge tunnel outlet. Figure 5-3-11 shows its sectional view.



The outlet of the discharge tunnel is installed in an area where no fishing is conducted on a daily basis*, and the amount of water in the area is estimated to be about 60 billion liters.

*Areas where common fishery rights are not established

Source: the Geographical Survey Institute map (national land electronic website) revised by Tokyo Electric Power Company Holdings Corporation
https://maps.gsi.go.jp/#13/37.422730/141.044970/&base=std&ls=std&disp=1&vs=c1j0h0k0l0u0t0z0r0s0m0f1

Figure 5-3-6 Discharge location map

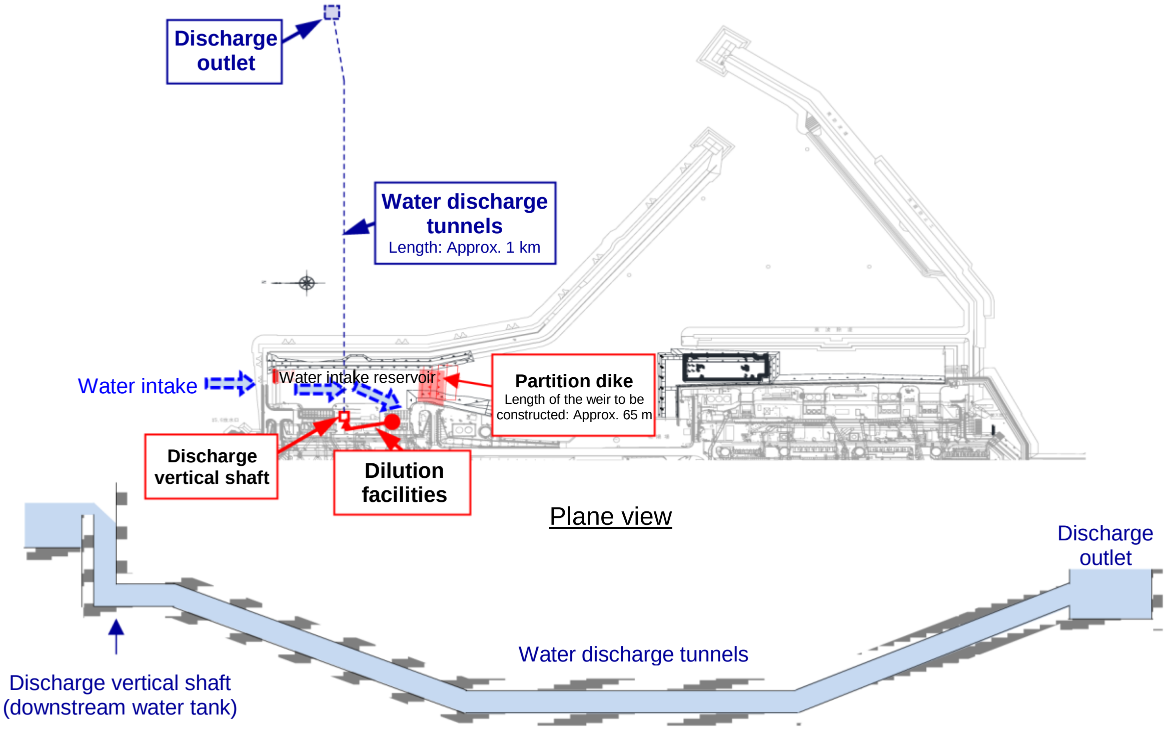


Figure 5-3-7 General view of the intake and discharge facilities

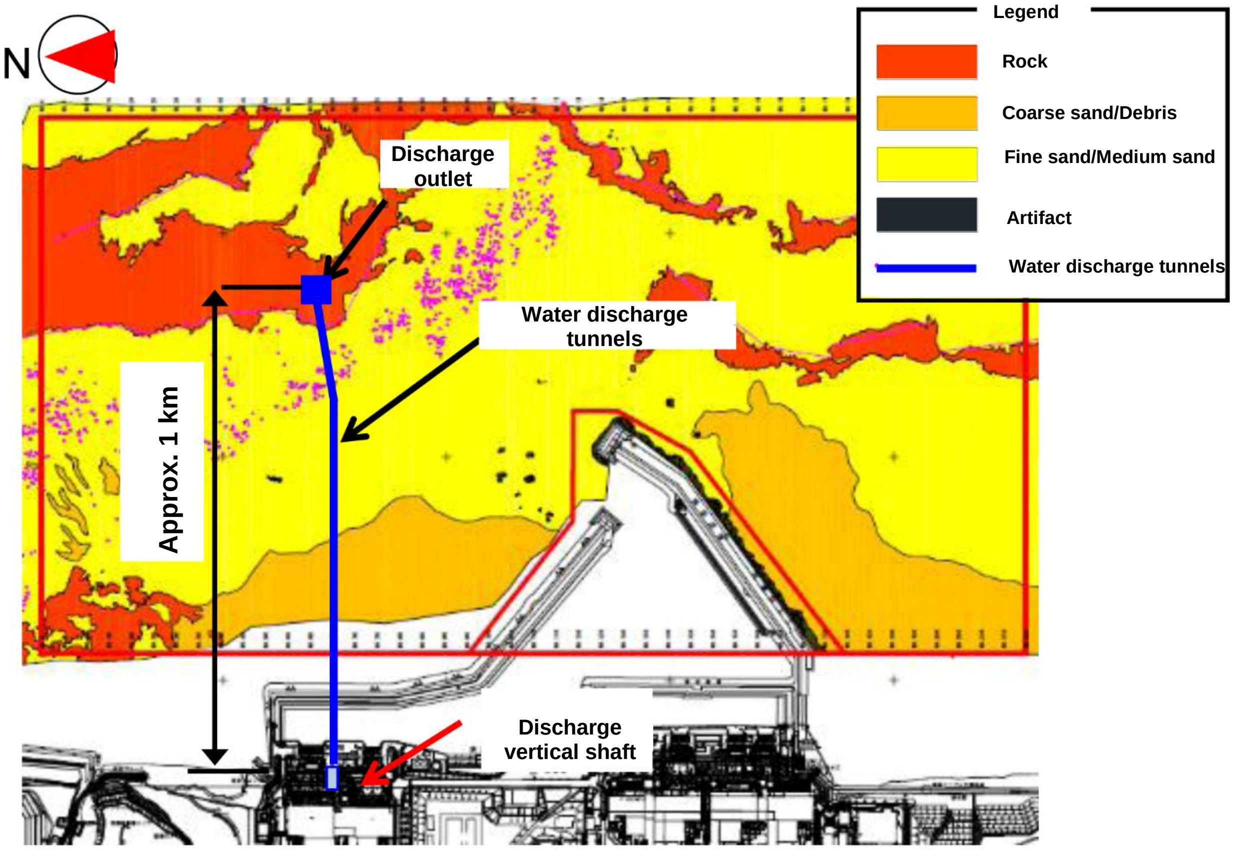


Figure 5-3-8 Plane view of assumed geology

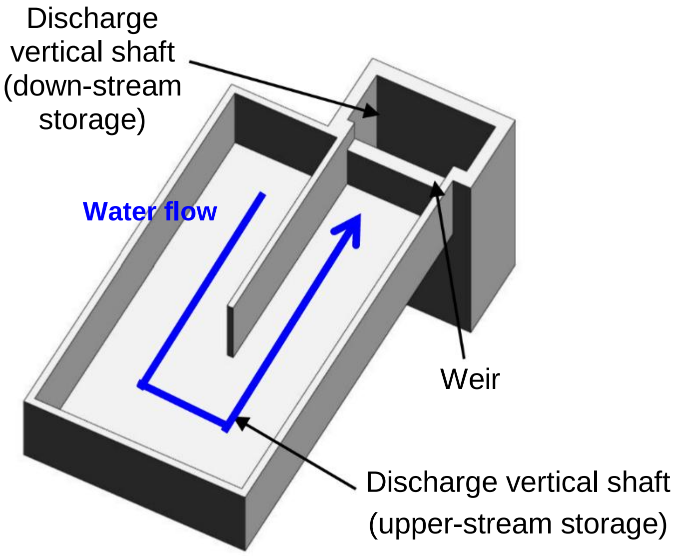


Figure 5-3-9 Schematic diagram of the discharge vertical shaft (upper-stream storage/down-stream storage)

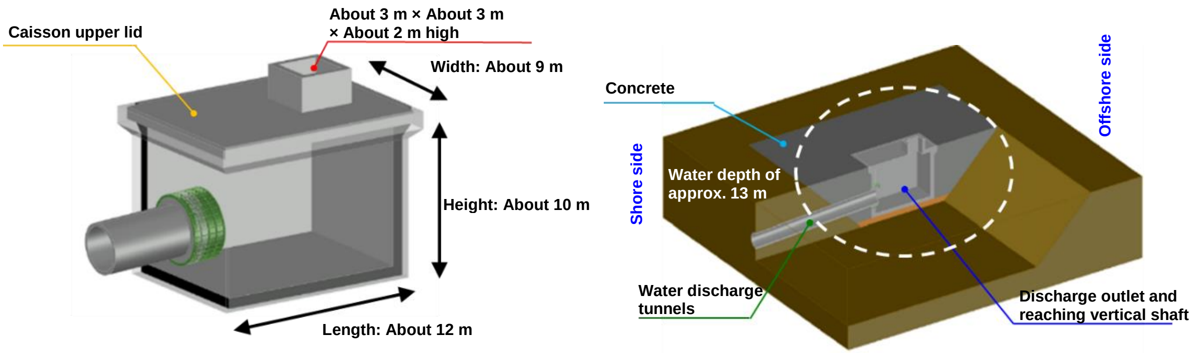


Figure 5-3-10　Image drawing of discharge outlet

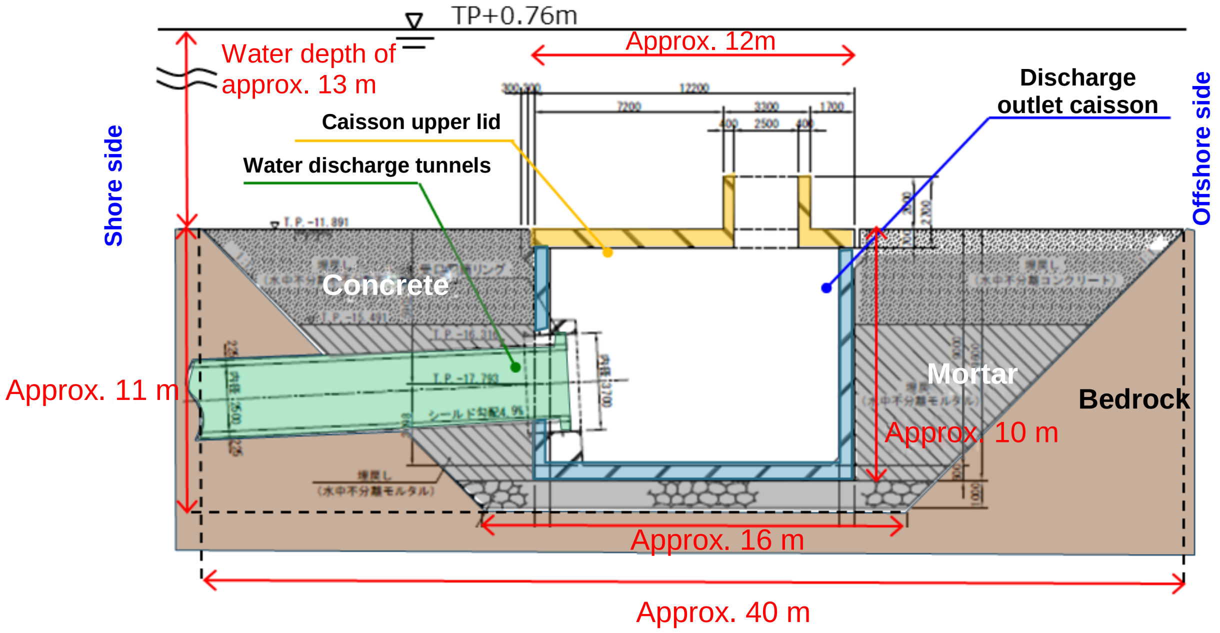


Figure 5-3-11　Section view of the discharge outlet

6. Assessment of protection of humans (general public)

6-1. Exposure assessment under normal conditions

6-1-1. Assessment procedure

We assess the dose of the representative person in order to verify the risk from the viewpoint of radiation protection for human based on the current consideration situation. The specific procedure of the assessment is as shown in the procedure of Figure 6-1-1 shown in GSG-10.

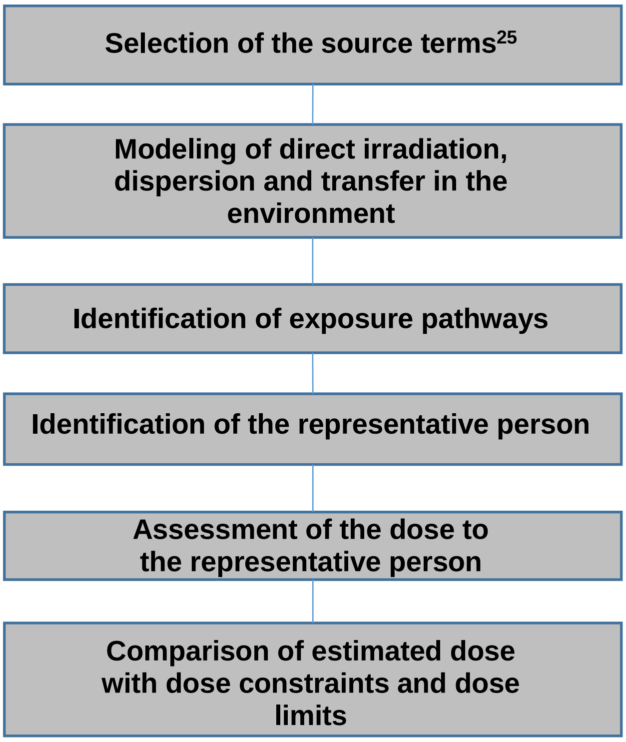


Figure 6-1-1 Exposure assessment procedure (prepared from GSG-10)

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[25] In this assessment, the source term means the annual discharge amount (total amount) of each nuclide contained in the ALPS treated water discharged into the sea in a certain period (e.g. one year).

6-1-2. Assessment method

(1) Source term (annual discharge amount of each nuclide)

As shown in 5-1, the target nuclides of the radiological environmental impact assessment related to discharge into the sea of ALPS treated water are a total of 64 were nuclides: 62 nuclides subject to removal by ALPS, tritium and C-14. However, TEPCO performs the radioactive environmental impact assessment with 30 nuclides, as target nuclides for dose assessment, which include tritium and 29 selected nuclides as nuclides to be measured and assessed (Table 5-1-2) in response to findings pointed by the NRA and the IAEA.

In “TEPCO’s Action in response to Government’s Policy,” the upper limit of the annual discharge amount of tritium is set to 22 TBq (2.2E+13Bq), which is the discharge control value of the FDNPS before the accident, for the time being.

The discharge amount of 29 nuclides other than tritium is calculated by the product of the composition of nuclides in ALPS treated water (concentration of each nuclide) and the annual discharge volume of water. Though the composition of nuclides in ALPS treated water varies among tank groups, TEPCO continues to use the compositions of nuclides of three tank groups, namely K4, J1-C, and J1-G, of which the analysis results of all of the 64 nuclides, previously designated as target nuclides for dose assessment, are available. Although Se-79 and Fe-55, which is newly selected as nuclides to be measured and assessed and they have not been subject to analysis of 64 nuclides in each of three tank groups to date, were not detected in the additional measurement carried out for this nuclide’s selection process. For Se-79, the concentration at the outlet of ALPS (detection limit value) was used in common for all the three tank groups, Fe-55 in K4 tank group used the concentration (detection limit value) of the tank group and in J1-C and J1-G tank group uses in common the concentration at the outlet of ALPS (detection limit) in common and for U-234, U-238 and Np-237 of alpha nuclides, the results of analysis on gross alpha were used, like before.

In addition, half-life correction was performed to be the concentration as of March 2023, 12 years after the accident, since the inventory as of March 2023 was used for the selection of nuclides to be measured and assessed.

i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

The water in the K4 tank group has been treated by one treatment process using the performance of ALPS to make the sum of the ratios to regulatory concentrations limits less than 1, as described in b.2016 of II-7. “Reason for generation of treated water to be purified” of Attachment II “Properties of ALPS treated water, etc.”

On the other hand, the water in the J1-C and J1-G tank groups has been treated while the operating rate of ALPS was high and stored as treated water to be purified because the sum of the ratios to regulatory concentrations limits did not fall below 1 after the first treatment by ALPS. The tank groups were selected as groups with a higher concentration (J1-C tank group; the sum of the ratios to regulatory concentrations limits before secondary treatment is about 2,400) and with a lower concentration (J1-G tank group; the sum of the ratios to regulatory concentrations limits before secondary treatment is about 390). Secondary treatment was performed for each of them and the sums of the ratios to regulatory concentrations limits of both of them were much less than 1 after secondary treatment.

We compared the concentration of the 7 major nuclides[26] and Tc-99 of these three tank groups with the measurement results of the tank groups in which the sum of the ratios to regulatory concentrations limits other than tritium is estimated to be less than 1 from the analysis result of the tank groups currently used for storage of water. Figure 6-1-2 shows the result. Though I-129 varies in the three tank groups as well as the other tank groups, the concentrations of the other nuclides are normal in the analysis results of the other tank groups as well. The reason why the three tank groups have lower Cs-134 result, the detection limits of the three tank groups were 0.1 Bq/L, while the detection limits of many other tank groups were from 0.1 to 0.2 Bq/L. Cs-134, a short half-life nuclide, of most tank groups were nevertheless undetected.

In addition, tritium and C-14, which are not subject to removal by ALPS, were compared with the measurement results of all tank groups. The comparison result is shown in Figure 6-1-3. The concentration of C-14 is also normal in the analysis results of the other tank groups.

Based on these comparisons, the compositions of the nuclides of the three tank groups are considered typical as the composition of concentrations in ALPS treated water. These source terms include uncertainties, which is described in chapter 8.

The 62 nuclides to removal by ALPS had been selected from fission products derived from fuel in the reactors of Unit 1 to 3 and the corrosion products derived from water retained in operating nuclear reactors. However, a gap found later between sum of the measured radioactive concentration of the 7 major nuclides of ALPS treated water and measured gross beta. Examinations has identified Tc-99 and C-14 as the cause of the gap and C-14 has been added into the required nuclides to be measured.

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[26] Seven nuclides which are significantly detected in the process of ALPS treatment at the facility inlet and outlet (Cs-134, Cs-147, Co-60, Sb-125, Ru-106, Sr-90, I-129)

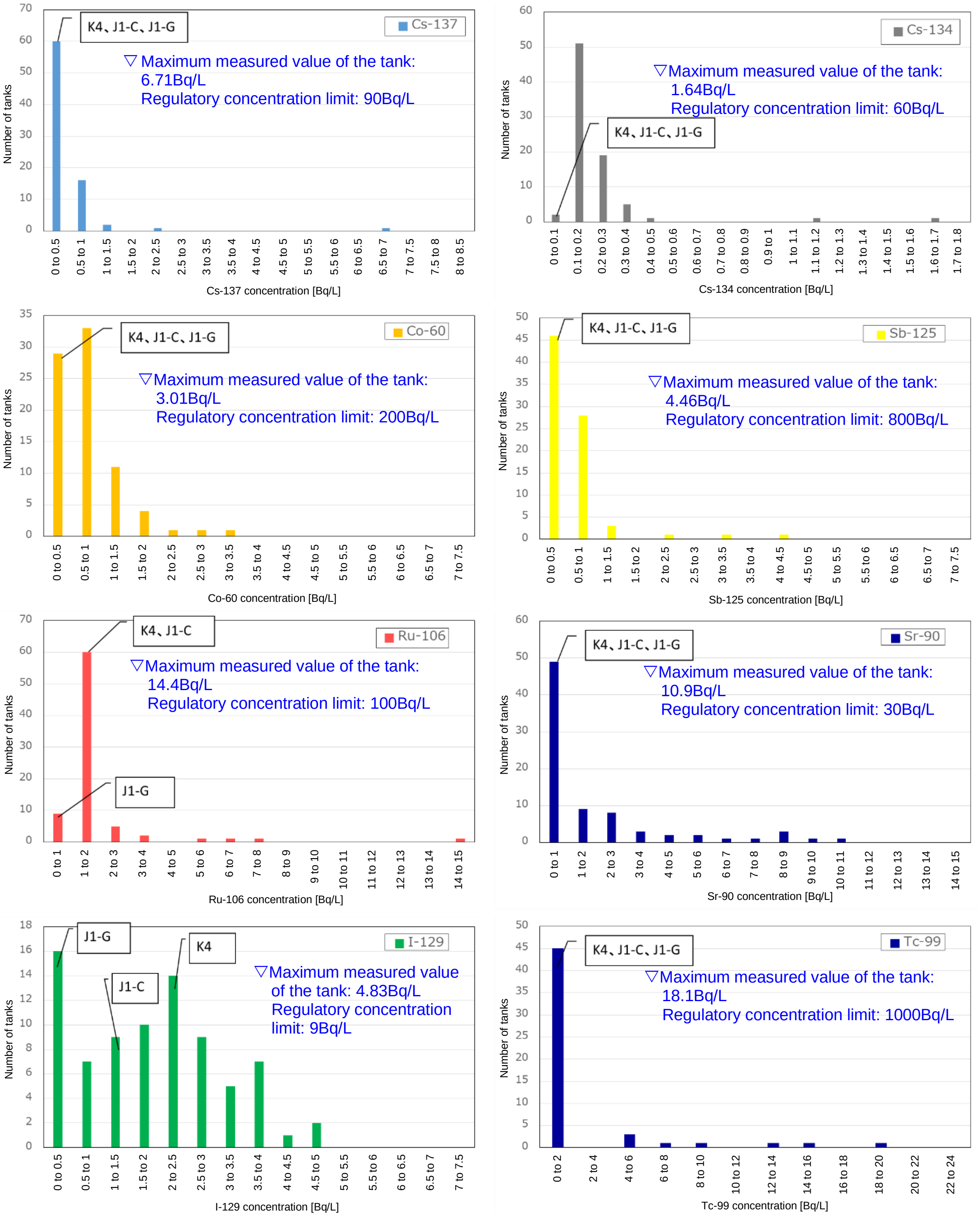

Figure 6-1-2 Concentration distribution of the seven major nuclides and Tc-99 in the analysis result of ALPS treated water (as of the end of March 2021), and comparison among the three tank groups

- * The analysis results in which the sum of the ratios to regulatory concentrations limits of the 7 major nuclides is less than 0.59 (for 80 tanks) (excluding secondary treatment test water)
- * The vertical axis indicates the number of tanks
- * Some maximum values are the detection limit values if they were not detected.
- * Values are measured values at the times and no half-life correction is considered.

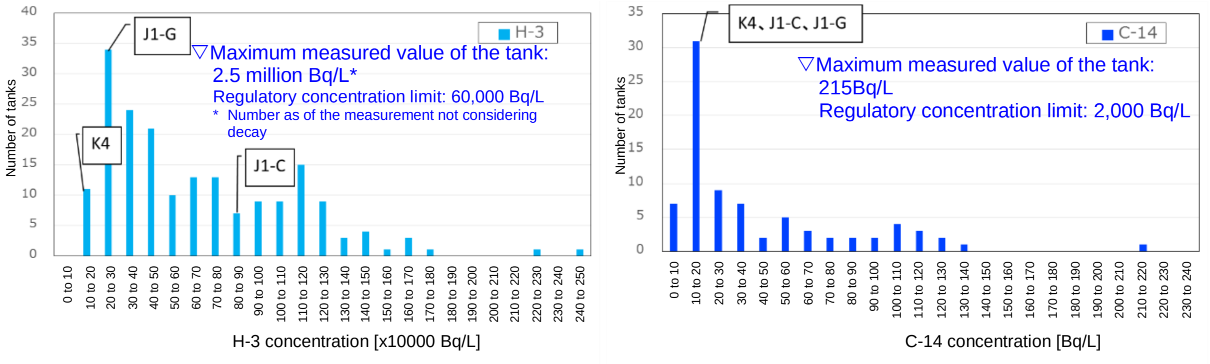

Figure 6-1-3 Concentration distribution of tritium and C-14 in the analysis result of ALPS treated water, etc. (as of the end of March 2021) and comparison among the three tank groups

* The analysis results of the tank group (189 tanks for tritium and 81 tanks for C-14) are plotted (excluding secondary treatment test water)

* The vertical axis indicates the number of tanks (counted as the detection limit if not detected)

* Values are measured values at the times and no half-life correction is considered.

On the other hand, the tritium concentration of stored ALPS treated water, etc., varies as shown in Figure 6-1-3, so the assumed annual discharge volume of treated water depends on the concentration of tritium contained in ALPS treated water to be discharged. The annual discharge volume of water is in inverse proportion to the tritium concentration; the lower the tritium concentration is, the greater the annual discharge amount of 29 nuclides other than tritium becomes. The relationships are as shown in the following equation.

$$S_i = V \times C_i = \frac{S_{H-3}}{C_{H-3}} \times C_i$$

where

S_i : Annual radioactivity amount of discharged nuclide i (Bq)

V : Annual discharge volume of ALPS treated water (L)

C_i: Concentration of nuclide i contained in the ALPS treated water discharged (Bq/L)

S_{H-3}: Annual radioactivity amount of tritium discharged
(= 22 TBq (2.2E+13Bq))

C_{H-3}: Concentration of tritium contained in the ALPS treated water discharged (Bq/L)

Among them the values of C_i and C_{H-3} are given by the definition of each nuclide’s compositions in this assessment, which means that the annual discharge amount of each nuclide is uniquely determined from the concentration of tritium of the nuclide’s compositions.

The source term using the analysis result of each tank group is set by the following procedure. In actual discharge, the source term varies among tank groups, but this assessment assumes that it does not vary throughout the year for simplification of the model.
Tables 6-1-1 to 6-1-3 show the concentration, annual discharge volume of water, and annual discharge amount of each nuclide based on these settings.

(1) The annual discharge amount of tritium will be the upper limit: 22 TBq (2.2E+13Bq).
(2) The annual discharge volume of water is calculated from (1) and the tritium concentration.
(3) The annual discharge amount of each nuclide is calculated from the concentration of 29 nuclides and the product of the annual discharge amount calculated in (2). Some of the nuclides below the detection limit value may not actually be present any more, but conservatively they are assumed to exist at the detection limit.

Actually, when ALPS treated water is discharged, the sum of the ratios to regulatory concentrations limits of nuclides other than tritium becomes less than 0.01 because as shown in 5-2, the water is diluted with seawater 100 or more times before discharge into the sea so that the tritium concentration falls below 1,500Bq/L, which is the target value of the groundwater bypass and subdrain.

Table 6-1-1 Source term based on the nuclide composition of measured values (K4 tank group) (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
H-3	1.4E+05	1.6E+08	2.2E+13	• For the annual discharge amount of tritium, the upper limit value of the annual discharge amount is used • Dilute with seawater 100 or more times before discharge so that the tritium concentration becomes less than 1,500Bq/L
C-14	1.5E+01		2.4E+09	
Mn-54	8.5E-05		1.3E+04	
Fe-55	2.1E+00		3.3E+08	
Co-60	2.2E-01		3.5E+07	
Ni-63	2.1E+00		3.3E+08	
Se-79	1.5E+00		2.4E+08	
Sr-90	1.9E-01		3.0E+07	
Y-90	1.9E-01		3.0E+07	
Tc-99	7.0E-01		1.1E+08	
Ru-106	4.2E-02		6.6E+06	
Sb-125	8.6E-02		1.4E+07	
Te-125m	8.6E-02		1.4E+07	
I-129	2.1E+00		3.3E+08	

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
Cs-134	7.4E-03		1.2E+06	
Cs-137	3.7E-01		5.8E+07	
Ce-144	5.3E-04		8.3E+04	
Pm-147	4.5E-02		7.1E+06	
Sm-151	8.6E-04		1.4E+05	
Eu-154	7.8E-03		1.2E+06	
Eu-155	1.5E-02		2.4E+06	
U-234	6.3E-04		9.9E+04	
U-238	6.3E-04		9.9E+04	
Np-237	6.3E-04		9.9E+04	
Pu-238	6.0E-04		9.4E+04	
Pu-239	6.3E-04		9.9E+04	
Pu-240	6.3E-04		9.9E+04	
Pu-241	2.2E-02		3.5E+06	
Am-241	6.2E-04		9.7E+04	
Cm-244	5.1E-04		8.0E+04	

Table 6-1-2 Source term based on the nuclide composition of measured values (J1-C tank group) (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
H-3	7.2E+05	3.1E+07	2.2E+13	• For the annual discharge amount of tritium, the upper limit value of the annual discharge amount is used • Dilute with seawater 100 or more times before discharge so that the tritium concentration becomes less than 1,500Bq/L
C-14	1.8E+01		5.5E+08	
Mn-54	5.3E-03		1.6E+05	
Fe-55	2.4E+00		7.3E+07	
Co-60	2.4E-01		7.3E+06	
Ni-63	8.3E+00		2.5E+08	
Se-79	1.5E+00		4.6E+07	
Sr-90	3.4E-02		1.0E+06	
Y-90	3.4E-02		1.0E+06	
Tc-99	1.2E+00		3.7E+07	
Ru-106	2.7E-01		8.3E+06	
Sb-125	1.2E-01		3.7E+06	
Te-125m	1.2E-01		3.7E+06	
I-129	1.2E+00		3.7E+07	
Cs-134	3.3E-02		1.0E+06	
Cs-137	1.7E-01		5.2E+06	
Ce-144	6.4E-02		2.0E+06	

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
Pm-147	4.2E-01		1.3E+07	
Sm-151	1.1E-02		3.4E+05	
Eu-154	9.4E-02		2.9E+06	
Eu-155	2.4E-01		7.3E+06	
U-234	3.2E-02		9.8E+05	
U-238	3.2E-02		9.8E+05	
Np-237	3.2E-02		9.8E+05	
Pu-238	3.2E-02		9.8E+05	
Pu-239	3.2E-02		9.8E+05	
Pu-240	3.2E-02		9.8E+05	
Pu-241	1.1E+00		3.4E+07	
Am-241	3.2E-02		9.8E+05	
Cm-244	3.0E-02		9.2E+05	

Table 6-1-3 Source term based on the nuclide composition of measured values (J1-G tank group) (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
H-3	2.4E+05	9.2E+07	2.2E+13	• For the annual discharge amount of tritium, the upper limit value of the annual discharge amount is used • Dilute with seawater 100 or more times before discharge so that the tritium concentration becomes less than 1,500Bq/L
C-14	1.6E+01		1.5E+09	
Mn-54	5.4E-03		5.0E+05	
Fe-55	2.4E+00		2.2E+08	
Co-60	1.7E-01		1.6E+07	
Ni-63	8.7E+00		8.0E+08	
Se-79	1.5E+00		1.4E+08	
Sr-90	3.0E-02		2.8E+06	
Y-90	3.0E-02		2.8E+06	
Tc-99	1.3E+00		1.2E+08	
Ru-106	9.4E-02		8.6E+06	
Sb-125	7.5E-02		6.9E+06	
Te-125m	7.5E-02		6.9E+06	
I-129	3.3E-01		3.0E+07	
Cs-134	3.0E-02		2.8E+06	
Cs-137	3.1E-01		2.8E+07	
Ce-144	6.5E-02		6.0E+06	
Pm-147	3.8E-01		3.5E+07	
Sm-151	9.8E-03		9.0E+05	
Eu-154	8.4E-02		7.7E+06	

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
Eu-155	1.2E-01		1.1E+07	
U-234	2.8E-02		2.6E+06	
U-238	2.8E-02		2.6E+06	
Np-237	2.8E-02		2.6E+06	
Pu-238	2.7E-02		2.5E+06	
Pu-239	2.8E-02		2.6E+06	
Pu-240	2.8E-02		2.6E+06	
Pu-241	8.9E-01		8.2E+07	
Am-241	2.8E-02		2.6E+06	
Cm-244	2.6E-02		2.4E+06	

(2) Modeling of diffusion and transfer after discharge

(1) Selection of the migration model

As the migration model of radioactive materials discharged into the sea, the following was selected referring to GSG-10, domestic cases, etc. For the timeline of selection, etc., see Attachment VI “Transfer pathways and exposure pathways other than the assessment targets.”

i. Advection and diffusion by tidal currents, etc.

Advection and diffusion in the sea were selected because the water will be discharged into the sea.

ii. Advection and diffusion by tidal currents, etc. -> Adhesion to hulls

Adhesion to hulls is selected because ships sail for fishing, etc., in the sea.

iii. Advection and diffusion by tidal currents, etc. -> Adhesion to seabed sediment and beach sand

Selected because radioactive materials will be advected and diffused by tidal currents, etc., and migrate to seabed sediment, beach sand, etc.

iv. Advection and diffusion by tidal currents, etc. -> Adhesion to fishing nets

Migration to fishing nets is selected because radioactive materials will be advected and diffused by tidal currents, etc., and adhered to fishing nets used in the surrounding area.

v. Advection and diffusion by tidal currents -> Resuspension to air by seawater spray

Selected because radioactive materials will be advected and diffused by tidal currents, etc., and seawater spray will occur due to waves, etc., at beaches.

vi. Advection and diffusion by tidal currents, etc. -> Intake and concentration by marine organisms such as fish

Selected because radioactive materials will be advected and diffused by tidal currents, etc., and migrate to and concentrate in fish.

(2) Assessment of advection and diffusion in the sea area

For the calculation of diffusion of radioactive materials in the sea area, the area sea model “ROMS: Regional Ocean Modeling System” applied to off-shore of Fukushima by Central Research Institute of Electric Power Industry (CRIEPI) is used. This model was verified to have high reproducibility by reproduction calculation of the cesium concentration in the seawater from actual past meteorological and oceanographic data and comparison with actual data for diffusion of cesium leaked into the sea due to the Accident at the FDNPS (Tsumune et al., 2020) [4], and also used in “TEPCO Draft Study Responding to the Subcommittee Report on Handling ALPS Treated Water,” [22] which was issued on March 24, 2020. The concentration was calculated from the model of the sea area near the FDNPS at high resolution in order to set the discharge point and the FDNPS port facilities more correctly. It was verified that higher resolution improved the reproducibility of the concentration in the seawater of cesium leaked due to the accident at the FDNPS. Attachment VII “Validity of the diffusion simulation” shows discussion about the validity of diffusion simulation.

In this report, the concentration in the seawater was calculated from this model in the case of discharge of a total of 22 TBq (2.2E+13Bq) of tritium per year at an even pace throughout the year, and those of the other nuclides were calculated by proportionate calculation of the annual discharge amount with tritium.

In this model, tritium equivalent to the discharge rate is added to the mesh including the discharge point so that it instantaneously spreads evenly in the mesh. Due to the characteristics of the model, dilution of ALPS treated water with the seawater and the promotion effect of the discharge flow velocity on mixing dilution are not considered, so it may be different from the contribution distribution in the actual discharge near the discharge outlet, but there is considered to be no significant difference in the case of diffusion away from the discharge outlet.

This can also be verified by comparing the diffusion simulation results with different discharge points, shown in Attachment VIII “Difference in the diffusion area by discharge location.” The annual mean concentration in the 10 km × 10 km area when ALPS treated water is discharged from the unit 5/6 discharge outlet on the sea surface is higher only by 20% than the concentration when ALPS treated water is discharged from an outlet on the seabed 1 km off the coast.

The following shows the major calculation conditions.

Flow data of the sea area

- For the advection term of the flow and tracer as a setting of ROMS (term representing migration with the flow velocity), third-order upwind difference and MPDATA, respectively, were used; for the harmonic viscosity and diffusion terms, forth-order central difference. The horizontal viscosity and diffusion coefficients are set to 5.0 m^2/s. For the vertical viscosity and diffusion, the K-profile parameterization mixing (KPP) model (Large et al., 1994) is used and the minimum limit value of the vertical viscosity and diffusion coefficients are set 10^{-5} m^2/s and 10^{-6} m^2/s, respectively.
- For the drive force of the sea surface, we used the result of reanalysis (wind velocity, short wave, long wave, atmospheric pressure, ambient temperature, humidity, and precipitation) with a short-term weather prediction system (Numerical Weather Forecasting and Analysis System (NuWFAS), Hashimoto et al., 2010) [23], which interpolate the short-term weather prediction of the Japan Meteorological Agency (JMA-GSM) using the mesoscale weather model (Weather Research and Forecasting model (WRF), Skamarock, et al, 2008 [24]). The time resolution of the output of NuWFAS is about 1 hour and the horizontal resolution is 5 km, so in the simulation, the result with the time and horizontal direction interpolated was given.
- As the original data of the boundary conditions and data assimilation (nudging)[27], we used the results (water temperature, salt content, and sea surface height) of the reanalysis data of tidal currents updated in real-time (Japan Coastal Ocean Prediction Experiment 2 (JCOPE2, Miyazawa et al., 2009)[28] [25].
- Since the off-shore of Fukushima, which is a mixed area of Oyashio and Kuroshio (a cold current form north and a warm current from south, respectively) is affected by the mesoscale vortex, data assimilation (nudging) was applied which mitigates the simulation result into the reanalysis result of the water temperature and salt content by JCOPE2 (The mitigation factor is a daily reciprocal) for the purpose of reproducing complex behavior such as the mesoscale vortex.
- The drive force by tide was set by interpolating the result (8-divided tide: M2, S2, N2, K2, K1, O1, P1, Q1) of the global tide model (TPXO; Egbert and Erofeeva, 2002) as the tidal level, the tidal ellipse, and their phases near the open boundary. Since the resolution of the result of TPXO is 0.25° × 0.25°, it is likely that the tidal level amplitude and phase associated with synthesis of reflected wave near the coast cannot be set correctly near the boundary. To correct the tidal components of the boundary, harmonic analysis to resolve each tidal level component for the simulation result at the tidal observation points of JMA (Ofunato, Ayukawa, Onahama, and Choshi) was performed to compare tidal level observation data to adjust the scales and phases of the tidal level and tide of the

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[27] Data assimilation: Method to incorporate actual data in numerical simulation.

[28] JCOPE2: Tidal current prediction model developed by JAMSTEC to ascertain the variations of the Kuroshio/Kuroshio Extension, the Oyashio current, the mesoscale vortex, etc., in the northwestern Pacific Ocean.

boundary conditions. Actually, the difference between the simulation and observation results was averaged, and adjustments were made with the averaged difference.

Range of the model (See Figure 6-1-4)

Resolution (overall): North-south about 925 m x East-west about 735 m (about 1 km), 30 vertical layers

Resolution (adjacent area): North-south about 185 m x East-west about 147 m (about 200 m), 30 vertical layers

Model range: The resolution of the sea area surrounded by the blue and red lines is improved in stages from a mesh of about 1 km mesh so that the sea area where the red and blue batches of the northern latitude of 35.30 to 39.71 degrees, the eastern longitude of 140.30 to 143.50 degrees (490 km × 270 km), and north-south about 22.5 km x east-west about 8.4 km around the FDNPS get crossed becomes a 200-m mesh

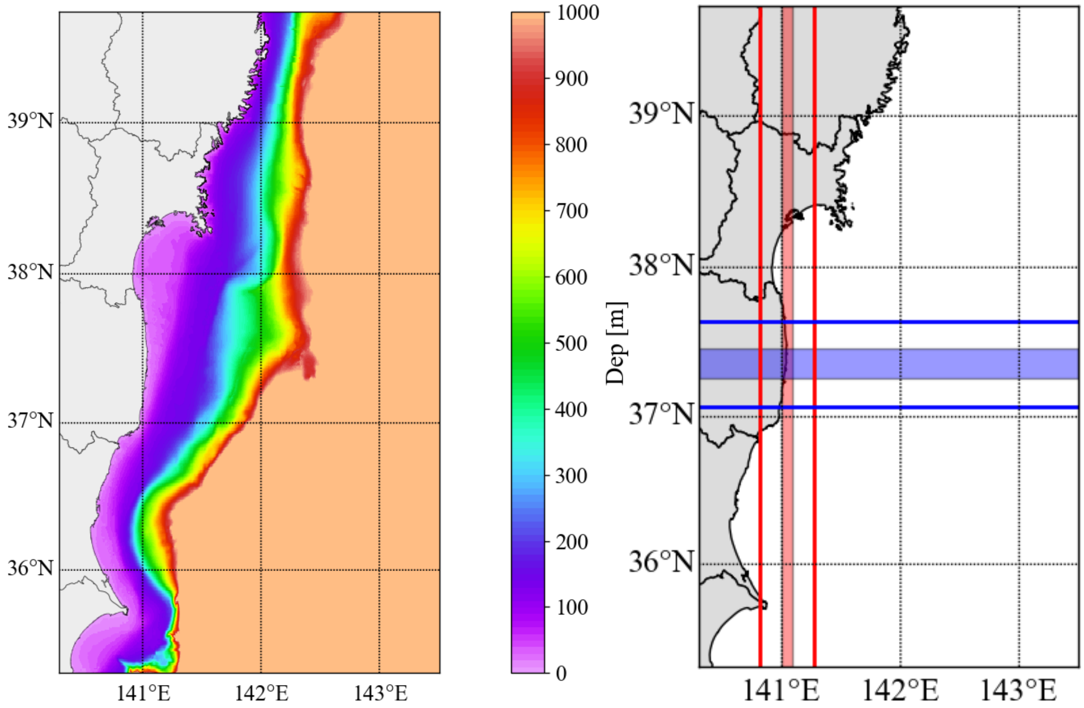

Figure 6-1-4 Range of the model and water depth distribution
(In the right figure, the resolution of the sea area where the red and blue hatches get crossed is improved into a 200-m mesh)

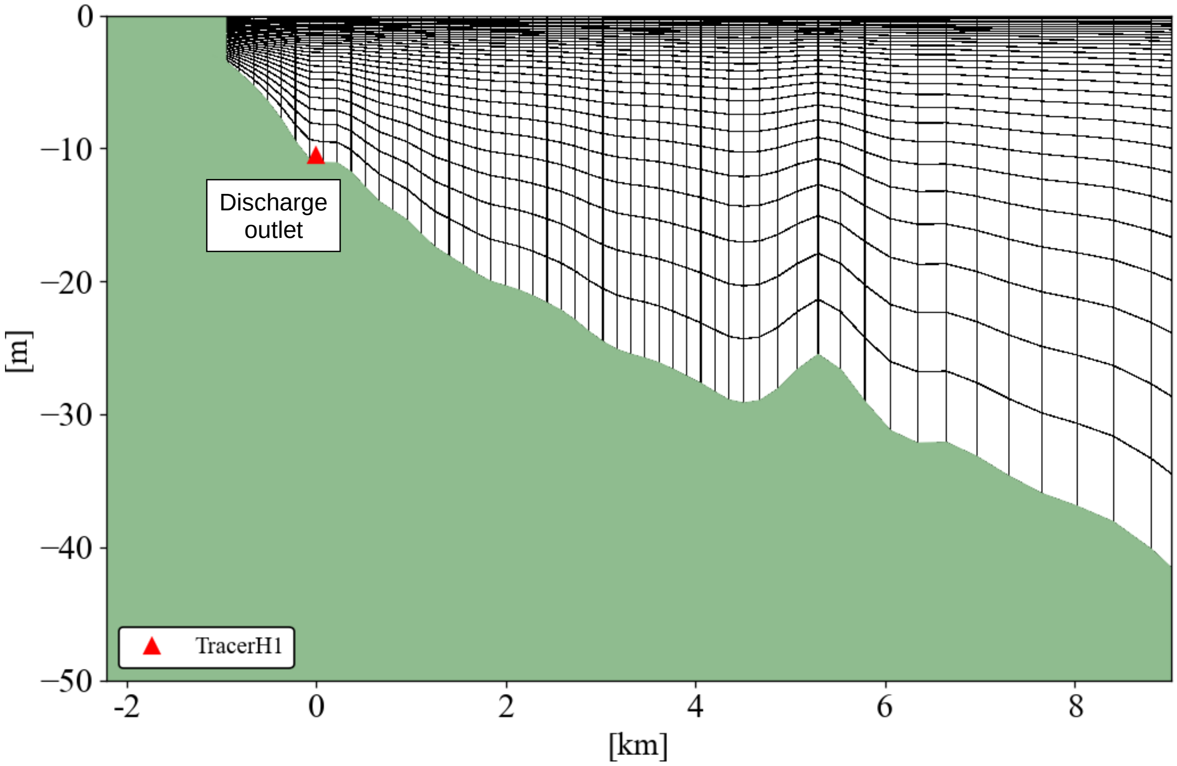

Figure 6-1-5 Section view of the seabed up to 10 km offshore and vertical division on the model

(3) Setting of exposure pathways

A total of eight exposure pathways are selected based on the existing assessments, GSG-10, etc.[29]: five external exposure pathways and three internal exposure pathways. The following shows the concept of selection. In revising the report, we clarified the beach assessment point described below and added ingestion of seawater and inhalation of seawater spray as express pathways related to beaches.

(1) External exposure from sea surface

Selected as an exposure pathway because external exposure may occur from radiation from radioactive materials in the seawater during offshore navigation by ship or offshore work.

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[29] IAEA-TECDOC-1759, "Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure" (2015)

(2) External exposure from hulls

Selected as an exposure pathway because external exposure may occur from radiation from radioactive materials that have migrated from the seawater to hulls (deck) during offshore navigation by ship or offshore work.

(3) Underwater external exposure during swimming, etc.

Selected as an exposure pathway because external exposure may occur from radiation from radioactive materials in the surrounding seawater during swimming, etc.

(4) External exposure from beach sand

Selected as an exposure pathway because external exposure may occur from radiation from radioactive materials that have moved from seawater to beach sand.

(5) External exposure from fishing nets

Selected as an exposure pathway because external exposure may occur from radiation from radioactive materials that have migrated from the seawater to fishing nets because fishing nets are used in the seawater for fishing.

(6) Internal exposure from ingestion of seawater

Selected as an exposure pathway because internal exposure may occur from radiation from radioactive materials in the seawater due to accidental ingestion of seawater.

(7) Internal exposure from inhalation of seawater spray

Selected as an exposure pathway because internal exposure may occur from radiation from radioactive materials in the seawater due to inhalation of seawater spray caused by waves on beaches.

(8) Internal exposure from ingestion of seafood

Selected as an exposure pathway because internal exposure may occur from ingestion of seafood that radioactive materials in the seawater have moved to and concentrated.

The following shows the assessment model and used parameters of each exposure pathway.

a. External exposure

To assess external exposures, the exposure assessment model and the effective dose conversion factor described in Handbook for Determining Environmental Impacts of Decommissioning Work [26] (hereinafter called “Decommissioning Handbook") is used. Because ICRP Publication 101a “Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public” [27] describes that “it is generally recognized that for external exposure in the environment, there is little variability in dose per unit of exposure with age,” age grouping is not set for assessment of external exposure.

(1) External exposure from sea surface

Assess the external exposure from radioactive materials in the seawater during swimming and offshore work by the model shown in Figure 6-1-6.

Equation (6-1-1) shows the calculation equation of the effective dose D_1(mSv/year) from radiation from the sea surface.

$$\mathrm{D}_1 = \sum_i (K_1)_i \cdot (x_1)_i \cdot t_1 \qquad (6\text{-}1\text{-}1)$$

where

$(K_1)_i$ is the effective dose conversion factor from gamma radiation from nuclide i from sea surface ((mSv/h)/(Bq/L))

$(x_1)_i$ is the concentration of nuclide i in seawater (Bq/L)

t_1 is the annual exposure time (h/year)

For the effective dose conversion factor[30] from the gamma rays from the sea surface, the value in the Decommissioning Handbook was used. For the calculation of the dose conversion factor for the effective dose, the simple shielding calculation code QAD-CGGP2 is used using the point attenuation nuclear integration method. For β and γ nuclides and α nuclides not shown in the Decommissioning Handbook, conservatively, the highest values, Co-60 and Am-243, respectively were used (Table 6-1-5).

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

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[30] Radiation dose per hour (mSv/h) from radiation from radioactive materials contained in the seawater ingested by those working above the sea surface when any radioactive materials are contained in the seawater at a concentration of 1Bq/L, as shown in the model of Figure 6-1-6.

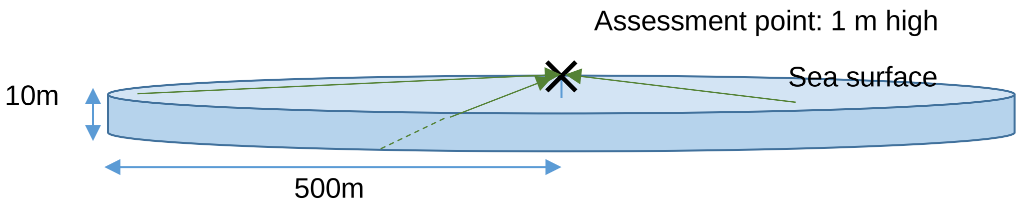

Figure 6-1-6 Assessment model of exposure from the sea surface in the decommissioning handbook

(2) External exposure from hulls

Assess the external exposure from radioactive materials that have migrated from the seawater to hulls during offshore work such as movement by ship by the model shown in Figure 6-1-7.

Equations (6-1-2) and (6-1-3) show the calculation equation of the effective dose D_2(mSv/year) from hulls.

$$\mathrm{D}_2 = \sum_i (K_2)_i \cdot (S_2)_i \cdot t_2 \tag{6-1-2}$$

$$(S_2)_i = (F_2)_i \cdot (x_2)_i \tag{6-1-3}$$

where

$(K_2)_i$	is the effective dose conversion factor from gamma radiation from nuclide i from hulls ((mSv/h)/(Bq/m^2))
$(S_2)_i$	is the contamination density of nuclide i in hulls (Bq/m^2)
t_2	is the annual exposure time (h/year)
$(F_2)_i$	is the migration factor of nuclide i from seawater to hulls ((Bq/m^2)/(Bq/L))
$(x_2)_i$	is the concentration of nuclide i in seawater (Bq/L)

For the effective dose conversion factor[31] from the gamma rays from radioactive materials adhered to hulls, the value of the Decommissioning Handbook was used. For the calculation of the dose conversion factor for the effective dose, the simple shielding calculation code QAD-CGGP2 is used using the point attenuation nuclear integration method. For β and γ nuclides and α nuclides not shown in the Decommissioning Handbook, conservatively, the highest values, Co-60 and Am-243, respectively were used (Table 6-1-6). The factor of migration to hulls[32] was assumed to be constantly in the equilibrium state with the concentration in the seawater at 100((Bq/m^2)/(Bq/L))

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[31] Radiation dose ingested by people on ships from radiation emitted from radioactive materials that have migrated from the seawater to hulls; evaluated by the model of Figure 6-1-7; and shown as a coefficient for the deposit density of radioactive materials adhered to hulls.

[32] Degree of adhesion of radioactive materials to what contacts the seawater if the concentration of radioactive materials contained in the seawater is 1Bq/L, shown as radiation per unit area.

according to “Application for the Designation of Reprocessing Business of Rokkasho Plant” (Japan Nuclear Fuel Service, 1989). [28]

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

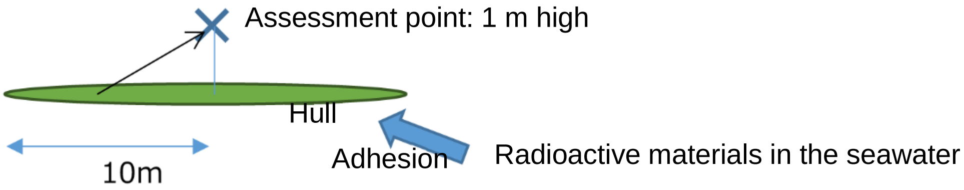

Figure 6-1-7 Assessment model of exposure from hulls in the decommissioning handbook

(3) Underwater external exposure during swimming, etc.

Assess the external exposure from gamma rays from radioactive materials in the surrounding seawater during swimming and underwater work by the submersion model[33].

Equation (6-1-4) shows the calculation equation of the effective dose D_3(mSv/year) from radiation during swimming and underwater work.

$$\mathrm{D}_3 = \sum_i (K_3)_i \cdot (x_3)_i \cdot t_3 \tag{6-1-4}$$

where

$(K_3)_i$ is the effective dose conversion factor from gamma radiation from nuclide i from seawater ((mSv/h)/(Bq/L))

$(x_3)_i$ is the concentration of nuclide i in seawater (Bq/L)

t_3 is the annual swimming time (h/year)

For the effective dose conversion factor from the gamma rays in the seawater, the value of the Decommissioning Handbook was used. For β and γ nuclides and α nuclides not shown in the Decommissioning Handbook, conservatively, the highest values, Co-60 and Am-243, respectively were used (Table 6-1-7).

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

(4) External exposure from beach sand

Assess the external exposure from radioactive materials migrated from seawater to beach sand while staying on a beach by the model shown in Figure 6-1-8.

Equation (6-1-5) shows the calculation equation of the effective dose D_4(mSv/year) from the gamma radiation from beach sand.

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[33] Model to calculate exposure from radiation from the surrounding radioactive materials.

$$D_4 = \sum_i (K_4)_i \cdot (x_4)_i \cdot (F_4)_i \cdot t_4 \qquad (6\text{-}1\text{-}5)$$

where

$(K_4)_i$	is the effective dose conversion factor from gamma radiation from nuclide *i* from beach sand ((mSv/h)/(Bq/kg))
$(x_4)_i$	is the concentration of nuclide i in seawater (Bq/L)
$(F_4)_i$	is the migration factor of nuclide i from seawater to beaches ((Bq/kg)/(Bq/L))
t_4	is the annual exposure time (h/year)

For the effective dose conversion factor from the gamma rays from beach sand, the value of the Decommissioning Handbook was used. For the calculation of the dose conversion factor for the effective dose, the simple shielding calculation code QAD-CGGP2 is used using the point attenuation nuclear integration method. For β and γ nuclides and α nuclides not shown in the Decommissioning Handbook, conservatively, the highest values, Co-60 and Am-243, respectively were used (Table 6-1-8). The migration factor of nuclides to beaches is assumed to constantly in the equilibrium state with the concentration in the seawater at 1,000((Bq/kg)/(Bq/L)) for all nuclides based on "Dose Assessment to the General Public in the Safety Review of Commercial Light Water Reactor Facilities."

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

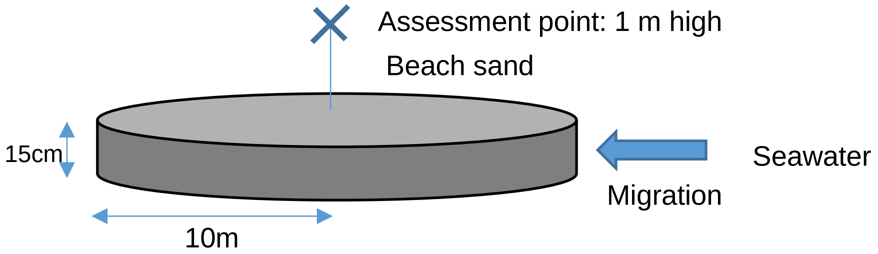

Figure 6-1-8 Assessment model of exposure from beach sand in the decommissioning handbook

(5) External exposure from fishing nets

Assess external exposure from radioactive materials that have migrated from the seawater to fishing nets and adhered to fishing nets when they are placed on a ship or ground during fishing work, by the model shown in Figure 6-1-9.

Equations (6-1-6) and (6-1-7) show the calculation equation of the effective dose D_5(mSv/year) from radioactive materials adhered to fishing nets.

$$D_5 = \sum_i (K_5)_i \cdot (S_5)_i \cdot t_5 \tag{6-1-6}$$

$$(S_5)_i = (F_5)_i \cdot (x_5)_i \tag{6-1-7}$$

where

$(K_5)_i$ is the effective dose conversion factor from gamma radiation from nuclide i from fishing nets ((mSv/h)/(Bq/kg))

$(S_5)_i$ is the concentration of nuclide i on fishing nets (Bq/kg)

t_5 is the annual exposure time (h/year)

$(F_5)_i$ is the migration factor of nuclide i from seawater to fishing nets ((Bq/kg)/(Bq/L))

$(x_5)_i$ is the concentration of nuclide i in seawater (Bq/L)

For the effective dose conversion factor, the value of the Decommissioning Handbook was used. For the calculation of the dose conversion factor for the effective dose, the simple shielding calculation code QAD-CGGP2 is used using the point attenuation nuclear integration method. For β and γ nuclides and α nuclides not shown in the Decommissioning Handbook, conservatively, the highest values, Co-60 and Am-243, respectively were used (Table 6-1-9). The factor of migration to fishing nets was assumed to be constantly in the equilibrium state with the concentration in the seawater at 4,000((Bq/kg)/(Bq/L)) for all nuclides other than tritium according to "Application for the Designation of Reprocessing Business of Rokkasho Plant."

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

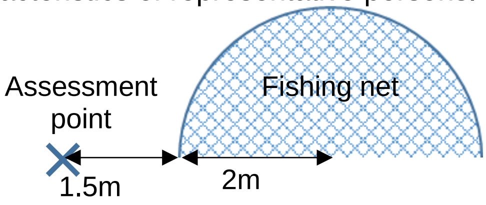

Figure 6-1-9 Assessment model of exposure from fishing nets in the decommissioning handbook

b. Internal exposure

Internal exposure is assessed from committed effective dose factor and the amount of ingestion of radioactive material in food or beverage. To assess internal exposure, the assessment is made in three groups by age (adult, child under school age, and infant) .

(6) Internal exposure from ingestion of water

Accidental ingestion of seawater while swimming in the sea may happen; therefore, assess internal exposure from ingestion of water while swimming.

Equation (6-1-8) shows the calculation equation of the effective dose D_6(mSv/year) from radioactive materials from ingestion of water.

$$D_6 = \sum_i t_6 \bullet Hs \bullet (x_6)_i \bullet \left(K_F^{50}\right)_i \qquad (6\text{-}1\text{-}8)$$

where

t_6 is the annual swimming time (h/year)

Hs is the seawater intake rate during swimming and conservatively set to 0.2L/h for adult and child under school age

$(x_6)_i$ is the concentration of nuclide i in seawater (Bq/L)

$(K_F^{50})_i$ is the committed effective dose factor from ingestion of nuclide i ((mSv)/(Bq))

For the committed effective dose factor from ingestion, the factor specified in Table III.2D. “Members of the Public: Committed Effective Dose per Unit Intake e(g) via ingestion (Sv/Bq)” of the IAEA No. GSR Part 3 “Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards” (hereinafter called “GSR Part 3”) was used (Table 6-1-10).

Infant was excluded from the assessment targets because it rarely swims.

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

(7) Internal exposure from inhalation of seawater spray

Internal exposure from inhalation of seawater spray is assessed because seawater spray caused by waves is considered to be inhaled at beaches. In this assessment, air concentration of seawater spray is set a recommended values of the air concentration of seawater spray in the IAEA-TECDOC-1759 “Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure” [29] (hereinafter called “TECDOC-1759.”)

Equation (6-1-9) shows the calculation equation of the effective dose D_7(mSv/year) from radioactive materials from inhalation of seawater spray.

$$D_7 = 10^3 \bullet \sum_i t_7 \bullet Rs \bullet \frac{C_s}{\rho_w} (x_7)_i \bullet \left(K_h^{50}\right)_i \qquad \text{(6-1-9)}$$

where

t_7 is the annual beach stay time (h/year)

Rs is the respiration rate, and 0.925 m^3/h, 0.363 m^3/h, and 0.119 m^3/h are used for adult, child under school age, and infant, respectively, according to “Guidelines for the Assessment of Dose Target Values Around Light Water Reactor Facilities” [30].

C_s is the air concentration of seawater spray (kg/m^3) and the recommended value of TECDOC-1759, 1.0E-02kg/m^3, is used

ρ_w is the density of seawater and 1.0E+03 kg/m^3 is used.

$(x_7)_i$ is the concentration of nuclide i in seawater (Bq/L)

$(K_h^{50})_i$ is the committed effective dose factor from inhalation of nuclide i (mSv/Bq)

10^3 is the factor converted to the unit ($10^3 L/m^3$)

For the committed effective dose factor from inhalation, the factor specified in Table III.2E. “Members of the Public: Committed Effective Dose per Unit Intake e(g) via inhalation (Sv/Bq)” of GSR Part 3 was used, but only for tritium, the one specified in Table III.2G. “Inhalation: Committed Effective Dose per Unit Intake e(g) (Sv/Bq) for soluble or reactive gases and vapours” was used. (Table 6-1-11).
The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

(8) Internal exposure from ingestion of seafood

Internal exposure from ingestion of radioactive materials that have migrated from the seawater to marine organisms through ingestion of seafood is assessed.
Equations (6-1-10) and (6-1-11) show the calculation equation of the effective dose D_8(mSv/year) from ingestion of seafood

$$D_8 = \sum_k \sum_i (K_F^{50})_i \cdot H_{ki} \qquad \text{(6-1-10)}$$

$$H_{ki} = 365 \cdot 10^{-3} \cdot (x_8)_i \cdot (CF)_{ki} \cdot F_k \cdot W_k \cdot f_{ki} \qquad \text{(6-1-11)}$$

where

$(K_F^{50})_i$ is the committed effective dose factor from ingestion of nuclide i (mSv/Bq)
H_{ki} is the ingestion rate (Bq/year) of nuclide i through ingestion of seafood k
(x_8) Concentration of nuclide i in seawater (Bq/L)
$(\mathrm{CF})_{ki}$ is the concentration factor of nuclide i to seafood k ((Bq/kg)/(Bq/L))[34]
F_k is the market dilution factor[35]
W_k is the ingestion amount of seafood k (g/day)
f_{ki} is the decay ratio of nuclide i from catching to ingestion of seafood k
$365 \cdot 10^{-3}$is the factor converted to the unit (365 days/year, 10^{-3}kg/g)

The committed effective dose coefficient from ingestion is the same as that from ingestion of water during swimming (Table 6-1-10).

For the concentration factor of seafood36, the factor specified in IAEA Technical Reports Series No.422 ”Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment” [31] (hereinafter called “TRS-422”) was used (Table 6-1-12).

Actually, market dilution which must occur during market distribution of seafood from other production areas and decay of nuclides from catching to ingestion of seafood were ignored to secure conservativeness.

The concentration in the seawater used for the assessment and the annual exposure time are set by the characteristics of representative persons.

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[34] Expedient factor indicating the relationship between the radioactive nuclide concentration in marine organisms (per wet weight) in marine organisms (in principle, edible parts) and the radioactive nuclide concentration in the seawater in the environment where such organisms live, which is used for the assessment model for migration to organisms (IAEA, 2004).

[35] Generally, it is extremely rare that all foods are local products, and products caught in other places not affected by discharge of radioactive materials considered are distributed together. This reduces the impact of discharge of radioactive materials to the environment to be performed, so it is instructed to set and assess the percentage of intake (market dilution factor) for each food, but conservatively all products are assumed to be caught in the sea area in question without considering market dilution in this assessment.

[36] Radioactive materials are ingested in organisms which live for a long time in the seawater containing radioactive materials depending on the types of elements, and it reaches equilibrium at a certain concentration. This refers to the ratio of the concentration of the radioactive materials in the seawater in the surrounding environment to the equilibrium concentration of radioactive materials in organisms.

Table 6-1-5 Dose conversion factor for the effective dose of radiation from the sea surface
(Decommissioning handbook [26] and others are shown in remarks)

Nuclide	Dose conversion factor for the effective dose ((mSv/h)/(Bq/L))	Remarks
H-3	0.0E+00	Defined 0 due to pure β nuclide
C-14	0.0E+00	Defined 0 due to pure β nuclide
Mn-54	1.7E-07	
Fe-55	0.0E+00	
Co-60	5.0E-07	
Ni-63	0.0E+00	Defined 0 due to pure β nuclide
Se-79	4.8E-12	
Sr-90	1.6E-09	
Y-90	-	Contained in the parent nuclide Sr-90
Tc-99	1.5E-11	
Ru-106	4.5E-08	
Sb-125	8.7E-08	
Te-125m	6.6E-09	
I-129	4.6E-09	
Cs-134	3.1E-07	
Cs-137	1.2E-07	
Ce-144	1.3E-08	
Pm-147	8.2E-12	
Sm-151	1.7E-12	
Eu-154	2.5E-07	
Eu-155	5.0E-07	Conservatively, the same value as that of Co-60 is set because no value is given to this nuclide in the source
U-234	5.9E-11	
U-238	5.2E-09	
Np-237	4.4E-08	
Pu-238	4.7E-11	
Pu-239	2.6E-11	
Pu-240	4.6E-11	
Pu-241	2.9E-08	
Am-241	4.6E-09	
Cm-244	4.5E-11	

Table 6-1-6 Dose conversion factor for the effective dose of radiation from hulls (Decommissioning handbook [26] and others are shown in remarks)

Nuclide	Dose conversion factor for the effective dose ((mSv/h)/(Bq/m^2))	Remarks
H-3	0.0E+00	Defined 0 due to pure β nuclide
C-14	0.0E+00	Defined 0 due to pure β nuclide
Mn-54	1.4E-09	
Fe-55	0.0E+00	
Co-60	3.5E-09	
Ni-63	0.0E+00	Defined 0 due to pure β nuclide
Se-79	1.5E-12	
Sr-90	5.8E-11	
Y-90	-	Contained in the parent nuclide Sr-90
Tc-99	2.8E-12	
Ru-106	4.0E-10	
Sb-125	8.3E-10	
Te-125m	4.4E-10	
I-129	3.0E-10	
Cs-134	2.4E-09	
Cs-137	9.5E-10	
Ce-144	1.6E-10	
Pm-147	1.9E-12	
Sm-151	8.7E-13	
Eu-154	1.8E-09	
Eu-155	3.5E-09	Conservatively, the same value as that of Co-60 is set because no value is given to this nuclide in the source
U-234	9.4E-11	
U-238	2.5E-10	
Np-237	1.4E-09	
Pu-238	1.1E-10	
Pu-239	3.9E-11	
Pu-240	1.0E-10	
Pu-241	7.7E-10	
Am-241	2.0E-10	
Cm-244	1.0E-10	

Table 6-1-7 Dose conversion factor for the effective dose of radiation from seawater during swimming and underwater work (Decommissioning handbook [26] and others are shown in remarks)

Nuclide	Dose conversion factor for the effective dose ((mSv/h)/(Bq/L))	Remarks
H-3	0.0E+00	
C-14	0.0E+00	
Mn-54	4.8E-07	
Fe-55	9.7E-10	
Co-60	1.4E-06	
Ni-63	0.0E+00	
Se-79	0.0E+00	
Sr-90	7.2E-13	
Y-90	-	Contained in the parent nuclide Sr-90
Tc-99	4.0E-13	
Ru-106	1.2E-07	
Sb-125	2.5E-07	
Te-125m	2.0E-08	
I-129	1.4E-08	
Cs-134	9.0E-07	
Cs-137	3.4E-07	
Ce-144	2.8E-08	
Pm-147	2.5E-12	
Sm-151	8.3E-12	
Eu-154	6.4E-07	
Eu-155	1.4E-06	Conservatively, the same value as that of Co-60 is set because no value is given to this nuclide in the source
U-234	1.0E-09	
U-238	1.6E-08	
Np-237	1.5E-07	
Pu-238	1.1E-09	
Pu-239	5.2E-10	
Pu-240	9.9E-10	
Pu-241	8.1E-08	
Am-241	1.9E-08	
Cm-244	9.0E-10	

Table 6-1-8 Dose conversion factor for the effective dose of radiation from beach sand (Decommissioning handbook [26] and others are shown in remarks)

Nuclide	Dose conversion factor for the effective dose ((mSv/h)/(Bq/kg))	Remarks
H-3	0.0E+00	Defined 0 due to pure β nuclide
C-14	0.0E+00	Defined 0 due to pure β nuclide
Mn-54	1.6E-07	
Fe-55	0.0E+00	
Co-60	4.7E-07	
Ni-63	0.0E+00	Defined 0 due to pure β nuclide
Se-79	1.8E-12	
Sr-90	1.2E-09	
Y-90	-	Contained in the parent nuclide Sr-90
Tc-99	6.3E-12	
Ru-106	4.3E-08	
Sb-125	8.3E-08	
Te-125m	1.9E-09	
I-129	1.3E-09	
Cs-134	3.1E-07	
Cs-137	1.2E-07	
Ce-144	1.0E-08	
Pm-147	3.5E-12	
Sm-151	6.3E-13	
Eu-154	2.3E-07	
Eu-155	4.7E-07	Conservatively, the same value as that of Co-60 is set because no value is given to this nuclide in the source
U-234	4.1E-11	
U-238	3.9E-09	
Np-237	3.7E-08	
Pu-238	3.6E-11	
Pu-239	2.1E-11	
Pu-240	3.5E-11	
Pu-241	2.0E-08	
Am-241	1.7E-09	
Cm-244	3.6E-11	

Table 6-1-9 Dose conversion factor for the effective dose of radiation from fishing nets (Decommissioning handbook [26] and others are shown in remarks)

Nuclide	Dose conversion factor for the effective dose ((mSv/h)/(Bq/kg))	Remarks
H-3	0.0E+00	Defined 0 due to pure β nuclide
C-14	0.0E+00	Defined 0 due to pure β nuclide
Mn-54	3.2E-08	
Fe-55	0.0E+00	
Co-60	9.9E-08	
Ni-63	0.0E+00	Defined 0 due to pure β nuclide
Se-79	2.0E-13	
Sr-90	2.1E-10	
Y-90	-	Contained in the parent nuclide Sr-90
Tc-99	7.9E-13	
Ru-106	8.2E-09	
Sb-125	1.5E-08	
Te-125m	2.3E-10	
I-129	1.6E-10	
Cs-134	5.9E-08	
Cs-137	2.2E-08	
Ce-144	2.0E-09	
Pm-147	4.2E-13	
Sm-151	5.8E-14	
Eu-154	4.7E-08	
Eu-155	9.9E-08	Conservatively, the same value as that of Co-60 is set because no value is given to this nuclide in the source
U-234	2.9E-12	
U-238	7.1E-10	
Np-237	6.2E-09	
Pu-238	1.7E-12	
Pu-239	1.9E-12	
Pu-240	1.8E-12	
Pu-241	3.1E-09	
Am-241	2.1E-10	
Cm-244	2.1E-12	

Table 6-1-10 Effective dose factor of ingestion (GSR Part 3 [13])

Target nuclide	Effective dose factor (mSv/Bq)			Remarks
	Adult	Child under school age	Infant	
H-3 (THO)	1.8E-08	3.1E-08	6.4E-08	Used for the assessment of ingestion of water
H-3 (considering OBT)	2.0E-08	3.5E-08	7.0E-08	Used for the assessment of ingestion of seafood assuming that 10% of tritium to be ingested is OBT
C-14	5.8E-07	9.9E-07	1.4E-06	
Mn-54	7.1E-07	1.9E-06	5.4E-06	
Fe-55	3.3E-07	1.7E-06	7.6E-06	
Co-60	3.4E-06	1.7E-05	5.4E-05	
Ni-63	1.5E-07	4.6E-07	1.6E-06	
Se-79	2.9E-06	1.9E-05	4.1E-05	
Sr-90	2.8E-05	4.7E-05	2.3E-04	
Y-90	2.7E-06	1.0E-05	3.1E-05	
Tc-99	6.4E-07	2.3E-06	1.0E-05	
Ru-106	7.0E-06	2.5E-05	8.4E-05	
Sb-125	1.1E-06	3.4E-06	1.1E-05	
Te-125m	8.7E-07	3.3E-06	1.3E-05	
I-129	1.1E-04	1.7E-04	1.8E-04	
Cs-134	1.9E-05	1.3E-05	2.6E-05	
Cs-137	1.3E-05	9.6E-06	2.1E-05	
Ce-144	5.2E-06	1.9E-05	6.6E-05	
Pm-147	2.6E-07	9.6E-07	3.6E-06	
Sm-151	9.8E-08	3.3E-07	1.5E-06	
Eu-154	2.0E-06	6.5E-06	2.5E-05	
Eu-155	3.2E-07	1.1E-06	4.3E-06	
U-234	4.9E-05	8.8E-05	3.7E-04	
U-238	4.5E-05	8.0E-05	3.4E-04	
Np-237	1.1E-04	1.4E-04	2.0E-03	
Pu-238	2.3E-04	3.1E-04	4.0E-03	
Pu-239	2.5E-04	3.3E-04	4.2E-03	
Pu-240	2.5E-04	3.3E-04	4.2E-03	
Pu-241	4.8E-06	5.5E-06	5.6E-05	
Am-241	2.0E-04	2.7E-04	3.7E-03	
Cm-244	1.2E-04	1.9E-04	2.9E-03	

Table 6-1-11 Effective dose factor of inhalation (GSR Part 3 [13])

Target nuclide	Effective dose factor (mSv/Bq)			Remarks
	Adult	Child under school age	Infant	
H-3	1.8E-08	3.1E-08	6.4E-08	The conversion factor of tritium vapor is used
C-14	5.8E-06	1.1E-05	1.9E-05	
Mn-54	1.5E-06	3.8E-06	7.5E-06	
Fe-55	7.7E-07	2.2E-06	4.2E-06	
Co-60	3.1E-05	5.9E-05	9.2E-05	
Ni-63	1.3E-06	2.7E-06	4.8E-06	
Se-79	6.8E-06	1.3E-05	2.3E-05	
Sr-90	1.6E-04	2.7E-04	4.2E-04	
Y-90	1.5E-06	4.2E-06	1.3E-05	
Tc-99	1.3E-05	2.4E-05	4.1E-05	
Ru-106	6.6E-05	1.4E-04	2.6E-04	
Cd-113m	1.1E-04	1.8E-04	3.0E-04	
Sb-125	1.2E-05	2.4E-05	4.2E-05	
Te-125m	4.2E-06	7.8E-06	1.7E-05	
I-129	3.6E-05	6.1E-05	7.2E-05	
Cs-134	2.0E-05	4.1E-05	7.0E-05	
Cs-137	3.9E-05	7.0E-05	1.1E-04	
Ce-144	5.3E-05	1.4E-04	3.6E-04	
Pm-147	5.0E-06	1.1E-05	2.1E-05	
Sm-151	4.0E-06	6.7E-06	1.1E-05	
Eu-154	5.3E-05	9.7E-05	1.6E-04	
Eu-155	6.9E-06	1.4E-05	2.6E-05	
U-234	9.4E-03	1.9E-02	3.3E-02	
U-238	8.0E-03	1.6E-02	2.9E-02	
Np-237	5.0E-02	6.0E-02	9.8E-02	
Pu-238	1.1E-01	1.4E-01	2.0E-01	
Pu-239	1.2E-01	1.5E-01	2.1E-01	
Pu-240	1.2E-01	1.5E-01	2.1E-01	
Pu-241	2.3E-03	2.6E-03	2.8E-03	
Am-241	9.6E-02	1.2E-01	1.8E-01	
Cm-244	5.7E-02	8.3E-02	1.5E-01	

Table 6-1-12 Concentration factor for seafood (TRS-422 [31])

Target Nuclide	Concentration factor ((Bq/kg)/(Bq/L))			Remarks
	Fish	Invertebrate	Seaweeds	
H-3	1.0E+00	1.0E+00	1.0E+00	
C-14	2.0E+04	2.0E+04	1.0E+04	
Mn-54	1.0E+03	5.0E+04	6.0E+03	
Fe-55	3.0E+04	5.0E+04	2.0E+04	
Co-60	7.0E+02	2.0E+04	6.0E+03	
Ni-63	1.0E+03	2.0E+03	2.0E+03	
Se-79	1.0E+04	1.0E+04	1.0E+03	
Sr-90	3.0E+00	1.0E+01	1.0E+01	
Y-90	-	-	-	Equilibrium state with the parent nuclide Sr-90
Tc-99	8.0E+01	1.0E+03	3.0E+04	
Ru-106	2.0E+00	5.0E+02	2.0E+03	
Sb-125	6.0E+02	3.0E+02	2.0E+01	
Te-125m	1.0E+03	1.0E+03	1.0E+04	Equilibrium state with the parent nuclide Sb-125
I-129	9.0E+00	1.0E+01	1.0E+04	
Cs-134	1.0E+02	6.0E+01	5.0E+01	
Cs-137	1.0E+02	6.0E+01	5.0E+01	
Ce-144	5.0E+01	2.0E+03	5.0E+03	
Pm-147	3.0E+02	7.0E+03	3.0E+03	
Sm-151	3.0E+02	7.0E+03	3.0E+03	
Eu-154	3.0E+02	7.0E+03	3.0E+03	
Eu-155	3.0E+02	7.0E+03	3.0E+03	
U-234	1.0E+00	3.0E+01	1.0E+02	
U-238	1.0E+00	3.0E+01	1.0E+02	
Np-237	1.0E+00	4.0E+02	5.0E+01	
Pu-238	1.0E+02	3.0E+03	4.0E+03	
Pu-239	1.0E+02	3.0E+03	4.0E+03	
Pu-240	1.0E+02	3.0E+03	4.0E+03	
Pu-241	1.0E+02	3.0E+03	4.0E+03	
Am-241	1.0E+02	1.0E+03	8.0E+03	
Cm-244	1.0E+02	1.0E+03	5.0E+03	

* For invertebrates, the value of mollusks (excluding cephalopods) was used.

(4) Setting of the representative person subject to the exposure assessment

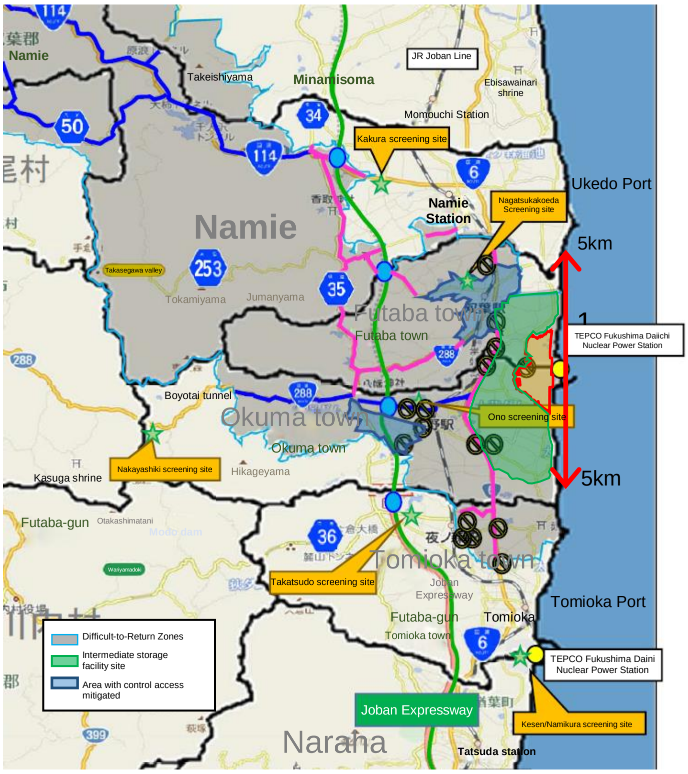
(i) Situation around the FDNPS

According to GSG-9, the living habits and characteristics of the representative person for some of the exposure pathways should be based on the highest group from the distribution of the living habit data (e.g. 95 percentile value), etc.

However, as shown in Figure 6-1-10, in the area around the FDNPS, measures to prevent the general public from living in the area are taken by setting Difficult-to-Return Zones set in response to the accident, installing intermediate storage facilities surrounding the land side of the FDNPS, etc. In addition, fishing industry in Fukushima is yet in the middle of reconstruction.

This situation is expected to improve gradually thanks to the lifting of the setting of Difficult-to-Return Zones, mitigation of residence restriction, etc., but it is not desirable as a future prediction to make judgment based on the current data, so no assessment will be performed based on the actual data of the current situation and instead an assessment will be performed using the data used for the safety review of the existing reactor facilities, etc.

We will consider the adoption of the actual data about living habits and characteristics of the representative person which will be accumulated in the future as the reconstruction of this area will proceed.



Source: Support for victims of the nuclear accident of the Ministry of Economy, Trade and Industry (Regarding evacuation orders)] Prepared by Tokyo Electric Power Company Holdings, Inc. based on the map of the area surrounding Difficult-to-Return Zones (from R2.12.10)
https://www.meti.go.jp/earthquake/nuclear/kinkyu.html

Figure 6-1-10 Condition of Difficult-to-Return Zones, etc. around the FDNPS

(ii) Characteristics of the representative person

The characteristics of the representative person subject to exposure assessment was set as a person who is engage in fisheries industry in surrounding sea, since it is an impact assessment, according to “Dose Assessment to the General Public in the Safety Review of Commercial Light Water Reactor Facilities,” etc.

- Engage in fishing 120 days (2,880 hours) a year, of which 80 days (1,920 hours) are spent near fishing nets.
- Stay at the beach 500 hours a year and swim for 96 hours.

As mentioned in the previous section 6-1-2. (3) a. “External exposure,” groups by ages were not set for the external exposure assessment, but were set in three groups by ages (adult, child under school age, infant) for internal exposure to assess.
The time spent at the beach and swimming time used to assess internal exposure from ingestion of water and inhalation intake were set to be the same as those for adults.
The ingestion of seafood was set based on classification into fish (total of the fishery product (excluding shellfish, squid, octopus, shrimp, and crab) and processed fishery products), invertebrates (total of shellfish, squid, octopus, shrimp, and crab), and seaweeds (algae) extracting the data of ingestion of fishery products, processed fishery products, and algae from “National Health and Nutrition Survey (2019)”[37] of the Ministry of Health, Labour and Welfare, which is the latest large-scale survey result regarding ingestion of foods of the entire Japanese people. The assessment is performed in two different cases, a person who ingests seafood with average amount and who ingests more than average amount.

i. Individual who ingests the average amount of seafood
   The average ingestion amount of those who are aged 20 or older is used as the value of adult. 1/2 and 1/5 of the value of adult are used as the values of child under school age (assumed to be aged 5 or older) and infant (assumed to be aged 1), respectively, based on “Guidelines for the Assessment of Dose Target Values Around Light Water Reactor Facilities” [30].
ii. Person who ingests the large amount of seafood
   The value of adult is set to the average ingestion of those who are aged 20 or older plus twice the value of the standard deviation. Those of child under school age and infant are set to 1/2 and 1/5, respectively, of the value of adult.
   Tables 6-1-13 and 6-1-14 show the set ingestion of seafood.

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[37] In 2020 and 2021, the survey itself was not performed due to the novel coronavirus.

The assessment points related to exposure and the seawater concentration used for the assessment are as follows.

i. External exposure from sea surface and external exposure from hulls

The nearest ports to the south and north of the FDNPS is 5 km or more away from the FDNPS. Fishing is widely performed by ships from fishing ports in the sea area, including the area around the FDNPS centering on the fishing ports. Therefore, to assess the external exposure from sea surface and external exposure from hulls, it seems appropriate to assess the entire sea area centering on the fishing ports. But in this assessment, the assessment area is conservatively set within 5 km to the north and south and 10 km off the coast of the FDNPS (range of 10 km × 10 km around the FDNPS (Figure 6-1-11)). The concentration in the seawater used for the assessment is the annual average concentration on the sea surface (top layer) within 10 km × 10 km around the FDNPS, including areas where no fishing is conducted on a daily basis.

ii. External exposure from seawater during swimming, etc., external exposure from beach sand, internal exposure from ingestion of water, and internal exposure from inhalation of seawater spray

The coastline around the FDNPS is a Difficult-to-Return Zone and intermediate storage facilities are installed there, but there is a beach in the habitable area in the north side. Since the result of dispersion assessment shows that the annual average concentration of radioactive materials in seawater near those sand beaches is high, the assessment point for these pathways is set to be the nearby beach to the north of the FDNPS and the concentration in the seawater used for the assessment is set to be the annual average concentration in the seawater (all layers) in front of the beach. Since the water depth is less than 5m near the coast, mixing of the upper and lower layers is remarkable, so that there is little difference between the concentration on the sea surface and the average concentration of all layers.

iii. External exposure from fishing nets and internal exposure from ingestion of seafood

It is considered that radioactive materials will migrate from seawater to fishing nets at the time of fishing. In addition, fish are caught by fishing and delivered to the dinner table as seafood. Therefore, only within the range of 10 km × 10 km around the FDNPS for point of assessment as with i. conservatively, but fish are found from the surface layer to the bottom layer and fishing nets are used at depths appropriate for the fish to be caught, so the concentration in the seawater is the annual average concentration in the seawater (all layers) in front of the beach.

In addition, although there is a possibility of ingesting the seafood which caught by fishing at the beach assessment point on the north side nearby the FDNPS, there is no need to assess the ingestion of that seafood separately, because the ingestion of that seafood is a very small part of the annual ingestion of seafood, the point is the part of the range of 10 km x 10 km where the exposure from ingestion is assessed, and the fishing area for seafood ingestion is conservatively set to the range of 10km x 10km.

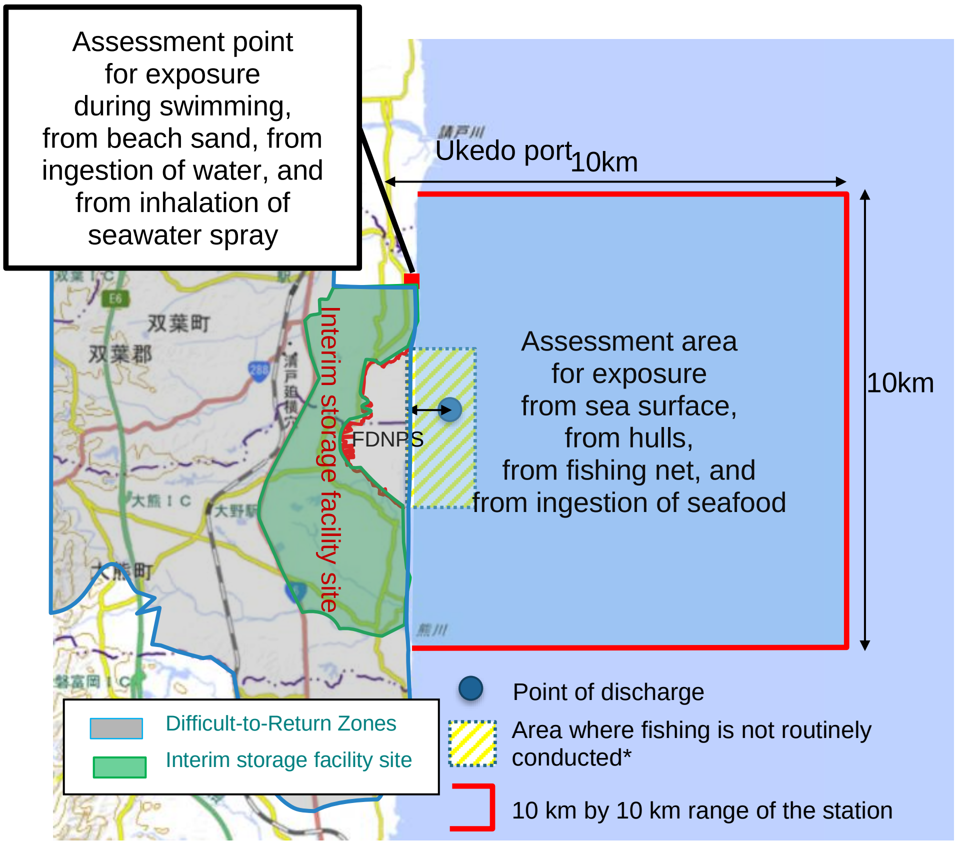
The specific calculation method of the concentration in the seawater is shown in 6-1-3.(1) to (3).

Table 6-1-13 Ingestion of persons who ingest the average amount of seafood (g/day) (Set based on the National Health and Nutrition Survey in Japan in 2019 (Ministry of Health, Labour and Welfare) [6])

	Fish	Invertebrate	Seaweeds
Adult	58	10	11
Child under school age	29	5.1	5.3
Infant	12	2.0	2.1

Table 6-1-14 Ingestion of persons who consume a large amount of seafood (g/day) (Set based on the National Health and Nutrition Survey in Japan in 2019 (Ministry of Health, Labour and Welfare) [6])

	Fish	Invertebrate	Seaweeds
Adult	190	62	52
Child under school age	97	31	26
Infant	39	12	10



*Area where common fishery rights are not set

Figure 6-1-11 Point to determine concentrations in seawater used for the assessment of exposures in normal conditions

Source: Geographical Survey Institute (Electronic Map Web) and support for victims of the nuclear accident of the Ministry of Economy, Trade and Industry (Regarding evacuation orders) Prepared by Tokyo Electric Power Company Holdings, Inc. based on the map of the area surrounding Difficult-to-Return Zones (from R2.12.10)
https://maps.gsi.go.jp/#13/37.422730/141.044970/&base=std&ls=std&disp=1&vs=c1j0h0k0l0u0t0z0r0s0m0f1

(5) Dose assessment method

Exposure is calculated by the assessment method set in 6-1-2.(3).
The calculation result is compared with the dose limit of 1 mSv/year for the general public, and the dose target of 0.05 mSv/year for domestic nuclear power plants, which is deemed to be equivalent to the dose constraint by the Nuclear Regulation Authority, as shown in 4.(1).

6-1-3. Assessment result

(1) Diffusion simulation result

The tritium concentration in the seawater after advection and diffusion was calculated using the model shown in 6-1-2.(2) assuming discharge of a total of 22 TBq (2.2E+13Bq) of tritium per year at an even pace throughout the year from the seabed about 1 km off the coast of the FDNPS. The calculation based on the meteorological and oceanographic conditions was performed for two years: 2014 and 2019. Though there is no large difference between the results of the two years, we decided to use the calculation result based on the meteorological and oceanographic conditions of 2019, in which the average concentration around the FDNPS is higher, for the assessment. Figures 6-1-12 to 6-1-18 show the calculation result.

Figures 6-1-12 and 6-1-13 show the annual average concentrations of the sea surfaces of a wide area and the area around the FDNPS, respectively. The range of concentrations over 1Bq/L on the sea surface is about 3 km around the FDNPS.

Figures 6-1-14 and 6-1-15 diagrammatically show the annual average concentrations in the seawater with east-west and north-south sectional views, respectively. The stored water amount of the assessed cell near the discharge point of the seabed is large, so the concentration is assessed to be about 30Bq/L and immediately drop in the area around the power station.

Figure 6-1-16 shows the average concentration distribution diagram of the sea surface in each season. The range of concentrations over 1Bq/L on the sea surface has more seasonal variation than in Figure 6-1-12, but it is limited to the area around the FDNPS.

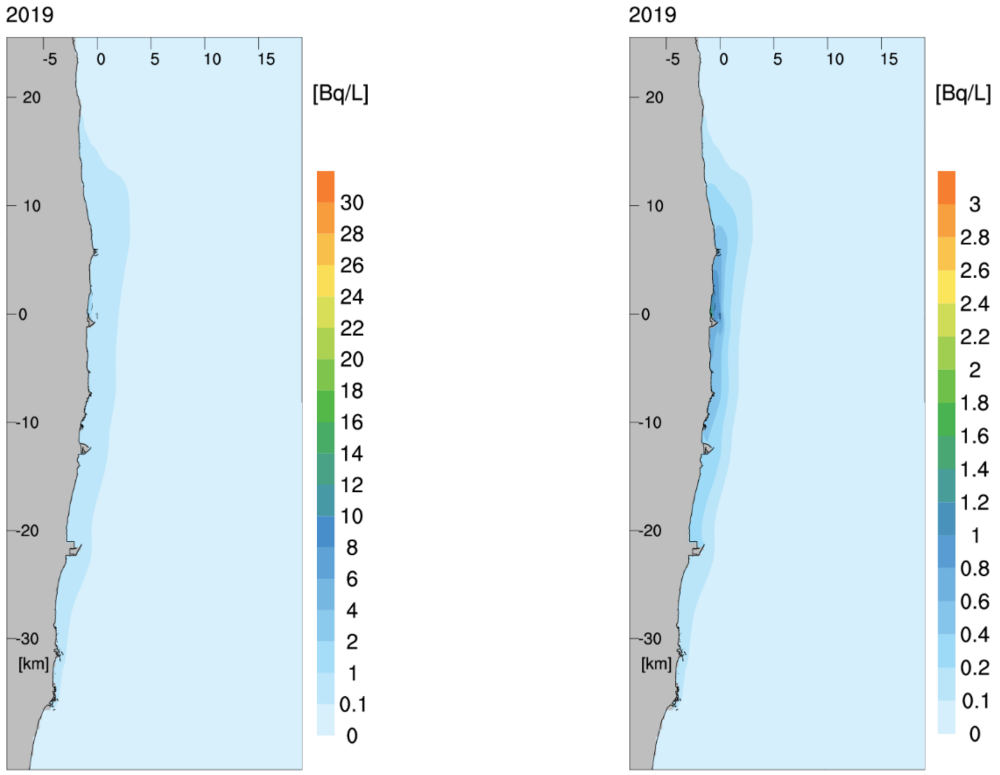
Figures 6-1-17 and 6-1-18 diagrammatically show the daily average concentrations on the sea surface throughout the year, which are expanded the most to the north, south, and east, respectively.

Attachment VIII “Difference in the diffusion range in the discharge position” shows the comparison between the discharge from the coast compared in the consideration of the discharge method and the calculation result.

To verify the impact of the variation of meteorological and oceanographic data between years, simulation calculation was performed using the meteorological and oceanographic data of 2015 to 2018 and 2020. Table 6-1-15 and Figure 6-1-19 show the calculation results of 7 years from 2014 and 2020. The calculation of the seven years is not a continuous calculation of the seven years but a collection of calculations of individual years, but the flow in the sea area changes on a daily basis and no accumulation trend is observed in calculation results of each year. On the other hand, the annual variation of the average concentration and diffusion range within 10 km × 10 km from the FDNPS is so small that there is no problem with using the calculation result of 2019 for a long-term assessment.

We also verified the concentration on the boundary of the calculation area from the calculation result of seven years mentioned above. As a result, it turned out that the maximum value of daily average concentrations on the boundary of the calculation area was 1.4E-02Bq/L. The maximum annual mean concentration of the calculation region boundary was up to 2.6E-04 Bq/L (2015, top layer), measured at the eastern boundary of the region.

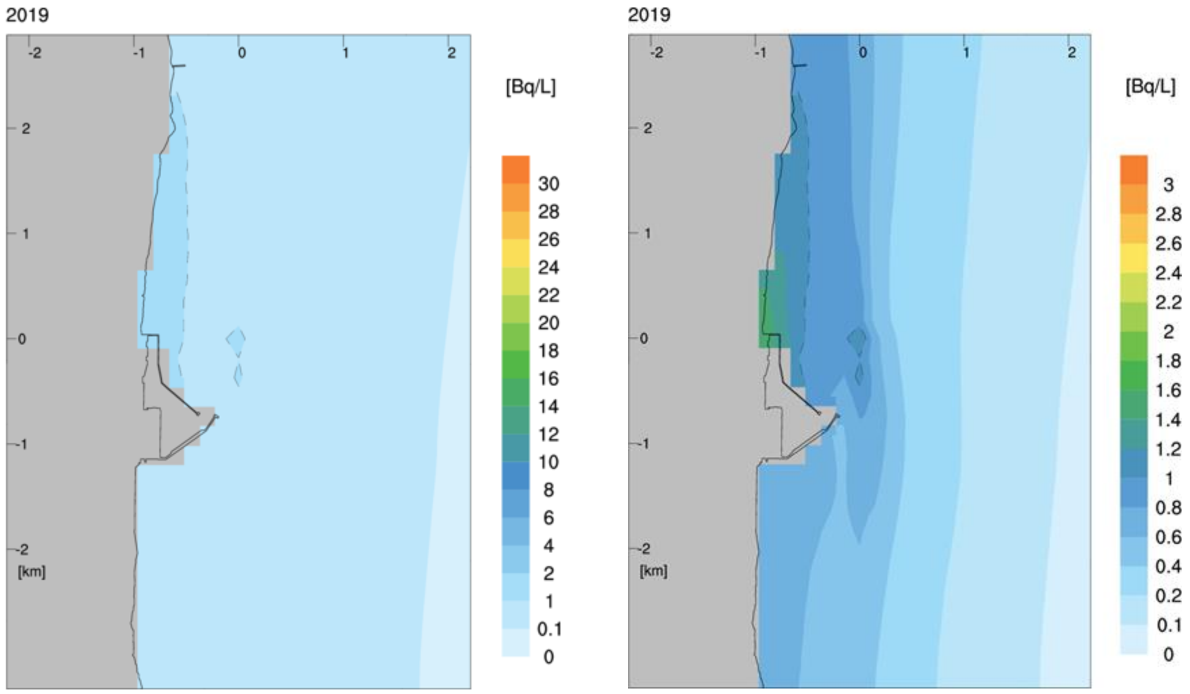
This concentration is 3 to 4 orders of magnitude lower than the tritium concentration in the sea water in the sea area around Japan (about 0.1 to 1Bq/L) and 2 to 3 orders of magnitude lower than the assessment result of 10 km × 10 km around the FDNPS, and no large variation in the concentration between years is observed, so the scale of the calculation area is sufficient and the impact of radiation on the environment outside the calculation area of this assessment is sufficiently small. Table 6-1-16 shows the maximum value of annual mean concentration on the calculation area boundary of each assessment year.



Detailed concentration classification in the left figure

Figure 6-1-12 Distribution of annual mean concentration on the sea surface

(Discharge tritium 2.2E+13Bq constantly throughout the year)



Detailed concentration classification in the left figure

Figure 6-1-13 Distribution of annual mean concentration on the sea surface (expanded diagram of neighborhood)

(Discharge tritium 2.2E+13Bq constantly throughout the year)

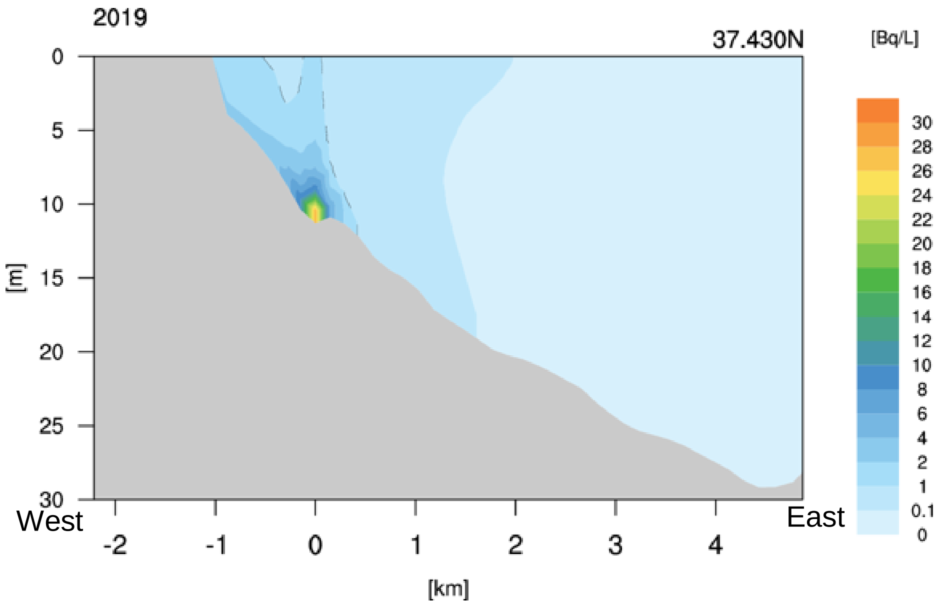


Figure 6-1-14 Distribution of annual mean concentration on the sea surface (east-west section view of the discharge position)

(Discharge tritium 2.2E+13Bq constantly throughout the year)

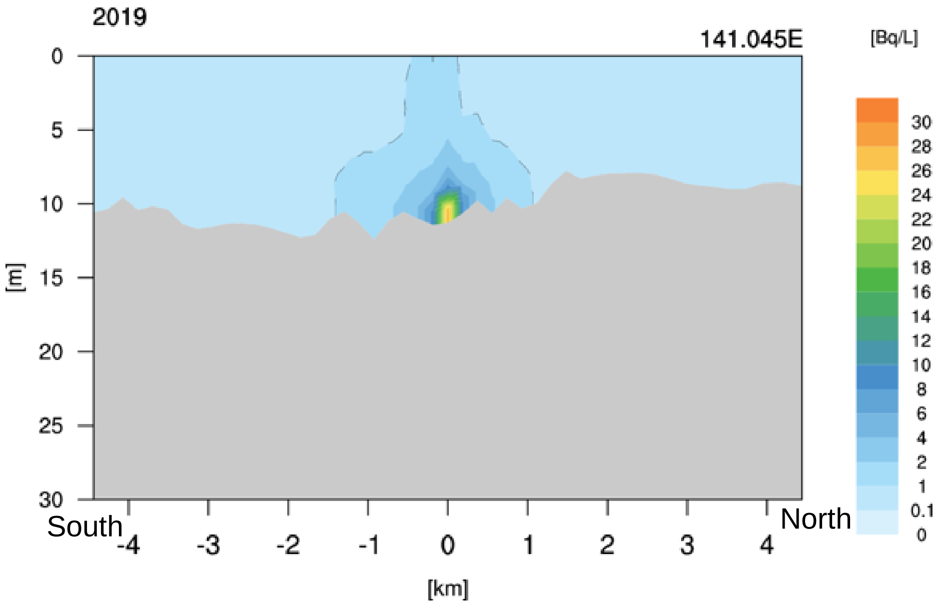
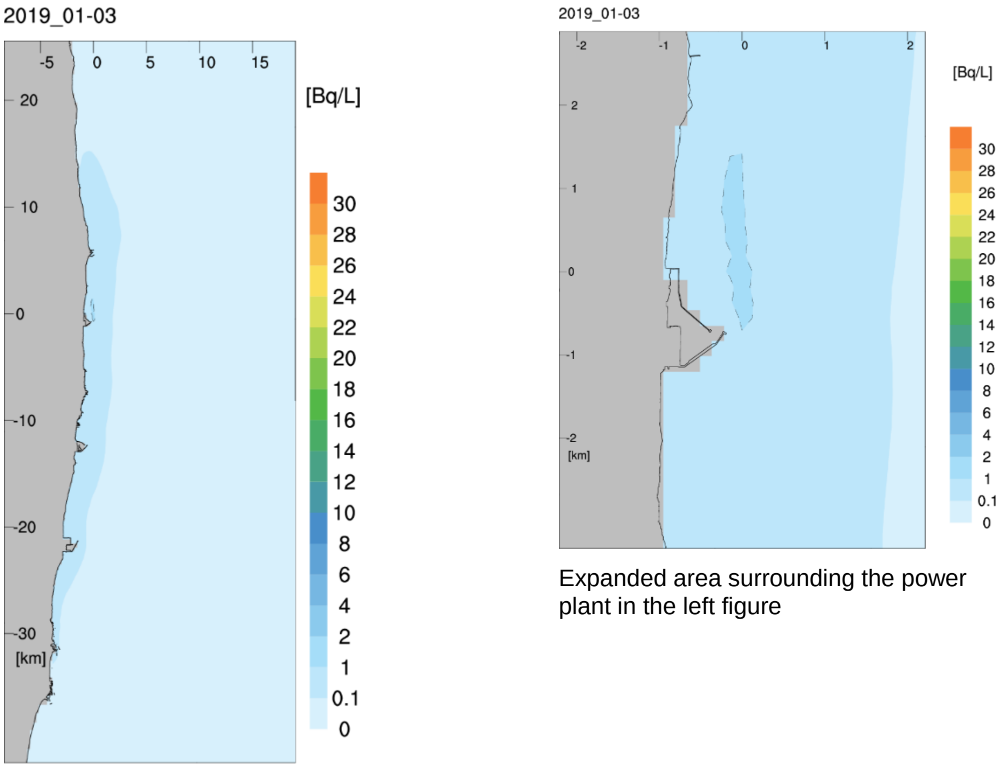


Figure 6-1-15 Distribution of annual mean concentration on the sea surface (north-south section view of the discharge position)

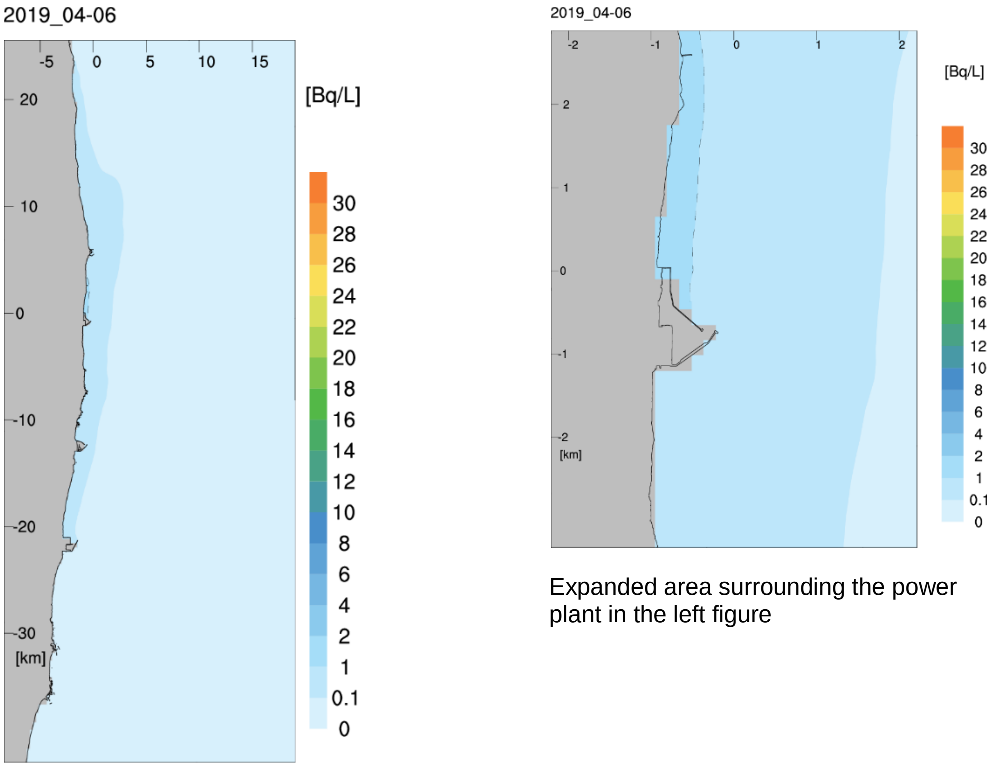
(Discharge tritium 2.2E+13Bq constantly throughout the year)



Expanded area surrounding the power plant in the left figure

Figure 6-1-16(1) Average concentration distribution diagram of the sea surface in each season

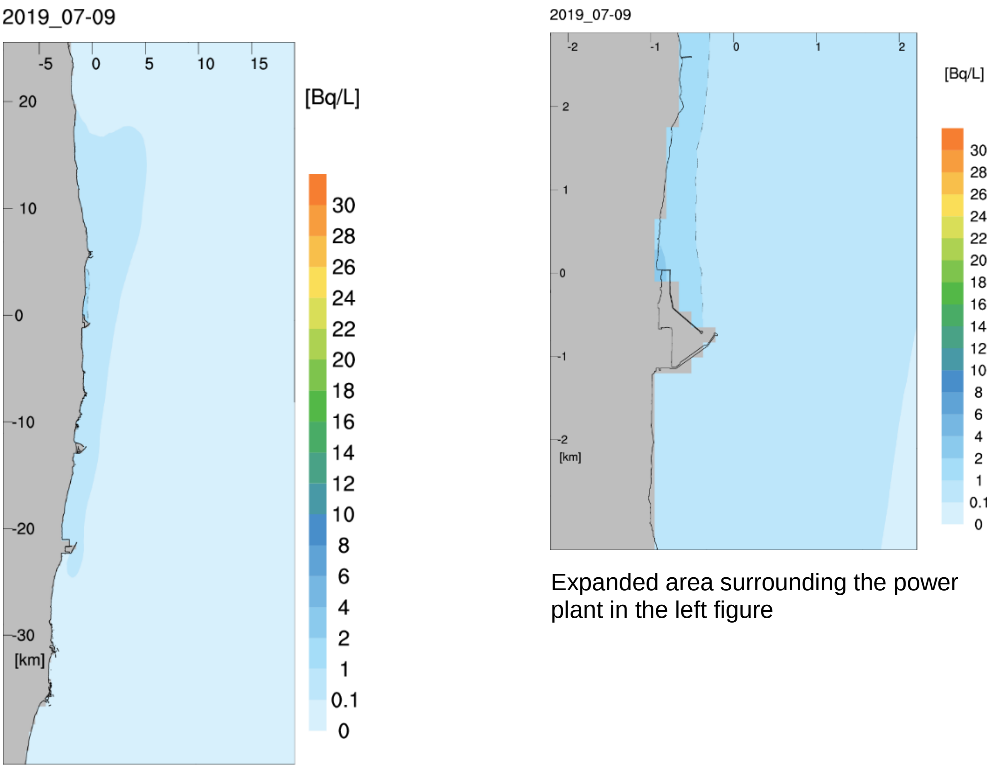
(Average of January to March)



Expanded area surrounding the power plant in the left figure

Figure 6-1-16(2) Average concentration distribution diagram of the sea surface in each season

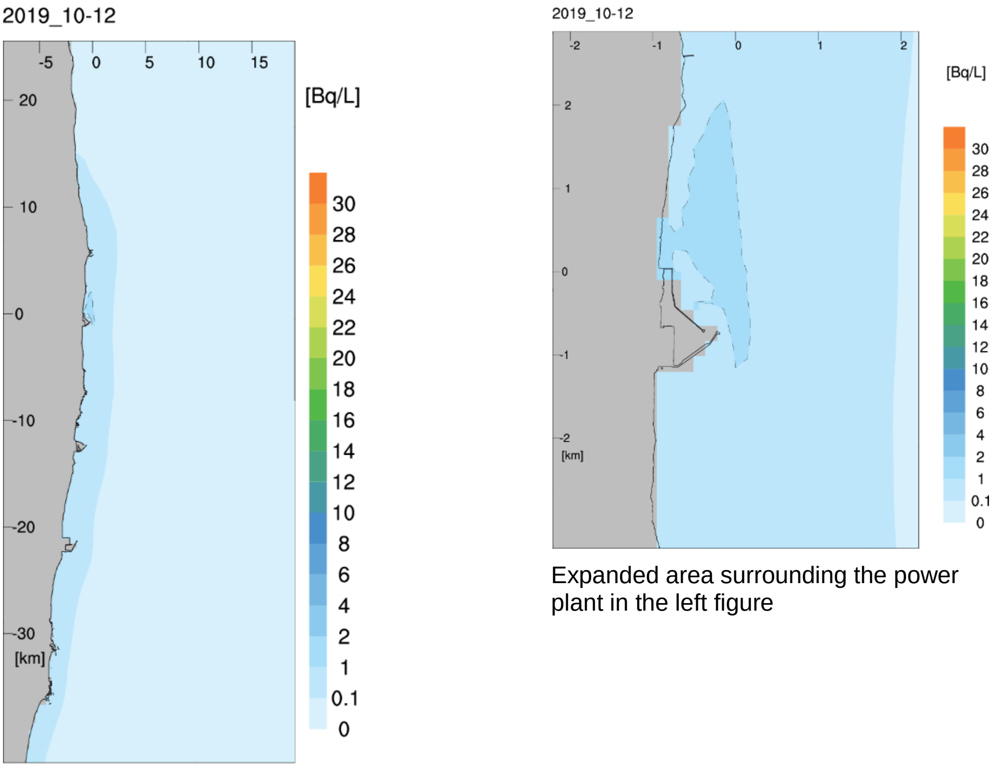
(Average of April to June)



Expanded area surrounding the power plant in the left figure

Figure 6-1-16(3) Average concentration distribution diagram of the sea surface in each season

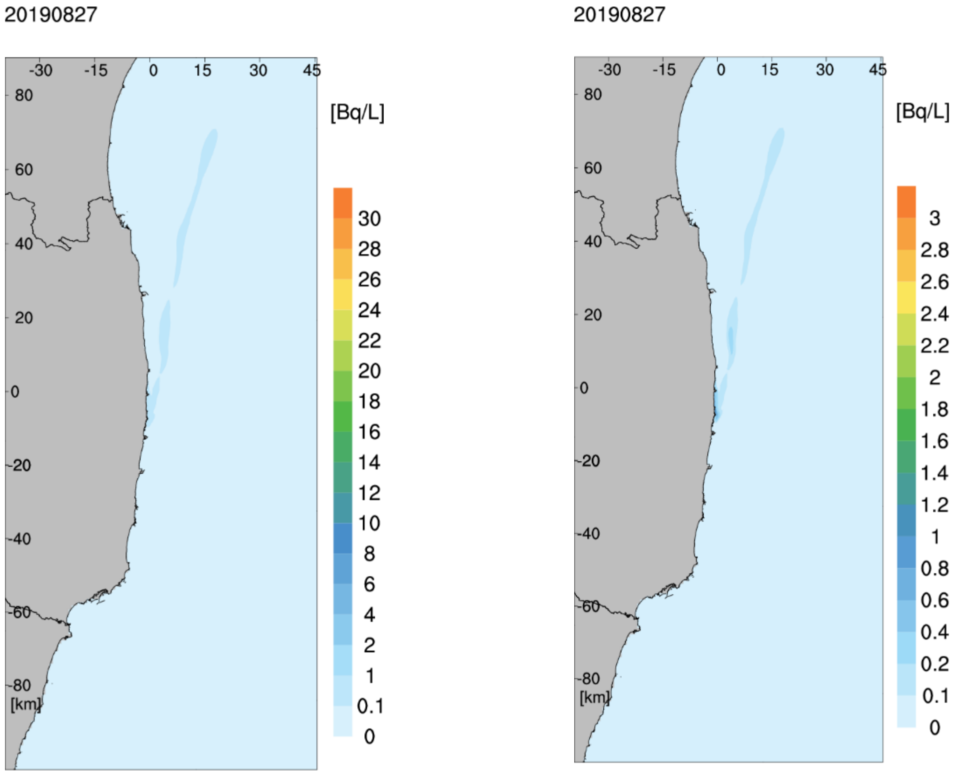
(Average of July to September)



Expanded area surrounding the power plant in the left figure

Figure 6-1-16(4) Average concentration distribution diagram of the sea surface in each season

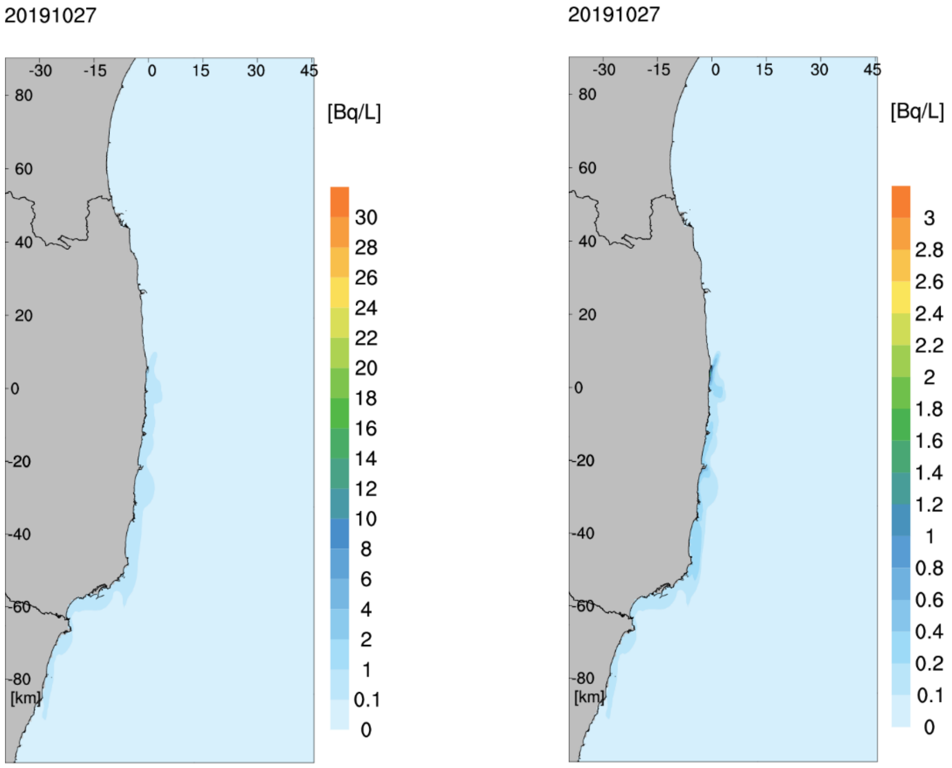
(Average of October to December)



Detailed concentration classification in the left figure

Figure 6-1-17(1) Distribution of daily mean concentration on the sea surface

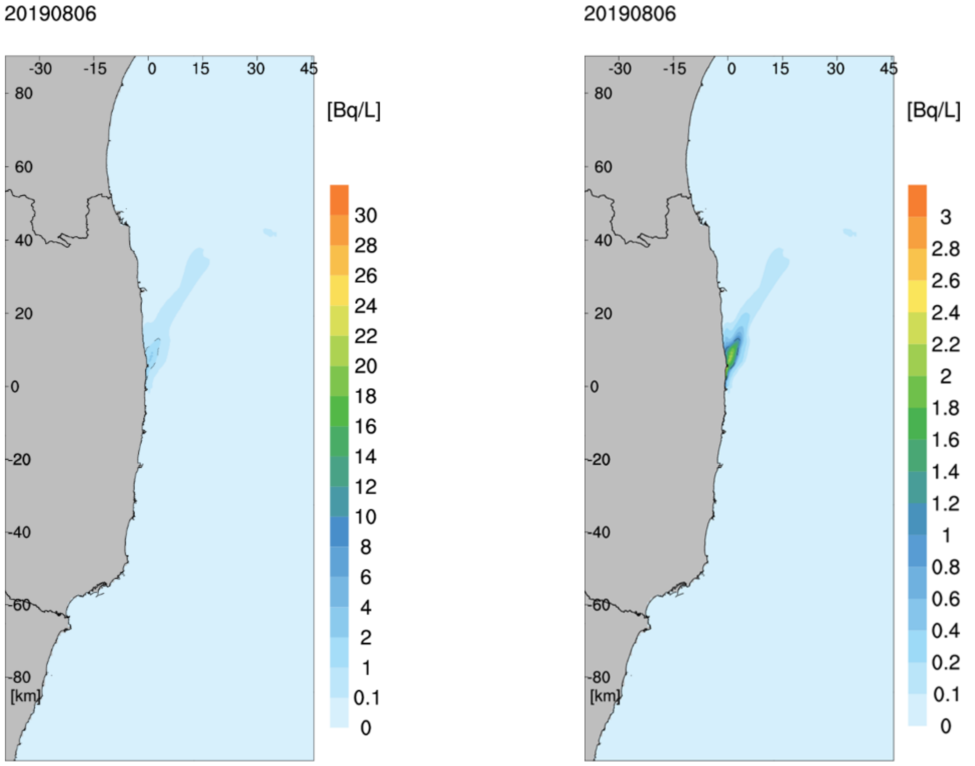
(When the range of 0.1 Bq/L extends to the northernmost point)



Detailed concentration classification in the left figure

Figure 6-1-17(2) Distribution of daily mean concentration on the sea surface

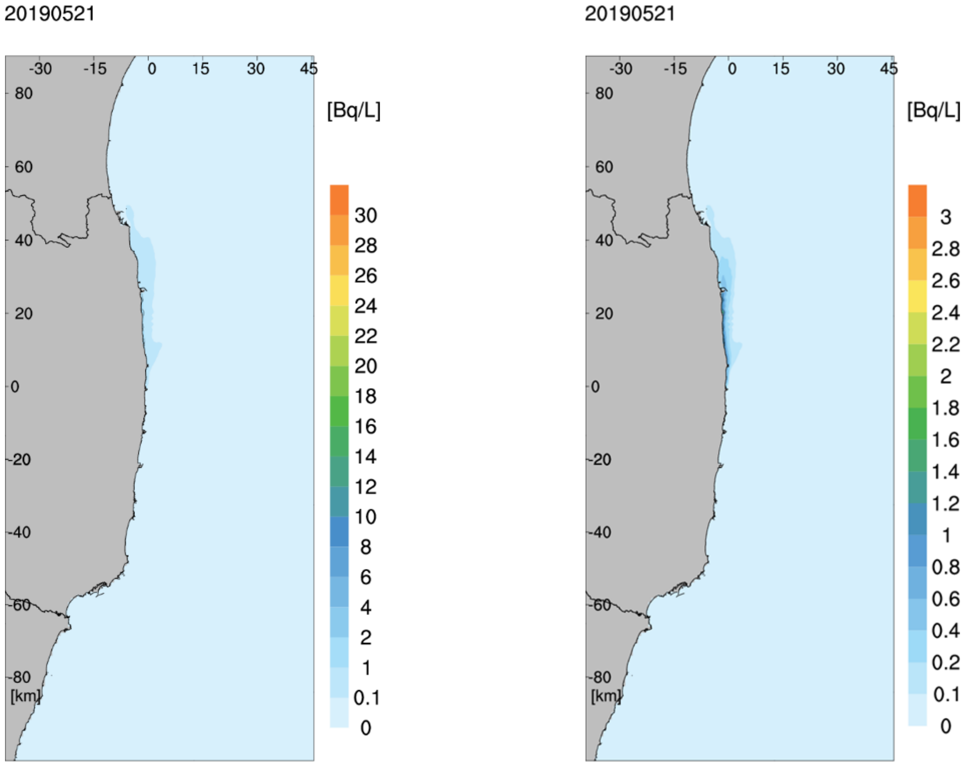
(When the range of 0.1 Bq/L extends to the southernmost point)



Detailed concentration classification in the left figure

Figure 6-1-17(3) Distribution of daily mean concentration on the sea surface

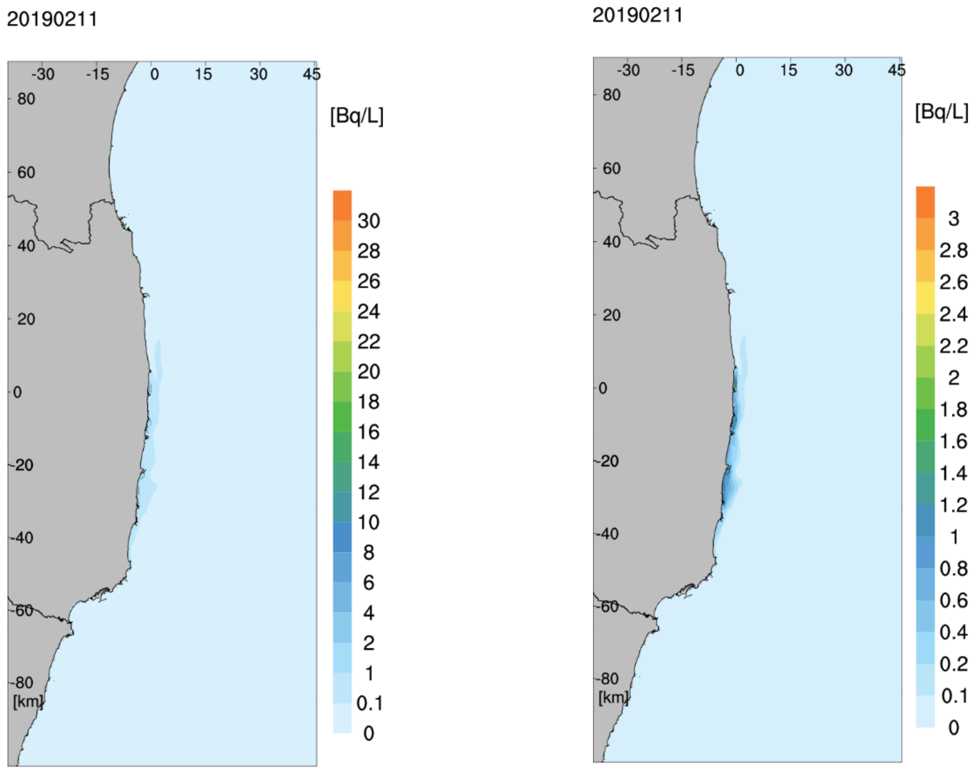
(When the range of 0.1 Bq/L extends to the easternmost point)



Detailed concentration classification in the left figure

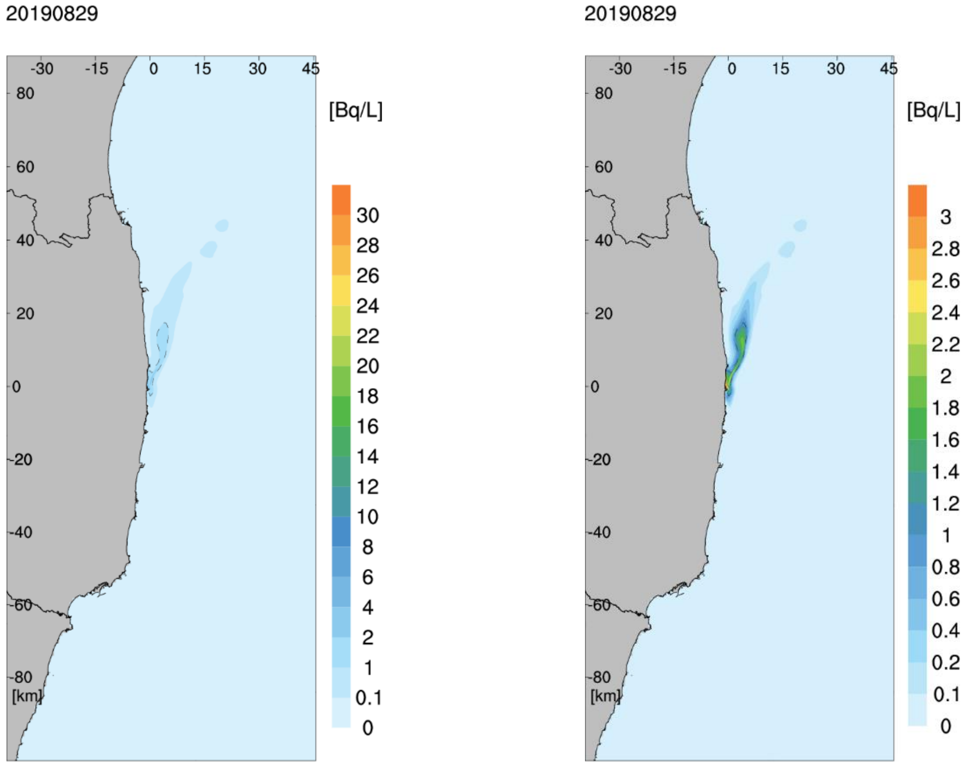
Figure 6-1-18(1) Distribution of daily mean concentration on the sea surface

(When the range of 1 Bq/L extends to the easternmost point)



Detailed concentration classification in the left figure

Figure 6-1-18(2) Distribution of daily mean concentration on the sea surface
(When the range of 1 Bq/L extends to the southernmost point)



Detailed concentration classification in the left figure

Figure 6-1-18(3) Distribution of daily mean concentration on the sea surface
(When the range of 1 Bq/L extends to the easternmost point)

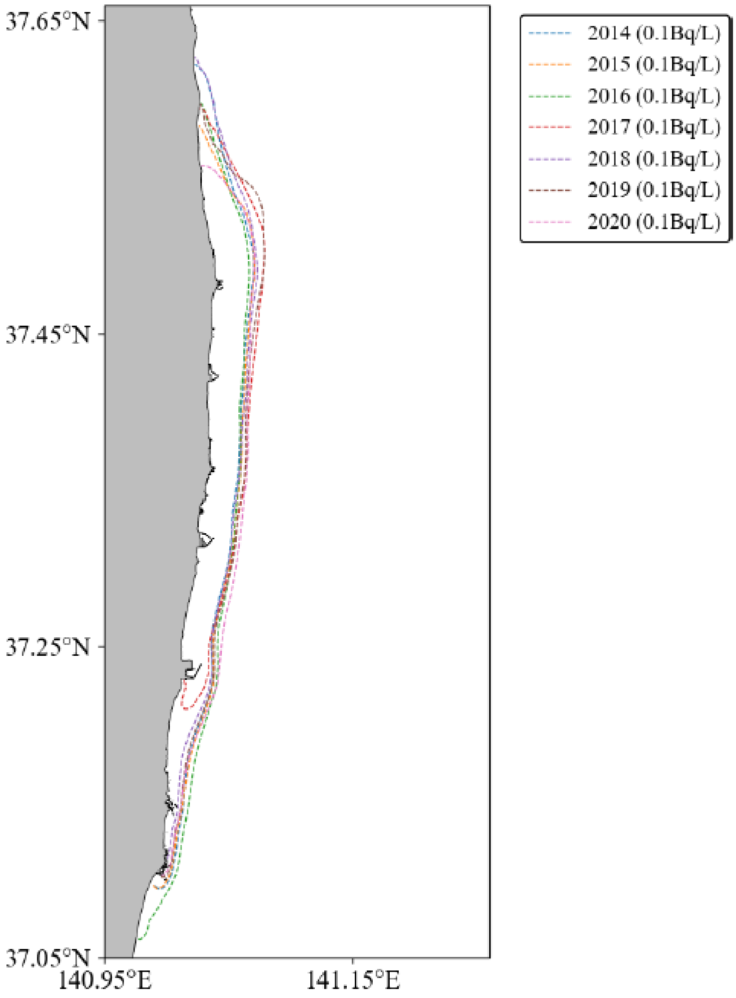


Figure 6-1-19 Range of the annual average concentration of 0.1Bq/L between 2014 and 2020

Table 6-1-15 Calculation result of the annual average concentration within the range of 10 km × 10 km between 2014 and 2020

Year	Annual average concentration within 10 km × 10 km around the FDNPS (Bq/L)		
	All layers	Top layer	Bottom layer
2014	4.8E-02	1.0E-01	5.0E-02
2015	4.9E-02	9.6E-02	5.3E-02
2016	4.9E-02	9.6E-02	5.3E-02
2017	5.8E-02	1.2E-01	6.3E-02
2018	5.0E-02	1.1E-01	5.4E-02
2019	5.6E-02	1.2E-01	6.0E-02
2020	5.4E-02	1.1E-01	6.0E-02
Mean	5.2E-02	1.1E-01	5.6E-02
Standard deviation	3.8E-03	9.3E-03	4.4E-03

Table 6-1-16 Maximum concentration on the boundary of the calculation area (all of the north, east, and south sides)

Year	Concentration (Bq/L)	Coordinate		
		East - West (0: West boundary, 460: East boundary)	North - South (0: South boundary, 658: North boundary)	Depth (0: Bottom layer, 29: Top layer)
2014	1.1E-04	460 (East boundary)	80	23
2015	2.6E-04	460 (East boundary)	145	29
2016	1.4E-04	460 (East boundary)	318	25
2017	2.4E-04	460 (East boundary)	224	23
2018	1.9E-04	460 (East boundary)	150	29
2019	1.6E-04	460 (East boundary)	181	28
2020	1.9E-04	460 (East boundary)	232	28

(2) Concentration of each nuclide used for the assessment in the seawater

The concentration of the other nuclides was calculated from the ratio of tritium to the annual discharge amount of the other nuclides in the source term based on the assessment result of advection and diffusion to tritium.

Table 6-1-17 shows the concentration of tritium in the seawater within 10 km × 10 km around the FDNPS and at the beach assessment point to the north of the FDNPS (annual discharge amount) in the case of the annual discharge amount of 22 TBq (2.2E+13Bq) of tritium. The change rate of the concentration of 2019 from the concentration of 2014 is about 20%. Though the impact of annual variation is small, we decided to use the concentration of 2019, which is higher, for the exposure assessment.

Tables 6-1-18 to 20 show this result and the radioactive material concentration in the seawater for the assessment calculated from the annual discharge amount of each nuclide shown in Tables 6-1-1 to 6-1-3.

Table 6-1-17 Tritium concentration in the seawater in the case of the annual tritium discharge amount of 2.2E+13Bq

	Depth	Calculation result (Bq/L)			Concentration for assessment (Bq/L)
		Meteorological and oceanographic data of 2014	Meteorological and oceanographic data of 2019	Difference (%)	
Annual average concentration within 10 km × 10 km around the FDNPS	All layers	4.8E-02	5.6E-02	17	5.6E-02
	Top layer	1.0E-01	1.2E-01	20	1.2E-01
Annual average concentration of the beach assessment point	All layers	7.2E-01	8.8E-01	22	8.8E-01

Table 6-1-18 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the K4 tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (Bq/L)		
		Within 10 km × 10 km Average of all layers	Within 10 km × 10 km Average of the top layer	Beach assessment point Average of all layers
H-3	2.2E+13	5.6E-02	1.2E-01	8.8E-01
C-14	2.4E+09	6.0E-06	1.3E-05	9.4E-05
Mn-54	1.3E+04	3.4E-11	7.3E-11	5.3E-10
Fe-55	3.3E+08	8.4E-07	1.8E-06	1.3E-05
Co-60	3.5E+07	8.8E-08	1.9E-07	1.4E-06
Ni-63	3.3E+08	8.4E-07	1.8E-06	1.3E-05
Se-79	2.4E+08	6.0E-07	1.3E-06	9.4E-06
Sr-90	3.0E+07	7.6E-08	1.6E-07	1.2E-06
Y-90	3.0E+07	7.6E-08	1.6E-07	1.2E-06
Tc-99	1.1E+08	2.8E-07	6.0E-07	4.4E-06
Ru-106	6.6E+06	1.7E-08	3.6E-08	2.6E-07
Sb-125	1.4E+07	3.4E-08	7.4E-08	5.4E-07
Te-125m	1.4E+07	3.4E-08	7.4E-08	5.4E-07
I-129	3.3E+08	8.4E-07	1.8E-06	1.3E-05
Cs-134	1.2E+06	3.0E-09	6.3E-09	4.7E-08
Cs-137	5.8E+07	1.5E-07	3.2E-07	2.3E-06
Ce-144	8.3E+04	2.1E-10	4.5E-10	3.3E-09
Pm-147	7.1E+06	1.8E-08	3.9E-08	2.8E-07
Sm-151	1.4E+05	3.4E-10	7.4E-10	5.4E-09
Eu-154	1.2E+06	3.1E-09	6.7E-09	4.9E-08
Eu-155	2.4E+06	6.0E-09	1.3E-08	9.4E-08
U-234	9.9E+04	2.5E-10	5.4E-10	4.0E-09
U-238	9.9E+04	2.5E-10	5.4E-10	4.0E-09
Np-237	9.9E+04	2.5E-10	5.4E-10	4.0E-09
Pu-238	9.4E+04	2.4E-10	5.1E-10	3.8E-09
Pu-239	9.9E+04	2.5E-10	5.4E-10	4.0E-09
Pu-240	9.9E+04	2.5E-10	5.4E-10	4.0E-09
Pu-241	3.5E+06	8.8E-09	1.9E-08	1.4E-07
Am-241	9.7E+04	2.5E-10	5.3E-10	3.9E-09
Cm-244	8.0E+04	2.0E-10	4.4E-10	3.2E-09
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	During swimming From beach sand Ingestion of seawater Inhalation of seawater spray

Table 6-1-19 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-C tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (Bq/L)		
		Within 10 km × 10 km Average of all layers	Within 10 km × 10 km Average of the top layers	Beach assessment point Average of all layers
H-3	2.2E+13	5.6E-02	1.2E-01	8.8E-01
C-14	5.5E+08	1.4E-06	3.0E-06	2.2E-05
Mn-54	1.6E+05	4.1E-10	8.8E-10	6.5E-09
Fe-55	7.3E+07	1.9E-07	4.0E-07	2.9E-06
Co-60	7.3E+06	1.9E-08	4.0E-08	2.9E-07
Ni-63	2.5E+08	6.5E-07	1.4E-06	1.0E-05
Se-79	4.6E+07	1.2E-07	2.5E-07	1.8E-06
Sr-90	1.0E+06	2.6E-09	5.7E-09	4.2E-08
Y-90	1.0E+06	2.6E-09	5.7E-09	4.2E-08
Tc-99	3.7E+07	9.3E-08	2.0E-07	1.5E-06
Ru-106	8.3E+06	2.1E-08	4.5E-08	3.3E-07
Sb-125	3.7E+06	9.3E-09	2.0E-08	1.5E-07
Te-125m	3.7E+06	9.3E-09	2.0E-08	1.5E-07
I-129	3.7E+07	9.3E-08	2.0E-07	1.5E-06
Cs-134	1.0E+06	2.6E-09	5.5E-09	4.0E-08
Cs-137	5.2E+06	1.3E-08	2.8E-08	2.1E-07
Ce-144	2.0E+06	5.0E-09	1.1E-08	7.8E-08
Pm-147	1.3E+07	3.3E-08	7.0E-08	5.1E-07
Sm-151	3.4E+05	8.6E-10	1.8E-09	1.3E-08
Eu-154	2.9E+06	7.3E-09	1.6E-08	1.1E-07
Eu-155	7.3E+06	1.9E-08	4.0E-08	2.9E-07
U-234	9.8E+05	2.5E-09	5.3E-09	3.9E-08
U-238	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Np-237	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Pu-238	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Pu-239	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Pu-240	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Pu-241	3.4E+07	8.6E-08	1.8E-07	1.3E-06
Am-241	9.8E+05	2.5E-09	5.3E-09	3.9E-08
Cm-244	9.2E+05	2.3E-09	5.0E-09	3.7E-08
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	During swimming From beach sand Ingestion of seawater Inhalation of seawater spray

Table 6-1-20 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-G tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (Bq/L)		
		Within 10 km × 10 km Average of all layers	Within 10 km × 10 km Average of the top layers	Beach assessment point Average of all layers
H-3	2.2E+13	5.6E-02	1.2E-01	8.8E-01
C-14	1.5E+09	3.7E-06	8.0E-06	5.9E-05
Mn-54	5.0E+05	1.3E-09	2.7E-09	2.0E-08
Fe-55	2.2E+08	5.6E-07	1.2E-06	8.8E-06
Co-60	1.6E+07	4.0E-08	8.5E-08	6.2E-07
Ni-63	8.0E+08	2.0E-06	4.4E-06	3.2E-05
Se-79	1.4E+08	3.5E-07	7.5E-07	5.5E-06
Sr-90	2.8E+06	7.0E-09	1.5E-08	1.1E-07
Y-90	2.8E+06	7.0E-09	1.5E-08	1.1E-07
Tc-99	1.2E+08	3.0E-07	6.5E-07	4.8E-06
Ru-106	8.6E+06	2.2E-08	4.7E-08	3.4E-07
Sb-125	6.9E+06	1.8E-08	3.8E-08	2.8E-07
Te-125m	6.9E+06	1.8E-08	3.8E-08	2.8E-07
I-129	3.0E+07	7.7E-08	1.7E-07	1.2E-06
Cs-134	2.8E+06	7.0E-09	1.5E-08	1.1E-07
Cs-137	2.8E+07	7.2E-08	1.6E-07	1.1E-06
Ce-144	6.0E+06	1.5E-08	3.3E-08	2.4E-07
Pm-147	3.5E+07	8.9E-08	1.9E-07	1.4E-06
Sm-151	9.0E+05	2.3E-09	4.9E-09	3.6E-08
Eu-154	7.7E+06	2.0E-08	4.2E-08	3.1E-07
Eu-155	1.1E+07	2.8E-08	6.0E-08	4.4E-07
U-234	2.6E+06	6.5E-09	1.4E-08	1.0E-07
U-238	2.6E+06	6.5E-09	1.4E-08	1.0E-07
Np-237	2.6E+06	6.5E-09	1.4E-08	1.0E-07
Pu-238	2.5E+06	6.3E-09	1.4E-08	9.9E-08
Pu-239	2.6E+06	6.5E-09	1.4E-08	1.0E-07
Pu-240	2.6E+06	6.5E-09	1.4E-08	1.0E-07
Pu-241	8.2E+07	2.1E-07	4.5E-07	3.3E-06
Am-241	2.6E+06	6.5E-09	1.4E-08	1.0E-07
Cm-244	2.4E+06	6.1E-09	1.3E-08	9.5E-08
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	During swimming From beach sand Ingestion of seawater Inhalation of seawater spray

(3) Exposure assessment result

Tables 6-1-21 to 22 show the result of the exposure assessments of the following three cases using the concentrations in the seawater shown in Tables 6-1-18 to 6-1-20.
Source term based on the measured composition of nuclides

- i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
- ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
- iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

The result of human exposure assessment is 0.000002 (2E-06) to 0.00003 (3E-05) mSv/year.
In all cases, the results were much smaller than the dose limit of 1 mSv/year for the general public and the dose target of 0.05 mSv/year for domestic nuclear power plants, which is equivalent to the dose constraint value.
The assessment in the source term based on the measured value was assessed assuming that nuclides below the detection limits (undetected nuclides) were contained at the detection limits, so the assessment result is considered to be conservative. Attachment IX “Contribution to the undetected nuclides in the source term based on the measured value” shows the contribution of undetected nuclides in the assessment result.
Even in the exposure assessment of infant, of which the assessed value of internal exposure is high because the effective dose factor is large, the assessment result of internal exposure is 0.0000017 (1.7E-06) mSv/year to 0.000032 (3.2E-05) mSv/year. This result is much lower than the dose limit of 1mSv/year as well as the target dose value of 0.05mSv/year, which is equivalent to the dose constraint.
Attachment X “Breakdown of the exposure assessment result by nuclide” shows the nuclide-specific breakdown of these assessment results. In addition, in Attachment XI " Conservativeness of the external exposure dose conversion factor" the conservatism of the dose conversion coefficients in the decommissioning handbook was confirmed through trial calculations using the dose conversion coefficients in FGR15 published by U.S. Environmental Protection Agency.

Table 6-1-21 Results of human exposures assessment

Assessed case	Source term	Source term based on measured values					
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
External exposure (mSv/year)	Sea surface	4.6E-10		1.7E-10		3.7E-10	
	Hull	4.9E-10		1.8E-10		3.7E-10	
	During swimming	3.2E-10		1.2E-10		2.5E-10	
	Beach sand	5.4E-07		2.0E-07		4.3E-07	
	Fishing net	1.1E-07		3.9E-08		8.3E-08	
Internal exposure (mSv/year)	Ingestion of water	3.4E-07		3.1E-07		3.1E-07	
	Inhalation of spray	9.2E-08		1.9E-07		3.8E-07	
	Ingestion of seafood	6.9E-06	3.1E-05	1.2E-06	5.5E-06	2.6E-06	1.1E-05
Total (mSv/year)		8E-06	3E-05	2E-06	6E-06	4E-06	1E-05

Table 6-1-22 Results of internal exposures assessment by age

Assessed case	Source term	Source term based on measured values					
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Internal exposure from ingestion of water (mSv/year)	Adult	3.4E-07		3.1E-07		3.1E-07	
	Child under school age	5.8E-07		5.3E-07		5.4E-07	
	Infant	—		—		—	
Internal exposure from inhalation of spray (mSv/year)	Adult	9.2E-08		1.9E-07		3.8E-07	
	Child under school age	6.0E-08		1.1E-07		2.0E-07	
	Infant	3.9E-08		6.2E-08		1.1E-07	
Internal exposure from ingestion of seafood (mSv/year)	Adult	6.9E-06	3.1E-05	1.2E-06	5.5E-06	2.6E-06	1.1E-05
	Child under school age	7.8E-06	3.6E-05	1.5E-06	6.8E-06	3.6E-06	1.6E-05
	Infant	6.9E-06	3.2E-05	1.7E-06	8.1E-06	4.6E-06	2.2E-05

(4) Annual Discharge Limit for Each Radionuclide based on the Dose Constraint and the Optimization

In terms of the basic concept of radiation protection[38], which is to make every effort to reduce exposure as low as reasonably achievable while also considering social and economic balance, optimization of radiation protection does not necessarily equal to the minimization of exposure. Radiation protection is optimized to the extent that it does not exceed the dose constraint.

Regarding tritium, if the calculation is performed the annual discharge amount of tritium from the assessment result of the K4 tank group of which value of the exposure assessment result is the largest among the source terms based on the measured values, the result is as follows considering the dose constraint is 0.05mSv/year and the exposure assessment result based

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[38] The principle of “ALARA” (As Low As Reasonably Achievable), which means radiation can be utilized with optimizing exposure as low as reasonably achievable when benefits from a practice with the radiation outweigh risks by the exposure

on the source term of the K4 tank group (if the ingestion of seafood is large amount) is 3E-05mSv/year:

2.2E+13(Bq/year)×0.05 (mSv/year)÷0.00003(mSv/year)= 3.7E+16(Bq/year)= 37 PBq/year (37,000 TBq/year)

As the same calculation, if the calculation is performed using the assessment result of the J1-C tank group of which value of the exposure assessment result is the smallest, the result is as follows:

2.2E+13(Bq/year)×0.05 (mSv/year)÷0.000002(mSv/year)= 5.5E+17(Bq/year)= 550 PBq/year (550,000 TBq/year)

The actual discharge amount will be determined setting the minimum value of 37 PBq (source term: K4 tank group, seafood ingestion: large amount) as the limit value, which is the lowest value depends on source term and seafood ingestion at a result of optimization of radiation protection. “The annual discharge amount of treated water”, “Dose constraints”, and “Exposure assessment result by the source term” together with the other nuclides are used for the preliminary calculation of the allowable upper limit of discharge amount and optimization. The calculation result and optimization result was summarized in Reference G “Upper limit of annual discharge and optimization assessment result of each nuclide based on the dose constraint.”

On the other hand, the Basic Policy of the government in April 2021 stipulates “The total annual amount of tritium to be discharged will be at a level below the operational target value for tritium discharge of the Fukushima Daiichi NPS before the accident (22 TBq/year).” This is a policy-making decision with consideration of the viewpoint of risk optimization of the whole decommissioning process as well as ALPS treated water, the effect of natural decay of radioactive materials expected to occur during land storage of ALPS treated water, leakage risk and occupational exposure during long-term storage, and social acceptance such as understanding from stakeholders. Based on this circumstance, we set the annual discharge amount of tritium 22 TBq/year (2.2E+13Bq/year) in accordance with above mentioned “TEPCO’s Action in response to Government’s Policy (April, 2021),” and assessed radiological environmental impact.

In accordance with the Basic Policy of the government, the annual discharge amount of tritium is to be reviewed periodically below the dose constraint, by closely examining the circumstances of contaminated water generation and tritium concentration of newly generated ALPS treated water, and paying sufficient attention to the optimization including viewpoint of stakeholders.

6-2. Potential exposure assessment

Potential exposure was assessed according to the assessment procedure of potential exposure shown in GSG-10 (Figure 6-2-1).

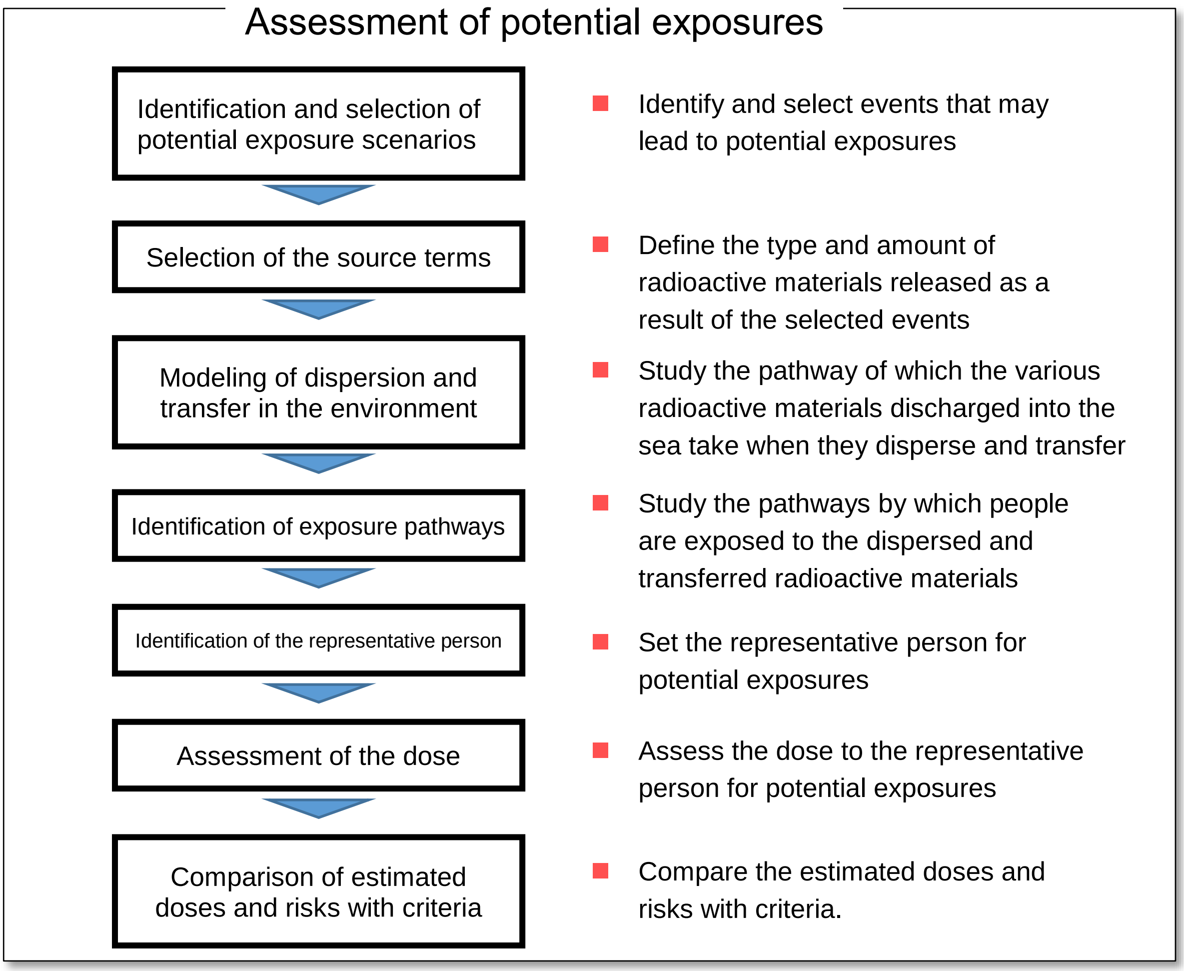


Figure 6-2-1. Assessment procedure of potential exposures

6-2-1. Assessment method

(1) Identification and selection of potential exposure scenarios

The facilities for discharging ALPS treated water into the sea are measurement/confirmation facility, transfer facility, dilution facility, and discharge facility. The target facilities contain two types of radioactive water: diluted and undiluted ALPS treated water. Therefore, unintentional discharge of ALPS treated water into the ocean is defined as the top event, and the following three types of specific abnormal events are defined:

(1) Discharge radioactive materials with defective measurement/ confirmation
(2) Discharge with insufficient seawater dilution
(3) Leakage from facilities

In the design, to prevent these:

For (1)

- Set up interlock for discharge
- Duplication of tank valves
- Comparison with the analysis by a third-party institution
- Homogenization of samples by stirring and circulation equipment

For (2)

- Surveillance of the dilution rate based on the flow rate
- Set up interlock to stop discharge when the seawater flow rate is abnormal
- Installation of double emergency isolation valves

For (3)

- Stop in the event of earthquake
- Implementation of periodic patrol inspection
- Connection between the polyethylene pipes will be a fusion structure.
- Installation of a leakage detector and weir in the flange
- Installation of a water level gauge in the receiving tank

Thanks to these and other measures, the unintentional discharge amount of ALPS treated water in the event of a single failure is limited to about 1.2 m^3 at the most.
As for (1) and (2), discharge is prevented or mitigated by design and operation, but as for (3) leakage from facilities, there remains a possibility of occurrence caused by external events beyond design assumptions, etc., so we selected scenarios.
As mentioned at the beginning, the facilities for discharging ALPS treated water into the sea are measurement/confirmation facility, transfer facility, dilution facility, and discharge facility. Among these facilities, dilution facility and discharge facility are facilities containing ALPS treated water after dilution and the risk of exposure from leakage is negligible.
On the other hand, the measurement/confirmation facility mainly consists of tanks for measurement and confirmation, pumps, piping, and valves, and the transfer facility mainly

consists of pumps, piping, and valves. As scenarios of leakage from these facilities, we selected case 1: leakage from piping, and case 2: leakage from tanks as the severest event, as follows.

- Case 1 Leakage from piping

In the case of leakage from piping, the flow rate of ALPS treated water is considered to be the same as in normal conditions, but the water flows into the sea without dilution. As the severest scenario of leakage from piping, selected is the event of leakage of the whole amount of the maximum flow rare in the normal operation (500 m^3/day) from near the north breakwater due to piping rupture near the sea. In addition, in reality, leakage is considered to stop on the following day because the flow rate is monitored constantly and a patrol inspection is performed every day, but here it is assumed that leakage was overlooked and continued for 20 days until one tank series for measurement/confirmation of 10,000 m^3 became empty.

In the case of a break in the transfer pipes of ALPS treated water, the water may leak out to the vicinity of the Units 5/6 intakes or the Units 5/6 discharge outlets, depending on the location of the break, however, the Units 5/6 intakes are connected to the Units 5/6 discharge outlets due to the intake of seawater for dilution of ALPS treated water, so it is conservatively assumed that the entire amount of water would directly flow out the vicinity of the Units 5/6 discharge outlets.

- Case 2 Leakage from tanks

As the severest scenario, selected is the event of leakage of ALPS treated water of 30,000 m^3 per day into the sea due to damage of all of the 3 tank groups for measurement/confirmation caused by an enormous earthquake, etc. In reality, it is conceivable that some of ALPS treated water may remain in the tanks and weirs or penetrate into the ground within the site, but it was decided that the whole volume would flow into the sea in this case.

The location of the outflow into the sea is assumed to be the same as in Case 1, with the entire amount of water discharged directly to the vicinity of the Units 5/6 discharge outlets.

(2) Source term (daily discharge amount of each nuclide)

Case 1 (Piping rupture)

Leaked ALPS treated water is the one which is usually discharged after dilution, and the source term was calculated from the product of the composition of nuclides based on the measured value and the maximum daily discharge volume of water (500 m^3/day). Tables 6-2-1 to 6-2-3 show the source term used for the assessment.

Table 6-2-1 Source term based on the nuclide composition of measured values (K4 tank group) (Case 1)

Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	1.4E+05	5.0E+05	7.0E+10	• The daily discharge amount was calculated from the product of the maximum value of the daily discharge volume of water in normal operation, 500 m^3, and the concentrations of each nuclide
C-14	1.5E+01		7.5E+06	
Mn-54	8.5E-05		4.3E+01	
Fe-55	2.1E+00		1.1E+06	
Co-60	2.2E-01		1.1E+05	
Ni-63	2.1E+00		1.1E+06	
Se-79	1.5E+00		7.5E+05	
Sr-90	1.9E-01		9.5E+04	
Y-90	1.9E-01		9.5E+04	
Tc-99	7.0E-01		3.5E+05	
Ru-106	4.2E-02		2.1E+04	
Sb-125	8.6E-02		4.3E+04	
Te-125m	8.6E-02		4.3E+04	
I-129	2.1E+00		1.1E+06	
Cs-134	7.4E-03		3.7E+03	
Cs-137	3.7E-01		1.9E+05	
Ce-144	5.3E-04		2.7E+02	
Pm-147	4.5E-02		2.3E+04	
Sm-151	8.6E-04		4.3E+02	
Eu-154	7.8E-03		3.9E+03	
Eu-155	1.5E-02		7.5E+03	
U-234	6.3E-04		3.2E+02	
U-238	6.3E-04		3.2E+02	
Np-237	6.3E-04		3.2E+02	
Pu-238	6.0E-04		3.0E+02	
Pu-239	6.3E-04		3.2E+02	
Pu-240	6.3E-04		3.2E+02	
Pu-241	2.2E-02		1.1E+04	
Am-241	6.2E-04		3.1E+02	
Cm-244	5.1E-04		2.6E+02	

Table 6-2-2 Source term based on the nuclide composition of measured values (J1-C tank group) (Case 1)

Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	7.2E+05	5.0E+05	3.6E+11	• The daily discharge amount was calculated from the product of the maximum value of the daily discharge volume of water in normal operation, 500 m^3, and the concentrations of each nuclide
C-14	1.8E+01		9.0E+06	
Mn-54	5.3E-03		2.7E+03	
Fe-55	2.4E+00		1.2E+06	
Co-60	2.4E-01		1.2E+05	
Ni-63	8.3E+00		4.2E+06	
Se-79	1.5E+00		7.5E+05	
Sr-90	3.4E-02		1.7E+04	
Y-90	3.4E-02		1.7E+04	
Tc-99	1.2E+00		6.0E+05	
Ru-106	2.7E-01		1.4E+05	
Sb-125	1.2E-01		6.0E+04	
Te-125m	1.2E-01		6.0E+04	
I-129	1.2E+00		6.0E+05	
Cs-134	3.3E-02		1.7E+04	
Cs-137	1.7E-01		8.5E+04	
Ce-144	6.4E-02		3.2E+04	
Pm-147	4.2E-01		2.1E+05	
Sm-151	1.1E-02		5.5E+03	
Eu-154	9.4E-02		4.7E+04	
Eu-155	2.4E-01		1.2E+05	
U-234	3.2E-02		1.6E+04	
U-238	3.2E-02		1.6E+04	
Np-237	3.2E-02		1.6E+04	
Pu-238	3.2E-02		1.6E+04	
Pu-239	3.2E-02		1.6E+04	
Pu-240	3.2E-02		1.6E+04	
Pu-241	1.1E+00		5.5E+05	
Am-241	3.2E-02		1.6E+04	
Cm-244	3.0E-02		1.5E+04	

Table 6-2-3 Source term based on the nuclide composition of measured values (J1-G tank group) (Case 1)

Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	2.4E+05	5.0E+05	1.2E+11	• The daily discharge amount was calculated from the product of the maximum value of the daily discharge volume of water in normal operation, 500 m^3, and the concentrations of each nuclide
C-14	1.6E+01		8.0E+06	
Mn-54	5.4E-03		2.7E+03	
Fe-55	2.4E+00		1.2E+06	
Co-60	1.7E-01		8.5E+04	
Ni-63	8.7E+00		4.4E+06	
Se-79	1.5E+00		7.5E+05	
Sr-90	3.0E-02		1.5E+04	
Y-90	3.0E-02		1.5E+04	
Tc-99	1.3E+00		6.5E+05	
Ru-106	9.4E-02		4.7E+04	
Sb-125	7.5E-02		3.8E+04	
Te-125m	7.5E-02		3.8E+04	
I-129	3.3E-01		1.7E+05	
Cs-134	3.0E-02		1.5E+04	
Cs-137	3.1E-01		1.6E+05	
Ce-144	6.5E-02		3.3E+04	
Pm-147	3.8E-01		1.9E+05	
Sm-151	9.8E-03		4.9E+03	
Eu-154	8.4E-02		4.2E+04	
Eu-155	1.2E-01		6.0E+04	
U-234	2.8E-02		1.4E+04	
U-238	2.8E-02		1.4E+04	
Np-237	2.8E-02		1.4E+04	
Pu-238	2.7E-02		1.4E+04	
Pu-239	2.8E-02		1.4E+04	
Pu-240	2.8E-02		1.4E+04	
Pu-241	8.9E-01		4.5E+05	
Am-241	2.8E-02		1.4E+04	
Cm-244	2.6E-02		1.3E+04	

Case 2 (Tank damage)

Leaked ALPS treated water is the one which is usually discharged after dilution, and the source term was calculated from the product of the composition of nuclides based on the measured value and the daily discharge volume of water (30,000 m^3/day). Tables 6-2-4 to 6-2-6 show the source term used for the assessment.

Table 6-2-4 Source term based on the nuclide composition of measured values (K4 tank group) (Case 2)

Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	1.4E+05	3.0E+07	4.2E+12	• It was assumed that all of 3 tank groups for measurement/confirmation were damaged and whole capacity (30,000 m^3) leaked in 1 day • The daily discharge amount was calculated from the product of the daily discharge volume of water, 30,000 m^3, and the nuclide concentration
C-14	1.5E+01		4.5E+08	
Mn-54	8.5E-05		2.6E+03	
Fe-55	2.1E+00		6.3E+07	
Co-60	2.2E-01		6.6E+06	
Ni-63	2.1E+00		6.3E+07	
Se-79	1.5E+00		4.5E+07	
Sr-90	1.9E-01		5.7E+06	
Y-90	1.9E-01		5.7E+06	
Tc-99	7.0E-01		2.1E+07	
Ru-106	4.2E-02		1.3E+06	
Sb-125	8.6E-02		2.6E+06	
Te-125m	8.6E-02		2.6E+06	
I-129	2.1E+00		6.3E+07	
Cs-134	7.4E-03		2.2E+05	
Cs-137	3.7E-01		1.1E+07	
Ce-144	5.3E-04		1.6E+04	
Pm-147	4.5E-02		1.4E+06	
Sm-151	8.6E-04		2.6E+04	
Eu-154	7.8E-03		2.3E+05	
Eu-155	1.5E-02		4.5E+05	
U-234	6.3E-04		1.9E+04	
U-238	6.3E-04		1.9E+04	
Np-237	6.3E-04		1.9E+04	
Pu-238	6.0E-04		1.8E+04	
Pu-239	6.3E-04		1.9E+04	
Pu-240	6.3E-04		1.9E+04	
Pu-241	2.2E-02		6.6E+05	
Am-241	6.2E-04		1.9E+04	
Cm-244	5.1E-04		1.5E+04	

Table 6-2-5 Source term based on the nuclide composition of measured values (J1-C tank group) (Case 2)

Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	7.2E+05	3.0E+07	2.2E+13	• It was assumed that all of 3 tank groups for measurement/confirmation were damaged and whole capacity (30,000 m^3) leaked in 1 day • The daily discharge amount was calculated from the product of the daily discharge volume of water, 30,000 m^3, and the nuclide concentration
C-14	1.8E+01		5.4E+08	
Mn-54	5.3E-03		1.6E+05	
Fe-55	2.4E+00		7.2E+07	
Co-60	2.4E-01		7.2E+06	
Ni-63	8.3E+00		2.5E+08	
Se-79	1.5E+00		4.5E+07	
Sr-90	3.4E-02		1.0E+06	
Y-90	3.4E-02		1.0E+06	
Tc-99	1.2E+00		3.6E+07	
Ru-106	2.7E-01		8.1E+06	
Sb-125	1.2E-01		3.6E+06	
Te-125m	1.2E-01		3.6E+06	
I-129	1.2E+00		3.6E+07	
Cs-134	3.3E-02		9.9E+05	
Cs-137	1.7E-01		5.1E+06	
Ce-144	6.4E-02		1.9E+06	
Pm-147	4.2E-01		1.3E+07	
Sm-151	1.1E-02		3.3E+05	
Eu-154	9.4E-02		2.8E+06	
Eu-155	2.4E-01		7.2E+06	
U-234	3.2E-02		9.6E+05	
U-238	3.2E-02		9.6E+05	
Np-237	3.2E-02		9.6E+05	
Pu-238	3.2E-02		9.6E+05	
Pu-239	3.2E-02		9.6E+05	
Pu-240	3.2E-02		9.6E+05	
Pu-241	1.1E+00		3.3E+07	
Am-241	3.2E-02		9.6E+05	
Cm-244	3.0E-02		9.0E+05	

Table 6-2-6 Source term based on the nuclide composition of measured values (J1-G tank group) (Case 2)

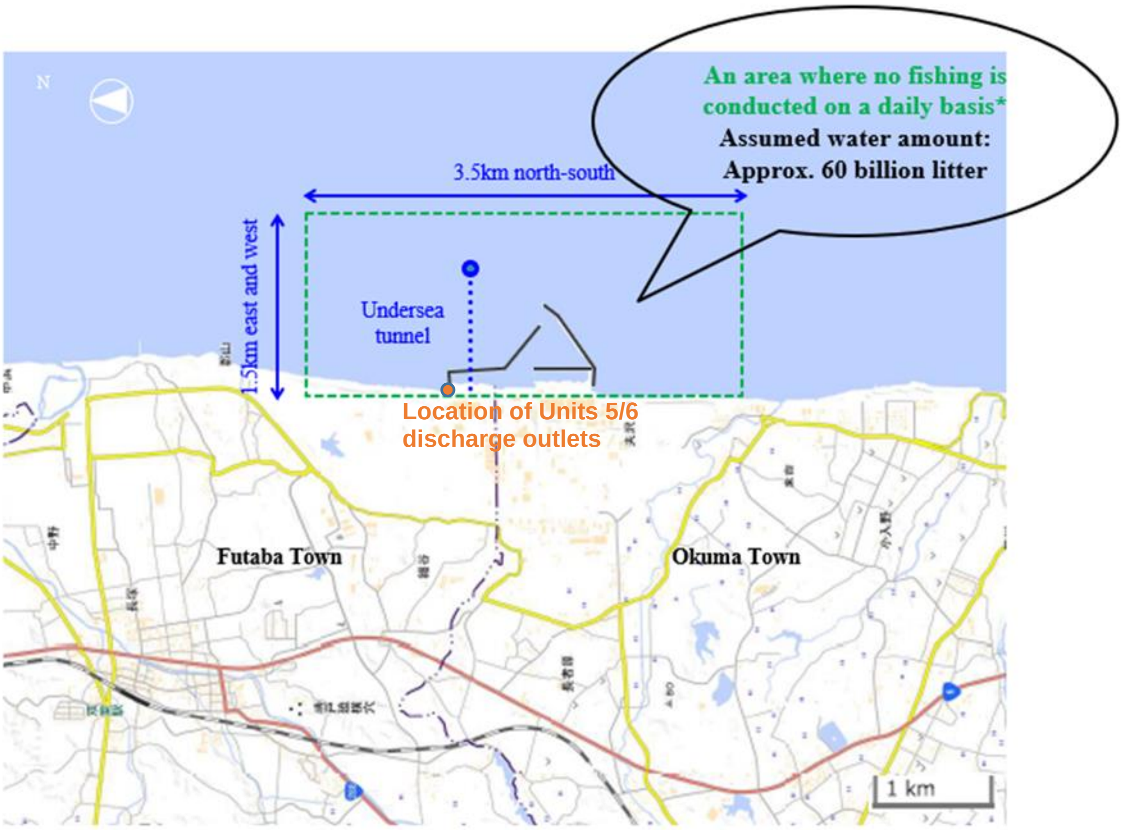
Target nuclide	Nuclide concentration (Bq/L)	Daily discharge volume of water (L/day)	Daily discharge amount (Bq/day)	Remarks
H-3	2.4E+05	3.0E+07	7.2E+12	• It was assumed that all of 3 tank groups for measurement/confirmation were damaged and whole capacity (30,000 m^3) leaked in 1 day • The daily discharge amount was calculated from the product of the daily discharge volume of water, 30,000 m^3, and the nuclide concentration
C-14	1.6E+01		4.8E+08	
Mn-54	5.4E-03		1.6E+05	
Fe-55	2.4E+00		7.2E+07	
Co-60	1.7E-01		5.1E+06	
Ni-63	8.7E+00		2.6E+08	
Se-79	1.5E+00		4.5E+07	
Sr-90	3.0E-02		9.0E+05	
Y-90	3.0E-02		9.0E+05	
Tc-99	1.3E+00		3.9E+07	
Ru-106	9.4E-02		2.8E+06	
Sb-125	7.5E-02		2.3E+06	
Te-125m	7.5E-02		2.3E+06	
I-129	3.3E-01		9.9E+06	
Cs-134	3.0E-02		9.0E+05	
Cs-137	3.1E-01		9.3E+06	
Ce-144	6.5E-02		2.0E+06	
Pm-147	3.8E-01		1.1E+07	
Sm-151	9.8E-03		2.9E+05	
Eu-154	8.4E-02		2.5E+06	
Eu-155	1.2E-01		3.6E+06	
U-234	2.8E-02		8.4E+05	
U-238	2.8E-02		8.4E+05	
Np-237	2.8E-02		8.4E+05	
Pu-238	2.7E-02		8.1E+05	
Pu-239	2.8E-02		8.4E+05	
Pu-240	2.8E-02		8.4E+05	
Pu-241	8.9E-01		2.7E+07	
Am-241	2.8E-02		8.4E+05	
Cm-244	2.6E-02		7.8E+05	

(3) Modeling of diffusion and transfer, and exposure pathways

In the assessment of potential exposure, the location of discharge into the sea changes from 1 km offshore to the coast, but these discharge destinations are the same sea area and diffusion and advection are assumed as same as those of the normal exposure, so the migration pathways are the same as those of the normal exposure set in 6-1-2.(2). Though the same model is also used for simulation, the calculation result based on discharge from near the Units 5/6 discharge outlets was used because it is the leakage from the coast. The location of the Units 5/6 discharge outlets are shown in Figure 6-2-1.

The target regions, sea areas, and migration pathways are the same, so exposure pathways are the same as those of the normal exposure.

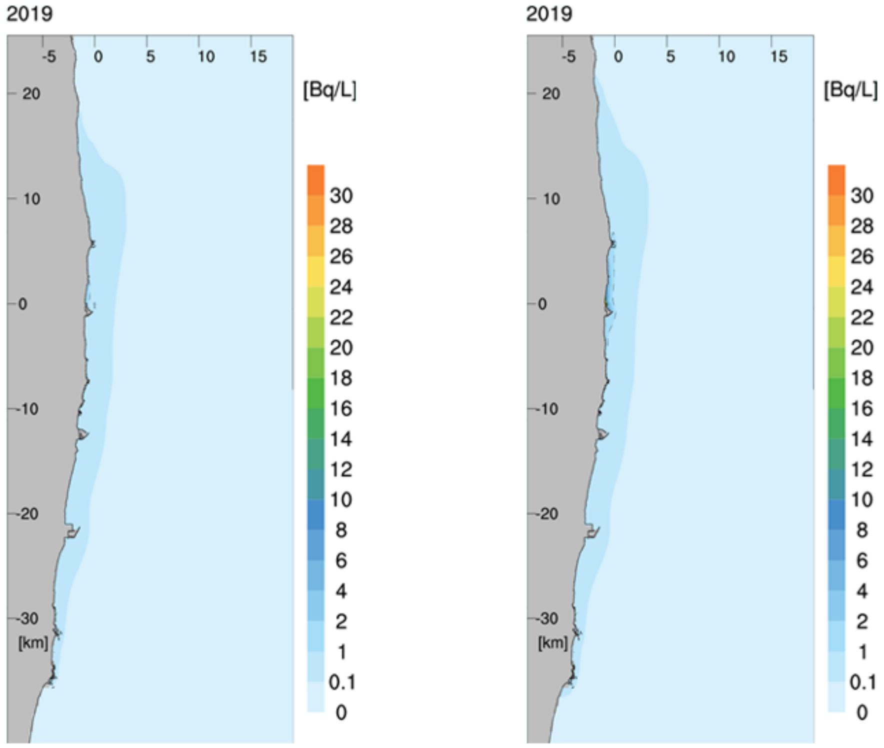
Figures 6-2-2 to 6-2-4 show the comparison figures of dispersion simulation results (annual mean concentration) for the different water discharge location. No significant difference in dispersion of the wide area are observed, but in the coastal area near the FDNPS the concentration is higher in the case of discharge from Units 5/6 discharge outlets.



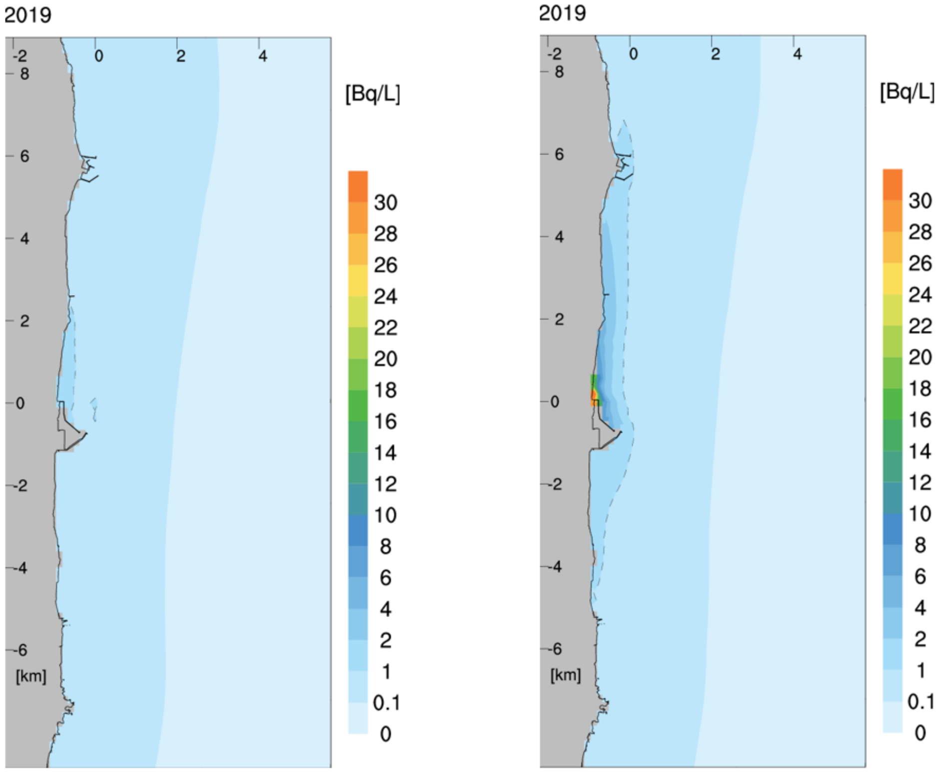
Source: Prepared by Tokyo Electric Power Company Holdings, Inc. based on the map developed by the Geospatial Information Authority of Japan (Electronic territory web)
https://maps.gsi.go.jp/#13/37.422730/141.044970/&base=std&ls=std&disp=1&vs=c1j0h0k0l0u0t0z0r0s0m0f1

※Areas where common fishery rights are not set

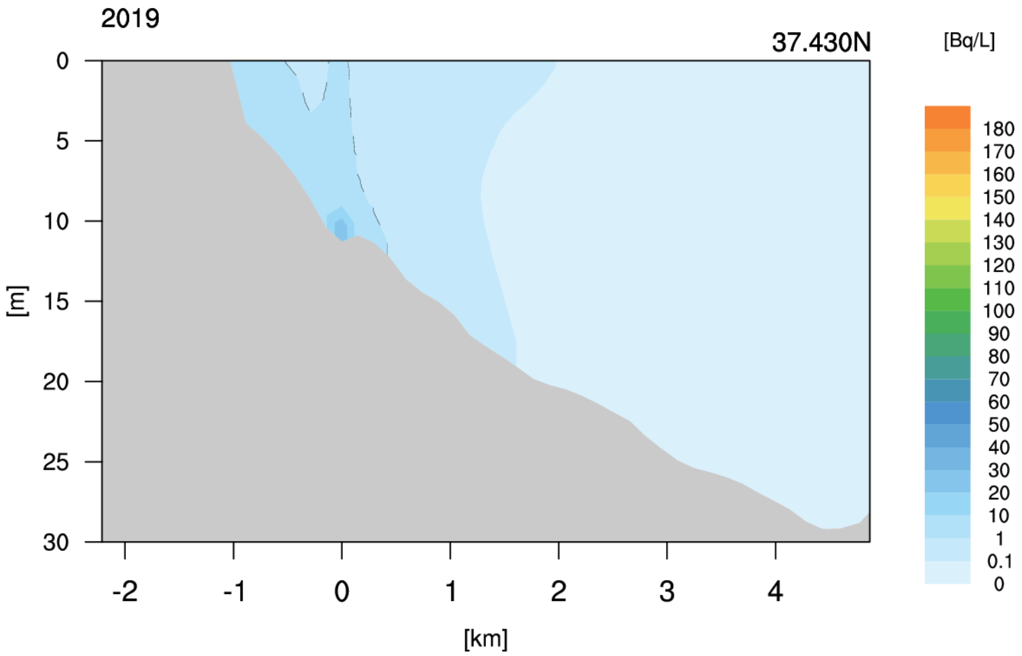
Figure 6-2-1 Discharge location in present plan and the location of Units 5/6 discharge outlets



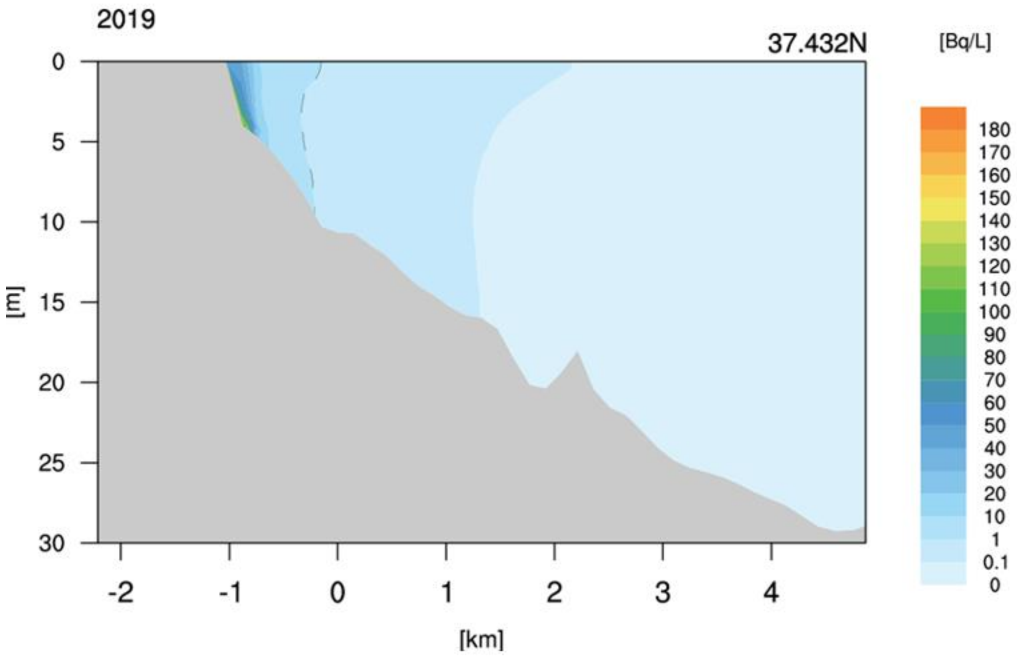
(Discharge from 1km from the coast) (Discharge from the Units 5/6 discharge outlets)
Figure 6-2-2 comparison of annual mean concentration distribution figures by the difference in discharge location (wide area diagram)



(Discharge from 1km from the coast) (Discharge from the Units 5/6 discharge outlets)
Figure 6-2-3 comparison of annual mean concentration distribution figures by the difference in discharge location (enlarged diagram)



(Discharge from 1km from the coast)



(Discharge from the Units 5/6 discharge outlets)

Figure 6-2-4 comparison of annual mean concentration distribution figures by the difference in discharge location (cross-section diagram)

(4) Setting of the representative person

For the representative person subject to the potential exposure assessment, the region, sea area, migration pathways, and exposure pathways are the same, so the same as 6-1-2.(4) are applied and the representative person keeps the same living habit in case of the potential exposure. After leakage of ALPS treated water, diffusion proceeds due to tidal currents and the concentration immediately drops, but in this assessment, it is assumed conservatively that the same concentration in the seawater and the exposure will continue for one week even after the outflow end, considering the case that the flow velocity continues to be small for 3 to 4 days. For each case, the exposure time, etc., was set by a time proportional calculation of the exposure continuation period from the annual operation hours, etc. The set exposure time, etc., are as shown in Table 6-2-7.

Table 6-2-7 Exposure time of the representative person used for the potential exposure assessment, etc.

Item	Case 1 (27 days)	Case 2 (8 days)
Operation hours on a ship	210 hours	63 hours
Swimming time	7.1 hours	2.1 hours
Coastline stay time	37 hours	11 hours
Operation hours near fishing nets	140 hours	42 hours
Ingestion of seafood	Ingestion of persons who consume a large amount of seafood in 27 days	Ingestion of persons who consume a large amount of seafood in 8 days

The exposure assessment point is near the beach assessment point to the north of the FDNPS used for the normal exposure, where is the nearest habitable area from the Units 5/6 discharge outlets. In the case of the normal exposure assessed throughout the year, the entire area of 10km×10km surrounding the FDNPS was selected as the assessment area for the exposure pathways related to fishing (sea surface, hull, fishing nets, and seafood ingestion) because fishing is conducted in a wide area. However, in the case of the potential exposure, because the period of exposure could be short and fishing may be conducted mainly in areas with higher concentrations in seawater, the concentration of radioactive materials in the seawater used in the assessment is the concentration of radioactive materials in the seawater at the beach assessment point for all pathways.

(5) Dose assessment method

The exposure amount of the representative person is compared with 5mSv, which is the typical decision criteria for simple assessment based on conservatively defined potential exposure scenarios for facilities and activities as described in 5.69 of GSG-10.

At the discharge of ALPS treated water, what is discharged is merely ALPS treated water even in the case of emergency, and there is not a big difference in situations from the normal discharge except it is not diluted in this case, nor changes in the composition of the discharged radionuclides, the migration pathways and the exposure pathways.

In addition, ALPS treated water is the water purified as the concentrations of radionuclides other than tritium become lower than the regulatory standards, and even in the case that 30,000 m^3 in measurement/confirmation facility were supposed to be released without dilution, the dose is never expected to surpass the range of definitive effect. Thus the assessment of effective committed dose is solely conducted since there is no possibility that each organ receives a high radiation dose.

6-2-2. Assessment result

(1) Concentration in the seawater used for the assessment

The concentration in the seawater is the concentration near the beach assessment point to the north of the FDNPS calculated based on the result of simulation of the case of discharge from the Unit 5/6 discharge outlets of a total of 22 TBq (2.2E+13Bq) of tritium per year at an even pace throughout the year (equivalent to 6.0E+10Bq/day) as follows.

- Case 1 (Piping rupture)

We calculated the 20 days moving average of the daily average tritium concentration at the assessment point from the simulation results of tritium of 2014 and 2019, and then calculated the maximum value of each year. Table 6-2-8 shows the result. We selected the result of 2014, of which concentration is higher, 5.6Bq/L from the results of the two years.

Since this concentration assumed the daily discharge amount of tritium 6.0E+10Bq/day, we calculated the concentration of each nuclide by comparing the daily discharge amount of each nuclide in Tables 6-2-1 to 3. Tables 6-2-9 to 6-2-11 show the concentration of each nuclide used for the assessment.

- Case 2 (Tank damage)

From the simulation results of tritium of 2014 and 2019, we calculated the maximum daily average tritium concentration of each year at the assessment point. Table 6-2-8 shows the result. We selected the higher result, namely 15Bq/L in 2014, from the results of two years.

Since this concentration assumed the daily discharge amount of tritium 6.0E+10Bq/day, we calculated the concentration of each nuclide by comparing the daily discharge amount of each nuclide in Tables 6-2-4 to 6. Tables 6-2-9 to 6-2-11 show the concentration of each nuclide used for the assessment.

Table 6-2-8 Concentration of tritium in the seawater near the beach assessment point on which the potential exposure assessment is based

(Calculated daily average concentration from a simulation of the case of discharge from the Unit 5 and 6 discharge outlets at an even pace throughout the year of a total of 22 TBq (2.2E+13Bq) per year)

Assessment year	Case 1 (Piping rupture)	Case 2 (Tank damage)
	Maximum value of the 20-day moving average concentration (Bq/L)	Maximum value of the daily average concentration (Bq/L)
2014	5.6	15
2019	5.5	12

Table 6-2-9 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the K4 tank group)

Target nuclide	Case 1 (Piping rupture)		Case 2 (Tank damage)	
	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)
H-3	7.0E+10	6.5E+00	4.2E+12	1.0E+03
C-14	7.5E+06	7.0E-04	4.5E+08	1.1E-01
Mn-54	4.3E+01	3.9E-09	2.6E+03	6.3E-07
Fe-55	1.1E+06	9.8E-05	6.3E+07	1.6E-02
Co-60	1.1E+05	1.0E-05	6.6E+06	1.6E-03
Ni-63	1.1E+06	9.8E-05	6.3E+07	1.6E-02
Se-79	7.5E+05	7.0E-05	4.5E+07	1.1E-02
Sr-90	9.5E+04	8.8E-06	5.7E+06	1.4E-03
Y-90	9.5E+04	8.8E-06	5.7E+06	1.4E-03
Tc-99	3.5E+05	3.3E-05	2.1E+07	5.2E-03
Ru-106	2.1E+04	2.0E-06	1.3E+06	3.1E-04
Sb-125	4.3E+04	4.0E-06	2.6E+06	6.4E-04
Te-125m	4.3E+04	4.0E-06	2.6E+06	6.4E-04
I-129	1.1E+06	9.8E-05	6.3E+07	1.6E-02
Cs-134	3.7E+03	3.4E-07	2.2E+05	5.5E-05
Cs-137	1.9E+05	1.7E-05	1.1E+07	2.8E-03
Ce-144	2.7E+02	2.5E-08	1.6E+04	4.0E-06
Pm-147	2.3E+04	2.1E-06	1.4E+06	3.4E-04
Sm-151	4.3E+02	4.0E-08	2.6E+04	6.4E-06
Eu-154	3.9E+03	3.6E-07	2.3E+05	5.8E-05
Eu-155	7.5E+03	7.0E-07	4.5E+05	1.1E-04
U-234	3.2E+02	2.9E-08	1.9E+04	4.7E-06
U-238	3.2E+02	2.9E-08	1.9E+04	4.7E-06
Np-237	3.2E+02	2.9E-08	1.9E+04	4.7E-06
Pu-238	3.0E+02	2.8E-08	1.8E+04	4.5E-06
Pu-239	3.2E+02	2.9E-08	1.9E+04	4.7E-06
Pu-240	3.2E+02	2.9E-08	1.9E+04	4.7E-06
Pu-241	1.1E+04	1.0E-06	6.6E+05	1.6E-04
Am-241	3.1E+02	2.9E-08	1.9E+04	4.6E-06
Cm-244	2.6E+02	2.4E-08	1.5E+04	3.8E-06

Table 6-2-10 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-C tank group)

Target nuclide	Case 1 (Piping rupture)		Case 2 (Tank damage)	
	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)
H-3	3.6E+11	3.3E+01	2.2E+13	5.4E+03
C-14	9.0E+06	8.4E-04	5.4E+08	1.3E-01
Mn-54	2.7E+03	2.5E-07	1.6E+05	4.0E-05
Fe-55	1.2E+06	1.1E-04	7.2E+07	1.8E-02
Co-60	1.2E+05	1.1E-05	7.2E+06	1.8E-03
Ni-63	4.2E+06	3.9E-04	2.5E+08	6.2E-02
Se-79	7.5E+05	7.0E-05	4.5E+07	1.1E-02
Sr-90	1.7E+04	1.6E-06	1.0E+06	2.5E-04
Y-90	1.7E+04	1.6E-06	1.0E+06	2.5E-04
Tc-99	6.0E+05	5.6E-05	3.6E+07	9.0E-03
Ru106	1.4E+05	1.3E-05	8.1E+06	2.0E-03
Sb-125	6.0E+04	5.6E-06	3.6E+06	9.0E-04
Te-125m	6.0E+04	5.6E-06	3.6E+06	9.0E-04
I-129	6.0E+05	5.6E-05	3.6E+07	9.0E-03
Cs-134	1.7E+04	1.5E-06	9.9E+05	2.5E-04
Cs-137	8.5E+04	7.9E-06	5.1E+06	1.3E-03
Ce-144	3.2E+04	3.0E-06	1.9E+06	4.8E-04
Pm-147	2.1E+05	2.0E-05	1.3E+07	3.1E-03
Sm-151	5.5E+03	5.1E-07	3.3E+05	8.2E-05
Eu-154	4.7E+04	4.4E-06	2.8E+06	7.0E-04
Eu-155	1.2E+05	1.1E-05	7.2E+06	1.8E-03
U-234	1.6E+04	1.5E-06	9.6E+05	2.4E-04
U-238	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Np-237	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Pu-238	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Pu-239	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Pu-240	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Pu-241	5.5E+05	5.1E-05	3.3E+07	8.2E-03
Am-241	1.6E+04	1.5E-06	9.6E+05	2.4E-04
Cm-244	1.5E+04	1.4E-06	9.0E+05	2.2E-04

Table 6-2-11 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-G tank group)

Target nuclide	Case 1 (Piping rupture)		Case 2 (Tank damage)	
	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)	Daily discharge amount (Bq/day)	Concentration in the seawater near the beach assessment point (Bq/L)
H-3	1.2E+11	1.1E+01	7.2E+12	1.8E+03
C-14	8.0E+06	7.4E-04	4.8E+08	1.2E-01
Mn-54	2.7E+03	2.5E-07	1.6E+05	4.0E-05
Fe-55	1.2E+06	1.1E-04	7.2E+07	1.8E-02
Co-60	8.5E+04	7.9E-06	5.1E+06	1.3E-03
Ni-63	4.4E+06	4.0E-04	2.6E+08	6.5E-02
Se-79	7.5E+05	7.0E-05	4.5E+07	1.1E-02
Sr-90	1.5E+04	1.4E-06	9.0E+05	2.2E-04
Y-90	1.5E+04	1.4E-06	9.0E+05	2.2E-04
Tc-99	6.5E+05	6.0E-05	3.9E+07	9.7E-03
Ru-106	4.7E+04	4.4E-06	2.8E+06	7.0E-04
Sb-125	3.8E+04	3.5E-06	2.3E+06	5.6E-04
Te-125m	3.8E+04	3.5E-06	2.3E+06	5.6E-04
I-129	1.7E+05	1.5E-05	9.9E+06	2.5E-03
Cs-134	1.5E+04	1.4E-06	9.0E+05	2.2E-04
Cs-137	1.6E+05	1.4E-05	9.3E+06	2.3E-03
Ce-144	3.3E+04	3.0E-06	2.0E+06	4.9E-04
Pm-147	1.9E+05	1.8E-05	1.1E+07	2.8E-03
Sm-151	4.9E+03	4.6E-07	2.9E+05	7.3E-05
Eu-154	4.2E+04	3.9E-06	2.5E+06	6.3E-04
Eu-155	6.0E+04	5.6E-06	3.6E+06	9.0E-04
U-234	1.4E+04	1.3E-06	8.4E+05	2.1E-04
U-238	1.4E+04	1.3E-06	8.4E+05	2.1E-04
Np-237	1.4E+04	1.3E-06	8.4E+05	2.1E-04
Pu-238	1.4E+04	1.3E-06	8.1E+05	2.0E-04
Pu-239	1.4E+04	1.3E-06	8.4E+05	2.1E-04
Pu-240	1.4E+04	1.3E-06	8.4E+05	2.1E-04
Pu-241	4.5E+05	4.1E-05	2.7E+07	6.6E-03
Am-241	1.4E+04	1.3E-06	8.4E+05	2.1E-04
Cm-244	1.3E+04	1.2E-06	7.8E+05	1.9E-04

(2) Exposure assessment result

Table 6-2-12 to 13 shows the potential exposure result calculated using the concentration in the seawater calculated in (1). The result is 0.0002 (2E-04) mSv to 0.01(1E-02) mSv, which falls below 5mSv, which is the standard at the time of accident.

Table 6-2-12 Results of the potential exposure assessment

Assessed case	Source term	Case 1 (Piping rupture)			Case 2 (Tank damage)		
		K4 tank group	J1-C tank group	J1-G tank group	K4 tank group	J1-C tank group	J1-G tank group
	Ingestion of seafood	Large	Large	Large	Large	Large	Large
External exposure (mSv)	Sea surface	1.8E-09	3.5E-09	2.5E-09	8.8E-08	1.7E-07	1.2E-07
	Hull	1.9E-09	3.6E-09	2.5E-09	9.4E-08	1.7E-07	1.2E-07
	During swimming	1.7E-10	3.3E-10	2.3E-10	8.3E-09	1.6E-08	1.1E-08
	Beach sand	2.9E-07	5.6E-07	4.0E-07	1.4E-05	2.7E-05	1.9E-05
	Fishing net	8.9E-07	1.7E-06	1.2E-06	4.3E-05	8.3E-05	5.8E-05
Internal exposure (mSv)	Ingestion of water	1.8E-07	8.7E-07	2.9E-07	8.7E-06	4.1E-05	1.4E-05
	Inhalation of spray	5.0E-08	5.4E-07	3.5E-07	2.4E-06	2.6E-05	1.7E-05
	Ingestion of seafood	2.6E-04	2.4E-04	1.6E-04	1.3E-02	1.2E-02	7.8E-03
Total (mSv)		3E-04	2E-04	2E-04	1E-02	1E-02	8E-03

Table 6-2-13 Results of the internal exposure assessment by age

Assessed case	Source term	Case 1 (Piping rupture)			Case 2 (Tank damage)		
		K4 tank group	J1-C tank group	J1-G tank group	K4 tank group	J1-C tank group	J1-G tank group
	Ingestion of seafood	Large	Large	Large	Large	Large	Large
Internal exposure by ingestion of water (mSv)	Adult	1.8E-07	8.7E-07	2.9E-07	8.7E-06	4.1E-05	1.4E-05
	Child	3.1E-07	1.5E-06	5.0E-07	1.5E-05	7.1E-05	2.4E-05
	Infant	-	-	-	-	-	-
Internal exposure by inhalation of spray (mSv)	Adult	5.0E-08	5.4E-07	3.5E-07	2.4E-06	2.6E-05	1.7E-05
	Child	3.3E-08	3.1E-07	1.9E-07	1.6E-06	1.5E-05	9.1E-06
	Infant	2.1E-08	1.7E-07	1.0E-07	1.0E-06	8.3E-06	4.8E-06
Internal exposure by ingestion of seafood (mSv)	Adult	2.6E-04	2.4E-04	1.6E-04	1.3E-02	1.2E-02	7.8E-03
	Child	3.1E-04	3.0E-04	2.4E-04	1.5E-02	1.4E-02	1.1E-02
	Infant	2.8E-04	3.6E-04	3.2E-04	1.3E-02	1.7E-02	1.5E-02

7. Assessment regarding environmental protection

The assessment method of environmental protection is as shown in GSG -10 Annex I. In this report, environmental protection was assessed according to the procedure of GSG -10 Annex I.

7-1. Concept of assessment

The assessment for protection of plants and animals in the normal operation is performed according to GSG -10 Annex I.

7-1-1. Assessment procedure

The assessment is performed according to the procedure shown in Figure 7-1.

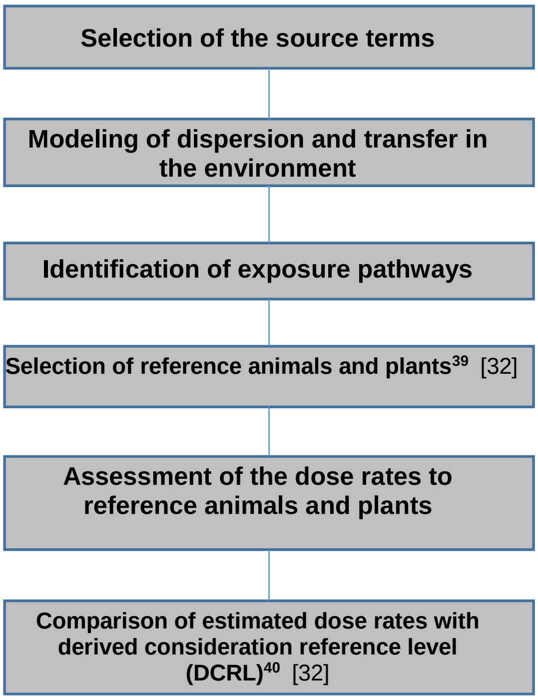


Figure 7-1 Environmental protection assessment procedure (prepared from GSG-10)

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[39] Reference animals and plants: Specific types of animals and plants assumed in order to associate radiation exposure from the environment with the dose and impact.

[40] Derived consideration reference level (DCRL): Range of the dose rates within a range of one digit specified for each species advocated by ICRP. Dose rate level at which the impact has to be considered if is exceeded.

7-2. Assessment method

7-2-1. Source term

Use the same source term as the one shown in 6-1-2.(1) Source term.

7-2-2. Modeling of diffusion and transfer after discharge

(1) Selection of the migration model

As the migration model of radioactive materials discharged into the sea, the following was selected from the migration model of human exposure assessment, considering habitat environment of marine plants and animals, referring to GSG-10.

i. Advection and diffusion by tidal currents, etc.

Selected because advection and diffusion will occur after discharge into the sea.

ii. Advection and diffusion by tidal currents, etc. -> Migration to seabed sediment

Selected because ALPS treated water will migrate to seabed sediment, etc., due to advection and diffusion caused by tidal currents, etc., after discharge into the sea.

iii. Advection and diffusion by tidal currents, etc. -> Intake and concentration by marine plants and animals such as fish

Selected because migration to and concentration in fish, etc. will occur after discharge into the sea.

(2) Assessment of advection and diffusion in the sea area

The same model as that for the human protection assessment is used.

7-2-3. Setting of exposure pathways

The following pathways were selected according to GSG -10 Annex I-21.

i. Internal exposure from radioactive materials ingested or inhaled by plants and animals
ii. External exposure from the surrounding seawater
iii. External exposure from the surrounding seabed sediment

The following shows the specific assessment method.

(1) Internal exposure from radioactive materials ingested or inhaled by plants and animals

Equation (7-1) shows the calculation equation of the absorbed dose rate D_{int} (mGy/day) of radiation from radioactive materials ingested from the seawater by standard animals and plants.

$$D_{int} = \sum_i (DCF_{int})_{ki} \cdot (x_9)_i \cdot (CR)_{ki} \tag{7-1}$$

where

$(DCF_{int})_{ki}$ is the internal exposure dose conversion factor to marine plants and animals k of nuclide i ((mGy/day)/(Bq/kg))

$(x_9)_i$ is the concentration of nuclide i in seawater (Bq/L)

$(CR)_{ki}$ is the ration of the concentration in the seawater to marine plants and animals k in nuclide i ((Bq/kg)/(Bq/L))

(2) External exposure from the seawater and seabed sediment

The absorbed dose rate $D_{\mathrm{ext,sw}}$ (mGy/day) of plants and animals surrounded by the seawater is calculated by equation (7-2).

$$D_{ext,sw} = \sum_i (DCF_{ext})_{ki} \cdot \frac{(x_9)_i}{\rho_w} \tag{7-2}$$

where

$(DCF_{ext})_{ki}$ is the external exposure dose conversion factor to marine plants and animals k of nuclide i ((mGy/day)/(Bq/kg))

$(x_9)_i$ is the concentration of nuclide i in seawater (Bq/L)

ρ_{w} is the density of seawater (kg/L)

Similarly, the absorbed dose rate $D_{\mathrm{ext,sed}}$ (mGy/day) of plants and animals surrounded by seabed sediment is calculated by equation (7-3).

$$D_{ext,sed} = \sum_i (DCF_{ext})_{ki} \cdot (x_9)_i \cdot (K_{\mathrm{d}})_i \tag{7-3}$$

where

$(DCF_{ext})_{ki}$ is the external exposure dose conversion factor to marine plants and animals k of nuclide i ((mGy/day)/(Bq/kg))

$(x_9)_i$ is the concentration of nuclide i in seawater (Bq/L)

$(K_d)_i$ is the concentration distribution coefficient from seawater to sediment of nuclide i ((Bq/kg)/(Bq/L))

External exposure in the case of exposure from the seawater and seabed sediment D_{ext} is the total of both, but plants and animals that live on the seabed are exposed to half each of the seawater of upper half and the seabed sediment of the lower half, respectively, so it is calculated by Equation (7-4).

$$D_{ext}=0.5 \bullet D_{ext,sw}+0.5 \bullet D_{ext,sed} \tag{7-4}$$

The internal and external exposure dose conversion factors to plants and animals[41] is excerpted from ICRP Publication 136 “Dose Coefficients for Non-human Biota Environmentally Exposed to Radiation”(ICRP,2017) [33] (hereinafter called “ICRP pub.136”) and the BiotaDC program of ICRP [34] (See Tables 7-2-1 and 7-2-2).
The concentration ratios of plants and animals and the seawater[42] are excerpted from ICRP Publication 114 “Environmental Protection : Transfer Parameters for Reference Animals and Plants”(ICRP,2009) [35] (hereinafter called “ICRP pub.114”) and IAEA Technical report series No.479 “Handbook of Parameter Values for the Prediction of Radionuclide Transfer to Wildlife” (hereinafter called “TRS-479”). (See Table 7-2-3). For the concentration distribution coefficients of the seawater and seabed sediment, those specified in 2.3.OCEAN MARGIN *Kd*s of TRS-422 [31] are used (See Table 7-2-4).

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[41] Dose conversion factor to plants and animals: Value set for simplified calculations of internal and external exposure doses to organism by radioactive nuclides in the environment.

[42] Concentration ratio (CR): The ratio of the radioactive nuclides in aquatic organisms living in hydrosphere to the underwater concentration in the environment for the assessment of radiation exposure to plants and animals from the environment (ICPR, 2009). Unlike the concentration factor, it is not limited to the edible part.

7-2-4. Selection of reference plants and animals (organisms to be assessed)

Small seaweed beds mainly consisting of Eisenia bicyclis, which is a perennial marine alga, are distributed on the coast of Fukushima, in which the FDNPS is located [36]. There is no special sea area like a habitat of a marine plant or animal designated as a protected species around the FDNPS [37] so the following plants and animals are selected as those clarified in ICRP Pub.136.

- Reference flat fish (Left-eyed and right-eyed flounders widely inhabit in the sea area around the FDNPS)
- Reference crabs (Ovalipes punctatus and Portunus trituberculatus widely inhabit in the sea area around the FDNPS)
- Reference brown seaweeds (Sargassum and Eisenia bicyclis widely inhabit in the sea area around the FDNPS)

These plants and animals are widely distributed in the sea area around the FDNPS, so the radioactive material concentration in the seawater used for the assessment is the annual average concentration of 10 km × 10 km around the FDNPS, which matches 100-400 km^2 as recommended in I-23. of GSG -10 Annex I. In addition, in the assessment of plants and animals, the concentration near the seabed (bottom layer) is used because the impact of external exposure from radioactive materials migrated to the seabed sediment is greater than in the seawater and the selected standard flatfish live on the seabed.

7-2-5. Dose assessment

The dose is assessed by comparison with the derived consideration reference level (DCRL) shown in ICRP Publication 124 “Protection of the Environment under Different Exposure Situations” for each type of the reference plants and animals.

Table 7-2-1 Internal exposure conversion factor to marine plants and animals

(ICRP Pub.136 and others are shown in remarks)

	Target nuclide	Internal exposure dose conversion factor ((mGy/day)/(Bq/kg))			Remarks
		Flatfish	Crab	Brown seaweed	
1	H-3	7.9E-08	7.9E-08	7.9E-08	
2	C-14	7.0E-07	7.0E-07	7.0E-07	
3	Mn-54	1.1E-06	1.4E-06	9.4E-07	
4	Fe-55	8.0E-08	8.0E-08	8.0E-08	Calculated from BiotaDC
5	Co-60	3.8E-06	5.0E-06	3.6E-06	
6	Ni-63	2.4E-07	2.4E-07	2.4E-07	
7	Se-79	7.2E-07	7.2E-07	7.2E-07	
8	Sr-90	1.4E-05	1.5E-05	1.4E-05	
9	Y-90	—	—	—	Contained in the parent nuclide Sr-90
10	Tc-99	1.4E-06	1.4E-06	1.4E-06	
11	Ru-106	1.7E-05	1.9E-05	1.7E-05	
12	Sb-125	2.0E-06	2.2E-06	1.9E-06	
13	Te-125m	1.7E-06	1.8E-06	1.6E-06	Calculated from BiotaDC
14	I-129	1.0E-06	1.1E-06	1.0E-06	
15	Cs-134	4.1E-06	4.8E-06	3.8E-06	
16	Cs-137	4.1E-06	4.3E-06	4.1E-06	
17	Ce-144	1.6E-05	1.7E-05	1.6E-05	
18	Pm-147	8.6E-07	8.6E-07	8.5E-07	Calculated from BiotaDC
19	Sm-151	2.8E-07	2.8E-07	2.8E-07	Calculated from BiotaDC
20	Eu-154	5.0E-06	5.8E-06	5.0E-06	
21	Eu-155	1.0E-06	1.0E-06	9.8E-07	
22	U-234	6.7E-05	6.7E-05	6.7E-05	
23	U-238	6.0E-05	6.0E-05	6.0E-05	
24	Np-237	6.7E-05	6.7E-05	6.7E-05	
25	Pu-238	7.7E-05	7.7E-05	7.7E-05	
26	Pu-239	7.2E-05	7.2E-05	7.2E-05	
27	Pu-240	7.2E-05	7.2E-05	7.2E-05	
28	Pu-241	7.4E-08	7.4E-08	7.4E-08	
29	Am-241	7.7E-05	7.7E-05	7.7E-05	
30	Cm-244	8.2E-05	8.2E-05	8.2E-05	

Table 7-2-2 External exposure conversion factor to marine plants and animals

(ICRP Pub.136 and others are shown in remarks)

	Target nuclide	External exposure dose conversion factor ((mGy/day)/(Bq/kg))			Remarks
		Flatfish	Crab	Brown seaweed	
1	H-3	1.9E-14	2.4E-16	2.4E-16	
2	C-14	4.3E-10	5.3E-10	5.3E-10	
3	Mn-54	1.1E-05	1.0E-05	1.1E-05	
4	Fe-55	3.3E-10	3.9E-10	1.0E-09	Calculated from BiotaDC
5	Co-60	3.1E-05	3.1E-05	3.4E-05	
6	Ni-63	2.6E-11	4.1E-11	4.1E-11	
7	Se-79	4.8E-10	5.8E-10	6.2E-10	
8	Sr-90	1.2E-06	5.5E-07	1.2E-06	
9	Y-90	—	—	—	Contained in the parent nuclide Sr-90
10	Tc-99	3.1E-09	3.4E-09	3.6E-09	
11	Ru-106	5.3E-06	3.8E-06	5.3E-06	
12	Sb-125	5.5E-06	5.3E-06	5.5E-06	
13	Te-125m	2.9E-07	2.4E-07	4.3E-07	Calculated from BiotaDC
14	I-129	2.2E-07	1.9E-07	2.4E-07	
15	Cs-134	2.0E-05	1.9E-05	2.0E-05	
16	Cs-137	7.2E-06	7.0E-06	7.2E-06	
17	Ce-144	2.6E-06	1.5E-06	2.6E-06	
18	Pm-147	9.9E-10	1.1E-09	1.0E-08	Calculated from BiotaDC
19	Sm-151	7.7E-11	8.4E-11	7.6E-10	Calculated from BiotaDC
20	Eu-154	1.6E-05	1.5E-05	1.6E-05	
21	Eu-155	7.4E-07	7.0E-07	7.4E-07	
22	U-234	4.8E-09	4.1E-09	5.5E-09	
23	U-238	3.1E-09	2.6E-09	3.6E-09	
24	Np-237	3.1E-07	2.9E-07	3.1E-07	
25	Pu-238	4.6E-09	3.8E-09	5.5E-09	
26	Pu-239	2.6E-09	2.3E-09	3.1E-09	
27	Pu-240	4.3E-09	3.6E-09	5.3E-09	
28	Pu-241	1.9E-11	1.9E-11	2.0E-11	
29	Am-241	2.9E-07	2.6E-07	2.9E-07	
30	Cm-244	4.8E-09	3.8E-09	5.5E-09	

Table 7-2-3 Concentration ratio to marine plants and animals (ICRP Pub.114 and others, shown in remarks)

	Target nuclide	Concentration ratio ((Bq/kg-f.w)/(Bq/L))			Remarks
		Flatfish	Crab	Brown seaweed	
1	H-3	1.0E+00	1.0E+00	3.7E-01	Excerpted from ICRP Pub.114
2	C-14	1.2E+04	1.0E+04	8.0E+03	Excerpted from ICRP Pub.114
3	Mn-54	2.6E+03	4.5E+04	1.1E+04	Excerpted from TRS-479 (fish and crab) Excerpted from ICRP Pub.114 (brown seaweed)
4	Fe-55	3.0E+04	5.0E+05	2.0E+04	Excerpted from concentration coefficient of TRS-422 since No description in ICRP Pub.114 and TRS-479
5	Co-60	1.1E+04	5.5E+03	1.7E+03	Excerpted from TRS-479
6	Ni-63	2.7E+02	6.4E+03	2.0E+03	Excerpted from TRS-479 (crab) Excerpted from ICRP Pub.114 (fish and crab brown seaweed)
7	Se-79	1.0E+04	1.0E+04	4.3E+02	Excerpted from TRS-479 (brown seaweed) Excerpted from ICRP Pub.114 (fish and crab)
8	Sr-90	4.4E+01	2.3E+02	4.3E+01	Excerpted from TRS-479 (crab and brown seaweed) Excerpted from ICRP Pub.114 (fish)
9	Y-90	-	-	-	Assessed with the parent nuclide Sr-90.
10	Tc-99	8.0E+01	1.8E+04	5.3E+04	Excerpted from TRS-479 (fish and crab) Excerpted from ICRP Pub.114 (brown seaweed)
11	Ru-106	2.9E+01	1.6E+03	1.2E+03	Excerpted from TRS-479
12	Sb-125	6.0E+02	4.7E+02	1.5E+03	Excerpted from TRS-479 (crab) Excerpted from ICRP Pub.114 (fish and brown seaweed)
13	Te-125m	1.0E+03	1.0E+03	1.0E+04	Excerpted from ICRP Pub.114
14	I-129	9.0E+00	8.8E+03	4.2E+03	Excerpted from ICRP Pub.114 (fish) Excerpted from TRS-479 (crab and brown seaweed)
15	Cs-134	1.2E+02	6.3E+01	9.6E+01	Excerpted from TRS-479
16	Cs-137	1.2E+02	6.3E+01	9.6E+01	Excerpted from TRS-479
17	Ce-144	3.9E+02	2.2E+03	2.1E+03	Excerpted from TRS-479
18	Pm-147	7.3E+02	2.4E+04	5.9E+03	Excerpted from ICRP Pub.114
19	Sm-151	7.3E+02	2.4E+04	5.9E+03	Excerpted from ICRP Pub.114
20	Eu-154	7.3E+02	2.4E+04	1.4E+03	Excerpted from TRS-479 (brown seaweed) Excerpted from ICRP Pub.114 (fish and crab)
21	Eu-155	7.3E+02	2.4E+04	1.4E+03	Excerpted from TRS-479 (brown seaweed) Excerpted from ICRP Pub.114 (fish and crab)
22	U-234	8.8E+00	3.5E+01	8.3E+01	Excerpted from TRS-479
23	U-238	8.8E+00	3.5E+01	8.3E+01	Excerpted from TRS-479

	Target nuclide	Concentration ratio ((Bq/kg-f.w)/(Bq/L))			Remarks
		Flatfish	Crab	Brown seaweed	
24	Np-237	2.1E+01	4.3E+02	5.4E+01	Excerpted from TRS-479 (crab) Excerpted from ICRP Pub.114 (fish and brown seaweed)
25	Pu-238	2.5E+03	1.7E+03	4.1E+03	Excerpted from TRS-479
26	Pu-239	2.5E+03	1.7E+03	4.1E+03	Excerpted from TRS-479
27	Pu-240	2.5E+03	1.7E+03	4.1E+03	Excerpted from TRS-479
28	Pu-241	2.5E+03	1.7E+03	4.1E+03	Excerpted from TRS-479
29	Am-241	3.2E+02	9.9E+03	4.3E+02	Excerpted from ICRP Pub.114
30	Cm-244	1.9E+02	3.2E+04	1.2E+04	Excerpted from TRS-479 (crab and brown seaweed) Excerpted from ICRP Pub.114 (fish)

Table 7-2-4 Concentration distribution coefficient of the seawater and seabed sediment (Excerpted from TRS-422)

	Target nuclide	Concentration distribution coefficient ((Bq/kg)/(Bq/L))	Remarks
1	H-3	1.00E+00	
2	C-14	1.00E+03	
3	Mn-54	2.00E+06	
4	Fe-55	3.00E+08	
5	Co-60	3.00E+05	
6	Ni-63	2.00E+04	
7	Se-79	3.00E+03	
8	Sr-90	8.00E+00	
9	Y-90	-	Assessed with the parent nuclide Sr-90
10	Tc-99	1.00E+02	
11	Ru-106	4.00E+04	
12	Sb-125	2.00E+03	
13	Te-125m	1.00E+03	Assessed with the parent nuclide Sb-125
14	I-129	7.00E+01	
15	Cs-134	4.00E+03	
16	Cs-137	4.00E+03	
17	Ce-144	3.00E+06	
18	Pm-147	2.00E+06	
19	Sm-151	3.00E+06	
20	Eu-154	2.00E+06	
21	Eu-155	2.00E+06	
22	U-234	1.00E+03	
23	U-238	1.00E+03	
24	Np-237	1.00E+03	
25	Pu-238	1.00E+05	
26	Pu-239	1.00E+05	
27	Pu-240	1.00E+05	
28	Pu-241	1.00E+05	
29	Am-241	2.00E+06	
30	Cm-244	2.00E+06	

7-3. Assessment result

7-3-1. Concentration in the seawater used for the assessment

As with the human protection assessment, the concentration in the seawater used for the exposure assessment of each nuclide was calculated by proportion calculation with the calculation result of advection and diffusion of tritium and the annual discharge amount of each nuclide. Here the concentration of the bottom layer is used because the impact of seabed sediment is considered in the exposure assessment.

Table 7-3-1 shows the concentration of tritium in the seawater in the bottom layer within 10 km × 10 km around the FDNPS (annual discharge amount) in the case of the annual discharge amount of 22 TBq (2.2E+13Bq) of tritium. The concentration for the assessment is the concentration based on the 2019 meteorological and oceanographic data as with the human exposure assessment.

Tables 7-3-2 to 4 show this result, and the concentration in the seawater used for the exposure assessment of each nuclide calculated from the source terms shown in Tables 6-1-1 to 3.

Table 7-3-1 Tritium concentration in the seawater in the case of the annual tritium discharge amount of 2.2E+13Bq

Assessment point	Depth	Calculation result (Bq/L)			Concentration for assessment (Bq/L)
		2014 Meteorological and oceanographic data	2019 Meteorological and oceanographic data	Difference (%)	
Average concentration within 10 km × 10 km around the FDNPS	Bottom layer	5.0E-02	6.0E-02	19	6.0E-02

Table 7-3-2 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the K4 tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)
		Average concentration of the bottom layer (Bq/L)
H-3	2.2E+13	6.0E-02
C-14	2.4E+09	6.4E-06
Mn-54	1.3E+04	3.6E-11
Fe-55	3.3E+08	9.0E-07
Co-60	3.5E+07	9.4E-08
Ni-63	3.3E+08	9.0E-07
Se-79	2.4E+08	6.4E-07
Sr-90	3.0E+07	8.1E-08

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)
		Average concentration of the bottom layer (Bq/L)
Y-90	3.0E+07	8.1E-08
Tc-99	1.1E+08	3.0E-07
Ru-106	6.6E+06	1.8E-08
Sb-125	1.4E+07	3.7E-08
Te-125m	1.4E+07	3.7E-08
I-129	3.3E+08	9.0E-07
Cs-134	1.2E+06	3.2E-09
Cs-137	5.8E+07	1.6E-07
Ce-144	8.3E+04	2.3E-10
Pm-147	7.1E+06	1.9E-08
Sm-151	1.4E+05	3.7E-10
Eu-154	1.2E+06	3.3E-09
Eu-155	2.4E+06	6.4E-09
U-234	9.9E+04	2.7E-10
U-238	9.9E+04	2.7E-10
Np-237	9.9E+04	2.7E-10
Pu-238	9.4E+04	2.6E-10
Pu-239	9.9E+04	2.7E-10
Pu-240	9.9E+04	2.7E-10
Pu-241	3.5E+06	9.4E-09
Am-241	9.7E+04	2.7E-10
Cm-244	8.0E+04	2.2E-10
Target exposure assessment		Environmental protection

Table 7-3-3 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-C tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)
		Average concentration of the bottom layer (Bq/L)
H-3	2.2E+13	6.0E-02
C-14	5.5E+08	1.5E-06
Mn-54	1.6E+05	4.4E-10
Fe-55	7.3E+07	2.0E-07
Co-60	7.3E+06	2.0E-08
Ni-63	2.5E+08	6.9E-07
Se-79	4.6E+07	1.3E-07
Sr-90	1.0E+06	2.8E-09
Y-90	1.0E+06	2.8E-09
Tc-99	3.7E+07	1.0E-07
Ru-106	8.3E+06	2.3E-08
Sb-125	3.7E+06	1.0E-08
Te-125m	3.7E+07	1.0E-07
I-129	3.7E+07	1.0E-07
Cs-134	1.0E+06	2.8E-09
Cs-137	5.2E+06	1.4E-08
Ce-144	2.0E+06	5.3E-09
Pm-147	1.3E+07	3.5E-08
Sm-151	3.4E+05	9.2E-10
Eu-154	2.9E+06	7.8E-09
Eu-155	7.3E+06	2.0E-08
U-234	9.8E+05	2.7E-09
U-238	9.8E+05	2.7E-09
Np-237	9.8E+05	2.7E-09
Pu-238	9.8E+05	2.7E-09
Pu-239	9.8E+05	2.7E-09
Pu-240	9.8E+05	2.7E-09
Pu-241	3.4E+07	9.2E-08
Am-241	9.8E+05	2.7E-09
Cm-244	9.2E+05	2.5E-09
Target exposure assessment		Environmental protection

Table 7-3-4 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the J1-G tank group)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)
		Average concentration of the bottom layer (Bq/L)
H-3	2.2E+13	6.0E-02
C-14	1.5E+09	4.0E-06
Mn-54	5.0E+05	1.4E-09
Fe-55	2.2E+08	6.0E-07
Co-60	1.6E+07	4.3E-08
Ni-63	8.0E+08	2.2E-06
Se-79	1.4E+08	3.8E-07
Sr-90	2.8E+06	7.5E-09
Y-90	2.8E+06	7.5E-09
Tc-99	1.2E+08	3.3E-07
Ru-106	8.6E+06	2.4E-08
Sb-125	6.9E+06	1.9E-08
Te-125m	6.9E+06	1.9E-08
I-129	3.0E+07	8.3E-08
Cs-134	2.8E+06	7.5E-09
Cs-137	2.8E+07	7.8E-08
Ce-144	6.0E+06	1.6E-08
Pm-147	3.5E+07	9.5E-08
Sm-151	9.0E+05	2.5E-09
Eu-154	7.7E+06	2.1E-08
Eu-155	1.1E+07	3.0E-08
U-234	2.6E+06	7.0E-09
U-238	2.6E+06	7.0E-09
Np-237	2.6E+06	7.0E-09
Pu-238	2.5E+06	6.8E-09
Pu-239	2.6E+06	7.0E-09
Pu-240	2.6E+06	7.0E-09
Pu-241	8.2E+07	2.2E-07
Am-241	2.6E+06	7.0E-09
Cm-244	2.4E+06	6.5E-09
Target exposure assessment		Environmental protection

7-3-2. Exposure assessment result

Table 7-3-5 shows the result of the exposure assessment of reference plants and animals. All results are low dose rates that are lower than 1/1000,000 of the minimum limit value of the derived consideration reference level.

Table 7-3-5 Assessment result regarding environmental protection

Assessed case		Source term based on measured values		
		i. K4 tank group	ii. J1-C tank group	iii. J1-G tank group
Exposure (mGy/day)	Flatfish	6E-07	3E-07	7E-07
	Crab	7E-07	3E-07	7E-07
	Brown seaweed	7E-07	3E-07	8E-07
Derived consideration reference level (DCRL) [33] Flatfish: 1-10 mGy/day Crab: 10-100 mGy/day Brown seaweed: 1-10 mGy/day				

8. Discussion about the uncertainty of the assessment

This assessment was performed adding various data related to the disposal plan of ALPS treated water, assumptions of the exposure assessment, etc., to the assessment model including parameters created from obtained findings, etc. The assessment model including these parameters, the data, the set assumptions, etc., include uncertainty. So does the assessment result.

Generally, the uncertainty is roughly divided into (1) aleatory uncertainty (or variability) and (2) epistemic uncertainty. “Aleatory uncertainty (or variability)” is uncertainty caused by statistical distribution such as initial variation in data, and cannot be reduced even if data and knowledge to be obtained in the future are considered. “Epistemic uncertainty” is uncertainty due to lack of knowledge, though there is considered to be the one and only state.

The following shows the result of consideration of the degree of uncertainty referring to the result of simulation performed in each assessment process for each type, etc.

8-1. Uncertainty included in the selection of the source term

The following items are examples of uncertainty of the source term.

8-1-1. Uncertainty of the composition of nuclide (epistemic uncertainty)

The treated water to be purified in storage is planned to be subject to secondary treatment by ALPS, etc., and the composition of nuclides is unknown until measurement is performed after secondary treatment. Though it is guaranteed that the sum of the ratios to regulatory concentrations limits is less than 1, the composition of nuclides depends on various factors such as the composition and concentration of radioactive materials at the ALPS inlet at the time of treatment, the stage of the adsorbent in the ALPS adsorption vessel in the performance life period at the time of treatment, etc. The same applies to the contaminated water generated in the future.

On the other hand as a result of the revision of target nuclides, the impact by undetected nuclides to the value of exposure assessment become smaller. Among the exposure assessment value by three source terms, there is about five-fold difference between the source terms based on the K4 tank group and J1-C tank group, which could be occurred due to the fact that volume of the ALPS treated water discharged based on the K4 tank group is about five times larger than J1-C tank group due to the difference in the tritium concentration of each tank group. On the other hand, the difference in the exposure assessment values between the source terms based on the K4 tank group and J1-G tank group, where the difference in tritium concentrations is small about three-fold. Since the difference in the tritium concentration is not large, this difference is mainly caused by the difference in the composition of nuclides, but the difference caused by the composition of nuclides is small. The sum of the ratios to regulatory concentrations limits of the composition of nuclides in the three tanks is around 0.1 to 0.3, and the sum of the ratios to regulatory concentrations limits of the composition of the nuclides of the K4 tank group with the highest exposure assessment value is 0.26. The limit value in discharge control is the sum of the ratios to regulatory concentrations limits of less than 1, so if ALPS treated water in which the sum of the ratios to regulatory concentrations limits is close to 1, exposure may become 3 to 4 times larger.

If the tritium concentration in ALPS treated water is low, the discharge volume of water instead increases, so there is uncertainty due to the tritium concentration that exposure increases due to an increase in the discharge amount of nuclides other than tritium, but the discharge volume of water is, even if the tritium concentration is low, limited to up to 500 m^3/day due to the capacity of facility and the annual discharge volume of water is maximum 1.5E+08L (capacity factor: 80%), which is just 1.25 times larger than that of the K4 tank group (annual discharge volume of water: 1.6E+08L) and about as large as the J1-G tank group (annual discharge volume of water: 9.2E+07L).

8-1-2. Uncertainty of analysis (aleatory uncertainty)

The compositions of nuclides of the three tank groups used for the setting of the source term includes uncertainty of analysis. To verify the impact of the uncertainty of analysis on the exposure assessment value, we applied the expanded uncertainty calculated from the analysis result of the J1-C tank group to the measurement result of the K4 tank group with a high exposure assessment value for the normal exposure assessment. Table 8-1 shows the composition of nuclides considering expanded uncertainty in the composition of nuclides of the K4 tank group. Table 8-2 shows the concentration in the seawater used for the set source term and assessment. Table 8-3 shows the exposure assessment result.

The exposure assessment result of the source term considering the uncertainty of analysis is about 1.5 times larger than that not considering the uncertainty, so the uncertainty of the exposure assessment due to the uncertainty of the analysis is considered to be less than 2 times greater.

8-1-3. Summary of the uncertainty of the source term

As for the uncertainty of the source term, the difference due to the composition of nuclides of the tank group is about ±2-3 fold centering on the source term based on the J1-G group, the uncertainty of tritium concentration is about 2-fold and the uncertainty of analysis is considered to be about ±1.5-fold.

Table 8-1 Composition of nuclides considering the uncertainty of analysis for the composition of nuclides of the K4 tank group

Target nuclide	Regulatory concentration limit (Bq/L)	Composition of nuclides of the K4 tank group (Bq/L)	Composition of nuclides of the k4 tank group considering expanded uncertainty (Bq/L)	Ratio to regulatory concentration limit
H-3	6.0E+04	1.4E+05	1.4E+05	―
C-14	2.0E+03	1.5E+01	1.9E+01	9.4E-03
Mn-54	1.0E+03	8.5E-05	1.4E-04	1.4E-07
Fe-55	2.0E+03	2.1E+00	3.6E+00	1.8E-03
Co-60	2.0E+02	2.2E-01	2.6E-01	1.3E-03
Ni-63	6.0E+03	2.1E+00	2.2E+00	3.7E-04
Se-79	2.0E+02	1.5E+00	2.5E+00	1.2E-02
Sr-90	3.0E+01	1.9E-01	2.5E-01	8.3E-03
Y-90	3.0E+02	1.9E-01	2.5E-01	8.3E-04
Tc-99	1.0E+03	7.0E-01	7.1E-01	7.1E-04
Ru-106	1.0E+02	4.2E-02	5.3E-02	5.3E-04
Sb-125	8.0E+02	8.6E-02	1.2E-01	1.5E-04
Te-125m	9.0E+02	8.6E-02	1.2E-01	1.4E-04
I-129	9.0E+00	2.1E+00	2.4E+00	2.7E-01
Cs-134	6.0E+01	7.4E-03	1.2E-02	2.1E-04
Cs-137	9.0E+01	3.7E-01	4.5E-01	5.0E-03
Ce-144	2.0E+02	5.3E-04	9.0E-04	4.5E-06
Pm-147	3.0E+03	4.5E-02	7.7E-02	2.6E-05
Sm-151	8.0E+03	8.6E-04	1.5E-03	1.8E-07
Eu-154	4.0E+02	7.8E-03	1.3E-02	3.3E-05
Eu-155	3.0E+03	1.5E-02	2.5E-02	8.4E-06
U-234	2.0E+01	6.3E-04	7.5E-04	3.8E-05
U-238	2.0E+01	6.3E-04	7.5E-04	3.8E-05
Np-237	9.0E+00	6.3E-04	7.5E-04	8.4E-05
Pu-238	4.0E+00	6.0E-04	7.2E-04	1.8E-04
Pu-239	4.0E+00	6.3E-04	7.5E-04	1.9E-04
Pu-240	4.0E+00	6.3E-04	7.5E-04	1.9E-04
Pu-241	2.0E+02	2.2E-02	2.6E-02	1.3E-04
Am-241	5.0E+00	6.2E-04	7.4E-04	1.5E-04
Cm-244	7.0E+00	5.1E-04	6.1E-04	8.7E-05
Sum of the ratios to regulatory concentrations limits				3.1E-01

Table 8-2 Concentration in the seawater used for the assessment (Source term based on the composition of nuclides in the K4 tank group reflecting the uncertainty of analysis)

Target nuclide	Source term (annual discharge amount) (Bq)	Concentration in the seawater used for the assessment (Bq/L)		
		Within 10 × 10 km Average of all layers	Within 10 × 10 km Average of the top layers	Beach assessment point Average of all layers
H-3	2.2E+13	5.6E-02	1.2E-01	8.8E-01
C-14	3.0E+09	7.5E-06	1.6E-05	1.2E-04
Mn-54	2.2E+04	5.7E-11	1.2E-10	9.0E-10
Fe-55	5.6E+08	1.4E-06	3.1E-06	2.2E-05
Co-60	4.1E+07	1.0E-07	2.2E-07	1.6E-06
Ni-63	3.4E+08	8.8E-07	1.9E-06	1.4E-05
Se-79	3.9E+08	1.0E-06	2.1E-06	1.6E-05
Sr-90	3.9E+07	9.9E-08	2.1E-07	1.6E-06
Y-90	3.9E+07	9.9E-08	2.1E-07	1.6E-06
Tc-99	1.1E+08	2.8E-07	6.1E-07	4.5E-06
Ru-106	8.3E+06	2.1E-08	4.6E-08	3.3E-07
Sb-125	1.9E+07	4.9E-08	1.1E-07	7.8E-07
Te-125m	1.9E+07	4.9E-08	1.1E-07	7.8E-07
I-129	3.8E+08	9.7E-07	2.1E-06	1.5E-05
Cs-134	2.0E+06	5.0E-09	1.1E-08	7.8E-08
Cs-137	7.1E+07	1.8E-07	3.9E-07	2.8E-06
Ce-144	1.4E+05	3.6E-10	7.7E-10	5.7E-09
Pm-147	1.2E+07	3.1E-08	6.6E-08	4.8E-07
Sm-151	2.3E+05	5.8E-10	1.3E-09	9.2E-09
Eu-154	2.1E+06	5.3E-09	1.1E-08	8.3E-08
Eu-155	4.0E+06	1.0E-08	2.2E-08	1.6E-07
U-234	1.2E+05	3.0E-10	6.4E-10	4.7E-09
U-238	1.2E+05	3.0E-10	6.4E-10	4.7E-09
Np-237	1.2E+05	3.0E-10	6.4E-10	4.7E-09
Pu-238	1.1E+05	2.9E-10	6.1E-10	4.5E-09
Pu-239	1.2E+05	3.0E-10	6.4E-10	4.7E-09
Pu-240	1.2E+05	3.0E-10	6.4E-10	4.7E-09
Pu-241	4.1E+06	1.1E-08	2.3E-08	1.7E-07
Am-241	1.2E+05	3.0E-10	6.3E-10	4.7E-09
Cm-244	9.6E+04	2.4E-10	5.2E-10	3.8E-09
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	During swimming From beach sand Ingestion of seawater Inhalation of seawater spray

Table 8-3 Exposure assessment result based on the composition of nuclides in the K4 tank group reflecting the uncertainty of analysis (Assessment area: 10 km × 10 km)

Assessed case	Source term	(1) Source term based on measured values						(2) Source term considering the uncertainty of analysis (K4)	
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group			
	Ingestion of seafood	Average	Large	Average	Large	Average	Large	Average	Large
External exposure (mSv/year)	Sea surface	4.6E-10		1.7E-10		3.7E-10		5.7E-10	
	Hull	4.9E-10		1.8E-10		3.7E-10		6.0E-10	
	During swimming	3.2E-10		1.2E-10		2.5E-10		3.9E-10	
	Beach sand	5.4E-07		2.0E-07		4.3E-07		6.7E-07	
	Fishing net	1.1E-07		3.9E-08		8.3E-08		1.3E-07	
Internal exposure (mSv/year)	Ingestion of water	3.4E-07		3.1E-07		3.1E-07		3.4E-07	
	Inhalation of spray	9.2E-08		1.9E-07		3.8E-07		9.6E-08	
	Ingestion of seafood	6.9E-06	3.1E-05	1.2E-06	5.5E-06	2.6E-06	1.1E-05	8.7E-06	3.9E-05
Total (mSv/year)		8E-06	3E-05	2E-06	6E-06	4E-06	1E-05	1E-05	4E-05

Table 8-4 Results of internal exposures assessment by age based on the composition of nuclides in the K4 tank group reflecting the uncertainty of analysis (Assessment area: 10 km × 10 km)

Assessed case	Source term	(1) Source term based on measured values						(2) Source term considering the uncertainty of analysis (J1-G)	
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group			
	Ingestion of seafood	Average	Large	Average	Large	Average	Large	Average	Large
Internal exposure from ingestion of water (mSv/year)	Adult	3.4E-07		3.1E-07		3.1E-07		3.4E-07	
	Child under school age	5.8E-07		5.3E-07		5.4E-07		5.9E-07	
	Infant	-		-		-		-	
Internal exposure from inhalation of spray (mSv/year)	Adult	9.2E-08		1.9E-07		3.8E-07		9.6E-08	
	Child under school age	6.0E-08		1.1E-07		2.0E-07		6.3E-08	
	Infant	3.9E-08		6.2E-08		1.1E-07		4.0E-08	
Internal exposure from ingestion of seafood (mSv/year)	Adult	6.9E-06	3.1E-05	1.2E-06	5.5E-06	2.6E-06	1.1E-05	8.7E-06	3.9E-05
	Child under school age	7.8E-06	3.6E-05	1.5E-06	6.8E-06	3.6E-06	1.6E-05	1.1E-05	5.0E-05
	Infant	6.9E-06	3.2E-05	1.7E-06	8.1E-06	4.6E-06	2.2E-05	1.0E-05	4.9E-05

8-2. Uncertainty of modeling of diffusion and transfer in the environment

8-2-1. Uncertainty of meteorological and oceanographic data, etc. (aleatory uncertainty)

The diffusion simulation is considered to include uncertainty caused by variations such as the annual variations of meteorological and oceanographic data.

For this assessment, the meteorological and oceanographic data of 2014 to 2020 are used, but the biggest observed difference in the annual average concentration of 10 km × 10 km used for the assessment is up to about 20%. A document that simulated the diffusion of cesium using the same model to reproduce the monitoring results shows no difference in the shape of diffusion of each year and that the scale of uncertainty is not twice as great.

8-2-2. Uncertainty of the simulation model itself (epistemic uncertainty)

The diffusion simulation model does not reproduce all of the natural phenomena and scientific findings that the model is constructed based on is not complete. However, the model used this time has been verified by a reproduction calculation of the cesium concentration in the same sea area and the simulation result matches the measured value well. There could be a charge to verify this with another modeling to confirm the magnitude of uncertainty more accurately, but the uncertainty of the model itself is estimated to be not so great.

8-2-3. Uncertainty in the selection of migration pathways (epistemic uncertainty)

In the external exposure assessment, the external exposure from radioactive materials migrated to hulls, beach sand, and fishing nets are assessed. The factor of migration to hulls, beaches, and fishing nets are excerpted from domestic cases such as past guidelines, but not all data regarding the nuclides required for this assessment was obtained. The assessment was based on the data of limited nuclides.

Though there are few findings about these migration factors, the migration to sandy beaches can be assessed by the method of TECDOC-1759 (using the external exposure dose conversion factor of FGR15 issued by U.S. Environmental Protection Agency), so the exposure from sandy beaches was calculated and the result of this report was about 2 times larger. However, it turned out that as the contribution to the overall exposure, the contribution of external exposure is smaller than internal exposure and the total exposure value does not differ so much from that of this report. Attachment XI “Conservativeness of the external exposure dose conversion factor” shows the details of the assessment result using the external exposure dose conversion factor of FGR15 issued by U.S. Environmental Protection Agency.

8-2-4. Uncertainty in the concentration factor of seafood and the distribution coefficient of seabed sediment (epistemic uncertainty)

The concentration coefficient of fish, etc. used for internal exposure from ingestion of seafood shown in TRS-422 is calculated assuming that the concentration in the seawater and marine organisms are in the equilibrium state from the investigation results of the concentration in the seawater and fish, etc.

However, while the process of migration to organisms and seabed sediment takes much time, whereas movement of the seawater is fast, and it is uncertain whether they were in the equilibrium state at the time of the investigation. In addition, there are also great deal of variations depending on the type of fishes and seabed sediment, and survey locations, and TRS-422 indicates that insufficient reliable data are available to allow accurate assessments of ranges around a recommended value for most element–organism combinations. On the other hand, where a reliable database does exist for a given element and type of organism, in nearly every case the range of minimum and maximum CFs is one order of magnitude (or less) from the recommended value. Therefore, TRS-422 indicate that maximum and minimum CFs are one order of magnitude above and below the recommended value. This is same for the distribution coefficient of seabed sediment, where a range of values is required, maximum and minimum values could be assumed to be a factor of 10 higher and lower than the recommended value.

8-2-5. Uncertainty in the transition of tritium in the environment (epistemic uncertainty)

As stated in 4 (2), some portion of tritiated water (HTO) is converted into Organically Bound Tritium (OBT) by animals and/or plants in the environment. In this report, referring to the kinetic model in human body by HTO ingestion, 10% out of the tritium ingested with marine products is supposed to be converted into OBT, and there still is an uncertainty to the transition of tritium in the environment.

However, the contribution of exposure by the tritium to the total dose is minor. Since the effective dose factor by internal exposure of OBT through ingestion compared to HTO is merely a factor of about three times, the uncertainty in the transition of tritium would not affect on the result of the dose assessment. The impact of uncertainty in the transition of tritium in the environment is summarized in Attachment III, “Impact of the organically bound tritium in the exposure assessment of tritium”.

Note that above mentioned content are within the current discharge level of less than 22TBq per year, if tritium discharge will be increase a great deal, due to a part of future optimization, for example, further specific assessment will be required.

8-3. Uncertainty in the setting of exposure pathways

8-3-1. Uncertainty in the selection of exposure pathways (epistemic uncertainty)

The setting of exposure pathways may be insufficient. In TECDOC-1759, most of the pathways set as external exposure ones such as exposure from the sea surface and hulls in this assessment are not subject to the assessment, but pathways not set in this report such as ingestion of beach sediment, ingestion of seawater, and inhalation of seawater spray are picked up. As a result of a verification calculation of unselected pathways by the method of TECDOC-1759, pathways of which exposure assessment results exceeded the pathways selected in this report were found such as ingestion of seawater and inhalation of seawater spray, so they were added as pathways. However, the total value did not change because the impact of internal exposure from ingestion of seafood is great in the exposure assessment. For the result of the verification calculation., see Attachment VI “Transfer pathways and exposure pathways other than the assessment targets.” Please note that the difference from TECDOC-1759 is due to the inclusion of modeling of dispersion and transfer.

8-4. Uncertainty in the selection of the representative person

8-4-1. Uncertainty in the actual life of the representative person (aleatory uncertainty)

In this assessment, the life habit data of the critical group in the case of exposure simulation from domestic nuclear power plants is used. The latest data of the national health and nutrition survey is used for the ingestion of seafood, which has a slight annual variation of about 10 to 20%. However, considering this uncertainty, ingested fish assessed in this report is assumed to be consumed immediately after being caught in the area around the FDNPS without considering market dilution, decay of radioactive nuclides after catching, etc., so there is considered to be not uncertainty which may lead to underestimation.

8-4-2. Uncertainty in the selection of the representative pathway (epistemic uncertainty)

The area around the FDNPS is still in the middle of reconstruction: e.g. even now Difficult-to-Return Zones are set. It is still prohibited to live in Difficult-to-Return Zones. Even for the other zones, return of residents is very limited. Under such circumstances, it is very difficult to ascertain detailed life habits available for the setting of the representative person including the prediction of the future situation.

Therefore, in this assessment, the life habit data of the critical group used in the case of simulation of exposure from domestic nuclear power plants is used, but it includes uncertainty due to the difference from the actual life habits of residents in the surrounding area after reconstruction.

On the other hand, in this assessment, the reprocessing plant located in Aomori, which is also in Tohoku, applies the setting based on the social environment survey and the time of exposure from fishing nets is longer than that of this assessment, but it is less than two times longer. Moreover, the impact of external exposure is smaller than that of internal exposure from the ingestion of seafood, so there is no impact on the exposure assessment.

For the ingestion of seafood which affects the internal exposure result, nation-wide statistical data aggregated by age is used and about 10% different from the data of Tohoku. Fish and invertebrates (total of shellfish, cephalopods, and crustacea at reprocessing plant) of the reprocessing plant are 20 to 30% more and seaweeds of this report are 30% more, but the uncertainty of the food ingestion is unlikely to be two times greater and ingested fish assessed in this report is assumed to be consumed immediately after being caught in the area around the FDNPS without considering market dilution, decay of radioactive nuclides after catching, etc., so there is considered to be no uncertainty which may lead to underestimation.

8-4-3. Uncertainty depending on the range of the sea area to be assessed (epistemic uncertainty)

The further it is from the discharge outlet, the lower the concentration in the seawater becomes in the case of discharge of ALPS treated water, so there is uncertainty of variation of the concentration in the seawater used for the assessment depending on the scale of the range to be assessed.

To verify the impact due to the scale of the range to be assessed, we calculated the annual average concentration within 5 km × 5 km and 20 km × 10 km in addition to 10 km × 10 km and assessed exposure of human under normal conditions. The exposure assessment result of 20 km×10 km has small difference to that of 10 km×10 km. That of 5 km × 5 km was about 3 times higher than that of 10 km × 10 km. In reality, it is unlikely that fishing is performed only within 5 km×5 km around the FDNPS; and in this report, exposure is assessed assuming that only seafood caught in the assessed sea area but in reality, it is unlikely that only fish caught in the area around the FDNPS is ingested, so it is considered to be unnecessary to consider uncertainty about the range of the sea area. Even assumed that 10% of ingested seafood are caught within the 5 km × 5 km sea area, the increase of internal exposure caused by ingested seafood is not large about 20 %. Attachment XII “Impact of the assessment range of concentrations in seawater used for the assessment of exposures" shows the result of the exposure assessment of 5 km × 5 km and 20 km × 10 km from the power station.

8-5. Summary about uncertainty

Table 8-5 summarizes these contents.
There is great uncertainty in the composition of nuclides in the source term and migration pathways such as the concentration factor of fish, but the exposure assessment result is sufficiently lower than the dose constraint and it is considered that the conservativeness of the assessment is not lost.

Table 8-5 Summary of uncertainty in this assessment

Item	Details of uncertainty	Assessment of uncertainty
Selection of the source terms	The composition of nuclides of ALPS treated water is unknown until secondary treatment and measurement is completed, so it has epistemic uncertainty.	The exposure assessment result of the K4 tank group with larger value of sum of the ratios to regulatory concentration limits in the source term based on the measured value is about three times of the J1-G tank group with the lowest one. On the other hand, the sum of ratios to regulatory concentration limit of the K4 tank group is 0.26. If the sum of the ratios to regulatory concentration limit is 1 with the same nuclide ratio, exposure will be about 3 to 4 times greater.
	The measured value incudes aleatory uncertainty based on uncertainty of analysis.	The impact of uncertainty of analysis seems to be less than double.
Modeling of diffusion and transfer in the environment	The meteorological and oceanographic data has annual variations and includes aleatory uncertainty.	We calculated the average concentration of 10 km × 10 km of 7 years and found a difference of about 20%. In the comparison with the measured value, the parts with high concentrations match well, so uncertainty is assumed to be less than two times greater in the calculation of the average calculation of 10 km × 10 km.
	The diffusion simulation model has epistemic uncertainty in the model itself.	
For the migration pathways	and the migration factor of external exposure, differences in elements are not considered, so the dose conversion factor of external exposure has epistemic uncertainty which does not cover all nuclides.	We calculated exposure from beaches from the external exposure dose conversion factor of FGR15 and it turned out that the result of the radiological environmental impact assessment report was 2 times. Even so, the effect of external exposure on exposure is smaller than that of internal exposures, and the total exposure value does not differ so much from that of this report.
	The concentration factor of fish used for the internal exposure assessment from ingestion of seafood includes epistemic uncertainty due to insufficiency of data.	For the concentration factor, TRS-422 indicate that maximum and minimum CFs are one order of magnitude above and below the recommended value in the case of existence of reliable data for element–organism combination, and for the distribution coefficient, maximum and minimum values could be assumed to be a factor of 10 higher and lower than the recommended value.
Exposure pathways	There are epistemic uncertainties because the selected migration and exposure pathways do not cover all the pathways.	We calculated the unselected exposure pathways by the method of TECDOC-1759 and added pathways with higher exposure assessments than those of the previous selected pathways. However, the total value did not change because the impact of internal exposure from ingestion of seafood is great.
Selection of a representative person	The area around the FDNPS is undergoing reconstruction, so we used life habit data from domestic precedent cases. As a result, it includes epistemic uncertainty due to the difference in the actual life habits. The food ingestion is set from nationwide data and also includes epistemic uncertainty.	The external exposure time is shorter than that of the Rokkasho reprocessing plant, but it is smaller than internal exposure from ingestion of seafood and does not affect the exposure assessment result. For the ingestion of seafood which affects the internal exposure result, nation-wide statistical data aggregated by age is used and about 10% different from the data of Tohoku, but in the report, all ingested fish are assumed to have been caught in the area around the FDNPS in the assessment, so there is considered to be not uncertainty which may lead to underestimation.
	It includes epistemic uncertainty about the range of the appropriate area as the sea area to be assessed.	We assessed 5 km × 5 km, which is smaller, and 20 km × 10 km, which is larger, than 10 km × 10 km and it turned out that the exposure is about three times greater in the range of 5 km × 5 km and not much different in the range of 20 km × 10 km. Actually, it is unrealistic to perform fishing only within the range of 5 km × 5 km and the assessment in this report assumes that all ingested fish are caught in the area around the FDNPS, so it is considered to be unnecessary to consider uncertainty due to the setting of the assessed sea area.

9. Monitoring to be performed in response to discharge of ALPS treated water into the sea

This section describes our analytical capabilities at the FDNPS as well as the plan of monitoring to be performed inside and outside the site in relation to the discharge of ALPS treated water of the FDNPS (as of the issuance of this revised report; to be revised as needed).

All of these enhance and expand the monitoring program which has been performed continuously since the accident at the FDNPS.

Through the monitoring activity in the site, we will ensure that ALPS treated water discharged into the environment is safe. Through the monitoring activity outside the site, we will correctly ascertain the impact of discharge of ALPS treated water into the sea on the environment.

9-1. Analytical capability in the Fukushima Daiichi Nuclear Power Station

In the site of the FDNPS, the environment control building for environmental sample analysis and the Unit 5/6 analysis rooms (hot lab.) for analysis of samples with high activity concentration, which have been operated before the earthquake, are still in operation. In addition to these, we started the operation of the chemical analysis building for samples with low activity concentration for which measures to prevent contamination in the site and eliminate the impact of the environmental dose were performed in 2013. The analysis and measurement functions of the environment control building were terminated due to the contamination state of the facility and facility aging, and only the pretreatment function remains.

After the earthquake, initially we especially focused on handling of samples with high activity concentration in order to deal with the problem of contaminated water. However, in July 2013, when the chemical analysis building was completed and environmental samples were able to be analyzed, we started to develop human resources to analyze samples of which radioactive concentrations had been confirmed to be low such as the seawater. After that, as drainage of groundwater bypass water (hereinafter called “groundwater bypass”) and treated water of the purification facilities such as the subdrain (hereinafter called “subdrain”) to reduce the contaminated water generation, we have been expanding the training of workers for the Unit 5/6 analysis rooms and the chemical analysis building in parallel. For discharge of ALPS treated water into the sea, we will enhance and expand the analysis framework in terms of facilities and competence.

9-1-1. Analytical capability in terms of facilities

Since all analyses related to discharge of ALPS treated water into the sea are classified into analyses of samples with low activity concentration, it is planned to perform analyses and assessments using the facilities of the chemical analysis building. The layout arrangement, addition of analysis devices, etc., for the chemical analysis building will be performed flexibly as needed. Table 9-1 shows the overview and functions of the analysis facilities in the site of the FDNPS. Table 9-2 shows the overview of the analysis devices installed in the chemical analysis buildings.

Table 9-1 Overview and functions of the analysis facility

Facility name	Function	Overview of the facility	Remarks
Environmental management building	Pretreatment (pretreatment of fish)	Analysis room + Measurement room: 480m^2 Experimental table: 4	● Before the earthquake, we analyzed environmental samples but transferred the functions to the chemical analysis building and the Unit 5/6 analysis rooms after the earthquake ● The functions are limited to pretreatment
Units 5/6 analysis room	Analysis of samples with high activity concentration	Analysis room + Measurement room: 850m^2 Experimental table: 23 Fume hood: 26	● Expanded the facility which had been operated since before the earthquake in 2016
Chemical analysis building	Analysis of samples with low activity concentration	Analysis room + Measurement room: 1,000m^2 Experimental table: 15 Fume hood: 35	● This facility was put into use in 2013. ● The analysis of ALPS treated water is planned to be performed here
Chemical analysis building (for expansion, planned)	Pretreatment operation and analysis of a sample of a low radioactive concentration	Analysis room + Measurement room: About 600 m^2 [Facility proposal] Experimental table: 8 Fume hood: 21 Rotary evaporator: 5 Electrolytic condenser: 10 Lyophilizer: 6 H-3 -> He converter: 2	● The construction work is scheduled to be completed by the end of FY 2023. ● The number of analyzers, etc. may be changed in the future

Table 9-2 Analyzers in the chemical analysis building (including those planned to be expanded in the future)

Sample handled	Analyzer	Target nuclides to be measured	Number of units deployed
Monitoring samples: seawater, etc. Drainage sample: Groundwater bypass and sub-drain ALPS outlet water: last stage etc.	Ge semiconductor detector	γ-ray emitting nuclides (e.g. Cs -134.137)	12
	Automatic α-measuring device	Total α	2
	Low back gas flow counter	Total β, Sr -90	5
	β-nuclide analysis equipment	Sr-90	2
	Low background liquid scintillation counter	Tritium, C -14 , Ni-63	9 (Three more to be expanded)
	Inductively coupled plasma mass spectrometer (ICP-MS)	I-129, Tc-99	2
	Noble gas mass spectrometer (He-MS)	Tritium	2 (To be expanded)
	High purity Ge semiconductor detector for low energy photons (LEPS)	Low-energy γ-ray emitting nuclide (including Fe-55)	2 (To be expanded)

For the measuring instruments used for measurement, we verify the detection efficiency with the standard source and the standard solution as daily inspections at the start of work to maintain the device performance and measure samples. Table 9-3 shows the overview of daily inspections of the measuring instruments installed in the FDNPS (verification of the detection efficiency).

Table 9-3 Verification of the detection efficiency in the daily inspection of measuring instruments

Measuring instrument	Standard source	Confirmation method
Ge semiconductor detector	Co-57, Ba-133, Cs-137, Mn-54, Co-60	Frequency: At the beginning of daily work Method: Obtain the detection efficiency for each nominal energy of the standard source and confirm that it is within the judgment value (±10%) Actions to be taken in case of deviation: The measured sample after the value judged last time is evaluated again, and the sample during the deviation period is measured if necessary
Automatic α-measuring device	Am-241	
β-nuclide analysis equipment	Sr-90 Cs-137	
Low background liquid scintillation counter	Tritium	
Inductively coupled plasma mass spectrometer (ICP-MS)	Li, Co, Y, Tl	Frequency: Each use Method: Measure the strength of each element. After checking the judged value or above, prepare a calibration curve before measurement. Strength of standard solution: Li: >1000 Co, Y: >200 Tl: >800

9-1-2. Analytical capability in terms of competence

The analysis work led by us will be consigned to Tokyo Power Technology[43] (hereinafter called "TPT"). We will formulate the plan for analysis and prepare resources suitable for the plan, supervise the work by TPT, judge the possibility of discharge based on the analysis result, manage and announce analysis data, etc.

Our employees who supervise analysis work will have been certified to have skill levels sufficient for their roles through the on-site technique and skills certification system, and competence is secured in a planned manner by periodic competence assessments and effectiveness reviews.

On the other hand, TPT, which is the consignee of the analysis work, increases and secure competent analysts in order to maintain the capabilities to surely analyze the nuclides for which high skills are required (hereinafter called "difficult-to-measure nuclides") such as C-14. Moreover, to have objective confirmation of skills from the viewpoint of a third party, we will participate in IAEA Proficiency Test Exercise[44] and continuously conduct crosschecking, etc., with analytical institutes inside Japan.

In the chemical analysis building, ISO/IEC-17025 certification[45] for Cs-134, Cs-137, and tritium has been acquired and maintained and it is planned to acquire certification for the Sr-90 analysis as well. In addition, the appropriateness of the data to be used for decision of discharge was confirmed by comparison with the analysis value of the third-party institute

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[43] We are a wholly owned subsidiary of Tokyo Electric Power Company Holdings, Inc. and have advantages in terms of design, construction, operation, and maintenance of electricity-related facilities including our company; environment investigation measurements and their assessments; investigations/analyses and measurements of substances, etc.; control of radioactive materials and radiation; decontamination in general; processing treatment/disposal of radioactive waste, etc.

[44] The IAEA prepares a sample with a known result for the test and provide it to each participating analysis institute. Then, each institute analyzes it and the IAEA compares the result with the components of the sample for the test to assess the accuracy of the analysis by each institute.

[45] Examining authority examine the ability of test places and correction organizations to authorize their capability.

specified as the consignee by us. Table 9-4 shows the certification acquisition status by the certification institute for us (TPT) and each consignee analysis institute.

Table 9-4 Certification acquisition statuses of us (TPT) and consignee analysis institutes

Organization	Certification	Acquisition status (17025)
TPT (Fukushima Daichi)	ISO/IEC17025 ISO9001	(Chemical analysis building) Cs-134,Cs-137,H-3
KAKEN Co.,Ltd.	ISO/IEC17025	Cs-134,Cs-137 I-131 Sr-90 H-3
Japan Chemical Analysis Center	ISO/IEC17025 ISO9001	Gamma-emitting nuclide H-3 Radioactive strontium Plutonium
Tohoku Greening Environmental Conservation Co., Ltd.	ISO/IEC17025 ISO9001	Cs-134,Cs-137 I-131 H-3

To ascertain the competence of each analyst, we increase those who can deal with analyses of difficult-measure nuclides by OJT and verify the competence with the Z score (within two times wider range as detected concentration ± standard deviation), which is an ISO review method, by measurements using samples with known concentrations once a year for the nuclides subject to ISO/IEC-17025 authentication [46] for all the personnel in charge of tritium and cesium (See Figure 9-1).

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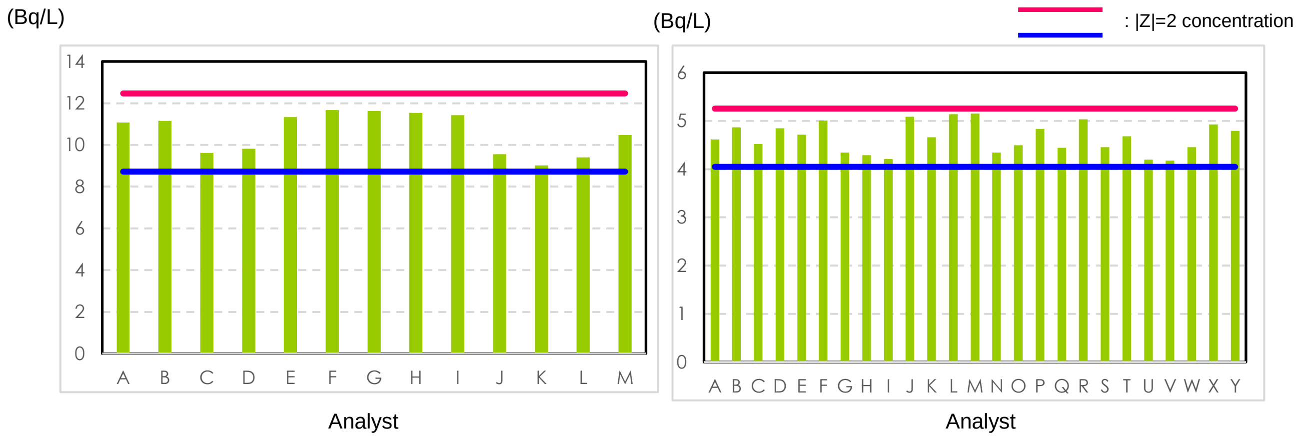
[46] "Analytical test of radionuclide (including Cs134/Cs137 and H-3) in public waters, wastewater, soil, ash and sludge" (Certification institute: Perry Johnson Laboratory Accreditation Inc., Certificate: L22-389)



Persons targeted for H -3 Skill Test: 13 analysts (A to M)
Sample concentration: 10.2Bq/L
Intermediate value of 10 times repeated measured of 3 samples by the sample creator
Implementation period: October 9-29, 2020
Implementation location: Chemical Analysis Building
Judgment method: Z score (ISO inspection method)
Judgment value: | Z | ≤ 2

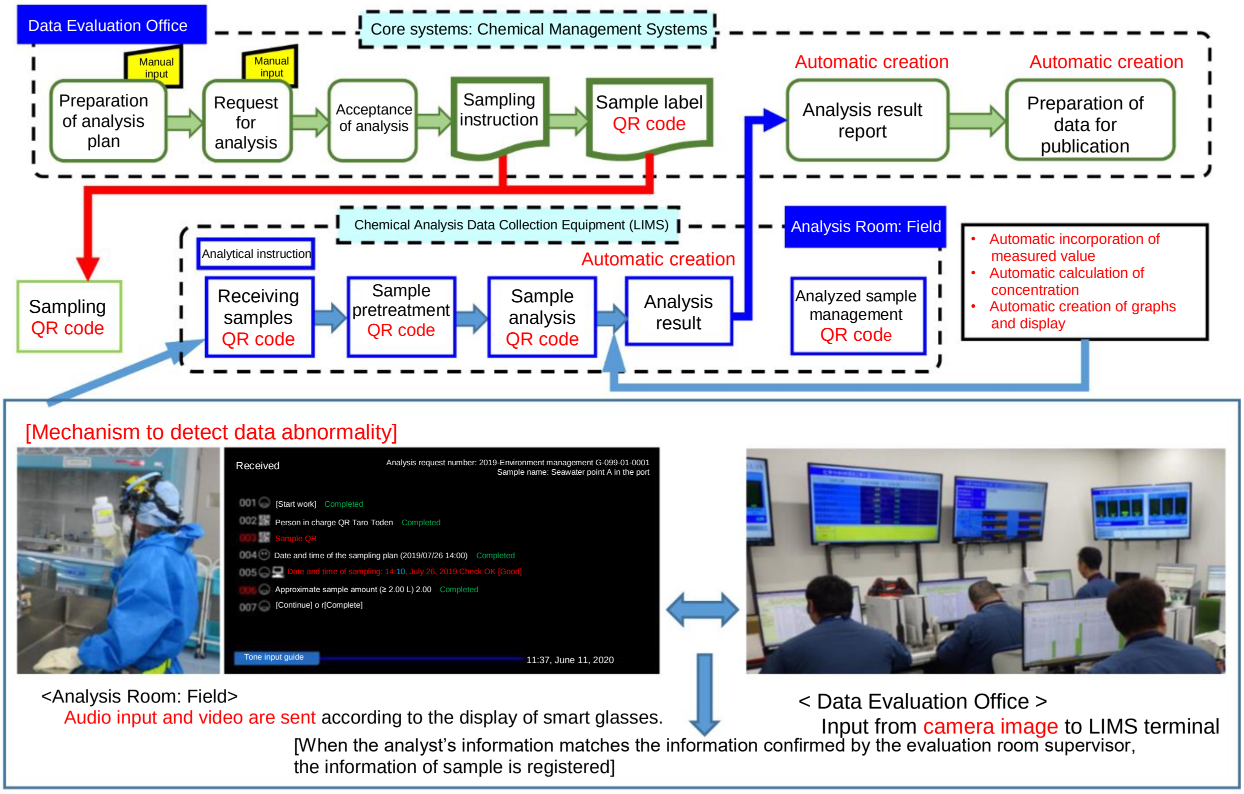
Persons targeted for Cs-137 Skill Test: 25 analysts (A to Y)
Sample concentration: 4.5Bq/L
Intermediate value of 10 times repeated measured by the sample creator
Implementation period: July 29 to August 6, 2020
Implementation location: Chemical Analysis Building
Judgment method: Z score (ISO inspection method)
Judgment value: | Z | ≤ 2

Figure 9-1 Example of competence check of analysts (result of FY 2020)

9-1-3. Our management and supervision

We request consignees to comply with the determined analysis procedures and secure the competence of analysts based on contracts, and receive and verify analysis procedures and competence control records.

Figure 9-2 shows the overview of the system that maintains the flow and quality of analysis, which means that the quality of the analysis process is kept constant and a mechanism to detect abnormalities of data is constructed.



```
Received                    Analysis request number: 2019-Environment management G-099-01-0001
                                                   Sample name: Seawater point A in the port

001 [Start work]   Completed
002 Person in charge QR Taro Toden   Completed
003 Sample QR
004 Date and time of the sampling plan (2019/07/26 14:00)   Completed
005 Date and time of sampling: 14:10, July 26, 2019 Check OK [Good]
006 Approximate sample amount (≥ 2.00 L) 2.00   Completed
007 [Continue] o r[Complete]

Tone input guide                                              11:37, June 11, 2020
```

<Analysis Room: Field>
Audio input and video are sent according to the display of smart glasses.

< Data Evaluation Office >
Input from camera image to LIMS terminal

[When the analyst's information matches the information confirmed by the evaluation room supervisor, the information of sample is registered]

Figure 9-2 Flow of analysis and overview of the system to maintain quality

In addition, the following activities are performed.

- Usage status of procedures and the implementation status of specifications are regularly checked in all analysis rooms (it is applied to all analytical work performed within the premises of the FDNPS)
- In order to ensure the quality of operation and work safety, it is stipulated as a requirement that work can be performed with the same procedure even when an analyst is replaced.
- Methods for checking procedures are standardized.
- The third-party organizations are required to submit work procedures in their specifications as well, and our company's involvement in the quality control of work processes will be enhanced.
- Guidance is given to contractors for identifying risks in the prior safety assessment before starting operation. TEPCO explains previous nonconformity cases and gives guidance to raise their awareness and ensure the thorough compliance with the rules

- Every month, TEPCO discusses with contractors on issues in analytical operation and the implementation status of the preventive measures for the recurrence of previous nonconformities to maintain performance
- Every month, TEPCO conducts on-site observations for analysis work with contractors to identify unsafe conditions to ensure safety at the site and maintain work quality
- Implementation status of analysis procedures established by contractors, is checked, and guidance is given for the identification and correction of the area to be improved in the work.

9-2. Monitoring within the premises of the Fukushima Daiichi Nuclear Power Station

The following three activities are to be performed at the site: (1) measurement and assessment of 30 nuclides by the measurement/confirmation facility in addition to 39 nuclides, which are target nuclides to be removed by ALPS of which results are used to judge the possibility of discharge and determine the dilution ratio (source monitoring), (2) monitoring with samples collected at the discharge vertical shaft (upper-stream storage) to confirm the dilution and mixing states of treated water with the seawater used for judgment of discharge immediately after the start of discharge, and (3) monitoring with samples collected from the seawater piping performed to confirm the dilution state every day during continuous discharge, all of which are led by us. This section describes the procedures, etc., used for maintaining the accuracy of monitoring as well.

Figure 9-3 shows monitoring to be performed within the premises of the FDNPS.

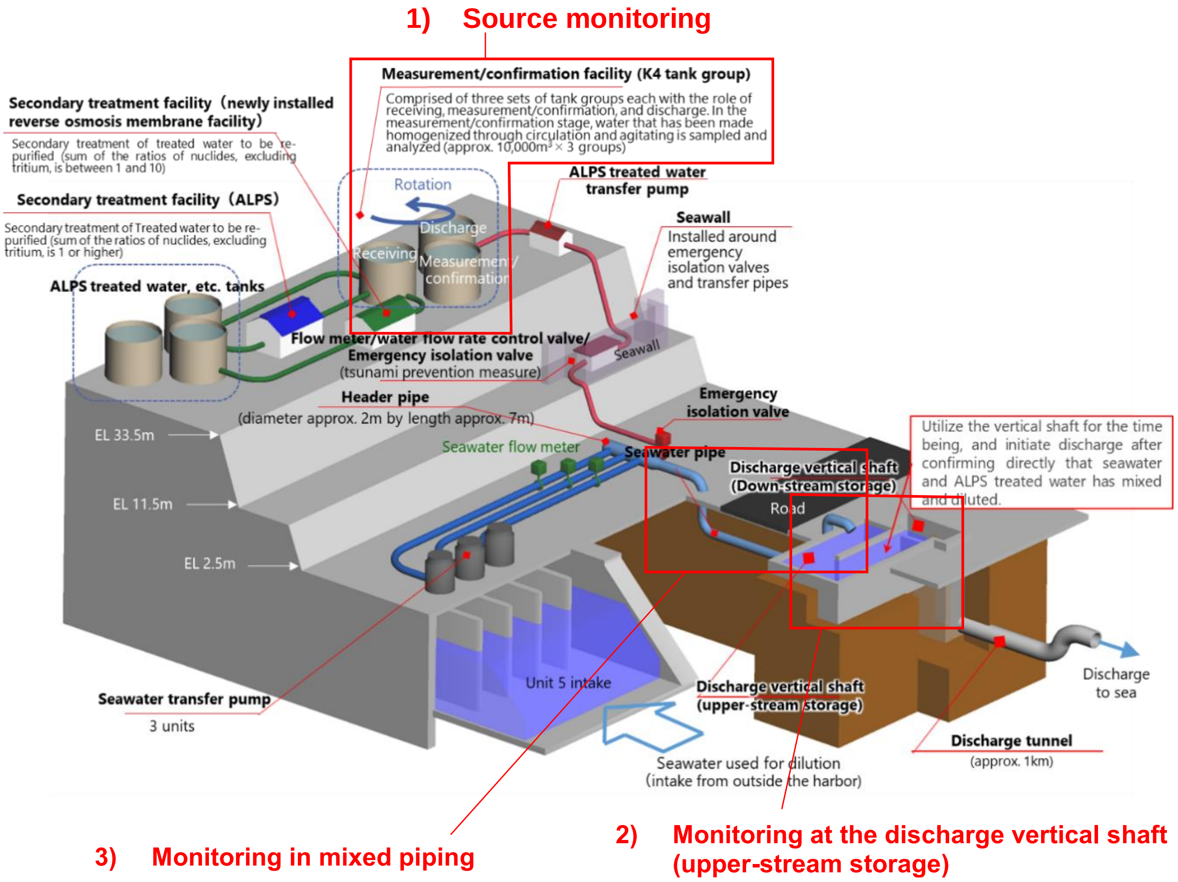


Figure 9-3 Monitoring within the premises of the FDNPS

9-2-1. Source monitoring

Source monitoring is monitoring of the source term (annual discharge amount (total amount) of each nuclide contained in the ALPS treated water, which is diluted and discharged into the sea). In this analysis, we collect samples after homogenization of ALPS treated water every time the measurement/confirmation facility is fully filled with ALPS treated water, and all nuclides to be measured in ALPS treated water (the 29 nuclides subject to measurement and assessment when ALPS treated water is discharged into the sea, tritium, and not including other nuclides subject to removal by ALPS, except for the 29 nuclides) are analyzed and assessed[47]. From the analysis results, we verified that:

- The sum of the ratios to regulatory concentrations limits[48] of the concentrations of 29 nuclides subject to measurement and assessment for discharge of ALPS treated water into the sea nuclides excluding tritium falls below 1, which is the regulatory standard
- This is the basis for the determination of the flow rate of the ALPS treated amount to be diluted and discharged based on the measured tritium concentration to surely make the concentration after dilution less than 1,500Bq/L, which is the concentration specified in the fundamental policy of the government.

Therefore, the homogeneity of ALPS treated water stored in the measurement/confirmation facility is extremely important for securing the representativeness of collected samples. The measurement/confirmation facility where samples are collected consists of three tank groups each of which consists of 10 tanks with capacity of about 1,000 m^3 connected by connecting piping so that they can be managed uniformly. For each tank group, the circulation/stirring facility is installed to stir and circulate the ALPS treated water stored in the tanks for homogenization. By operating the facility properly, we secure the representativeness of samples.

Samples are analyzed by TPT analysts in the chemical analysis building installed in the site of the FDNPS and planned to be expanded in the future (See Table 9-2). In addition, the mechanism for multiple parties to verify the analysis result has been established involving the analysis institute we designated as a third party; an analysis laboratory designated as a third

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[47] Some of the nuclides to be measured take time and actually took about two months for the measurement and assessment in the secondary treatment performance verification test (We are considering how to shorten the required time). Therefore, we plan to secure the storage capacity of about 10,000 m^3 (amount generated in 2 months (150 m^3/day)) as the capacity of the measurement/confirmation facility.

[48] See Reference A “Site boundary dose assessment of Fukushima Daiichi Nuclear Power Station and the regulatory concentration limit in the Japanese laws”

party by the government; and the IAEA laboratories and the analysis laboratories of the member countries specified by the IAEA as a part of review of discharge of ALPS treated water. The results are also planned to be announced.

Table 9-5 shows the measurement and assessment method of each nuclides in the measurement/confirmation facility. Table 9-6 shows the minimum limit value and compliance method of each nuclide

Table 9-5 Measurement and assessment methods of each nuclide

	No.	Nuclide	Measurement object	Measurement or assessment method
	-	Tritium (FWT)	β^-	Isolated by distillation, mixed scintillator and counted by low-back liquid scintillation counter
ALPS treated water Target nuclides for Measurement/assessment during Discharge into the sea	1	C-14	β^-	Converted to CO_2, collected and isolated on absorbent, mixed with a scintillator, and counted by a low back liquid scintillation counter.
	2	Mn-54	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	3	Fe-55	X	Isolated with resin, mixed with scintillators, counted by Ge detector for low-energy γ-rays and X-rays
	4	Co-60	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	5	Ni-63	β^-	Isolated with resin, mixed with scintillators, and counted with a low-back liquid scintillation counter
	6	Se-79	β^-	Isolated with resin, mixed with scintillators, and counted with a low-back liquid scintillation counter
	7	Sr-90	β^-	Isolated with resin, precipitated and recovered, mounted, and counted with the β nuclide analyzer in stainless steel dish
	8	Y-90	-	[Evaluation value] Concentration assessment as radioactive equilibrium with Sr-90
	9	Tc-99	Mass	Samples are diluted with dilute nitric acid and counted with the inductively coupled plasma mass spectrometry (ICP-MS).
	10	Ru-106	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	11	Sb-125	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	12	Te-125m	-	[Evaluation value] Concentration assessment as radioactive equilibrium with Sb-125
	13	I-129	Mass	Samples were counted with the inductively coupled plasma mass spectrometry (ICP-MS) after adjusting to iodate ion by the addition of reagents.
	14	Cs-134	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	15	Cs-137	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	16	Ce-144	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	17	Pm-147	-	[Assessed value] Assessed from the measured value of the radioactive concentration of congener Eu-154 and the calculated nuclide abundance ratio.
	18	Sm-151	-	[Assessed value] Assessed from the measured value of the radioactive concentration of congener Eu-154 and the calculated nuclide abundance ratio
	19	Eu-154	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
	20	Eu-155	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.

	No.	Nuclide	Measurement object	Measurement or assessment method
	21	U-234	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	22	U-238	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	23	Np-237	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	24	Pu-238	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	25	Pu-239	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	26	Pu-240	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	27	Pu-241	-	[Evaluation value] Assessed from the total α discrete value and the isotopic ratio of Pu-238
	28	Am-241	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
	29	Cm-244	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
Other nuclides subject to ALPS Removal		Fe-59	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Co-58	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Zn-65	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Rb-86	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Sr-89	β^-	Isolated with resin and recovered from sedimentation are mounted and counted by β nuclide analyzer in a stainless steel dish.
		Y-91	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Nb-95	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Ru-103	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Rh-103m	-	[Evaluation value] Concentration assessment as radioactive equilibrium with Ru-103γ
		Rh-106	-	[Evaluation value] Concentration assessment as radioactive equilibrium with Ru-106
		Ag-110m	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.

	No.	Nuclide	Measurement object	Measurement or assessment method
		Cd-113m	β^-	Isolated with resin, mixed with scintillators, and counted with a low-back liquid scintillation counter
		Cd-115m	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Sn-119m	-	[Evaluation value] Assessed from the measured value of the radioactive concentration of Sn-123 and the calculated nuclide abundance ratio
		Sn-123	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Sn-126	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Sb-124	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Te-123m	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Te-127	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector, and evaluated using the half-life of the parent nuclide (Te-127m).
		Te-127m	-	[Evaluation value] Assessed from the measured value of the radioactive concentration of Te-127 and the calculated nuclide abundance ratio
		Te-129	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector., and evaluated using the half-life of the parent nuclide (Te-129m).
		Te-129m	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Cs-135	-	[Evaluation value] Assessed from the measured value of the of the calculated nuclide abundance ratio
		Cs-136	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Ba-137m	γ	[Evaluation value] Concentration assessment as radioactive equilibrium with Cs-137
		Ba-140	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Ce-141	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Pr-144	-	[Evaluation value] Concentration assessment as radiation equilibrium with Ce-144, using half-life of parent nuclide (Pr-144m)
		Pr-144m	-	[Evaluation value] Concentration assessment as radioactive equilibrium with Ce-144
		Pm-146	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Pm-148	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Pm-148m	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Eu-152	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Gd-153	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Tb-160	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Am-242m	-	[Evaluation value] Assessed from the isotopic ratio of Am-241
		Am-243	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides

	No.	Nuclide	Measurement object	Measurement or assessment method
		Cm-242	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
Target nuclides to be monitored (Reference) *		Cl-36	β-	Sedimentation with silver chloride, mixed with scintillator, counted by low-back liquid scintillation counter, or counted by β-nuclide analyzer
		Nb-93m	γ	Isolated with resin and counted by Ge detector for low-energy γ and X rays
		Nb-94	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.
		Mo-93	γ	Isolated with resin and counted by Ge detector for low-energy γ-rays and X rays
		Cd-113m	β-	Isolated with resin, mixed with scintillators, and counted with a low-back liquid scintillation counter
		Ba-133	γ	Homogenized sample is collected in marinelli containers and counted by a Ge detector.

*Target nuclides to be monitored is out of scope of source monitoring.

Table 9-6 Target detection limit and compliance method of each analyzed nuclide

Nuclide	Analysis method	Target minimum limit of detection value[49]	Applicable technique
γ-ray emitting nuclides	Samples are dispensed in a Marinelli container and measured with a Ge semiconductor detector.	0.07Bq/L Set in Cs-137[50]	Series of Radioactivity Measuring Methods. No. 7 (Gamma ray spectrometry with germanium semiconductor detector)
Sr-89/90	Sr was refined by Sr resin, precipitated and recovered as carbonate, and measured with a β-nuclide analysis equipment.	0.04Bq/L Set in Sr-90[51]	JAEA-Technology2009-051 (Simple and rapid analytical method for nuclides, contained in waste from research facilities, etc. (analytical guidelines))
I-129	Hypochlorous acid was added to the sample to adjust it to iodic acid ion, and then measured with an inductively coupled plasma mass analysis equipment.	0.2Bq/L	Series of Radioactivity Measuring Methods. No. 32 (Method for rapid analysis of iodine 129 in environmental samples)
Tritium	After mixing the sample from which impurities have been removed by distillation with the scintillator, measurement is performed with a low back liquid scintillation counter.	30Bq/L	Series of Radioactivity Measuring Methods. No. 9 (Tritium analysis method)
C-14	The sample is heated by adding concentrated nitric acid and potassium persulfate, and the generated CO2 is collected in an absorbent, mixed with a scintillator, and measured by a low back liquid scintillation counter.	10Bq/L	Series of Radioactivity Measuring Methods. No. 25 (Radiocarbon Analysis Method) JGC: Radiochemical Analysis of Radioactive Waste
Tc-99	The sample is diluted with nitric acid and measured with an inductively coupled plasma mass spectrometer.	2Bq/L	Radioactive waste management funding and research center: Research on upgrading and streamlining of radiochemical analytical technique
Total-α radioactivity	After α-nuclide is coprecipitated with iron hydroxide and iron is removed by extraction, it is evaporated to dryness and then baked to the stainless plate, and measured with an α automatic measuring device	0.04Bq/L	Manual of standard procedures for analysis of radioactive effluents and gases from Tokai Works of Power Reactor and Nuclear Fuel Development Corporation
Cd-113m	Cd is refined and recovered by ion exchange, mixed with a scintillator, and measured by a low back liquid scintillation counter.	0.2Bq/L	Analytical Chemistry, vol.63, No. 4. (Review of Analysis method with β-rays measurement method using low back liquid scintillation counter for ^{113m}Cd in stagnant water in FDNPS)

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[49] Value for each nuclide set to confirm that the sum of the ratios to regulatory concentrations limits is less than 1

[50] Other nuclides vary with baseline, interfering nuclides, background and gamma ray emission rate

[51] Sr-89 varies with Sr-90 concentration

Nuclide	Analysis method	Target minimum limit of detection value[49]	Applicable technique
Ni-63	Ni is refined and recovered by Ni resin, mixed with a scintillator, and measured by a low back liquid scintillation counter.	20Bq/L	JAEA-Technology2009-051 (Simple and rapid analytical method for nuclides, contained in waste from research facilities, etc. (analytical guidelines))

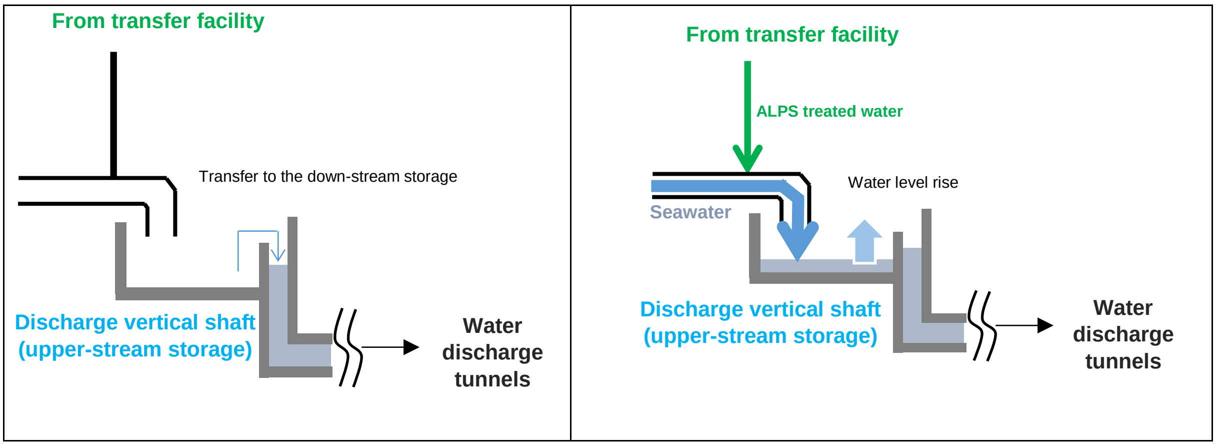
9-2-2. Monitoring at the discharge vertical shaft (upper-stream storage)

ALPS treated water to be discharged into the sea is treated by ALPS until the sum of the ratios to regulatory concentrations limits of nuclides excluding tritium fall below 1, in order to ensure the safety of ALPS treated water to be discharged into the environment.

On the other hand, to the extent of the available knowledge, ALPS treated water, etc., contains 0.15 to 2.16 million Bq/L of tritium, which exceeds the regulatory concentration limit (60,000 Bq/L), which is the upper limit on the discharge into the environment specified by laws. In addition, the Basic Policy of the government in April 2021 stipulates that the tritium concentration be less than 1,500 Bq/L as with the groundwater bypass and subdrain. In response to it, we decided to dilute ALPS treated water, etc., with a lot of seawater before discharge in order to meet the regulatory concentration limit and dispel concerns of consumers, etc., as much as possible for minimization of reputation damage.

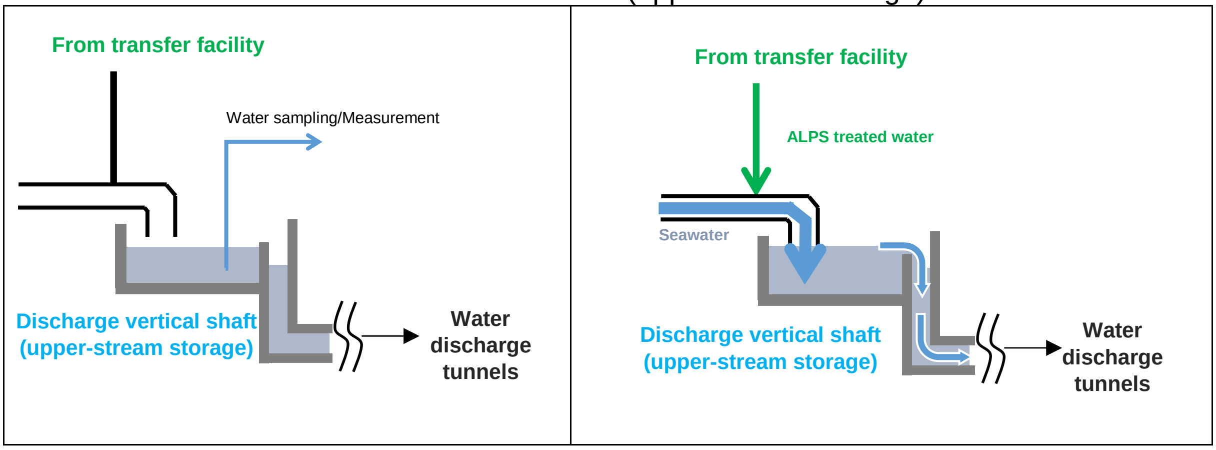
Tritium is a nuclide that emits week beta rays, which cannot be monitored continuously, unlike gamma rays from Cs-137. Therefore, the appropriateness of dilution is verified by collecting samples and measurement with the liquid scintillation counting device.

To start discharge into the sea, for the time being, we will verify that appropriate dilution is performed by the dilution facility by the procedure shown in Figure 9-4 below and the tritium concentration is less than 1,500 Bq/L at the discharge vertical shaft (upper-stream storage) immediately before discharge into the environment, for each type of ALPS treated water (about 10,000 m^3/tank group) of which sum of the ratios to regulatory concentrations limits of 29 nuclides other than tritium is less than 1 by the analysis and assessment by the measurement/confirmation facility (See 9-2-1).



(1) Empty the discharge vertical shaft (upper-stream storage).

(2) Store ALPS treated water transferred by the transfer facility and diluted by the dilution facility, in the discharge vertical shaft (upper-stream storage).



(3) Stop the pump before the discharge vertical shaft (upper-stream storage) is fully filled with water, and collect and measure sample water in the discharge vertical shaft (upper-stream storage) (suspend the discharge until the result is given).

(4) Verify that the actual concentration is comparable to the calculated tritium concentration and less than 1,500 Bq/L.

(5)Continuously moving to step 2, Activate two or more seawater pumps. After getting stable volume of seawater flow, continuously discharge the water into the sea by activating the transfer pumps of ALPS treated water as the step 2. Stored water in the discharge vertical shaft (upper-stream storage) in step 1 will be drained into the discharge facility.

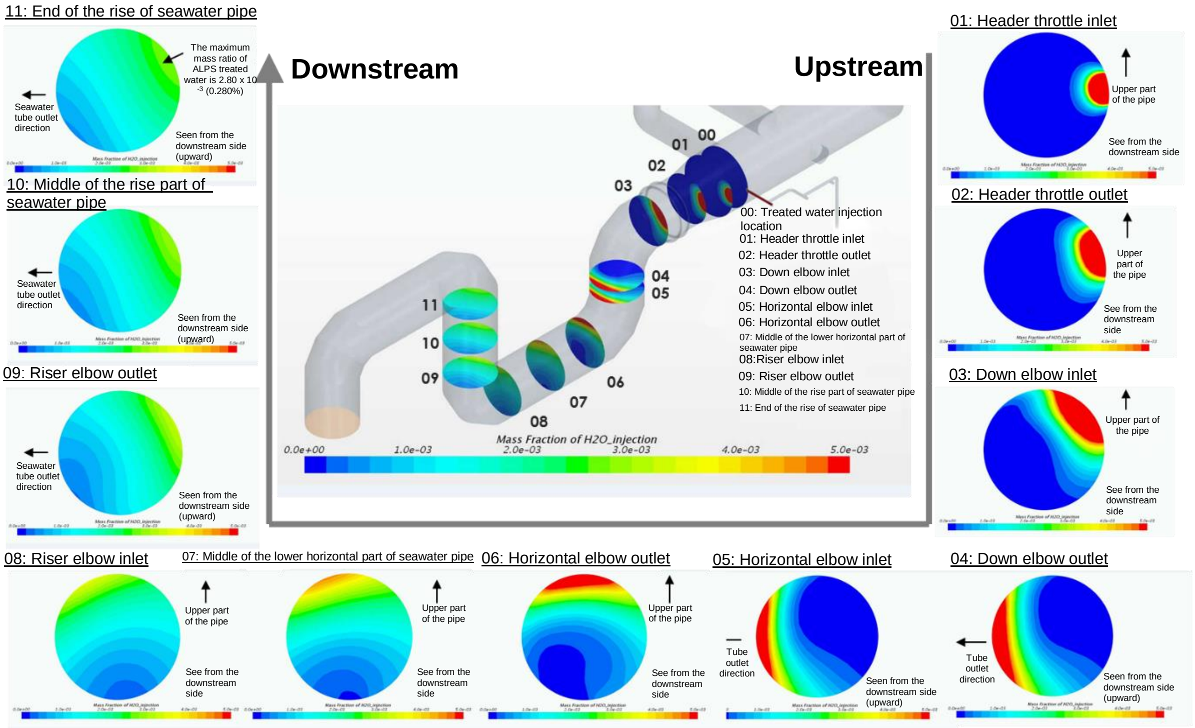
Figure 9-4 Analysis and discharge procedure at the discharge vertical shaft (upper-stream storage)

9-2-3. Monitoring in seawater piping

After verification of the appropriateness of dilution described in 9-2-2. above, dilute the remaining ALPS treated water (about 10,000 m^3/tank group), transfer it to the discharge vertical shaft (upper-stream storage), and discharge it continuously or intermittently. The capacity of the ALPS treated water transfer pump is 500 m^3/day. Considering the capacity of each tank group of the measurement/confirmation facility (about 10,000 m^3/tank group), it takes about 20 days to discharge the whole of the remaining ALPS treated water measured even by continuous discharge.

Collect samples every day by the sampling facility installed in the seawater piping, analyze the tritium concentration, and, in principle, announce the result on the following day, in order to verify the appropriateness of dilution of tritium during this discharge period.

To verify whether appropriate dilution mixing is performed in the seawater piping, mass concentration of injected ALPS treated water in each section of piping was calculated by fluid analysis (seawater flow rate of 340,000 m^3/day and ALPS treated water flow rate of 500 m^3/day, the theoretical mass concentration of 0.14%). As a result of the assessment, it was verified that 100 or more times higher dilution effect than the target of this facility was obtained at 04: Down elbow outlet in Figure 9-5 in the downstream side from the ALPS treated water injection position.



Name	Maximum concentration value at the section (%)
00: Treated water injection location	100
01: Header throttle inlet	14.26
02: Header throttle outlet	4.16
03: Down elbow inlet	1.79
04: Down elbow outlet	0.90
05: Horizontal elbow inlet	0.84
06: Horizontal elbow outlet	0.71
07: Middle of the lower horizontal part of seawater pipe	0.46
08:Riser elbow inlet	0.37
09: Riser elbow outlet	0.33
10: Middle of the rise part of seawater pipe	0.30
11: End of the rise of seawater pipe	0.28

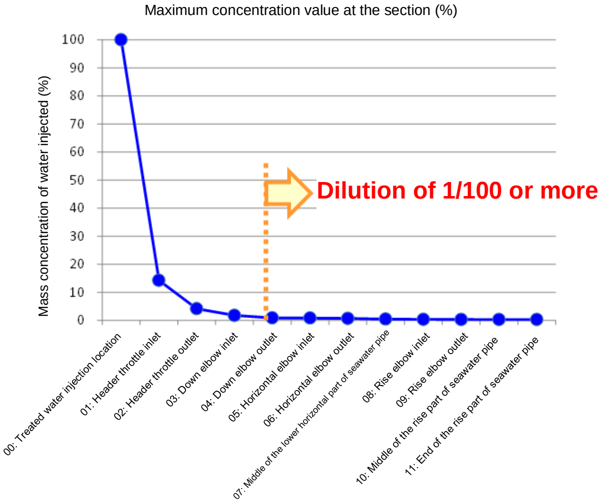


Figure 9-5 Fluid analysis result regarding dilution mixing in the seawater piping

9-3. Monitoring outside of the premises of the Fukushima Daiichi Nuclear Power Station

After the accident at the FDNPS, the “Monitoring Coordination Meeting” was set up under the Nuclear Emergency Response Headquarters of the government and the “Comprehensive Radiation Monitoring Plan” was formulated in August 2011 for secure and planned implementation of find monitoring about the environment[52]. Based on this plan, we have been monitoring mainly Cs-134, Cs-137, and Sr-90 in the sea area for the purpose of ascertaining the states of diffusion and advection of radioactive materials discharged into the environment, etc., in cooperation with each monitoring executing body such as the related ministries, local governments, and us (hereinafter called “implementation entity”). The Comprehensive Radiation Monitoring Plan defines the division of roles of each implementation entity and each implementation entity has been fulfilling their roles according to the definition.

After the announcement of the Basic Policy on handling of the ALPS treated water in April 2021, each implementation entity has considered enhancement and expansion of sea area monitoring (See 9-3-1 and 9-3-2). We recognize that in discharging ALPS treated water into the sea, it is important to enhance and expand sea area monitoring from the viewpoints of compliance with legal regulatory standards, etc., and actions based on international laws and practices, as well as prevention of reputation damage, dispelling of concerns of people inside and outside Japan, and deepening of understanding. Our consideration result was reflected in the Comprehensive Radiation Monitoring Plan at the Monitoring Coordination Meeting held on March 30, 2022.

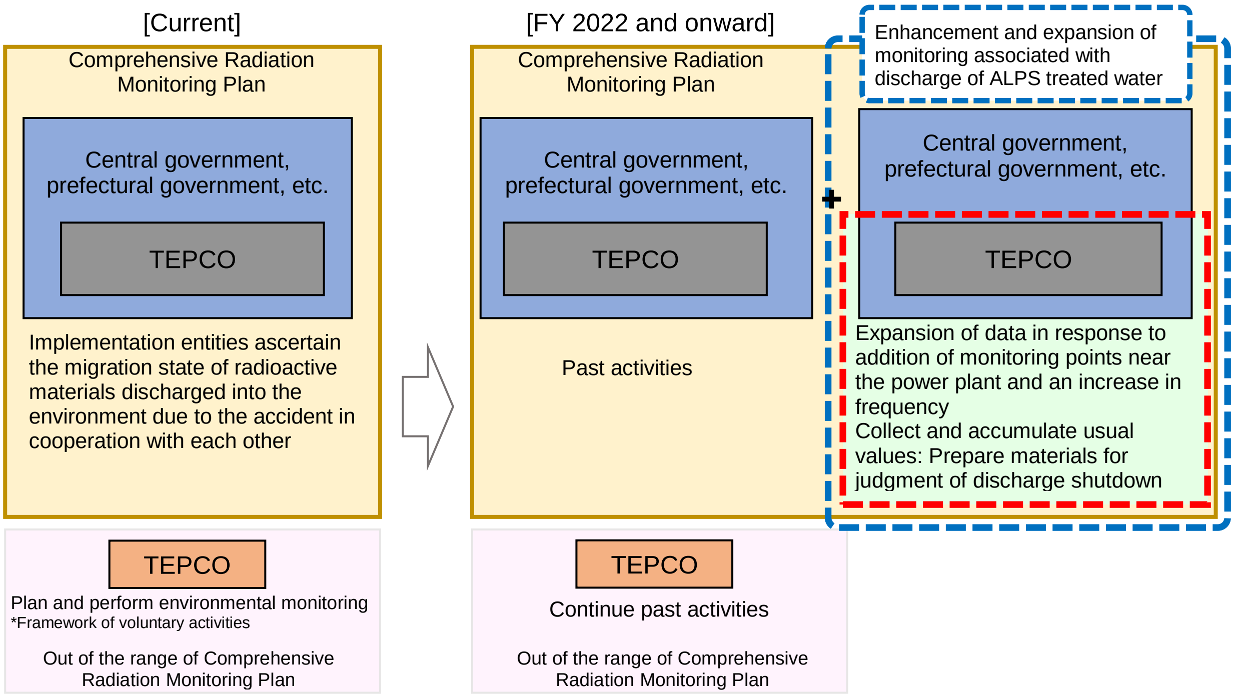


Figure 9-6 Position of sea area monitoring by each implementation entity

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[52] Monitoring Coordination Meeting of the Nuclear Emergency Response Headquarters (revised on March 30, 2022) https://radioactivity.nsr.go.jp/en/list/274/list-1.html

Figure 9-6 shows the position of monitoring by each implementation entity. Each monitoring implementing by TEPCO outside the port of FDNPS is stipulated in governmental comprehensive monitoring plan. However, the monitoring within the port of FDNPS and the premises are not given status under the said plan and TEPCO itself conduct it. We will conduct monitoring in the port and premises to confirm environmental impact by the discharge of ALPS treated water into the sea.

The following shows the monitoring plan conducted and to be performed in the future outside the port of FDNPS by each implementation entity as of the end of March 2022.

9-3-1. Sea area monitoring around outside the port of Fukushima Daiichi Nuclear Power Station by TEPCO

In the past, we performed the following monitoring as a part of the total monitoring plan.

Table 9-7 Overview of our sea area monitoring based on the past total monitoring plan

Target	Target nuclide	Measurement frequency (depending on the location and nuclide)
Seawater	Cs-134/137, strontium, tritium, and plutonium	Every day or every six months
Seabed sediment	Cs-134/137, strontium, and plutonium	Every month or every six months
Fish, etc.	Cs-134/137	Once a month

Based on the Basic Policy of the government in April 2021, in the same month, we announced “TEPCO’s Action in response to Government’s Policy” including further enhancement and expansion of sea area monitoring in order to minimize reputation damage associated with discharge of ALPS treated water into the sea[53].

After that, we announced sea area monitoring (plan) in August 2021, as the executing body of discharge of ALPS treated water into the sea[54], and then assessed the state of diffusion of ALPS treated water by simulation in the radiological impact assessment in November 2021. We considered sea area monitoring for verification of the diffusion state and the migration state of radiological materials to fish and seaweeds in the sea area off the coast of Fukushima centering on the area adjacent to the FDNPS, in which the tritium concentration was assessed to change[55].[56]

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[53] TEPCO Holdings’ Action in Response to the Government’s Policy on the Handling of ALPS Treated Water from the Fukushima Daiichi Nuclear Power Station
https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210416_01.html

[54] Status of Review Regarding the Handling of ALPS Treated Water
https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210825e0101.pdf

[55] However, the change in the concentration is assessed to be 1 to 2Bq/L, which is as little as 1/10,000 to 1/5,000 of 10,000Bq/L, which is the WHO Guidelines for Drinking Water Quality.

[56] The sampling points are added from the diffusion simulation result in March 2020, and consequently the results showed this assessment requires no change. The frequency to ascertain usual values increased as well as enhance the verification of the state of migration to marine organisms

To continuously get data for comparison with the diffusion state and migration state after discharge, it is planned to formulate the sea area monitoring plan setting the detection limit in addition to the consideration result announced in August 2021. Understanding the environmental status before actual discharge is important to assess environmental impact after the beginning of the discharge. Therefore we started the implementation of the plan in April 2022 before starting discharge, for the purpose of understanding the variation range as a baseline monitoring. For this monitoring (sampling, radiation measurement, etc.), it is planned to ask agriculture, forestry and fisheries workers, related parties in local governments, etc. participate in and observe monitoring, and request an analysis by a third party organization specified by us and involvement of the IAEA as with source monitoring in order to secure objectivity and reliability of the monitoring result.
We have been monitoring not only the seawater but also fish and seaweeds to verify the state of migration of radioactive materials to marine plants and animals due to discharge.

As a result of considerations based on the results of this radiological environmental impact assessment, TEPCO selected sites and nuclides to be monitored in light of following points:

- The result of dispersion simulation shown that there was no area where the concentration is significantly higher than the value of the surroundings in every assessment point in this report, because dispersion was occurred quickly in the environment after the discharge at the discharge point.
- The concentration of each nuclide in the ALPS treated water is below the detection limit, except for the seven major nuclides, tritium, and C-14. In addition, the ALPS treated water containing those nuclides will be discharged from the outlet after being diluted more than 100 times, and the diluted water will be dispersed in the environment. Therefore, even if environmental distribution or concentration are considered, the concentration in environmental samples of these nuclides of which concentration in the treated water below the detection limit is very low, and even if the detection limit is lowered to a feasible extent, it is considered difficult to detect the concentrations.
- Therefore, it is appropriate to screen a wide range of nuclides to be monitored, focusing on those that are particularly easy to observe (in addition to H-3 and Cs-137, and I-129 which tends to accumulate in seaweed) among the detected nuclides described above, to be analyzed in detail if abnormal values are found.

We decided to enhance and expand sea area monitoring as follows. Figure 9-7 shows the details of enhancement and expansion of our sea area monitoring. The items shown below are implemented as part of the Government’s Comprehensive Radiation Monitoring Plan.

- Increase in measurement points and targets
    - Considering that we are the executing body of discharge of ALPS treated water into the sea, we decided to perform monitoring focusing on the area around the discharge outlet and added a total of 13 tritium measurement points of the seawater and marine organisms (fish) in the area near the FDNPS and the coast of Fukushima (See red and orange boxes in Figure 9-7).
    - For seawater monitoring, we added three new monitoring points on the boundary of the "area where no fishing is conducted on a daily basis" considered in this assessment of radiological impact on human and environment (See the red texts in Figure 9-7).
    - For fish, we currently analyze cesium, which is representative[57] in the measurement of radiological environmental impact, based on samples collected in 11 locations within 20 km off the coast of Fukushima (in one of which tritium analysis is still performed), and will analyze tritium in fish caught in a total of 11 locations including 10 new locations where currently tritium is not analyzed, in order to verify the impact of concentration of tritium (See orange boxes in the right figure in Figure 9-7). Tritium analysis is also performed for the seawater on the point.
    - We will collect and analyze seaweeds in two new locations outside the port as well as the location in the port where currently gamma nuclides are analyzed (See green boxes in Figure 9-7). We will add tritium to the measured nuclides, verify whether it concentrates, etc., and add iodine, which is easy to concentrate in seaweeds, to the measured nuclides.
    - We will continue the current measurements of nuclides other than tritium and I-129, of which measurements are to be enhanced and expanded (Cs-134, Cs-137, Sr-90, Pu-238, and Pu-239+240)[58].

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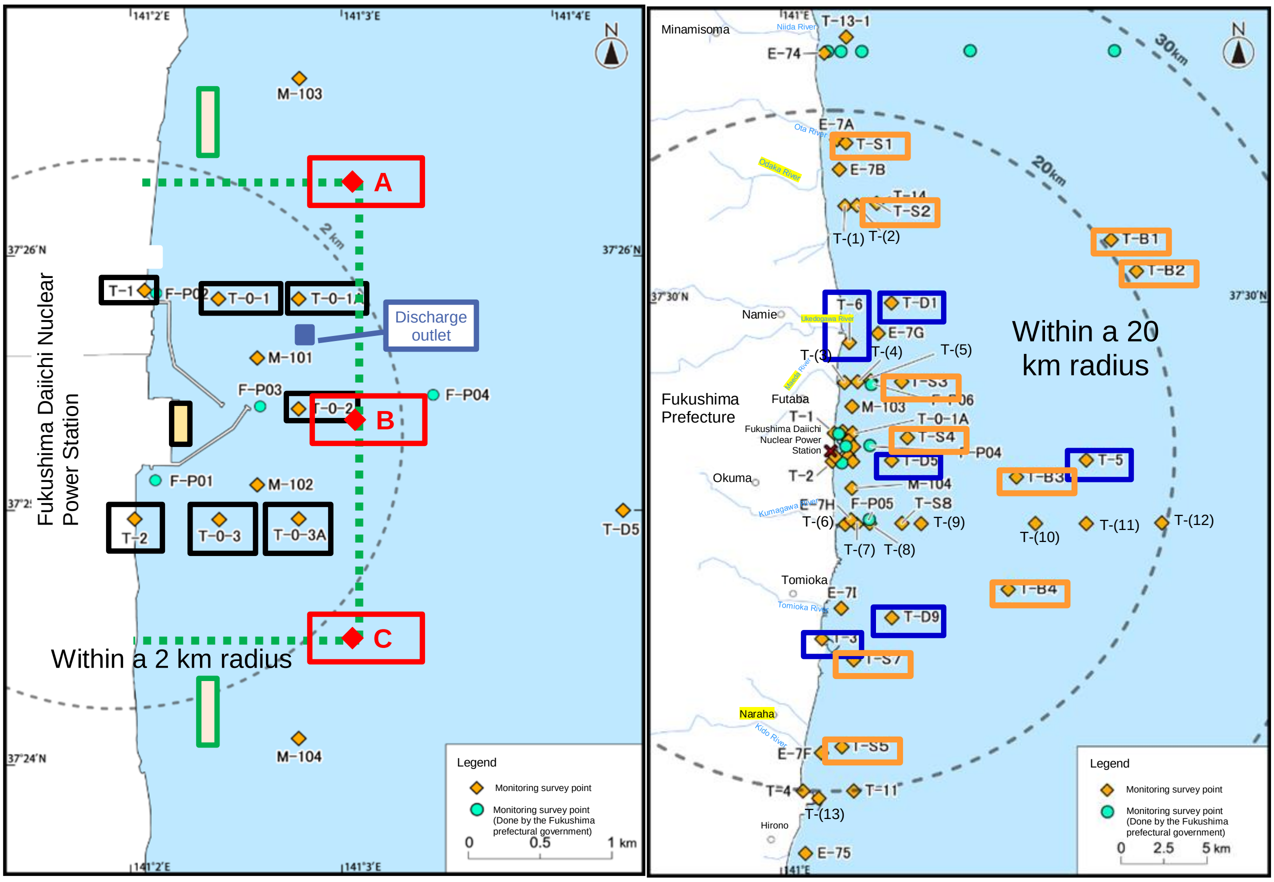
[57] This is because there are some nuclides which emit strong gamma rays.

[58] We shall perform monitoring of mainly tritium considering the migration and advection processes in the environment, but if any abnormality is found in the enhanced monitoring, we shall consider the necessity for additional monitoring of such nuclides and C-14.

- Increase in the frequency
  - As measurement points increase, the frequency is increased at points where tritium in the seawater has been measured (For measurement points, see blue boxes in Figure 9-7. For the frequency, see Table 9-9).
- The detection limit is set to match the target value set by the government
  - To verify the diffusion state of radioactive materials in the seawater and the state of marine organisms, the minimum limit values of detection of tritium and iodine 129 are reduced to be consistent with the target detection limit set by the government (For measurement points, see black boxes in Figure 9-7. For the detection limit, see Table 9-9)
- Response to exposure assessment at the nearest beach on the north side of the FDNPS
  - On the north side of the FDNPS, the monitoring of sea water and sediment has been conducted at the northern point of the discharge outlet of Unit 5 and 6 (T-1). Although monitoring at the nearest beach on the north side of the NPS is not yet planned, there is no special landform around the sand beach to accumulate tritium and the result of simulation revealed no tendency for higher concentration, the ongoing monitoring at the northern point of the discharge outlet of Units 5 and 6, where the impact of the discharge of ALPS treated water is considered to be relatively larger, is continued.



<Legend>

[Current total monitoring plan]
Nuclear Regulation Authority M-○
Ministry of the Environment E-○
Fisheries Agency (marine products)
Fukushima Prefecture F-○
TEPCO T-○

[Enhancement plan of TEPCO]

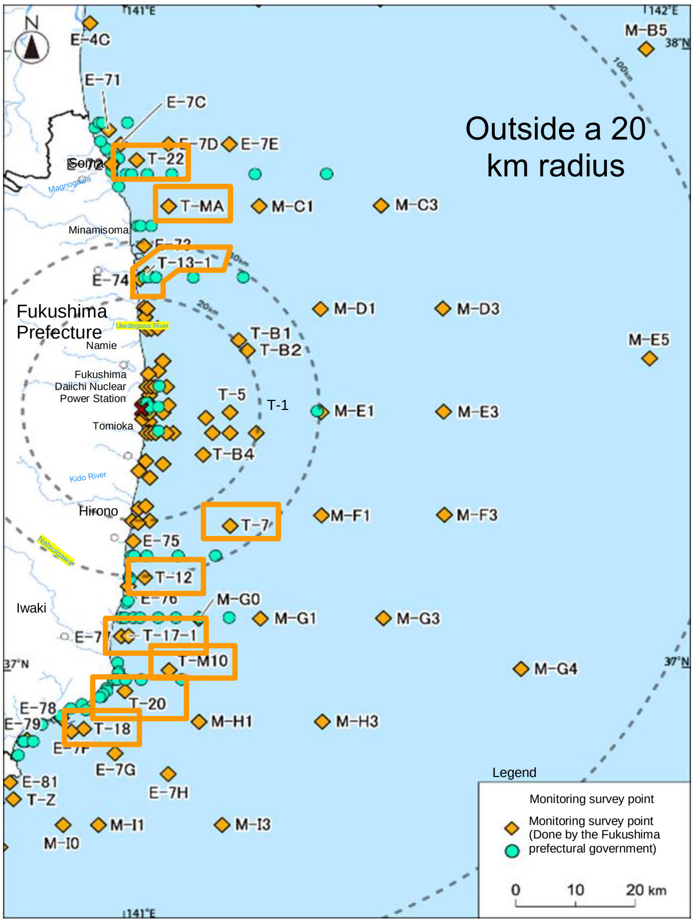
- ⬛ Points where the detection limit are to be revised (seawater)
- 🟥 New sampling points (seawater)
- 🟦 Points where frequencies are increased (seawater)
- 🟧 Points where tritium is analyzed in addition to cesium (seawater and fish)
- 🟨 Same points as before (seaweeds)
- 🟩 New sampling points (seaweeds)

⬚ An area where no fishing is conducted on a daily basis 1.5 km east to west, 3.5 km north to south

*: Areas where common fishery rights are not established

Figure 9-7 Sampling point of sea area monitoring enhanced and expanded by us (Near the FDNPS/Coast within a 20 km radius)

Moreover, we decided to perform monitoring in 9 new points even in “Outside the area of 20 km off the coast of the FDNPS,” in which tritium has not been analyzed and the concentration is estimated not to exceed the background of seawater in our marine diffusion simulation.



<Legend>
[Current total monitoring plan]
Nuclear Regulation Authority M-○
Ministry of the Environment E-○
Fisheries Agency (marine products)
Fukushima Prefecture F-○
TEPCO T-○

[Enhancement plan of TEPCO]
▭ : Point where tritium is analyzed in addition to cesium, which was analyzed before (seawater)

Figure 9-8 Sampling point of sea area monitoring enhanced and expanded by us (Coast outside a 20 km radius)

Based on the above, the frequency and the number of sampling points of tritium analysis in sea area monitoring by us increases as shown in Table 9-8 below compared to the previous sea area monitoring.

Table 9-8 Frequency and the number of sampling points of tritium analysis in sea area monitoring near the FDNPS and in the coastal sea area by us

Implementation entity	Tritium analysis			
	Measurement frequency	Number of samples		
		Seawater	Fish	Seaweeds
Tokyo Electric Power Company Holdings	Once a week	17 -> **20**	-	-
	Twice/month -> **Once a week**	6	-	-
	Once a month	1 -> **20**	1 -> **11**	-
	Three times/year	-	-	0 -> **2**

The detection limit is set as shown in the following table including the past analysis targets associated with enhancement and expansion of this sea area monitoring.

Table 9-9 Samples and nuclides to be measured, and detection limit (The parts in thick frames indicate the points to be enhanced and expanded)

Target	Sampling site	Number of samples	Nuclides to be measured	Measurement frequency	Target detection limit
Seawater (Surface layer)	Within the port	10	Cs-134/137	Every day	0.4 Bq/L
			Tritium	Once a week	3 Bq/L
	Outside the port Within a 2 km radius	2	Cs-134/137	Once a week	0.003 Bq/L
				Every day	1 -> **0.4** Bq/L
		5 -> **8**	Cs-134/137	Once a week	1 -> **0.4** Bq/L
		7 -> **10**	H-3	Once a week	1 -> **0.4** Bq/L[*1]
	Coast Within a 20 km radius	6	Cs-134/137	Once a week	0.003 Bq/L
			Tritium	Twice/month -> **Once a week**[*2]	0.4 -> **0.1** Bq/L[*3]
	Coast within a 20 km radius (fish catching point)	1	Tritium	Once a month	0.1 Bq/L
		0 -> **10**	**Tritium**	None -> **Once a month**	**0.1 Bq/L**
	Coast outside a 20 km radius	9	Cs-134/137	Once a month	0.003 Bq/L
		0 -> **9**	**Tritium**	None -> **Once a month**	**0.1 Bq/L**
Fish	Coast Within a 20 km radius	11	Cs-134/137	Once a month	10 Bq/kg (raw)
			Sr-90 (Only the top five samples in terms of the Cs concentration)	Quarterly	0.02 Bq/kg (raw)
		1	Tritium (FWT)	Once a month	0.1 Bq/L
			Tritium (OBT)		0.5 Bq/L
		0 -> **10**	**Tritium (FWT)**[*4]	None -> **Once a month**	**0.1 Bq/L**[*6]
			Tritium (OBT)[*5]		**0.5 Bq/L**
Seaweeds	Within the port	1	Cs-134/137	Once a year -> Three times/year	0.2 Bq/kg (raw)
	Outside the port Within a 2 km radius	0 -> **2**	**Cs-134/137**	None -> **Three times/year**	**0.2 Bq/kg (raw)**
			I-129		**0.1 Bq/kg (raw)**
			Tritium (FWT)		**0.1 Bq/L**
			Tritium (OBT)		**0.5 Bq/L**

*1: Get the value of detection by the electrolytic concentration method (concentration method making use of the characteristic of tritium being hard to be decomposed by an electric current) as needed.

*2: The measurement with the detection limit set to 0.1Bq/L is performed once/month

*3: Performed at 0.4Bq/L for the time being depending on the state of the installation of the electrolytic condenser.

*4: Tritium which exists as water in tissues of organisms. It does not remain in organisms for a long time.

*5: Tritium which is connected to tissues in organisms. It remains in organisms longer than organization free water.

*6: The measurement is performed at 0.4Bq/L for the time being depending on the state of the installation of the electrolytic condenser.

For all of these measurements, analyses by not only us but also a third party organization specified by us are performed to secure objectivity and transparency.
For the announcement of measurement data, we will perform the following activities to deepen understanding from inside and outside Japan.

- Announce the results of the measurement and assessment correctly and timely in our web site as soon as they are prepared.
- Announce data in a manner easy for local and domestic consumers to understand Moreover, describe the safety-related information regarding the announced measurement values.
- Prepare a report describing the monitoring result and the assessment, and plan to make it available in our web site, etc., every quarter.
- In the assessment, verify, for example, whether the result is within the marine diffusion simulation result, whether the result is equivalent to the concentration used for the radiological environmental impact assessment, etc., and express them in an easy-to-understand manner.
- Also plan to report the result in opportunities where related parties in local governments, etc. and academics confirm and assess it.

9-3-2. Monitoring by the government and Fukushima prefecture

(1) Previous sea area monitoring performed by the government and Fukushima

This section covers sea area monitoring by implementation entities other than us in the Comprehensive Radiation Monitoring Plan, namely the government (mainly the Ministry of the Environment, the Nuclear Regulation Authority, and the Fisheries Agency), Fukushima prefecture, etc. based on disclosed information. The relevant Ministries and Agencies started monitoring immediately after the accident and has been announcing the result[59] in cooperation with Fukushima, research institutes, fisheries cooperatives, etc., and reviewing the contents, measurement points, etc., of monitoring and announcing the result[60]. Table 9-10 shows the details of sea area monitoring by implementation entities other than us[61]. In the previous plan, sea area monitoring was performed for seawater, seabed sediment, and marine organisms in the following areas:

(1) Sea area vicinity of FDNPS (within about 3 km from the middle between the Unit 2 and 3 exhaust stacks)
(2) Coastal sea area (within about 30 km from the coastline from a part of Aomori and Iwate to Miyagi, Fukushima, and Ibaraki (including the estuary, excluding the vicinity sea area))
(3) Offshore sea area (sea area within about 30 to 90 km from the coastline)
(4) Ocean area (sea area within about 90 km to 300 km from the coastline)
(5) Tokyo Bay (bay about 200 km away from FDNPS)

Table 9-10 Previous sea area monitoring by implementation entities other than us

a. Seawater

Implementation entity	Measurement point	Measured nuclide	Measurement frequency (depending on the location and nuclide)
Government (mainly the Nuclear Regulation Authority and the Ministry of the Environment)	Vicinity sea area, coastal sea area, offshore sea area, ocean sea area, and Tokyo Bay	Cs-134/137, Sr-90, tritium	Every month to every year
Fukushima Prefecture	Vicinity sea area and coastal sea area	Cs-134/137, Sr-90, tritium, Pu-238/239+240	Every month
(Reference) Tokyo Electric Power Company HD	Vicinity sea area and coastal sea area	Cs-134/137, Sr-90, tritium, Pu-238/239+240	Every day or every six months

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[59] Radiation monitoring information
https://radioactivity.nsr.go.jp/en/

[60] Comprehensive Radiation Monitoring Plan
https://radioactivity.nsr.go.jp/en/list/191/list-1.html

[61] Attachment of the total monitoring plan formulated at the monitoring adjustment meeting, which is chaired by the Minister of the Environment
https://radioactivity.nsr.go.jp/en/contents/16000/15098/24/274_20210401_s.pdf

b. Seabed sediment

Implementation entity	Measurement point	Measured nuclide	Measurement frequency (depending on the location and nuclide)
Government (mainly the Nuclear Regulation Authority and the Ministry of the Environment)	Coastal sea area, offshore sea area, and Tokyo Bay	Cs-134/137	Every month to every year
Fukushima Prefecture	Vicinity sea area and coastal sea area	Cs-134/137, Sr-90, Pu-238/239+240	Every month to every six months
(Reference) Tokyo Electric Power Company HD	Vicinity sea area and coastal sea area	Cs-134/137, Sr-90, Pu-238/239+240	Every month to every six months

c. Marine organisms

Implementation entity	Measurement point	Measured nuclide	Measurement frequency (depending on the location and nuclide)
Government (Fisheries Agency and Ministry of the Environment)	Coastal sea area, offshore sea area, and ocean area	Cs-134/137	Every week to every three or four months
(Reference) Tokyo Electric Power Company HD	Coastal sea area	Cs-134/137	Every month

(2) Sea area monitoring enhanced and expanded by the government in response to discharge of ALPS treated water

In response to the Basic Policy of the government announced in April 2021, the future sea area monitoring was discussed at the Surveillance and Measurement Task Force of the sea area environment set up under the Monitoring Coordination Meeting, in which the relevant Ministries and Agencies such as the Nuclear Regulation Authority and the Ministry of Environment and the Sea Area Monitoring Expert Meeting on ALPS treated water set up under the Ministry of Environment. Then, the Comprehensive Radiation Monitoring Plan was revised at the Monitoring Coordination Meeting held in March 2022. They planned to enhance and expand the sea area monitoring before and after discharge of ALPS treated water such as setting of more sampling points within 10 km from the discharge outlet considering our discharge plan and the contents of this report[62]. The plan is as follows.

a. Seawater

(1) Perform monitoring to ascertain the variation of the tritium concentration in the sea area before and after discharge.

- There is considered to be almost no significant difference from the condition before discharge in a location about 10 km away from the discharge outlet

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[62] Material 1 of the monitoring coordination meeting (March 30, 2022) for enhancement and expansion of sea area monitoring by the government
http://www.env.go.jp/water/shorisui/monitoring/014/mat01.pdf

(The result of the diffusion simulation by TEPCO shows a possibility of a minor variation even in a location about 30 km away depending on the day)

- Set more sampling points within 10 km from the discharge outlet.
- To be on safeside, also perform monitoring at sampling points 30 km and 50 km away, offshore to the south of Miyagi, and offshore to the north of Ibaraki.
- Also perform monitoring at nearby swimming beaches.

(2) Basically, the measurement frequency of newly added points will be four times a year (considering seasonal variations). Immediately after discharge, the frequency of the measurement is increased including the bulletin figure with the detection limit raised.

(3) To be on safeside, measure the seven major nuclides (Cs-134, Cs-137, Co-60, Ru-106, Sb-125, Sr-90, and I-129) four times a year in some sampling points. In addition, perform it once a year for a wide range of related nuclides[63].

Table 9-11 shows the sea area monitoring plan for seawater of FY 2022.

Table 9-11 Sea area monitoring plan of the government for seawater enhanced and expanded

Target nuclide	Sampling point	Sampling depth[*1]	Analysis frequency	Target detection limit	Analysis method
Tritium	Near the discharge outlet (about 300m from the discharge outlet)	Surface layer/Bottom layer	Four times a year	0.1Bq/L[*3]	Electrolytic concentration method
	1 km to 10 km from the discharge outlet	Surface layer/Bottom layer	Four times a year	0.1Bq/L[*3]	Electrolytic concentration method
	About 30 km to 50 km from the discharge outlet, offshore to the south of Miyagi, and offshore to the north of Ibaraki	Surface layer/Bottom layer[*2]	Four times a year	0.1Bq/L[*3]	Electrolytic concentration method
	Bathing beaches (Two points in each of the north and south are selected considering the opening conditions)	Surface layer	Twice a year (before and during the season)	0.1Bq/L[*3]	Electrolytic concentration method
Seven major nuclides	Three points on the boundary with the area switch fishery rights (north, south, and east)	Surface layer/Bottom layer	Four times a year	Basically, follow the radioactivity measurement method series (Set the detection limit of Cs-134, Cs-137, and Sr-90 to 0.001Bq/L)	
Other related nuclides (basically 62 nuclides subject to removal by ALPS, and C-14)	Three points on the boundary with the area switch fishery rights (north, south, and east)	Surface layer/Bottom layer	Once a year	Basically, follow the radioactivity measurement method series (Set the detection limit of Cs-134, Cs-137, and Sr-90 to 0.001Bq/L)	

*1: Surface layer: Sea surface to about 2 m, Bottom layer: About 2 m to 5 m or 10 m to 40 m from the seabed depending on the water depth
*2: Surface layer only for sampling points shown by blue stars and green circles outside the 50 km radius
*3: A detection limit of about 0.05Bq/L (specifically 0.02-0.07Bq/L) was obtained from the result of the measurement of seawater consigned by the Nuclear Regulation Authority based on this target detection limit.

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[63] Basically C-14 and 62 nuclides subject to removal by ALPS.

b. Marine biota

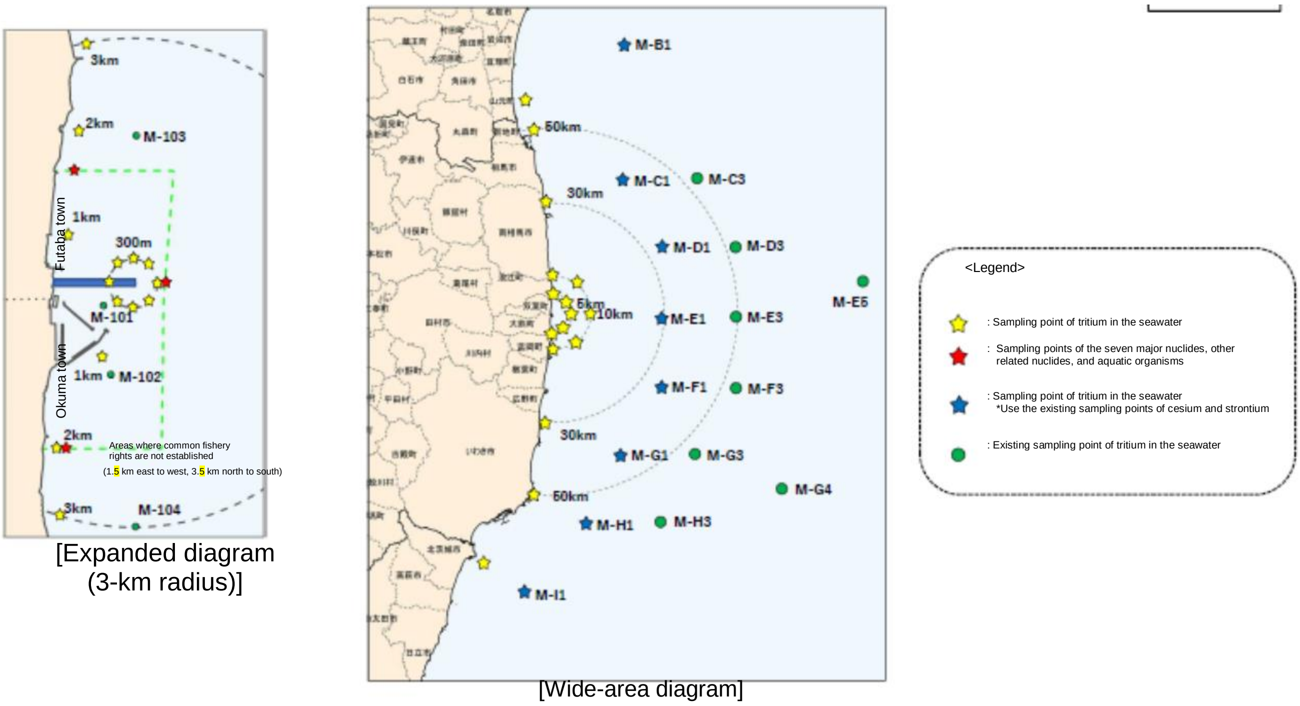
(1) Perform monitoring of tritium in marine biota (FWT and OBT) near the boundary with the area switch fishery right.
(2) Also perform monitoring at the same points as (1) for C-14 in fish and I-129 in seaweeds.

Table 9-12 and Figures 9-9 and 9-10 show the sea area monitoring plan for marine biota of FY 2022.

Table 9-12 Sea area monitoring plan of the government for marine biota enhanced and expanded

Target nuclide	Sampling point	Target organisms	Analysis frequency	Target detection limit	Analysis method
Tritium[*1]	Three points on the boundary with the area switch fishery rights (north, south, and east)	Fish (demersal fish)	Four times a year	FWT: 0.1Bq/L[*2] OBT: 0.5Bq/L	FWT: Electrolytic concentration method OBT: Distillation method
I-129	Three points on the boundary with the area switch fishery rights (north, south, and east)	Seaweeds	Four times a year	0.1Bq/kg (raw)	ICP-MS
C-14	Three points on the boundary with the area switch fishery rights (north, south, and east)	Fish (demersal fish)	Four times a year	2Bq/kg (raw)	Follow the radiation measurement series (beta ray analysis)

*1: Freeze-dry or burn aquatic organism samples to measure the concentration of tritium in water
*2: Aim to measure up to 0.05Bq/L, if possible



[Expanded diagram (3-km radius)]

[Wide-area diagram]

* Two additional sampling points of bathing beaches are to be set in the north and south sides, respectively

Figure 9-9 Sea area monitoring sampling point diagram of the government enhanced and expanded

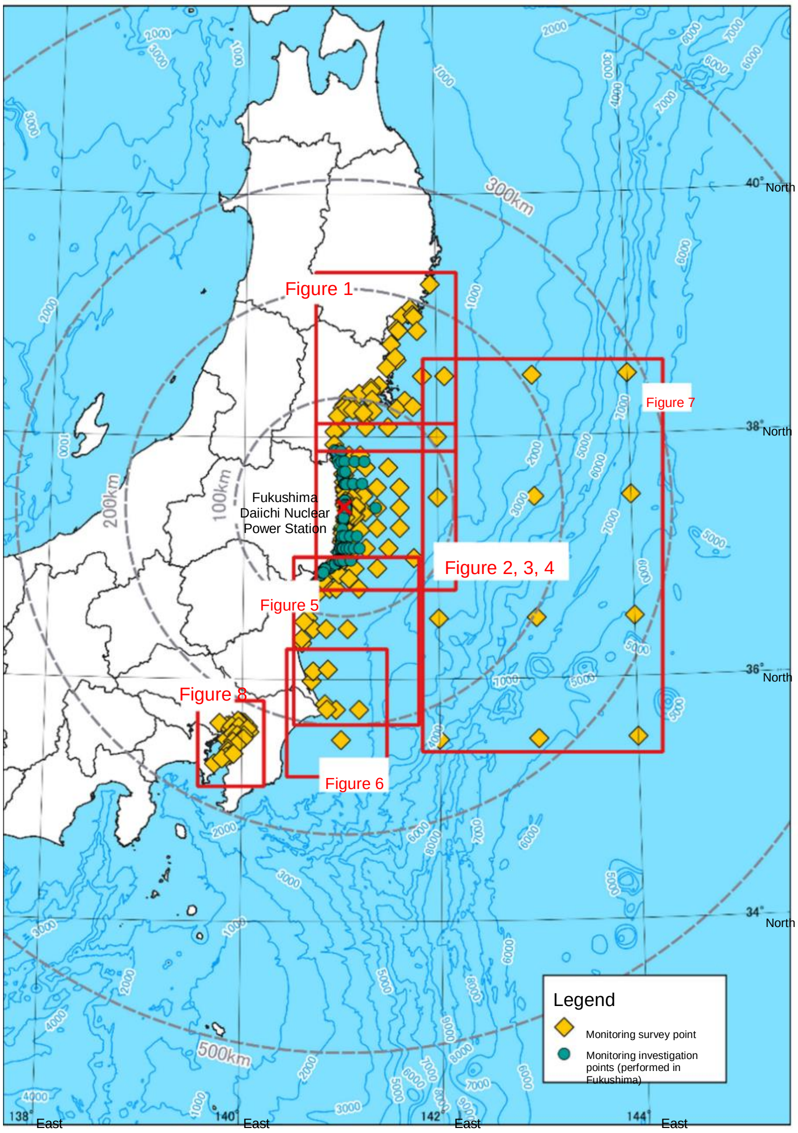


Figure 9-10 Sea area monitoring sampling point diagram enhanced and expanded (wide area)

(3) Seawater monitoring enhanced and expanded by Fukushima prefecture in response to discharge of ALPS treated water

In response to discharge of ALPS treated water into the sea, Fukushima prefecture is monitoring seawater in a wide observation area which consists a total of 9 locations, namely the existing 6 locations around the FDNPS and 1 additional location in each of the northern, eastern, and southern directions, as shown in Table 9-13 in the range where the concentration was assessed to be higher than the tritium concentration in the seawater in the surrounding sea water (0.1 to 1 Bq/L) considering the assessment of the advection and diffusion simulation in our report. Figure 9-11 shows the sampling points[64].

Table 9-13 Seawater monitoring in relation to ALPS treated water by Fukushima prefecture (FY 2-22)

Sampling point	Sampling depth	Analysis frequency	Measurement item	Target detection limit	Analysis method
Existing locations near the FDNPS (six locations)	Surface layer	12 times a year	γ-nuclides	Approx. 0.001 to 0.002Bq/L (Cs-134/137)	Based on the Series of Radioactivity Measuring Methods
			Tritium	Approx. 0.3 to 0.5Bq/L	
			Total-β	Approx. 0.01Bq/L	
Additional locations (3 locations)		Four times a year (Before discharge)	Sr-90	Approx. 0.0005Bq/L	
		12 times a year (After discharge)	Pu-238/239+240	Approx. 0.000003 to 0.00001Bq/L	

Table 9-14 shows the monitoring to be performed by Fukushima as other seawater monitoring not related to discharge of ALPS treated water into the sea.

Table 9-14 Other seawater monitoring (FY 2022)

Investigation type	Location	Number of points	Nuclides and frequency					
			γ-ray emitting nuclides	Tritium	Total-β radioactivity	Sr-90	Pu-238	Pu-239+240
Surveillance investigation around the nuclear power plant	Near the Fukushima Daiichi NPS	9 points	Existing points 12 times a year **Additional points Before discharge 4 times a year** **After discharge 12 times a year**					
	Near the Fukushima Daini NPS	2 points	Four times a year				Once a year	
	Comparison points	1 point	Once a year					
Port/Sea surface fishing ground investigation	Important port	3 points	12 times a year (Cs-134, Cs-137)	-	-	-	-	-
	Fishing ports	13 points		-	-	-	-	-
	Shallow fishing ground	7 points		12 times a year (6 points)		-	-	-
Bathing beach investigation	Bathing beach	13 points	Twice a year (Cs-134, Cs-137)	Twice a year (7 points)		-	-	-
Public water area investigation	Sea area	15 points (surface layer and bottom layer)	-	Twice a year	-	-	-	-

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[64] 35th Environmental Monitoring and Evaluation Sub-committee of the Safety Monitoring Council on Decommissioning of the Nuclear Power Station of Fukushima Prefecture Material 2-1, p.1 (Revised after discussion) http://www.pref.fukushima.lg.jp/uploaded/attachment/507135.pdf

Investigation type	Location	Number of points	Nuclides and frequency					
			γ-ray emitting nuclides	Tritium	Total-β radioactivity	Sr-90	Pu-238	Pu-239+240
Seawater monitoring associated with discharge of groundwater bypass water	Around the south discharge outlet at the Fukushima Daiichi	1 point	Four times a year (Cs-134, Cs-137)	Four times a year	-	-	-	-
Seawater monitoring associated with discharge of treated water of the subdrain and groundwater drain	Around the north discharge outlet at the Fukushima Daiichi	1 point	Four times a year (Cs-134, Cs-137)	Four times a year	-	-	-	-

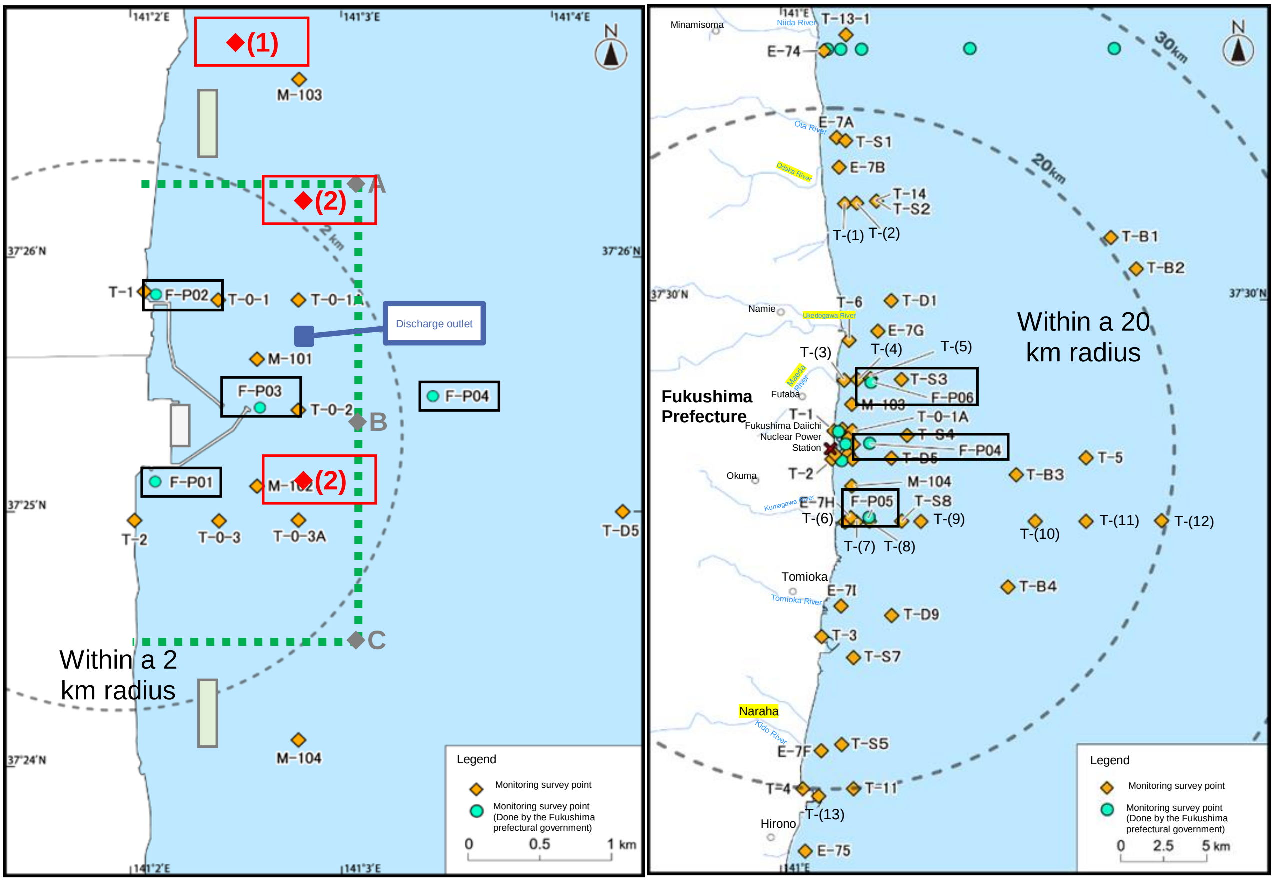

Figure9-11 Investigation points of seawater monitoring for ALPS treated water by Fukushima Prefecture

(4) Cooperation with the IAEA for sea area monitoring by the government and IAEA marine monitoring

Since 2014, the government has been conducting the IAEA Marine Monitoring with the aim of obtaining objective evaluation from the IAEA on the appropriateness of monitoring implementation methods and analytical capabilities of Japan's laboratories participating in sea area monitoring conducted by the government.

In the IAEA Marine Monitoring, samples of seawater, sediment off the coast of the FDNPS, and marine biota unloaded in Fukushima Prefecture which had been collected off the coast of the FDNPS were collected in the presence of the IAEA and occasionally from third-country laboratories. The samples were divided into analytical laboratories and analyzed individually, and an interlaboratory comparison (ILC) was conducted to compare the results. ILC Report (2017-2020)[65] published in August 2021 states that "Japan's sample collection procedures follow the appropriate methodological standards required to obtain representative samples" and "The results obtained demonstrate a continued high level of accuracy and competence on the part of the Japanese laboratories involved in the analyses of radionuclides in marine samples for the Sea Area Monitoring Plan." IAEA marine monitoring will be continued in the future.

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[65] IAEA, Preliminary Report 2021 Interlaboratory Comparisons 2017–2020: Determination of Radionuclides in Seawater, Sediment and Fish https://www.iaea.org/sites/default/files/21/07/preliminary-report-2021-interlaboratory-comparison-2017-2020-determination-of-radionuclides-in-seawater-sediment-and-fish.pdf

9-4. Actions to be taken in case of abnormalities

If any abnormal value in sea area monitoring described in 9-3 should be detected, the discharge into the sea should be suspended to confirm the results of other implementation entities and identify the cause.

The term “any abnormal value in sea area monitoring” is the case that to determine the state quickly the analysis results of tritium concentration in the sea is in the following status 1) or 2):

1) When values near the discharge outlet exceed the operating value for discharge in consideration with uncertainty of facilities and measurement that is set no more than 1,500Bq/L, which is the maximum value of tritium concentration specified by government Basic Policy.
2) When values that are clearly judged abnormal are detected from analysis result outside the area stated 1)

Sampling locations for above mentioned 1) and 2) should be chosen from the sampling locations in Comprehensive Monitoring Plan set based on the tritium dispersion simulation and an in-house manual will be created separately for items required for operation such as specific sampling locations, setting values to determine abnormality, and confirmation points for restart after pending water discharge into the sea.
Furthermore, when an abnormal incident is confirmed or determined under Comprehensives Monitoring Plan, the measurement will be taken as appropriately.
Therefore, we will accumulate the analysis results of sea area monitoring from April 2022 to ascertain them as usual values before discharge into the sea.

9-5. Summary of monitoring

As mentioned above, while the government, Fukushima prefecture and we are proceeding with sea area monitoring, the monitoring was enhanced and expanded before and after discharge of ALPS treated water. In case if any abnormal value is detected in enhanced and expanded sea area monitoring or any abnormal value is detected in monitoring in the future, we will make sure to stop discharge until it is verified that discharge can be performed safely.

10. Summary

For planned discharge of ALPS treated water into the sea in the FDNPS, the exposure assessment on human and environment is performed based on the current information (construction stage/ revised version).

The result of a calculation setting multiple source terms and multiple food ingestions assuming that 0.05mSv/year is equivalent to the dose constraint with the optimization based on the Basic Policy of the government in April 2021, shows the annual exposure amount of the set representative person 2E-06 to 3E-05mSv/year, which is much smaller than 1mSv/year, which is the dose limit to public shown in the ICRP recommendation, as well as 0.05mSv/year deemed by the Nuclear Regulation Authority to be equivalent to the dose constraint.

The result of a calculation setting multiple source terms for the impact on the environment as with the assessment for the human shows that the value for the reference plants and animals set based on the ICRP recommendation is 3E-07 to 8E-07mGy/day, which is much lower than 1 to 10mGy/day for flatfish and brown seaweeds and 10 to 100mGy/day for crabs, which as the derived consideration reference levels (DCRL) shown in the ICRP recommendation for the reference plants and animals.

Chapter 8 shows the uncertainty of this assessment result.

Even after discharge, TEPCO plans to review the assessment and revise this report as necessary to reflect the progress of studies on implementation, opinions from various sectors, and the knowledge obtained through cross-checks by third-party assessments, etc. and to reflect in the plan any other necessary items respectively

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Terms

Term	Description
Advanced liquid processing system (ALPS)	Water treatment facility which can purify 62 types of radioactive materials other than tritium contained in contaminated water up to a level which meets the standard set by laws. (Multi-Nuclide Removal Facility)
ALPS treated water	Water purified by ALPS, etc. so that the radioactive materials other than tritium surely fall below the regulatory standards for safety. (The sum of the ratios to regulatory concentrations limits of nuclides excluding tritium is less than 1)
Treated water to be purified	Water which is purified by ALPS, etc., but does not meet the regulatory standard for safety (The sum of the ratios to regulatory concentrations limits of nuclides excluding tritium is less than 1)
ALPS treated water, etc.	Generic term for ALPS treated water and treated water to be purified
Strontium treated water	Contaminated water with most of the cesium and strontium removed.
Secondary treatment	Purifying treated water to be purified in which radioactive materials other than tritium are not purified until the sum of the ratios to regulatory concentrations limits is less than 1 by ALPS, etc.
Groundwater bypass	Measure to reduce the amount of groundwater approaching the reactor building, etc., by pumping groundwater flowing from the mountain side to the sea side from a well far away from the reactor building, etc., and discharging it to the sea after verification that the discharge standard is met.
Subdrain	Measure to perform purification by pumping with the subdrain (well near the building) and discharge the sea after verification that the discharge standard is met, in order to reduce the amount of contaminated water increased by inflow of groundwater into the reactor building, etc.
Regulatory concentration limit	Standard of discharge of radioactive waste into the sea set in “Pronouncement which set the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials.” If the corresponding radioactive waste contains radioactive materials, the sum of the ratios to regulatory concentrations limits has to be less than 1.
Target discharge control value	Target control value set for each nuclide to be discharge in order to control the amount of radioactive materials discharged by the nuclear power plant per year. For the FDNPS, the target discharge control value of tritium before the accident is set to 22 TBq (2.2E+13Bq).
Operation and management value	Discharge limit value set by TEPCO for nuclides which for impacts on exposure are considered to be relatively great by the discharge of ALPS treated water. If any discharge over this is predicted, we consider to decrease the discharge amount of the nuclide.
WHO Guidelines for Drinking Water Quality	Guidelines for drinking water quality set by the World Health Organization for securing of the safety of drinking water. These guidelines show water quality which do not cause any problem when a person keep drinking the water from the viewpoints of radioactive materials, microorganisms, chemical substances, etc. As radioactive material concentrations, 10Bq/L and 10,000Bq/L are shown for Cs-137 and tritium, respectively.
International Commission on Radiological Protection (ICRP) recommendation	Document that shows the Basic Policy (concept) of radiation protection recommended by ICRP and the basic numerical standards.

Term	Description
International Atomic Energy Agency (IAEA) safety standard document	Document issued by the IAEA which shows the standards for protection of safety such as human health, lives, and assets in using radiation and radioactive materials as activities for securing nuclear safety. It consists of the safety principles, the safety requirements, the safety guidelines, etc., and shows the policy, the standards, etc., to follow. The IAEA safety standard document is prepared reflecting the comments of all IAEA member countries.
Representative person	Virtual person set as the target of exposure in the exposure assessment of public for consideration of radiation protection. Consider environments, life habits, etc., in which the exposure amounts increase, etc.
Potential exposure	Exposure caused by possible events in operation or events or possible events sequences including accidents of radiation sources or failures and operation mistakes of equipment. It was considered for the future. It is used for consideration of radiation protection.
An area where no fishing is conducted on a daily basis	Area where members of fisheries cooperatives jointly use a certain water area and rights to perform fishing (common fishery rights) are not established. Areas where common fishery rights are not established.
Area sea model	Numerical analysis model of tidal currents developed in Rutgers University in the U.S.
Submersion model	External exposure dose calculation model assuming the state that people are surrounded by radioactive materials (submersion).
Concentration factor	Expedient factor indicating the relationship between the radioactive nuclide concentration in marine organisms (per wet weight) in marine organisms (in principle, edible parts) and the radioactive nuclide concentration in the seawater in the environment where such organisms live, which is used for the assessment model for migration to organisms.
Dose conversion factor for the effective dose	Conversion factor to assess the human exposure amount from radiation from radioactive materials.
Effective dose factor	Conversion factor to assess the human internal exposure dose from the inhalation amount and ingestion of radioactive nuclides.
Environmental protection	Protecting organisms other than human from adverse effects of ionizing radiation.
Reference plants and animals	Specific types of animals and plants assumed in order to associate radiation exposure from the environment with the dose and impact.
Dose conversion coefficients for plants and animals	Conversion factor for simplified calculations of internal and external exposure doses to organism by radioactive nuclides in the environment.
Derived consideration reference level (DCRL)	Range of the dose rate with a range of one order of magnitude set for each species advocated by ICRP. Dose rate level at which the impact has to be considered if is exceeded. (Derived consideration reference level)
Concentration ratio	Migration factor from an empirical calculation of the ratio of the (overall) radioactive nuclide concentration in aquatic organisms to the underwater concentration in the environment to be used for radiation exposure to plants and animals from the environment.
Distribution coefficient	Ratio of radioactive materials at which the concentration in the seawater (Bq/L) and the concentration in the seabed sediment (Bq/kg) are in the equilibrium state. It is used for the assessment of migration of radioactive materials from the seawater to seabed sediment.

Preparation member (As of February 8, 2023)

For preparation of this report, in-house personnel with knowledge on the radiological impact assessment were appointed and external experts were invited as members in three fields, which are especially important for the radiological impact assessment: human radiation protection, environmental protection, and marine dispersion calculation.

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Junichi Matsumoto (Tokyo Electric Power Company Holdings, Inc.)

- Assessment member

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	Yutaka Tateda	(Guest Research Fellow, Sustainable System Research Laboratory, Central Research Institute of Electric Power Industry, marine animals and plants exposure assessment)
	Daisuke Tsumune	(Senior Research Scientist, Sustainable System Research Laboratory, Central Research Institute of Electric Power Industry, dispersion calculation)
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End

Attachment I Rationale behind the selection of nuclides subject to be measured and assessed for discharge of ALPS treated water into the sea

I-1. Overview

With regard to radionuclides other than tritium in ALPS treated water, the result of the analysis of the radioactivity concentrations of the seven major nuclides plus carbon 14 and technetium 99 in ALPS treated water, and the measured value of gross β shows no discrepancies that would raise suspicion regarding radionuclides except for radionuclides of the current 64 nuclides. In addition, some of the nuclides subject to removal by ALPS will be considered sufficiently decayed and become less abundant by the time of the discharge of ALPS treated water into the sea. Therefore, the sum of the ratios to regulatory concentration limits is considered to satisfy less than 1.

In order to ensure that the sum of the ratios to regulatory concentration limits is less than 1, target nuclides to be measured and assessed (hereinafter "nuclides to be measured and assessed") are selected after thorough verification whether they are significantly present in contaminated water based on domestic knowledge of decommissioning and disposal facilities.

The examination will be carried out in accordance with the flow (See Figure I-1), and a nuclide analysis and inventory assessment are planned to be performed. This document supplements the explanation about the nuclide analysis.

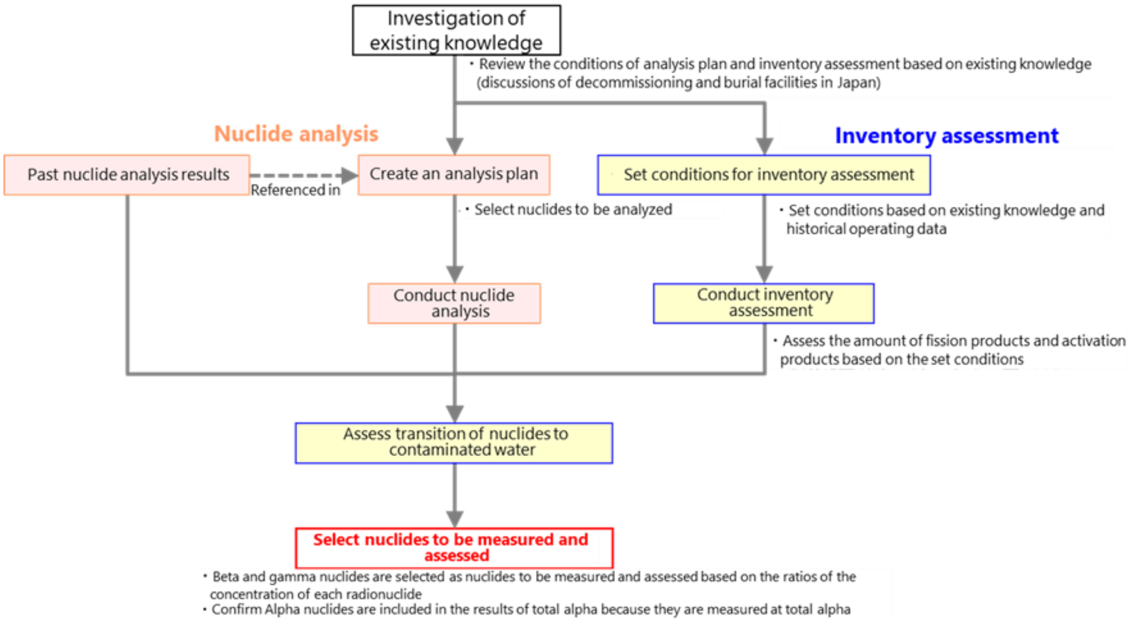


Figure I-1 Overall procedure for examining the selection of the nuclides to be measured and assessed

I-2. Selection of nuclides to be measured and assessed at the discharge of ALPS treated water to the sea

I-2-1. Policy on the selection of nuclides to be measured and assessed

For verification of nuclides which have possibility to be significantly contained in contaminated water at the FDNPS, nuclide analyses are conducted based on the domestic knowledge on decommissioning and disposal facilities are conducted and inventory assessments are conducted considering to the fuel and structural materials in Units 1 to 3.

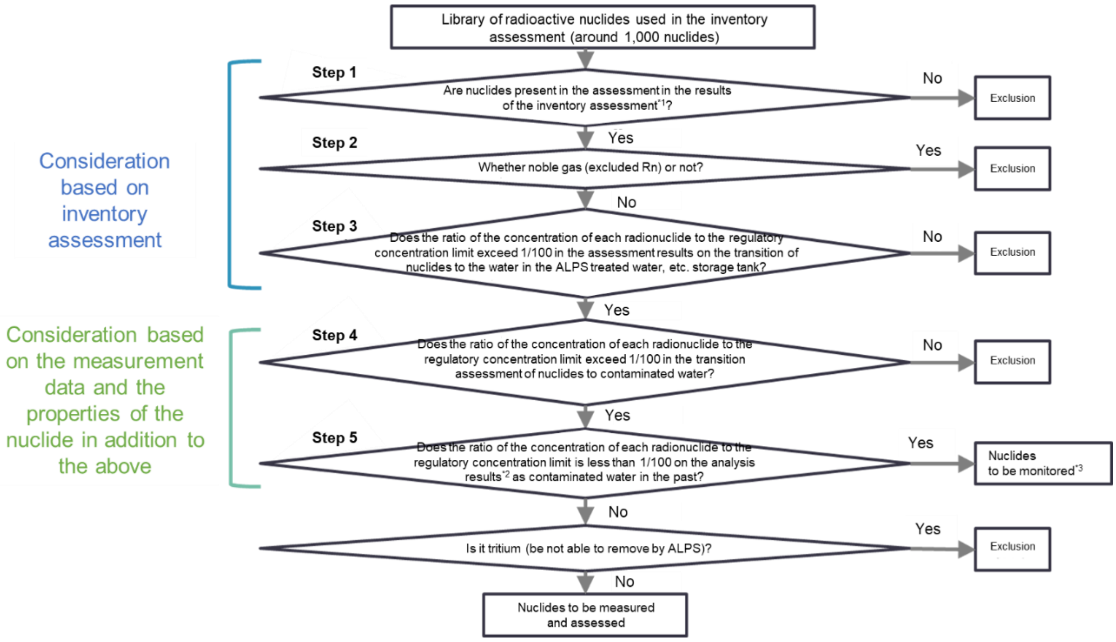
Table I-1 Elements considered in the selection of nuclides to be measured and assessed

Nuclide analysis
Verify whether or not the nuclides to be assessed in the research on decommissioning and disposal facilities are significantly present in contaminated water by actual analysis of water. Also verify the results of past nuclide analyses.
Inventory assessment
Assess an inventory of fission products in the same way as in the study of nuclides subject to removal by ALPS. Assess the inventory quantity generated by activation of such as structures in reactor pressure vessel based on the studies on decommissioning and disposal facilities. In the above assessments, taken into account the reduction of inventory quantity due to decay as the 12 years have passed since the earthquake until discharge. Based on the above assessment results, verify the existence of nuclides that may be significantly contained in contaminated water, taking into account such as the ease of transfer to water.

I-2-2. Selection of nuclides to be measured and assessed of ALPS treated water

(1) Rationale behind the selection of nuclides subject to be measured and assessed for discharge of ALPS treated water into the sea

Based on the results of nuclide analysis and inventory assessment in section I-2-1 above, the nuclides to be measured and assessed are selected according to the flowchart, shown in Figure I-2.



*1: The decay period of the inventory evaluation is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))

*2: Nuclides that have been detected in the past are confirmed by the maximum value of the detection value, and nuclides that have never been detected are confirmed by the minimum value of the detection limit value

*3: Nuclides that shall be continuously confirmed if significantly exists in contaminated water.

Figure I-2 Flow for selecting nuclides to be measured and assessed at the discharge of ALPS treated water into the sea

I-3. Nuclide analysis

I-3-1. Survey of past analysis results

So far, Japan Atomic Energy Agency (hereinafter referred to as “JAEA”) and TEPCO have analyzed 20 nuclides except for the nuclides (62 nuclides) to be removed by ALPS, tritium, and C-14 as shown in Table I-2.

A nuclide analysis plan has been laid out for examining the selection of nuclides to be measured and assessed, and in developing this plan, the results of past analyses were taken into account as well as previous studies to select nuclides subject to the nuclide analysis (hereinafter referred to as “nuclides for analysis”).

Table I-2 List of nuclides analyzed in the past

Fission products (56 nuclides)						
Rb-86	Sr-89	Sr-90	Y-90	Y-91	Nb-95	Tc-99
Ru-103	Ru-106	Rh-103m	Rh-106	Ag-110m	Cd-113m	Cd-115m
Sn-119m	Sn-123	Sn-126	Sb-124	Sb-125	Te-123m	Te-125m
Te-127	Te-127m	Te-129	Te-129m	I-129	Cs-134	Cs-135
Cs-136	Cs-137	Ba-137m	Ba-140	Ce-141	Ce-144	Pr-144
Pr-144m	Pm-146	Pm-147	Pm-148	Pm-148m	Sm-151	Eu-152
Eu-154	Eu-155	Gd-153	Tb-160	Pu-238	Pu-239	Pu-240
Pu-241	Am-241	Am-242m	Am-243	Cm-242	Cm-243	Cm-244
Corrosion products (6 nuclides)						
Mn-54	Fe-59	Co-58	Co-60	Ni-63	Zn-65	
Nuclides other than the above (2 nuclides)						
H-3	C-14					
Nuclides other than the 64 nuclides (20 nuclides)						
Cl-36	Ca-41	Ni-59	Se-79	Nb-94	Mo-99	Tc-99m
Te-132	I-131	I-132	La-140	U-233	U-234	U-235
U-236	U-238	Np-237	Pu-242	Cm-245	Cm-246	

I-3-2. Previous studies used in developing the analysis plan

To develop the nuclide analysis plan, the nuclides for analysis were selected from the nuclides pointed out in previous studies, which are shown below square chart, and applying the following criteria.

- Nuclides that have not been analyzed in the past or have not been analyzed sufficiently
- Nuclides that were not studied at the time of selecting nuclides to be removed by ALPS
- β and γ nuclides which, according to previous studies, exist in reactor water as activation products at a concentration 1/100 or more of the concentration of Co-60 in stagnant water
- α nuclides except nuclides whose concentration can be assessed by decay chain.

Even when nuclides fall under the above criteria, if they have a half-life of less than 1 year and reduced to about 1/1000 or less due to decay over 12 years up to discharge, those nuclides were excluded. On the other hand, even when nuclides do not fall under the above conditions, if it is possible to analyze them at external analysis organizations, some of them were included in the plan.

[Previous studies]

(1) Joint Electric Power Research Project "Study related to decommissioning of BWR nuclear reactor (Part 2)" (FY 1996)

(2) Tokai low-level radioactive waste burial facility, Type II waste disposal business license application "selection of major radioactive nuclides" (February 2018, Japan Atomic Power Company)

(3) Study data when JAEA examined nuclides for analysis to grasp 1F radioactive waste physical properties

- The upper three orders of magnitude for the nuclides with the highest relative importance D/C among the nuclides included in either the nuclear reactor waste or the cycle waste targeting trench disposal, pit disposal, and surplus depth disposal in "about the upper limit of activity concentration for burial disposal of low-level radioactive waste"
- Those selected as important nuclides in the "TRU waste disposal technology review report - second TRU waste disposal research and development report"
- Those selected as important nuclides in “technical reliability of geological disposal of high-level radioactive waste in Japan - second summary of research and development on geological disposal - general report”
- “Application for burying business license for Japan Nuclear Fuel Rokkasho low level radioactive waste storage center (near surface pit disposal) and JPDR (near surface trench disposal)”

I-3-3. Nuclides for analysis that have been identified based on previous studies (β and γ nuclides, etc.)

Based on the previous studies in paragraph I-3-2, β, γ and other nuclides for analysis were identified as shown in Table I-3.

Since it is currently difficult for TEPCO to measure the identified nuclides on their own, the measurement is planned to be commissioned to an external organization.

Table I-3 shows that the identified nuclides' energy is generally lower than that of the nuclides that are representative at FDNPS: Cs-137 (Ba-137m), 0.662 MeV (γ-rays); Sr-90 (Y-90), 2.28 MeV (β-rays).

Table I-3 Nuclides for analysis that have been identified based on previous studies (β and γ nuclides, etc.)

Candidate nuclides	Previous studies[1]	Disintegration form	Energy [MeV]	Regulatory concentration limit [Bq/cm^3]	Measuring method	Remarks
Cl-36	(1) (2) (3)	β-	0.709550	9.0E-01	After pretreatment (separation, precipitation), a low-background β-ray spectrometer	Has ever been analyzed by an external organization
Se-79	(1) (3)	β-	0.150630	2.0E-01	After pretreatment (separation, precipitation, and resolution), liquid scintillation counter	Has ever been analyzed by an external organization
Zr-93	(1) (2) (3)	β-	0.090800	1.0E+00	After pretreatment (separation), inductively coupled plasma mass spectrometer (ICP-MS)	—
Pd-107	(3)	β-	0.034000	2.0E+01		—
Ca-41	(1) (2) (3)	EC	0.003310	4.0E+00	After pretreatment (separation, precipitation, and resolution), Si (Li) detector	Has ever been analyzed by an external organization
Fe-55	(1) (2)	EC	0.005900	2.0E+00	After pretreatment (separation), low-energy photon measuring device (LEPS)	—
Ni-59	(1) (2) (3)	EC	0.006930	1.0E+01		—
Nb-93m	(2)	IT	0.016615	7.0E+00		—
Mo-93	(1) (2) (3)	EC	0.016615	3.0E-01		—
Sn-121m	(3)[2]	β- IT	0.359800 0.026359	2.0E+00		—
Ba-133	(1) (2)	EC	0.356013	5.0E-01	Germanium semiconductor detector (Ge)	—

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[1] Refer to the numbers in section I-3-2 "Previous studies."

[2] Selected because the study shows the nuclide is generated the most among Sn isotopes from zircaloy contained in cladding tubes, etc.

I-3-4. Nuclides for analysis that have been identified based on previous studies (α nuclides)

Based on the previous studies in paragraph I-3-2, α nuclides for analysis were identified as shown in Table I-4.

Since it is currently difficult for TEPCO to measure the identified nuclides on their own, the measurement is planned to be commissioned to an external organization.

The following nuclides were analyzed to identify α nuclides that may be contained in building stagnant water at significant concentrations.

Table I-4 Nuclides for analysis that have been identified based on previous studies (α nuclides)

Candidate nuclides	Previous studies[*2]	Disintegration form	Energy [MeV]	Regulatory concentration limit [Bq/cm^3]	Half-life [y]	Measuring method	Remarks
U-233	(3)	α	4.824200	2.0E-02	1.6E+05	After pretreatment (separation), inductively coupled plasma mass spectrometer (ICP-MS)	Has ever been analyzed by an external organization
U-234	(1) (3)	α	4.774600	2.0E-02	2.5E+05		Has ever been analyzed by an external organization
U-235	(1) (3)	α	4.395400	2.0E-02	7.0E+08		Has ever been analyzed by an external organization
U-236	(1) (3)	α	4.494000	2.0E-02	2.3E+07		Has ever been analyzed by an external organization
U-238	(1) (3)	α	4.198000	2.0E-02	4.5E+09		Has ever been analyzed by an external organization
Np-237	(1) (3)	α	4.788000	9.0E-03	2.1E+06		Has ever been analyzed by an external organization
Pu-238	(1) (2) (3)	α	5.499030	4.0E-03	8.8E+01	After pretreatment (separation), α-spectrometer	Pu-238 to Pu-241 are nuclides to be removed by ALPS. The concentration of Pu-241 was estimated using an isotope.
Pu-239	(1) (2) (3)	α	5.156590	4.0E-03	2.4E+04		
Pu-240	(1) (2) (3)	α	5.168170	4.0E-03	6.6E+03		
Pu-241	(1) (2) (3)	β-	0.020780	2.0E-01	1.4E+01	—	
Pu-242	(1) (3)	α	4.902300	4.0E-03	3.7E+05	After pretreatment (separation), α-spectrometer	Has ever been analyzed by an external organization
Am-241	(1) (2) (3)	α	5.485560	5.0E-03	4.3E+02		Am-241 to Am-243 are nuclides to be removed by ALPS. The concentration of Am-242m was estimated using an isotope.
Am-242m	(1) (3)	IT	0.018856	5.0E-03	1.4E+02	—	
Am-243	(1) (3)	α	5.275300	5.0E-03	7.4E+03	After pretreatment (separation), α-spectrometer	
Cm-242	(3)	α	6.112720	6.0E-02	4.5E-01		Cm 242 to Cm-234 are nuclides to be removed by ALPS. Cm-243 and Cm-244, and Cm-245 and Cm-246 were measured as combined values as their energies are close to each other. Cm-245 and Cm-246 have ever been analyzed by an external organization.
Cm-243	(3)	α	5.785200	6.0E-03	2.9E+01		
Cm-244	(1) (3)	α	5.804770	7.0E-03	1.8E+01		
Cm-245	(3)	α	5.361100	5.0E-03	8.4E+03		
Cm-246	(3)	α	5.386500	5.0E-03	4.7E+03		

1-3-5 Analysis result of nuclides for analysis

The nuclides for analysis which have been identified in section I-3-3 through I-3-4 were checked to see if they exist in building stagnant water, strontium removed water and ALPS treated water at significant concentrations.

As a result, some of them were detected in building stagnant water and water before treatment by ALPS, but nuclides (including α nuclides) pointed out in previous studies were 1/100 or less of the regulatory concentration limit and below the lower detection limit[3] in ALPS treated water.

(1) ALPS treated water, etc. analysis results (β and γ nuclides, etc.)

Table I-5 shows the analysis results of β and γ nuclides in ALPS treated water, etc. Since the presence of suspended mattes was visually confirmed in the building stagnant water and strontium removed water before the treatment by ALPS, they were filtered with a 0.45 μm filter, and the filtrate and the residual were analyzed separately (for elements that are likely to be precipitated). Therefore, some analytical results are reported separately for the filtrate and the residue. In this case, considering the conservativity of the analytical results of the entire sample, the sum of the results of the filtrate and the residue shall be used as the analytical value of the entire sample when both or either of them are detected, and the higher value of the detection limit shall be used as the analytical value of the entire sample when neither is detected. Some of the ALPS treated water was also filtered and γ-rays of the used filter was measured. As a result, Cs-134, Cs-137, Co-60, which were found in filters for water up to ALPS treatment, were not detected. That shows that most of insoluble radionuclides have been removed through the ALPS treatment and that the filtering has no impacts.

The analysis result of β and γ nuclides in each sample has confirmed that most nuclides were below the detection limit, but Fe-55, Ni-59, Se-79 and Pd-107 were detected in the building stagnant water at concentrations about 1/100, 1/1000, 1/20 and 1/80000 of the regulatory concentration limits respectively. And Ni-59, Se-79 and Pd-107 were detected before ALPS treatment at a concentration of about 1/5000, 1/20, and 1/80000 of the regulatory concentration limits respectively. On the other hand, in water after ALPS treatment, each nuclide was 1/100 or less of the regulatory limit and below the detection limit.

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[3] For uranium, natural uranium in the environment was detected.

Corrected parts are displayed as underlined.

Table I-5 Results of nuclide analysis targeting nuclides for analysis (β and γ nuclides, etc.) (1/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen	Sampling location	Date of collection	Sampling method[4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Fe-55	2.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 7, 2022	< 2.7E+00	NFD[5]	Low-energy photon measuring device
		-	H4-B7 tank	Nov. 1, 2021		Apr. 14, 2022	< 2.3E+00		
		-	After treatment by additional ALPS	Oct. 28, 2021		May. 17, 2022	< 3.0E+00		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jun. 23, 2022	< 1.5E+01		
		Residue				Sep. 15, 2022	< 4.3E+00		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 22, 2022	< 4.1E+00		
		Residue				Sep. 5, 2022	1.7E+01±0.1E+01		
Ni-59	1.00E+04	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 9, 2022	< 2.3E+00		
		-	H4-B7 tank	Nov. 1, 2021		Apr. 19, 2022	< 6.6E+00		
		-	After treatment by additional ALPS	Oct. 28, 2021		May 23, 2022	< 2.3E+00		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jun. 27, 2022	2.2E+00±0.3E+00		
		Residue				Sep. 26, 2022	< 1.0E+00		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 26, 2022	9.4E+00±0.7E+00		
		Residue				Sep. 8, 2022	3.5E+00±0.5E+00		
Nb-93m	7.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 8, 2022	< 8.6E+00		
		-	H4-B7 tank	Nov. 1, 2021		May 10, 2022	< 1.5E+01		
		-	After treatment by additional ALPS	Oct. 28, 2021		May 18, 2022	< 7.8E+00		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jun. 13, 2022	< 5.6E+01		
		Residue				Sep. 20, 2022	< 5.2E+00		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 21, 2022	< 5.2E+01		
		Residue				Sep. 6, 2022	< 4.4E+00		

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[4] Details are shown in Figure I-3.

[5] Nippon Nuclear Fuel Development Co., Ltd.

Corrected parts are displayed as underlined.

Table I-5 Results of nuclide analysis targeting nuclides for analysis (β and γ nuclides, etc.) (2/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen[*1]	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Mo-93	3.00E+02	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 10, 2022	< 1.1E+00	NFD [5]	Low-energy photon measuring device
		-	H4-B7 tank	Nov. 1, 2021		Apr. 18, 2022	< 2.0E+00		
		-	After treatment by additional ALPS	Oct. 28, 2021		May 19, 2022	< 1.0E+00		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jun. 14, 2022	< 1.7E+00		
		Residue				Sep. 21, 2022	< 5.0E-01		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 25, 2022	< 1.2E+00		
		Residue				Sep. 7, 2022	< 1.5E+00		
Sn-121m	2.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 22, 2022	< 1.7E+00		
		-	H4-B7 tank	Nov. 1, 2021		Apr. 8, 2022	< 5.3E+00		
		-	After treatment by additional ALPS	Oct. 28, 2021		May 20, 2022	< 2.0E+00		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jun. 16, 2022	< 1.2E+01		
		Residue				Sep. 22, 2022	< 2.9E+00		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 28, 2022	< 9.2E+00		
		Residue				Sep. 2, 2022	< 1.1E+00		
Cl-36	9.00E+02	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 13, 2022	< 4.2E+00	NDC[6]	Low-background β-ray spectrometer
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 5.5E+00		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 13, 2022	< 3.9E+00		
		Filtrate	Before treatment by additiona ALPS	Feb. 10, 2022		May. 17, 2022	< 3.7E+00		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	May 23, 2022	< 4.3E+00		

Attachment I-10

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[6] MHI Nuclear Development Corporation

Corrected parts are displayed as underlined.

Attachment I-11

Table I-5 Results of nuclide analysis targeting nuclides for analysis (β and γ nuclides, etc.) (3/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Ca-41	4.00E+03	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	Jun. 3, 2022	< 7.9E+00	NDC [6]	Si (Li) semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		Jun. 6, 2022	< 7.9E+00		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		Jun. 1, 2022	< 7.4E+00		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 14, 2022	< 1.9E+01		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 13, 2022	< 1.4E+01		
Zr-93	1.00E+03	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 24, 2022	< 8.4E-01		Inductively coupled plasma mass spectrometer
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 24, 2022	< 8.4E-01		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 24, 2022	< 8.4E-01		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		May 24, 2022	< 8.4E-01		
		Residue				Jun. 7, 2022	< 1.3E+00		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	May 24, 2022	< 8.4E-01		
		Residue				Jun. 7, 2022	< 1.3E+00		
Ba-133	5.00E+02	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	Apr. 23, 2022	< 7.3E-01		Ge semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		Apr. 22, 2022	< 7.0E-01		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		Apr. 24, 2022	< 7.0E-01		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Apr. 21, 2022	< 4.3E+00		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 2, 2022	< 2.6E+00		
Se-79	2.00E+02	Filtrate	After treatment by additional ALPS	Apr. 22, 2022	(1)	*2	< 1.5E+00	JAEA	Liquid scintillation counter
		Filtrate	Before treatment by additional ALPS	Apr. 22, 2022		*3	9.0E+00[7]		
		Filtrate	Process Main Building	Apr. 21, 2022	(2)-b	*4	9.7E+00 [7] [8]		
Pd-107	2.00E+04	Filtrate	After treatment by additional ALPS	Apr. 22, 2022	(1)	Oct. 6, 2022	< 7.1E-02		Inductively coupled plasma mass spectrometer
		Filtrate	Before treatment by additional ALPS	Apr. 22, 2022		Oct. 6, 2022	2.4E-01 [7]		
		Filtrate	Process Main Building	Apr. 21, 2022	(2)-b	Oct. 6, 2022	7.8E-02 [7] [8]		

*2: Sep.27, 2022, Sep. 27, 2022 Oct. 14, 2022   *3: Oct. 2, 2022; Oct. 2, 2022 Oct. 14, 2022   *4: Sep. 21, 2022; Oct. 8, 2022 ; Oct. 8, 2022

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[7] Uncertainty assessment of measurement is not performed

[8] The same specimen was analyzed three times, and the value detected once was recorded. (In water before/after ALPS treatment, all of the three results were detected/below the detection limit, so the mean value was recorded)

(2) ALPS treated water, etc. analysis results (α nuclides)

Table I-6 shows the analysis results of α nuclides in ALPS treated water, etc.

In order to identify α nuclides that are contained in the building stagnant water at significant concentrations, the measurement of them were tried up to 1/100 or less of the regulatory concentration limits. In ALPS treated water, most nuclides were 1/100 or less of the regulatory concentration limits and below the detection limits, but trace amounts of U-235 and U-238 were detected. However, considering that the mass ratio[9] changed in the order of 1.8% (the ratio equivalent to spent fuel), 1.2% to 0.7% (the ratio of natural composition) in the process of treatment and based on other reasons[10], they are considered to be natural uranium contained in ALPS treated water.

In this analysis too, suspended matter was visually confirmed in the building stagnant water and strontium removed water before ALPS treatment. So, they were filtered with a 0.45 μm filter, and then the filtrate and the residue were analyzed separately (for elements that are likely to be precipitated). Therefore, some analytical results are reported separately for the filtrate and the residue. In this case, considering the conservativity of the analytical results of the entire sample, the sum of the results of the filtrate and the residue shall be used as the analytical value of the entire sample when both or either of them are detected, and the higher value of the detection limit shall be used as the analytical value of the entire sample when neither is detected. As is the case with β, γ and other nuclides, some of the ALPS treated water was also filtered, and γ-rays of the used filter was measured. As a result, Cs-134, Cs-137, Co-60, which were found in filters for water up to ALPS treatment, were not detected. That shows that most of insoluble radionuclides have been removed through the ALPS treatment and that the filtering has no impacts.

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[9] Calculated from $X = \lambda w/A \times NA$ (X: radioactivity, λ: decay constant, w: mass, A: number of atoms, NA: Avogadro constant)

[10] Within the range of uranium concentrations in Japanese rivers (excluding Okinawa), 0.47 to 488 ng/L [Natural level uranium concentration in Japanese rivers (Mochizuki et al.)] (approx. 6E-06 to 6E-03 Bq/L: U-238 equivalent), or U-236 derived from fuel was not detected.

Table I-6 Results of nuclide analysis targeting nuclides for analysis (α nuclides) (1/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method[4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
U-233	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 1.4E-02	NFD[5]	Inductively coupled plasma mass spectrometer
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 1.3E-02		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	< 1.3E-02		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	< 1.3E-02		
		Residue				Sep. 27, 2022	< 2.4E-03		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	< 1.3E-02		
		Residue				Sep. 27, 2022	< 1.4E-03		
U-234	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 8.7E-03		
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 8.7E-03		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	< 8.7E-03		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	< 8.7E-03		
		Residue				Sep. 27, 2022	< 1.6E-03		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	1.3E-01±1.7E-02		
		Residue				Sep. 26, 2022	2.8E-02±4.3E-03		
U-235	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	5.0E-05±6.0E-06		
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	9.9E-06±8.0E-07		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	8.8E-06±7.8E-07		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	2.0E-05±6.0E-06		
		Residue				Sep. 27, 2022	3.9E-06±3.3E-07		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	3.7E-03±9.0E-05		
		Residue				Sep. 26, 2022	6.0E-04±7.0E-06		

Corrected parts are displayed as underlined.

Table I-6 Results of nuclide analysis targeting nuclides for analysis (α nuclides) (2/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
U-236	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 9.1E-05	NFD [5]	Inductively coupled plasma mass spectrometer
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 9.1E-05		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	< 9.0E-05		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	1.2E-04±2.4E-05		
		Residue				Sep. 27, 2022	< 1.6E-05		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	2.2E-02±3.8E-04		
		Residue				Sep. 26, 2022	3.8E-03±1.3E-04		
U-238	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	1.2E-03±2.0E-05		
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	2.3E-04±1.8E-05		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	2.1E-04±1.8E-05		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 14, 2022	2.3E-04±1.8E-05		
		Residue				Sep. 26, 2022	7.5E-05±2.7E-06		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	3.1E-02±2.3E-04		
		Residue				Sep. 26, 2022	5.5E-03±6.5E-05		
Np-237	9.00E+00	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 15, 2022	< 1.5E-03		
		-	H4-B7 tank	Nov. 1, 2021		Jul. 15, 2022	< 1.5E-03		
		-	After treatment by additional ALPS	Oct. 28, 2021		Jul. 15, 2022	< 1.5E-03		
		Filtrate	Before treatment by additional ALPS	Oct. 28, 2021		Jul. 15, 2022	1.2E-02±4.3E-04		
		Residue				Sep. 26, 2022	8.0E-04±1.6E-04		
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 15, 2022	2.1E-01±2.2E-03		
		Residue				Sep. 27, 2022	8.5E-03±2.0E-04		

Corrected parts are displayed as underlined.

Table I-6 Results of nuclide analysis targeting nuclides for analysis (α nuclides) (3/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Pu-238	4.00E+00	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 27, 2022	< 1.9E-03	NDC [6]	Surface barrier silicon semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 1.9E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 27, 2022	< 2.5E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		May 31, 2022	2.8E-01±8.7E-03		
		Residue				Jun. 30, 2022	4.1E-01±1.2E-02		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 13, 2022	1.2E+00±2.4E-02		
		Residue				Jul. 4, 2022	2.8E+00±4.9E-02		
Pu-239+ Pu240	8.00E+00	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 27, 2022	< 1.9E-03		
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 1.9E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 27, 2022	< 1.9E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		May 31, 2022	9.1E-02±4.6E-03		
		Residue				Jun. 30, 2022	1.4E-01±6.0E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 13, 2022	3.9E-01±1.1E-02		
		Residue				Jul. 4, 2022	9.2E-01±2.0E-02		
Pu-242	4.00E+00	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 27, 2022	< 1.9E-03		
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 2.2E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 27, 2022	< 1.9E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		May 31, 2022	< 4.4E-03		
		Residue				Jun. 30, 2022	< 6.1E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 13, 2022	< 7.9E-03		
		Residue				Jul. 4, 2022	< 1.3E-02		

Corrected parts are displayed as underlined.

Table I-6 Results of nuclide analysis targeting nuclides for analysis (α nuclides) (4/5)

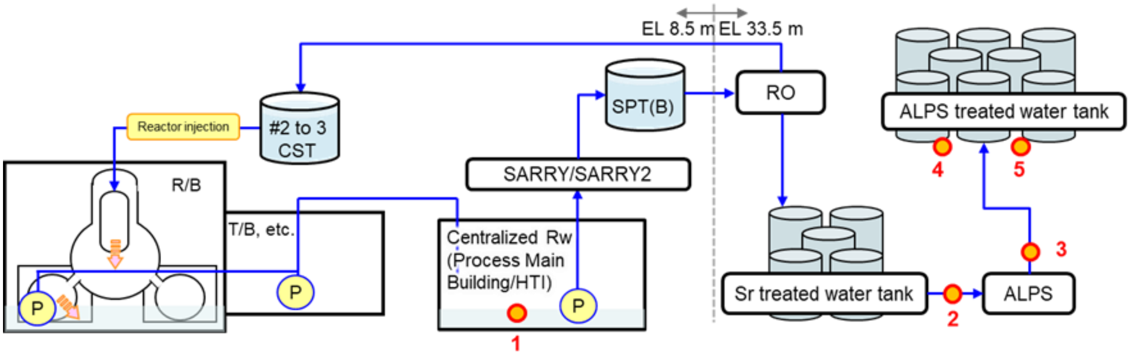
Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Am-241	5.00E+00	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 2, 2022	< 1.8E-03	NDC [6]	Surface barrier silicon semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 3, 2022	< 1.8E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 2, 2022	< 1.8E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 2, 2022	6.8E-02±3.6E-03		
		Residue				Jun. 3, 2022	1.2E-01±5.2E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 2, 2022	4.0E-02±2.8E-03		
		Residue				Jul. 4, 2022	5.7E-01±1.4E-02		
Am-243	5.00E+00	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 2, 2022	< 1.5E-03		
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 3, 2022	< 1.5E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 2, 2022	< 1.5E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 2, 2022	< 7.7E-03		
		Residue				Jun. 3, 2022	< 5.5E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 2, 2022	< 5.1E-03		
		Residue				Jul. 4, 2022	< 1.7E-02		
Cm-242	6.00E+01	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 2, 2022	< 1.5E-03		
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 3, 2022	< 1.5E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 2, 2022	< 1.6E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 2, 2022	< 1.6E-03		
		Residue				Jun. 3, 2022	5.5E-03±1.0E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 2, 2022	< 1.5E-03		
		Residue				Jul. 4, 2022	9.9E-03±1.4E-03		

Attachment I-16

Corrected parts are displayed as underlined.

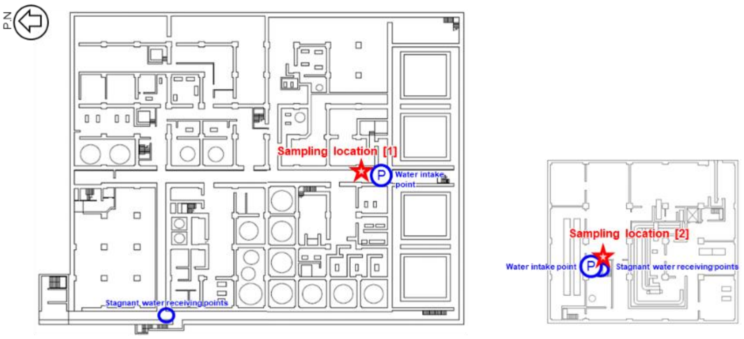
Table I-6 Results of nuclide analysis targeting nuclides for analysis (α nuclides) (5/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method [4]	Base date	Analytical value [Bq/L]	External analytical organization	Measuring instrument
Cm-243 +Cm-244	1.30E+01	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 27, 2022	< 1.5E-03	NDC [6]	Surface barrier silicon semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 1.5E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 27, 2022	< 1.8E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 22, 2022	6.4E-02±3.4E-03		
		Residue				Jun. 30, 2022	9.1E-02±4.4E-03		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 28, 2022	2.7E-02±2.3E-03		
		Residue				Jul. 4, 2022	4.4E-01±1.1E-02		
Cm-244 +Cm-245	1.00E+01	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 27, 2022	< 1.5E-03		
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 4.7E-03		
		Filtrate	After treatment by additional ALPS	Feb. 10, 2022		May 27, 2022	< 1.5E-03		
		Filtrate	Before treatment by additional ALPS	Feb. 10, 2022		Jun. 22, 2022	< 2.1E-02		
		Residue				Jun. 30, 2022	< 2.6E-02		
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 28, 2022	< 1.4E-02		
		Residue				Jul. 4, 2022	< 6.0E-02		



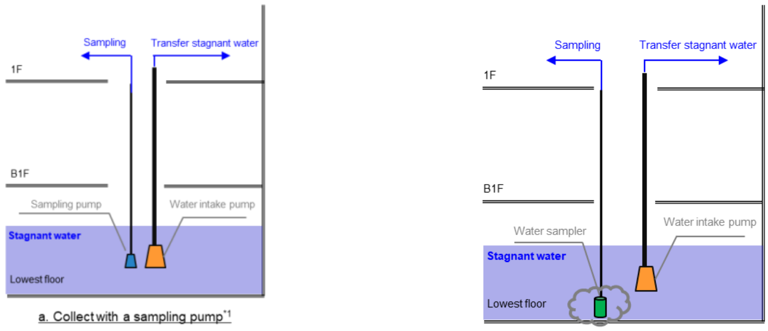
No.	Sampling location	Sampling method
1	Process Main Building	See (2).
2	Before treatment by ALPS	Collect from sampling rack installed at the inlet of ALPS
3	After treatment by ALPS	Collect from sampling rack installed at the outlet of ALPS
4	H4-B7 tank	Collected from the upper part of the tank using a water sampler.
5	K4-A10 tank	

(1) Sampling locations and methods for current nuclide analysis



PMB Lowest Floor Plan

HTI Lowest Floor Plan



a. Collect with a sampling pump*1

b. Collect with a water samplers*2

*1: The suction point of the sampling pump are set at the same height as that of the sampling pump.

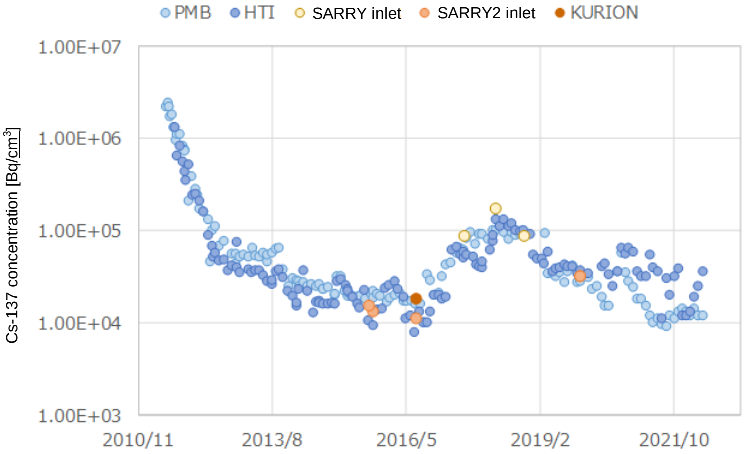
*2: Since sediment on the bottom of the building was stirred up during sampling, samples collected contained more sludge than usual.

(2) Method for collecting samples from the Process Main Building and High-temperature Incinerator Building

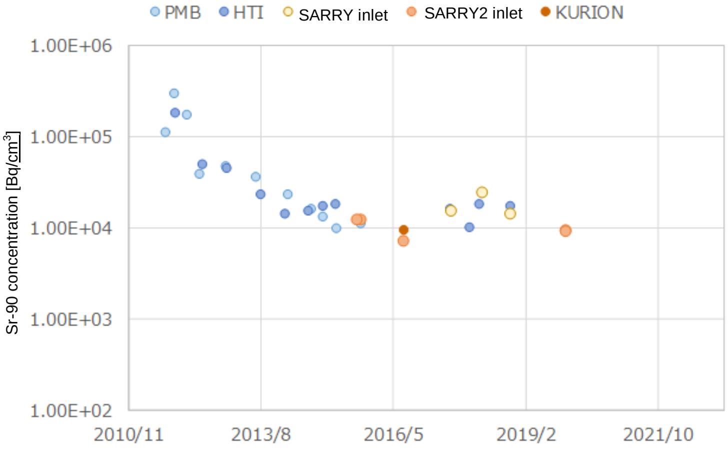
Figure I-3 Sampling locations and methods for the nuclide analysis targeting nuclides for analysis

Corrected parts are displayed as underlined.

This time, for the samples for which additional analysis was performed, samples were taken from the same places as routine sampling points for checking the performance of normal stagnant water and water treatment facilities. However, as shown in Figure I-3 (2), two types of sampling were performed for the process main building. In routine sampling during normal operation, water is sampled with a sampling pump as in (a). As a result, shown in Figure I-4, it was confirmed that the analytical results of Cs-137 and Sr-90 showed the same concentration as the water at the inlet of the cesium adsorption equipment after the intake pump. On the other hand, in the sampling carried out in (b), the stagnant water in buildings containing sludge settled at the bottom of the building was sampled, and considering the performance of ALPS capable of removing up to 20 nm with a cross-flow filter, the plan is to remove it with a 0.45 μm filter and analyze the nuclides dissolved in water that require treatment with ALPS, etc.



a. Analytical results of Cs-137



b. Analytical results of Sr-90

Figure I-4 Comparison of analysis results between process main building and cesium adsorption equipment inlet

I-4. Inventory assessment

As the inventory assessment, fission products and radioactive materials such as actinoids generated from nuclear fuel materials (hereinafter referred to as "fission products") have been assessed in nuclear power plant safety assessments (used to examine nuclides to be removed by ALPS), while in studies regarding decommissioning and disposal facilities, activation of equipment in nuclear power plants has been calculated. In this examination, assessment of fission products and activation products will be performed while referring to the above assessments.

In both assessments, reduction in the inventory due to decay will also be assessed while taking into account that 12 years will have passed at the time of the discharge since the earthquake.

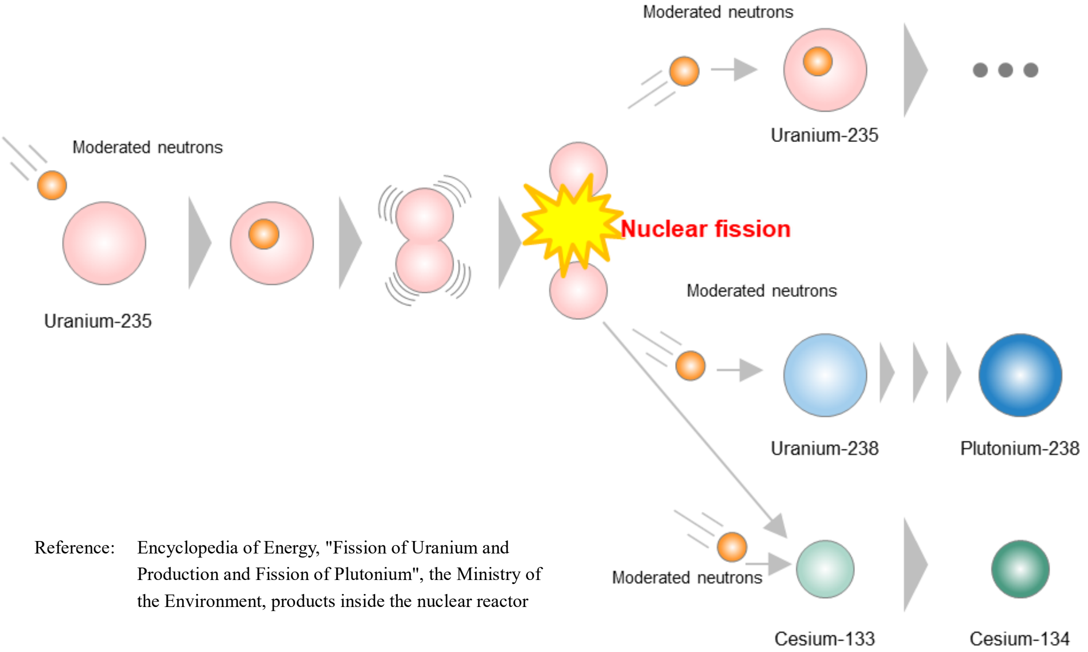
ORNL Isotope Generation and Depletion Code (ORIGEN: code system for calculating the generation, disintegration, and depletion of radioactive materials) will be used for the assessment as was the case with safety assessments, previous studies and other assessments so far.

Based on the result of ORIGEN assessment, the easiness of transfer into water will be taken into account, and then nuclides that may be contained at significant concentrations in building stagnant water will be identified.

I-4-1. Assessment of fission products

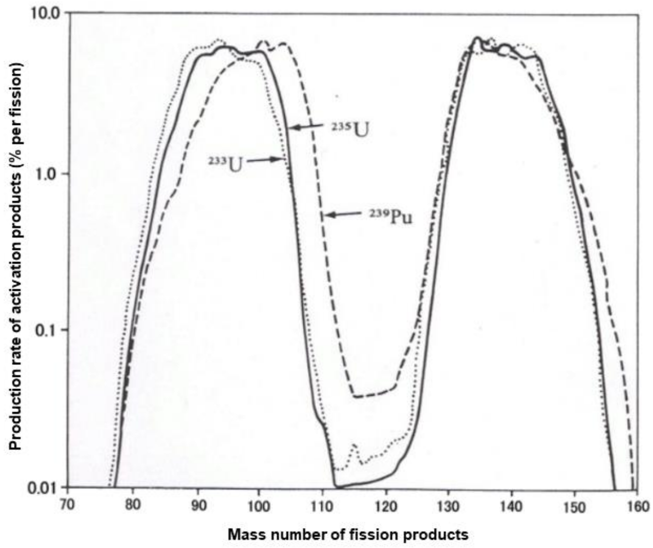
In the assessment of fission products, safety assessments at normal nuclear power plants will be referred to as they were in the examination of nuclides to be removed by ALPS, and the inventory as of March, 2011 will be assessed based on the condition of the fuel loaded in the Units 1 to 3 reactor pressure vessels at FDNPS as well as on the condition of the burnup assumed from the loading period of each piece of fuel. After March of 2011, the decrease in the inventory due to decay over 12 years will be calculated.

ORIGEN can assess inventories which are generated from nuclear fuel, disintegrated, and depleted. Regarding nuclear fission, it can assess that uranium 235 produces two nuclides mainly at peaks around mass numbers 95 and 140 in the process of fission. In addition, it is also capable of assess the generation of nuclides produced when uranium 238 absorbs neutrons, such as plutonium, as well as nuclides produced when fission products absorb neutrons, such as cesium 134.



Reference: Encyclopedia of Energy, "Fission of Uranium and Production and Fission of Plutonium", the Ministry of the Environment, products inside the nuclear reactor

Figure I-5 Fission of uranium, and production and fission of plutonium, and actinoid



Based on the ATOMICA's "atomic mass number distribution of fission products."

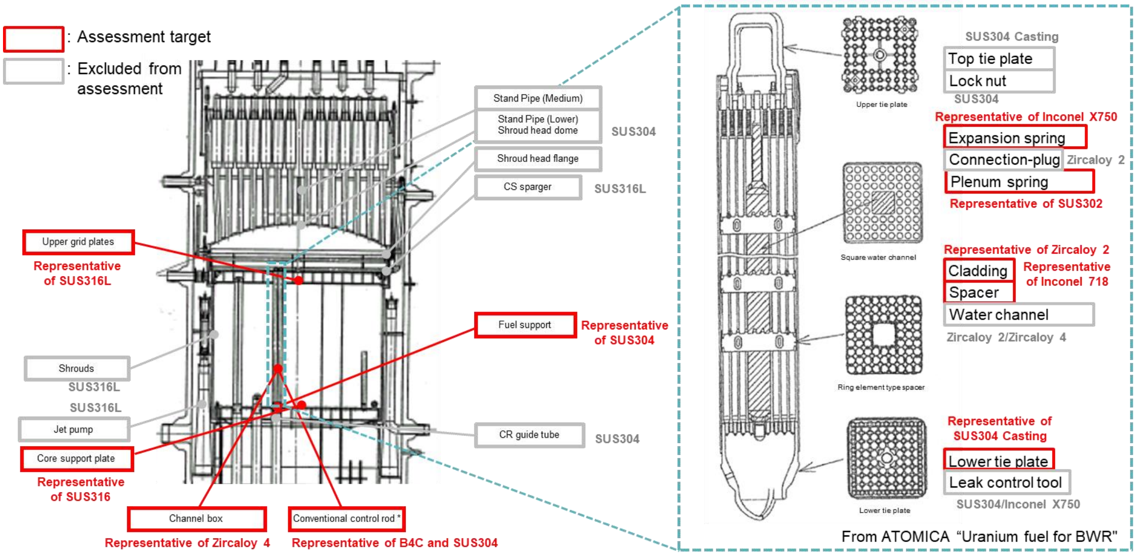
Source: W. Marshall, ed.: Development of Reactor Technology (Vol.1), Shoukabou, p. 72

Figure I-6 Distribution of mass numbers of fission products

I-4-2. Assessment of activation products

In the assessment of activation products, studies on decommissioning and disposal facilities will be used as a reference, and inventories as of March 2011 will be assessed, while taking into account the irradiation period from the core, for four kinds of equipment and structures: reactor internals, fuel assemblies (excluding nuclear fuel materials), pressure vessels, and pedestals, which exist in the reactor pressure vessels and lower part of them. In addition, inventories as of March of 2011 of corrosion products which will be produced as a result of corrosion and activation of materials comprising the equipment of the reactor coolant system will be assessed as well using water supply and metal data during operation, etc. In both of the assessments, for the period after March 2011, reduction in inventories due to decay over 12 years will be calculated.

Regarding reactor internals and fuel assemblies, rather than assessing all pieces of equipment, when same materials are used, those that are closer to the core (larger activation amount) will be selected for assessment to be conservative.



From ATOMICA "Uranium fuel for BWR"

*It was confirmed that there were no Hf-type control rods in the reactor of units 1-3 of the 1F at the time of the Earthquake.

Based on "the structure drawing of BWR reactor internals", Inspection and Evaluation Guideline for BWR reactor internals

Reactor internals

Fuel assembly (excluding nuclear fuel materials)

Figure I-7 Targets of the inventory assessment of reactor internals

I-4-3. Inventory assessment results

Tables I-7 to I-9 show the results of the inventory assessment performed under the conditions described in section I-4-1 and I-4-2.

In the assessment of fission products, all of the inventories produced from fuel are taken into account. When assessing the inventories of fission products, only inventories produced from fuel are taken into account and the presence of combustible poisons is not considered as is the case with normal nuclear power plant safety assessments and in the examination of nuclides subject to removal by ALPS.

In the assessment of activation products, the inventory is calculated from the reactor pressure vessel and pedestal in addition to the upper grid plates, channel box, fuel assembly (all components), conventional control rods, fuel support, and core support plate which exist in the core while the reactor is in operation and assumed to have melted through past investigations and accident analyses. The activation of each piece of equipment are assessed based on operation records and conditions (element concentration condition, neutron flux) for waste subject to marginal depth disposal (L1), high-level radioactive waste (vitrified waste) and hull wastes[11], which have been studied by the Electric Technology Research Association.

In the assessment of inventories using ORIGEN, as is the case with past safety assessments and research of decommissioning, the inventories such as the fuel, channel box, fuel assembly, and conventional control rods, which can be assessed by point kinetics of neutron flux in reactors, are assessed by ORIGEN2, while upper grid, core support plate, fuel support, reactor pressure vessel and pedestal, whose neutron spectrum is different from that of fuel, are assessed by SCALE5.1/ORIGEN-S. The data embedded in JENDL4.0 and SCALE5.1 are used as nuclear data respectively.

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[11] When spent nuclear fuel is reprocessed through the Purex method, nuclear fuel is made into thin fragments by chopping it, and the clad waste material of the nuclear fuel is called the (hull) (from ATOMICA).

Table I-7　Inventory assessment results: Unit 1 (1/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	4.8E+14	Nb-94	1.9E+11	Te-123m	1.5E+04
Be-10	8.4E+08	Mo-93	2.4E+11	Te-125m	2.9E+14
C-14	5.4E+12	Tc-97	2.9E+06	Te-127	7.8E+03
Na-22	3.6E+07	Tc-98	9.6E+06	Te-127m	8.0E+03
Si-32	7.1E+05	Tc-99	2.7E+13	I-129	4.9E+10
P-32	7.1E+05	Ru-106	2.1E+14	Cs-134	6.9E+15
Cl-36	5.1E+09	Rh-101	1.1E+05	Cs-135	1.1E+12
Ar-39	1.7E+11	Rh-102	7.1E+06	Cs-137	1.5E+17
Ar-42	4.9E+03	Rh-102m	1.6E+07	Ba-133	5.0E+10
K-40	1.6E+08	Rh-106	2.1E+14	Ba-137m	1.5E+17
K-42	4.9E+03	Pd-107	1.9E+11	La-137	1.4E+07
Ca-41	3.5E+09	Ag-108	3.3E+09	La-138	3.1E+04
Ca-45	4.8E+06	Ag-108m	3.8E+10	Ce-139	5.4E+03
Sc-46	3.7E+01	Ag-109m	8.8E+09	Ce-142	5.3E+07
V-49	2.3E+04	Ag-110	3.5E+08	Ce-144	4.1E+13
Mn-54	4.1E+11	Ag-110m	2.6E+10	Pr-144	4.1E+13
Fe-55	2.6E+15	Cd-109	8.8E+09	Pr-144m	6.2E+11
Co-60	8.1E+15	Cd-113m	2.5E+13	Nd-144	3.3E+03
Ni-59	1.4E+13	In-113m	1.7E+04	Pm-144	2.8E+01
Ni-63	1.6E+15	In-115	4.5E+03	Pm-145	1.8E+10
Zn-65	9.9E+08	Sn-113	1.7E+04	Pm-146	1.0E+12
Se-75	1.0E+03	Sn-119m	1.6E+10	Pm-147	1.5E+16
Se-79	1.1E+11	Sn-121	2.1E+13	Sm-145	3.1E+07
Kr-81	1.1E+10	Sn-121m	2.7E+13	Sm-146	2.3E+05
Kr-85	9.2E+15	Sn-123	1.1E+05	Sm-147	1.3E+07
Rb-87	9.4E+07	Sn-126	4.8E+11	Sm-148	8.2E+01
Sr-90	1.1E+17	Sb-125	7.9E+14	Sm-149	1.5E+00
Y-90	1.1E+17	Sb-126	6.8E+10	Sm-151	5.7E+14
Zr-93	3.9E+12	Sb-126m	4.8E+11	Eu-150	3.9E+07
Nb-91	1.0E+05	Te-121	6.1E+02	Eu-152	2.8E+12
Nb-92	1.7E+06	Te-121m	6.1E+02	Eu-154	3.8E+15
Nb-93m	1.8E+12	Te-123	1.3E+04	Eu-155	1.1E+15
Gd-152	4.3E+00	Pb-212	3.8E+10	Th-228	3.8E+10
Gd-153	3.2E+08	Pb-214	5.2E+06	Th-229	4.6E+05
Tb-157	6.8E+08	Bi-208	6.5E+05	Th-230	6.8E+08

Table I-7 Inventory assessment results: Unit 1 (2/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Tb-158	6.9E+08	Bi-210	1.8E+06	Th-231	8.4E+10
Dy-159	1.9E+01	Bi-210m	1.7E+05	Th-232	6.3E+06
Ho-163	1.5E+07	Bi-211	2.2E+07	Th-234	8.0E+11
Ho-166m	6.9E+09	Bi-212	3.8E+10	Pa-231	7.6E+07
Tm-170	5.0E+05	Bi-213	4.6E+05	Pa-233	5.0E+11
Tm-171	1.4E+12	Bi-214	5.2E+06	Pa-234	1.0E+09
Lu-176	5.1E+05	Po-210	1.8E+06	Pa-234m	8.0E+11
Lu-177	4.7E+05	Po-211	6.2E+04	U-232	3.9E+10
Lu-177m	2.0E+06	Po-212	2.4E+10	U-233	1.1E+08
Hf-182	2.1E+06	Po-213	4.6E+05	U-234	3.4E+12
Ta-182	2.2E+06	Po-214	5.2E+06	U-235	8.4E+10
W-181	8.3E+02	Po-215	2.2E+07	U-236	5.6E+11
Re-187	1.4E+06	Po-216	3.8E+10	U-237	3.0E+12
Os-194	1.4E+08	Po-218	5.2E+06	U-238	8.0E+11
Ir-192	5.7E+06	At-217	4.6E+05	U-240	5.7E+05
Ir-192m	5.7E+06	Rn-219	2.2E+07	Np-235	2.2E+06
Ir-194	1.4E+08	Rn-220	3.8E+10	Np-236	7.6E+06
Ir-194m	3.6E+03	Rn-222	5.2E+06	Np-237	5.0E+11
Pt-190	2.2E+03	Fr-221	4.6E+05	Np-238	7.9E+10
Pt-193	2.5E+12	Fr-223	3.1E+05	Np-239	2.7E+13
Tl-204	3.6E+12	Ra-223	2.2E+07	Np-240m	5.7E+05
Tl-206	1.7E+05	Ra-224	3.8E+10	Pu-236	3.3E+10
Tl-207	2.2E+07	Ra-225	4.6E+05	Pu-238	4.4E+15
Tl-208	1.4E+10	Ra-226	5.2E+06	Pu-239	6.7E+14
Tl-209	1.0E+04	Ra-228	6.2E+06	Pu-240	8.7E+14
Pb-205	5.1E+05	Ac-225	4.6E+05	Pu-241	1.2E+17
Pb-209	4.6E+05	Ac-227	2.2E+07	Pu-242	3.2E+12
Pb-210	1.8E+06	Ac-228	6.2E+06	Pu-243	2.2E+05
Pb-211	2.2E+07	Th-227	2.2E+07	Pu-244	5.7E+05
Am-241	3.5E+15	Cm-243	2.3E+13	Bk-249	1.8E+05
Am-242	1.6E+13	Cm-244	2.3E+15	Cf-249	5.4E+06
Am-242m	1.6E+13	Cm-245	4.0E+11	Cf-250	3.0E+07
Am-243	2.7E+13	Cm-246	6.9E+10	Cf-251	3.1E+05
Am-245	2.6E+00	Cm-247	2.2E+05	Cf-252	4.3E+06
Cm-242	1.3E+13	Cm-248	5.9E+05		

Table I-8 Inventory assessment results: Unit 2 (1/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	6.1E+14	Nb-93m	2.3E+12	Te-123	1.2E+04
Be-10	1.1E+09	Nb-94	3.6E+11	Te-123m	2.0E+04
C-14	9.8E+12	Mo-93	6.0E+11	Te-125m	3.9E+14
Na-22	5.0E+07	Tc-97	4.1E+06	Te-127	1.2E+04
Si-32	1.5E+06	Tc-98	1.1E+07	Te-127m	1.2E+04
P-32	1.5E+06	Tc-99	3.4E+13	I-129	5.9E+10
Cl-36	1.3E+10	Ru-106	2.8E+14	Cs-134	9.1E+15
Ar-39	2.4E+11	Rh-101	1.5E+05	Cs-135	1.2E+12
Ar-42	1.3E+04	Rh-102	9.7E+06	Cs-137	1.9E+17
K-40	1.5E+08	Rh-102m	2.1E+07	Ba-133	6.0E+10
K-42	1.3E+04	Rh-106	2.8E+14	Ba-137m	1.8E+17
Ca-41	6.8E+09	Pd-107	2.2E+11	La-137	1.7E+07
Ca-45	6.8E+06	Ag-108	5.8E+09	La-138	4.1E+04
Sc-46	5.2E+01	Ag-108m	6.7E+10	Ce-139	7.5E+03
V-49	3.8E+04	Ag-109m	1.3E+10	Ce-142	6.7E+07
Mn-54	5.8E+11	Ag-110	4.5E+08	Ce-144	6.4E+13
Fe-55	4.2E+15	Ag-110m	3.3E+10	Pr-144	6.4E+13
Co-60	1.4E+16	Cd-109	1.3E+10	Pr-144m	9.7E+11
Ni-59	2.9E+13	Cd-113m	2.9E+13	Nd-144	4.1E+03
Ni-63	3.4E+15	In-113m	2.4E+04	Pm-144	3.8E+01
Zn-65	1.5E+09	In-115	4.9E+03	Pm-145	3.0E+10
Se-75	1.5E+03	Sn-113	2.4E+04	Pm-146	1.3E+12
Se-79	1.3E+11	Sn-119m	2.2E+10	Pm-147	2.1E+16
Kr-81	1.7E+10	Sn-121	2.6E+13	Sm-145	4.4E+07
Kr-85	1.2E+16	Sn-121m	3.3E+13	Sm-146	2.5E+05
Rb-87	1.1E+08	Sn-123	1.6E+05	Sm-147	1.7E+07
Sr-90	1.5E+17	Sn-126	5.8E+11	Sm-148	9.4E+01
Y-88	1.1E+00	Sb-125	1.1E+15	Sm-149	2.3E+00
Y-90	1.5E+17	Sb-126	8.1E+10	Sm-151	7.8E+14
Zr-93	4.9E+12	Sb-126m	5.8E+11	Eu-150	4.1E+07
Nb-91	4.1E+05	Te-121	9.3E+02	Eu-152	3.1E+12
Nb-92	3.8E+06	Te-121m	9.3E+02	Eu-154	4.6E+15
Eu-155	1.4E+15	Pb-211	2.5E+07	Th-227	2.5E+07
Gd-152	4.7E+00	Pb-212	4.2E+10	Th-228	4.2E+10
Gd-153	3.8E+08	Pb-214	5.5E+06	Th-229	4.4E+05

Table I-8 Inventory assessment results: Unit 2 (2/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Tb-157	9.5E+08	Bi-208	9.1E+05	Th-230	8.7E+08
Tb-158	7.6E+08	Bi-210	1.7E+06	Th-231	1.4E+11
Dy-159	2.5E+01	Bi-210m	2.4E+05	Th-232	5.9E+06
Ho-163	2.2E+07	Bi-211	2.5E+07	Th-234	1.1E+12
Ho-166m	9.5E+09	Bi-212	4.2E+10	Pa-231	9.4E+07
Tm-170	7.0E+05	Bi-213	4.4E+05	Pa-233	6.2E+11
Tm-171	1.9E+12	Bi-214	5.5E+06	Pa-234	1.5E+09
Lu-176	7.2E+05	Po-210	1.7E+06	Pa-234m	1.1E+12
Lu-177	6.5E+05	Po-211	7.1E+04	U-232	4.4E+10
Lu-177m	2.8E+06	Po-212	2.7E+10	U-233	1.5E+08
Hf-182	2.9E+06	Po-213	4.3E+05	U-234	5.1E+12
Ta-182	3.0E+06	Po-214	5.5E+06	U-235	1.4E+11
W-181	1.2E+03	Po-215	2.5E+07	U-236	7.3E+11
Re-187	2.2E+06	Po-216	4.2E+10	U-237	3.6E+12
Os-194	2.0E+08	Po-218	5.5E+06	U-238	1.1E+12
Ir-192	6.9E+06	At-217	4.4E+05	U-240	6.1E+05
Ir-192m	6.9E+06	Rn-219	2.5E+07	Np-235	2.8E+06
Ir-194	2.0E+08	Rn-220	4.2E+10	Np-236	9.4E+06
Ir-194m	4.4E+03	Rn-222	5.5E+06	Np-237	6.2E+11
Pt-190	2.1E+03	Fr-221	4.4E+05	Np-238	7.7E+10
Pt-193	3.6E+12	Fr-223	3.5E+05	Np-239	2.8E+13
Tl-204	5.4E+12	Ra-223	2.5E+07	Np-240m	6.1E+05
Tl-206	2.4E+05	Ra-224	4.2E+10	Pu-236	4.0E+10
Tl-207	2.5E+07	Ra-225	4.4E+05	Pu-238	4.8E+15
Tl-208	1.5E+10	Ra-226	5.5E+06	Pu-239	8.7E+14
Tl-209	9.5E+03	Ra-228	5.8E+06	Pu-240	1.1E+15
Pb-205	1.2E+06	Ac-225	4.4E+05	Pu-241	1.5E+17
Pb-209	4.4E+05	Ac-227	2.5E+07	Pu-242	3.4E+12
Pb-210	1.7E+06	Ac-228	5.8E+06	Pu-243	1.9E+05
Pu-244	6.1E+05	Cm-242	1.3E+13	Cm-248	4.8E+05
Am-241	4.1E+15	Cm-243	2.3E+13	Bk-249	1.5E+05
Am-242	1.5E+13	Cm-244	2.2E+15	Cf-249	4.5E+06
Am-242m	1.5E+13	Cm-245	3.9E+11	Cf-250	2.5E+07
Am-243	2.8E+13	Cm-246	6.1E+10	Cf-251	2.5E+05
Am-245	2.2E+00	Cm-247	1.9E+05	Cf-252	3.3E+06

Table I-9 Inventory assessment results: Unit 3 (1/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	5.7E+14	Nb-93m	2.2E+12	Te-123	1.2E+04
Be-10	1.1E+09	Nb-94	3.6E+11	Te-123m	2.0E+04
C-14	9.8E+12	Mo-93	6.1E+11	Te-125m	3.8E+14
Na-22	5.0E+07	Tc-97	4.1E+06	Te-127	1.2E+04
Si-32	1.5E+06	Tc-98	1.0E+07	Te-127m	1.2E+04
P-32	1.5E+06	Tc-99	3.2E+13	I-129	5.6E+10
Cl-36	1.3E+10	Ru-106	2.7E+14	Cs-134	8.6E+15
Ar-39	2.4E+11	Rh-101	1.5E+05	Cs-135	1.2E+12
Ar-42	1.3E+04	Rh-102	9.4E+06	Cs-137	1.8E+17
K-40	1.5E+08	Rh-102m	2.0E+07	Ba-133	5.6E+10
K-42	1.3E+04	Rh-106	2.7E+14	Ba-137m	1.7E+17
Ca-41	6.8E+09	Pd-107	2.0E+11	La-137	1.6E+07
Ca-45	6.8E+06	Ag-108	5.8E+09	La-138	4.1E+04
Sc-46	5.2E+01	Ag-108m	6.7E+10	Ce-139	6.9E+03
V-49	3.8E+04	Ag-109m	1.3E+10	Ce-142	6.3E+07
Mn-54	6.1E+11	Ag-110	4.1E+08	Ce-144	6.2E+13
Fe-55	4.4E+15	Ag-110m	3.0E+10	Pr-144	6.2E+13
Co-60	1.4E+16	Cd-109	1.3E+10	Pr-144m	9.4E+11
Ni-59	3.0E+13	Cd-113m	2.8E+13	Nd-144	3.9E+03
Ni-63	3.4E+15	In-113m	2.4E+04	Pm-144	3.7E+01
Zn-65	1.5E+09	In-115	4.9E+03	Pm-145	3.0E+10
Se-75	1.5E+03	Sn-113	2.4E+04	Pm-146	1.2E+12
Se-79	1.3E+11	Sn-119m	2.2E+10	Pm-147	2.0E+16
Kr-81	1.7E+10	Sn-121	2.4E+13	Sm-145	4.4E+07
Kr-85	1.1E+16	Sn-121m	3.1E+13	Sm-146	2.3E+05
Rb-87	1.1E+08	Sn-123	1.7E+05	Sm-147	1.6E+07
Sr-90	1.4E+17	Sn-126	5.5E+11	Sm-148	8.6E+01
Y-88	1.0E+00	Sb-125	1.0E+15	Sm-149	2.3E+00
Y-90	1.4E+17	Sb-126	7.7E+10	Sm-151	8.0E+14
Zr-93	4.7E+12	Sb-126m	5.5E+11	Eu-150	3.8E+07
Nb-91	4.1E+05	Te-121	9.3E+02	Eu-152	3.1E+12
Nb-92	3.9E+06	Te-121m	9.3E+02	Eu-154	4.2E+15
Eu-155	1.3E+15	Pb-211	2.4E+07	Th-227	2.4E+07
Gd-152	4.6E+00	Pb-212	3.8E+10	Th-228	3.8E+10
Gd-153	3.6E+08	Pb-214	5.5E+06	Th-229	4.0E+05

Table I-9 Inventory assessment results: Unit 3 (2/2)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Tb-157	9.5E+08	Bi-208	9.1E+05	Th-230	8.6E+08
Tb-158	6.8E+08	Bi-210	1.8E+06	Th-231	1.4E+11
Dy-159	2.5E+01	Bi-210m	2.4E+05	Th-232	5.9E+06
Ho-163	2.2E+07	Bi-211	2.4E+07	Th-234	1.1E+12
Ho-166m	9.2E+09	Bi-212	3.8E+10	Pa-231	9.0E+07
Tm-170	7.0E+05	Bi-213	4.0E+05	Pa-233	5.8E+11
Tm-171	1.9E+12	Bi-214	5.5E+06	Pa-234	1.4E+09
Lu-176	7.2E+05	Po-210	1.8E+06	Pa-234m	1.1E+12
Lu-177	6.5E+05	Po-211	6.8E+04	U-232	3.9E+10
Lu-177m	2.8E+06	Po-212	2.4E+10	U-233	1.4E+08
Hf-182	2.9E+06	Po-213	3.9E+05	U-234	5.1E+12
Ta-182	3.0E+06	Po-214	5.5E+06	U-235	1.4E+11
W-181	1.2E+03	Po-215	2.4E+07	U-236	7.0E+11
Re-187	2.2E+06	Po-216	3.8E+10	U-237	4.0E+12
Os-194	2.0E+08	Po-218	5.5E+06	U-238	1.1E+12
Ir-192	6.9E+06	At-217	4.0E+05	U-240	5.5E+05
Ir-192m	6.9E+06	Rn-219	2.4E+07	Np-235	2.5E+06
Ir-194	2.0E+08	Rn-220	3.8E+10	Np-236	8.6E+06
Ir-194m	4.4E+03	Rn-222	5.5E+06	Np-237	5.8E+11
Pt-190	2.1E+03	Fr-221	4.0E+05	Np-238	3.0E+11
Pt-193	3.6E+12	Fr-223	3.4E+05	Np-239	2.9E+13
Tl-204	5.4E+12	Ra-223	2.4E+07	Np-240m	5.5E+05
Tl-206	2.4E+05	Ra-224	3.8E+10	Pu-236	3.6E+10
Tl-207	2.4E+07	Ra-225	4.0E+05	Pu-238	6.7E+15
Tl-208	1.4E+10	Ra-226	5.5E+06	Pu-239	1.1E+15
Tl-209	8.6E+03	Ra-228	5.9E+06	Pu-240	1.4E+15
Pb-205	1.2E+06	Ac-225	4.0E+05	Pu-241	1.6E+17
Pb-209	4.0E+05	Ac-227	2.4E+07	Pu-242	4.6E+12
Pb-210	1.8E+06	Ac-228	5.9E+06	Pu-243	1.3E+05
Pu-244	5.5E+05	Cm-242	4.9E+13	Cm-248	3.3E+05
Am-241	5.6E+15	Cm-243	2.9E+13	Bk-249	1.0E+05
Am-242	5.9E+13	Cm-244	1.9E+15	Cf-249	3.0E+06
Am-242m	5.9E+13	Cm-245	3.1E+11	Cf-250	1.6E+07
Am-243	2.9E+13	Cm-246	4.6E+10	Cf-251	1.6E+05
Am-245	1.5E+00	Cm-247	1.3E+05	Cf-252	2.0E+06

I-4-4. Uncertainty in inventory assessment

In this assessment, the study is based on the conditions for marginal depth disposal waste (L1), high-level radioactive waste (vitrified waste), and hull waste, as examined in safety assessments of normal nuclear power plants, the study of the nuclides to be removed by ALPS, and joint research by electric power companies. However, some conditions include uncertainty in the input conditions, and therefore, there is uncertainty in the assessment results.

The details of the input conditions and uncertainties are shown in Table I-10. As to fission products, uncertainties due to the input conditions hardly exist, and we believe realistic evaluations can be performed, but as for activation products, there is uncertainty in the elemental concentration condition, etc., on the conservative side.

Corrected part is displayed as underlined.

Table I-10 Uncertainty in inventory assessment

Condition		Input state		Uncertainty
Assessment of fission products	Fuel type	Data of fuel loaded in the reactor core of Units 1 - 3 of Fukushima Daiichi NPS on March 11, 2011		Small
	Uranium weight			
	Enrichment			
	Fuel composition	U-234: U-235 enrichment × 0.008 (natural composition ratio) U-235: From the enrichment of the fuel data U-238: Difference from weight% of U-234, U-235		Small
	Burnup	Burnup of each fuel assembly as of March 11, 2011		Small
	Irradiation condition	Continuous operation at 100% thermal output without considering periodic inspection		Small[12]
	Cooling period	12 years (from March 11, 2023)		Small
Assessment of activation products	Equipment to be evaluated and equipment weight	Fuel assembly	: Total weight	Small to large[13]
		Channel box (CB) Control rod (CR) Other structural materials	: Total weight of each piece of equipment	
		RPV	: Total weight x 25%	
		Pedestal	: Set from IRID's subsidized project "Sophistication of assessing conditions inside reactors by accident progress analysis and actual equipment data, etc." (about 160 tons/unit).	
		Corrosion products	: The results of the past 4 cycles of metals brought in from the water supply (without consideration of removal by the reactor coolant clean-up system).	
	Element concentration condition	For each piece of equipment, we consider the principal components and impurity components regulated by material standards and other regulations, as well as minor components not controlled by these regulations, based on past joint research by electric power companies. Based on this concept, the targets are 83 elements, excluding radioelements (20 elements) other than Bi, Th, and U from atomic numbers 1 - 103 of the periodic table of elements. In this evaluation, element concentration conditions are set, excluding rare gases.		Large[14]
	Amount of irradiation/ neutron flux and irradiation period	Fuel assembly/CB	: Set equal to the average fuel burnup	Small to medium
		CR	: Set with a margin in the results of CR irradiation amount (overall average) of 1F-1 to 3.	
		Other structural materials	: Calculated from the neutron flux at the center of the equipment and the duration of its presence in the reactor.	
		RPV and pedestal	: Calculated from neutron flux and service life at the center of each equipment and structure.	
		Corrosion products	: Calculated by the loading period (4 cycles) of the cladding into the reactor, assuming neutron flux and adhesion when the cladding adheres.	
	Irradiation condition	Continuous operation at 100% thermal output without considering periodic inspection		Small [12]
	Cooling period	12 years (from March 11, 2023)		Small

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[12] It is a nuclide with a short half-life, and it is conservative but has little impact after a cooling period of 12 years.

[13] Though the weight actually contributed is unknown, it is set to the weight in the above table from diagrams, etc.

[14] The concentration of the element listed in the standard is set at the maximum value, and even for the minor component which is not controlled by the standard, it is set conservatively from the survey in the past, or the conservative initial condition is set for the minor component which has not been investigated.

I-5. Selection of nuclides

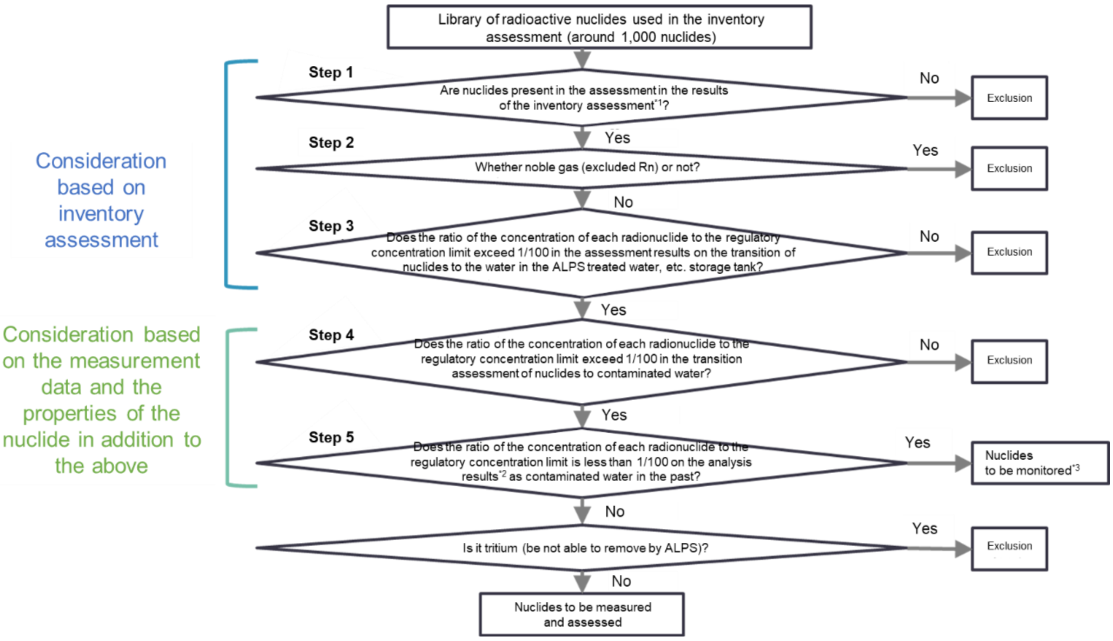
I-5-1. Overview

Section I-3 and I-4 provide supplementary explanations on the nuclide analysis and inventory assessment which are performed in order to ensure that the sum of the ratios to regulatory concentration limits of radionuclides other than tritium in ALPS treated water is less than 1 while taking into account previous studies on decommissioning and disposal facilities in Japan.

This document supplements the explanation about how to select nuclides to be measured and assessed at the discharge of ALPS treated water into the sea based on the results obtained through the nuclide analysis and inventory assessment.

I-5-2. Selection process of nuclides to be measured and assessed

The nuclides to be measured and assessed at the discharge of ALPS treated water into the sea will be selected in accordance with the flow shown in Figure I-8. This section gives supplementary explanations about each steps of the procedures.



*1: The decay period of the inventory evaluation is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))

*2: Nuclides that have been detected in the past are confirmed by the maximum value of the detection value, and nuclides that have never been detected are confirmed by the minimum value of the detection limit value

*3: Nuclides that shall be continuously confirmed if significantly exists in contaminated water.

Figure I-8 Flowchart for selection of nuclides to be measured and assessed for discharge of ALPS treated water into the sea

I-5-2.1 Step 1

In Step 1 “Are nuclides present in the assessment in the results of the inventory assessment? ,” nuclides will be evaluated by the criteria whether they are found to exist through the inventory assessment (if 1 Bq or more of the nuclide exists in each core of Units 1 to 3), and nuclides that are not found to exist through the assessment will be excluded.

In the selection flow, it is stated that the decay period for the inventory assessment shall be set appropriately. In the assessment this time, the decay period is set to March 2023, 12 years after the huge earthquake in 2011 when the discharge of ALPS treated water into the sea starts.

As a result, the 210 nuclides that are shown in Table I-11 were found to exist (See I-4 section for details about the inventory assessment).

Table I-11 Nuclides that were valuated in the inventory assessment (Step 1) (1/2)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*21*	Zn-65	*41*	Rh-102	*61*	Sb-126	*81*	Pr-144
2	Be-10	*22*	Se-75	*42*	Rh-102m	*62*	Sb-126m	*82*	Pr-144m
3	C-14	*23*	Se-79	*43*	Rh-106	*63*	Te-121	*83*	Nd-144
4	Na-22	*24*	Kr-81	*44*	Pd-107	*64*	Te-121m	*84*	Pm-144
5	Si-32	*25*	Kr-85	*45*	Ag-108	*65*	Te-123	*85*	Pm-145
6	P-32	*26*	Rb-87	*46*	Ag-108m	*66*	Te-123m	*86*	Pm-146
7	Cl-36	*27*	Sr-90	*47*	Ag-109m	*67*	Te-125m	*87*	Pm-147
8	Ar-39	*28*	Y-88	*48*	Ag-110	*68*	Te-127	*88*	Sm-145
9	Ar-42	*29*	Y-90	*49*	Ag-110m	*69*	Te-127m	*89*	Sm-146
10	K-40	*30*	Zr-93	*50*	Cd-109	*70*	I-129	*90*	Sm-147
11	K-42	*31*	Nb-91	*51*	Cd-113m	*71*	Cs-134	*91*	Sm-148
12	Ca-41	*32*	Nb-92	*52*	In-113m	*72*	Cs-135	*92*	Sm-149
13	Ca-45	*33*	Nb-93m	*53*	In-115	*73*	Cs-137	*93*	Sm-151
14	Sc-46	*34*	Nb-94	*54*	Sn-113	*74*	Ba-133	*94*	Eu-150
15	V-49	*35*	Mo-93	*55*	Sn-119m	*75*	Ba-137m	*95*	Eu-152
16	Mn-54	*36*	Tc-97	*56*	Sn-121	*76*	La-137	*96*	Eu-154
17	Fe-55	*37*	Tc-98	*57*	Sn-121m	*77*	La-138	*97*	Eu-155
18	Co-60	*38*	Tc-99	*58*	Sn-123	*78*	Ce-139	*98*	Gd-152
19	Ni-59	*39*	Ru-106	*59*	Sn-126	*79*	Ce-142	*99*	Gd-153
20	Ni-63	*40*	Rh-101	*60*	Sb-125	*80*	Ce-144	*100*	Tb-157

Table I-11 Nuclides that were found to exist through Step 1 (2/2)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
101	Tb-158	*123*	Tl-207	*145*	Po-216	*167*	Th-234	*189*	Pu-240
102	Dy-159	*124*	Tl-208	*146*	Po-218	*168*	Pa-231	*190*	Pu-241
103	Ho-163	*125*	Tl-209	*147*	At-217	*169*	Pa-233	*191*	Pu-242
104	Ho-166m	*126*	Pb-205	*148*	Rn-219	*170*	Pa-234	*192*	Pu-243
105	Tm-170	*127*	Pb-209	*149*	Rn-220	*171*	Pa-234m	*193*	Pu-244
106	Tm-171	*128*	Pb-210	*150*	Rn-222	*172*	U-232	*194*	Am-241
107	Lu-176	*129*	Pb-211	*151*	Fr-221	*173*	U-233	*195*	Am-242
108	Lu-177	*130*	Pb-212	*152*	Fr-223	*174*	U-234	*196*	Am-242m
109	Lu-177m	*131*	Pb-214	*153*	Ra-223	*175*	U-235	*197*	Am-243
110	Hf-182	*132*	Bi-208	*154*	Ra-224	*176*	U-236	*198*	Am-245
111	Ta-182	*133*	Bi-210	*155*	Ra-225	*177*	U-237	*199*	Cm-242
112	W-181	*134*	Bi-210m	*156*	Ra-226	*178*	U-238	*200*	Cm-243
113	Re-187	*135*	Bi-211	*157*	Ra-228	*179*	U-240	*201*	Cm-244
114	Os-194	*136*	Bi-212	*158*	Ac-225	*180*	Np-235	*202*	Cm-245
115	Ir-192	*137*	Bi-213	*159*	Ac-227	*181*	Np-236	*203*	Cm-246
116	Ir-192m	*138*	Bi-214	*160*	Ac-228	*182*	Np-237	*204*	Cm-247
117	Ir-194	*139*	Po-210	*161*	Th-227	*183*	Np-238	*205*	Cm-248
118	Ir-194m	*140*	Po-211	*162*	Th-228	*184*	Np-239	*206*	Bk-249
119	Pt-190	*141*	Po-212	*163*	Th-229	*185*	Np-240m	*207*	Cf-249
120	Pt-193	*142*	Po-213	*164*	Th-230	*186*	Pu-236	*208*	Cf-250
121	Tl-204	*143*	Po-214	*165*	Th-231	*187*	Pu-238	*209*	Cf-251
122	Tl-206	*144*	Po-215	*166*	Th-232	*188*	Pu-239	*210*	Cf-252

I-5-2.2 Step 2

In Step 2 "Whether noble gas (excluded Rn) or not?," given that noble gas nuclides generated while the reactor is in operation are not considered to exist in the core due to the release at the time of operation and the earthquake and that, even if they exists, noble gas are stable elements and therefore insoluble in the contaminated water, they are judged not to fall within the scope of nuclides to be measured and assessed at the discharge of ALPS treated water into the sea and exclude. On the other hand, radon (Rn) is considered to still exist in the core due to the decay chains of uranium, neptunium, etc. Therefore, even though Rn is noble gas, it is not excluded in this step. The noble gas nuclides identified in this step, except for Rn, are the following four nuclides, and Table I-12 shows their half-lives and biosynthetic pathways which have been confirmed as well.

Table I-12 Nuclides excluded in Step 2 and their biosynthetic pathways

Nuclides (noble)	Half-life [y]	Major biosynthetic pathway
Ar-39	2.7E+02	Produced by activation of trace component (K) in structural materials
Ar-42	3.3E+01	Produced by activation of trace component (K, Ca, etc.) in structural materials
Kr-81	2.3E+05	Produced by fission of fuel Produced by activation of trace component (Br) in structural materials
Kr-85	1.1E+02	Produced by fission of fuel

I-5-2.3 Step 3

In Step 3 "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the assessment results on the transition of nuclides to the water in the ALPS treated water, etc. storage tank?," nuclides are evaluated to see whether their impacts on the dose assessment are sufficiently small or not (1/100 or less of ratio to the regulatory concentration limit), and nuclides with sufficiently small impact on the dose assessment are excluded by this criteria. This evaluation is performed under the assumption that all of the inventory existing in the PCV will have been dissolved in ALPS treated water, etc. tanks (prediction)* as of March 2023. Therefore, given the current status confirmed through the PCV inside investigation, an adequate level of conservativeness is secured under this assumption.

*: The same timing as for the inventory assessment will be adopted.

$$\text{Concentration of nuclide } i = \text{Inventory of nuclide } i \text{ (Bq)} \div \underset{\text{1.33 million m}^3\text{ (estimated value) as of March 2023}}{\underline{\text{Amount of ALPS treated water, etc. stored (m}^3\text{)}}} < \text{Regulatory concentration limit of nuclide } i \times 0.01\ (\text{Bq/cm}^3)$$

In addition, it has been confirmed that the sum of the ratios to regulatory concentrations limits (assessed values) of the nuclides excluded in Step 3 is sufficiently small at 6.7E-02, compared to 2.4E+07, the sum of the ratios to regulatory concentrations limits (assessed values) of the nuclides that proceed to Step 4.
As a result, 93 nuclides proceed to Step 4, while 113 nuclides are excluded.

Table I-13 Nuclides that proceed to Step 4 (93 nuclides)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*46*	Ag-108m	*81*	Pr-144	*159*	Ac-227	*189*	Pu-240
3	C-14	*49*	Ag-110m	*82*	Pr-144m	*162*	Th-228	*190*	Pu-241
7	Cl-36	*50*	Cd-109	*86*	Pm-146	*164*	Th-230	*191*	Pu-242
16	Mn-54	*51*	Cd-113m	*87*	Pm-147	*165*	Th-231	*194*	Am-241
17	Fe-55	*55*	Sn-119m	*93*	Sm-151	*167*	Th-234	*195*	Am-242
18	Co-60	*56*	Sn-121	*95*	Eu-152	*168*	Pa-231	*196*	Am-242m
19	Ni-59	*57*	Sn-121m	*96*	Eu-154	*169*	Pa-233	*197*	Am-243
20	Ni-63	*59*	Sn-126	*97*	Eu-155	*172*	U-232	*199*	Cm-242
21	Zn-65	*60*	Sb-125	*104*	Ho-166m	*173*	U-233	*200*	Cm-243
23	Se-79	*61*	Sb-126	*106*	Tm-171	*174*	U-234	*201*	Cm-244
27	Sr-90	*62*	Sb-126m	*120*	Pt-193	*175*	U-235	*202*	Cm-245
29	Y-90	*67*	Te-125m	*121*	Tl-204	*176*	U-236	*203*	Cm-246
30	Zr-93	*70*	I-129	*130*	Pb-212	*177*	U-237	*208*	Cf-250
33	Nb-93m	*71*	Cs-134	*136*	Bi-212	*178*	U-238		
34	Nb-94	*72*	Cs-135	*141*	Po-212	*182*	Np-237		
35	Mo-93	*73*	Cs-137	*145*	Po-216	*183*	Np-238		
38	Tc-99	*74*	Ba-133	*149*	Rn-220	*184*	Np-239		
39	Ru-106	*75*	Ba-137m	*153*	Ra-223	*186*	Pu-236		
43	Rh-106	*79*	Ce-142	*154*	Ra-224	*187*	Pu-238		
44	Pd-107	*80*	Ce-144	*157*	Ra-228	*188*	Pu-239		

I-5-2.4 Step 4

I-5-2.4.1 Overview of evaluation of the transition of nuclides to contaminated water

In Step 4 "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the transition assessment of nuclides to contaminated water?," nuclides that have proceeded to Step 4 are grouped to the extent possible, and then "evaluation of the transition of nuclides to contaminated water" is performed using actual analysis results to check if the impact on the dose assessment is sufficiently small (1/100 or less of the regulatory concentration limit) , nuclides with a sufficiently small impact on the dose assessment are excluded in the relevant step.

Specifically, nuclides advanced to Step 4 are grouped according to their radioactive equilibrium, isotopes, the similarity of nuclide properties, etc., and the relative relationship of dose effects (inventory/regulatory concentration limit) is confirmed within the group, and nuclides with sufficiently small dose effects (relative ratio 1/100 or less) on representative nuclides are excluded. Then, based on the results of actual analysis of individual groups, the easiness of transfer into water is calculated by radionuclide (hereinafter, "transfer coefficient"). Then, the concentrations in contaminated water of individual radionuclides are evaluated using the coefficient. Concretely, the following equation is used for the evaluation.

Evaluated concentration of radionuclides in contaminated water (Bq/L) = inventory[*1] (Bq) × transfer coefficient[*2] (1/L)

[*1] In consideration of the timing when ALPS treated water is to be discharged into the sea, the evaluation result in 12 years after the earthquake is used.
[*2] Calculated by the equation of Analysis result of contaminated water (Bq/L) ÷ Inventory (Bq).
For this evaluation, the analysis date for the results of detected value is set to March 11, 2011, and the date for the results of detection limit value is set to the actual analysis date.

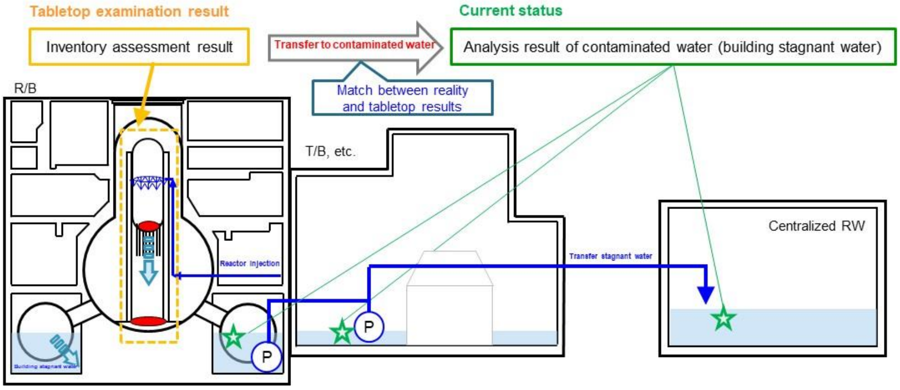


Figure I-9 Image of the evaluation of transfer to contaminated water

Here, the reason why the relative ratio of the dose effect to the representative nuclides in the group is set at 1/100 or less, and for the transfer evaluation to contaminated water, it is set at 1/100 or less of the regulatory concentration limit, is that the dose effect of the nuclides is sufficiently small. For each, it was confirmed that in the case of the relative ratio, the dose effect of the nuclides to be excluded was 0.09% of the total, and in the assessment of the transition of nuclides to contaminated water, the sum of the ratios to regulatory concentrations limits (evaluation) of the nuclides to be excluded was sufficiently small at 3.6E-02 as compared with the sum of the ratios to regulatory concentrations limits (evaluation) 7.7E+07 of the nuclides to be advanced to Step 5.
In addition, since the sites to be assessed in this assessment are the stagnant water in buildings and the strontium removed water before treatment by ALPS, even if the total dose effect (assessed value) of the nuclides excluded in this step exceeds 1/100, the dose effect is considered to be negligibly small considering the subsequent treatment by ALPS.

I-5-2.4.2 Analysis results to be used for the evaluation of the transition of nuclides to contaminated water

As shown in Table I-14 and Figure I-10, the analysis results to be used in the calculation of the transfer coefficient were classified and summarized into four types. Since all contaminated water is collected in Centralized Rw (Process Main Building (PMB), High Temperature Incinerator Building (HTI)) and then treated with cesium adsorption system (SARRY/SARRY2), and this water finally becomes ALPS treated water. Therefore, the analysis results of Centralized Rw will be used in principle. However, only with the analysis results of Centralized Rw, it is impossible to obtain data on all radionuclides, and due to the reason that detection limits are high for building stagnant water because Cs concentration is high, available data on some nuclides is not enough. Therefore, as for those nuclides, analysis results of Units 1 to 4 building stagnant water, etc. and water before ALPS treatment will be used to complement the data.

Table I-14 Classification of analysis results

No.	Classification of analyses	Details
(1)	Stagnant water in Unit 1 to 4 buildings	Analysis results of stagnant water in Unit 1 to 4 PCVs and buildings
(2)	Stagnant water in Centralized Rw building	Analysis results of water in Centralized Rw (PMB/HTI), at the inlet of SARRY, etc.
(3)	Cesium adsorption system - inlet of ALPS	Analysis results of water from the outlet of cesium adsorption system to the inlet of ALPS
(4)	Outlet of ALPS	Analysis results of water after ALPS treatment

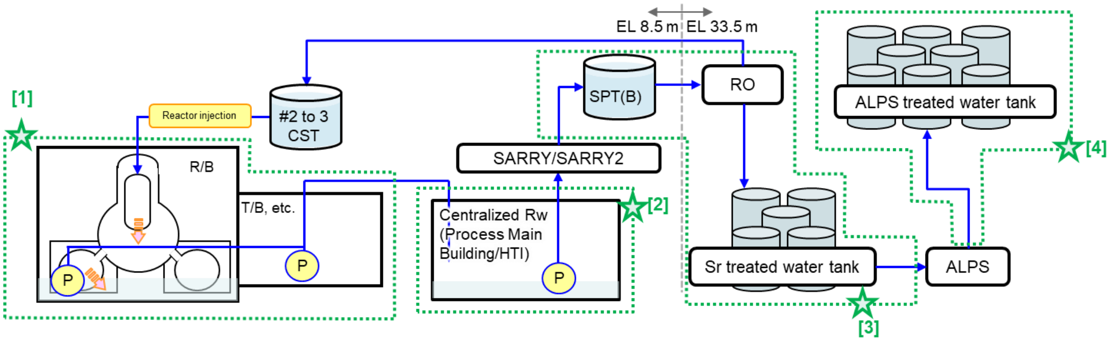
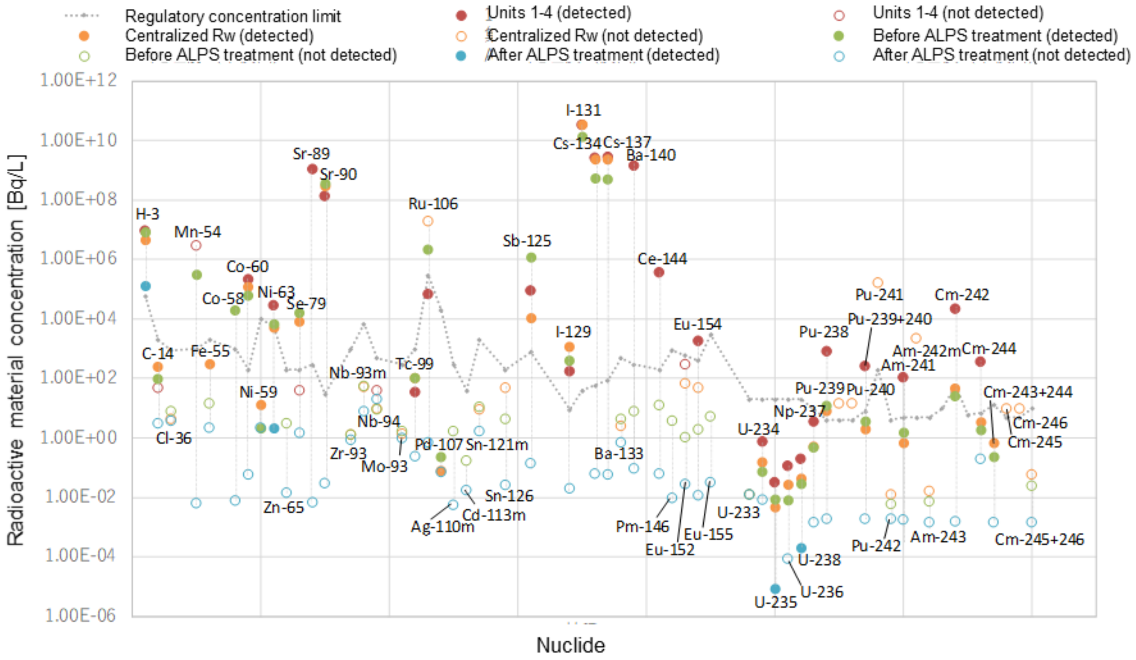


Figure I-10 Classification of analysis results to be used for the evaluation of transfer

The data is classified according to the sampling locations shown in Table I-14, and analysis results of the radionuclides which proceeded to Step 4 (including detected values of isotopes with a short half-life) is summarized in Figure I-11. In Figure I-11, the detected values for No.(1) to (3) in Table I-14 are the maximum values which have been corrected decay until March 11, 2011, while non-detected values are minimum values of the analytical data. The values for No.(4) are minimum values of the analysis results. For nuclides that have never been detected in the past, the minimum values of the analytical data are used because although the detection limit indicates that there is a possibility of the presence at a concentration lower than that value, it guarantees that it cannot be higher than the concentration. Therefore, if the nuclide has never been detected in the past, even if it is assessed with the minimum detection limit among the analytical results, it is considered sufficiently conservative.

The figure shows the concentration ranges of individual radionuclides throughout the process from building stagnant water to ALPS treated water. It shows regulatory concentration limits as well to enable the comparison of the analysis results with regulatory limits. The data used in this evaluation of migration to contaminated water are shown in Reference-1.



*1: Sr -89 was detected at the inlet of the existing ALPS between 2013 and 2014, and Pm -146 was detected at the inlet of the high-performance ALPS in 2014. However, this is not subject to evaluation because it is a pseudo detection.

*2: For the FRAnDLi data on Pu-238, Am-241, and Cm-242, the analyzed values were simply decay corrected up to March 11, 2011. However, given that those nuclides are produced from parent nuclides, decay correction that takes into account the production of the parent nuclides was performed.

Figure I-11 Summary of analysis results

Figure I-11 is developed using the following data: FRAnDLi data published by JAEA that are available in September 2022 (including data published by TEPCO), analyses of 62 nuclides at the time of ALPS performance confirmation, etc. (FY 2013 to 2021), data of water before and after ALPS treatment which is available on the treated water portal, data of ALPS treated water, etc. tanks, etc. When using data on detection limits, only data which shows detection limit values is included in the aggregation, while data which only shows “N.D.” is excluded. Table I-15 shows the number of pieces of analytical data for each radionuclide. *

* Te-123m (half-life: 119 days), which didn’t proceed to step 4, was detected at the outlet of additional ALPS (B) on September 9, 2019 and its concentration was 1.1E-01Bq/L that was less than 1/100 of regulatory concentration limit (6.0E+01Bq/L) (the detection limit was 0.9E-01Bq/L).

Table I-15 Number of analyzed data (1/2)

Nuclide	(1) Units 1 - 4	(2) Centralized Rw	(3) Before ALPS treatment	(4) After ALPS treatment
	Number of data items (number of items detected)	Number of data items (number of items detected)	Number of data items (number of items detected)	Number of data items (number of items detected)
H-3	22(22)	28(28)	312(312)	483(483)
C-14	5(0)	15(1)	27(15)	339(338)
Cl-36	0(0)	10(0)	12(0)	3(0)
Mn-54	2(0)	0(0)	1195(290)	1893(14)
Fe-55	0(0)	1(1)	1(0)	3(0)
Co-58	0(0)	0(0)	27(5)	42(0)
Co-60	40(20)	37(25)	1569(1405)	2321(2177)
Ni-59	0(0)	3(1)	12(1)	3(0)
Ni-63	13(10)	17(15)	93(49)	55(1)
Zn-65	0(0)	0(0)	22(0)	42(0)
Se-79	10(0)	15(9)	47(12)	5(0)
Sr-89	4(3)	0(0)	66(17[15])	128(0)
Sr-90	41(40)	36(36)	845(834)	1773(768)
Zr-93	0(0)	1(0)	1(0)	3(0)
Nb-93m	0(0)	1(0)	1(0)	3(0)
Nb-94	36(0)	33(0)	68(0)	5(0)
Mo-93	0(0)	1(0)	1(0)	3(0)
Tc-99	5(2)	17(7)	247(222)	896(105)
Ru-106	6(1)	2(0)	1256(974)	2369(1425)
Pd-107	0(0)	1(1)	1(1)	1(0)
Ag-110m	0(0)	0(0)	22(0)	42(0)
Cd-113m	0(0)	0(0)	22(0)	42(0)
Sn-121m	0(0)	1(0)	1(0)	3(0)
Sn-126	0(0)	2(0)	34(0)	44(0)
Sb-125	27(9)	10(9)	1619(1606)	2369(1583)
I-129	22(4)	30(10)	450(381)	1833(1558)
I-131	4(0)	16(2)	43(22)	0(0)

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[15] The results show that Sr-89 was detected at the inlet of existing ALPS during the period from 2013 to 2014, but it was excluded from the evaluation because it is a pseudo detection

Corrected part is displayed as underlined.

Table I-15 Number of analyzed data (2/2)

Nuclide	[1] Units 1 - 4	[2] Centralized Rw	[3] Before ALPS treatment	[4] After ALPS treatment
	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)
Cs-134	190(190)	260(260)	1503(1262)	2377(360)
Cs-137	224(224)	296(296)	1746(1700)	2382(1505)
Ba-133	0(0)	1(0)	2(0)	6(0)
Ba-140	4(2)	0(0)	22(0)	42(0)
Ce-144	3(3)	0(0)	22(0)	42(0)
Pm-146	0(0)	0(0)	22(1[16])	42(0)
Eu-152	36(0)	36(0)	93(0)	44(0)
Eu-154	38(2)	36(0)	114(0)	47(0)
Eu-155	0(0)	0(0)	22(0)	42(0)
U-233	0(0)	3(0)	8(0)	3(0)
U-234	25(7)	19(11)	22(7)	3(0)
U-235	26(19)	19(14)	44(14)	6(3[17])
U-236	20(7)	19(12)	22(8)	3(0)
U-238	31(26)	19(17)	44(20)	6(3[17])
Np-237	9(9)	13(9)	16(7)	3(0)
Pu-238	38(17)	37(22)	73(16)	8(0)
Pu-239	0(0)	1(0)	0(0)	0(0)
Pu-240	0(0)	1(0)	0(0)	0(0)
Pu-239+240	38(12)	36(12)	73(10)	8(0)
Pu-241	0(0)	1(0)	0(0)	0(0)
Pu-242	0(0)	4(0)	8(0)	3(0)
Am-241	37(11)	37(6)	62(3)	7(0)
Am-242m	0(0)	1(0)	0(0)	0(0)
Am-243	0(0)	3(0)	8(0)	3(0)
Cm-242	7(2)	1(1)	2(1)	3(0)
Cm-244	37(7)	36(2)	61(6)	4(0)
Cm-243+244	0(0)	1(1)	1(1)	3(0)
Cm-245	0(0)	1(0)	0(0)	0(0)
Cm-246	0(0)	1(0)	0(0)	0(0)
Cm-245+246	0(0)	1(0)	1(0)	3(0)

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[16] The results show that Pu-146 was detected at the inlet of high-performance ALPS in 2014, but it was excluded from the evaluation because it is a pseudo-detection.

[17] Natural uranium contained in ALPS treated water was detected (See section I-3)

I-5-2.4.3 Grouping of nuclides

I-5-2.4.3.1 Concept behind the grouping of nuclides

(1) Progeny nuclides in radioactive equilibrium

Among the nuclides which have proceeded to Step 4, nuclides that exist in the radioactive equilibrium are shown in Tables I-16 and I-17. The progeny nuclides shown in Table I-16 have short half-lives, and in 12 years after the earthquake when ALPS treated water is set to be discharged into the sea, they exist only as nuclides produced by decay of parent nuclides. Therefore, in the evaluation of transfer to contaminated water, they are assumed to behave together with the parent nuclides. In the meantime, the discharge of the treated water is planned to be completed by the period of about 7 - 10 times the half-life of the progeny nuclide shown in Table I-17, in which the half-life of the progeny nuclide is long, and the parent nuclide and the progeny nuclide are in the radioactive equilibrium. Based on this, in this evaluation, the parent nuclides and the progeny nuclides are assessed separately.

Table I-16 Progeny nuclides that are in radioactive equilibrium and assumed to behave together with the parent

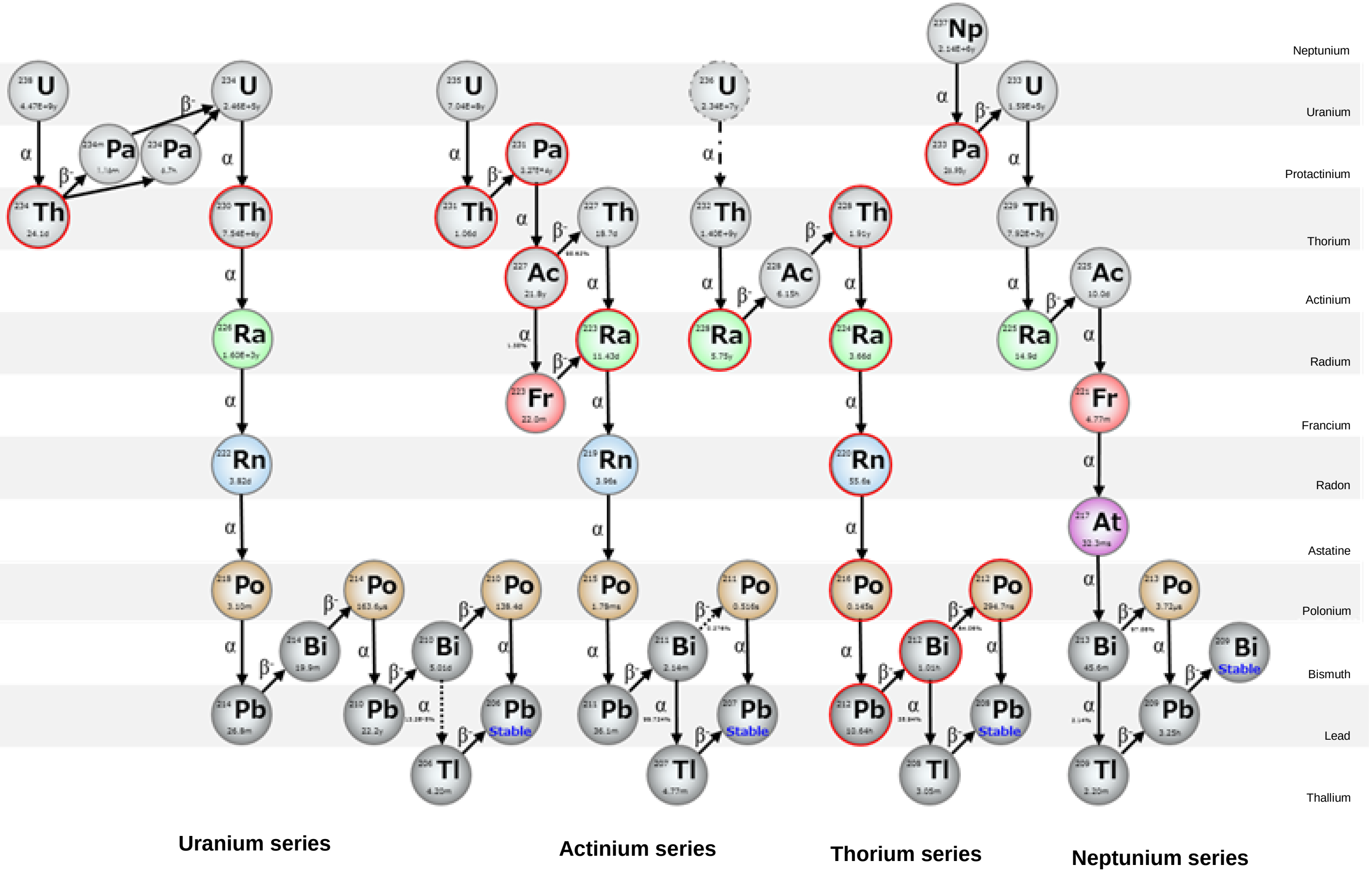
No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Sr-90	2.9E+01 [y]	Y-90	2.67 [d]
2	Ru-106	1.0E+00 [y]	Rh-106	30.07 [s]
3	Sn-121m	4.4E+01 [y]	Sn-121	1.13 [d]
4	Sn-126	2.3E+05 [y]	Sb-126 Sb-126m	12.35 [d] 19.15 [m]
5	Sb-125	2.8E+00 [y]	Te-125m	57.40 [d]
6	Cs-137	3.0E+01 [y]	Ba-137m	2.552 [m]
7	Ce-144	7.8E-01 [y]	Pr-144 Pr-144m	17.28 [m] 7.2 [m]
8	Pu-241	1.4E+01 [y]	U-237	6.752 [d]
9	Am-242m	1.4E+02 [y]	Np-238	2.117 [d]
10	Am-242m	1.4E+02 [y]	Am-242 Cm-242	16.02 [h] 162.9 [d]
11	Am-243	7.4E+03 [y]	Np-239	2.356 [d]

Table I-17 Progeny nuclides that are in radioactive equilibrium but assumed to behave differently with the parent

No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Zr-93 Mo-93	1.6E+06 [y] 4.0E+03[y]	Nb-93m	1.6E+01 [y]

(2) Nuclides produced from decay chains of uranium, neptunium, etc.

Among the nuclides which have proceeded to Step 4, the nuclides shown in red frames in Figure I-12 are nuclides produced from decay chains of uranium, neptunium, etc. In the evaluation of the transition of nuclides to contaminated water, those nuclides will be evaluated under assumption that they are behaving together with the parent nuclides (Neptunium and Uranium).



*: Compiled from the Nuclear Data Library (JENDL4.0).

Figure I-12 Nuclides produced from decay chains of uranium, neptunium, etc.

(3) Isotope

Of the nuclides advanced to Step 4, the nuclides that exist as isotopes regardless of (1) and (2) are shown in Table I-18.

Isotopes refer to nuclides with the same number of protons and a different number of neutrons. Since the chemical properties of materials are determined by the number of the outermost electrons, the chemical properties of isotopes with the same number of electrons are almost the same. Therefore, in assessing the transition fo nuclides to contaminated water, each isotope will be evaluated, assuming that they behave together.

Figure I-18 Nuclides that are assessed to behave together because of their isotopes

No.	Element	Nuclide
1	Ni isotope	Ni-59,Ni-63
2	Nb isotope	Nb-93m,Nb-94
3	Ag isotope	Ag-108m,Ag-110m
4	Cd isotope	Cd-109,Cd-113m
5	Sn isotope	Sn-119m,Sn-121m,Sn-126
6	Cs isotope	Cs-134,Cs-135,Cs-137
7	Ce isotope	Ce-142,Ce-144
8	Pm isotope	Pm-146,Pm-147
9	Eu isotope	Eu-152,Eu-154,Eu-155
10	U isotope	U-232,U-233,U-234,U-235,U-236,U-238
11	Pu isotope	Pu-236,Pu-238,Pu-239,Pu-240,Pu-241,Pu-242
12	Am isotope	Am-241,Am-242m,Am-243
13	Cm isotope	Cm-243,Cm-244,Cm-245,Cm-246

(4) Nuclides showing similarities in characteristics underwater

In addition to nuclides in (1), (2) and (3),there are nuclides for which there is no available analytical data because analytical techniques have not been established as of 2022, because it is difficult to analyze individually, or for other reasons. These nuclides are evaluated as having characteristics similar to those of the nuclides with which the similarity has been confirmed after the similarity of chemical forms of nuclides in water (using the Eh-pH figure[18], etc.), ionic radii, adsorption characteristics in water treatment, etc. is confirmed.

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[18] The Eh-pH diagram shows the change of dissolved dominant chemical species and solid species in an aqueous solution given chemical composition with Eh and pH on the vertical and horizontal axes, respectively, as a function of Eh and pH. This time, it was used to confirm the similarity of the underwater chemical behavior of nuclides, and the actual dissolved form in ALPS treated water is not shown in this figure

(i) Lanthanoids (Pm, Sm, Ho, Tm)

As lanthanoids to be removed by ALPS, Ce-141, Ce-144, Pm-146, Pm-148, Pm-148m, Eu-152, Eu-154, Eu-155, Gd-153, Tb-160 are analyzed and evaluated. However, they have never been detected in the analyses of water before ALPS treatment. Eu-152 and Eu-154 have not been detected in stagnant water in buildings in approximately 80 analyses performed in the past. On the other hand, Ce-144 and Eu-154 have been detected in samples of PCV stagnant water, which were collected during past internal investigations in Unit 2 and 3 PCVs.

This data on Ce-144 and Eu-154, which were detected in the PCVs, will be used for this evaluation of the transition of nuclides to contaminated water for other lanthanoids, too. Therefore, the validity was checked with Eh-pH figures.

The verification has revealed that lanthanoids have a similarity in that they are stable trivalent cations at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and building stagnant water (see Figure I-13). Rare earth ions, including lanthanoids, generally have respective similar chemical properties and behaviors, and they are produced together in minerals, and it is difficult to separate them from each other during the refining process19[19]. Therefore, assessing all lanthanoids as the same group is considered appropriate.

The transfer coefficients of Ce-144 and Eu-154, which belong to this group and have been analyzed, were evaluated in Section I-5-2.4.4, which will be described later, and it was confirmed that they were almost the same value and that they actually behaved similarly in the FDNPS.

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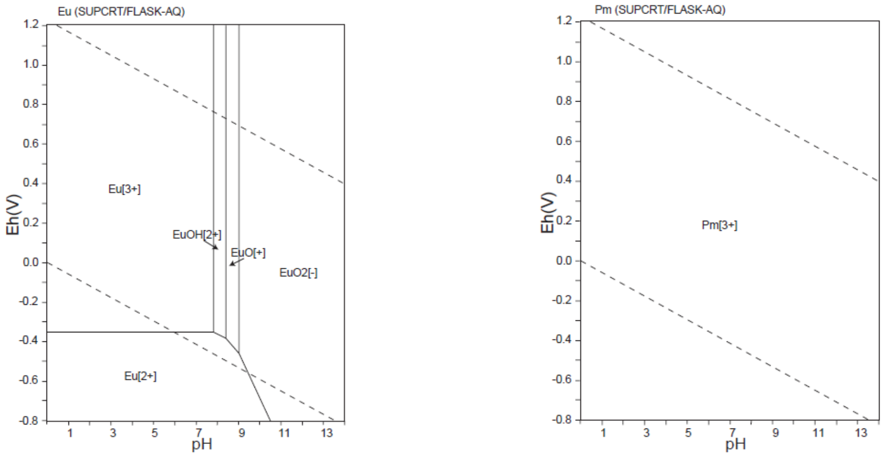
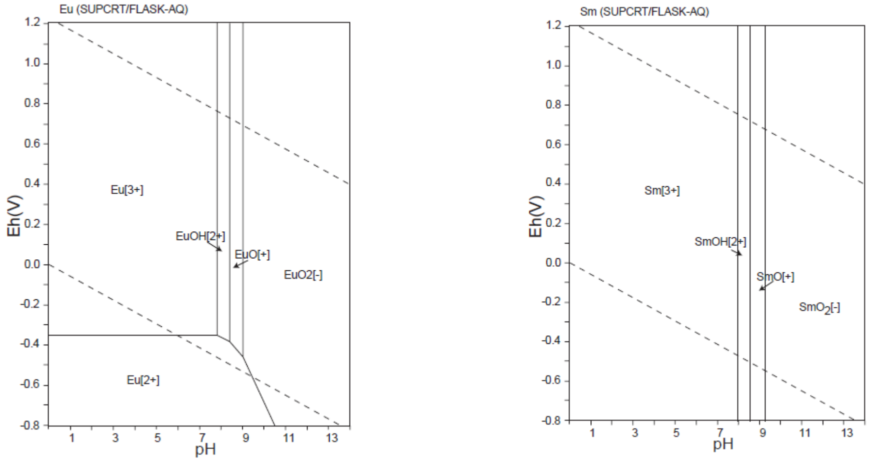
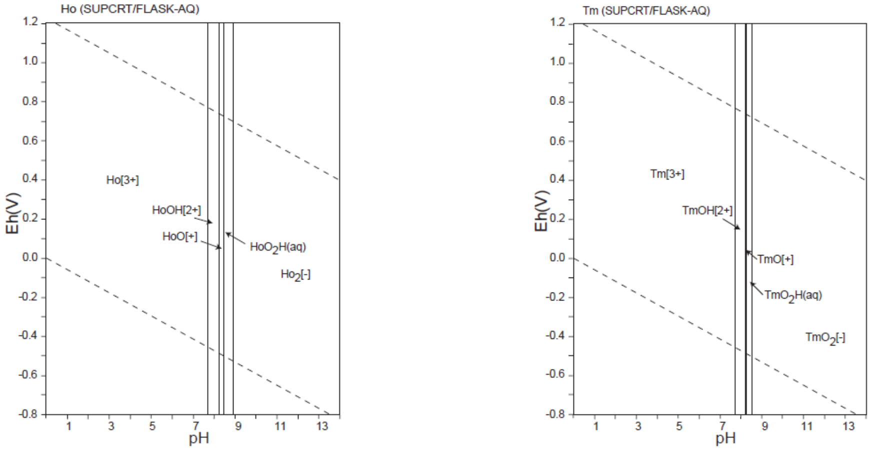
[19] Jiro Shiokawa, "Characteristics of Rare Earth Elements and Their Applications"



(1) Cerium (Ce)　(2) Promethium (Pm)



(3) Europium (Eu)　(4) Samarium (Sm)



(5) Holmium (Ho)　(6) Thulium (Tm)

Source: Takeno Naoto, Eh-pH Atlas - Intercomparison of the thermodynamics database, Geological Survey of Japan, research material No. 419, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (2005)

Cited thermodynamics database:

- Johnson, J.W., Oelkers, E.H. and Helgeson, H.C., SUPCRT92 - A software package for calculating the standard molal thermodynamic properties of minerals, gases, aqueous species, and reactions from 1-bar to 5000-bar and 0°C to 1000°C. Computer and Geosciences 18, 899-947(1992)

Figure I-13 Comparison of lanthanoids

(ii) Platinum group (Ru, Pd, Pt)

As for the platinum group, Ru-103 (Rh-103m) and Ru-106 (Rh-106) have been analyzed as nuclides to be removed by ALPS, and Ru-106 (Rh -106) has been detected so far (both of the Rh are produced from the decay of Ru). Ru-106 has been selected as one of the seven main nuclides, which are representative nuclides for the performance check of ALPS. Additionally, Pd-107 was analyzed through the additional analysis shown in section I-3, and it was found to exist at a very low concentration in stagnant water in buildings and strontium removed water. Although Pt-193 has proceeded to Step 4, it has yet to be analyzed due to the lack of a measurement method that can measure the nuclide independently.

Therefore, when evaluating the transfer of Pt to contaminated water based on the analysis results of Ru-106 and Pd-107, the validity was checked with Eh-pH diagrams and solubility. The verification has revealed that the platinum group exists in a solid state at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and stagnant water in buildings (see Figure I-14). Ru was found to exist as a single metal or solid of oxides, and Pd and Pt as solids of single metals. Their solubility in water was found to be very small: 2.0E-10 mol/L[20] for Ru (single metal), 6.0E-10 mol/L[20] for Ru (oxides), 1.0E-09 mol/L[21] for Pd, 4.1E-10 mol/L[20] for Pt. (The solubility of Ru (oxides) was calculated based on values mentioned in reference documents and from the solubility of anhydrous compounds, which is the most conservative solubility.) Given that the physical and chemical properties of platinum group elements are generally similar to one another and that they do not react with water and are not easily affected by acids and bases, it is appropriate to handle Pt-193 together with Ru-106 and Pd-107 as one group in evaluating the transfer to contaminated water.

The transfer coefficients of Ru-106 and Pd-107, which belong to this group and have been analyzed, were evaluated in Section I-5-2.4.4, which will be described later, and it was confirmed that they were almost the same value and that they actually behaved similarly in the FDNPS.

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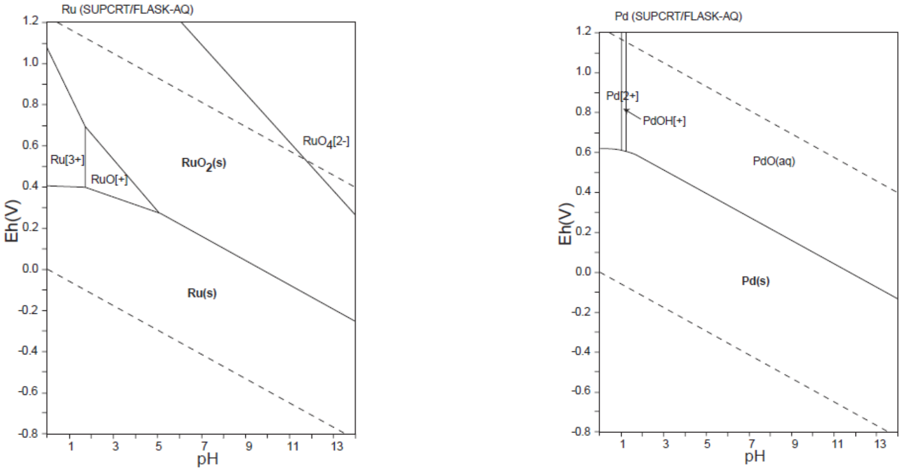
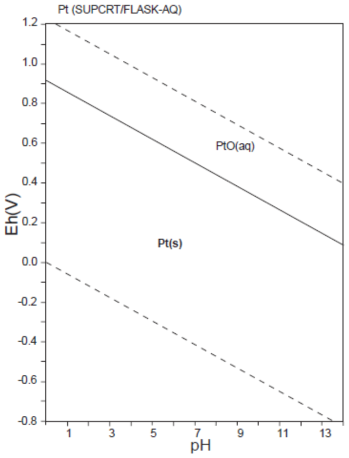
[20] Excerpt from “The International Platinum Group Metals Association, “Safe Use of Platinum Group Metals in the Workplace”, Chapter 2 PHYSICAL AND CHEMICAL PROPERTIES OF PLATINUM GROUP METALS (2017)”

[21] Excerpt from “Technical reliability of geological disposal of high-level radioactive waste in Japan - second summary of research and development on geological disposal -” (2000 Report)



(1) Ruthenium (Ru) (2) Palladium (Pd)



(3) Platinum (Pt)

Source: Takeno Naoto, Eh-pH Atlas - Intercomparison of the thermodynamics database, Geological Survey of Japan, research material No. 419, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (2005)

Cited thermodynamics database:

- Johnson, J.W., Oelkers, E.H. and Helgeson, H.C., SUPCRT92 - A software package for calculating the standard molal thermodynamic properties of minerals, gases, aqueous species, and reactions from 1-bar to 5000-bar and 0°C to 1000°C. Computer and Geosciences 18, 899-947(1992)

Figure I-14 Comparison among platinum group elements

(iii) Thallium (Tl)

As for thallium, although Tl-204 has proceeded to Step 4, it has yet to be analyzed due to the lack of a measurement method that can measure the nuclide independently. However, this nuclide generally emits beta particles when disintegrating, and the energy is as high as about 760 keV. Considering that there is no deviation between the result of total beta analysis in ALPS treated water and the analysis of the major seven nuclides plus Tc-99 and C-14, it is reasonable to conclude that the nuclide does not exist in ALPS treated water at a significant concentration.

On the other hand, through the survey performed this time when evaluating transfer to contaminated water, Tl was found to have properties similar to alkali metal (Cs). Therefore, the validity will be explained with Eh-pH figures, ion radius, and adsorption properties during treatment.

Checking the Eh-pH figures has revealed that Tl, which is element 13, is a stable monovalent cation at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and stagnant water in buildings (See Figure I-15). In addition, the radius of TI ion, which is 1.64 Å (6-coordinate) and 1.73 Å (8-coordinate), is in between the radius of alkali metal Cs ion, 1.81 Å (6-coordinate) and 1.81 Å (8-coordinate), and that of K ion, 1.51 Å (4-coordinate), 1.52Å (6-coordinate), and 1.65 Å (8-coordinate); the selectivity of positive ions using zeolite has been evaluated as equal to that of alkali metal K ions*1. It is also known[22] that TI ions in waste liquid generated in mines are adsorbed to ferrocyanide compounds, activated carbon, titanic acid, and clay minerals in the same way as Cs ions, and a report[23] says they have the same level of adsorption property as Cs to soil[24].

Given the above, it is reasonable to evaluate Tl together with alkali metals as the same group while assuming that it will behave in the same way throughout the process from the transfer to contaminated water to water treatment.

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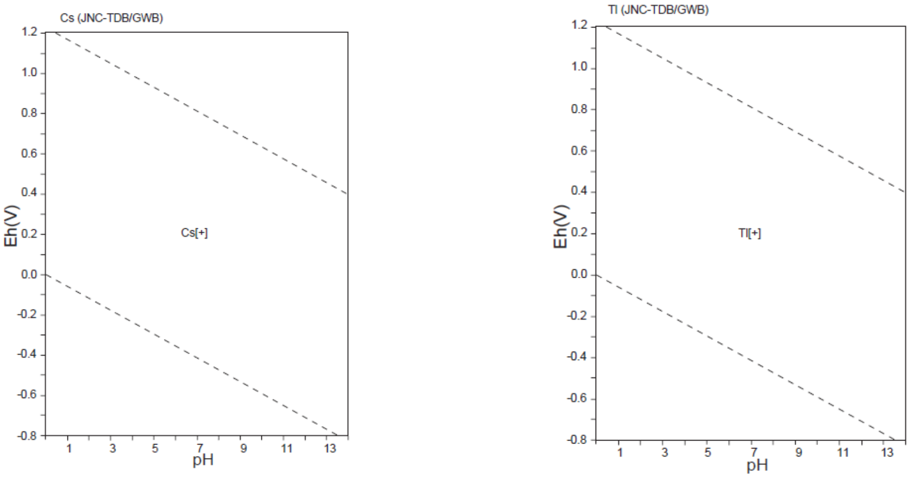
[22] Nitta and Aomura, "Study on the Site Selectivity of Exchangeable Cation in Synthetic Zeolite A"

[23] Hariyin Xu, Yuanling Luo, et al."Removal of thallium in water-wastewater", 2019-Water Research
Juan Liu, Xuwen Luo, et al."hallium pollution in China and removal technologies for waters", 2019-Environment International
L.G.Twidwell, C. Williams-Beam, "Potential Technologies for Removing Thallium from Mine and Process Wastewater", Twidwell2002
Kobayashi, Yamamoto, and Akashi, “Prussian Blue as an Agent for Decontamination of 137-Cs in Radiation Accidents”

[24] John E. Till, Helen A. Grogan, "Radiobiological Risk Assessment and Environmental Analysis" Oxford University Press (2008).



(1) Cesium (Cs) (2) Thallium (Tl)

Source: Takeno Naoto, Eh-pH Atlas - Intercomparison of the thermodynamics database, Geological Survey of Japan, research material No. 419, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (2005)

Cited thermodynamics database:

- Yoshida Yasushi, Yui Miwa, JNC Thermodynamic Database Available for Geochemical Computational Codes, JNC TN8400 2003-005, Japan Nuclear Cycle Development Institute (2003)
- Yasushi Yoshida, Masahiro Shibata, Development of an Environment Using a Thermodynamic Database Prepared by OECD/NEA Part 2, JNC TN8400 2004-025, Japan Nuclear Cycle Development Institute (2005)

Figure I-15 Comparison between thallium and cesium

(iv) Californium (Cf)

As for californium, although Cf-250 has proceeded to Step 4, no analysis has been performed. However, this nuclide emits alpha particle when disintegrating. Considering that it was not detected in the ALPS treated water in the gross α analysis, it is reasonable to conclude that the nuclide does not exist in ALPS treated water at a significant concentration. On the other hand, based on the analytical results of Am and Cm, in assessing the transfer of Cf to contaminated water, the validity was checked by confirming the dissolution form in water and ionic radius, etc.

For Cf although it was impossible to check the validity with Eh-pH figures, it is considered a stable trivalent cation in a solution whose chemical behavior is very similar to that of trivalent transplutonium elements[25] (Am, Cm). It has also been confirmed that the trivalent cations, Am, Cm, and Cf, have almost the same radii: 1.12 Å (6-coordinate), 1.11 Å (6-coordinate), and 1.09 Å (6-coordinate)[26] respectively.

Given the above, it is reasonable to evaluate the transfer of Cf to contaminated water together with Am and Cm as one group.

The transfer coefficients of Am-241, Cm-242, and Cm-244, which belong to this group and have been analyzed, were evaluated in Section I-5-2.4.4, which will be described later, and found to be almost the same values. It has been confirmed that this group actually behaves similarly even in the FDNPS.

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[25] Laster R.Morss, Norman M.Edelstein, Jean Fuger, "The Chemistry of The Actinide And Transactinide Elements_4thEd"

[26] R.D. Shannon, "Revised Effective Ionic Radii and Systematic Studies of Interatomic Distances in Halides and Chalcogenides"

I-5-2.4.3.2 Results of the grouping of nuclides

Tables I-19 to I-35 show the nuclide groups obtained as a result of the grouping in Step 4 based on the concept behind the grouping of nuclides which are shown in section I-5-2.4.3.1. The nuclides in one group will be evaluated while assuming that they will behave in the same way throughout the process up to ALPS treatment. As explained in (2), the nuclides produced in the uranium, actinium, and thorium series are evaluated as a subgroup of uranium isotopes because they are considered to behave together with the original uranium. Additionally, except for the nuclides shown here, nuclides cannot be grouped, and the transfer to the contaminated water is assessed individually.

Nuclides that have been classified into a group will be compared with the representative nuclide that has the largest impact on the dose assessment among the nuclides in the group. If the relative ratio of a nuclide to the representative one (ratio of inventory/ regulatory concentration limit) is 1/100 or less, it will be excluded.

In addition, as explained in section I-4, there is uncertainty in the inventory evaluation of activation products (AP) on the conservative side. Therefore, if fission products (FP) and AP are mixed in the group, FP is selected as the representative nuclide for this evaluation. This prevents the evaluation of the relative ratio from becoming unconservative due to the uncertainty of the assessment.

Table I-19 Group 1 (Ni isotopes)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ni-59	AP	7.6E+04 [y]	7.3E+13	1.0E+04	0.0052	Excluded
Ni-63	AP	1.0E+02 [y]	8.5E+15	6.0E+03	1	Representative nuclide

Table I-20 Group 2 (Sr-90 radioactive equilibrium)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sr-90	FP	2.9E+01 [y]	3.9E+17	3.0E+01	1	Representative nuclide
Y-90	FP	2.67 [d]	3.9E+17	3.0E+02	0.10	

Table I-21 Group 3 (Nb isotopes)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Nb-93m	FP	1.6E+01 [y]	6.3E+12	7.0E+03	1	Representative nuclide
Nb-94	AP	2.0E+04 [y]	9.0E+11	5.0E+02	2	

Table I-22 Group 4 (Platinum group, Ru-106 radioactive equilibrium)

Nuclide	Type	Half-life	Inventory amount (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ru-106	FP	1.0E+00 [y]	7.5E+14	1.0E+02	1	Representative nuclide
Rh-106	FP	30.07 [s]	7.6E+14	3.0E+05	0.00033	*Excluded*
Pd-107	FP	6.5E+06 [y]	6.1E+11	2.0E+04	0.0000041	*Excluded*
Pt-193	AP	5.0E+01 [y]	9.7E+12	3.0E+04	0.000043	*Excluded*

TableI-23 Group 5 (Ag isotope)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ag-108m	AP	4.4E+02 [y]	1.7E+11	4.0E+02	1.5	
Ag-110m	FP	249.8 [d]	8.8E+10	3.0E+02	1	Representative nuclide

TableI-24 Group 6 (Cd isotope)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Cd-109	AP	1.3E+00[y]	3.6E+10	4.0E+02	0.000044	Excluded
Cd-113m	FP	1.4E+01 [y]	8.2E+13	4.0E+01	1	Representative nuclide

Table I-25 Group 7 (Sn isotopes, Sn-126 radioactive equilibrium)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sn-119m	AP	293.1 [d]	5.9E+10	2.0E+03	0.00065	Excluded
Sn-121	FP	1.13 [d]	7.1E+13	4.0E+03	0.39	
Sn-121m	FP	4.4E+01 [y]	9.1E+13	2.0E+03	1	Representative nuclide
Sn-126	FP	2.3E+05 [y]	1.6E+12	2.0E+02	0.18	
Sb-126	FP	12.35 [d]	2.3E+11	4.0E+02	0.012	
Sb-126m	FP	19.15 [m]	1.6E+12	2.0E+04	0.0018	Excluded

TableI-26 Group 8 (Sb-125 radioactive equilibrium)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sb-125	FP	2.8E+00 [y]	2.9E+15	8.0E+02	1	Representative nuclide
Te-125m	FP	57.40 [d]	1.1E+15	9.0E+02	0.33	

Table I-27 Group 9 (Cs isotopes, Cs-137 radioactive equilibrium, Tl-204)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Cs-134	FP+ AP	2.1E+00 [y]	2.5E+16	6.0E+01	0.070	
Cs-135	FP	2.3E+06 [y]	3.5E+12	6.0E+02	0.00000099	Excluded
Cs-137	FP	3.0E+01 [y]	5.3E+17	9.0E+01	1	Representative nuclide
Ba-137m	FP	2.552 [m]	5.0E+17	8.0E+05	0.00011	Excluded
Tl-204	AP	3.8E+00 [y]	1.4E+13	7.0E+02	0.0000035	Excluded

Table I-28 Group 10 (Lanthanoids)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ce-142	FP	5.0E+16 [y]	1.8E+08	7.0E-01	0.0000083	*Excluded*
Ce-144	FP	284.91 [d]	1.7E+14	2.0E+02	0.027	
Pr-144	FP	17.28 [m]	1.7E+14	2.0E+04	0.00027	*Excluded*
Pr-144m	FP	7.2 [m]	2.5E+12	4.0E+04	0.000002	*Excluded*
Pm-146	FP	5.5E+00 [y]	3.6E+12	9.0E+02	0.00013	*Excluded*
Pm-147	FP	2.6E+00 [y]	5.6E+16	3.0E+03	0.59	
Sm-151	FP	9.0E+01 [y]	2.2E+15	8.0E+03	0.0085	*
Eu-152	FP	1.4E+01 [y]	9.0E+12	6.0E+02	0.00048	*Excluded*
Eu-154	FP	8.6E+00 [y]	1.3E+16	4.0E+02	1	Representative nuclide
Eu-155	FP	4.8E+00 [y]	3.8E+15	3.0E+03	0.04	
Ho-166m	AP	1.2E+03 [y]	2.6E+10	4.0E+02	0.000002	*Excluded*
Tm-171	AP	1.9E+00 [y]	5.3E+12	7.0E+03	0.000024	*Excluded*

* Not excluded because it has a longer half-life than the representative nuclide Eu-154 and the relative ratio exceeds 0.01 during the discharge period.

Table I-29 Group 11 (U isotopes)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
U-232	FP	6.9E+02 [y]	1.2E+11	3.0E+00	0.06	
U-233	FP	1.6E+05 [y]	4.0E+08	2.0E+01	0.00003	Excluded
U-234	FP	2.5E+05 [y]	1.4E+13	2.0E+01	1	Representative nuclide
U-235	FP	7.0E+08 [y]	3.7E+11	2.0E+01	0.027	
U-236	FP	2.3E+07 [y]	2.0E+12	2.0E+01	0.15	
U-238	FP	4.5E+09 [y]	3.0E+12	2.0E+01	0.22	

Table I-30 Group 11-1 (Uranium decay series)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
U-238	FP	4.5E+09 [y]	3.0E+12	2.0E+01	0.22	
Th-234	FP	24.1 [d]	3.0E+12	2.0E+02	0.022	
U-234	FP	2.5E+05 [y]	1.4E+13	2.0E+01	1	
Th-230	FP+AP	7.5E+04 [y]	2.4E+09	4.0E+00	0.00089	Excluded

Table I-31 Group 11-2 (Actinium decay series)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
U-235	FP	7.0E+08 [y]	3.7E+11	2.0E+01	0.027	
Th-231	FP	1.063 [d]	3.7E+11	2.0E+03	0.00027	Excluded
Pa-231	FP	3.3E+04 [y]	2.6E+08	1.0E+00	0.00038	Excluded
Ac-227	FP	2.2E+01 [y]	7.2E+07	8.0E-01	0.00013	Excluded
Ra-223	FP	11.43 [d]	7.2E+07	5.0E+00	0.000021	Excluded

TableI-32 Group 11-3 (Thorium decay series)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
U-236	FP	2.3E+07 [y]	2.0E+12	2.0E+01	0.15	
Ra-228	AP	5.8E+00 [y]	1.8E+07	7.0E-01	0.000038	Excluded
Th-228	FP	1.9E+00 [y]	1.2E+11	9.0E+00	0.019	
Ra-224	FP	3.66 [d]	1.2E+11	9.0E+00	0.019	
Rn-220	FP	55.6 [s]	1.2E+11	4.0E+03	0.000044	Excluded
Po-216	FP	0.145 [s]	1.2E+11	4.0E+03	0.000044	Excluded
Pb-212	FP	10.64 [h]	1.2E+11	1.0E+02	0.0017	Excluded
Bi-212	FP	1.01 [h]	1.2E+11	3.0E+03	0.000058	Excluded
Po-212	FP	294.7 [ns]	7.6E+10	4.0E+03	0.000028	Excluded

TableI-33 Group 12 (Neptunium decay series)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Np-237	FP	2.1E+06 [y]	1.7E+12	9.0E+00	1	Representative nuclide
Pa-233	FP	26.98 [d]	1.7E+12	9.0E+02	0.01	

TableI-34 Group 13 (Pu isotope, Pu-241 radioactive equilibrium)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Pu-236	FP	2.9E+00 [y]	1.1E+11	1.0E+01	0.0000027	Excluded
Pu-238	FP	8.8E+01 [y]	1.6E+16	4.0E+00	1	Representative nuclide
Pu-239	FP	2.4E+04 [y]	2.6E+15	4.0E+00	0.17	
Pu-240	FP	6.6E+03 [y]	3.3E+15	4.0E+00	0.21	
Pu-241	FP	1.4E+01 [y]	4.3E+17	2.0E+02	0.55	
Pu-242	FP	3.7E+05 [y]	1.1E+13	4.0E+00	0.00071	Excluded
U-237	FP	6.752 [d]	1.1E+13	1.0E+03	0.0000027	Excluded

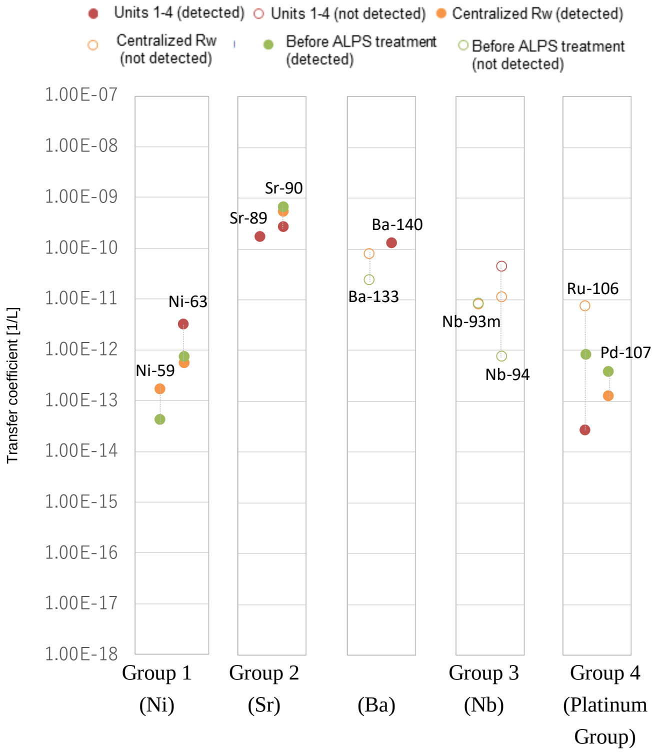
TableI-35 Group 14 (Am isotope, Cm isotope, Am 242m/Am-243 radioactive equilibrium, Cf-250)

Nuclide	Type	Half-life	Inventory (12 years later) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Am-241	FP	4.3E+02 [y]	1.3E+16	5.0E+00	1	Representative nuclide
Am-242	FP	16.02 [h]	9.0E+13	3.0E+03	0.000011	Excluded
Am-242m	FP	1.4E+02 [y]	9.0E+13	5.0E+00	0.0069	Excluded
Am-243	FP	7.4E+03 [y]	8.5E+13	5.0E+00	0.0065	Excluded
Np-238	FP	2.117 [d]	4.5E+11	9.0E+02	0.00000019	Excluded
Np-239	FP	2.356 [d]	8.5E+13	1.0E+03	0.000032	Excluded
Cm-242	FP	162.9 [d]	7.4E+13	6.0E+01	0.00047	Excluded
Cm-243	FP	2.9E+01 [y]	7.5E+13	6.0E+00	0.0048	Excluded
Cm-244	FP	1.8E+01 [y]	6.5E+15	7.0E+00	0.35	
Cm-245	FP	8.4E+03 [y]	1.1E+12	5.0E+00	0.000083	Excluded
Cm-246	FP	4.8E+03 [y]	1.8E+12	5.0E+00	0.000013	Excluded
Cf-250	FP	1.3E+01[y]	7.1E+07	5.0E+00	0.0000000054	Excluded

I-5-2.4.4 Evaluation of transfer coefficients

For the group set in Section I-5-2.4.3 and individual nuclides that could not be grouped, transfer coefficients are calculated from the analysis results (including isotope detected values) shown in Figure I-11 using the inventory evaluation results from March 11, 2011. As described previously, the maximum value among the results of the centralized Rw is generally used for the evaluation of transfer coefficients, and transfer coefficients rounded up to a higher order of magnitude are used for the evaluation to account for the variation in the analytical values. The results of evaluating the transfer coefficient are shown in Figure I-16 In addition, as explained in section I-4, there is uncertainty in the inventory evaluation of AP on the conservative side. Therefore, when FP and AP coexist in a group and the transfer coefficient of AP is low, FP should be selected as the representative nuclide for this evaluation. This prevents the evaluation of the transfer coefficient from becoming unconservative due to the uncertainty of the evaluation.

First, the results of groups 1 - 4 were shown, and it was confirmed that these tended to be similar in each group. In addition, though the result of barium, which is also an alkaline earth metal, was shown next to group 2 (Sr), it was confirmed that Ba-140 (it was excluded in step 1 due to its short half-life) of FP nuclide showed the same transfer coefficient as Sr-89 and Sr-90 of the same FP nuclide.



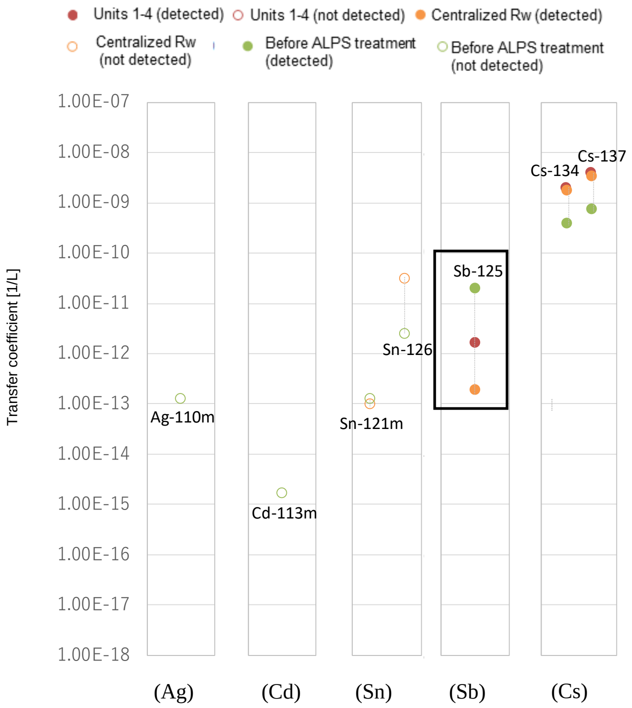
Group		Transfer coefficient* [1/L]	Applicable element	Remarks
1	Nickel	1.0E-12	Ni	
2	Strontium	1.0E-09	Sr	
	Barium	1.0E-09	Ba	
3	Niobium	1.0E-10	Nb	No detected value
4	Platinum group	1.0E-12	Ru	

*: Generally, the maximum value of the centralized Rw rounded up to a higher order of magnitude is indicated.

Figure I-16 Transfer coefficients (1/4)

The results of groups 5 - 9 are shown below.

Since silver, cadmium, and tin have not been detected before, the transfer coefficient is calculated from the lower detection limit. As for antimony, the transfer coefficient is calculated using the same value because the number of detected data of the centralized Rw is 9, compared with 1606 before treatment by ALPS, and the activity concentration before treatment by ALPS is higher. It was confirmed that cesium showed almost the same behavior in its isotopes, Cs-134 and Cs-137.

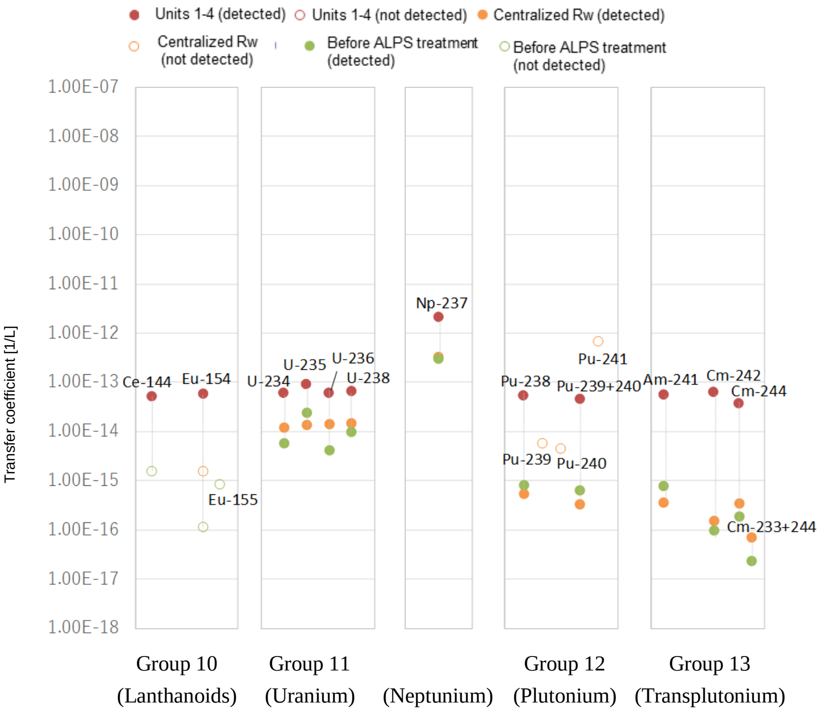


Group		Transfer coefficient* [1/L]	Applicable element	Remarks
5	Silver	1.0E-15	Ag	No detected value
6	Cadmium	1.0E-14	Cd	No detected value
7	Tin	1.0E-13	Sn	Since there is no detected value, the detection limit for Sn-121 m is used.
8	Antimony	1.0E-10	Sb	Data before treatment by ALPS with many data points is used.
9	Cesium	1.0E-08	Cs	

*: Generally, the maximum value of the centralized Rw rounded up to a higher order of magnitude is indicated.

Figure I-16 Transfer coefficients (2/4)

The results of groups 10 - 13 are shown below.
As for lanthanoids, it was confirmed that Ce and Eu showed almost the same transfer behavior as in the documents. In addition, uranium, plutonium, americium, and curium were also confirmed to behave almost the same in isotope and group, and the result of neptunium was also described. It was confirmed that neptunium was easier to transfer to water than other actinoids.
Lanthanoids and actinoids showed almost the same transfer behavior in the stagnant water in the buildings of Units 1 to 4 except for neptunium, but slightly different behavior in each group after the centralized Rw. Based on these trends, the transfer coefficient is calculated.

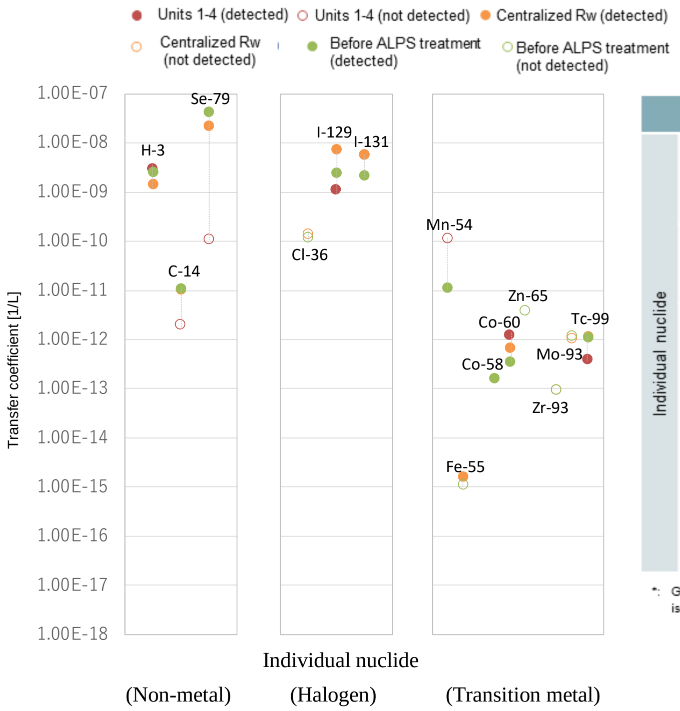


Group		Transfer coefficient* [1/L]	Applicable element	Remarks
10	Lanthanoid	1.0E-13	Ce, Pm, Sm, Eu	Since there is no detected value after the centralized Rw, the detection values of Ce-144 and Eu-154 detected in the past (in the PCV of Units 2 and 3) are used.
11	Uranium	1.0E-13	U	
	Neptunium	1.0E-11	Np	
12	Plutonium	1.0E-15	Pu	
13	Transplutonium element	1.0E-15	Am, Cm	

*: Generally, the maximum value of the centralized Rw rounded up to a higher order of magnitude is indicated.

Figure I-16 Transfer coefficients (3/4)

Finally, nuclides that were not grouped but were assessed individually are indicated. Relatively high transfer coefficients were confirmed for tritium, selenium, carbon, and halogen iodine, which are nonmetals. Since there was no detected value for chlorine in the past, the transfer coefficient was calculated from the detection limit. For transition metals, data before treatment by ALPS with detected values for manganese were used, and iron reflected the results detected by the present additional analysis. In addition to confirming that cobalt had almost the same behavior in isotopes, the transfer coefficients of zinc, zirconium, and molybdenum were calculated from the lower detection limits because there were no detected values, and the transfer coefficients of technetium were calculated using the detected values of the centralized Rw.



Group			Transfer coefficient* [1/L]	Applicable element	Remarks
Individual nuclide	Non-metal	Tritium	1.0E-08	H	
		Carbon	1.0E-10	C	
		Selenium	1.0E-07	Se	
	Halogen	Chlorine	1.0E-09	Cl	No detected value
		Iodine	1.0E-08	I	
	Transition metal	Manganese	1.0E-10	Mn	Data before treatment by ALPS with detected values is used.
		Iron	1.0E-14	Fe	
		Cobalt	1.0E-12	Co	
		Zinc	1.0E-14	Zn	No detected value
		Zirconium	1.0E-13	Zr	No detected value
		Molybdenum	1.0E-11	Mo	No detected value
		Technetium	1.0E-11	Tc	

*: Generally, the maximum value of the centralized Rw rounded up to a higher order of magnitude is indicated.

Figure I-16 Transfer coefficients (4/4)

I-5-2.4.5 Results of the evaluation of transfer to contaminated water

As a result of the evaluation of transfer performed with the transfer coefficients obtained in section I-5-2.4.4, the number of nuclides that are to proceed to Step 5 is 36 nuclides, while 57 nuclides are to be excluded.

Table I-36 Nuclides to proceed to Step 5 (36 nuclides)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*27*	Sr-90	*60*	Sb-125	*93*	Sm-151	*189*	Pu-240
3	C-14	*29*	Y-90	*67*	Te-125m	*96*	Eu-154	*190*	Pu-241
7	Cl-36	*33*	Nb-93m	*70*	I-129	*97*	Eu-155	*194*	Am-241
16	Mn-54	*34*	Nb-94	*71*	Cs-134	*174*	U-234	*201*	Cm-244
17	Fe-55	*35*	Mo-93	*73*	Cs-137	*178*	U-238		
18	Co-60	*38*	Tc-99	*74*	Ba-133	*182*	Np-237		
20	Ni-63	*39*	Ru-106	*80*	Ce-144	*187*	Pu-238		
23	Se-79	*51*	Cd-113m	*87*	Pm-147	*188*	Pu-239		

I-5-2.5 Step 5

In Step 5, "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit is less than 1/100 on the analysis results as contaminated water in the past?," the nuclides that have proceeded to this step are checked if they have been detected significantly (1/100 or more of the regulatory concentration limit) with detection limit set to 1/100 of the regulatory concentration limit in past analyses of contaminated water. Then, nuclides which have not been detected are classified as nuclides to be monitored, and the other nuclides except tritium that cannot be removed by ALPS are classified as nuclides to be measured and assessed.

The rationale behind this step is as follows. In the evaluation up to step 4 is conservative, and nuclides that have been confirmed to be less than 1/100 of the regulatory concentration limit in the analysis of contaminated water in the past are considered to be very unlikely to be included in ALPS treated water. Therefore, it is considered very conservative to select them as the target nuclides for measurement and assessment to be confirmed each time they are released. Even so, given that they have proceeded to Step 5 (relatively large inventories) and that their half-lives are long, the situation may change, depending on the progress of decommissioning even though they have not been found to exist at significant concentrations so far. Therefore, those nuclides are classified as nuclides that are not to be measured at each discharge but to be monitored constantly to check for significant presence in contaminated water. As analytical data will be collected through periodical checking of nuclides to be measured and assessed, which will be described later, the concerned will be reviewed as necessary in accordance with the selection flow based on the obtained data.

As the analysis data will be collected for the nuclides to be monitored, the nuclides will be re-evaluated in accordance with the selection flow based on the data.

Table I-37 shows the six nuclides to be monitored which have been selected this time.

Table I-37 Nuclides to be monitored

Nuclide	Number of analyses (Numbers in parentheses are number of detections)			Analysis result [Bq/L]	Regulatory concentration limit [Bq/L]
	(1) Units 1 to 4	(2) Centralized Rw	(3) Before treatment by ALPS		
Cl-36	0(0)	10(0)	12(0)	< 4.3E+00	9.0E+02
Nb-93m	0(0)	1(0)	1(0)	< 5.2E+01	7.0E+03
Nb-94	36(0)	33(0)	68(0)	< 6.8E-01	5.0E+02
Mo-93	0(0)	1(0)	1(0)	< 1.5E+00	3.0E+02
Cd-113m	0(0)	0(0)	22(0)	< 1.7E-01	4.0E+01
Ba-133	0(0)	1(0)	2(0)	< 2.6E+00	5.0E+02

Although the numbers of analyses for three of the six nuclides are small, given that the water used for the injection to reactors is RO plain water and that the quality standard specified by the Chapter III, Part 1 of Implementation Plan for the water to be used for injection, whose conductivity is 40 mS/m or less at 25°C (if the conductivity exceeds 40 mS/m, the chloride ion concentration of 100 ppm or less is confirmed), has been satisfied constantly, the environment in reactors and transition status of radionuclides to the contaminated water are unlikely to change. Therefore, this selection is reasonably considered as appropriate.

Other nuclides with a small number of analyses are Ni-59, Sn-121m, Zr-93 and Nb-93m. In Ni-59 and Sn-121 m, there are isotopes (Ni-63, Sn-126) that are to be removed by ALPS. Therefore, the necessity of measurement is determined based on their measurement results and relative ratios (ratio of inventory/ regulatory concentration limit) described in section 2.4.3.2. In addition, since Zr-93 has an established measurement method (ICP-MS) and a long half-life (1.6E + 06 years), it was possible to measure up to about 1/1000 of the regulatory concentration limit in 2 samples of stagnant water in buildings and strontium removed water, and 3 samples of ALPS treated water. The result was that it was not detected. With this, it is considered that it rarely transfers to the contaminated water, and it was determined that further measurement was not required.

Although Eu-155 has not been detected above 1/100 of the regulatory concentration limit, they are set as the nuclides that are not monitored but are set as nuclides to be measured and evaluated. The concept of this is described in the table below.

Table I-38 Nuclides not subject to monitoring, though the analysis confirmed that they were below 1/100 of the regulatory concentration limit.

Nuclide	Step 4			Regulatory concentration limit [Bq/L]	Reason for selection
	Sampling point	Sampling date	Measured value [Bq/L]		
Eu-155	ALPS inlet	Aug 2, 2019	<5.3E+00	3.0E+03	Eu-155 was measured only at the ALPS inlet, and although it was not detected at this place, the isotope Eu-154 was confirmed in the PCV of Unit 3, and its concentration was 1.9 E + 03 Bq/L. At that time, Eu-155 was not measured, but the concentration was assessed 5.7 E + 02 Bq/L considering the result of Eu-154 (0.3 times Eu-154*), exceeding 1/100 of the regulatory concentration limit. For this reason, it was selected.

* Calculated based on the inventory ratio 12 years after the earthquake

On the other hand, Step 5 confirms the actual condition, unlike Step 4. Therefore, assuming the future transition to the downstream side, the target to be checked was set conservatively up to the stagnant water in buildings of Units 1 to 4. For this reason, there are nuclides to be measured and evaluated, although they have not been detected at 1/100 or more of the regulatory concentration limit downstream from the centralized Rw used to assess transfer to contaminated water in Step 4, the conditions are as shown in Table I-39

Table I-39 Nuclides that were not detected at 1/100 or more of the regulatory concentration limit downstream from the centralized Rw but were set as the nuclides to be measured and evaluated.

Nuclide	Step 4			Step 5			Regulatory concentration limit [Bq/L]	Remarks
	Sampling point	Sampling date	Measured value [Bq/L]	Sampling point	Sampling date	Measured value [Bq/L]		
U-234	PMB	Nov 2, 2021	1.6E-01	Units 1 to 4	Oct 22, 2015	7.7E-01	2.0E+01	The sampling point of Step 5 is inside the PCV of Unit 3.
U-238	PMB	Dec 21, 2018	4.5E-02	Units 1 to 4	Jul 8, 2021	2.0E-01	2.0E+01	The sampling location of Step 5 is the MSIV room of Unit 3.

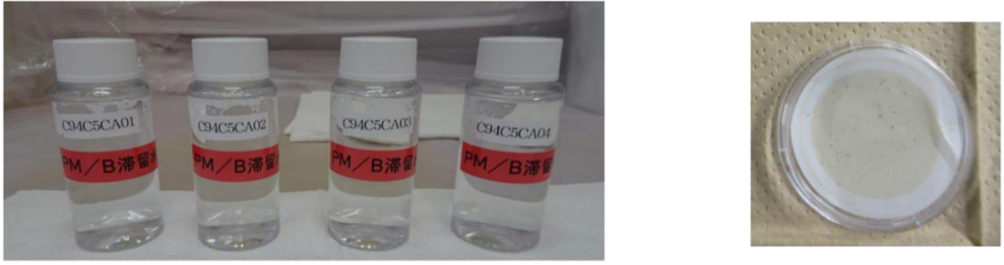
I-5-2.6 Results of the selection

Table I-40 shows the 29 nuclides to be measured and assessed that have been selected in accordance with the flow shown in Figure I-8. The table also shows quantification methods that are currently planned for these nuclides. When the discharge standard (the sum of ratio to the regulatory concentration limits of radionuclides other than tritium is less than 1) is confirmed in the measurement and confirmation facility, the ratio to the regulatory concentration limit of α nuclides is calculated by dividing the gross α value by the lowest regulatory concentration limit (4 Bq/L) among the selected α nuclides. In addition to the 29 nuclides shown in the table below, H-3 concentration will also be measured before the discharge into the sea in order to set dilution ratio.

Table I-40 Nuclides to be measured and assessed and quantification methods

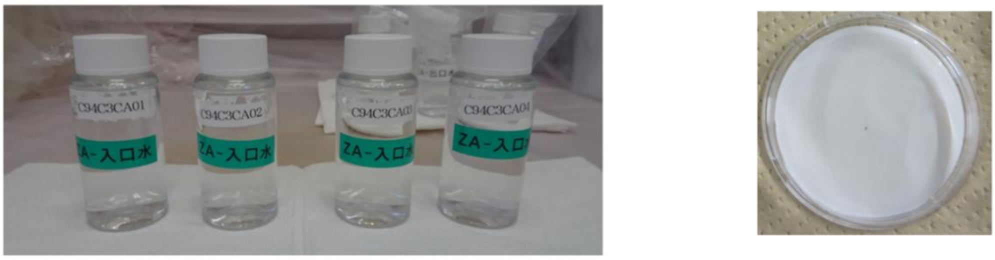
No.	Nuclide	Quantification method	*No.*	Nuclide	Quantification method
1	C-14	After chemical separation, measure β-rays	*16*	Ce-144	γ-ray nuclide analysis
2	Mn-54	γ-ray nuclide analysis	*17*	Pm-147	Assessed from the activity concentration of representative nuclide (Eu-154)
3	Fe-55	After chemical separation, X-ray measurement	*18*	Sm-151	
4	Co-60	γ-ray nuclide analysis	*19*	Eu-154	γ-ray nuclide analysis
5	Ni-63	After chemical separation, measure β-rays	*20*	Eu-155	γ-ray nuclide analysis
6	Se-79	After chemical separation, measure β-rays	*21*	U-234	Assessed as included in the gross α radioactivity
7	Sr-90	After chemical separation, measure β-rays	*22*	U-238	
8	Y-90	Radioactive equilibrium with Sr-90	*23*	Np-237	
9	Tc-99	ICP-MS	*24*	Pu-238	
10	Ru-106	γ-ray nuclide analysis	*25*	Pu-239	
11	Sb-125	γ-ray nuclide analysis	*26*	Pu-240	
12	Te-125m	Radioactive equilibrium with Sb-125	*27*	Pu-241	Assessed from the activity concentration of representative nuclide (Pu-238)
13	I-129	ICP-MS			
14	Cs-134	γ-ray nuclide analysis	*28*	Am-241	Assessed as included in the gross α radioactivity
15	Cs-137	γ-ray nuclide analysis	*29*	Cm-244	

(Reference) Supplemental remarks on the analysis method for the additional analysis
In the analysis this time, suspended matter was visually confirmed in the stagnant water from the Process Main Building and in the strontium removed water before the ALPS treatment. Therefore, they were filtered with a 0.45 µm filter before analysis. (See Figure I-17)
This analysis method has been adopted for light water reactors as a method to separate soluble from insoluble nuclides. It was used in this analysis to separate and identify which nuclides are insoluble and can be easily removed and which nuclides are dissolved in water and need to be removed by ALPS, etc.



Filtrate samples
(Stagnant water in Process Main Building)

Residue sample
(Stagnant water in Process Main Building)



Filtrate samples
(Strontium removed water before treatment by ALPS)

Residue sample
(Strontium removed water before treatment by ALPS)

Figure I-17 Filtrate samples and residue samples from samples to be analyzed (stagnant water in Process Main Building and strontium removed water before ALPS treatment)

I-5-3. Summary of the nuclide analysis
This time, in examining the nuclides to be measured and assessed at the discharge of ALPS treated water into the sea, among nuclides that have been the focus of studies about decommissioning and burial facilities, etc., excluding those with short half-lives, nuclides that have never been analyzed or have not been analyzed sufficiently so far were analyzed. As a result, they were not detected in the ALPS treated water, being 1/100 or less of the regulatory concentration limits.
The analysis have revealed that the nuclides that may exist in the ALPS treated water at significant concentrations are the major seven nuclides, carbon 14 and technetium 99.
With regard to the nuclides to be measured and assessed when discharging ALPS treated water into the sea, in addition to the above 9 nuclides, the selection is based on a process of confirming that nuclides that may exist at significant concentrations in stagnant water in buildings and strontium removed water before treatment by ALPS have been removed from

ALPS treated water to be discharged into the sea to the point that the discharge standards are satisfied.

END

Reference-1

Comparison of the sum of the ratios to regulatory concentrations limits at ALPS inlet/outlet

1 .Introduction

In the nuclide analysis, we confirmed again that the nuclides that may exist significantly in ALPS treated water are the main seven nuclides, Carbon-14 and Technetium-99. However, we confirmed that this tendency was similar in the sum of the ratio to regulatory concentration limit based on the actual analysis evaluation.

2. Data for calculating the sum of the ratio to regulatory concentration limit and Methods

For calculation of the sum of the ratio to regulatory concentration limit, the analytical evaluation results of the four samples of additional ALPS inlet port, K-4 tank, J1-C tank, and J1-G tank in FY2021 are used. In addition, the analytical evaluation results are classified according to (1) to (6) shown in the Table I-41 from the target nuclides to be measured and assessed selected in section I-4 and 35 nuclides selected as target nuclides to be monitored. The ratio to regulatory concentration limit of α nuclides is calculated by dividing gross α by 4Bq/L, which is the lowest regulatory concentration limit among the selected α nuclides.

Table I-41 Classification of nuclides in calculating the ratio to regulatory concentration limit

No.	Classification					Specific nuclides
(1)	Nuclides mainly detected in ALPS treated water					7 major nuclides (including radioactive equilibrium Y-90, Te-125 m), C-14, Tc-99
(2)	Nuclides rarely detected in ALPS treated water	α nuclide				U-234, U-238, Np-237, Pu-238, Pu-239, Pu-240, Am-241, Cm-244
(3)		Other than α nuclides	Subject to removal by ALPS (other than (1) and (2))			Mn-54, Ni-63, Cd-113m, Ce-144, Pm-147, Sm-151, Eu-154, Eu-155, Pu-241
(4)			Other than those subject to removal	A large number of measurements		Cl-36, Se-79, Nb-94
(5)				Small number of measurements	[1] Countable for gross β or Ge	Ba-133
(6)					[2] Not countable for gross β and Ge	Fe-55, Nb-93m, Mo-93

3. Evaluation results

3.1 Comparison on the sum of the ratio to regulatory concentration limit

Table I-42 and Figure I-18 show the results of comparing the sum of the ratio to regulatory concentration limit, which are described in Section 2. From this result, it was confirmed that most of the sum of the ratio to regulatory concentration limit was main seven nuclides, Carbon-14 and Technetium-99 in the analysis evaluation result of actual ALPS inlet/outlet as well as in the nuclide analysis.

Table I-42 Comparison of the ratio to regulatory concentration limit by classification at ALPS inlet/outlet

No.	Classification					ALPS inlet	ALPS outlet		
							K-4	J1-C	J1-G
(1)	Nuclides mainly detected in ALPS treated water					1.7E+03	2.7E-01	1.6E-01	5.8E-02
(2)	Nuclides rarely detected in ALPS treated water	α nuclide				1.0E+00	1.6E-04	8.1E-03	7.0E-3
(3)		Other than α nuclides	Subject to removal by ALPS (other than the above)			2.2E+00	1.4E-03	1.3E-02	1.2E-02
(4)			Other than those subject to removal	A large number of measurements		5.0E-02	1.2E-02	1.2E-02	1.2E-02
(5)				Small number of measurements	[1] Countable for gross β or Ge	8.7E-03	1.8E-05	1.4E-04	1.3E-04
(6)					[2] Not countable for gross β and Ge	2.1E-02	9.3E-03	6.8E-03	6.8E-03

*For J1-C and J1-G, the analysis and evaluation results for Cl-36, Se-79, Fe-55, Nb-93m, and Mo-93 are not available, and the results from the additional ALPS outlet are used.

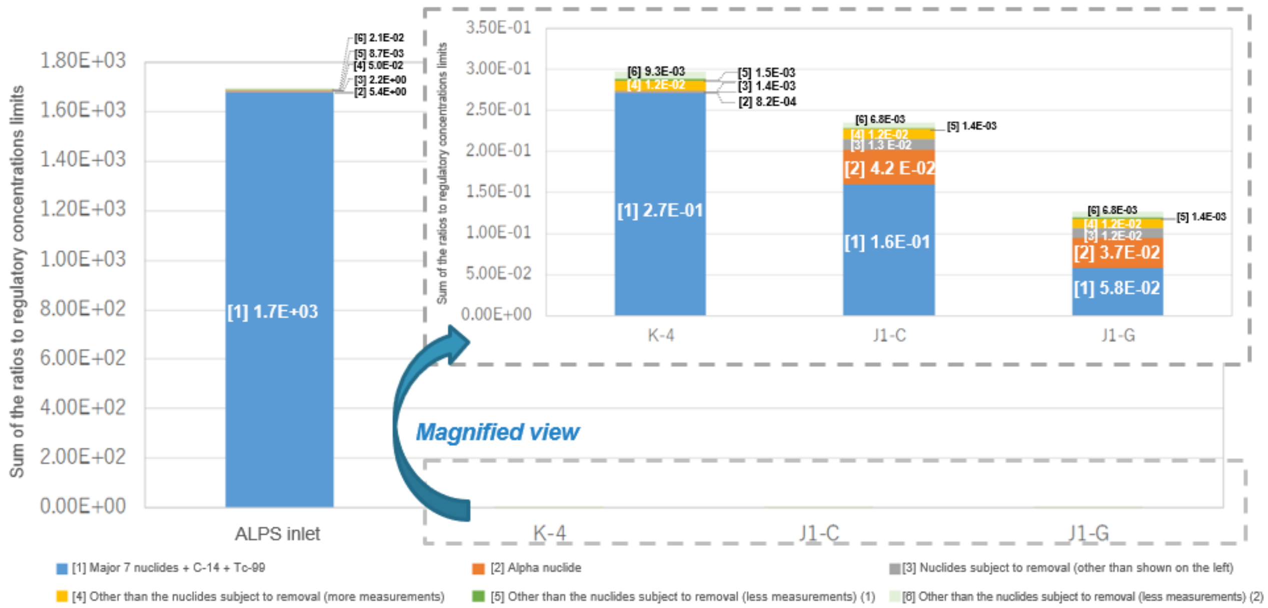


Figure I-18 Comparison of the sum of the ratios to regulatory concentrations limits at ALPS inlet/outlet

3.2 Ratio of ALPS treated water against discharge standards

Based on ratio to regulatory concentration limit of ALPS outlet by classification calculated Table I-42, the results is shown in Figure I-19 below, which shows the ratio of 35 nuclides to be measured and evaluated and the nuclides to be monitored to the discharge criteria for the nuclides..Each ALPS treated water in K-4 tank, J1-C tank, and J1-G tank used for this assessment have margins of approximately 7.0E-01 to 9.0E-01 relative to the discharge criteria.have 7.0E-01～9.0E-01 allowances for the criteria.

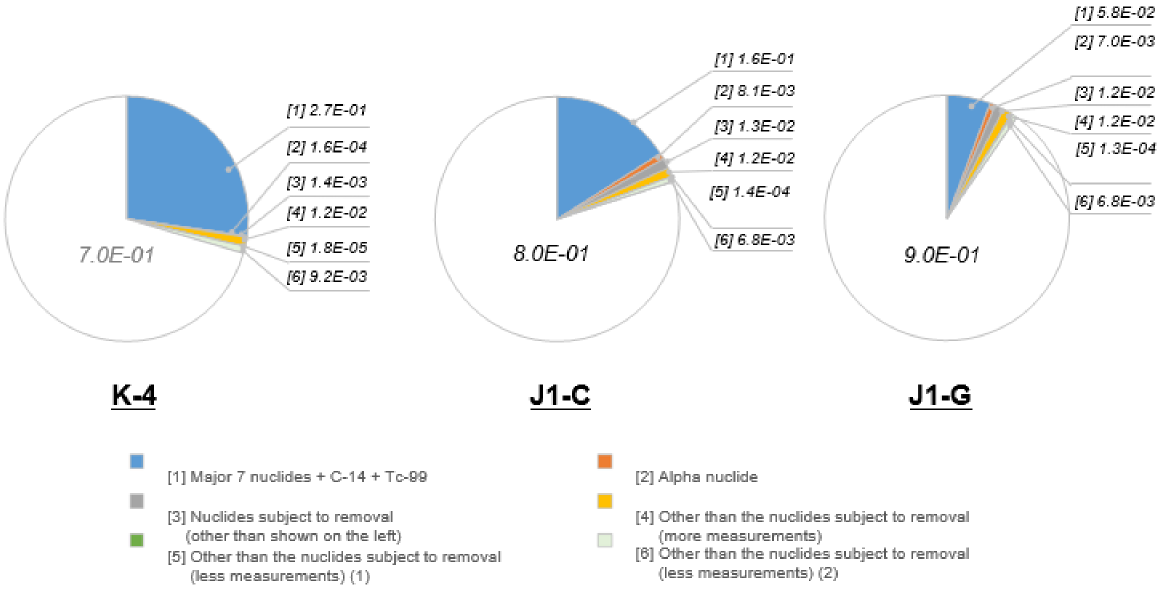


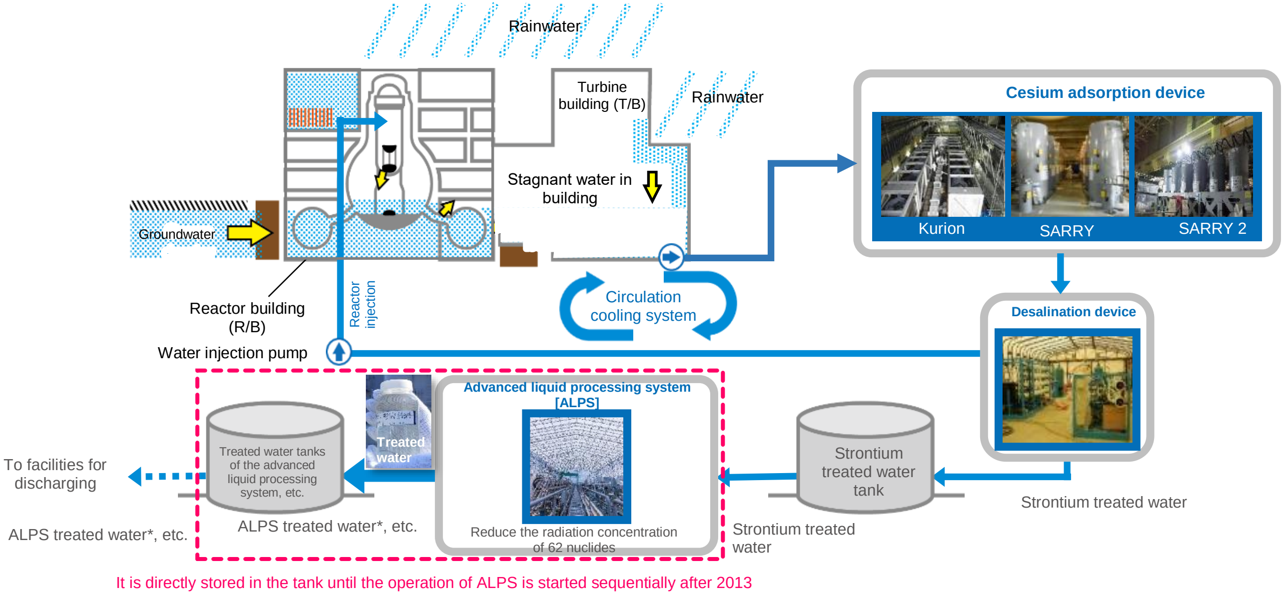
Figure I-19 Ratio of ALPS treated water to discharge criteria

Attachment II Properties of ALPS treated water, etc.

At the FDNPS, the sequence of events of the station since the accident has led to various analyses. Various analyses also have been conducted on the treatment of contaminated water, which is very complicated.
This section describes the overview of contaminated water treatment and the analysis result of the properties of ALPS treated water.

II-1. Overview of the occurrence of contaminated water (stagnant water in the building) and the system of the contaminated water treatment facility

In the FDNPS, the residual fuel debris in the building is cooled with water, and mixing of the cooling water and the groundwater or rainwater entering the building causes contaminated water. The daily average amount of contaminated water was reduced to about 130m^3 in the result of FY2021 thanks to the reduction of water entering the reactor building by countermeasures such as land side impermeable wall (frozen soil wall) and sub-drains.
To reduce the risks caused by radioactive materials contained in contaminated water, at first cesium and strontium were removed preferentially, which accounts for most of the radioactive materials contained in contaminated water, using cesium adsorption devices such as Kurion, SARRY and SARRY2. After that, the water desalinated with desalination devices is recirculated for cooling the burst slug in the core, and the residual concentrated water is treated with the advanced liquid processing system (hereinafter called “ALPS”) as “strontium treated water (water before treated by ALPS)” to remove the 62 nuclides subject to removal[1], which accounts for most of the nuclides, other than tritium, and then stored in tanks installed on high ground.



* ALPS treated water, etc., which is purified with the advanced liquid processing system, etc., until the radioactive materials other than tritium surely fall below the regulatory limit of safety is defined as “ALPS treated water,” and the other water as “treated water to be purified”

Figure II-1 Overall outline figure of contaminated water treatment

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[1] For details of the selection process and the selected nuclides, see Reference F “Rationale behind the selection of nuclides subject to removal by ALPS.”

II-2. Overview of the system of ALPS

ALPS is designed to be able to remove up to less than the regulatory concentration limit without dilution of the 62 nuclides estimated to be contained in the above-mentioned strontium treated water at such high concentrations that they should be removed except tritium, which ALPS cannot remove, by treatment using physical and chemical properties such as coprecipitation with chemicals, adsorption by active carbon and physical materials, and filtration with a physical filter; this capability has already been demonstrated through the actual operation (For details of the performance, see II-3. “Performance of ALPS”).
In the FDNPS, three types of ALPS are installed: existing ALPS, additional ALPS, and high-performance ALPS. Since all of them have similar removal performance (DF: decontamination factor), current treatment is performed mainly in the existing and additional ALPS considering ease of adjustments of the treatment amount. Table II-1 shows the overview of ALPS.

Table II-1 Overview of the facility of ALPS

Name	Put into service	Capacity	Characteristics
Existing ALPS	2013.3	250m^3/day/series × 3 series (Total: 750m^3/day)	After putting into service, added adsorption vessels and changed the adsorption material to improve the performance
Additional ALPS	2014.9	250m^3/day/series × 3 series (Total: 750m^3/day)	Deleted iron coprecipitation by pretreatment with the existing ALPS and performed addition of adsorption vessels, change of the adsorption material, etc.
High-performance ALPS	2014.10	500m^3/day/series × 1 series (Total: 500m^3/day)	Unlike the existing and additional ones, this has no coprecipitation process

Table II-2 shows the overview of the nuclide removal system of ALPS.

Table II-2 Overview of the nuclide Removal system with ALPS

Removal system		Main nuclides subject to removal	Role
Pretreatment facilities	Iron coprecipitation treatment (Existing ALPS only)	α nuclides, Co-60, and Mn-54	Decomposition of the complexes that inhibit adsorption, and removal of heavy metal and α nuclides, etc., by iron coprecipitation
	Carbonate coprecipitation treatment (excluding the high-performance ALPS)	Adsorption inhibition ions (Mg, Ca, etc.) Sr-89/90	Remove the inhibition ions of Sr adsorption and improve the Sr removal performance by adsorption
Advanced liquid processing system (Adsorption vessel)	Active carbon	Colloidal nuclides (I-129, Co-60, etc.)	Remove the nuclides that have various ionic and colloidal forms with multiple types of adsorption materials
	Sr adsorbent	Sr-89/90	
	Cs adsorbent	Cs-134/137	
	I,Sb adsorbent	I-129 (IO^{3-}), Sb-125	
	I adsorbent	I-129(I^-)	
	Ru adsorbent	Ru-106	

ALPS is operated efficiently by backing up the subsequent adsorption vessels in the case of break-through of the first vessel and changing the order of the adsorption vessels by merry-go-round operation of some of the adsorption vessels. Figure II-2 shows an example of an adsorption vessel composition[2] and Figure III-3 the details of the merry-go-round operation of some of the adsorption vessels.

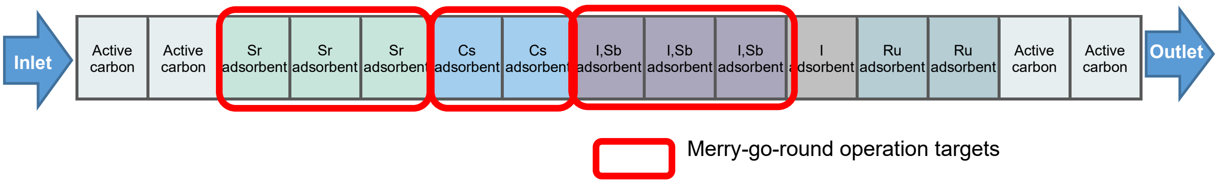
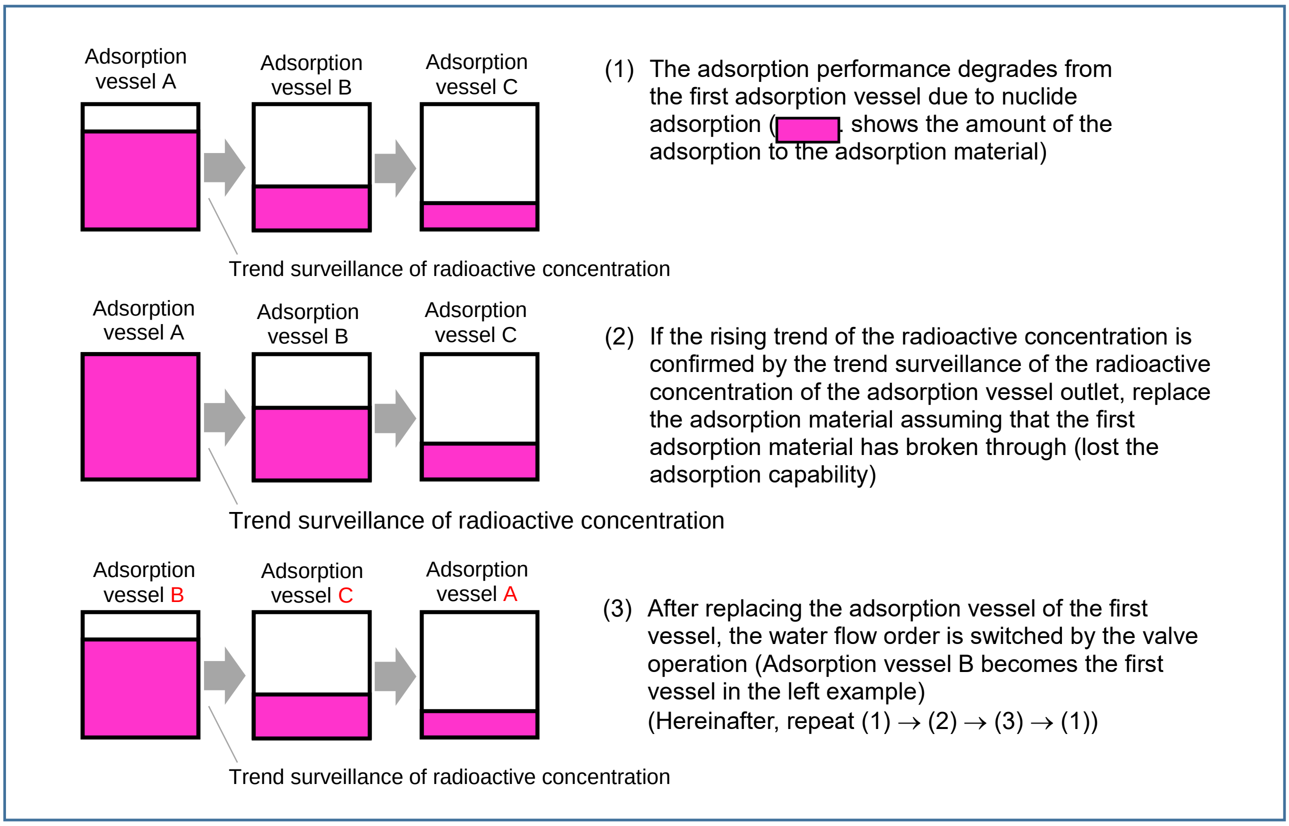


Figure II-2 Example of an adsorption vessel composition (example as of September 2018)



(1) The adsorption performance degrades from the first adsorption vessel due to nuclide adsorption (■ shows the amount of the adsorption to the adsorption material)

(2) If the rising trend of the radioactive concentration is confirmed by the trend surveillance of the radioactive concentration of the adsorption vessel outlet, replace the adsorption material assuming that the first adsorption material has broken through (lost the adsorption capability)

(3) After replacing the adsorption vessel of the first vessel, the water flow order is switched by the valve operation (Adsorption vessel B becomes the first vessel in the left example)
(Hereinafter, repeat (1) → (2) → (3) → (1))

Figure II-3 Image of replacement and operation of the adsorption material (merry-go-round operation) (for a composition of three adsorption vessels)

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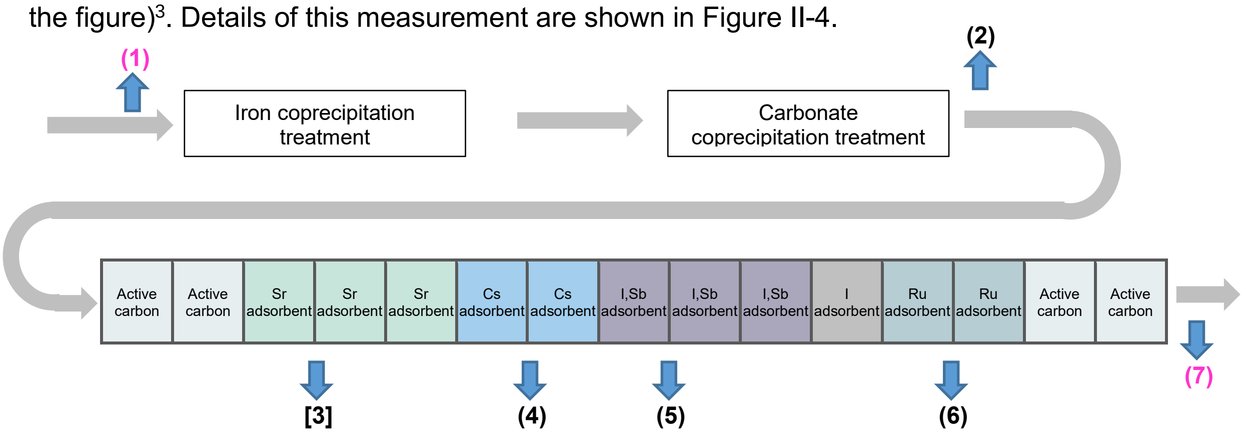
[2] The composition of the adsorption vessels has been reassessed as needed according to the properties of water to be treated, etc.

II-3. Performance of ALPS

In ALPS, the concentrations of radioactive materials, mainly 7 nuclides (Cs-134, Cs-137, Co-60, Sb-125, Ru-106, Sr-90, I-129) which are nuclides to removal by ALPS and significantly detected nuclides through the process of treatment, at the facility inlet and outlet are measured ((1) and (7) in the figure) to verify the removal performance of radioactive materials, as well as in the middle of the treatment process to verify the break-through trend of the adsorption vessels ((2) to (6) in the figure)[3]. Details of this measurement are shown in Figure II-4.



Measured point (1):	Facility inlet (water to be treated)
Measured nuclide:	Cs-134/137, Co-60, Mn-54, Sb-125, Ru-106, Sr-90, Tc-99, I-129, total β, and total α
Measurement frequency:	About once a week
Purpose of measurement:	Confirmation of properties before treatment
Measured point (2):	Outlet of carbonate coprecipitation treatment
Measured nuclide:	Cs-134/137, Co-60, Mn-54, Sb-125, and total β
Measurement frequency:	About once a week
Purpose of measurement:	Confirmation of properties before treatment
Measured point (3):	Outlet of the Sr first adsorption vessel
Measured nuclide:	Sr-90
Measurement frequency:	About once
Purpose of measurement:	Verification of the break-through trend of the adsorption vessels for Sr

Measured point (4):	Outlet of the Cs first adsorption vessel
Measured nuclide:	Cs-134/137
Measurement frequency:	About once a week
Purpose of measurement:	Verification of the break-through trend of the adsorption vessels for Cs
Measured point (5):	Outlet of the I,Sb first adsorption vessel
Measured nuclide:	I-129,Sb-125
Measurement frequency:	About once a week
Purpose of measurement:	Verification of the break-through trend of the adsorption vessels for I-129 and Sb-125
Measured point (6):	Outlet of the Ru first adsorption vessel
Measured nuclide:	Ru-106
Measurement frequency:	About once a week
Purpose of measurement:	Verification of the break-through trend of the adsorption vessels for Ru
Measured point (7):	Facility outlet (treated water)
Measured nuclide:	Cs-134/137, Co-60, Mn-54, Sb-125, Ru-106, Sr-90, Tc-99, I-129, total β, and total α
Measurement frequency:	About once a week
Purpose of measurement:	Confirmation of properties of treated water

Figure II-4 Measurement performed in ALPS

After the start of the operation of ALPS, about 70% of the treated water contains radioactive properties over the sum of the ratios to regulatory concentrations limits of 1 due to various circumstances (see II-7, “Reason for generation of treated water to be purified”), but ALPS has been working properly except special circumstances.

Figure II-5-1 to 13 show the trend regarding the measurement results of the inlet and outlet of

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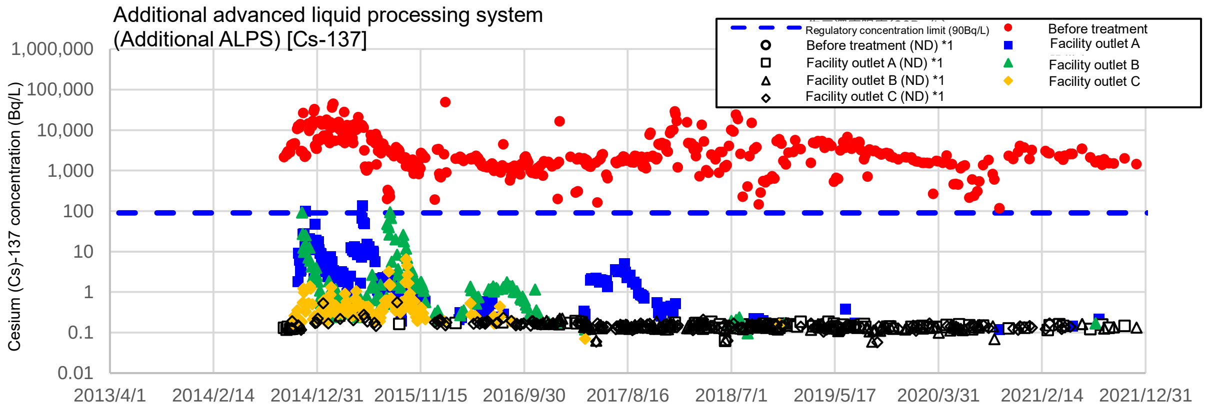
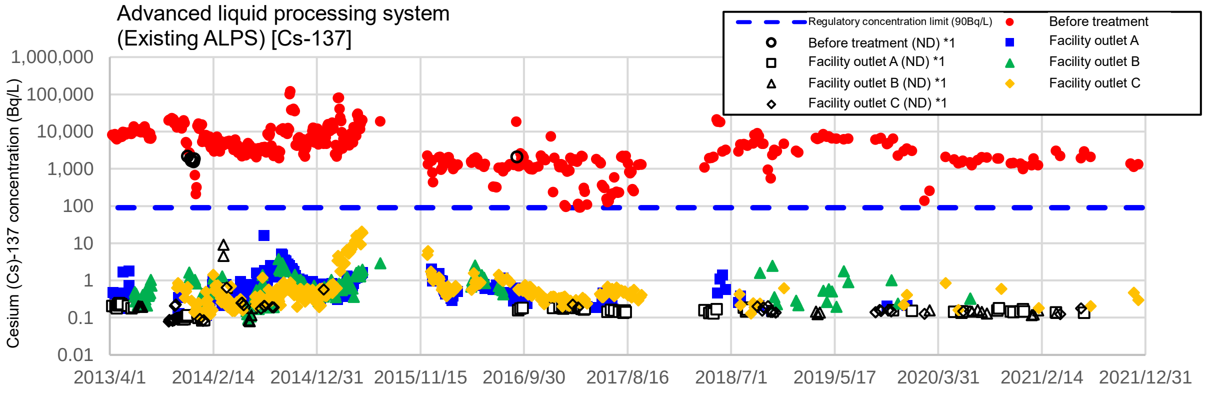
[3] The measurement items and measurement frequency have been reassessed as needed according to the properties of water to be treated, etc.

ALPS for the seven major nuclides, etc. Especially after 2019, in which the above-mentioned special circumstances disappeared, ALPS has been operated stably and each nuclide has been removed stably and appropriately.


Additional advanced liquid processing system (Additional ALPS) [Cs-137]


Advanced liquid processing system (Existing ALPS) [Cs-137]

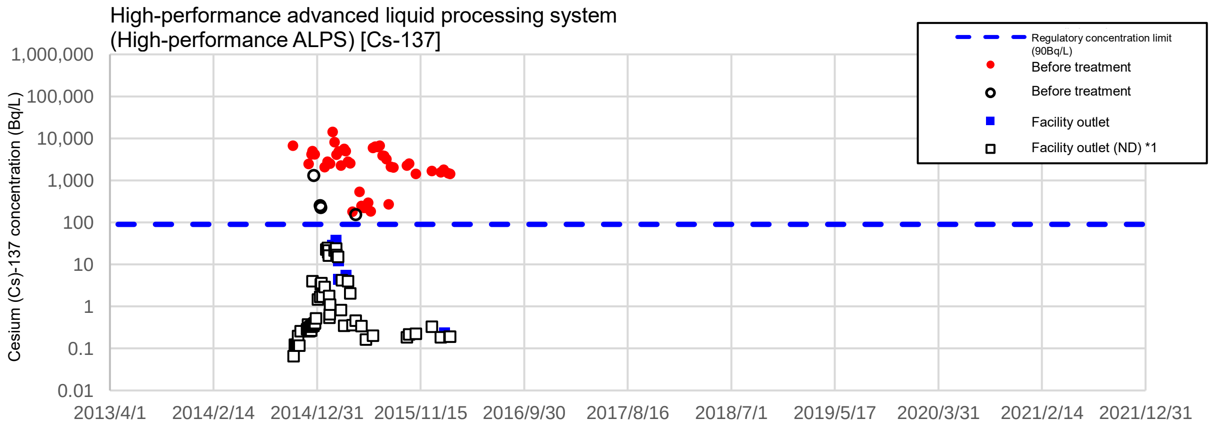

High-performance advanced liquid processing system (High-performance ALPS) [Cs-137]

Figure II-5-1 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Cs-137)
(*1 ND indicates less than the detection limit.)

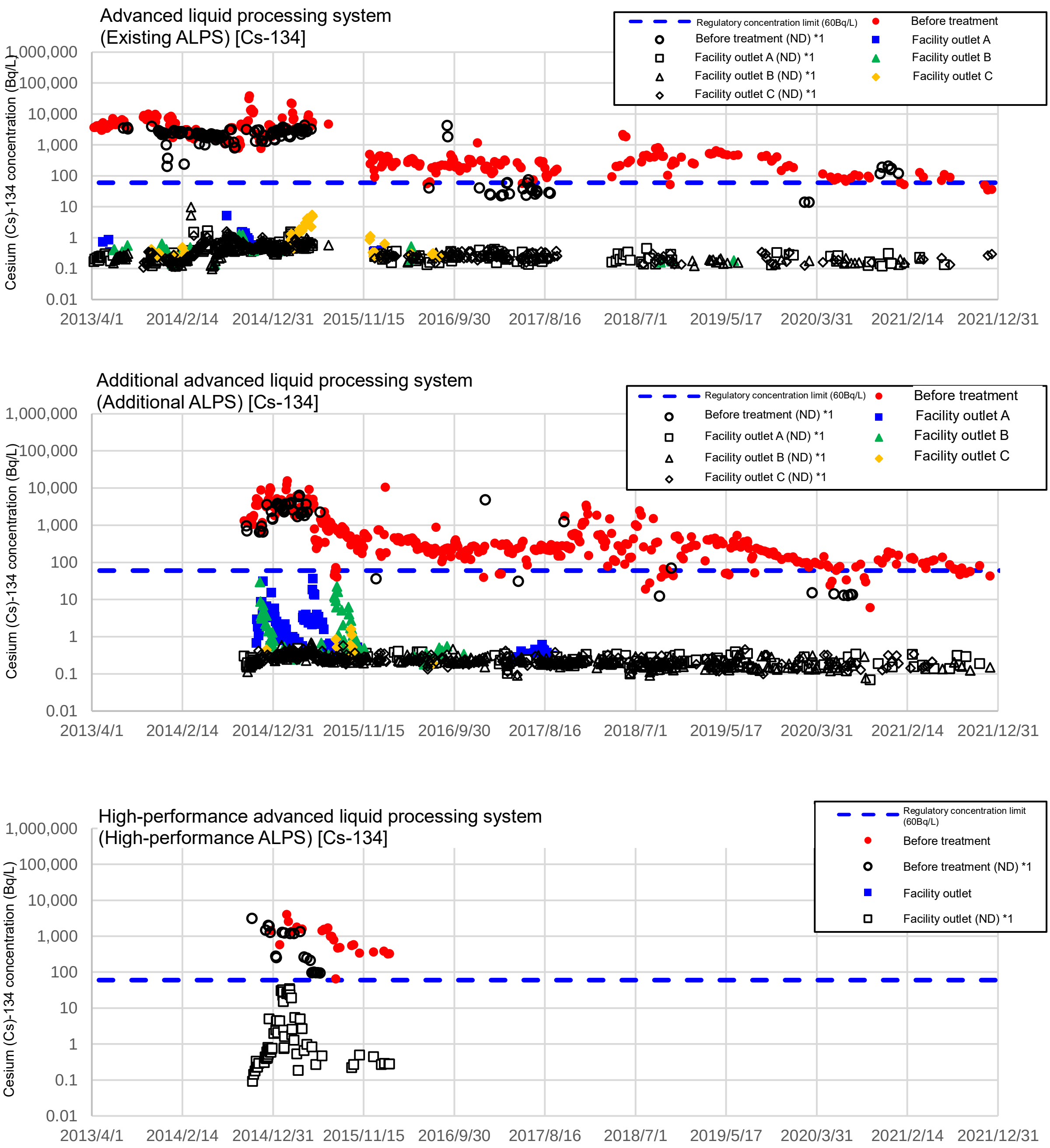


Figure II-5-2 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Cs-134)

(*1 ND indicates less than the detection limit.)

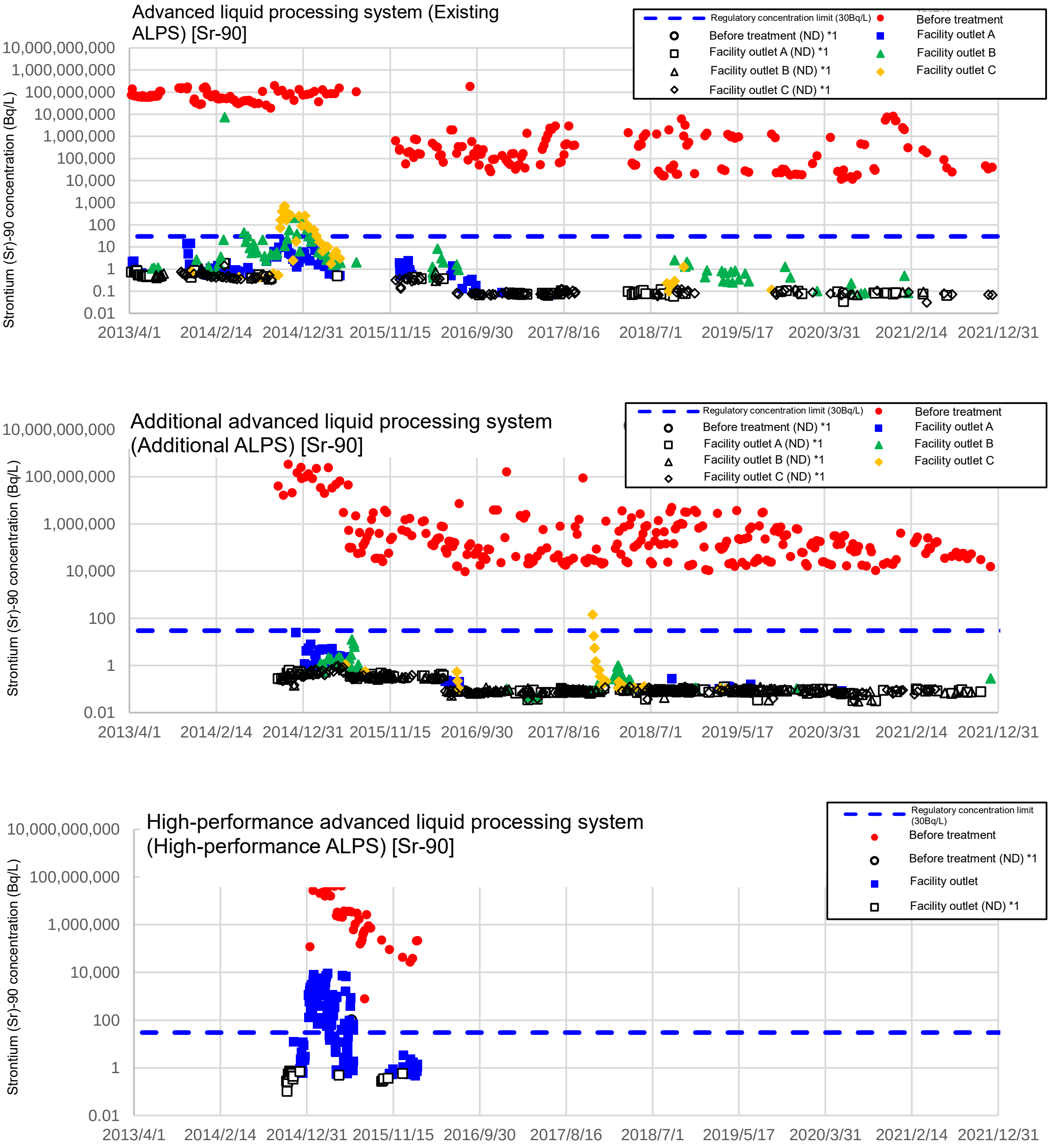
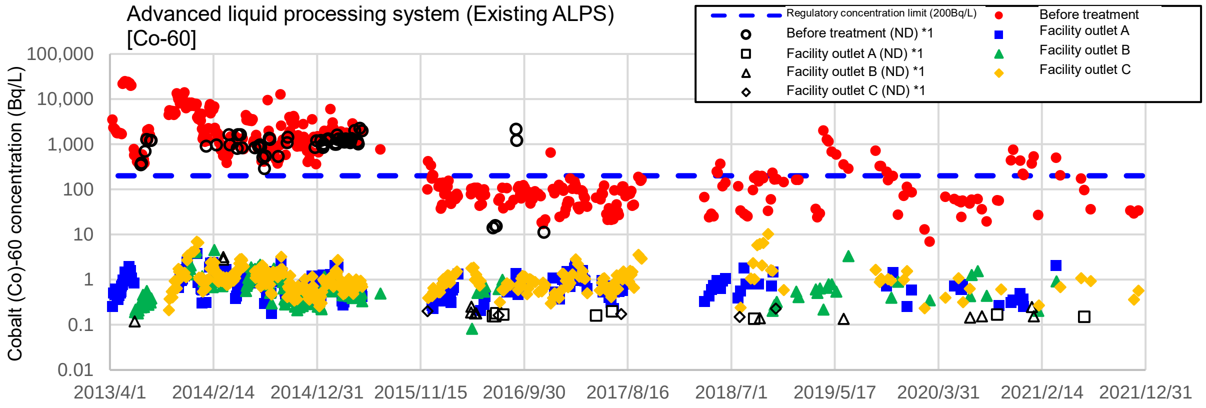
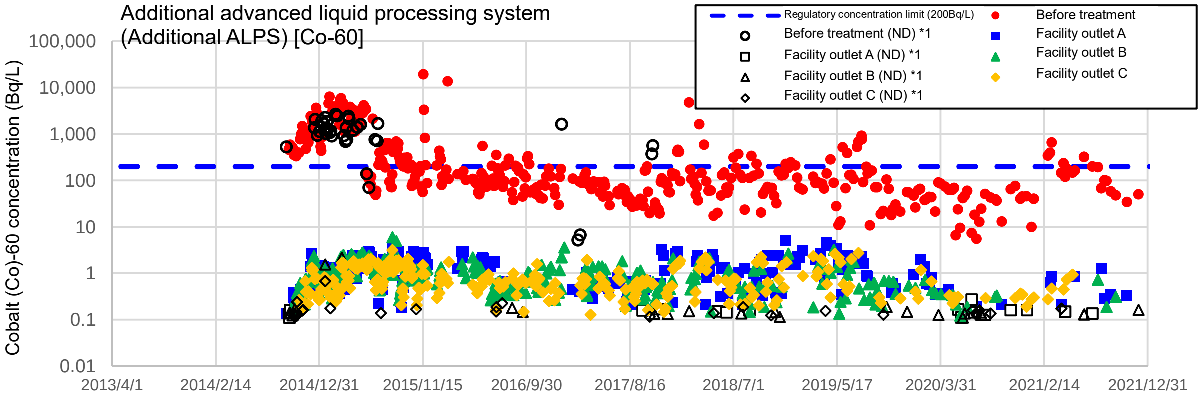


Figure II-5-3 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Sr-90)
(*1 ND indicates less than the detection limit.)





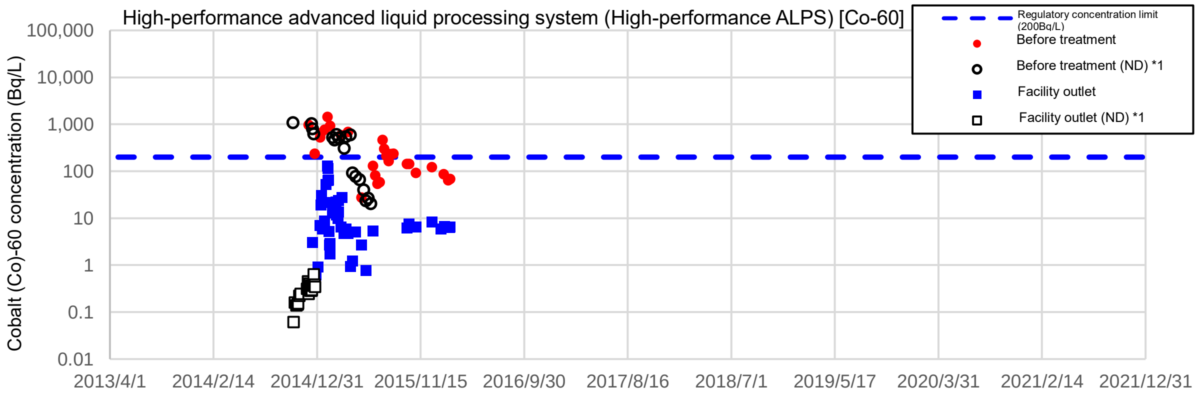


Figure II-5-4 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Co-60)
(*1 ND indicates less than the detection limit.)

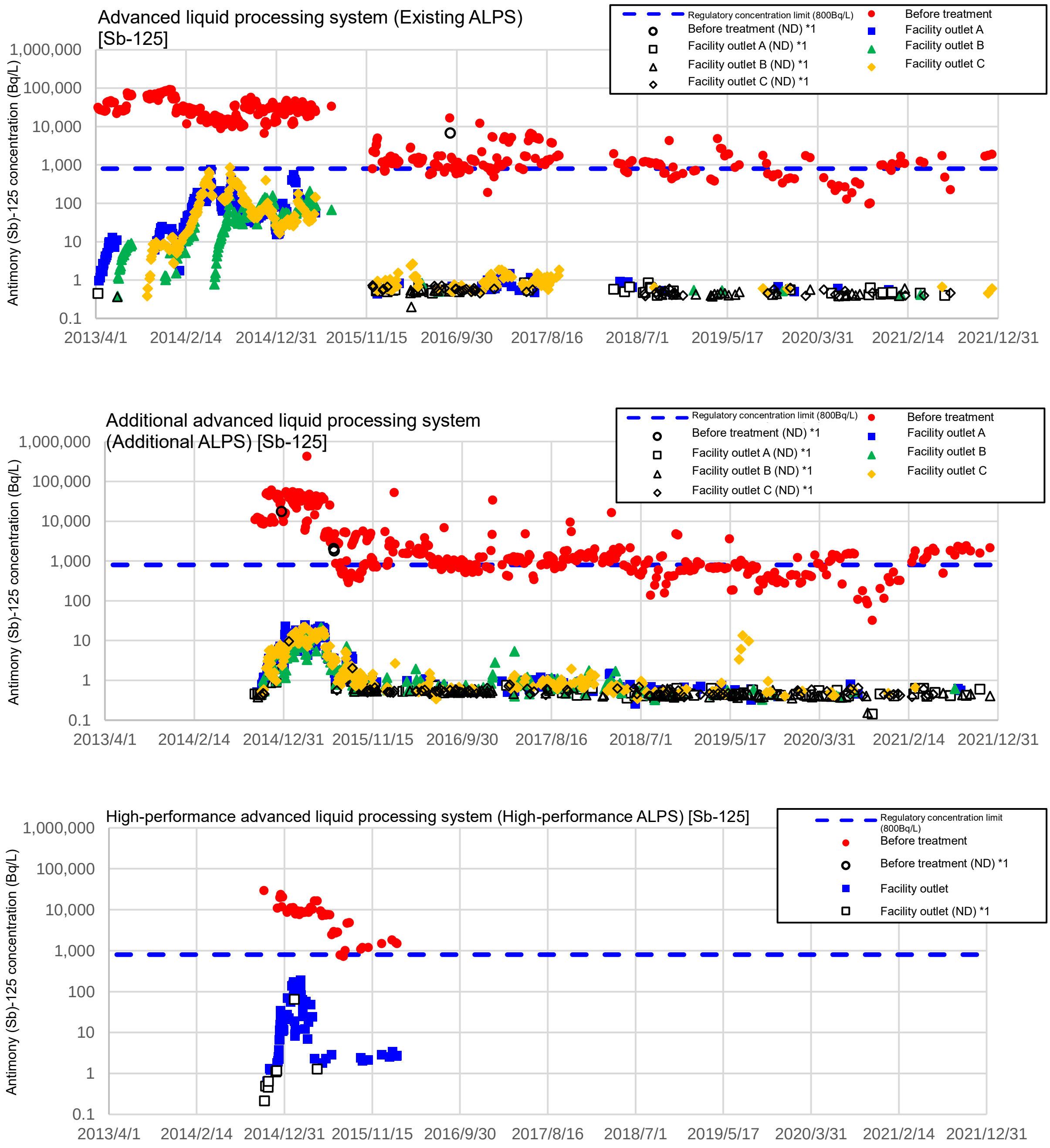


Figure II-5-5 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Sb-125)
(*1 ND indicates less than the detection limit.)

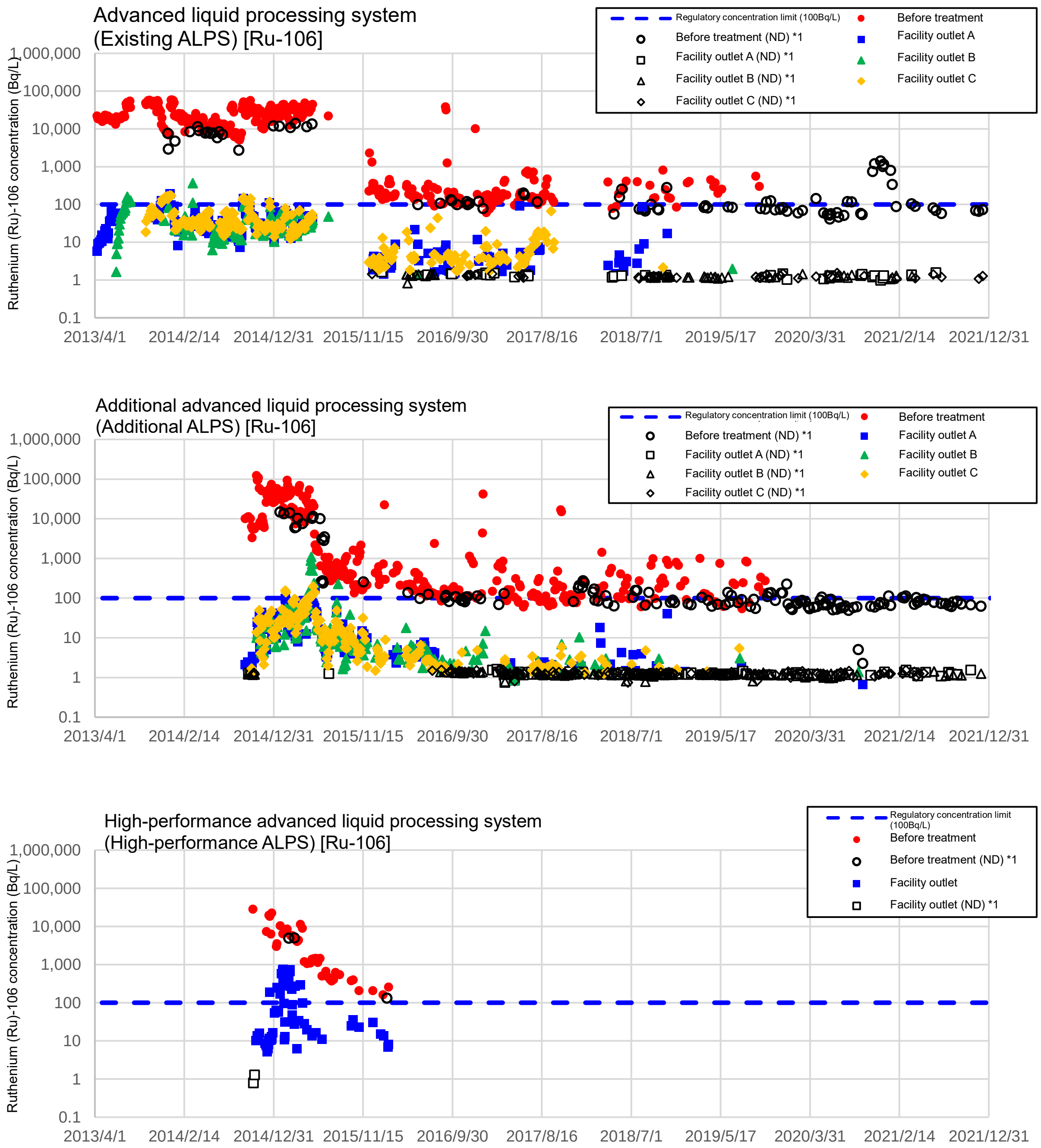


Figure II-5-6 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Ru-106)

(*1 ND indicates less than the detection limit.)

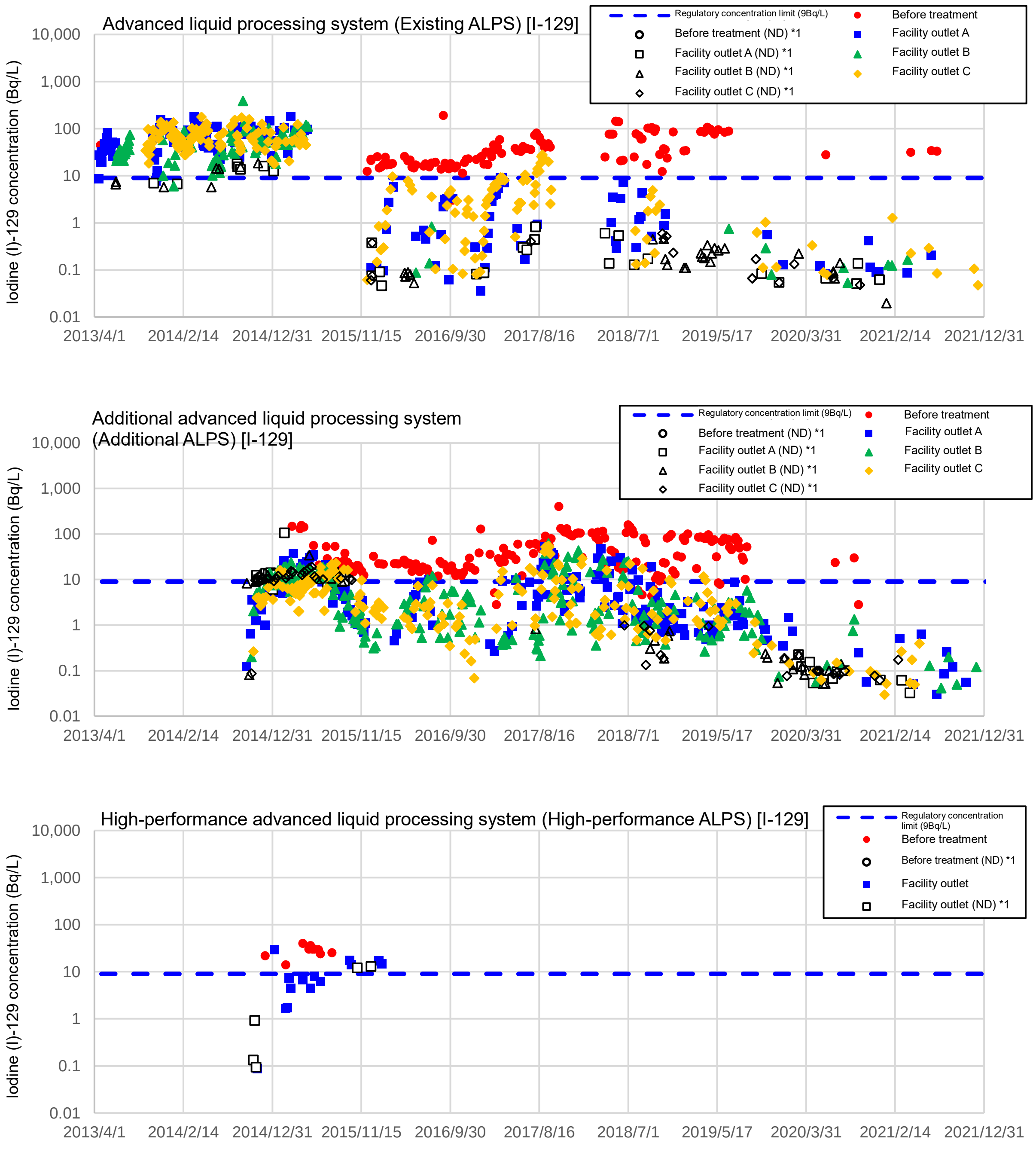


Figure II-5-7 Radioactive concentration in the inlet and outlet of each advanced liquid processing system I-129)

(*1 ND indicates less than the detection limit.)

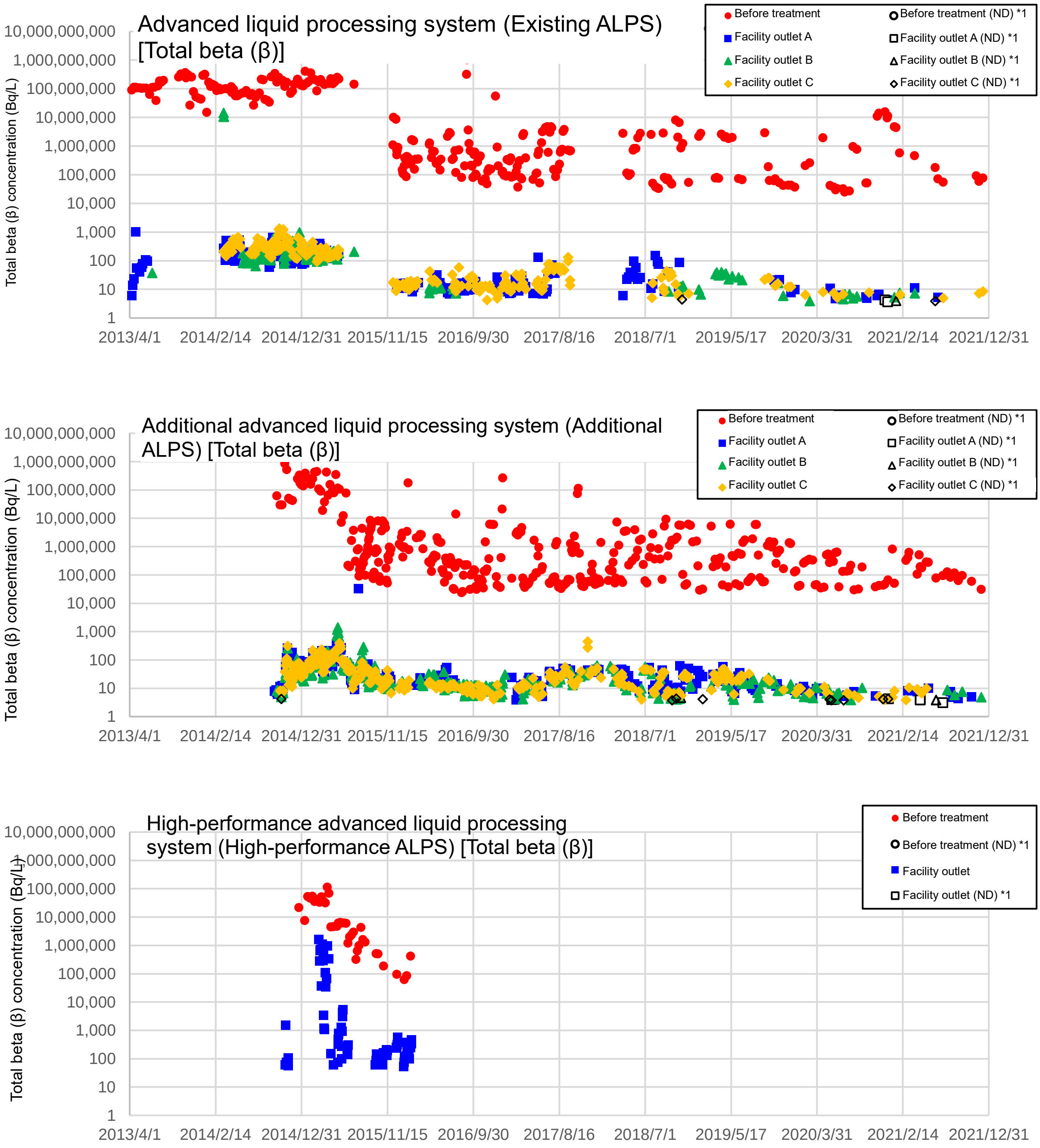


Figure II-5-8 **Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Total beta nuclide)**

(*1 ND indicates less than the detection limit.)

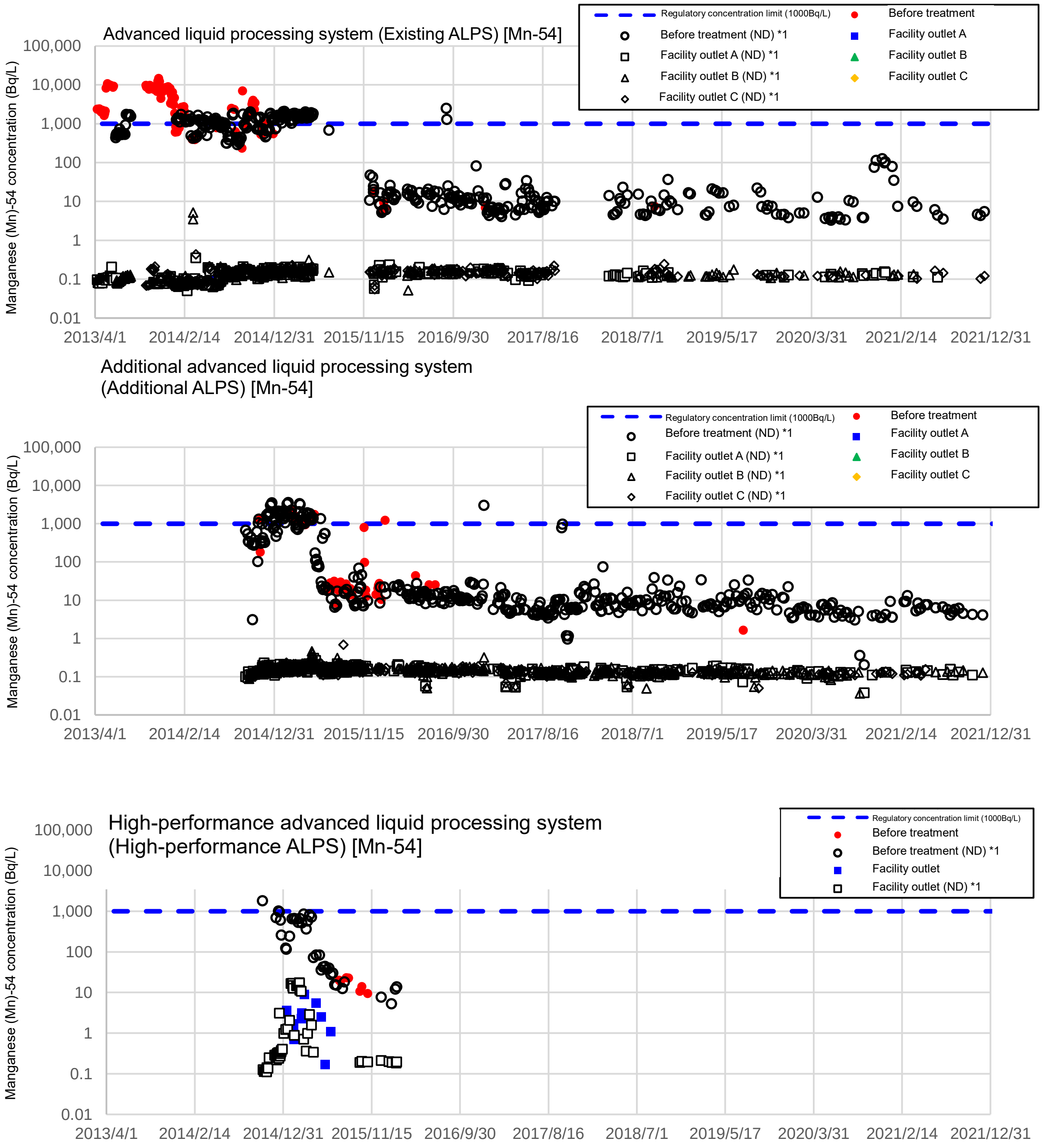


Figure II-5-9 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Mn-54)

(*1 ND indicates less than the detection limit.)

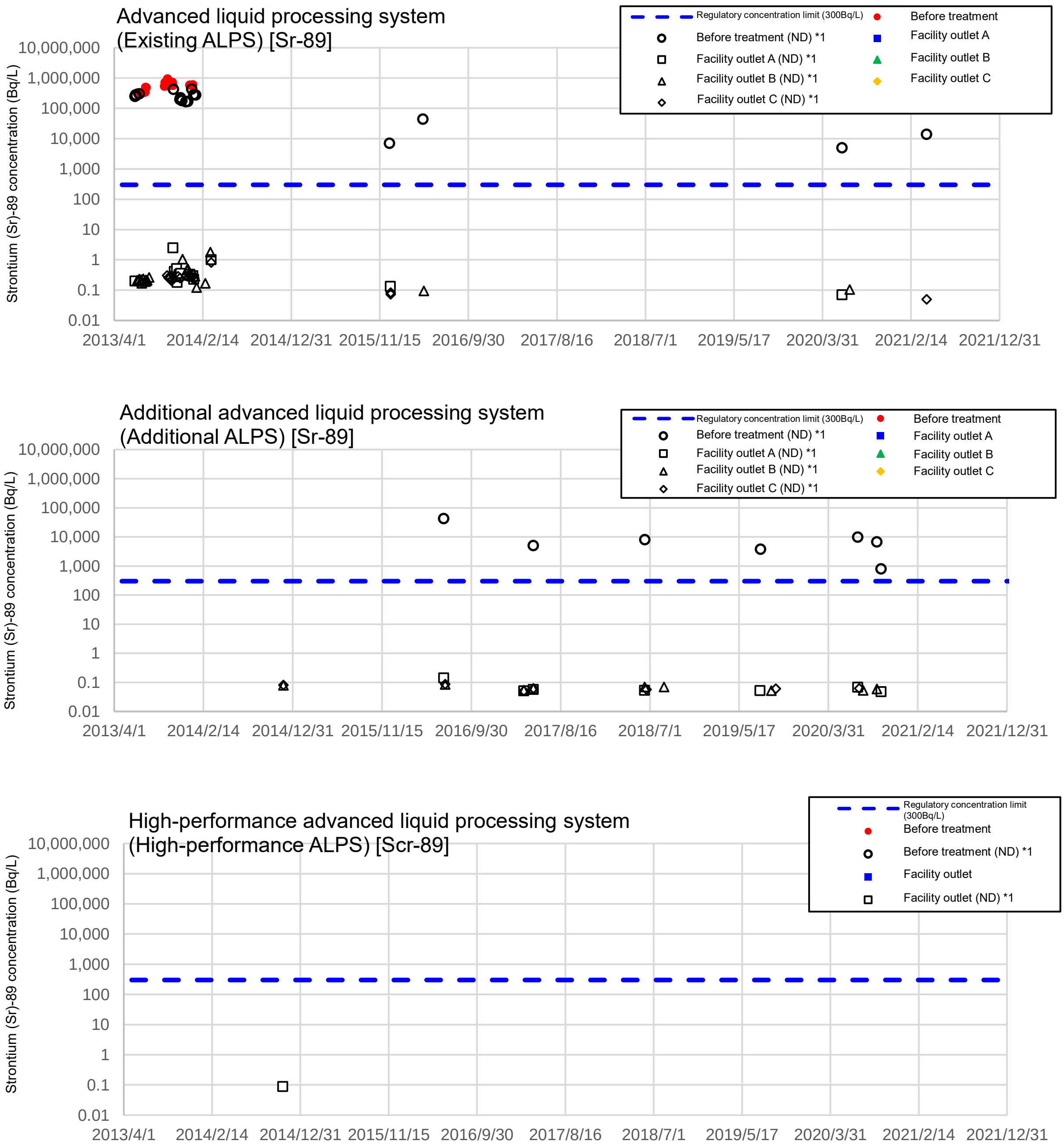


Figure II-5-10　Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Sr-89)
(*1 ND indicates less than the detection limit.)

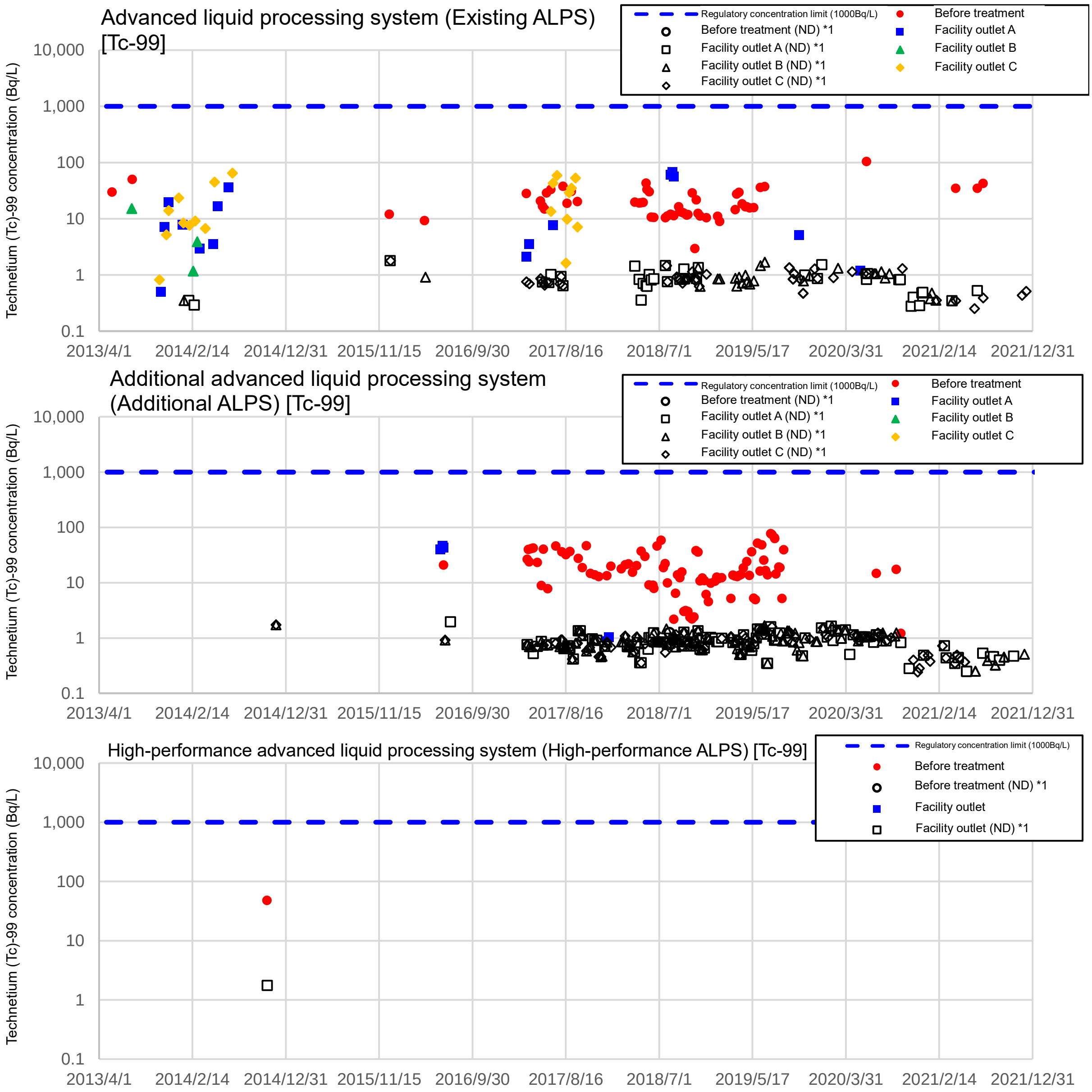


Figure II-5-11 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Tc-99)

(*1 ND indicates less than the detection limit.)

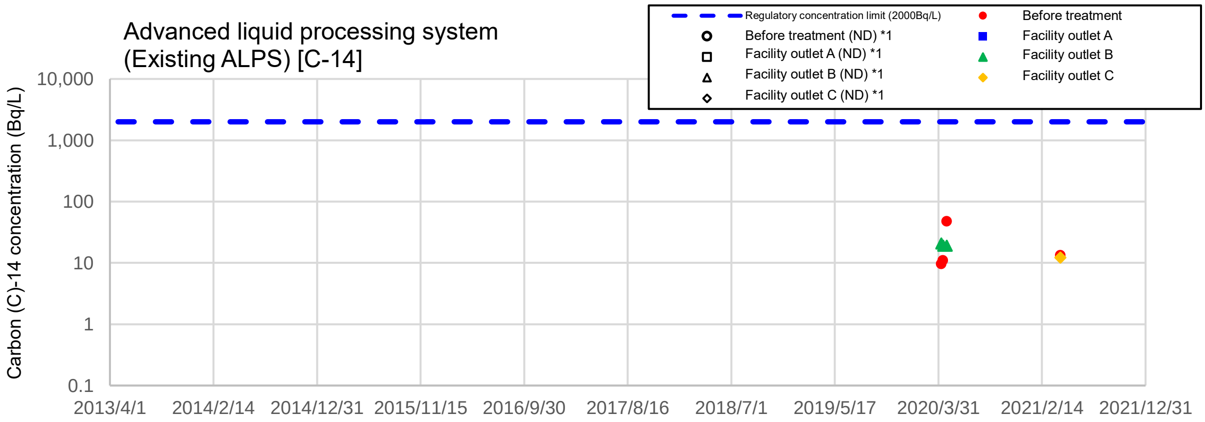


Figure II-5-12 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (C-14)

(*1 ND indicates less than the detection limit.)

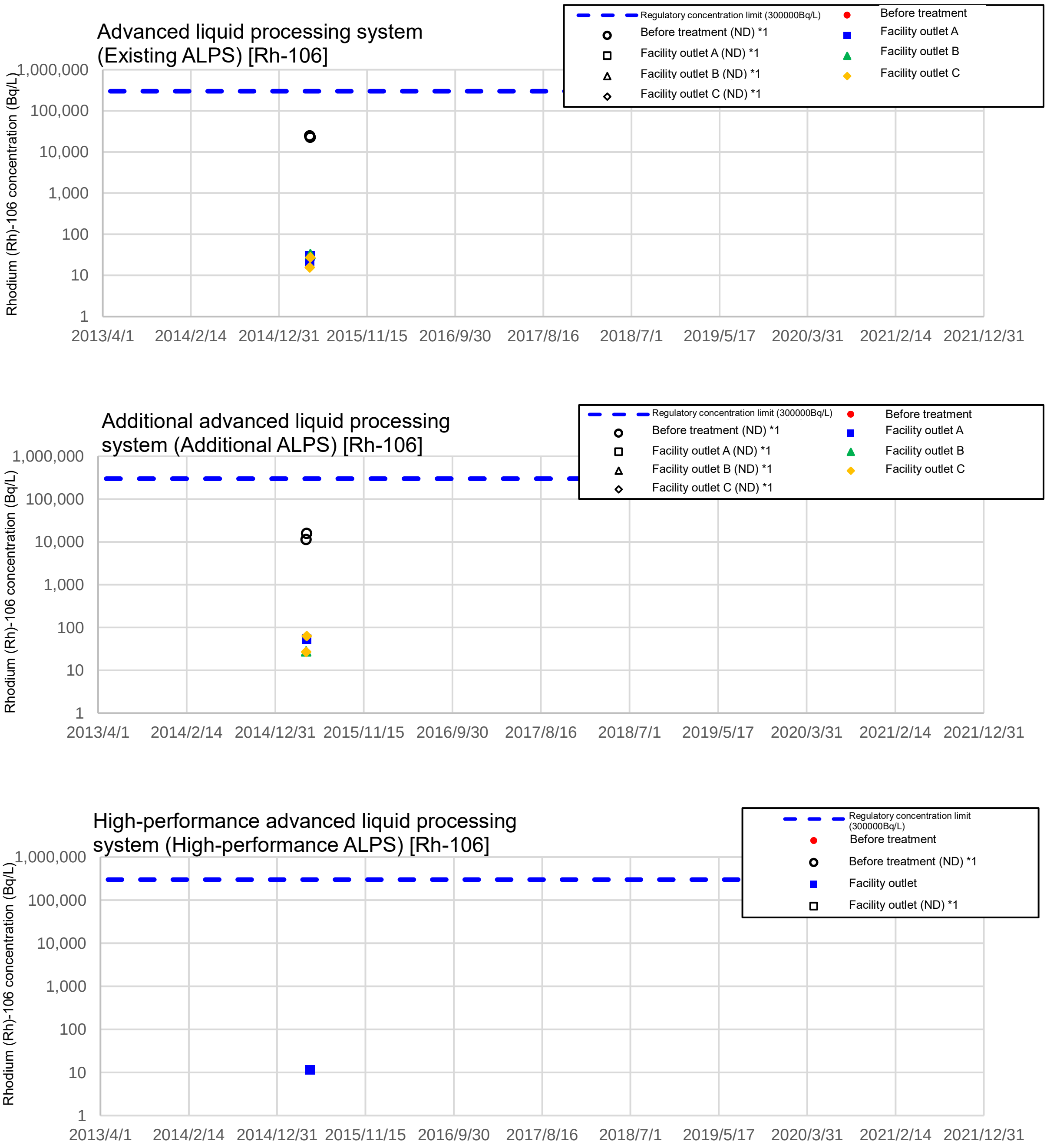


Figure II-5-13 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Rh-106)

(*1 ND indicates less than the detection limit.)

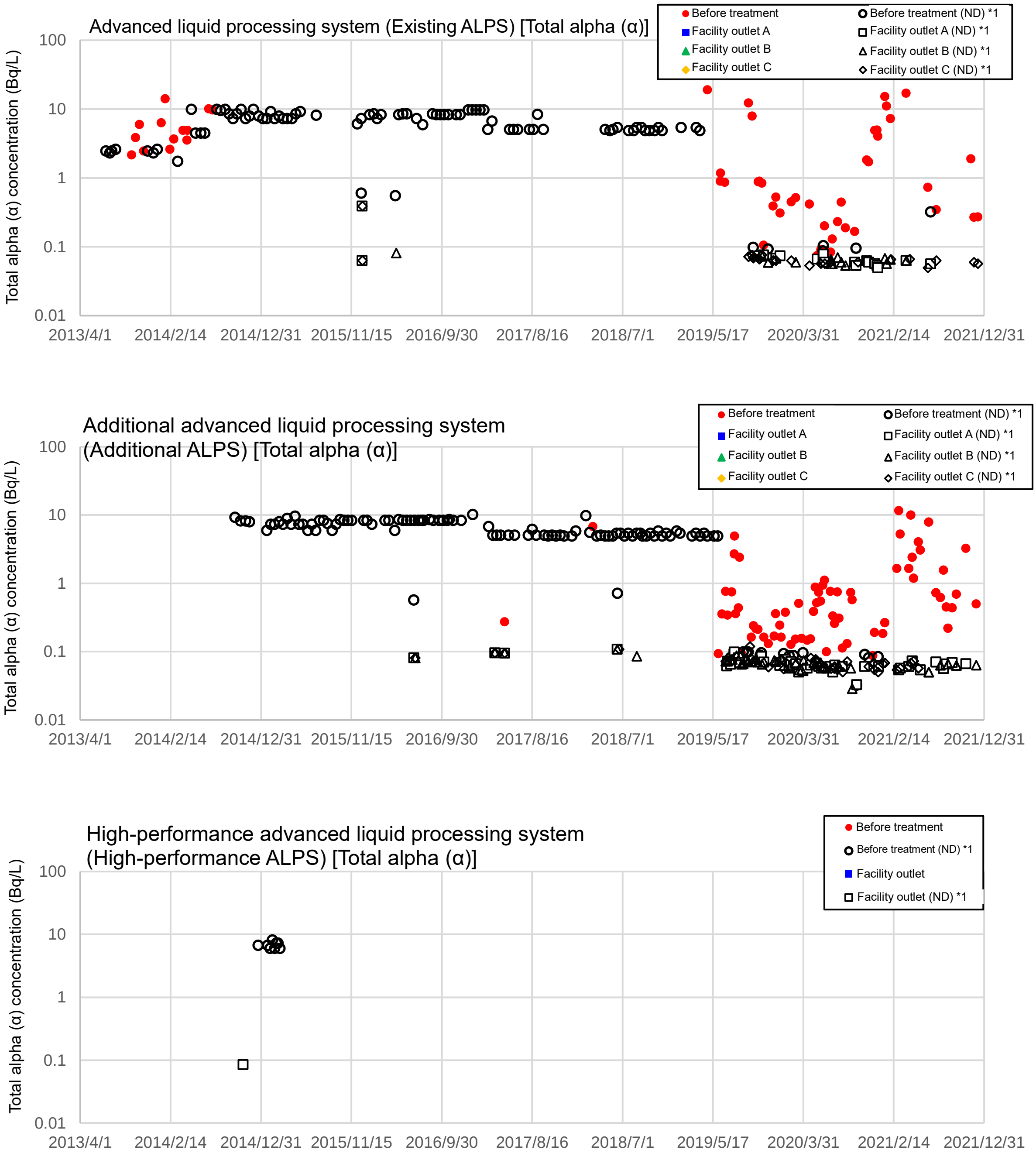


Figure II-5-14 Radioactive concentration in the inlet and outlet of each advanced liquid processing system (Total alpha nuclide)

(*1 ND indicates less than the detection limit.)

II-4. Secondary treatment performance of ALPS for treated water to be purified

II-4-1 Background of the secondary performance test

As of January 2023, approx. 70% of the water stored in the FDNPS is water of which sum of the ratios to regulatory concentrations limits is assessed to be 1 or more (so-called “treated water to be purified”) due to the various reasons shown in II-7. As described in the section about the discharge method in the main text, the secondary treatment of this treated water to be purified is surely performed before discharge to verify that sum of the ratios to regulatory concentrations limits other than tritium before dilution is less than 1.

ALPS is designed to be able to treat strontium treated water with a high radioactive material concentration, etc., and its capability to remove radioactive materials has been proven in actual operation, but there was an opinion that the secondary treatment of ALPS was very important and it should be proven immediately with measured values that radioactive materials other than tritium can be removed by secondary treatment up to the sum of the ratios to regulatory concentration limits of less than 1[4].

In response to this opinion, we decided to perform the secondary treatment test of treated water to be purified of a high concentration (sum of the ratios to regulatory concentrations limits of 100 or more) in ALPS, and started the secondary treatment performance test using the additional ALPS in September 2020 and completed it by December of the same year.

II-4-2 Overview of the secondary performance test

In this secondary treatment performance test, two tank groups (J1-C tank group as the high concentration side (sum of the ratios to regulatory concentrations limits: approx. 2,400) and J1-G tank group as the low concentration side (sum of the ratios to regulatory concentrations limits: approx. 390)) were selected from the tank groups of the sum of the ratios to regulatory concentrations limits of 100 or higher, and 1,000m^3 was treated from each of the tanks. For the piping used for the transfer, water replacement operation already included in the system was performed before the test.

Afterward, the treated water was sampled and the concentrations of the 62 nuclides subject to removal by ALPS, C-14, and tritium were measured to verify that the sum of the ratios to regulatory concentrations limits of the 63 nuclides except tritium became less than 1 by secondary treatment, and the procedure and process of the nuclide analysis were performed.

II-4-3 Result of the secondary performance test

Table II-3 and 4 show the results. It was verified that the sum of the ratios to regulatory concentrations limits of any treated water to be purified became less than 1 by secondary treatment.

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[4] Minutes of the 17th Subcommittee on Handling of the ALPS treated water p.11

Table II-3 Secondary treatment performance test result by ALPS (J1-C tank group)

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[5]		After secondary treatment[6]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
H-3 (About 12 years)	6.0E+04	8.51E+05	1.4E+01	8.22E+05	1.4E+01	Dilute to less than 1,500Bq/L before discharge
C-14 (About 5700 years)	2.0E+03	1.53E+01	7.6E-03	1.76E+01	8.8E-03	
Mn-54 (About 310 days)	1.0E+03	< 3.62E-01	3.6E-04	< 3.83E-02	3.8E-05	
Fe-59 (About 44 days)	4.0E+02	< 6.41E-01	1.6E-03	< 8.66E-02	2.2E-04	
Co-58 (About 71 days)	1.0E+03	< 3.44E-01	3.4E-04	< 4.11E-02	4.1E-05	
Co-60 (About 5.3 years)	2.0E+02	3.63E+01	1.8E-01	3.33E-01	1.7E-03	
Ni-63 (About 100 days)	6.0E+03	5.19E+01	8.6E-03	< 8.45E+00	1.4E-03	
Zn-65 (About 240 days)	2.0E+02	< 7.19E-01	3.6E-03	< 9.41E-02	4.7E-04	
Rb-86 (About 19 days)	3.0E+02	< 4.11E+00	1.4E-02	< 4.97E-01	1.7E-03	
Sr-89 (About 51 days)	3.0E+02	< 6.72E+03	2.2E+01	< 5.37E-02	1.8E-04	

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[5] Composite (mixing/stirring) was performed for the samples collected between September 19 and 21, 2020, and then analysis was performed.

[6] Samples were collected from the middle layer in the sample tank installed latter part of the additional ALPS outlet on September 27, 2020, and then analysis was performed.

[7] If the result falls below the lower limit of detection, describe the lower limit of detection following "<."

[8] If the analysis result is less than the lower limit of detection, the lower limit of detection is used for the calculation.

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[5]		After secondary treatment[6]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Sr-90 (About 29 years)	3.0E+01	6.46E+04	2.2E+03	3.57E-02	1.2E-03	
Y-90 (About 64 hours)	3.0E+02	6.46E+04	2.2E+02	3.57E-02	1.2E-04	Radioactive equilibrium with Sr-90
Y-91 (About 59 days)	3.0E+02	< 8.45E+01	2.8E-01	< 1.65E+01	5.5E-02	
Nb-95 (About 35 days)	1.0E+03	< 3.50E-01	3.5E-04	< 4.96E-02	5.0E-05	
Tc-99 (About 210 thousand years)	1.0E+03	1.74E+01	1.7E-02	< 1.23E+00	1.2E-03	
Ru-103 (About 39 days)	1.0E+03	< 7.21E-01	7.2E-04	< 5.27E-02	5.3E-05	
Ru-106 (About 370 days)	1.0E+02	< 5.00E+00	5.0E-02	< 1.43E+00	1.4E-02	
Rh-103m (About 56 minutes)	2.0E+05	< 7.21E-01	3.6E-06	< 5.27E-02	2.6E-07	Radioactive equilibrium with Ru-103
Rh-106 (About 30 seconds)	3.0E+05	< 5.00E+00	1.7E-05	< 1.43E+00	4.8E-06	Radioactive equilibrium with Ru-106
Ag-110m (About 250 days)	3.0E+02	< 5.41E-01	1.8E-03	< 4.26E-02	1.4E-04	
Cd-113m (About 14 years)	4.0E+01	< 2.05E+01	5.1E-01	< 8.52E-02	2.1E-03	
Cd-115m (45 days)	3.0E+02	< 2.26E+01	7.5E-02	< 2.70E+00	9.0E-03	
Sn-119m (About 290 days)	2.0E+03	< 3.90E+02	1.9E-01	< 4.24E+01	2.1E-02	Assessed from the radioactive concentration of Sn-123
Sn-123 (About 130 days)	4.0E+02	< 6.06E+01	1.5E-01	< 6.59E+00	1.6E-02	
Sn-126 (About 230 thousand years)	2.0E+02	< 2.88E+00	1.4E-02	< 2.92E-01	1.5E-03	
Sb-124 (About 60 days)	3.0E+02	< 2.79E-01	9.3E-04	< 9.67E-02	3.2E-04	
Sb-125 (About 2.8 years)	8.0E+02	8.30E+01	1.0E-01	2.26E-01	2.8E-04	
Te-123m (About 120 days)	6.0E+02	< 8.32E-01	1.4E-03	< 9.19E-02	1.5E-04	

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[5]		After secondary treatment[6]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Te-125m (About 57 days)	9.0E+02	8.30E+01	9.2E-02	2.26E-01	2.5E-04	Radioactive equilibrium with Sb-125
Te-127 (About 9.4 hours)	5.0E+03	< 7.25E+01	1.5E-02	< 4.69E+00	9.4E-04	
Te-127m (About 110 days)	3.0E+02	< 7.53E+01	2.5E-01	< 4.87E+00	1.6E-02	Assessed from the radioactive concentration of Te-127
Te-129 (About 70 minutes)	1.0E+04	< 1.27E+01	1.3E-03	< 6.15E-01	6.1E-05	
Te-129m (About 34 days)	3.0E+02	< 1.31E+01	4.4E-02	< 1.37E+00	4.6E-03	
I-129 (About 16 million years)	9.0E+00	2.99E+01	3.3E+00	1.16E+00	1.3E-01	
Cs-134 (About 2.1 years)	6.0E+01	< 2.93E+01	4.9E-01	< 7.60E-02	1.3E-03	
Cs-135 (About 2.3 million years)	6.0E+02	3.81E-03	6.4E-06	< 1.18E-06	2.0E-09	Assessed from the radioactive concentration of Cs-137
Cs-136 (About 13 days)	3.0E+02	< 3.77E-01	1.3E-03	< 4.68E-02	1.6E-04	
Cs-137 (About 30 years)	9.0E+01	< 5.99E+02	6.7E+00	< 1.85E-01	2.1E-03	
Ba-137m (About 2.6 minutes)	8.0E+05	5.99E+02	7.5E-04	< 1.85E-01	2.3E-07	Radioactive equilibrium with Cs-137
Ba-140 (About 13 days)	3.0E+02	< 2.40E+00	8.0E-03	< 2.02E-01	6.7E-04	
Ce-141 (About 33 days)	1.0E+03	< 1.51E+00	1.5E-03	< 2.62E-01	2.6E-04	
Ce-144 (About 280 days)	2.0E+02	< 6.84E+00	3.4E-02	< 5.69E-01	2.8E-03	
Pr-144 (About 17 minutes)	2.0E+04	< 6.84E+00	3.4E-04	< 5.69E-01	2.8E-05	Radioactive equilibrium with Ce-144
Pr-144m (About 7.2 minutes)	4.0E+04	< 6.84E+00	1.7E-04	< 5.69E-01	1.4E-05	Radioactive equilibrium with Ce-144
Pm-146 (About 5.5 years)	9.0E+02	< 1.23E+00	1.4E-03	< 6.66E-02	7.4E-05	
Pm-147 (About 2.6 years)	3.0E+03	< 4.08E+00	1.4E-03	< 8.04E-01	2.7E-04	Assessed from the radioactive concentration of Eu-154

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[5]		After secondary treatment[6]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Pm-148 (About 5.4 days)	3.0E+02	< 6.49E-01	2.2E-03	< 2.33E-01	7.8E-04	
Pm-148m (About 41 days)	5.0E+02	< 6.34E-01	1.3E-03	< 4.84E-02	9.7E-05	
Sm-151 (About 90 years)	8.0E+03	< 5.77E-02	7.2E-06	< 1.14E-02	1.4E-06	Assessed from the radioactive concentration of Eu-154
Eu-152 (About 14 years)	6.0E+02	< 2.70E+00	4.5E-03	< 2.84E-01	4.7E-04	
Eu-154 (About 8.6 years)	4.0E+02	< 5.77E-01	1.4E-03	< 1.14E-01	2.8E-04	
Eu-155 (About 4.8 years)	3.0E+03	< 3.43E+00	1.1E-03	< 3.36E-01	1.1E-04	
Gd-153 (About 240 days)	3.0E+03	< 3.17E+00	1.1E-03	< 2.64E-01	8.8E-05	
Tb-160 (About 72 days)	5.0E+02	< 1.66E+00	3.3E-03	< 1.43E-01	2.9E-04	
Pu-238 (About 88 years)	4.0E+00	< 5.70E-01	1.4E-01	< 3.25E-02	8.1E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-239 (About 24000 years)	4.0E+00	< 5.70E-01	1.4E-01	< 3.25E-02	8.1E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-240 (About 6600 years)	4.0E+00	< 5.70E-01	1.4E-01	< 3.25E-02	8.1E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-241 (About 14 years)	2.0E+02	< 2.07E+01	1.0E-01	< 1.18E+00	5.9E-03	Assessed from the radioactive concentration of Pu-238
Am-241 (About 430 years)	5.0E+00	< 5.70E-01	1.1E-01	< 3.25E-02	6.5E-03	Assessed as included in the measurement value of the total α radioactivity
Am-242m (About 140 years)	5.0E+00	< 1.03E-02	2.1E-03	< 5.87E-04	1.2E-04	Assessed from the radioactive concentration of Am-241
Am-243 (About 7400 years)	5.0E+00	< 5.70E-01	1.1E-01	< 3.25E-02	6.5E-03	Assessed as included in the measurement value of the total α radioactivity
Cm-242 (About 160 days)	6.0E+01	< 5.70E-01	9.5E-03	< 3.25E-02	5.4E-04	Assessed as included in the measurement value of the total α radioactivity
Cm-243 (About 29 years)	6.0E+00	< 5.70E-01	9.5E-02	< 3.25E-02	5.4E-03	Assessed as included in the measurement value of the total α radioactivity
Cm-244 (About 18 years)	7.0E+00	< 5.70E-01	8.1E-02	< 3.25E-02	4.6E-03	Assessed as included in the measurement value of the total α radioactivity
Sum of the ratios to regulatory concentrations limits of nuclides other than tritium		-	2.4E+03	-	3.5E-01	

Table II-4 Secondary treatment performance test result by ALPS (J1-G tank group)

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[9]		After secondary treatment[10]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
H-3 (About 12 years)	6.0E+04	2.73E+05	4.6E+00	2.72E+05	4.5E+00	Dilute to less than 1,500Bq/L before discharge
C-14 (About 5700 years)	2.0E+03	1.26E+01	6.3E-03	1.56E+01	7.8E-03	
Mn-54 (About 310 days)	1.0E+03	< 2.02E-01	2.0E-04	< 3.79E-02	3.8E-05	
Fe-59 (About 44 days)	4.0E+02	< 3.51E-01	8.8E-04	< 7.17E-02	1.8E-04	
Co-58 (About 71 days)	1.0E+03	< 2.11E-01	2.1E-04	< 3.74E-02	3.7E-05	
Co-60 (About 5.3 years)	2.0E+02	1.31E+01	6.5E-02	2.33E-01	1.2E-03	
Ni-63 (About 100 days)	6.0E+03	< 1.84E+01	3.1E-03	< 8.84E+00	1.5E-03	
Zn-65 (About 240 days)	2.0E+02	< 4.35E-01	2.2E-03	< 7.97E-02	4.0E-04	
Rb-86 (About 19 days)	3.0E+02	< 2.56E+00	8.5E-03	< 4.67E-01	1.6E-03	
Sr-89 (About 51 days)	3.0E+02	< 7.87E+02	2.6E+00	< 4.52E-02	1.5E-04	
Sr-90 (About 29 years)	3.0E+01	1.04E+04	3.5E+02	< 3.18E-02	1.1E-03	
Y-90 (About 64 hours)	3.0E+02	1.04E+04	3.5E+01	< 3.18E-02	1.1E-04	Radioactive equilibrium with Sr-90
Y-91 (About 59 days)	3.0E+02	< 4.82E+01	1.6E-01	< 1.18E+01	3.9E-02	
Nb-95 (About 35 days)	1.0E+03	< 2.56E-01	2.6E-04	< 4.70E-02	4.7E-05	
Tc-99 (About 210 thousand years)	1.0E+03	1.20E+00	1.2E-03	< 1.29E+00	1.3E-03	
Ru-103 (About 39 days)	1.0E+03	< 3.39E-01	3.4E-04	< 5.06E-02	5.1E-05	

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[9] Composite (mixing/stirring) was performed for the samples collected between October 5 and 7, 2020, and then analysis was performed.

[10] Samples were collected from the middle layer in the sample tank installed latter part of the additional ALPS outlet on October 13, 2020, and then analysis was performed.

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[9]		After secondary treatment[10]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Ru-106 (About 370 days)	1.0E+02	< 2.27E+00	2.3E-02	4.83E-01	4.8E-03	
Rh-103m (About 56 minutes)	2.0E+05	< 3.39E-01	1.7E-06	< 5.06E-02	2.5E-07	Radioactive equilibrium with Ru-103
Rh-106 (About 30 seconds)	3.0E+05	< 2.27E+00	7.6E-06	4.83E-01	1.6E-06	Radioactive equilibrium with Ru-106
Ag-110m (About 250 days)	3.0E+02	< 2.92E-01	9.7E-04	< 4.00E-02	1.3E-04	
Cd-113m (About 14 years)	4.0E+01	< 2.04E+01	5.1E-01	< 8.55E-02	2.1E-03	
Cd-115m (45 days)	3.0E+02	< 1.16E+01	3.9E-02	< 2.29E+00	7.6E-03	
Sn-119m (About 290 days)	2.0E+03	< 2.13E+02	1.1E-01	< 4.03E+01	2.0E-02	Assessed from the radioactive concentration of Sn-123
Sn-123 (About 130 days)	4.0E+02	< 3.31E+01	8.3E-02	< 6.26E+00	1.6E-02	
Sn-126 (About 230 thousand years)	2.0E+02	< 1.16E+00	5.8E-03	< 1.47E-01	7.3E-04	
Sb-124 (About 60 days)	3.0E+02	< 2.20E-01	7.3E-04	< 8.42E-02	2.8E-04	
Sb-125 (About 2.8 years)	8.0E+02	3.23E+01	4.0E-02	1.37E-01	1.7E-04	
Te-123m (About 120 days)	6.0E+02	< 3.83E-01	6.4E-04	< 6.67E-02	1.1E-04	
Te-125m (About 57 days)	9.0E+02	3.23E+01	3.6E-02	1.37E-01	1.5E-04	Radioactive equilibrium with Sb-125
Te-127 (About 9.4 hours)	5.0E+03	< 3.53E+01	7.1E-03	< 4.33E+00	8.7E-04	
Te-127m (About 110 days)	3.0E+02	< 3.67E+01	1.2E-01	< 4.50E+00	1.5E-02	Assessed from the radioactive concentration of Te-127
Te-129 (About 70 minutes)	1.0E+04	< 4.71E+00	4.7E-04	< 5.94E-01	5.9E-05	
Te-129m (About 34 days)	3.0E+02	< 6.61E+00	2.2E-02	< 1.21E+00	4.0E-03	
I-129 (About 16 million years)	9.0E+00	2.79E+00	3.1E-01	3.28E-01	3.6E-02	
Cs-134 (About 2.1 years)	6.0E+01	5.94E+00	9.9E-02	< 6.65E-02	1.1E-03	

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[9]		After secondary treatment[10]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Cs-135 (About 2.3 million years)	6.0E+02	7.51E-04	1.3E-06	2.10E-06	3.5E-09	Assessed from the radioactive concentration of Cs-137
Cs-136 (About 13 days)	3.0E+02	< 1.96E-01	6.5E-04	< 3.63E-02	1.2E-04	
Cs-137 (About 30 years)	9.0E+01	1.18E+02	1.3E+00	3.29E-01	3.7E-03	
Ba-137m (About 2.6 minutes)	8.0E+05	1.18E+02	1.5E-04	3.29E-01	4.1E-07	Radioactive equilibrium with Cs-137
Ba-140 (About 13 days)	3.0E+02	< 1.22E+00	4.1E-03	< 1.73E-01	5.8E-04	
Ce-141 (About 33 days)	1.0E+03	< 9.39E-01	9.4E-04	< 1.19E-01	1.2E-04	
Ce-144 (About 280 days)	2.0E+02	< 3.02E+00	1.5E-02	< 5.53E-01	2.8E-03	
Pr-144 (About 17 minutes)	2.0E+04	< 3.02E+00	1.5E-04	< 5.53E-01	2.8E-05	Radioactive equilibrium with Ce-144
Pr-144m (About 7.2 minutes)	4.0E+04	< 3.02E+00	7.6E-05	< 5.53E-01	1.4E-05	Radioactive equilibrium with Ce-144
Pm-146 (About 5.5 years)	9.0E+02	< 5.26E-01	5.8E-04	< 6.30E-02	7.0E-05	
Pm-147 (About 2.6 years)	3.0E+03	< 2.53E+00	8.4E-04	< 7.20E-01	2.4E-04	Assessed from the radioactive concentration of Eu-154
Pm-148 (About 5.4 days)	3.0E+02	< 5.19E-01	1.7E-03	< 4.52E-01	1.5E-03	
Pm-148m (About 41 days)	5.0E+02	< 2.76E-01	5.5E-04	< 4.09E-02	8.2E-05	
Sm-151 (About 90 years)	8.0E+03	< 3.57E-02	4.5E-06	< 1.02E-02	1.3E-06	Assessed from the radioactive concentration of Eu-154
Eu-152 (About 14 years)	6.0E+02	< 1.21E+00	2.0E-03	< 1.90E-01	3.2E-04	
Eu-154 (About 8.6 years)	4.0E+02	< 3.57E-01	8.9E-04	< 1.02E-01	2.5E-04	
Eu-155 (About 4.8 years)	3.0E+03	< 1.38E+00	4.6E-04	< 1.75E-01	5.8E-05	
Gd-153 (About 240 days)	3.0E+03	< 1.21E+00	4.0E-04	< 1.85E-01	6.2E-05	
Tb-160 (About 72 days)	5.0E+02	< 6.88E-01	1.4E-03	< 1.35E-01	2.7E-04	

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Before secondary treatment[9]		After secondary treatment[10]		Remarks
		Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	Analysis result[7] [Bq/L]	Ratio to regulatory limit[8]	
Pu-238 (About 88 years)	4.0E+00	< 3.19E-02	8.0E-03	< 2.80E-02	7.0E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-239 (About 24000 years)	4.0E+00	< 3.19E-02	8.0E-03	< 2.80E-02	7.0E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-240 (About 6600 years)	4.0E+00	< 3.19E-02	8.0E-03	< 2.80E-02	7.0E-03	Assessed as included in the measurement value of the total α radioactivity
Pu-241 (About 14 years)	2.0E+02	< 1.16E+00	5.8E-03	< 1.02E+00	5.1E-03	Assessed from the radioactive concentration of Pu-238
Am-241 (About 430 years)	5.0E+00	< 3.19E-02	6.4E-03	< 2.80E-02	5.6E-03	Assessed as included in the measurement value of the total α radioactivity
Am-242m (About 140 years)	5.0E+00	< 5.77E-04	1.2E-04	< 5.05E-04	1.0E-04	Assessed from the radioactive concentration of Am-241
Am-243 (About 7400 years)	5.0E+00	< 3.19E-02	6.4E-03	< 2.80E-02	5.6E-03	Assessed as included in the measurement value of the total α radioactivity
Cm-242 (About 160 days)	6.0E+01	< 3.19E-02	5.3E-04	< 2.80E-02	4.7E-04	Assessed as included in the measurement value of the total α radioactivity
Cm-243 (About 29 years)	6.0E+00	< 3.19E-02	5.3E-03	< 2.80E-02	4.7E-03	Assessed as included in the measurement value of the total α radioactivity
Cm-244 (About 18 years)	7.0E+00	< 3.19E-02	4.6E-03	< 2.80E-02	4.0E-03	Assessed as included in the measurement value of the total α radioactivity
Sum of the ratios to regulatory concentrations limits of nuclides other than tritium		-	3.9E+02	-	2.2E-01	

II-5. Analysis of the radioactive materials in the stored ALPS treated water, etc.

As shown in II-3. “Performance of ALPS”, in measured point (7) of the ALPS outlet, mainly the seven nuclides detected significantly in the process of treatment among those subject to removal by ALPS (Cs-134, Cs-137, Co-60, Sb-125, Ru-106, Sr-90, and I-129) were measured. The result is shown on our web site.

Our web site:
https://www.tepco.co.jp/decommission/progress/watertreatment/images/exit.pdf (ja)
https://www.tepco.co.jp/en/decommission/progress/watertreatment/images/exit_en.pdf (en)

The judgment of whether stored water is regarded as “ALPS treated water” and “treated water to be purified” shall be performed according to the following procedure based on this measurement result.

In other words, when the transfer destination tank group (8 to 10 tanks connected at the time of water reception) becomes full, water of which ratios to regulatory concentrations limits of nuclides other than tritium were estimated to be less than 1 using the following formula is judged as ALPS treated water and the other water as treated water to be purified, based on the measurement result of the sample (water) collected in the ALPS outlet (measured point (7)) during reception of water in the corresponding tanks group from ALPS.

$$C_{All} = C_{M7} + C_{C-14} + C_0 < 1$$

where

C_{All}: Sum of the ratios to regulatory concentrations limits of nuclides other than tritium

C_{M7}: Sum of the ratios to regulatory concentrations limits calculated from the measurement results of the seven major nuclides

C_{C-14}: Ratio to the regulatory concentrations limit of C-14 (conservatively set to the ratio to the regulatory concentrations limit of 0.11 calculated from the maximum concentration (215Bq/L) measured in the past)

C_0: Estimated value of the sum of the ratios to regulatory concentrations limits of the nuclides not included in the 7 nuclides among the nuclides other than tritium (The estimated value based on the past measurement results is set to 0.3)

Based on the result of the measurement, nuclides deemed to be less than the detection limit (ND) are assumed to be included at the concentration of the lower limit of detection and the lower limit of detection is used for the assessment of the above formula. The following table shows examples of measurement results and values in the calculation of the sum of the ratios to regulatory concentration limits.

Table II-5 Relationship between the analysis results of the seven major nuclides and the sum of the ratios to regulatory concentration limits of the seven major nuclides

Nuclide	Cs-137	Cs-134	Co-60	Sb-125	Ru-106	Sr-90	I-129
Measured concentration	ND (<1.26E-01)	ND (<1.66E-01)	2.35E-01	ND (<4.57E-01)	ND (<1.15E00)	ND (<3.90E-01)	2.02E-01
Calculated concentration	1.26E-01	1.66E-01	2.35E-01	4.57E-01	1.15E+00	3.90E-01	2.02E-01
Regulatory concentration limit	9.00E+01	6.00E+01	2.00E+02	8.00E+02	1.00E+02	3.00E+01	9.00E+00
Ratio to regulatory concentration limit	1.40E-03	2.76E-03	1.18E-03	5.71E-04	1.15E-02	1.30E-02	2.24E-02
Sum of the regulatory ratios of the 7 nuclides (C_{M7})	0.05 (5.28E-02)						
Sum of the regulatory ratios of the 63 nuclides (C_{All})	0.05 (=C_{M7})+0.11(=C_{C-14})+0.3(=C_{55})=0.46						

Figure II-5 shows the concentration distribution of the seven major nuclides arranged from the analysis result of the tank group of which sum of the ratios to regulatory concentrations limits other than tritium is estimated to be less than 1.

- Measured value of the radioactive concentration of each tank group (excluding reused tanks) (as of March 31, 2021)
- Secondary treatment test water
https://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2020/2h/rf_20201224_1.pdf

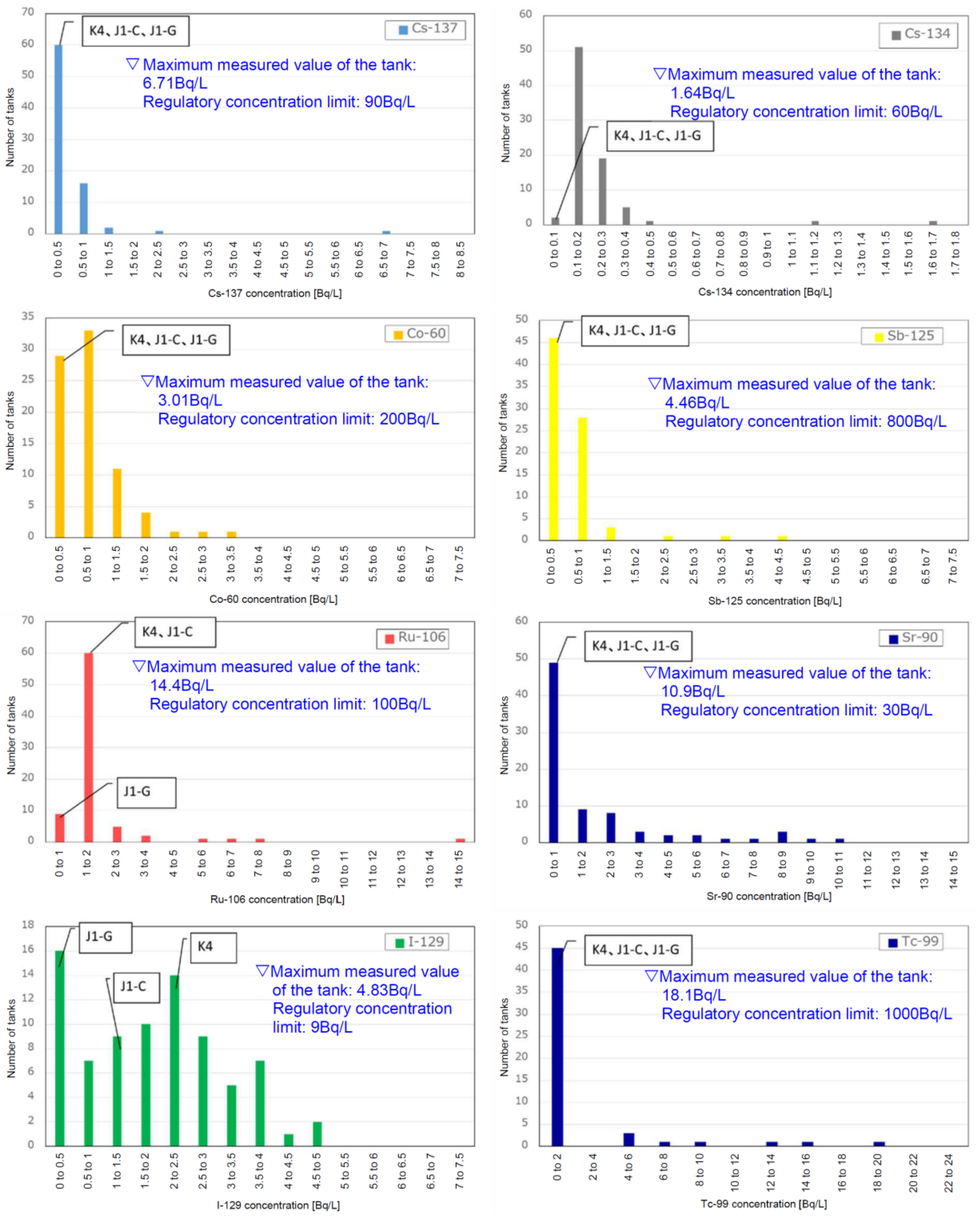

Figure II-5 Concentration distribution of the seven major nuclides in the analysis result of ALPS treated water (as of the end of March 2021)

* The analysis results in which sum of the ratios to regulatory concentrations limits of the 7 major nuclides is less than 0.59 (for 80 tanks) (excluding secondary treatment test water)

* The vertical axis indicates the number of tanks (counted as the lower detection limit if not detected)

* Some maximum values are the detection limit values because they were created using the detection limit value in the case of non-detection.

* Values are measured values at the times and no half-life correction is considered.

Figure II-6 shows the analysis result concentration distribution created by extracting the analysis results of the analyzed tanks for tritium and C-14, which are not subject to removal by ALPS.

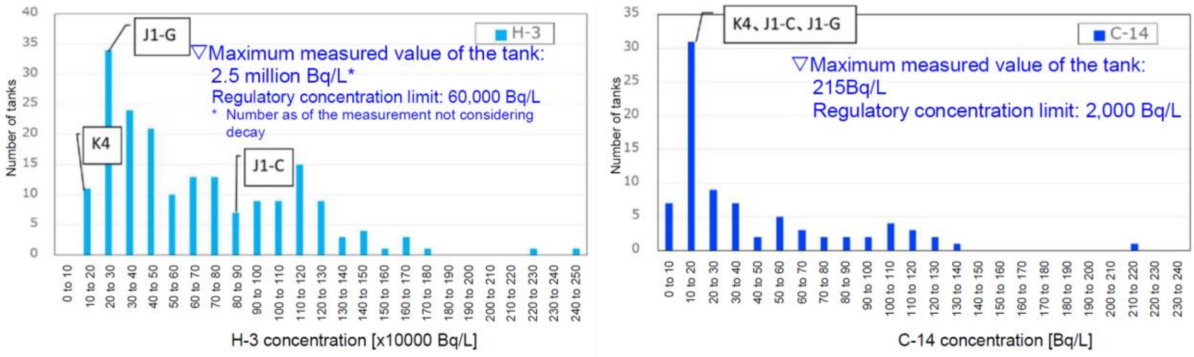

Figure II-6 Concentration distribution of tritium and C-14 in the analysis result of ALPS treated water, etc. (as of the end of March 2021)

- * The analysis results of the tank group (189 tanks for tritium and 81 tanks for C-14) are plotted (excluding secondary treatment test water)
- * The vertical axis indicates the number of tanks (counted as the lower detection limit if not detected)
- * Values are measured values at the times and no half-life correction is considered.

As a result of the above-mentioned estimation, as of January 2023, approx. 70% of the water stored in the tanks is judged to be “treated water to be purified,” which does not satisfy the above formula: in other words, the sum of the ratios to regulatory concentrations limits (C_{All}) of nuclides other than tritium is greater than 1. “Treated water to be purified” is discharged only after secondary treatment is conducted immediately before future discharge into the sea, and after it is confirmed that the regulatory concentration limit is less than 1 with the facility for measurement and confirmation.

In addition, this sample is not representative because each tank group does not have a necessary stirring device to guarantee the homogeneity. Therefore, for the actual judgment of whether the discharge is possible, the correct regulatory concentration limit obtained from the result of the measurement and assessment in the facility for measurement and confirmation is used.

All data of the past measurement and estimation results of the above-mentioned method are published on our web site. Our treatment water portal shows the measurement results of each tank group. The latest data is available in the following links.

Our web site (Japanese only):
https://www.tepco.co.jp/decommission/data/daily_analysis/tank/index-j.html

Treated water portal:
https://www.tepco.co.jp/decommission/progress/watertreatment/ (ja)
https://www.tepco.co.jp/en/decommission/progress/watertreatment/images/tankarea_en.pdf (en)

For the K4 tank group of which sum of the ratios to regulatory concentrations limits becomes less than 1 after treated by ALPS once, the 64 nuclides included in the collected sample are measured and assessed according to the measurement and assessment method shown in Table II-6 (however, the representativeness of the sample is not secured). The K4 tank group is the receiving tank group in the operation considering the sum of the ratios to regulatory concentrations limits of less than 1 in ALPS in FY 2016. For analysis, samples were collected from 24 locations, which are upper, middle, and lower layer of each 8 out of 35 tanks, the water samples were mixed (composite sample), and 62 nuclides were analyzed. For C-14, the average value of the results of analyses of samples taken from middle layer of five tanks after verification of the presence is shown. Table II-7 shows the results.

Table II-6 Measurement and assessment methods of each nuclide

No.	Nuclide	Radiation type	Measurement or assessment method
1	Mn-54	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
2	Fe-59	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
3	Co-58	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
4	Co-60	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
5	Ni-63	β	Isolated by resin, mixed with a scintillator, and counted by a low back liquid scintillation counter.
6	Zn-65	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
7	Rb-86	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
8	Sr-89	β	Isolated with resin, precipitated and recovered, mounted, and counted with the β nuclide analyzer in stainless steel dish
9	Sr-90	β	Isolated with resin, precipitated and recovered, mounted, and counted with the β nuclide analyzer in stainless steel dish
10	Y-90	β	Concentration assessment as Sr -90 and radioactive equilibrium
11	Y-91	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
12	Nb-95	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
13	Tc-99	β	Samples are diluted with dilute nitric acid and counted with the inductively coupled plasma mass spectrometry (ICP-MS).
14	Ru-103	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
15	Ru-106	β	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
16	Rh-103m	βγ	Concentration assessment as radioactive equilibrium with Ru-103
17	Rh-106	γ	Concentration assessment as radioactive equilibrium with Ru-106
18	Ag-110m	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
19	Cd-113m	γ	Isolated by ion exchange, mixed with a scintillator, and counted by a low back liquid scintillation counter.
20	Cd-115m	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
21	Sn-119m	γ	Assessed from the measured value of the radioactive concentration of Sn-123 and the calculated nuclide abundance ratio
22	Sn-123	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.

No.	Nuclide	Radiation type	Measurement or assessment method
23	Sn-126	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
24	Sb-124	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
25	Sb-125	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
26	Te-123m	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
27	Te-125m	γ	Concentration assessment as radioactive equilibrium with Sb-125
28	Te-127	βγ	Homogenized samples are collected in a Marinelli container, counted with a Ge semiconductor detector, and assessed using the half-life of the parent nuclide (Te-127m).
29	Te-127m	βγ	Assessed from the measured value of the radioactive concentration of Te-127 and the calculated nuclide abundance ratio
30	Te-129	βγ	Homogenized samples are collected in a Marinelli container, counted with a Ge semiconductor detector, and assessed using the half-life of the parent nuclide (Te-129m).
31	Te-129m	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
32	I-129	βγ	Samples were counted with the inductively coupled plasma mass spectrometry (ICP-MS) after adjusting to iodate ion by the addition of reagents.
33	Cs-134	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
34	Cs-135	β	Assessed from the measured value of the radioactive concentration of Cs-137 and the calculated nuclide abundance ratio
35	Cs-136	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
36	Cs-137	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
37	Ba-137m	γ	Concentration assessment as radioactive equilibrium with Cs-137
38	Ba-140	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
39	Ce-141	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
40	Ce-144	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
41	Pr-144	βγ	Concentration assessment as radioactive equilibrium with Ce-144, using half-life of parent nuclide (Pr-144m)
42	Pr-144m	γ	Concentration assessment as radioactive equilibrium with Ce-144
43	Pm-146	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
44	Pm-147	βγ	Assessed from the measured value of the radioactive concentration of Eu-154 and the calculated nuclide abundance ratio
45	Pm-148	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
46	Pm-148m	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
47	Sm-151	βγ	Assessed from the measured value of the radioactive concentration of Eu-154 and the calculated nuclide abundance ratio
48	Eu-152	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
49	Eu-154	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
50	Eu-155	βγ	Homogenized samples are collected in a Marinelli container and

No.	Nuclide	Radiation type	Measurement or assessment method
			counted with a Ge semiconductor detector.
51	Gd-153	γ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
52	Tb-160	βγ	Homogenized samples are collected in a Marinelli container and counted with a Ge semiconductor detector.
53	Pu-238	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
54	Pu-239	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
55	Pu-240	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
56	Pu-241	β	Assessed from the total α discrete value and the isotopic ratio of Pu-238
57	Am-241	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
58	Am-242m	α	Assessed from the isotopic ratio of Am-241
59	Am-243	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
60	Cm-242	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
61	Cm-243	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
62	Cm-244	α	After iron is removed by iron coprecipitation, the sample is evaporated to dryness in a stainless steel dish and the total α measured value counted with the ZnSα automatic measuring device is used as it is without proportionate division with other nuclides
-	H-3(FWT)	β	Isolated by distillation, mixed with a scintillator, and counted by a low back liquid scintillation counter.
-	C-14	β	Converted to CO_2, collected and isolated on absorbent, mixed with a scintillator, and counted by a low back liquid scintillation counter.

Table II-7 Analysis result of the K4 tank group

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Analysis result [Bq/L]	Ratio to regulatory limit	Remarks
H-3 (About 12 years)	6.0E+04	1.9E+05	3.2E+00	Dilute to less than 1,500Bq/L before discharge
C-14 (About 5700 years)	2.0E+03	1.5E+01	7.5E-03	
Mn-54 (About 310 days)	1.0E+03	< 6.7E-03	6.7E-06	
Fe-59 (About 44 days)	4.0E+02	< 1.7E-02	4.3E-05	
Co-58 (About 71 days)	1.0E+03	< 8.0E-03	8.0E-06	
Co-60 (About 5.3 years)	2.0E+02	4.4E-01	2.2E-03	
Ni-63 (About 100 days)	6.0E+03	2.2E+00	3.7E-04	
Zn-65 (About 240 days)	2.0E+02	< 1.5E-02	7.5E-05	
Rb-86 (About 19 days)	3.0E+02	< 1.9E-01	6.3E-04	
Sr-89 (About 51 days)	3.0E+02	< 1.0E-01	3.3E-04	
Sr-90 (About 29 years)	3.0E+01	2.2E-01	7.3E-03	
Y-90 (About 64 hours)	3.0E+02	2.2E-01	7.3E-04	Radioactive equilibrium with Sr-90
Y-91 (About 59 days)	3.0E+02	< 2.2E+00	7.3E-03	
Nb-95 (About 35 days)	1.0E+03	< 1.0E-02	1.0E-05	
Tc-99 (About 210 thousand years)	1.0E+03	7.0E-01	7.0E-04	
Ru-103 (About 39 days)	1.0E+03	< 1.0E-02	1.0E-05	
Ru-106 (About 370 days)	1.0E+02	1.6E+00	1.6E-02	
Rh-103m (About 56 minutes)	2.0E+05	< 1.0E-02	5.0E-08	Radioactive equilibrium with Ru-103
Rh-106 (About 30 seconds)	3.0E+05	1.6E+00	5.3E-06	Radioactive equilibrium with Ru-106
Ag-110m (About 250 days)	3.0E+02	< 5.6E-03	1.9E-05	
Cd-113m (About 14 years)	4.0E+01	< 1.8E-02	4.5E-04	
Cd-115m (45 days)	3.0E+02	< 6.4E-01	2.1E-03	
Sn-119m (About 290 days)	2.0E+03	< 1.7E-01	8.5E-05	Assessed from the radioactive concentration of Sn-123
Sn-123 (About 130 days)	4.0E+02	< 1.2E+00	3.0E-03	
Sn-126 (About 230 thousand years)	2.0E+02	< 2.7E-02	1.4E-04	

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Analysis result [Bq/L]	Ratio to regulatory limit	Remarks
Sb-124 (About 60 days)	3.0E+02	< 9.5E-03	3.2E-05	
Sb-125 (About 2.8 years)	8.0E+02	3.3E-01	4.1E-04	
Te-123m (About 120 days)	6.0E+02	< 9.2E-03	1.5E-05	
Te-125m (About 57 days)	9.0E+02	3.3E-01	3.7E-04	Radioactive equilibrium with Sb-125
Te-127 (About 9.4 hours)	5.0E+03	< 3.2E-01	6.4E-05	
Te-127m (About 110 days)	3.0E+02	< 3.2E-01	1.1E-03	Assessed from the radioactive concentration of Te-127
Te-129 (About 70 minutes)	1.0E+04	< 8.1E-02	8.1E-06	
Te-129m (About 34 days)	3.0E+02	< 3.2E-01	1.1E-03	
I-129 (About 16 million years)	9.0E+00	2.1E+00	2.3E-01	
Cs-134 (About 2.1 years)	6.0E+01	4.5E-02	7.5E-04	
Cs-135 (About 2.3 million years)	6.0E+02	2.5E-06	4.2E-09	Assessed from the radioactive concentration of Cs-137
Cs-136 (About 13 days)	3.0E+02	< 3.0E-02	1.0E-04	
Cs-137 (About 30 years)	9.0E+01	4.2E-01	4.7E-03	
Ba-137m (About 2.6 minutes)	8.0E+05	4.2E-01	5.3E-07	Radioactive equilibrium with Cs-137
Ba-140 (About 13 days)	3.0E+02	< 9.5E-02	3.2E-04	
Ce-141 (About 33 days)	1.0E+03	< 2.5E-02	2.5E-05	
Ce-144 (About 280 days)	2.0E+02	< 6.3E-02	3.2E-04	
Pr-144 (About 17 minutes)	2.0E+04	< 6.3E-02	3.2E-06	Radioactive equilibrium with Ce-144
Pr-144m (About 7.2 minutes)	4.0E+04	< 6.3E-02	1.6E-06	Radioactive equilibrium with Ce-144
Pm-146 (About 5.5 years)	9.0E+02	< 9.8E-02	1.1E-04	
Pm-147 (About 2.6 years)	3.0E+03	< 1.9E-01	6.3E-05	Assessed from the radioactive concentration of Eu-154
Pm-148 (About 5.4 days)	3.0E+02	< 5.0E-01	1.7E-03	
Pm-148m (About 41 days)	5.0E+02	< 8.4E-03	1.7E-05	
Sm-151 (About 90 years)	8.0E+03	< 9.0E-04	1.1E-07	Assessed from the radioactive concentration of Eu-154

Nuclide (Half-life)	Regulatory concentration limit [Bq/L]	Analysis result [Bq/L]	Ratio to regulatory limit	Remarks
Eu-152 (About 14 years)	6.0E+02	< 2.8E-02	4.7E-05	
Eu-154 (About 8.6 years)	4.0E+02	< 1.2E-02	3.0E-05	
Eu-155 (About 4.8 years)	3.0E+03	< 3.3E-02	1.1E-05	
Gd-153 (About 240 days)	3.0E+03	< 3.2E-02	1.1E-05	
Tb-160 (About 72 days)	5.0E+02	< 2.8E-02	5.6E-05	
Pu-238 (About 88 years)	4.0E+00	< 6.3E-04	1.6E-04	Assessed as included in the measurement value of the total α radioactivity
Pu-239 (About 24000 years)	4.0E+00	< 6.3E-04	1.6E-04	Assessed as included in the measurement value of the total α radioactivity
Pu-240 (About 6600 years)	4.0E+00	< 6.3E-04	1.6E-04	Assessed as included in the measurement value of the total α radioactivity
Pu-241 (About 14 years)	2.0E+02	< 2.8E-02	1.4E-04	Assessed from the radioactive concentration of Pu-238
Am-241 (About 430 years)	5.0E+00	< 6.3E-04	1.3E-04	Assessed as included in the measurement value of the total α radioactivity
Am-242m (About 140 years)	5.0E+00	< 3.9E-05	7.8E-06	Assessed from the radioactive concentration of Am-241
Am-243 (About 7400 years)	5.0E+00	< 6.3E-04	1.3E-04	Assessed as included in the measurement value of the total α radioactivity
Cm-242 (About 160 days)	6.0E+01	< 6.3E-04	1.1E-05	Assessed as included in the measurement value of the total α radioactivity
Cm-243 (About 29 years)	6.0E+00	< 6.3E-04	1.1E-04	Assessed as included in the measurement value of the total α radioactivity
Cm-244 (About 18 years)	7.0E+00	< 6.3E-04	9.0E-05	Assessed as included in the measurement value of the total α radioactivity
Sum of the ratios to regulatory concentrations limits of 63 nuclides other than tritium			2.9E-01	

*The analysis result of C-14 is the average value of measurement results of samples from middle layer of five tanks (K4-A1, B1, C5, D1, E1) taken between on May 21 and June 2, 2020, the analysis result of H-3 is the average value of measurement results of samples from three tanks (K4-A6, B6, E5; average value of measurement results of samples from upper, middle, lower layer respectively) taken between on October 26 and 31, 2017 and samples from five tanks, (K4-A1, B1, C5, D1, E1; measurement results of samples from middle layer) taken between on May 21 an Jun2, 2020.
The analysis results of the other nuclides are the results of composite sample of total of 24 sampling locations of upper, middle, and lower layer in each eight tanks (K4-A1, A6, B1, B6, C5, D1, E1, E5) taken between on October 26 and 31, 2017.

II-6. Water quality other than radioactive materials

As mentioned above, ALPS is equipped with coprecipitation, adsorption, and physical filters, etc., all of which are used to remove the 62 nuclides subject to removal regardless of their chemical forms. Judging from the past analysis results, not only radioactive materials but also materials that may affect the water quality are removed when passing through the filters.
Table II-8 shows the tank group from which samples were collected and the timing of receiving water stored in the tanks[11]. Table II-9-1 and 2 show the results of the 46 measurement items based on our “general wastewater treatment management guideline.” It was verified that all of them met the standards set by the laws in Japan and ordinances of Fukushima prefecture. It should be noted that since no facility to secure the representativeness of samples is installed in the tank group, in this analysis, one tank is randomly selected from the tank group and samples collected from the middle layer of the tank are analyzed without stirring or circulation, so the representativeness is not necessarily secured.

Table II-8 Tank group of which chemical substances were analyzed based on the general wastewater standard, and timing of receiving water

Area	Groups	Time of receiving ALPS treated water, etc.
G3	A	FY 2013
J4	B	FY 2014
H1	E	FY 2015
K3	A	FY 2016
K4	A	FY 2016
H2	C	FY 2017
G1S	A	FY 2018

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[11] December 28, 2018, “Analysis of chemical substance in tanks containing ALPS treated water etc.” https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/012_04_01.pdf

Table II-9-1 Results of analyses of chemical substances, etc., in tanks containing ALPS treated water, etc. (Part 1)

Item	Guideline or permissible limit	Unit	Area and tank group			
			G3	J4	H1	K3
			A	B	E	A
Hydrogen ion	5.0< /<9.0	pH	8.8	8.3	7.8	8.3
Mass of suspended solids (SS)	Permissible limit 200 (Daily average 150)	mg/L	<1	<1	<1	<1
Chemical oxygen demand (COD)	Permissible limit 160 (Daily average 120)	mg/L	2.4	2.8	3.9	3.9
Boron (mg/L)	Permissible limit 230 (Sea area)	mg/L	3.5	4.4	2.3	0.9
Soluble iron	Permissible limit 10	mg/L	<1	<1	<1	<1
Copper	Permissible limit 3	mg/L	<0.1	<0.1	<0.1	<0.1
Nickel	Permissible limit 2	mg/L	<0.1	<0.1	<0.1	<0.1
Chromium	Permissible limit 2	mg/L	<0.1	<0.1	<0.1	<0.1
Zinc	Permissible limit 2	mg/L	<0.1	<0.1	<0.1	<0.1
Biochemical oxygen demand (BOD)	Permissible limit 160 (Daily average 120)	mg/L	<1	<1	<1	<1
Coliform count	Permissible limit Daily average 3000	Pieces/cm^3	0	0	0	0
Cadmium	Permissible limit 0.03	mg/L	<0.01	<0.01	<0.01	<0.01
Cyan	Permissible limit 1	mg/L	<0.05	<0.05	<0.05	<0.05
Organic phosphorus	Permissible limit 1	mg/L	<0.1	<0.1	<0.1	<0.1
Lead	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01	<0.01
Hexavalent chromium	Permissible limit 0.5	mg/L	<0.05	<0.05	<0.05	<0.05
Arsenic	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01	<0.01
Mercury	Permissible limit 0.005	mg/L	<0.0005	<0.0005	<0.0005	<0.0005
Alkyl mercury	It should not be detected	mg/L	<0.0005	<0.0005	<0.0005	<0.0005
Polychlorinated biphenyls	Permissible limit 0.003	mg/L	<0.0005	<0.0005	<0.0005	<0.0005
Trichloroethylene	Permissible limit 0.1	mg/L	<0.03	<0.03	<0.03	<0.03
Tetrachloroethylene	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01	<0.01
Dichloromethane	Permissible limit 0.2	mg/L	<0.02	<0.02	<0.02	<0.02
Carbon tetrachloride	Permissible limit 0.02	mg/L	<0.002	<0.002	<0.002	<0.002
1,2-dichloroethane	Permissible limit 0.04	mg/L	<0.004	<0.004	<0.004	<0.004
1,1-dichloroethane	Permissible limit 1	mg/L	<0.1	<0.1	<0.1	<0.1

Item	Guideline or permissible limit	Unit	Area and tank group			
			G3	J4	H1	K3
			A	B	E	A
Cis-1, 2-dichloroethylene	Permissible limit 0.4	mg/L	<0.04	<0.04	<0.04	<0.04
1,1,1-trichloroethane	Permissible limit 3	mg/L	<0.3	<0.3	<0.3	<0.3
1,1,2-trichloroethane	Permissible limit 0.06	mg/L	<0.006	<0.006	<0.006	<0.006
1,3-dichloropropene	Permissible limit 0.02	mg/L	<0.002	<0.002	<0.002	<0.002
Thiuram	Permissible limit 0.06	mg/L	<0.006	<0.006	<0.006	<0.006
Simazine	Permissible limit 0.03	mg/L	<0.003	<0.003	<0.003	<0.003
Thiobencarb	Permissible limit 0.2	mg/L	<0.02	<0.02	<0.02	<0.02
Benzene	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01	<0.01
Selenium	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01	<0.01
Fenitrothion	Permissible limit 0.03	mg/L	<0.003	<0.003	<0.003	<0.003
Phenols	Permissible limit 5	mg/L	<0.1	<0.1	<0.1	<0.1
Fluorine	Permissible element 15 (Sea area)	mg/L	<0.5	<0.5	<0.5	<0.5
Soluble manganese	Permissible limit 10	mg/L	<1	<1	<1	<1
Ammonia, ammonium compounds	Permissible limit 100	mg/L	<1	<1	<1	<1
Nitrous acid compound and nitrous acid compound		mg/L	2	2	<1	11
1,4-dioxane	Permissible limit 0.5	mg/L	<0.05	<0.05	<0.05	<0.05
n-Hexane Extract (Mineral oil)	Permissible limit 5	mg/L	<0.5	<0.5	<0.5	<0.5
n-Hexane Extract (Animal and vegetable oil)	Permissible limit 30	mg/L	<1	<1	<1	<1
Nitrogen	Permissible limit 120 (Daily average 60)	mg/L	2	2.3	0.7	11.1
Phosphate	Permissible limit 16 (Daily average 8)	mg/L	<0.05	<0.05	<0.05	<0.05

Table II-9-2 Results of analyses of chemical substances, etc. in tanks containing ALPS treated water, etc. (Part 2)

Item	Guideline or permissible limit	Unit	Area and tank group		
			K4	H2	G1S
			A	C	A
Hydrogen ion	5.0< /<9.0	pH	8.3	8.5	8.3
Mass of suspended solids (SS)	Permissible limit 200 (Daily average 150)	mg/L	<1	<1	<1
Chemical oxygen demand (COD)	Permissible limit 160 (Daily average 120)	mg/L	0.9	1.8	1.5
Boron (mg/L)	Permissible limit 230 (Sea area)	mg/L	0.4	1.1	1.1
Soluble iron	Permissible limit 10	mg/L	<1	<1	<1
Copper	Permissible limit 3	mg/L	<0.1	<0.1	<0.1
Nickel	Permissible limit 2	mg/L	<0.1	<0.1	<0.1
Chromium	Permissible limit 2	mg/L	<0.1	<0.1	<0.1
Zinc	Permissible limit 2	mg/L	<0.1	<0.1	<0.1
Biochemical oxygen demand (BOD)	Permissible limit 160 (Daily average 120)	mg/L	2	<1	<1
Coliform count	Permissible limit Daily average 3000	Pieces/cm^3	0	0	0
Cadmium	Permissible limit 0.03	mg/L	<0.01	<0.01	<0.01
Cyan	Permissible limit 1	mg/L	<0.05	<0.05	<0.05
Organic phosphorus	Permissible limit 1	mg/L	<0.1	<0.1	<0.1
Lead	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01
Hexavalent chromium	Permissible limit 0.5	mg/L	<0.05	<0.05	<0.05
Arsenic	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01
Mercury	Permissible limit 0.005	mg/L	<0.0005	<0.0005	<0.0005
Alkyl mercury	It should not be detected	mg/L	<0.0005	<0.0005	<0.0005
Polychlorinated biphenyls	Permissible limit 0.003	mg/L	<0.0005	<0.0005	<0.0005
Trichloroethylene	Permissible limit 0.1	mg/L	<0.03	<0.03	<0.03
Tetrachloroethylene	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01
Dichloromethane	Permissible limit 0.2	mg/L	<0.02	<0.02	<0.02
Carbon tetrachloride	Permissible limit 0.02	mg/L	<0.002	<0.002	<0.002
1,2-dichloroethane	Permissible limit 0.04	mg/L	<0.004	<0.004	<0.004
1,1-dichloroethane	Permissible limit 1	mg/L	<0.1	<0.1	<0.1
Cis-1, 2-	Permissible limit 0.4	mg/L	<0.04	<0.04	<0.04

Item	Guideline or permissible limit	Unit	Area and tank group		
			K4	H2	G1S
			A	C	A
dichloroethylene					
1,1,1-trichloroethane	Permissible limit 3	mg/L	<0.3	<0.3	<0.3
1,1,2-trichloroethane	Permissible limit 0.06	mg/L	<0.006	<0.006	<0.006
1,3-dichloropropene	Permissible limit 0.02	mg/L	<0.002	<0.002	<0.002
Thiuram	Permissible limit 0.06	mg/L	<0.006	<0.006	<0.006
Simazine	Permissible limit 0.03	mg/L	<0.003	<0.003	<0.003
Thiobencarb	Permissible limit 0.2	mg/L	<0.02	<0.02	<0.02
Benzene	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01
Selenium	Permissible limit 0.1	mg/L	<0.01	<0.01	<0.01
Fenitrothion	Permissible limit 0.03	mg/L	<0.003	<0.003	<0.003
Phenols	Permissible limit 5	mg/L	<0.1	<0.1	<0.1
Fluorine	Permissible element 15 (Sea area)	mg/L	<0.5	<0.5	<0.5
Soluble manganese	Permissible limit 10	mg/L	<1	<1	<1
Ammonia, ammonium compounds	Permissible limit 100	mg/L	<1	<1	<1
Nitrous acid compound and nitrous acid compound		mg/L	25	7	10
1,4-dioxane	Permissible limit 0.5	mg/L	<0.05	<0.05	<0.05
n-Hexane Extract (Mineral oil)	Permissible limit 5	mg/L	<0.5	<0.5	<0.5
n-Hexane Extract (Animal and vegetable oil)	Permissible limit 30	mg/L	<1	<1	<1
Nitrogen	Permissible limit 120 (Daily average 60)	mg/L	24.6	7.5	10
Phosphate	Permissible limit 16 (Daily average 8)	mg/L	<0.05	<0.05	<0.05

II-7. Reason for generation of treated water to be purified

ALPS can remove the 62 nuclides subject to removal from contaminated water and make the sum of the ratios to regulatory concentrations limits of nuclides other than tritium less than 1 by performing treatment once, but as a result of estimation by the above-mentioned method, “treated water to be purified” of which contained radioactive material concentration is equivalent to or higher than the sum of the ratios to regulatory concentrations limits of 1 and which is to be subject to secondary treatment accounts for 70% of all water stored in the tank (about 66% as of September 2022). The following shows the reason depending on the timing of each treatment.

a. FY 2013 to 2015

Highly contaminated water with only cesium removed was stored in tanks at the site prior to the start of the operation of ALPS. Due to the direct radiation and skyshine rays from the highly contaminated water, the radiation dose at the boundary of the site was very large and assessed to be 9.76mSv/year at the site boundary, which greatly exceeded the standard set by the government, “The effective dose at the site boundary is less than 1mSv/year.”
In response to this situation, we continued the operation while accepting the outlet concentration of each adsorption vessel slightly exceeding the replacement standard and treated highly contaminated water raising the operating rate, aiming at early achievement of the effective dose of 1mSv/year at the site boundary.
As a result, the effective dose of 1mSv/year at the site boundary was achieved at the end of FY 2015, but naturally, treated water to be purified of which radioactive material concentration is equivalent to or higher than the sum of the ratios to regulatory concentrations limits of 1 was stored in the tanks.
It was immediately after the start of the operation of ALPS, so excessive concentrations also occurred due to facility trouble. Treated water to be purified of which sum of the ratios to regulatory concentrations limits exceeds 10 thousand was caused by the facility trouble, but the cause of the facility trouble has been removed and the event has not reoccurred.

b. FY 2016

In this period, the treatment capacity exceeded the speed of tank construction due to the advancement of treatment of highly concentrated water up to the preceding fiscal year, so tanks for storage of treated water were lacking, but treatment was performed to make the sum of the ratios to regulatory concentrations limits less than 1 by accelerating construction of tanks for storage of treated water and making use of the performance of ALPS.
Like this, the original performance of ALPS was used more appropriately than before, which reduced the frequency of treated water to be treated of which sum of the ratios to regulatory concentrations limits is 1 or more.

c. FY 2017 to 2018

Immediately after the accident, we hastened to collect tanks from all over Japan and used them for storage of contaminated water, etc. However, among these flange tanks, leak events occurred one after another, and the storage of strontium treated water (water from which most of the cesium and strontium has been removed before the treatment by ALPS) became an issue during this period.

Therefore, we decided to perform early treatment of the stored strontium treated water (water before treatment by ALPS) by ALPS to solve the issue of storage in flange tanks aiming at completion by the end of FY 2018, and raised the operating ratio while accepting slightly excessive concentrations at the outlet of each adsorption vessel again.

As a result, the treatment of all strontium treated water in the flange tanks was completed in November 2018, but compared to FY2016, the frequency of exceeding the regulatory concentration limit was higher.

All ALPS treated water, etc., stored in flange tanks have been transferred to weld tanks by March 2019.

Attachment III Impact of the organically bound tritium in the exposure assessment of tritium

ALPS treated water contains a lot of tritium water (HTO). If ingested, tritium water is converted to free water tritium (FWT), which behaves as normal water (H_2O) keeping the form of tritium water to organically bound tritium (OBT), a part of which is ingested into the tissue. OBT remains in the body longer and has greater exposure effects than FWT, so ICRP sets its effective dose factor of ingestion of OBT separately from tritium water. FWT is a name representing behavior in the body, but it is the same as tritium water, so it is written as HTO in this document.

III-1. Disposition of tritium

According to the model of ICRP Publication 56[III-1], about 3% of tritiated water (HTO) taken into the body changes into OBT and remains in the body longer than HTO. The half-life of HTO in the body is about 10 days, while that of OBT is about 40 days. (Figure III-1)
On the other hand, when tritium is taken into the body as OBT, 50% is assumed to be immediately converted to HTO in the blood. With the half-life mentioned above, each of OBT and HTO is eventually excreted from the blood as HTO. (Figure III-2)
Based on such a pharmacokinetic model in the body, ICRP Publication 72 [III-2] sets the effective dose factors for tritium as follows.

• Tritiated water (HTO)	1.8E-11 Sv/Bq
• Organically bound tritium (OBT)	4.2E-11 Sv/Bq

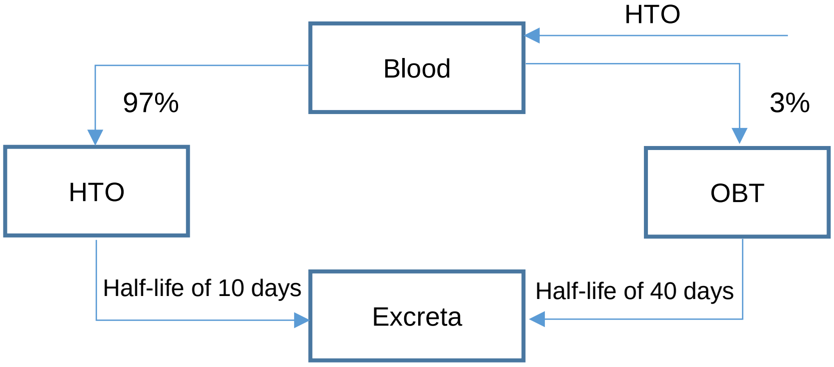


Figure III-1ICRP model for ingestion of tritiated water (HTO)
(Source: Annex C [III-3] of UNSCEAR2016)

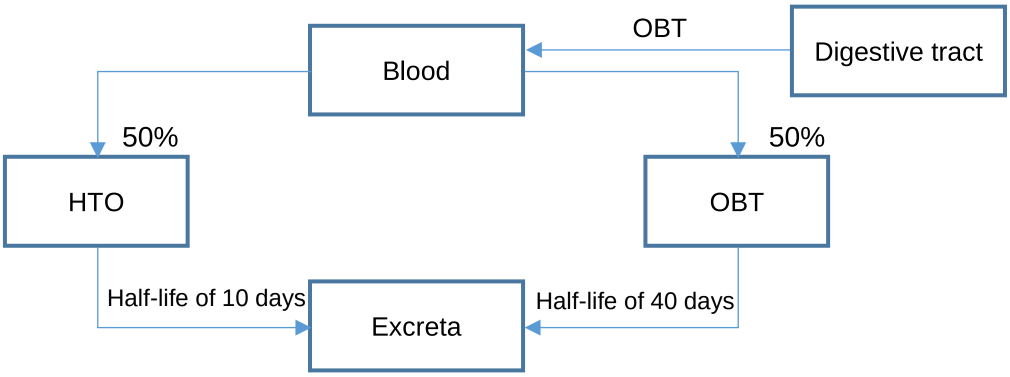
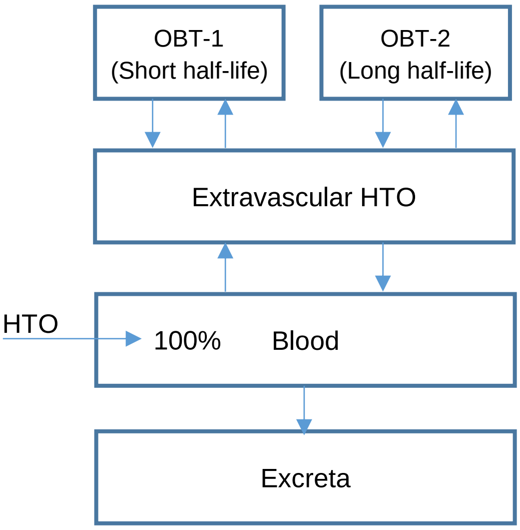


Figure III-2 ICRP model for ingestion of OBT
(Source: Annex C of UNSCEAR2016)

The ICRP Publication 134 [III-4] provides a new pharmacokinetic model that incorporates OBT with a biological half-life of about 40 days and OBT with a biological half-life of about 1 year, which remains in the body for a more extended period. (Figures III-3 and III-4)
The effective dose factors based on this model are higher than those presented in ICRP Publication 72, as shown below. Even so, calculating exposures using those factors does not significantly affect the exposure assessment results.

• Tritiated water (HTO)	1.9E-11 Sv/Bq
• Organically bound tritium (OBT)	5.1E-11 Sv/Bq

The model predicts that about 6% of total tritium in the body will be OBT if HTO is ingested continuously.



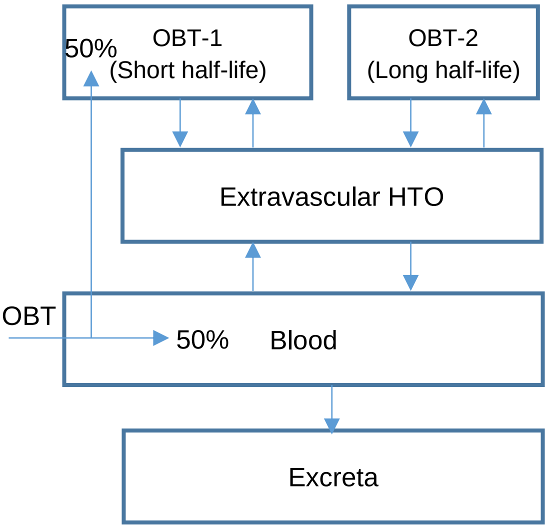


Figure III-3 New ICRP model for ingestion of HTO
(Source: Annex C of UNSCEAR2016)

Figure III-4 New ICRP model for ingestion of OBT
(Source: Annex C of UNSCEAR2016)

III-2. Impact of ingestion of OBT on the exposure assessment

ALPS is equipped with coprecipitation, adsorption, and physical filters, etc., which are used to eliminate the 62 nuclides subject to removal regardless of their chemical forms. None of the past analysis results show the inclusion of a lot of organic matters (See Attachment II "Water quality of ALPS treated water, etc."). Therefore, all tritium contained in ALPS treated water was assumed to be HTO in the assessment of internal exposure by drinking and ingestion of seawater spray without considering OBT.

On the other hand, a part of HTO is converted to OBT in animals and vegetables in the environment, so a part of the tritium ingested as seafood is considered to be OBT. Since no concentration in the environment that changes the isotopic ratio between tritium and hydrogen is seen, and water accounts for about 70 to 90% of seafood, it is not considered that the fraction of OBT in marine products is significantly increased. However, the impact of the fraction of OBT on the dose assessment was considered since there is an uncertainty in the transition of tritium in the environment.

The effective dose factor $DC_{correction}$ can be represented by the following formula where the effective dose factor of ingestion of HTO is DC_{FWT}, that of ingestion of OBT is DC_{OBT}, and the ratio of OBT to the ingested tritium is X%.

$$DC_{correction} = (1-X/100)\cdot DC_{FWT} + X/100\cdot DC_{OBT} \qquad \text{(III-1)}$$

Table III-1 shows the effective dose factor corrected by the formula (III-1).

Table III-1 Effective dose factor corrected by the percentage of OBT in tritium ingested from seafood

Percentage of OBT of seafood in tritium (%)	Effective dose factor (mSv/Bq)			Remarks
	Adult	Children under school age	Infants	
0	1.8E-08	3.1E-08	6.4E-08	
10	2.0E-08	3.5E-08	7.0E-08	Used for the assessment
20	2.3E-08	3.9E-08	7.5E-08	
100	4.2E-08	7.3E-08	1.2E-07	

Even in the case that the fraction of OBT is 100%, the impact of tritium on internal dose estimate is three times higher than for all HTO.

In addition, the impact on the dose assessment value of the representative person was examined.

Assessment Conditions

Assessment of dose under normal exposure situations

(Source term by the actually measured value (K4 tank group), ingesting larger amount of seafood)

Assessment Result

As shown in the Table III-2, although the dose from tritium is increased by about a factor of three times more compared to all HTO in the case the fraction of OBT is 100%, there was no impact on the total dose by 30 radionuclides.

Table III-2 Assessment Result of internal exposure by ingestion of seafood （source term by actual measurement value (K 4 tank group), ingests the large amount of seafood）

Percentage of OBT of seafood in tritium (%)	Exposure assessment result (mSv/year） ( ) indicates exposure due to tritium			remarks
	Adult	Child under school age	Infant	
0	3.1E-05 (1.1E-07)	3.6E-05 (9.8E-08)	3.2E-05 (8.0E-08)	
10	3.1E-05 (1.2E-07)	3.6E-05 (1.1E-07)	3.2E-05 (8.7E-08)	Used for assessment
20	3.1E-05 (1.4E-07)	3.6E-05 (1.2E-07)	3.2E-05 (9.4E-08)	
100	3.1E-05 (2.6E-07)	3.6E-05 (2.3E-07)	3.2E-05 (1.5E-07)	

In this report, by referring to 6% fraction of OBT indicated in the pharmacokinetic model of the ICRP Publication 134 described above, the calculation was made with the percentage of OBT as 10% in the assessment of internal exposure from ingestion of seafood, including the uncertainty in the environment. However, there was no impact on the dose assessment by the fraction of OBT.

III-3. OBT of marine plants and animals

For the concentration ratio between HTO and OBT in the environment, the result of monitoring performed around the La Hague reprocessing plant in France is shown (Figure III-5) [III-5]. The concentration ratio is the same in any species including fish and seaweed, so no trend of concentration has been observed.

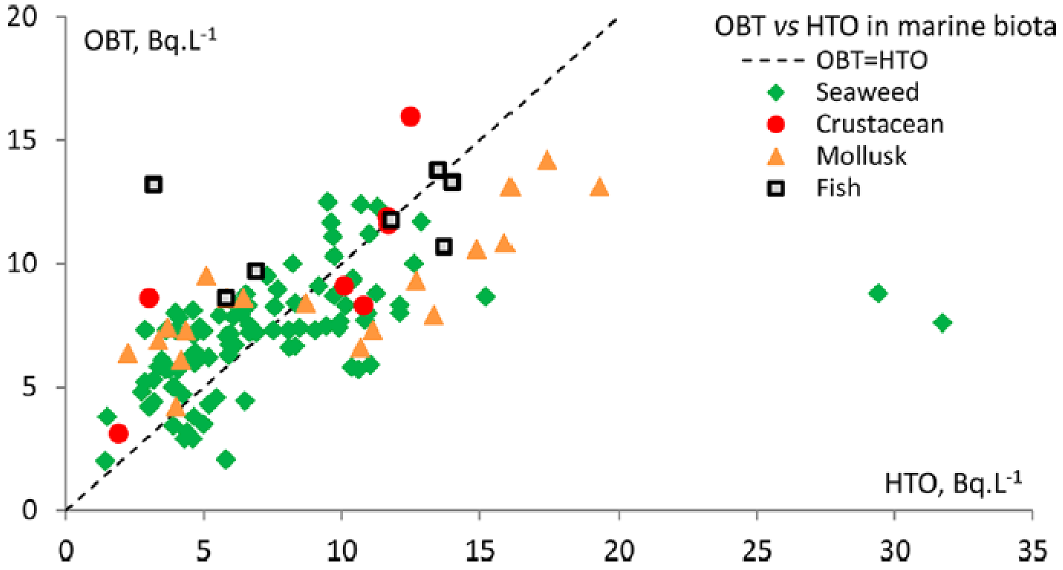


Figure III-5 Investigation result of the OBT and HTO concentrations in marine plants and animals performed in the sea area around the La Hague reprocessing plant

In our monitoring of fish continued since 2014 around the Fukushima Daiichi Nuclear Power Station, OBT has never been observed in the 83 samples measured so far.

References

[III-1] ICRP Publication 56 "Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part1",1989

[III-2] ICRP Publication 72 " Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients",1995

[III-3] UNSCEAR 2016 Report “SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION UNSCEAR 2016 Report ANNEX C BIOLOGICAL EFFECTS OF SELECTED INTERNAL EMITTERS - TRITIUM”,2017

[III-4] ICRP Publication 134 "Occupational Intakes of Radionuclides: Part 2",2016

[III-5] Bruno Fiévet, Julien Pommier, Claire Voiseux, Pascal Bailly du Bois, Philippe Laguionie, Catherine Cossonnet, and Luc Solier “Transfer of Tritium Released into the Marine Environment by French Nuclear Facilities Bordering the English Channel”,2013

Attachment IV Analysis on the period of discharge of ALPS treated water

At the FDNPS, it is planned to secure the site necessary for decommissioning based on the "Mid- and Long-term Roadmap toward Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc." and the "Reduction Target Map of Mid-term Risks of TEPCO Fukushima Daiichi NPS" by installing facilities for dilution and discharge of ALPS treated water and related facilities to discharge ALPS treated water stored in the tanks.

The following shows that the site necessary for decommissioning can be secured by discharging ALPS treated water and reducing the tanks according to the plan, using the ALPS treated water discharge simulation.

IV-1. Prerequisites for ALPS treated water discharge simulation

The following describes the simulation period, the specifications of the dilution and discharge facilities, and the conditions regarding the ALPS treated water to be discharged as the prerequisites of ALPS treated water discharge simulation.

The unit of the simulation period shall be one year from FY 2021[1]; discharge is to be started in FY 2023 and discharge is to be completed in FY 2051[2].

As the specifications of the dilution and discharge facilities, the flow rate of ALPS treated water is assumed to be up to 500m^3/day and the annual operating rate 80% (292 days of discharge). The seawater flow rate is assumed to be 170 to 510 thousand m^3/day with 1 to 3 seawater pumps assumed to be in operation.

As conditions regarding ALPS treated water to be discharged, the upper limit of the annual discharge amount of tritium is assumed to be 22 TBq. The tank capacity in each fiscal year shall be a constraint condition because the purpose of discharge of ALPS treated water into the sea is to secure the site necessary for decommissioning. In addition, tritium is a radioactive material of which half-life is about 12 years, so the annual reduction amount is assumed to be about 5.5%. It is planned to discharge a small amount in the early stage of discharge so the annual discharge amount of tritium of FY 2023 is set to half of that of FY 2024.

In addition, the ALPS treated water to be discharged in the future includes "(A) ALPS treated water to be generated daily" and "(B) ALPS treated water, etc., stored in the tanks." As the discharge order of the water, it is assumed that about 30 thousand m^3 of "ALPS treated water stored in the tank" in the K4 tanks used as facilities for measurement and confirmation will be discharged and then "ALPS treated water to be generated daily" and "ALPS treated water

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[1] The business year in Japan starts on April 1st and ends on March 31st of the following year.

[2] In the Mid- and Long-term Roadmap, the goal is set to the completion of decommissioning 30 to 40 years after December 2011, in which the discharge of radioactive materials was managed and the radiation dose was greatly inhibited.

stored in the tank” will be discharged in ascending order of the tritium concentration. Discharge of “ALPS treated water to be generated daily” is to be continued as long as it is generated until the total amount of tritium in the building becomes 0. In doing so, the generation amount of contaminated water is assumed to decrease 10m^3/day every year step by step so that the daily generation amount of “ALPS treated water to be generated daily” will become 100m^3/day after 2025.

Table IV-1 Prerequisites for ALPS treated water discharge simulation

Annual release of tritium (Less than 22 TBq/year)	Set the total amount of discharge so that discharge into the sea will be completed in FY 2051 to the extent that it will not affect the site utilization plan
Simulation assessment start date	April 1, 2021 (simulation by year)
Discharge start date	April 1, 2023
ALPS treated water flow rate	Up to 500 m^3/day
Seawater flow rate for dilution	170 thousand m^3/day (1 seawater pump) to 510 thousand m^3/day (3 seawater pumps)
ALPS treated water discharge order	About 30 thousand m^3 of water in the K4 tank used as facilities for measurement and confirmation will be discharged in ascending order of the tritium concentration After that, the water in the other tanks and the newly generated ALPS treated water will also be discharged in ascending order of the tritium concentration
Tritium decay	The half-life is considered to be about 12 years (decrease by about 5.5% in 1 year) and decay is considered for newly generation one as well
ALPS treated water generation amount	The generation amount of contaminated water is assumed to decrease 10m^3/day every year step by step so that it will become 100m^3/day after FY 2025
Number of days of discharge	292 days (Operating rate: 80%)

“ALPS treated water to be generated daily” will be generated in the future and is highly uncertain, so the assessment was performed in two cases: cases with the largest and smallest total amounts of tritium, respectively. In the case with the largest total amount of tritium, it is assumed that the concentration of newly generated tritium is the largest value, 448 thousand Bq/L, between January and June 2021 and the total amount of tritium in the building is about 1150 TBq assuming that the whole of 3400 TBq remain in the building or tanks at the time of the accident. In the case with the smallest total amount of tritium, it is assumed that the concentration of newly generated tritium is the smallest value, 215 thousand Bq/L, between January and June 2021 and the total amount of tritium in the building estimated from the stagnant water storage amount and concentration in the building is about 81 TBq.

Table IV-2 Assessment case of ALPS treated water discharge simulation

Case	Case with the largest total amount of tritium	Case with the smallest total amount of tritium
Concentration of newly generated tritium	448 thousand Bq/L (January 5, 2021, Largest in 2021)	215 thousand Bq/L (June 1, 2021, Smallest in 2021)
Total amount of tritium in the building (As of April 1, 2021)	About 1150 TBq (At the time of the accident, the whole of 3400 TBq remained in the building and tanks)	About 81 TBq (Estimated from the stagnant water storage amount and concentration in the building)

Based on these prerequisites, we assessed the minimum value of the annual tritium discharge amount of every year, the water storage amount of ALPS treated water, etc., the average flow rate of ALPS treated water, and the average tritium concentration before and after seawater dilution.

IV-2. ALPS treated water discharge simulation result

For each case, we changed the annual total tritium charge amount not to affect the site usage plan and assessed the total discharge amount, with which discharge into the sea will be assessed in FY 2051. As a result, it was verified that the maximum and minimum annual tritium discharge amounts of the case with the largest and smallest total tritium amount are up to 22 and 16 TBq, respectively, and discharge will be completed by FY 2051 with the annual amount below 22 TBq in both cases.
The annual tritium discharge amount of each fiscal year was 11 TBq/year in FY 2023, 22 TBq/year between FY 2024 and FY 2029, 18 TBq/year between FY 2030 and FY 2032, and 16 TBq/year in and after FY 2033 in the case with the largest total tritium amount. On the other hand, it was 8 TBq/year in FY 2023, 16 TBq/year between FY 2024 and FY 2028, and 11 TBq/year in and after FY 2029 in the case with the smallest total tritium amount.

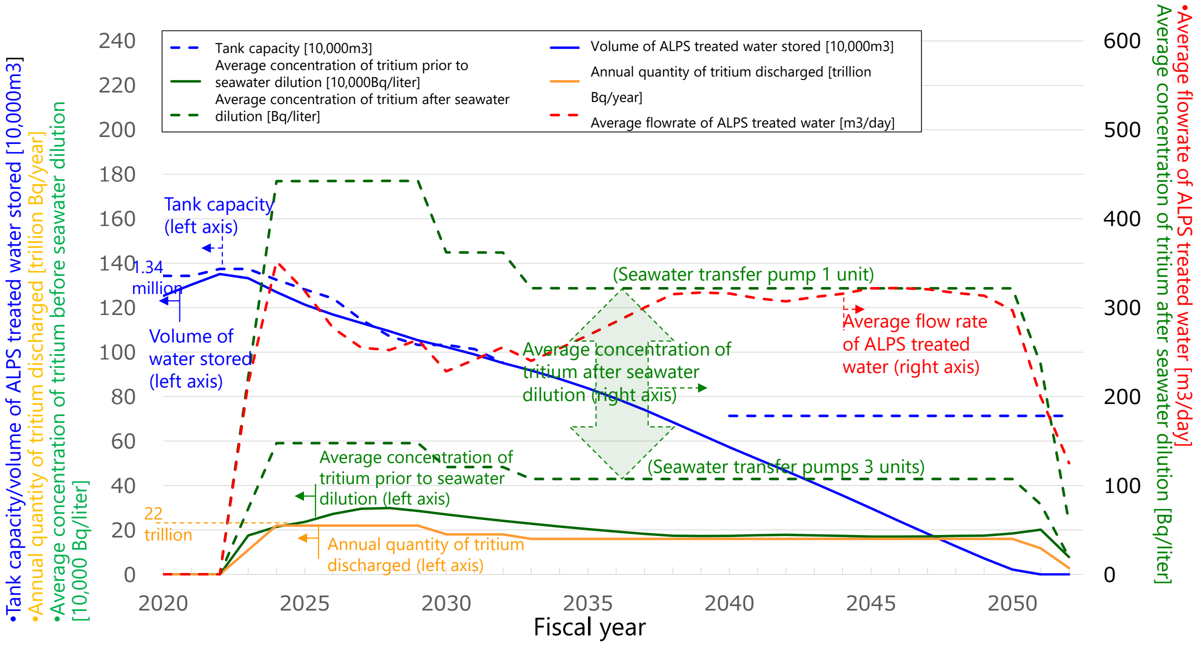


Figure IV-1 Case with the largest total amount of tritium

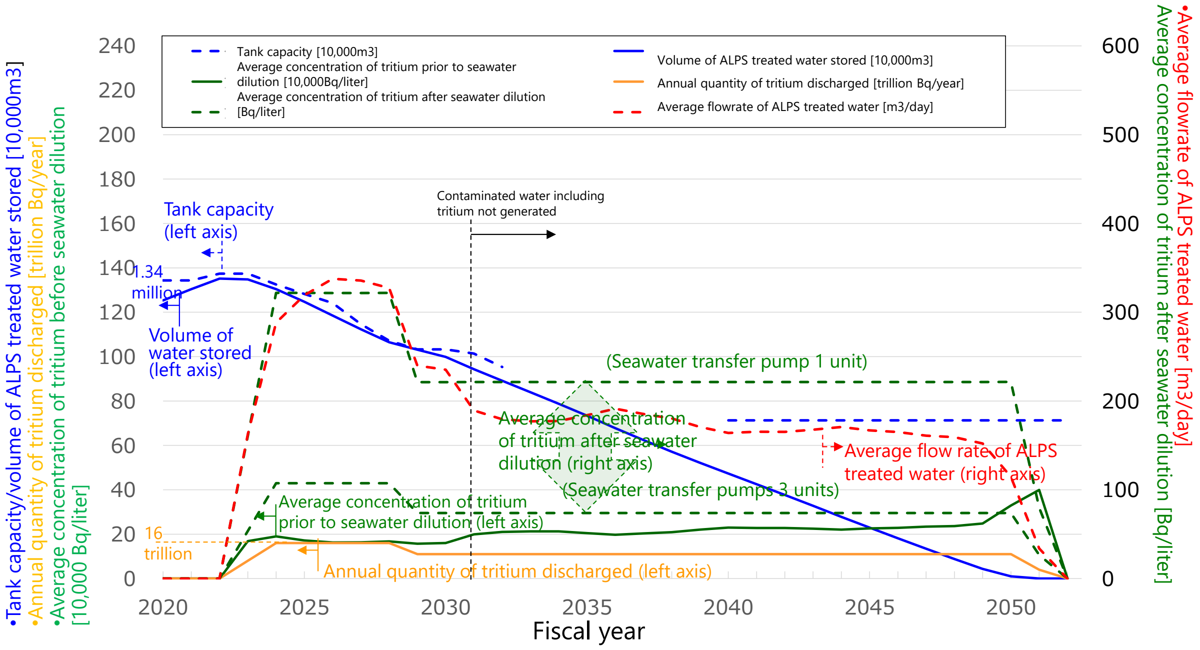


Figure IV-2 Case with the smallest total amount of tritium

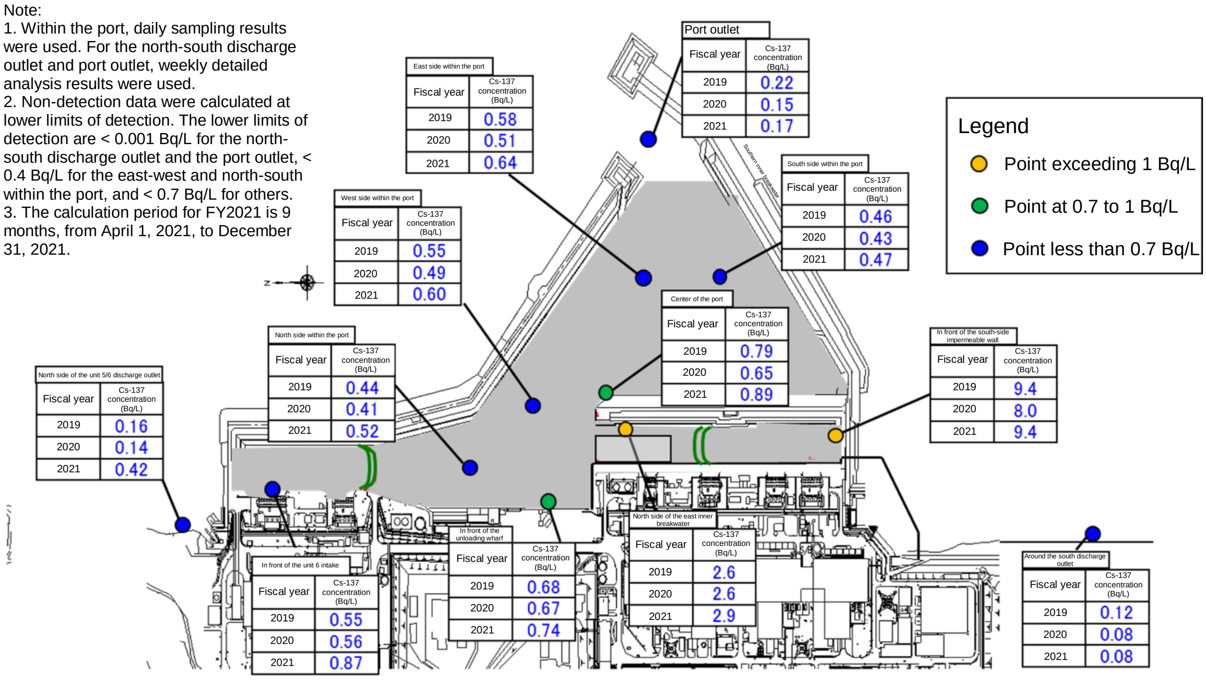
Attachment IV-4

Attachment V Impacts of intake and discharge of diluted water on outside

For discharge of ALPS treated water, the concentration of tritium, which is difficult to remove, is diluted with seawater 100 or more times until it becomes less than 1,500Bq/L, which is much lower than that specified in laws and regulations, before discharge. The seawater for diluting the ALPS treated water is planned to be taken from the unit 5 intake. However, regarding the seawater concentration within the port, the concentration of radioactive materials is slightly higher than that of the seawater in the surrounding sea area. Considering this point, as well as the impact of the seabed soil within the port, the seawater will be drawn from the north side of the unit 5/6 discharge outlet in the plan.

V-1. State of the concentration in seawater in the port

The current state of Cs-137 concentration in the port is shown in Figure V-1. The concentration near the water intake of units 1 to 4 is high, and it becomes lower as measurement points are away from the water intake of units 1 to 4 toward the port outlet or units 5/6.



Note:
1. Within the port, daily sampling results were used. For the north-south discharge outlet and port outlet, weekly detailed analysis results were used.
2. Non-detection data were calculated at lower limits of detection. The lower limits of detection are < 0.001 Bq/L for the north-south discharge outlet and the port outlet, < 0.4 Bq/L for the east-west and north-south within the port, and < 0.7 Bq/L for others.
3. The calculation period for FY2021 is 9 months, from April 1, 2021, to December 31, 2021.

Legend
- ● Point exceeding 1 Bq/L
- ● Point at 0.7 to 1 Bq/L
- ● Point less than 0.7 Bq/L

Port outlet

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.22
2020	0.15
2021	0.17

East side within the port

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.58
2020	0.51
2021	0.64

South side within the port

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.46
2020	0.43
2021	0.47

West side within the port

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.55
2020	0.49
2021	0.60

Center of the port

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.79
2020	0.65
2021	0.89

In front of the south-side impermeable wall

Fiscal year	Cs-137 concentration (Bq/L)
2019	9.4
2020	8.0
2021	9.4

North side within the port

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.44
2020	0.41
2021	0.52

North side of the unit 5/6 discharge outlet

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.16
2020	0.14
2021	0.42

In front of the unit 6 intake

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.55
2020	0.56
2021	0.87

In front of the unloading wharf

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.68
2020	0.67
2021	0.74

North side of the east inner breakwater

Fiscal year	Cs-137 concentration (Bq/L)
2019	2.6
2020	2.6
2021	2.9

Around the south discharge outlet

Fiscal year	Cs-137 concentration (Bq/L)
2019	0.12
2020	0.08
2021	0.08

Figure V-1 State of the Cs-137 concentration in the port

V-2. Assumed impacts of intake and discharge of seawater for dilution on outside and countermeasures

As shown in V-1., the radioactive material concentration in seawater in the port tends to be high near units 1 - 4 intake. Seawater for dilution is planned to be taken from near the unit 5 intake and seawater with high concentration may be drawn from the unit 1 - 4 intake open-channel to the unit 5/6 side.

As a countermeasure in the installation of intake facilities, a unit 5/6 intake open-channel will be separated with a partition weir (riprap sloping weir + sheet) for prevention of inflow of seawater from the units 1 - 4 side, and instead a part of the north breakwater permeation prevention work will be remodeled so that the seawater for dilution is taken in from outside the port. (Figure V-2)

As a result, the concentration of radioactive materials in seawater in the unit 5/6 intake open-channel may decrease. In contrast, the concentration around the unloading wharf, where diffusion to the unit 5/6 intake channel will be restricted, may slightly increase, but the impact of intake and discharge of seawater for dilution on outside is considered to be inhibited.

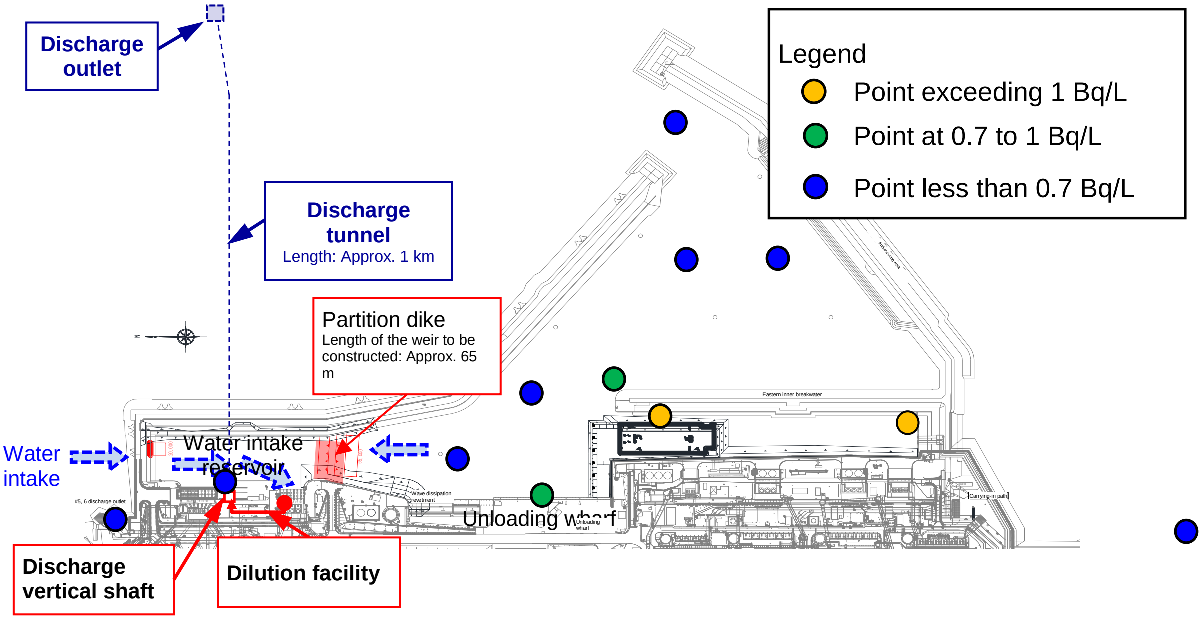


Figure V-2 Intake and discharge plan and state of the Cs-137 concentration in the port

V-3. Assessment of the impacts of intake and discharge of seawater for dilution on outside

To verify the effect of the countermeasure, external effects were compared and assessed in cases where seawater inside the port (area on the side of units 1 to 4) is taken in and where seawater outside the port (north side of the unit 5/6 discharge outlet) is taken in.

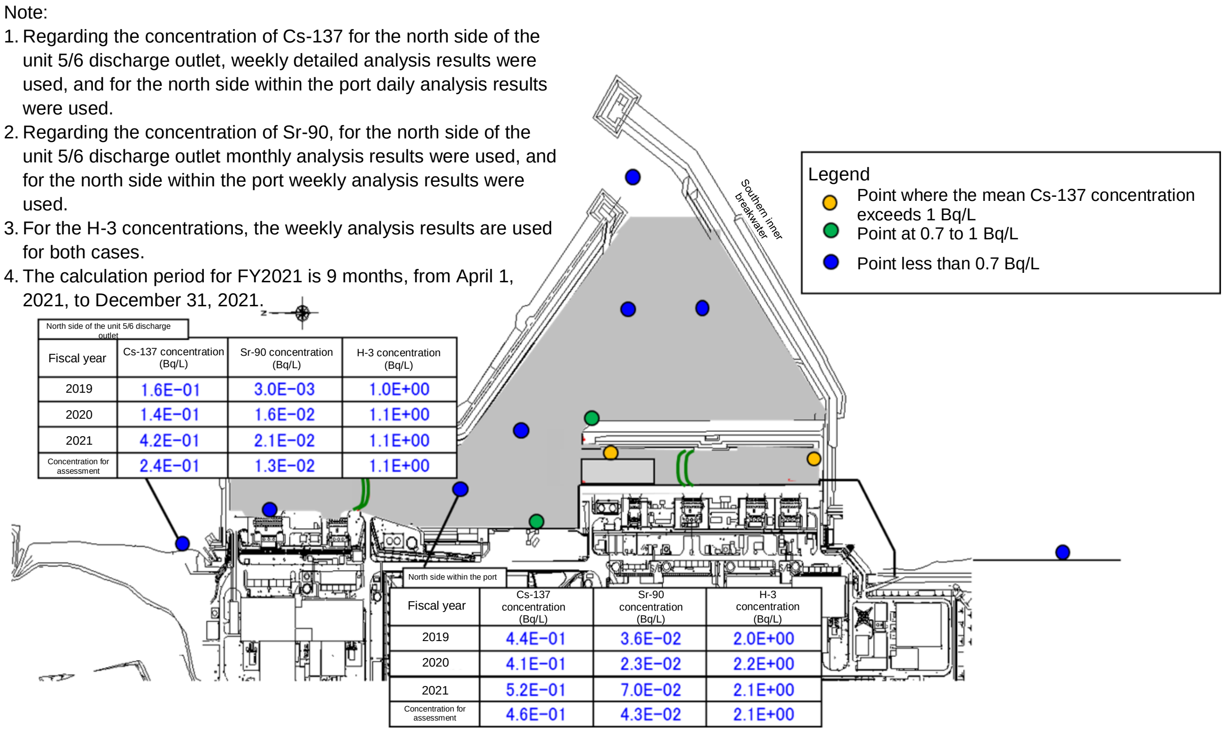
The assessment was performed by adding the movement amount of the radioactive materials that move to outside the port with seawater for dilution to the source term in the human exposure assessment of discharge of ALPS treated water.

(1) Setting of the movement amount of the radioactive materials added to the source term

Concentrations of seawater for dilution used for comparison and assessment are set based on the monitoring results (for about 3 years from FY 2019). The water taken from the outside of the port was on the north of the unit 5/6 discharge outlet, and the water taken within the port was north side within the port. (Figure V-3)

The target nuclides are Cs-137, Sr-90, and tritium whose presence in the seawater in the port was verified and which are subject to monitoring (For Cs-137 and Sr-90, the progeny nuclides, Ba-137 and Y-90, are assumed to be contained at the same concentration in the equilibrium state).

The minimum detection limits differ between the port and outside the port (it is higher within the port). Based on this, there is a possibility that the Cs-137 and tritium on the north side within the port are overestimated, but it is clear that the concentrations on the north side of the unit 5/6 discharge outlet are lower.



Note:

1. Regarding the concentration of Cs-137 for the north side of the unit 5/6 discharge outlet, weekly detailed analysis results were used, and for the north side within the port daily analysis results were used.
2. Regarding the concentration of Sr-90, for the north side of the unit 5/6 discharge outlet monthly analysis results were used, and for the north side within the port weekly analysis results were used.
3. For the H-3 concentrations, the weekly analysis results are used for both cases.
4. The calculation period for FY2021 is 9 months, from April 1, 2021, to December 31, 2021.

Legend

- ● Point where the mean Cs-137 concentration exceeds 1 Bq/L
- ● Point at 0.7 to 1 Bq/L
- ● Point less than 0.7 Bq/L

North side of the unit 5/6 discharge outlet

Fiscal year	Cs-137 concentration (Bq/L)	Sr-90 concentration (Bq/L)	H-3 concentration (Bq/L)
2019	1.6E-01	3.0E-03	1.0E+00
2020	1.4E-01	1.6E-02	1.1E+00
2021	4.2E-01	2.1E-02	1.1E+00
Concentration for assessment	2.4E-01	1.3E-02	1.1E+00

North side within the port

Fiscal year	Cs-137 concentration (Bq/L)	Sr-90 concentration (Bq/L)	H-3 concentration (Bq/L)
2019	4.4E-01	3.6E-02	2.0E+00
2020	4.1E-01	2.3E-02	2.2E+00
2021	5.2E-01	7.0E-02	2.1E+00
Concentration for assessment	4.6E-01	4.3E-02	2.1E+00

Figure V-3 Radioactive material concentration of seawater for dilution used for comparison and assessment

The movement amount M(i) of nuclide i, which is a radioactive material included in seawater for dilution (if three seawater pumps for dilution are in operation) and moving to outside the port, was calculated from the concentration in seawater for diluted water, C_D(i), set above by the following equation:

$$M(i)\ [\mathrm{Bq/year}] = C_D(i)\ [\mathrm{Bq/L}] \times 510{,}000\ [\mathrm{m^3/day}] \times 1000\ [\mathrm{L/m^3}] \times 365\ [\mathrm{day/year}] \times 0.8$$

(availability rate)

Two types of source terms were used for the assessment: “measured values of the K4 tank group” and “measured values of the J1-G tank group” used for radiological impact assessment. The amount of added radioactivity transferred is shown in Table V-1.

Table V-1 Annual amount of radioactivity transferred by nuclide of seawater for dilution

Nuclide	Water intake outside the port (North side of the unit 5/6 discharge outlet)		Water intake inside the port (North side within the port)	
	Concentration for assessment (Bq/L)	Volume to be transferred (Bq/year)	Concentration for assessment (Bq/L)	Volume to be transferred (Bq/year)
Cs-137	2.4E-01	3.6E+10	4.6E-01	6.9E+10
Sr-90	1.3E-02	1.9E+09	4.3E-02	6.4E+09
H-3	1.1E+00	1.6E+11	2.1E+00	3.1E+11

(2) Study results

The results of the exposure assessment are shown in Tables V-2 and V-3. Water intake outside the port has fewer impacts on the external exposures.

However, the results in both assessments are more minor compared with the dose limit of 1 mSv/year and the target dose for domestic nuclear power plant of 0.05 mSv/year, which is corresponding to the dose constraint. Even if seawater inside the port is taken in for dilution, the impact of radiation exposure is more minor.

Table V-2 Comparison of the exposure assessment results of representative persons (Large amount of ingestion of seafood)

Assessed case		Source term of the K4 tank group based on measured values			Source term of the J1-G tank group based on measured values			Remarks
		Exposure assessment under normal conditions	Water intake outside the port (North side of the unit 5/6 discharge outlet)	Water intake inside the port (North side within the port)	Exposure assessment under normal conditions	Water intake outside the port (North side of the unit 5/6 discharge outlet)	Water intake inside the port (North side within the port)	
External exposure (mSv/year)	Sea surface	4.6E-10	6.7E-08	1.3E-07	3.7E-10	6.7E-08	1.3E-07	
	Hull	4.9E-10	5.4E-08	1.0E-07	3.7E-10	5.3E-08	1.0E-07	
	During swimming	3.2E-10	4.7E-08	8.8E-08	2.5E-10	4.7E-08	8.8E-08	
	Beach sand	5.4E-07	8.6E-05	1.6E-04	4.3E-07	8.6E-05	1.6E-04	
	Fishing net	1.1E-07	1.5E-05	2.9E-05	8.3E-08	1.5E-05	2.9E-05	
Internal exposure (mSv/year)	Ingestion of water	3.4E-07	7.3E-07	1.2E-06	3.1E-07	7.1E-07	1.1E-06	Value of an adult
	Inhalation of spray	9.2E-08	4.1E-07	7.7E-07	3.8E-07	6.9E-07	1.0E-06	
	Ingestion of seafood	3.1E-05	4.1E-05	5.1E-05	1.1E-05	2.2E-05	3.2E-05	
Total		3E-05	1E-04	2E-04	1E-05	1E-04	2E-04	

Table V-3 Results of internal exposures assessment by age (Large amount of ingestion of seafood)

Assessed case		Source term of the K4 tank group based on measured values			Source term of the J1-G tank group based on measured values			Remarks
		Exposure assessment under normal conditions	Water intake outside the port (North side of the unit 5/6 discharge outlet)	Water intake inside the port (North side within the port)	Exposure assessment under normal conditions	Water intake outside the port (North side of the unit 5/6 discharge outlet)	Water intake inside the port (North side within the port)	
Internal exposure from ingestion of water (mSv/year)	Adult	3.4E-07	7.3E-07	1.2E-06	3.1E-07	7.1E-07	1.1E-06	
	Child under school year	5.8E-07	9.2E-07	1.3E-06	5.4E-07	8.8E-07	1.3E-06	
	Infant	—	—	—	—	—	—	
Internal exposure from inhalation of spray (mSv/year)	Adult	9.2E-08	4.1E-07	7.7E-07	3.8E-07	6.9E-07	1.0E-06	
	Child under school year	6.0E-08	2.8E-07	5.3E-07	2.0E-07	4.2E-07	6.7E-07	
	Infant	3.9E-08	1.5E-07	2.8E-07	1.1E-07	2.2E-07	3.5E-07	
Internal exposure from ingestion of seafood (mSv/year)	Adult	3.1E-05	4.1E-05	5.1E-05	1.1E-05	2.2E-05	3.2E-05	
	Child under school year	3.6E-05	4.0E-05	4.3E-05	1.6E-05	2.0E-05	2.4E-05	
	Infant	3.2E-05	3.5E-05	3.9E-05	2.2E-05	2.5E-05	2.9E-05	

Attachment VI Transfer pathways and exposure pathways other than the assessment targets

This report first describes the selection process of both transfer and exposure pathways from at the beginning of design stage to the construction stage specified in the Radiological Environmental Impact Assessment Report Regarding the Discharge of Advanced Liquid Processing System (ALPS) Treated Water into the Sea in section VI-1. As described below more specifically, TEPCO has selected exposure pathways following IAEA GSG-10, referring to guidelines and existing assessment in Japan and IAEA TECDOC-1759. Note that, TEPCO has just referred to IAEA TECDOC-1759 to select exposure pathways and was unused the method contained in it for exposure assessment for this report.
The described preliminary calculation in accordance with TECDOC-1759 method, described in section VI-2, has made only for a reference for the comparison of exposure assessment result of this report and the method was unused to assess exposure assessment.

VI-1 Selection of transfer and exposure pathways

The Radiological Impact Assessment Report Regarding the Discharge of ALPS Treated Water into the Sea (design stage) (November 2021, hereinafter called “the report (design stage/ first version)”) determined the selection of exposure pathways in reference to “Dose Assessment to the General Public in the Safety Review of Commercial Light Water Reactor Facilities” approved by the former Nuclear Safety Commission, which had been formulating the domestic safety guidelines, (hereinafter called “Dose Assessment of Light Water Reactor”) and the Application for the Designation of Reprocessing Business of Rokkasho Plant, (hereinafter called “Rokkasho Application”) which is a precedent case, as well as using IAEA GSG-10 as a reference. In “Dose Assessment of Light Water Reactor,” case studies of potentially important exposure pathways are performed as the examination of the basic concept of the dose assessment to the public in the safety review of reactor facilities for power generation, and the following pathways are simulated as the dose assessment with the radioactive materials in liquid waste.

(1) External exposure during work at sea
(2) External exposure during swimming
(3) External exposure during work at a beach
(4) External exposure during fishing operation
(5) Internal exposure from ingestion of seafood

As a result of the simulation, internal exposure from ingestion of seafood is considered to be the most important form of exposure from intake of liquid waste.
On the other hand, the following exposure pathways were assessed and reviewed in the Rokkasho Application.

(1) External exposure from sea surface
(2) External exposure from hulls
(3) External exposure during underwater work

(4) External exposure from fishing nets
(5) Internal exposure from ingestion of seafood

External exposure during work at a beach was not selected because there is no beach in the vicinity. In the report (design stage/ first version), migration and exposure pathways were first selected based on these documents.

On the other hand, IAEA GSG-10 comprehensively shows pathways to be considered for transfer and exposure pathways. At the compilation of the Radiological Impact Assessment Report Regarding the Discharge of ALPS Treated Water into the Sea (Design stage / Revised version) (April 2022, hereinafter called "the report (design stage / revised version)"), these transfer pathways and exposure pathways were examined again from the viewpoint of the comprehensiveness of the pathways, and after the simulation of the exposure dose, the additional pathways were examined from the viewpoint of the scale and comprehensiveness of exposure.

At the examination, the transfer and exposure pathways described in the IAEA-TECDOC-1759 [VI-1] (radiological assessment procedures for determining the suitability of materials for sea dumping) were assessed as a trial using the assessment method shown in this document and compared with the exposure to examine assessment results in the report (design stage/ first version). As the result, the exposure pathway of drinking water while swimming and inhalation of water spray at the beach were added in the report (design stage / revised version).

VI-2. Trial assessment using the method of TECDOC-1759

To assess and compare to this report, preliminary calculations was made using TECDOC-1759 for reference.

The report (construction stage) revised the comparison with assessment result using newly selected source terms and the preliminary calculation values using the method of TECDOC-1759, following the selection of target nuclides to be measured and assessed in ALPS treated water and the target nuclides to be assessed are revised.

While the method of TECDOC-1759 used for the examination is included the consideration of impacts to decrease dissolved concentration due to radioactive materials, which is discharged and floating in the sea, adsorb floating particles or seabed sediment, when addition to the report (design stage / revised version), the assessment was conducted using the same conservative method as the report (design stage/ first version) without taking the decrease of concentration due to the adsorption to suspended particles and seabed sediment into account, rather than the assessment method in IAEA-TECDOC-1759.

VI-2-1. Source term

Since nuclides with large exposure impacts differ depending on the exposure assessment method and pathway, the source term based on the measured values including all the 30 nuclides (Table 6-1-1 through Table 6-1-3) was used.

VI-2-2. Modeling of diffusion and transfer in the environment

The following migration pathways were selected in accordance with the pathways shown by IAEA in GSG-10.

(1) Direct radiation

The radioactive materials handled in the disposal of ALPS treated water is limited to ALPS treated water or diluted ALPS treated water. ALPS treated water is water purified in advance until the sum of the ratios to regulatory concentrations limits of the radioactive materials other than tritium becomes less than 1. Therefore, it was not selected as a migration pathway in the report (design stage/ first version) considering that there is almost no impact of exposure from ALPS treated water and the direct radiation from the facility.

This pathway is not selected for this trial assessment either.

(2) Diffusion in air, and deposition from the atmosphere onto the ground surface and subsequent resuspension

Since ALPS treated water is diluted with seawater and discharged into the sea as liquid and further diluted in the sea before migration to air, it was not selected as a migration pathway in the report (design stage/ first version) considering that there is almost no impact of exposure from the radioactive materials diffused into the air.

This pathway is not selected for this trial assessment either.

(3) Advection and diffusion in seawater

Since ALPS treated water is discharged into the sea as liquid, advection and diffusion in seawater were selected in the report (design stage/ first version).

This pathway is selected for this trial assessment either.

(4) Migration from seawater to hulls

Radioactive materials diffused in seawater may migrate to the hulls of ships continuously operating in the surrounding sea area, so it was selected as a migration pathway in the report (design stage/ first version).

In IAEA-TECDOC-1759, no example of a pathway or calculation method is exemplified, so this pathway is not selected for this trial assessment.

(5) Migration from seawater to coastal sediment

Since radioactive materials advected and diffused in seawater may migrate to coastal sediment, it was selected as a migration pathway in the report (design stage/ first version).

In IAEA-TECDOC-1759, examples of a pathway and a calculation method are also exemplified, so this pathway is selected for this trial assessment.

(6) Migration from seawater to suspended particles and seabed sediment

Radioactive materials advected and diffused in seawater are partly adsorbed by suspended particles and seabed sediment, and the concentration in seawater decreases due to the migration. On the other hand, radioactive materials accumulate in seabed sediment, and the concentration in seawater and the concentration in seabed sediment will reach equilibrium in the long term. In the report (design stage/ first version), the decrease of radionuclide concentration due to adsorption to particles such as seabed sediments was not considered in the stage of transition or diffusion for conservatism and it was considered that the equilibrium state was achieved with the distribution factor with seabed sediment in the exposure assessment of marine plants and animals.

In IAEA-TECDOC-1759, an example of a calculation method was exemplified with a model of discharged radioactive materials migrating from seawater to suspended particles and seabed sediment makes decrease dissolved concentration in the sea, so this pathway is selected for this trial assessment.

(7) Migration from seawater to fishing nets

Radioactive materials advected and diffused in seawater may migrate to fishing nets used in seawater. Since it was assessed in the domestic precedent case, it was selected in the report (design stage/ first version).

In IAEA-TECDOC-1759, no example of this pathway or calculation method is shown, so this pathway is not selected for this trial assessment.

(8) Migration from seawater to the atmosphere

Since ALPS treated water was diluted with seawater as liquid before being discharged into the sea and diluted in the sea before migration to air, it was not selected as a migration pathway in the report (design stage/ first version) considering that there is almost no impact of exposure from the radioactive materials diffused from seawater to air.

In IAEA-TECDOC-1759, examples of a transfer pathway as spray from seawater and a calculation method are exemplified, so this pathway is not selected for this trial assessment.

As a result of this review, this pathway was added as a transition/exposure pathway in the report (design stage / revised version).

(9) Migration from coastal sediment to the air

Since only a small amount of coastal sediment migrates to the air, and it remains on the seashore for only a short time, so the exposure impact was negligible and it was not selected as a transfer pathway in the report (design stage/ first version).

In IAEA-TECDOC-1759, examples of a pathway and a calculation method are exemplified, so this pathway is selected for this trial assessment.

As a result of this review, this pathway was added as a transition/exposure pathway in the report (design stage / revised version).

(10) Migration from seawater to seafood

Migration (concentration) from seawater to seafood is widely known and has been assessed in domestic precedent cases including light water reactors, so it was selected in the report (design stage/ first version).

In IAEA-TECDOC-1759, examples of a pathway and a calculation method are exemplified, so it was also this pathway is selected for this trial assessment.

Though the diffusion simulation uses the same calculation result as that of the first report, concentration of each nuclide in the sea water is calculated without taking the adsorption to suspended particles and seabed sediment into account in this radiological environmental impact assessment report. In contrast, in the trial assessment by the method of IAEA-TECDOC-1759, the dissolved concentration C_{DW}(j) is calculated considering the suspended particle concentration and migration to seabed sediment from the equilibrium concentration C_{BOX}(j) of nuclide j calculated from the annual discharge amount of the nuclides discharged into the calculation area and the amount of seawater which passes through the calculation area by the following equation:

$$C_{DW}(j)=\frac{C_{BOX}(j)}{1+K_d(j)(S+\frac{L_B\rho_B}{D})} \qquad \text{(VI-1)}$$

where

Kd(j)	is the sediment partition factor of radionuclide j (m^3/kg)
S	is the suspended sediment concentration (kg/m^3), 3E-03 kg/m^3 is used
L_B	is the thickness of the sediment boundary layer (m), 1E-02 m is used
ρ_B	is the density of the sediment boundary layer (kg/m^3), 1500 kg/m^3 is used
D	is the water depth of the model (m), A water depth of 12 m, the depth of the discharge point, is used

The mass density C_p(j) (Bq/kg) of the suspended particles was obtained by the following equation:

$$C_P(j)=K_d(j)C_{DW}(j) \quad \text{(VI-2)}$$

The total concentration in seawater $C_w(j)$ of dissolved and suspended particles was obtained by the following equation:

$$C_W(j)=(1+K_d(j)S)\ C_{DW}(j) \quad \text{(VI-3)}$$

VI-2-3. Identification of exposure pathways for the trial assessment

In this trial assessment, the following exposure pathways were selected from the pathways and calculation methods shown in IAEA-TECDOC-1759.

- External exposure from beach sand
- Internal exposure from accidental ingestion of coastal sediment
- Internal exposure from accidental ingestion of seawater
- Internal exposure from accidental inhalation of dispersed coastal sediment
- Internal exposure from inhalation of seawater spray
- Internal exposure from ingestion of seafood
- Exposure due to skin contamination

The calculation method is as follows:

(1) External exposure from beach sand

In this trial assessment, the external exposure from nuclide migrated to beaches $E_{ext,shore,public}$(Sv) is calculated by the following equation:

$$E_{ext,shore,public}=t_{public}\sum_j C_S(j)DC_{gr}(j) \quad \text{(VI-4)}$$

$$Cs(j)=\frac{C_P(j)\rho_S d_S}{10} \quad \text{(VI-5)}$$

where

t_{public} is the time spent at the beach (h)

$DC_{gr}(j)$ is the dose conversion factor for ground contamination of radionuclide j ((Sv/h)/(Bq/m^2)); Dose conversion factors for ground surface contamination specified in the latest FGR 15[VI-2] prepared by the United States Environmental Protection Agency were used (See in Table VI -1).

$C_s(j)$ is the surface contamination density of radionuclide j in the shore sediments (in Bq/m^2)

ρ_s is the density of coastal sediment (kg/m^3), 1.5 E + 03 kg/m^3 is used

d_s is the effective thickness of coastal sediment (m), 0.1 m is used

The activity concentration radionuclide j in suspended particles $C_p(j)$ (Bq/kg-dry weight) is calculated by equation (VI-2).

(2) Internal exposure from accidental ingestion of coastal sediment

In this trial assessment, the internal exposure from accidental ingestion of coastal sediment $E_{ing,\ shore,\ public}$ (Sv) is calculated by the following equation:

$$E_{ing,shore,public}=t_{public}H_{shore}\sum_j \frac{C_s(j)}{\rho_s L_B} DC_{ing}(j) \qquad \text{(VI-6)}$$

where

t_{public} is the time spent at the beach (h)

H_{shore} is the hourly ingestion rate of beach sediment (kg/h), 5.0E-06kg/h, the recommended value of IAEA-TECDOC-1759, is used

$C_s(j)$ is the surface contamination density of radionuclide j in the shore sediments (Bq/m^2)

ρ_s is the density of coastal sediment (kg/m^3), 1.5 E + 03 kg/m^3 is used

d_s is the effective thickness of coastal sediment (m), 0.1 m is used

$DC_{ing}(j)$ is the effective dose (Sv/Bq) [VI-3] per unit intake by ingestion of radionuclide j (See Table VI -2).

(3) Internal exposure from ingestion of seawater

In this trial assessment, the internal exposure from accidental drinking of seawater during swimming on the seashore $E_{drink,public}$ (Sv) is calculated by the following equation:

$$E_{drink,public}=t_{public}H_{swim}\sum_j C_w(j)\, DC_{ing}(j) \qquad \text{(VI-7)}$$

where

t_{public} is the time spent while swimming (h)

H_{swim} is the intake rate of seawater during swimming (L/h); conservatively, 0.2L/h is used.

$C_w(j)$ is the concentration of nuclide j in the seawater calculated by equation (VI-3) (Bq/m^3);

$DC_{ing}(j)$ is the effective dose (Sv/Bq) [VI-3] per unit intake by ingestion of radionuclide j (See Table VI -2).

(4) Internal exposure from accidental inhalation of dispersed coastal sediment

In this trial assessment, the internal exposure from inhalation of dispersed coastal sediment on the shore $E_{inh,shore,public}$ (Sv) is calculated by the following equation:

$$E_{inh,shore,public}=t_{public}R_{inh,public}DL_{shore}\sum_j C_p(j)DC_{inh}(j) \tag{VI-8}$$

where

t_{public} is the time spent at the beach (h)

$R_{inh,\ public}$ is the inhalation rate of a member of the public in m^3/h, the recommended value of IAEA-TECDOC-1759 ($0.92 m^3/h$ for adults) is used

DL_{shore} is the load factor (kg/m^3) for dust from coastal sediment, 2.5E-09 kg/m^3, the recommended value of IAEA-TECDOC-1759, is used

$DC_{inh}(j)$ is the effective dose (Sv/Bq) per unit intake by inhalation of radionuclide j (See in Table VI -3).

The concentration of radionuclides in sediment $C_p(j)$ (Bq/kg) can be calculated by equation (VI-2).

(5) Internal exposure from inhalation of seawater spray

In this trial assessment, the internal exposure from seawater spray caused by wave, etc., on the shore $E_{inh,spray,public}$ (Sv) is calculated by the following equation:

$$E_{inh,spray,public}=t_{public}\bullet R_{inh,public}\frac{C_{spray}}{\rho_w}\sum_j C_w(j)DC_{inh}(j) \tag{VI-9}$$

where

t_{public} is the time spent at the beach (h)

$R_{inh,\ public}$ is the inhalation rate of a member of the public (m^3/h), the recommended value ($0.92\ m^3/h$ for adults) is used

C_{spray} is the concentration of seawater spray in the air (kg/m^3), 1.0E-02kg/m^3, the recommended value of IAEA-TECDOC-1759, is used

ρ_w is the density of seawater (kg/m^3), 1E+03 kg/m^3 is used

$C_w(j)$ is the concentration of radionuclide j in the seawater (Bq/m^3)

$DC_{inh}(j)$ is the effective dose per unit intake by inhalation (Sv/Bq) (See Table VI - 3).

(6) Internal exposure from ingestion of seafood

In this trial assessment, the internal exposure from ingestion of seafood $E_{ing,food,public}$ (Sv) is calculated by the following equation:

$$E_{ing,food,public}=\sum_k H_B(k)\sum_j C_{EB}(j,k)DC_{ing}(j) \qquad \text{(VI-10)}$$

where

$H_B(k)$ is the annual ingestion of seafood k (kg)

$DC_{ing}(j)$ is the effective dose per unit intake by ingestion of radionuclide j (Sv/Bq) (See Table VI -2).

$C_{EB}(j,k)$ is the concentration of nuclide j in the edible part of seafood k and calculated by the following equation:

$$C_{EB}(j,k)=CF(j,k)C_{DW}(j)\cdot 1E\text{-}03 \qquad \text{(VI-11)}$$

where

$CF(j,k)$ is the concentration factor for nuclide j of seafood k ((Bq/kg)/(Bq/L)).

$C_{DW}(j)$ is the dissolved concentration of radionuclide j in the seawater (Bq/m^3) and is calculated by equation (VI-1).

1E-03 is unit conversion (m^3/L)

(7) Exposure of the skin from sea seabed sediment settled on the skin

Since the assessment method on how to assess the exposure of skin is not presented in IAEA-TECDOC-1759, exposure from sea seabed sediment that is adhered to fishing nets during fishing operation and settled on the skin was simulated and the skin effective dose E_{skin}(Sv) is calculated, using equivalent dose coefficient for skin shown in IAEA SRS44[VI-4], by the following equation:

$$E_{skin}=0.01t_{public}\sum_j S_d\, DC_{skin}(j)/8760 \qquad \text{(VI-12)}$$

where

0.01 is the skin tissue loading factor.

t_{public} is the duration of exposure (h).

$DC_{skin}(j)$ is the dose conversion factor for the skin ((Sv/y)/(Bq/cm^2)) specified in IAEA SRS44[VI-4] (beta and gamma-ray emitting nuclides) (See Table VI - 4).

8760 is the unit conversion factor (h/y)

S_d is the surface contamination density (Bq/cm^2) calculated by the following equation:

$$S_d=K_d(j)C_{DW}(j)\rho_d \qquad \text{(VI-13)}$$

where

$K_d(j)$ is the distribution factor of the nuclide j between seawater and sea seabed sediment ((Bq/kg)/(Bq/L))

$C_{DW}(j)$ is the concentration of nuclide j in seawater (Bq/L)

ρ is the density of sea seabed sediment (kg/cm^3), 1.5 E-03 kg/cm^3 is used.

d is the thickness of the sea seabed sediment settled on the skin (cm), 0.01 cm is used.

VI-2-4. Setting of the representative person subject to the exposure assessment

The features of representative persons subject to the exposure assessment were the same as 6-1-2.(4).

- Engage in fishing 120 days (2,880 hours) a year, of which 80 days (1,920 hours) are spent near fishing nets.
- Stay at the beach 500 hours a year and swim for 96 hours.
- The ingestion of seafood is the intake of persons who consume a large amount of seafood. (Table VI-5)

Table VI-1 Dose conversion factor for the effective dose from radiation from beach sand (Source: U.S. EPA FGR15)

Nuclide	Dose conversion factor for the effective dose $((Sv/s)/(Bq/m^2))$	Remarks
H-3	6.7E-22	
C-14	6.1E-19	
Mn-54	5.3E-16	
Fe-55	9.0E-26	
Co-60	1.5E-15	
Ni-63	8.0E-20	
Se-79	6.8E-19	
Sr-90	6.5E-18	
Y-90	1.5E-16	
Tc-99	2.0E-18	
Ru-106	1.7E-20	
Sb-125	2.7E-16	
Te-125m	4.1E-18	
I-129	4.4E-18	
Cs-134	1.0E-15	
Cs-137	7.9E-18	
Ce-144	1.1E-17	
Pm-147	9.4E-19	
Sm-151	1.1E-19	
Eu-154	7.9E-16	
Eu-155	3.1E-17	
U-234	6.4E-20	
U-238	1.4E-16	
Np-237	1.4E-16	
Pu-238	2.1E-20	
Pu-239	4.2E-20	
Pu-240	2.2E-20	
Pu-241	1.7E-21	
Am-241	9.9E-18	
Cm-244	3.1E-20	

Table VI-2　Committed effective dose per unit intake for ingestion (Source: IAEA GSR-Part3)

Target Nuclide	Effective dose factor (Sv/Bq)			Remarks
	Adult	Child under school age	Infant	
H-3 (HTO)	1.8E-11	3.1E-11	6.4E-11	Used for the assessment of ingestion of water
H-3 (considering OBT)	2.0E-11	3.5E-11	7.0E-11	Used for the assessment of ingestion of seafood assuming that 10% of tritium to be ingested is OBT
C-14	5.8E-10	9.9E-10	1.4E-09	
Mn-54	7.1E-10	1.9E-09	5.4E-09	
Fe-55	3.3E-10	1.7E-09	7.6E-09	
Co-60	3.4E-09	1.7E-08	5.4E-08	
Ni-63	1.5E-10	4.6E-10	1.6E-09	
Se-79	2.9E-09	1.9E-08	4.1E-08	
Sr-90	2.8E-08	4.7E-08	2.3E-07	
Y-90	2.7E-09	1.0E-08	3.1E-08	
Tc-99	6.4E-10	2.3E-09	1.0E-08	
Ru-106	7.0E-09	2.5E-08	8.4E-08	
Sb-125	1.1E-09	3.4E-09	1.1E-08	
Te-125m	8.7E-10	3.3E-09	1.3E-08	
I-129	1.1E-07	1.7E-07	1.8E-07	
Cs-134	1.9E-08	1.3E-08	2.6E-08	
Cs-137	1.3E-08	9.6E-09	2.1E-08	
Ce-144	5.2E-09	1.9E-08	6.6E-08	
Pm-147	2.6E-10	9.6E-10	3.6E-09	
Sm-151	9.8E-11	3.3E-10	1.5E-09	
Eu-154	2.0E-09	6.5E-09	2.5E-08	
Eu-155	3.2E-10	1.1E-09	4.3E-09	
U-234	4.9E-08	8.8E-08	3.7E-07	
U-238	4.5E-08	8.0E-08	3.4E-07	
Np-237	1.1E-07	1.4E-07	2.0E-06	
Pu-238	2.3E-07	3.1E-07	4.0E-06	
Pu-239	2.5E-07	3.3E-07	4.2E-06	
Pu-240	2.5E-07	3.3E-07	4.2E-06	
Pu-241	4.8E-09	5.5E-09	5.6E-08	
Am-241	2.0E-07	2.7E-07	3.7E-06	
Cm-244	1.2E-07	1.9E-07	2.9E-06	

Table VI-3 Committed effective dose per unit intake from inhalation (Source: IAEA GSR-Part3)

Target Nuclide	Effective dose factor (Sv/Bq)			Remarks
	Adult	Child under school age	Infant	
H-3	1.8E-11	3.1E-11	6.4E-11	The conversion factor of tritium vapor is used
C-14	5.8E-09	1.1E-08	1.9E-08	
Mn-54	1.5E-09	3.8E-09	7.5E-09	
Fe-55	7.7E-10	2.2E-09	4.2E-09	
Co-60	3.1E-08	5.9E-08	9.2E-08	
Ni-63	1.3E-09	2.7E-09	4.8E-09	
Se-79	6.8E-09	1.3E-08	2.3E-08	
Sr-90	1.6E-07	2.7E-07	4.2E-07	
Y-90	1.5E-09	4.2E-09	1.3E-08	
Tc-99	1.3E-08	2.4E-08	4.1E-08	
Ru-106	6.6E-08	1.4E-07	2.6E-07	
Sb-125	1.2E-08	2.4E-08	4.2E-08	
Te-125m	4.2E-09	7.8E-09	1.7E-08	
I-129	3.6E-08	6.1E-08	7.2E-08	
Cs-134	2.0E-08	4.1E-08	7.0E-08	
Cs-137	3.9E-08	7.0E-08	1.1E-07	
Ce-144	5.3E-08	1.4E-07	3.6E-07	
Pm-147	5.0E-09	1.1E-08	2.1E-08	
Sm-151	4.0E-09	6.7E-09	1.1E-08	
Eu-154	5.3E-08	9.7E-08	1.6E-07	
Eu-155	6.9E-09	1.4E-08	2.6E-08	
U-234	9.4E-06	1.9E-05	3.3E-05	
U-238	8.0E-06	1.6E-05	2.9E-05	
Np-237	5.0E-05	6.0E-05	9.8E-05	
Pu-238	1.1E-04	1.4E-04	2.0E-04	
Pu-239	1.2E-04	1.5E-04	2.1E-04	
Pu-240	1.2E-04	1.5E-04	2.1E-04	
Pu-241	2.3E-06	2.6E-06	2.8E-06	
Am-241	9.6E-05	1.2E-04	1.8E-04	
Cm-244	5.7E-05	8.3E-05	1.5E-04	

Table VI-4 Skin equivalent dose conversion factors (β and γ emitting nuclides)

Nuclide	Skin equivalent dose conversion factors ((Sv/year)/(Bq/cm^2))	Remarks
H-3	0.0E+00	
C-14	7.9E-03	
Mn-54	5.3E-04	
Fe-55	1.4E-04	
Co-60	1.7E-02	
Ni-63	1.6E-04	
Se-79	1.0E-02	
Sr-90	4.5E-02	
Y-90	2.4E-02	
Tc-99	1.4E-02	
Ru-106	2.5E-02	
Sb-125	1.8E-02	
Te-125m	2.6E-02	
Te-129m	3.7E-02	
I-129	5.8E-03	
Cs-134	1.7E-02	
Cs-137	2.2E-02	
Ce-144	3.9E-02	
Pm-147	1.1E-02	
Sm-151	2.5E-04	
Eu-154	3.1E-02	
Eu-155	7.6E-03	
U-234	3.7E-02	
U-238	3.7E-02	
Np-237	3.1E-02	
Pu-238	9.5E-04	
Pu-239	1.3E-05	
Pu-240	9.1E-07	
Pu-241	1.4E-08	
Am-241	6.3E-04	
Cm-244	1.9E-05	

Table VI-5 Intake of persons who consume a large amount of seafood (g/day)

	Fish	Invertebrate	Seaweeds
Adult	190	62	52
Children under school	97	31	26
Infants	39	12	10

VI-3. Trial assessment result

The source terms of the following three cases were assessed in a trial basis by the assessment method of IAEA-TECDOC-1759 and compared with the results in the body of the report.

i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

The results of the comparison are shown in Table VI-6(1) to (3).
Regardless of the source term, none of the assessment results exceeded the external exposure from beach sand, and internal exposure from the seafood of the report.

Table VI-6(1) Comparison of the exposure assessment results by the source term of the K4 tank group

Assessed case		The body of the report	IAEA-TECDOC-1759	Remarks
External exposure (mSv/year)	Exposure from sea surface	4.6E-10	Not to be assessed	
	Exposure from hulls	4.9E-10	Not to be assessed	
	Exposure during swimming	3.2E-10	Not to be assessed	
	Exposure from beach sand	5.4E-07	1.1E-07	In the assessment of the body of the report, conservative dose conversion factors were used for external exposures, and therefore the results are considered to be conservative.
	Exposure from fishing nets	1.1E-07	Not to be assessed	
Internal exposure (mSv/year) (Adult)	Ingestion of coastal sediment	Not to be assessed	5.6E-10	
	Ingestion of seawater	3.4E-07	3.3E-07	Since the tritium in the ALPS treated water before dilution, of which concentration exceed the regulatory concentration limit, has higher concentration than the other nuclides after discharge into the sea as well, the exposure through accidently ingestion of seawater is mainly caused by tritium and the result is not changed.
	Inhalation of dispersed coastal sediment	Not to be assessed	4.3E-12	
	Inhalation of seawater spray	9.2E-08	7.9E-08	
	Ingestion of seafood	3.1E-05	2.2E-05	In the assessment of the body of the original report, the concentration in seafood was assessed using conservative concentrations in seawater rather than taking into account adhesion to suspended particles and sea seabed sediment. Therefore, the assessment result is considered to be conservative.
Exposure of the skin (mSv/year)	When seabed sediment settles on the skin	Not to be assessed	1.2E-10	
Total (mSv/year)		3E-05	2E-05	

Table VI-6(2) Comparison of the exposure assessment results by the source term of the J1-C tank group

Assessed case		The body of the report	IAEA-TECDOC-1759	Remarks
External exposure (mSv/year)	Exposure from sea surface	1.7E-10	Not to be assessed	
	Exposure from hulls	1.8E-10	Not to be assessed	
	Exposure during swimming	1.2E-10	Not to be assessed	
	Exposure from beach sand	2.0E-07	2.9E-08	In the assessment of of the body of the oreport, conservative dose conversion factors were used for external exposures, and therefore the results are considered to be conservative.
	Exposure from fishing nets	3.9E-08	Not to be assessed	
Internal exposure (mSv/year) (Adult)	Ingestion of coastal sediment	Not to be assessed	2.9E-10	
	Ingestion of seawater	3.1E-07	3.1E-07	Since the tritium in the ALPS treated water before dilution, of which concentration exceed the regulatory concentration limit, has higher concentration than the other nuclides after discharge into the sea as well, the exposure through accidently ingestion of seawater is mainly caused by tritium and the result is not changed
	Inhalation of dispersed coastal sediment	Not to be assessed	3.6E-11	
	Inhalation of seawater spray	1.9E-07	8.2E-08	
	Ingestion of seafood	5.5E-06	3.1E-06	In the assessment of the body of the report, the concentration in seafood was assessed using conservative concentrations in seawater rather than taking into account adhesion to suspended particles and sea seabed sediment. Therefore, the assessment result is considered to be conservative.
Exposure of the skin (mSv/year)	When seabed sediment settles on the skin	Not to be assessed	3.3E-10	
Total (mSv/year)		6E-06	3E-06	

Table VI-6(3) Comparison of the exposure assessment results by the source term of the J1-G tank group

Assessed case		The body of the report	IAEA-TECDOC-1759	Remarks
External exposure (mSv/year)	Exposure from sea surface	3.7E-10	Not to be assessed	
	Exposure from hulls	3.7E-10	Not to be assessed	
	Exposure during Swimming	2.5E-10	Not to be assessed	
	Exposure from beach sand	4.3E-07	6.8E-08	In the assessment of the body of the report, conservative dose conversion factors were used for external exposures, and therefore the results are considered to be conservative.
	Exposure from fishing nets	8.3E-08	Not to be assessed	
Internal exposure (mSv/year) (Adult)	Ingestion of coastal sediment	Not to be assessed	6.7E-10	
	Ingestion of seawater	3.1E-07	3.1E-07	Since the tritium in the ALPS treated water before dilution, of which concentration exceed the regulatory concentration limit, has higher concentration than the other nuclides after discharge into the sea as well, the exposure through accidently ingestion of seawater is mainly caused by tritium and the result is not changed.
	Inhalation of dispersed coastal sediment	Not to be assessed	9.3E-11	
	Inhalation of seawater spray	3.8E-07	9.6E-08	
	Ingestion of seafood	1.1E-05	4.6E-06	In the assessment of the body of the report, the concentration in seafood was assessed using conservative concentrations in seawater rather than taking into account adhesion to suspended particles and sea seabed sediment. Therefore, the assessment result is considered to be conservative.
Exposure of the skin (mSv/year)	When seabed sediment settles on the skin	Not to be assessed	9.6E-10	
Total (mSv/year)		1E-05	5E-06	

References

[VI-1] IAEA, TECDOC-1759" Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure",2015

[VI-2] EPA, FEDERAL GUIDANCE REPORT NO.15 "EXTERNAL EXPOSURE TO RADIONUCLIDES IN AIR, WATER AND SOIL",2019

[VI-3] IAEA, General Safety Requirements Part 3" Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards",2014

[VI-4] IAEA, Safety Report Series No. 44" Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance",2005

Attachment VII Validity of the diffusion simulation

In the chapter 6-1-2.(2) “Modeling of diffusion and transfer after discharge”, the simulation model used to calculate the advection and diffusion of tritium is the model for the reproduction calculation of the diffusion of cesium leaked into the sea area due to the Accident at the Fukushima Daiichi Nuclear Power Station.
The following describes the validity of the diffusion simulation from various viewpoints.
The validity of the calculation area is also described by showing calculation results of radioactive material concentration on the boundary of calculating area.

VII-1. Reproducibility of the flow rate

As described in the chapter 6-1-2.(2) “Modeling of diffusion and transfer after discharge”, this simulation used actual meteorological and oceanographic data for the reproduction calculation of cesium leaked from the Fukushima Daiichi Nuclear Power Station, and confirmed the reproducibility by comparing it with actual sea area monitoring data.
Figure VII-1 shows a comparison of the north and south components of the flow rate measured with the acoustic doppler current profiler (ADCP; 600 kHz, RDI) in the locations about 5 km to the south of the Fukushima Daiichi Nuclear Power Station and about 2.8 km offshore (37°22.6’ N, 141°3.7’E) and the flow rate reproduced by simulation between October 8 and December 10, 2014 and between April 22 and June 25, 2015 [VII-1]. The match rate between the simulation and measured value is high no matter whether the river flow rate is considered.

Figure VII-1 Comparison between the flow rate measured near the Fukushima Daiichi Nuclear Power Station and the reproduction calculation by simulation

VII-2. Reproducibility of the cesium concentration

Figure VII-2 shows the result of comparison between the annual average value of the cesium 137 concentration [VII-2] of surface seawater obtained by coastal seawater monitoring in Fukushima by TEPCO and the annual average concentration distribution of the surface reproduced by simulation between 2013 and 2016. "○" shows the monitoring points, the colors show the measured Cs-137 concentrations, and the contour figure shows the calculation result of simulation. Similarly, Figure VII-3 shows a comparison with the annual average value of the Cs-137 concentration [VII-2] of surface seawater obtained by seawater monitoring in the offshore sea area by the Secretariat of the Nuclear Regulation Authority. The high concentration in the coastal area around the power station and the general concentration trend are reproduced well.

Moreover, Figure VII-4 shows the data in the scatter diagram. The measured values are almost similar to the simulated ones in the upper right region, where the concentration is high (blue dashed line).

On the other hand, in the lower-left region where the concentration is low (red dashed line), the measured values tend to be higher than the simulated results. Measured values are higher in the low concentration region probably because the simulation results do not adequately reflect some sources, such as the supply of cesium from rivers and inflow of cesium due to recirculation by currents in the North Pacific Ocean. Thus, this does not raise issues regarding the reproducibility of simulation results in this assessment conducted to evaluate the impact of the discharge of the ALPS treated water.

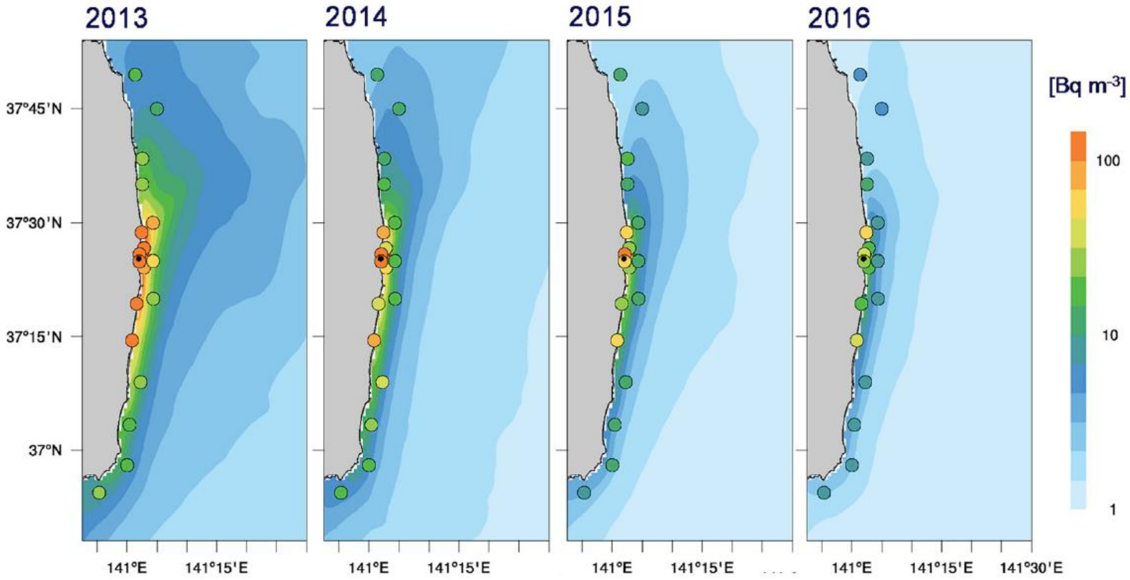


Figure VII-2 Comparison between the measured value and simulation of the Cs-137 concentration in the coastal area around the Fukushima Daiichi Nuclear Power Station

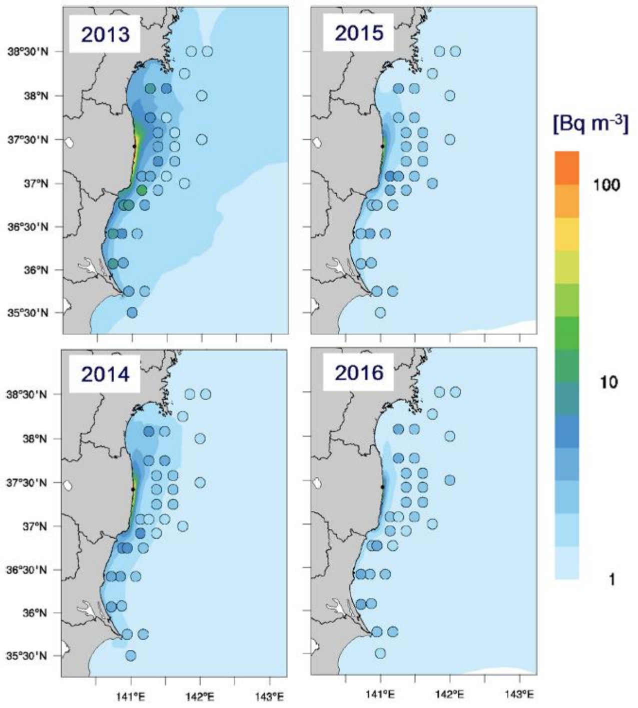


Figure VII-3 Comparison between the measured value and simulation of the Cs-137 concentration offshore in the sea area around the Fukushima Daiichi Nuclear Power Station

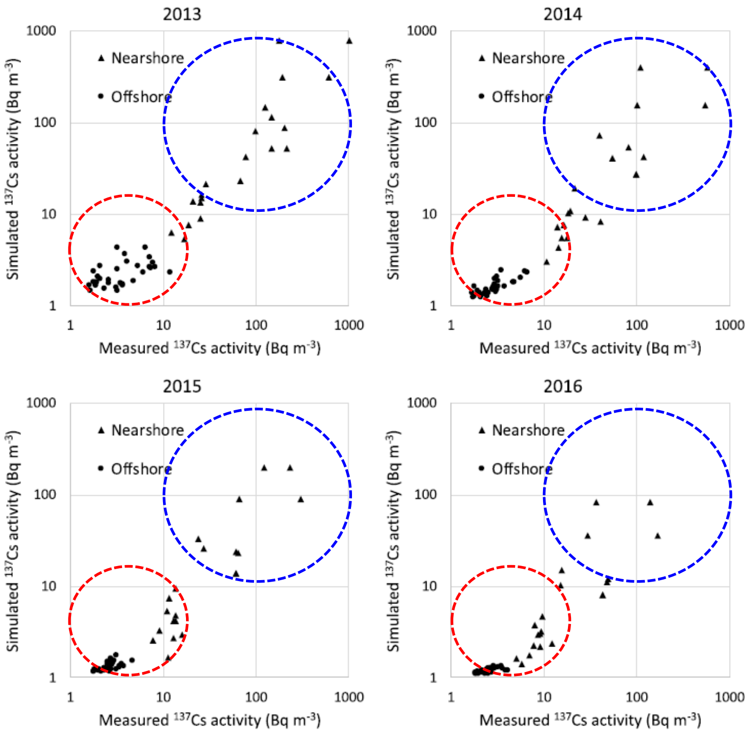


Figure VII-4 Comparison between the measured value and simulation of the Cs-137 concentration in the sea area around the Fukushima Daiichi Nuclear Power Station (Blue and red mainly show coast and offshore, respectively.)

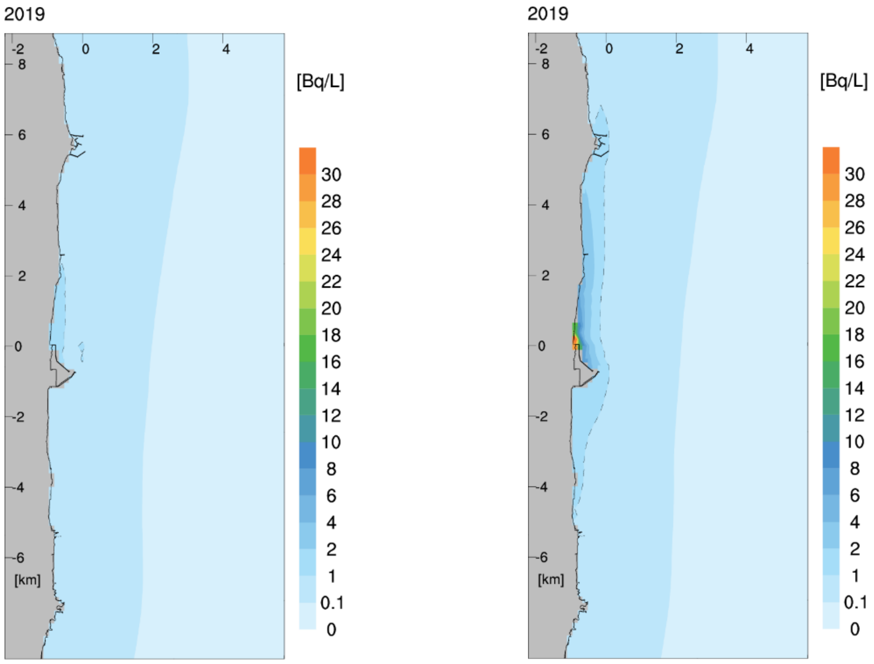
VII-3. Concentration distribution around the discharge outlet

The tritium simulation model used in 6-1-2.(2) “Modeling of diffusion and transfer after discharge” is a model to simulate migration and diffusion in vast areas and did not simulate the physical flow around the discharge outlet. Therefore, despite the upward discharge of water, the concentration near the seabed around the discharge outlet is higher than in the surrounding areas. Still, the result is that the concentration just above the discharge outlet does not show an increase much.

On the other hand, during the actual discharge, it will entrain surrounding seawater, facilitating the mixing and dilution. In addition, since the ALPS treated water to be discharged has already been diluted more than 100 times with seawater, the salinity and specific gravity of the water will be almost the same as those of the surrounding seawater. Therefore, although there is a slight difference in the concentration distribution around the discharge outlet, the diffusion in areas away from the outlet will not be expected to differ significantly to the simulated results.

Attachment VIII “Difference in the diffusion area by discharge location” of the report compares the simulated tritium diffusion when the discharge point is 1 km off the coast with the result when a discharge point is a unit 5/6 discharge outlet.

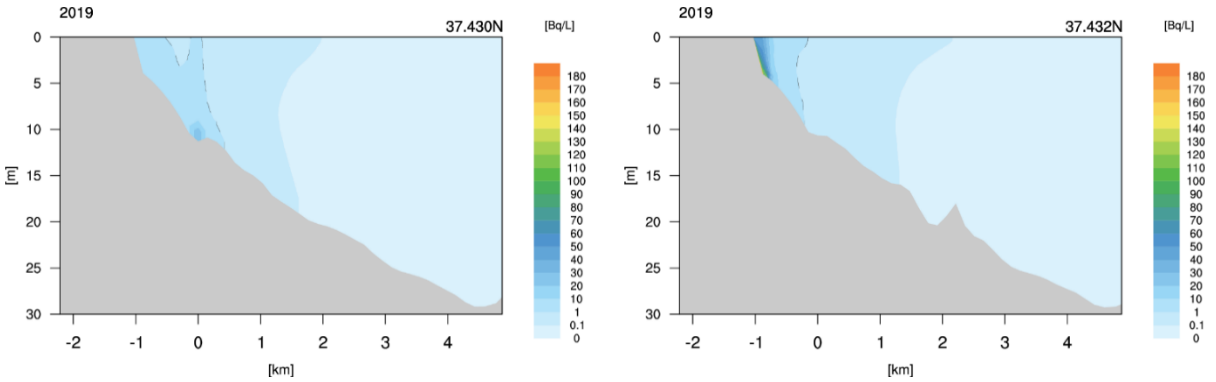
Although the concentration distribution around the discharge outlet is different, as shown in Figures VII-5 and VII-6, there is no notable difference in the diffusion in the surrounding sea area.



(Discharge from an outlet 1 km off the coast)

(Discharge from unit 5/6 discharge outlet)

Figure VII-5 Comparison of the distribution of annual mean tritium concentration in the sea between different discharge locations (sea surface)



(Discharge from an outlet
1 km off the coast)

(Discharge from unit 5/6
discharge outlet)

Figure VII-6 Comparison of the distribution of annual mean tritium concentration in the sea between different discharge locations (cross-sectional view)

In addition, even when the upward flow is not considered, the mean concentration in the 10 km × 10 km area calculated in the simulation is higher in the upper layer than the concentration around the discharge outlet, because as shown in Figures VII-7 to 10, the water depth in the surrounding sea gradually becomes deeper, and the concentration on the bottom offshore is much lower than in the surface layer.

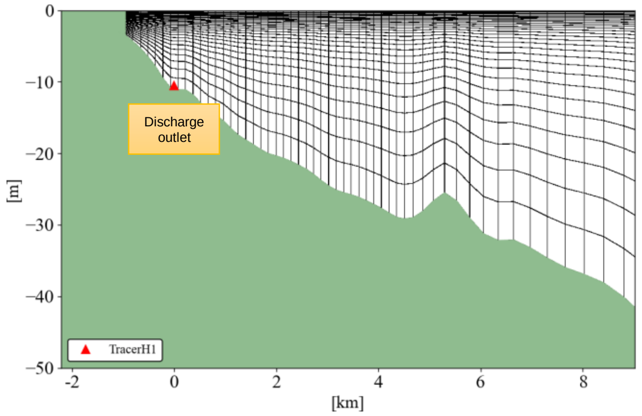


Figure VII-7 Cross-sectional view of the seabed up to about 10 km offshore

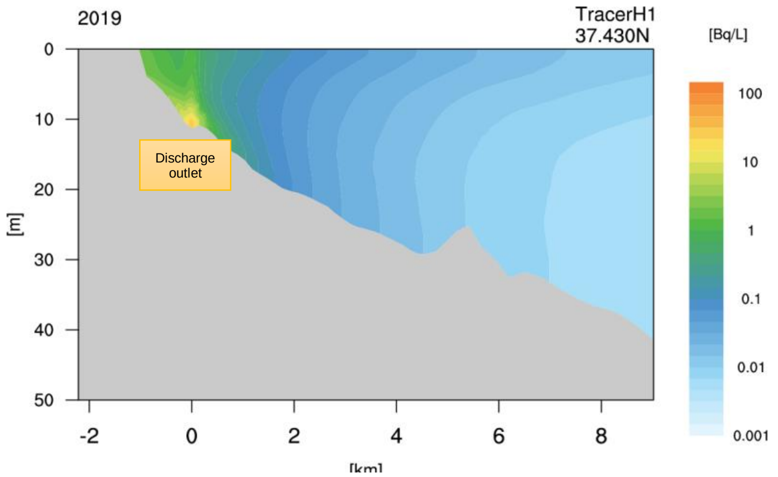


Figure VII-8 Cross-sectional view of distribution of annual mean tritium concentration up to 10 km offshore

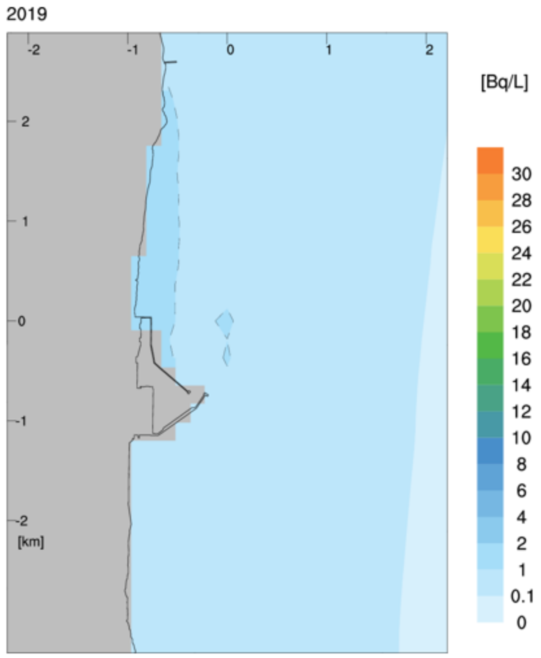


Figure VII-9 Distribution of annual mean tritium concentration on the sea surface up to 3 km offshore

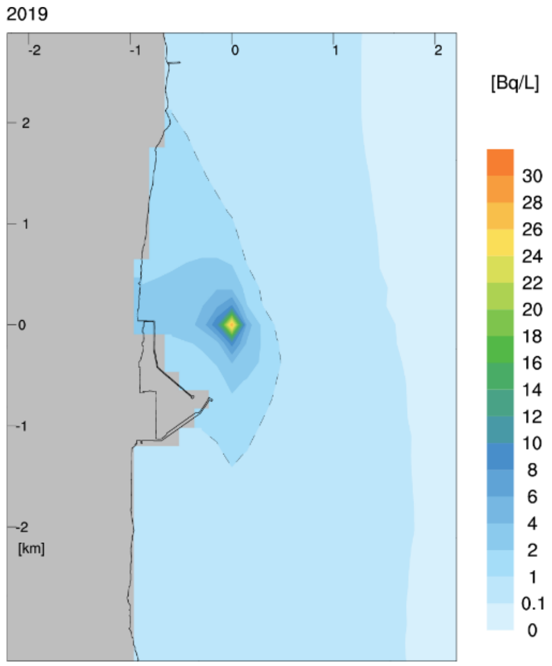


Figure VII-10 Distribution of annual mean tritium concentration on the sea bottom up to 3 km offshore

VII-4. Calculation period

As shown in 6-1-3, a simulation calculation of 7 years was performed in order to verify the fluctuation caused by the fluctuation in annual meteorological and oceanographic data. The result shows that the fluctuation in the annual average concentration of all layers within the range of 10 km × 10 km was small. Figure VII-11 shows the change in the daily average concentration in the same calculation. The concentration fluctuates significantly and no accumulation trend was observed in each calculation period (one year). No significant difference is expected to occur between the result of the calculations performed each year and the result of calculations performed for multiple consecutive years. Therefore, the result of the calculations for each year will be used because there is considered to be no problem in evaluating the impact over a long period of discharge with the assessment based on the result of one-year's calculations.

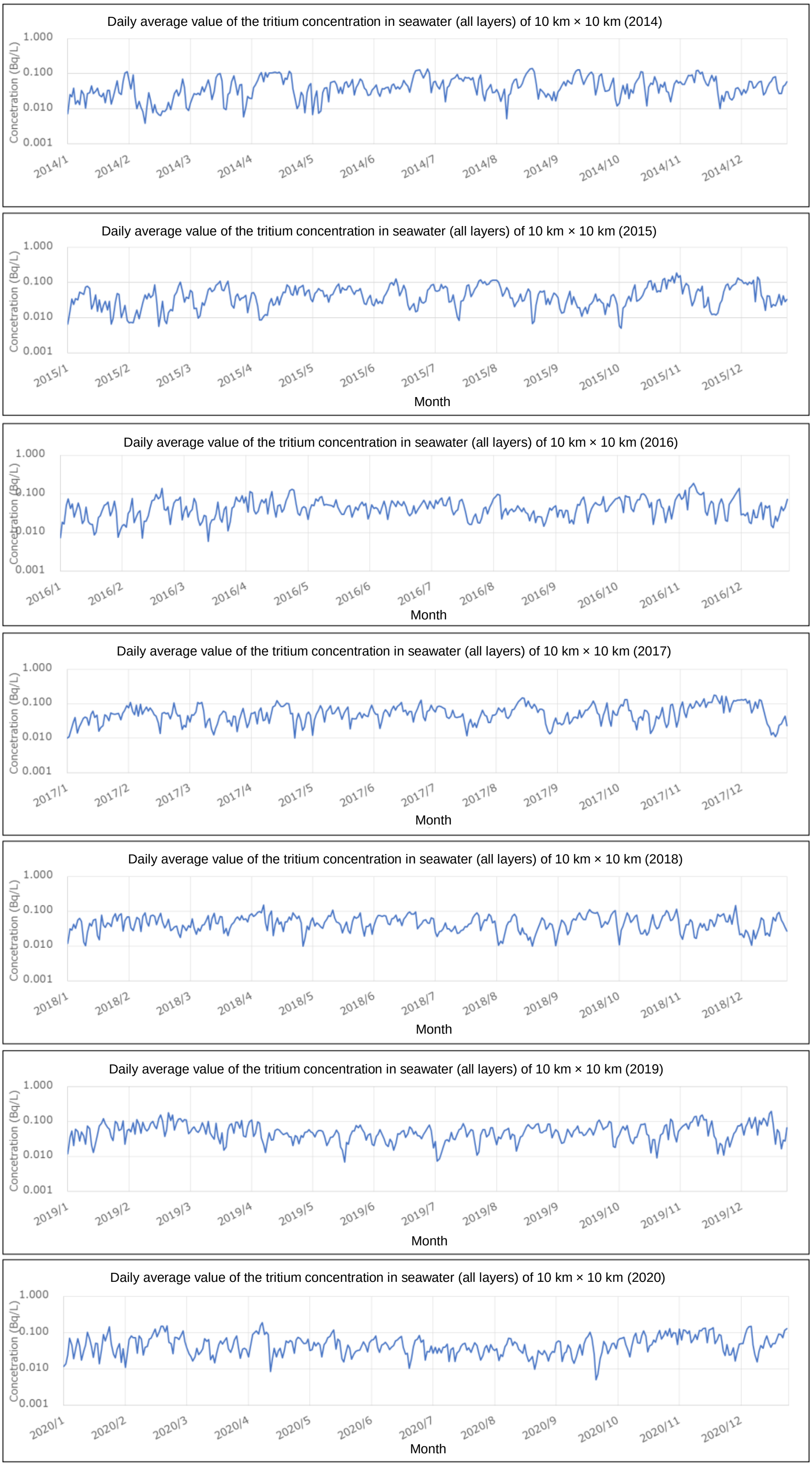


Figure VII-11 Calculation result of the daily average concentration within the range of 10 km × 10 km of each year

VII-5. Validity of the calculation area

The calculation area of the simulation used in the report is approximately 490 km north-south and 270 km east-west. Table VII-1 shows the maximum value and position of the area boundary from the annual average tritium concentration calculated from meteorological and oceanographic data for the years 2014 to 2020. Table VII-2 shows the annual maximum value, position, and date of occurrence of the area boundary based on the daily average concentration. The annual average concentration distribution diagram of tritium concentration of the entire area (result shown diagrammatically down to the lower limit of 1E-05Bq/L) is shown in Figure VII-12.

The maximum value of the annual average concentration range on the boundary of the calculation area is from 1.1E-04 to 2.6E-04Bq/L and maximum daily average concentration range is from 5.3E-03 to 1.4E-02Bq/L, all in the east side, and all much lower than the tritium concentration in sea water in sea area around Japan (about 1.0E-1Bq/L) [VII-3].

In addition, the result of calculation for the maximum concentrations of C-14 and I-129, which are major contributor to the total dose, at the boundary of calculation area for the case the discharge is conducted at the concentration of source term of K4 tank group, whose annual discharge amount is the largest among three source terms, is shown in Table VII-3 and 4.

As described in section 4.(4), C-14 is always generated from cosmic ray and emerged C-14, as mainly carbon dioxide, is diluted with stable carbon (C-12 and C-13) in the atmosphere. Since CO2 is always dissolving at the sea surface into seawater, the concentration of C-14 can be calculated from concentration of gross carbon in seawater at the sea surface and the ratio of C-14 to gross carbon (specific radioactivity). According to the 2008 Report[VII-4] on the Sources and Impacts of Ionizing Radiation to UN Scientific Committee on the Effects of Atomic Radiation, as the specific activity of C-14 to gross carbon is assumed to be about 230Bq/kg, the sea surface C-14 concentration is calculated by assuming that the gross carbon concentration near the sea surface is 2000µg/kg and the specific gravity of sea water is 1kg/L:

$$2000\ [\mu g/kg] \times 1E\text{-}09\ [kg/\mu g] \times 230\ [Bq/kg] \times 1\ [kg/L] = 4.6E\text{-}04 Bq/L$$

The impact of ALPS treated water discharge is negligible because the simulated annual mean concentration at the boundary area is much lower than this.

In addition, I-129 concentration in the sea area with no nuclear facilities in the sea area around Japan is 14 ~ 29nBq/L (1.4E-08 ~ 2.9E-08Bq/L) [VII-3] and the largest annual mean concentration at the simulated calculation area boundaries is lower than this concentration.

As mentioned above, the annual mean concentration of tritium and C-14, I-129 at the border of the calculation areas is lower than the background level of the sea area, and it is obvious that the concentration is lower outside the calculation area. Therefore, it is considered unnecessary to conduct dispersion simulations that further include the outer area to evaluate the radiation impact.

Table VII-1 Maximum value and position of the annual average tritium concentration on the model boundary (north, south, and east) of each year

Year	Concentration (Bq/L)	Coordinate		
		East - West (0: West boundary, 460: East boundary)	North - South (0: South boundary, 658: North boundary)	Depth (0: Bottom layer, 29: Top layer)
2014	1.1E-04	460 (East boundary)	80	23
2015	2.6E-04	460 (East boundary)	145	29
2016	1.4E-04	460 (East boundary)	318	25
2017	2.4E-04	460 (East boundary)	224	23
2018	1.9E-04	460 (East boundary)	150	29
2019	1.6E-04	460 (East boundary)	181	28
2020	1.9E-04	460 (East boundary)	232	28

Table VII-2 Maximum value, position, and date occurred of the daily average tritium concentration on the model boundary (north, south, and east) of each year

Date occurred	Concentration (Bq/L)	Coordinate		
		East - West (0: West boundary, 460: East boundary)	North - South (0: South boundary, 658: North boundary)	Depth (0: Bottom layer, 29: Top layer)
2014/9/21	6.7E-03	460 (East boundary)	198	19
2015/8/2	7.2E-03	460 (East boundary)	158	25
2016/8/6	1.4E-02	460 (East boundary)	341	28
2017/7/28	6.5E-03	460 (East boundary)	252	29
2018/8/15	5.3E-03	460 (East boundary)	215	21
2019/8/1	1.0E-02	460 (East boundary)	177	27
2020/5/30	1.1E-02	460 (East boundary)	234	28

Table VII-3 Annual average concentration of H-3, C-14 and I-129 on the model boundary (north, south, and east) of each year

Year	Tritium Concentration (Bq/L)	C-14 Concentration (Bq/L)	I-129 Concentration (Bq/L)	Note
2014	1.1E-04	8.5E-09	1.2E-09	Refer to Table VII-1 for the Coordinate
2015	2.6E-04	2.0E-08	2.8E-09	
2016	1.4E-04	1.1E-08	1.5E-09	
2017	2.4E-04	1.9E-08	2.6E-09	
2018	1.9E-04	1.5E-08	2.1E-09	
2019	1.6E-04	1.2E-08	1.7E-09	
2020	1.9E-04	1.5E-08	2.1E-09	

Table VII-4 Maximum value of daily average concentration of H-3, C-14 and I-129 on the model boundary (north, south, and east) of each year

Date Occurred	Tritium Concentration (Bq/L)	C-14 Concentration (Bq/L)	I-129 Concentration（Bq/L）	Note
2014/9/21	6.7E-03	5.2E-07	7.3E-08	Refer to Table VII-2 for the Coordinate
2015/8/2	7.2E-03	5.6E-07	7.9E-08	
2016/8/6	1.4E-02	1.1E-06	1.5E-07	
2017/7/28	6.5E-03	5.0E-07	7.1E-08	
2018/8/15	5.3E-03	4.1E-07	5.8E-08	
2019/8/1	1.0E-02	7.7E-07	1.1E-07	
2020/5/30	1.1E-02	8.5E-07	1.2E-07	

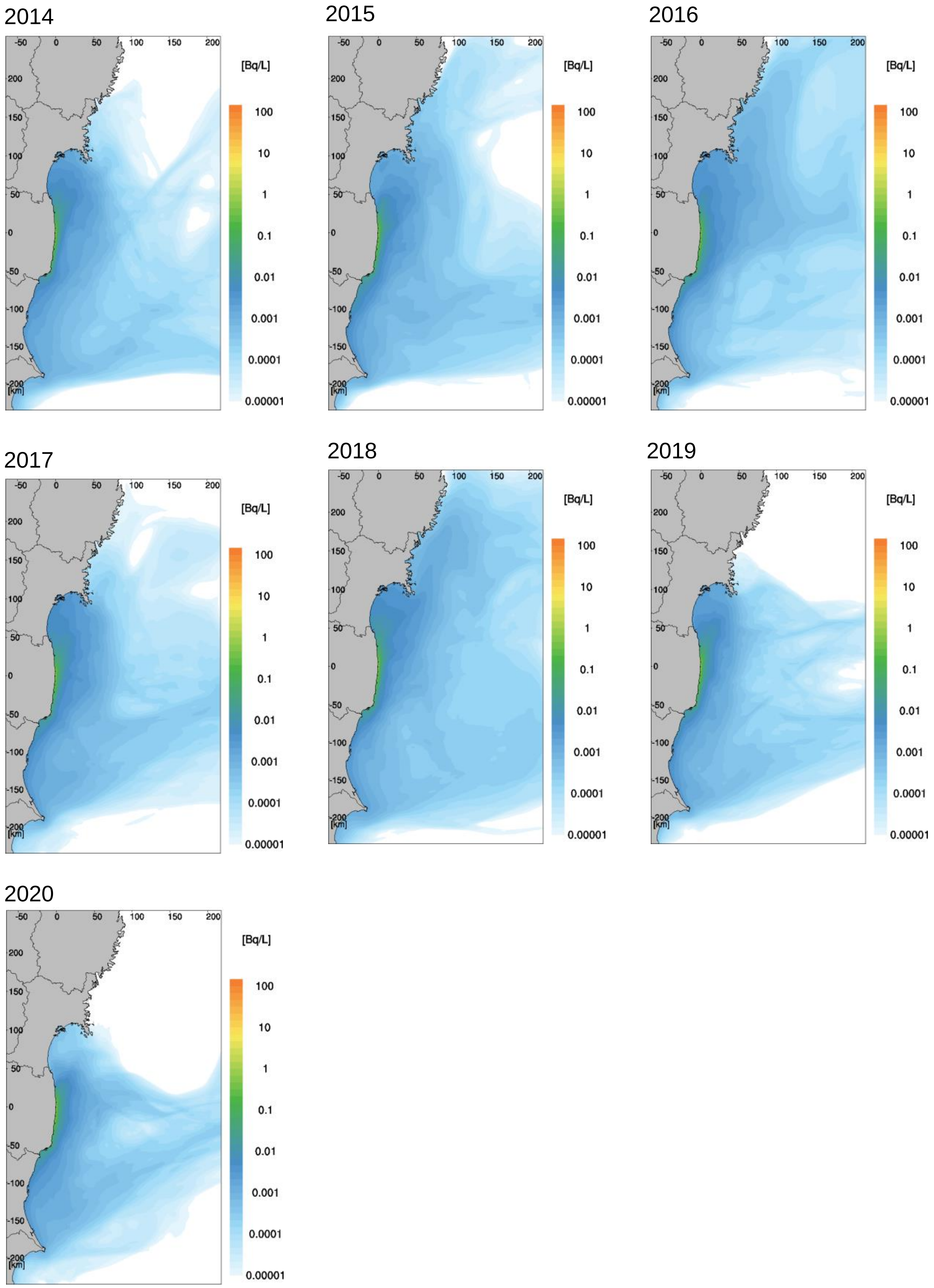


Figure VII-12 Annual average concentration distribution diagram of the tritium concentration (result shown diagrammatically up to 1E-05Bq/L as the lowest limit)

References

[VII-1] D.Tsumune, T.Tsubono, K.Misumi, Y.Tateda,Y.Toyoda, Y.Onda, and M.Aoyama, "Impacts of direct release and river discharge on oceanic 137Cs derived from the Fukushima Dai-ichi Nuclear Power Plant accident", 2020

[VII-2] https://radioactivity.nsr.go.jp/ja/list/428/list-1.html

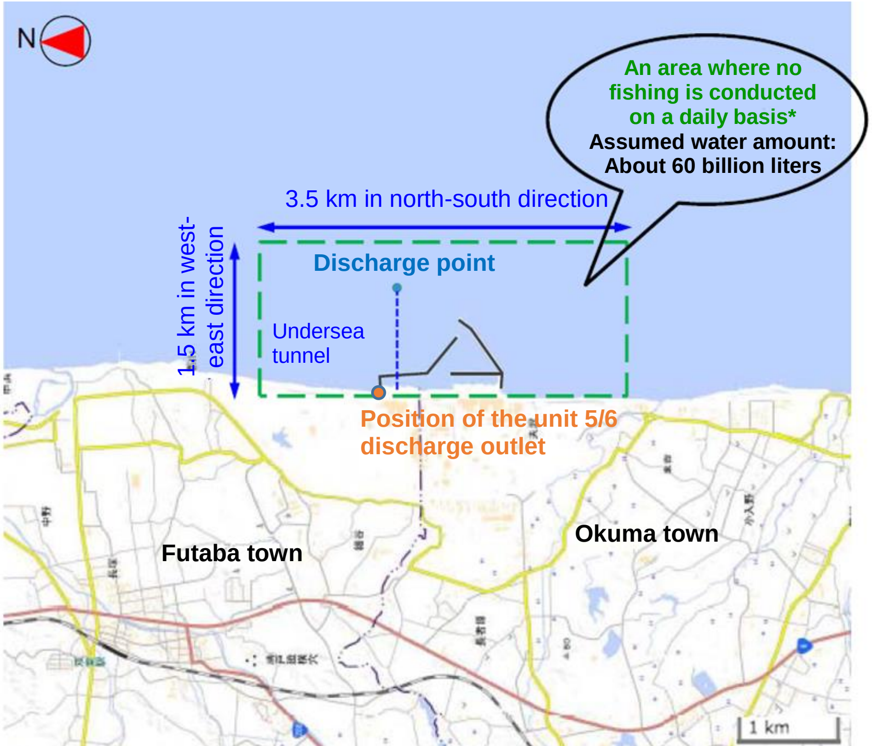
[VII-3] Marine Ecology Research Institute “FY2021 Commissioned Project Survey Report such as Disaster Prevention Measures, etc. for Nuclear Facilities (Investigation of radioactivity and comprehensive assessment in marine environment)” 2022

[VII-4] The United Nations Scientific Committee on the Effects of Atomic Radiation, ”SOURCES AND EFFECTS OF IONIZING RADIATION, UNSCEAR 2008 report” ,2010

Attachment VIII Difference in the diffusion area by discharge location

In the consideration of the discharge method of ALPS treated water, initially a plan of discharging from the unit 5/6 discharge outlet was considered as with the normal operation of units 5 and 6. Figure VIII-1 shows the water discharge position under consideration in this plan and the position of the unit 5/6 discharge outlet.

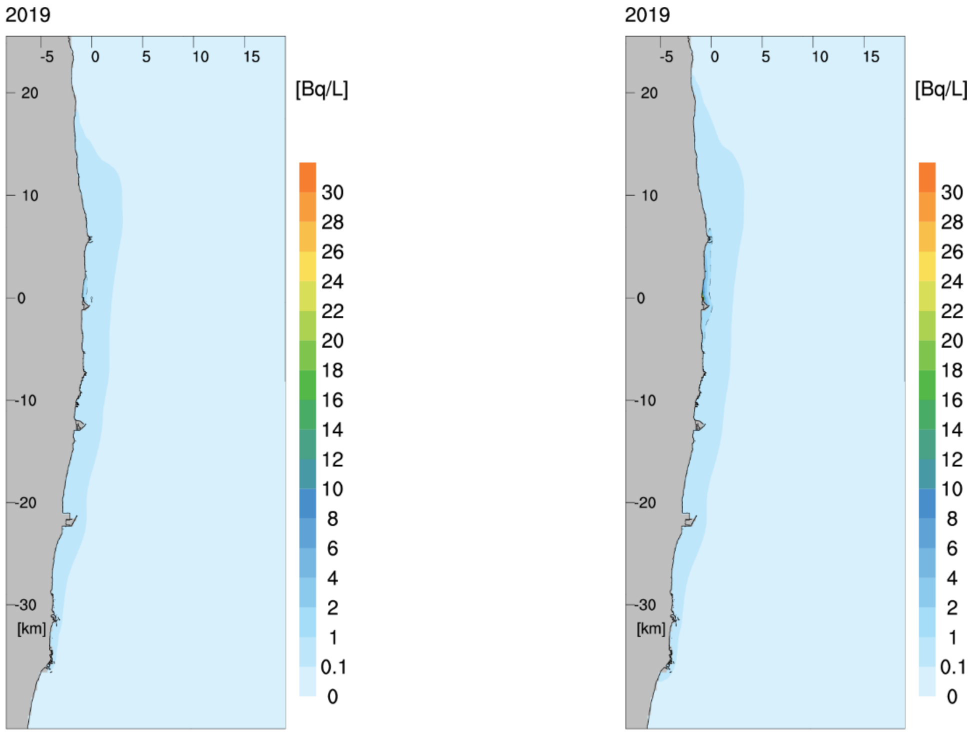
Figures VIII-2 to 4 show a comparison of diffusion simulation results among different discharge positions. Though no significant difference is observed in the concentration range of 0.1Bq/L, the concentration around the power station is lower in discharge from 1 km offshore.



Source: This map was created by Tokyo Electric Power Company Holdings, Inc. based on a map published by the Geographical Survey Institute (Electronic Map Web)
https://maps.gsi.go.jp/#13/37.422730/141.044970/&base=std&ls=std&disp=1&vs=c1j0h0k0l0u0t0z0r0s0m0f1

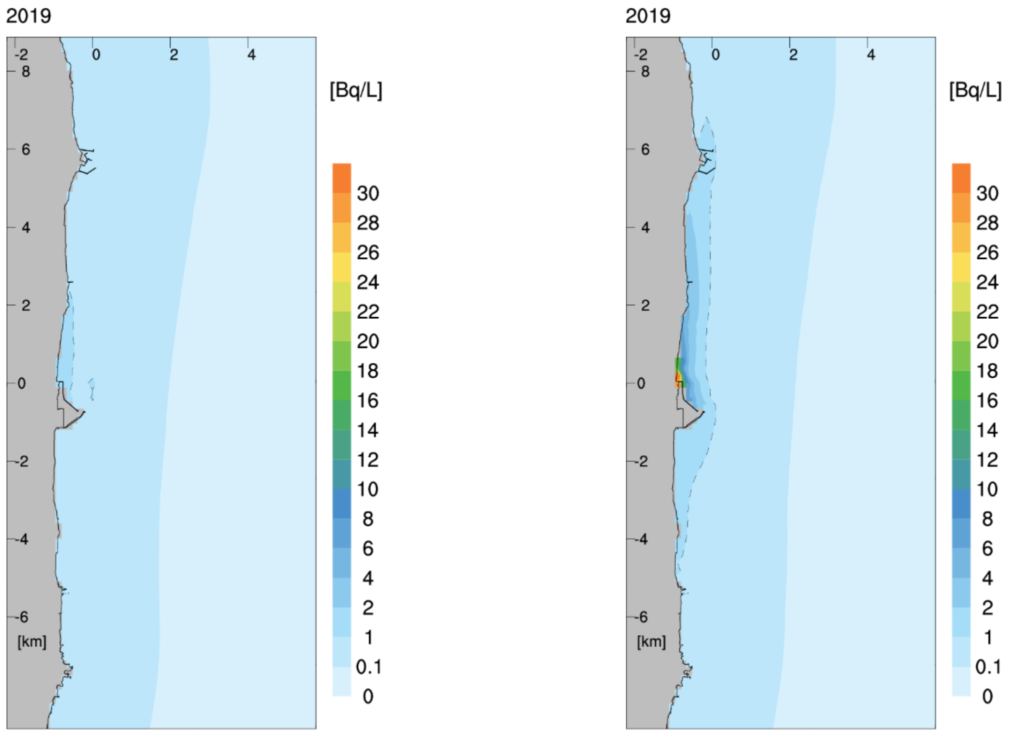
*Area where common fishery rights are not set.

Figure VIII-1 Discharge position and position of the unit 5/6 discharge outlet in the current plan



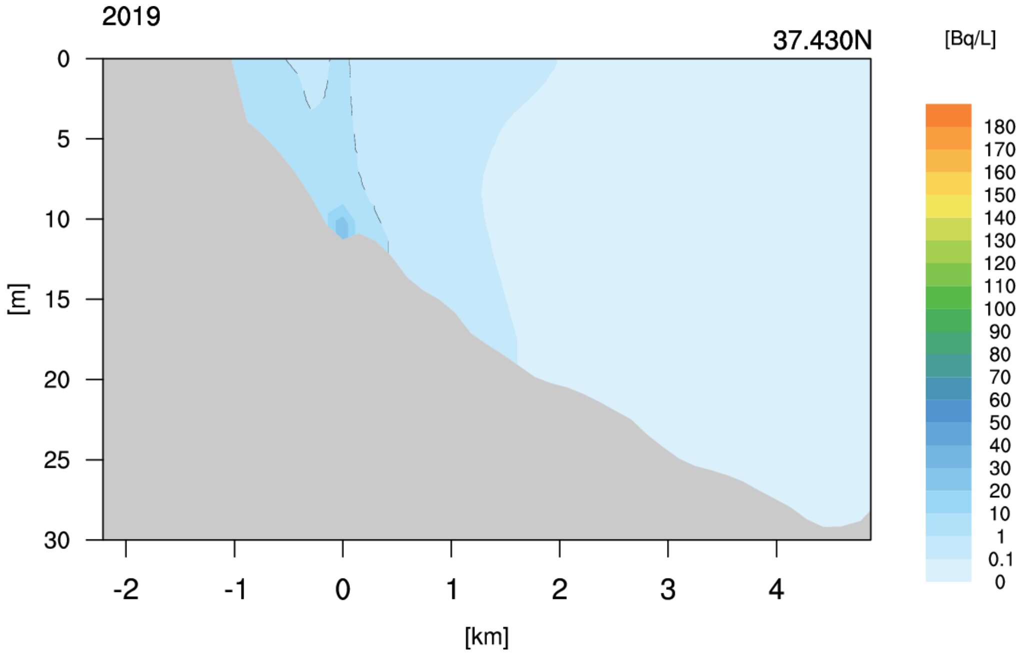
(Discharge from an outlet 1 km off the coast) (Discharge from unit 5/6 discharge outlet)

Figure VIII-2 Comparison of the distribution of annual mean concentration of the sea surface between different discharge locations (wide area)

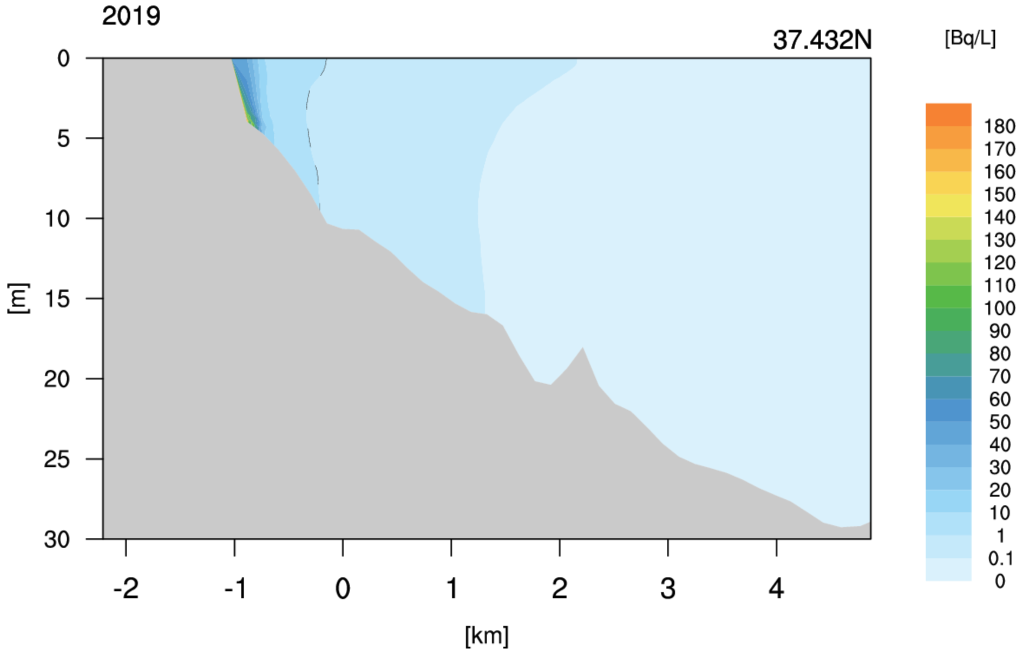


(Discharge from an outlet 1 km off the coast) (Discharge from unit 5/6 discharge outlet)

Figure VIII-3 Comparison of the distribution of annual mean concentration of the sea surface between different discharge locations (enlarged diagram)



(Discharge from an outlet 1 km off the coast)



(Discharge from unit 5/6 discharge outlet)

Figure VIII-4 Comparison of the distribution of annual mean concentration between different discharge locations (cross-sectional view)

Attachment IX Contribution to the undetected nuclides in the source term based on the measured value

The 30 nuclides subject to this assessment include many undetected nuclides which have never been detected in the past analysis assessments on ALPS treated water, etc. As shown in 6-1-2.(1) “Source term (annual discharge amount of each nuclide)” annual discharge amount is conservatively assumed to include nuclides below the detection limit in the source term based on actual measurement. However, it is estimated that the actual concentrations of many of the nuclides which have never been detected are much lower than the detection limit considering their half-lives, etc.

In order to verify the contribution from undetected nuclides in the result of the exposure assessment, the exposure assessment result of each nuclide is aggregated separating detected nuclides from undetected nuclides

Tables IX-1 to 4 show the result.

In both cases, the contribution from undetected nuclides was significant before selecting nuclides to be measured and assessed, but the contribution from undetected nuclides is decreased with the selection of nuclides to be measured and assessed.

Table IX-1(1) Contributions of detected and undetected nuclides (human exposure, 64 nuclides)

Assessed case	Source term	Source term based on measured values					
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Exposure* (mSv/year)	Detected nuclide	5.7E-06	2.0E-05	1.4E-06	4.0E-06	2.1E-06	6.4E-06
	Undetected nuclide	1.9E-05	5.1E-05	5.2E-05	1.3E-04	1.5E-04	3.6E-04
	Total	2.5E-05	7.1E-05	5.4E-05	1.3E-04	1.5E-04	3.7E-04
Percentage of undetected nuclides in total		77%	71%	97%	97%	99%	98%

* Exposure is the total of external exposure and internal exposure

Table IX-1(2) Contributions of detected and undetected nuclides (human exposure, 30 nuclides)

Assessed case	Source term	Source term based on measured values					
		i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Exposure* (mSv/year)	Detected nuclide	6.7E-06	2.6E-05	1.4E-06	4.3E-06	2.2E-06	6.9E-06
	Undetected nuclide	1.2E-06	5.5E-06	5.9E-07	1.9E-06	1.5E-06	5.4E-06
	Total	7.9E-06	3.2E-05	2.0E-06	6.2E-06	3.8E-06	1.2E-05
Percentage of undetected nuclides in total		15%	17%	30%	31%	41%	44%

* Exposure is the total of external exposure and internal exposure

Table IX-2(1) Contributions of detected and undetected nuclides (environmental protection and K4 tank group, 64 nuclides)

Assessed case		K4 tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	7.5E-07	7.6E-07	8.3E-07
	Undetected nuclide	1.7E-05	1.7E-05	1.8E-05
	Total	1.7E-05	1.7E-05	1.9E-05
Percentage of undetected nuclides in total		96%	96%	96%

Table IX-2(2) Contributions of detected and undetected nuclides (environmental protection and K4 tank group, 30 nuclides)

Assessed case		K4 tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	5.1E-07	5.1E-07	5.5E-07
	Undetected nuclide	1.1E-07	1.5E-07	2.0E-07
	Total	6.2E-07	6.6E-07	7.5E-07
Percentage of undetected nuclides in total		18%	23%	26%

Table IX-3(1) Contributions of detected and undetected nuclides (environmental protection and J1-C tank group, 64 nuclides)

Assessed case		J1-C tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	1.4E-07	1.4E-07	1.5E-07
	Undetected nuclide	2.2E-05	2.2E-05	2.3E-05
	Total	2.2E-05	2.2E-05	2.3E-05
Percentage of undetected nuclides in total		99%	99%	99%

Table IX-3(2) Contributions of detected and undetected nuclides (environmental protection and J1-C tank group, 30 nuclides)

Assessed case		J1-C tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	1.1E-07	1.1E-07	1.2E-07
	Undetected nuclide	1.8E-07	1.9E-07	2.1E-07
	Total	2.9E-07	3.0E-07	3.3E-07
Percentage of undetected nuclides in total		61%	62%	64%

Table IX-4(1) Contributions of detected and undetected nuclides (environmental protection and J1-G tank group, 64 nuclides)

Assessed case		J1-G tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	2.9E-07	2.8E-07	3.0E-07
	Undetected nuclide	5.6E-05	5.5E-05	5.8E-05
	Total	5.6E-05	5.5E-05	5.9E-05
Percentage of undetected nuclides in total		99%	99%	99%

Table IX-4(2) Contributions of detected and undetected nuclides (environmental protection and J1-G tank group, 30 nuclides)

Assessed case		J1-G tank group		
		Flatfish	Crab	Brown seaweed
Exposure (mGy/day)	Detected nuclide	2.4E-07	2.4E-07	2.5E-07
	Undetected nuclide	4.8E-07	4.9E-07	5.7E-07
	Total	7.2E-07	7.3E-07	8.2E-07
Percentage of undetected nuclides in total		66%	68%	70%

Attachment X Breakdown of the exposure assessment result by nuclide

X-1. Internal exposures assessment of human

For the following exposure assessments shown in 6-1. “Exposure assessment under normal conditions”, Tables X-1-1 to 4, X-2-1 to 4, and X-3-1 to 4 show the internal exposure assessment result of each nuclide.

As mentioned 4.(3), exposure from Am-241 in this assessment can be affected through depletion and accumulation of Pu-241, up to 2 times greater than the values assessed. The internal exposure to Am-241 from seafood ingestion, which largely affects to exposure assessment, remains 1/40 or less in the total exposure. The impact of accumulated Am-241 are insignificant, taking into account that exposure assessments are only small amount compared to 1mSv/year of exposure limits for the general public or 0.05mSv/year equivalent to dose constraint.

Source term based on measured values of 30 nuclides

i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

Table X-1-1 Internal exposure assessment result from ingestion of seawater (Source term based on measured values (K4 tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	3.0E-07	5.2E-07	Exempted	
I-129	2.8E-08	4.3E-08	Exempted	
C-14	1.0E-09	1.8E-09	Exempted	
Sr-90	6.4E-10	1.1E-09	Exempted	
Cs-137	5.8E-10	4.3E-10	Exempted	
Se-79	5.2E-10	3.4E-09	Exempted	
Co-60	9.0E-11	4.5E-10	Exempted	
Fe-55	8.4E-11	4.3E-10	Exempted	
Y-90	6.2E-11	2.3E-10	Exempted	
Tc-99	5.4E-11	1.9E-10	Exempted	
Ni-63	3.8E-11	1.2E-10	Exempted	
Ru-106	3.5E-11	1.3E-10	Exempted	
Pu-239	1.9E-11	2.5E-11	Exempted	
Pu-240	1.9E-11	2.5E-11	Exempted	
Cs-134	1.7E-11	1.2E-11	Exempted	
Pu-238	1.7E-11	2.2E-11	Exempted	
Am-241	1.5E-11	2.0E-11	Exempted	
Pu-241	1.3E-11	1.5E-11	Exempted	
Sb-125	1.1E-11	3.5E-11	Exempted	
Te-125m	9.0E-12	3.4E-11	Exempted	
Np-237	8.4E-12	1.1E-11	Exempted	
Cm-244	7.4E-12	1.2E-11	Exempted	
U-234	3.7E-12	6.7E-12	Exempted	
U-238	3.4E-12	6.1E-12	Exempted	
Eu-154	1.9E-12	6.1E-12	Exempted	
Pm-147	1.4E-12	5.2E-12	Exempted	
Eu-155	5.8E-13	2.0E-12	Exempted	
Ce-144	3.3E-13	1.2E-12	Exempted	
Sm-151	1.0E-14	3.4E-14	Exempted	
Mn-54	7.3E-15	1.9E-14	Exempted	
Total	3.4E-07	5.8E-07	Exempted	

Table X-1-2 Assessment result of internal exposure from inhalation of seawater spray (Source term based on measured values (K4 tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	7.3E-08	5.0E-08	3.4E-08	
C-14	2.5E-09	1.9E-09	1.1E-09	
I-129	2.2E-09	1.5E-09	5.7E-10	
Pu-239	2.2E-09	1.1E-09	4.9E-10	
Pu-240	2.2E-09	1.1E-09	4.9E-10	
Pu-238	1.9E-09	9.6E-10	4.5E-10	
Am-241	1.7E-09	8.5E-10	4.2E-10	
Pu-241	1.5E-09	6.5E-10	2.3E-10	
Np-237	9.2E-10	4.3E-10	2.3E-10	
Sr-90	8.8E-10	5.9E-10	3.0E-10	
Cm-244	8.5E-10	4.8E-10	2.9E-10	
Cs-137	4.2E-10	3.0E-10	1.5E-10	
Se-79	3.0E-10	2.2E-10	1.3E-10	
Tc-99	2.6E-10	1.9E-10	1.1E-10	
Co-60	2.0E-10	1.5E-10	7.6E-11	
U-234	1.7E-10	1.4E-10	7.8E-11	
U-238	1.5E-10	1.1E-10	6.8E-11	
Ru-106	8.1E-11	6.7E-11	4.1E-11	
Ni-63	7.9E-11	6.5E-11	3.8E-11	
Fe-55	4.7E-11	5.3E-11	3.3E-11	
Sb-125	3.0E-11	2.4E-11	1.4E-11	
Eu-154	1.2E-11	8.6E-12	4.7E-12	
Te-125m	1.1E-11	7.7E-12	5.5E-12	
Y-90	8.3E-12	9.1E-12	9.2E-12	
Pm-147	6.5E-12	5.6E-12	3.5E-12	
Cs-134	4.3E-12	3.5E-12	1.9E-12	
Eu-155	3.0E-12	2.4E-12	1.5E-12	
Ce-144	8.2E-13	8.5E-13	7.1E-13	
Sm-151	1.0E-13	6.6E-14	3.5E-14	
Mn-54	3.7E-15	3.7E-15	2.4E-15	
Total	9.2E-08	6.0E-08	3.9E-08	

Table X-1-3 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (K4 tank group), Average ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
I-129	3.7E-06	2.8E-06	1.2E-06	
C-14	1.9E-06	1.6E-06	9.2E-07	
Fe-55	7.0E-07	1.8E-06	3.3E-06	
Se-79	4.4E-07	1.4E-06	1.3E-06	
Co-60	3.3E-08	8.4E-08	1.1E-07	
H-3	3.2E-08	2.8E-08	2.3E-08	
Tc-99	2.3E-08	3.9E-08	6.7E-08	
Cs-137	4.9E-09	1.8E-09	1.6E-09	
Ni-63	4.6E-09	7.0E-09	9.9E-09	
Am-241	1.9E-09	1.2E-09	6.7E-09	
Pu-239	1.8E-09	1.2E-09	6.0E-09	
Pu-240	1.8E-09	1.2E-09	6.0E-09	
Pu-238	1.6E-09	1.1E-09	5.5E-09	
Pu-241	1.2E-09	7.0E-10	2.8E-09	
Ru-106	1.2E-09	2.0E-09	2.7E-09	
Cm-244	6.3E-10	4.9E-10	3.0E-09	
Sb-125	5.3E-10	8.1E-10	1.1E-09	
Te-125m	4.2E-10	7.9E-10	1.3E-09	
Sr-90	3.0E-10	2.5E-10	4.9E-10	
Eu-154	2.7E-10	4.5E-10	6.8E-10	
Pm-147	2.1E-10	3.8E-10	5.7E-10	
Cs-134	1.4E-10	4.9E-11	4.0E-11	
Eu-155	8.4E-11	1.5E-10	2.3E-10	
Np-237	4.7E-11	3.0E-11	1.7E-10	
Ce-144	3.1E-11	5.6E-11	7.7E-11	
Y-90	2.9E-11	5.3E-11	6.6E-11	
U-234	6.6E-12	5.8E-12	9.6E-12	
U-238	6.0E-12	5.2E-12	8.8E-12	
Mn-54	5.5E-12	7.4E-12	8.3E-12	
Sm-151	1.5E-12	2.5E-12	4.5E-12	
Total	6.9E-06	7.8E-06	6.9E-06	

Table X-1-4 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (K4 tank group), More ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
I-129	1.8E-05	1.4E-05	5.5E-06	
C-14	7.1E-06	6.1E-06	3.4E-06	
Fe-55	3.8E-06	9.9E-06	1.7E-05	
Se-79	1.6E-06	5.4E-06	4.7E-06	
Co-60	1.8E-07	4.6E-07	5.7E-07	
H-3	1.2E-07	1.1E-07	8.7E-08	
Tc-99	1.1E-07	1.9E-07	3.2E-07	
Ni-63	1.9E-08	3.0E-08	4.1E-08	
Cs-137	1.8E-08	6.7E-09	5.8E-09	
Pu-239	9.5E-09	6.3E-09	3.1E-08	
Pu-240	9.5E-09	6.3E-09	3.1E-08	
Am-241	9.0E-09	6.1E-09	3.2E-08	
Pu-238	8.3E-09	5.6E-09	2.8E-08	
Pu-241	6.4E-09	3.7E-09	1.4E-08	
Ru-106	5.8E-09	1.0E-08	1.3E-08	
Cm-244	3.0E-09	2.4E-09	1.4E-08	
Sb-125	1.8E-09	2.9E-09	3.8E-09	
Eu-154	1.5E-09	2.4E-09	3.6E-09	
Te-125m	1.5E-09	2.8E-09	4.4E-09	
Sr-90	1.3E-09	1.1E-09	2.2E-09	
Pm-147	1.1E-09	2.0E-09	3.0E-09	
Cs-134	5.2E-10	1.8E-10	1.4E-10	
Eu-155	4.5E-10	7.8E-10	1.2E-09	
Np-237	2.8E-10	1.8E-10	9.8E-10	
Ce-144	1.6E-10	2.9E-10	3.9E-10	
Y-90	1.3E-10	2.4E-10	2.9E-10	
U-234	3.3E-11	2.9E-11	4.8E-11	
Mn-54	3.2E-11	4.3E-11	4.7E-11	
U-238	3.0E-11	2.7E-11	4.4E-11	
Sm-151	8.0E-12	1.3E-11	2.4E-11	
Total	3.1E-05	3.6E-05	3.2E-05	

Table X-2-1 Internal exposure assessment result from ingestion of seawater (Source term based on measured values (J1-C tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	3.0E-07	5.2E-07	Exempted	
I-129	3.1E-09	4.8E-09	Exempted	
C-14	2.4E-10	4.2E-10	Exempted	
Pu-239	1.9E-10	2.5E-10	Exempted	
Pu-240	1.9E-10	2.5E-10	Exempted	
Pu-238	1.7E-10	2.3E-10	Exempted	
Am-241	1.5E-10	2.0E-10	Exempted	
Pu-241	1.2E-10	1.4E-10	Exempted	
Se-79	1.0E-10	6.7E-10	Exempted	
Cm-244	8.4E-11	1.3E-10	Exempted	
Np-237	8.3E-11	1.1E-10	Exempted	
Cs-137	5.2E-11	3.8E-11	Exempted	
Ru-106	4.4E-11	1.6E-10	Exempted	
U-234	3.7E-11	6.6E-11	Exempted	
U-238	3.4E-11	6.0E-11	Exempted	
Ni-63	2.9E-11	9.0E-11	Exempted	
Sr-90	2.2E-11	3.7E-11	Exempted	
Co-60	1.9E-11	9.6E-11	Exempted	
Fe-55	1.9E-11	9.6E-11	Exempted	
Tc-99	1.8E-11	6.5E-11	Exempted	
Cs-134	1.5E-11	1.0E-11	Exempted	
Ce-144	7.8E-12	2.9E-11	Exempted	
Eu-154	4.4E-12	1.4E-11	Exempted	
Sb-125	3.1E-12	9.6E-12	Exempted	
Pm-147	2.6E-12	9.5E-12	Exempted	
Te-125m	2.4E-12	9.3E-12	Exempted	
Y-90	2.2E-12	8.0E-12	Exempted	
Eu-155	1.8E-12	6.2E-12	Exempted	
Mn-54	8.8E-14	2.4E-13	Exempted	
Sm-151	2.5E-14	8.5E-14	Exempted	
Total	3.1E-07	5.3E-07	Exempted	

Table X-2-2 Assessment result of internal exposure from inhalation of seawater spray (Source term based on measured values (J1-C tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	7.3E-08	5.0E-08	3.4E-08	
Pu-239	2.2E-08	1.1E-08	4.9E-09	
Pu-240	2.2E-08	1.1E-08	4.9E-09	
Pu-238	2.0E-08	9.9E-09	4.7E-09	
Am-241	1.7E-08	8.5E-09	4.2E-09	
Pu-241	1.4E-08	6.3E-09	2.2E-09	
Cm-244	9.7E-09	5.5E-09	3.3E-09	
Np-237	9.0E-09	4.3E-09	2.3E-09	
U-234	1.7E-09	1.3E-09	7.7E-10	
U-238	1.4E-09	1.1E-09	6.7E-10	
C-14	5.9E-10	4.4E-10	2.5E-10	
I-129	2.4E-10	1.6E-10	6.3E-11	
Ru-106	1.0E-10	8.4E-11	5.1E-11	
Tc-99	8.8E-11	6.4E-11	3.6E-11	
Ni-63	6.1E-11	5.0E-11	2.9E-11	
Se-79	5.8E-11	4.3E-11	2.5E-11	
Co-60	4.2E-11	3.1E-11	1.6E-11	
Cs-137	3.7E-11	2.6E-11	1.4E-11	
Sr-90	3.1E-11	2.0E-11	1.0E-11	
Eu-154	2.8E-11	2.0E-11	1.1E-11	
Ce-144	1.9E-11	2.0E-11	1.7E-11	
Pm-147	1.2E-11	1.0E-11	6.4E-12	
Fe-55	1.0E-11	1.2E-11	7.3E-12	
Eu-155	9.4E-12	7.5E-12	4.5E-12	
Sb-125	8.1E-12	6.4E-12	3.7E-12	
Cs-134	3.7E-12	3.0E-12	1.7E-12	
Te-125m	2.8E-12	2.1E-12	1.5E-12	
Y-90	2.9E-13	3.2E-13	3.2E-13	
Sm-151	2.5E-13	1.6E-13	8.8E-14	
Mn-54	4.5E-14	4.5E-14	2.9E-14	
Total	1.9E-07	1.1E-07	6.2E-08	

Table X-2-3 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (J1-C tank group), Average ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
C-14	4.4E-07	3.7E-07	2.2E-07	
I-129	4.1E-07	3.1E-07	1.3E-07	
Fe-55	1.6E-07	4.1E-07	7.3E-07	
Se-79	8.5E-08	2.8E-07	2.5E-07	
H-3	3.2E-08	2.8E-08	2.3E-08	
Am-241	1.9E-08	1.2E-08	6.7E-08	
Pu-239	1.8E-08	1.2E-08	6.0E-08	
Pu-240	1.8E-08	1.2E-08	6.0E-08	
Pu-238	1.7E-08	1.1E-08	5.7E-08	
Pu-241	1.2E-08	6.8E-09	2.7E-08	
Tc-99	7.5E-09	1.3E-08	2.2E-08	
Cm-244	7.2E-09	5.6E-09	3.4E-08	
Co-60	7.1E-09	1.8E-08	2.2E-08	
Ni-63	3.5E-09	5.4E-09	7.6E-09	
Ru-106	1.5E-09	2.5E-09	3.4E-09	
Ce-144	7.4E-10	1.3E-09	1.8E-09	
Eu-154	6.4E-10	1.0E-09	1.6E-09	
Np-237	4.6E-10	3.0E-10	1.7E-09	
Cs-137	4.4E-10	1.6E-10	1.4E-10	
Pm-147	3.7E-10	6.9E-10	1.0E-09	
Eu-155	2.6E-10	4.5E-10	7.0E-10	
Sb-125	1.4E-10	2.2E-10	2.9E-10	
Cs-134	1.2E-10	4.2E-11	3.5E-11	
Te-125m	1.1E-10	2.1E-10	3.5E-10	
Mn-54	6.7E-11	9.0E-11	1.0E-10	
U-234	6.5E-11	5.7E-11	9.5E-11	
U-238	6.0E-11	5.2E-11	8.7E-11	
Sr-90	1.0E-11	8.7E-12	1.7E-11	
Sm-151	3.7E-12	6.2E-12	1.1E-11	
Y-90	1.0E-12	1.8E-12	2.3E-12	
Total	1.2E-06	1.5E-06	1.7E-06	

Table X-2-4 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (J1-C tank group), More ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
I-129	2.0E-06	1.5E-06	6.2E-07	
C-14	1.6E-06	1.4E-06	8.0E-07	
Fe-55	8.5E-07	2.2E-06	3.8E-06	
Se-79	3.2E-07	1.1E-06	9.1E-07	
H-3	1.2E-07	1.1E-07	8.7E-08	
Pu-239	9.4E-08	6.2E-08	3.0E-07	
Pu-240	9.4E-08	6.2E-08	3.0E-07	
Am-241	9.0E-08	6.1E-08	3.2E-07	
Pu-238	8.6E-08	5.8E-08	2.9E-07	
Pu-241	6.2E-08	3.6E-08	1.4E-07	
Co-60	3.9E-08	9.8E-08	1.2E-07	
Tc-99	3.6E-08	6.4E-08	1.1E-07	
Cm-244	3.5E-08	2.8E-08	1.6E-07	
Ni-63	1.5E-08	2.3E-08	3.1E-08	
Ru-106	7.3E-09	1.3E-08	1.7E-08	
Ce-144	3.7E-09	6.8E-09	9.1E-09	
Eu-154	3.5E-09	5.6E-09	8.4E-09	
Np-237	2.8E-09	1.8E-09	9.7E-09	
Pm-147	2.0E-09	3.7E-09	5.4E-09	
Cs-137	1.6E-09	6.0E-10	5.2E-10	
Eu-155	1.4E-09	2.4E-09	3.7E-09	
Sb-125	5.0E-10	7.9E-10	1.0E-09	
Cs-134	4.5E-10	1.6E-10	1.2E-10	
Te-125m	4.0E-10	7.6E-10	1.2E-09	
Mn-54	3.8E-10	5.2E-10	5.7E-10	
U-234	3.2E-10	2.9E-10	4.7E-10	
U-238	3.0E-10	2.6E-10	4.3E-10	
Sr-90	4.6E-11	3.9E-11	7.5E-11	
Sm-151	2.0E-11	3.3E-11	5.9E-11	
Y-90	4.5E-12	8.3E-12	1.0E-11	
Total	5.5E-06	6.8E-06	8.1E-06	

Table X-3-1 Internal exposure assessment result from ingestion of seawater (Source term based on measured values (J1-C tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	3.0E-07	5.2E-07	Exempted	
I-129	2.6E-09	3.9E-09	Exempted	
C-14	6.5E-10	1.1E-09	Exempted	
Pu-239	4.9E-10	6.5E-10	Exempted	
Pu-240	4.9E-10	6.5E-10	Exempted	
Pu-238	4.4E-10	5.9E-10	Exempted	
Am-241	3.9E-10	5.3E-10	Exempted	
Se-79	3.1E-10	2.0E-09	Exempted	
Pu-241	3.0E-10	3.4E-10	Exempted	
Cs-137	2.8E-10	2.1E-10	Exempted	
Cm-244	2.2E-10	3.5E-10	Exempted	
Np-237	2.2E-10	2.8E-10	Exempted	
U-234	9.7E-11	1.7E-10	Exempted	
Ni-63	9.2E-11	2.8E-10	Exempted	
U-238	8.9E-11	1.6E-10	Exempted	
Sr-90	5.9E-11	9.9E-11	Exempted	
Tc-99	5.9E-11	2.1E-10	Exempted	
Fe-55	5.6E-11	2.9E-10	Exempted	
Ru-106	4.6E-11	1.7E-10	Exempted	
Co-60	4.1E-11	2.0E-10	Exempted	
Cs-134	4.0E-11	2.7E-11	Exempted	
Ce-144	2.4E-11	8.7E-11	Exempted	
Eu-154	1.2E-11	3.8E-11	Exempted	
Pm-147	7.0E-12	2.6E-11	Exempted	
Sb-125	5.8E-12	1.8E-11	Exempted	
Y-90	5.7E-12	2.1E-11	Exempted	
Te-125m	4.6E-12	1.7E-11	Exempted	
Eu-155	2.7E-12	9.3E-12	Exempted	
Mn-54	2.7E-13	7.2E-13	Exempted	
Sm-151	6.8E-14	2.3E-13	Exempted	
Total	3.1E-07	5.4E-07	Exempted	

Table X-3-2 Assessment result of internal exposure from inhalation of seawater spray (Source term based on measured values (J1-G tank group))

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
H-3	7.3E-08	5.0E-08	3.4E-08	
Pu-239	5.7E-08	2.8E-08	1.3E-08	
Pu-240	5.7E-08	2.8E-08	1.3E-08	
Pu-238	5.0E-08	2.5E-08	1.2E-08	
Am-241	4.6E-08	2.2E-08	1.1E-08	
Pu-241	3.5E-08	1.5E-08	5.4E-09	
Cm-244	2.5E-08	1.4E-08	8.5E-09	
Np-237	2.4E-08	1.1E-08	6.0E-09	
U-234	4.5E-09	3.5E-09	2.0E-09	
U-238	3.8E-09	3.0E-09	1.8E-09	
C-14	1.6E-09	1.2E-09	6.6E-10	
Tc-99	2.9E-10	2.1E-10	1.2E-10	
Cs-137	2.1E-10	1.4E-10	7.4E-11	
I-129	2.0E-10	1.3E-10	5.2E-11	
Ni-63	1.9E-10	1.6E-10	9.1E-11	
Se-79	1.7E-10	1.3E-10	7.5E-11	
Ru-106	1.1E-10	8.8E-11	5.3E-11	
Co-60	8.9E-11	6.7E-11	3.4E-11	
Sr-90	8.1E-11	5.4E-11	2.7E-11	
Eu-154	7.5E-11	5.4E-11	2.9E-11	
Ce-144	5.8E-11	6.1E-11	5.1E-11	
Pm-147	3.2E-11	2.8E-11	1.7E-11	
Fe-55	3.1E-11	3.5E-11	2.2E-11	
Sb-125	1.5E-11	1.2E-11	6.9E-12	
Eu-155	1.4E-11	1.1E-11	6.8E-12	
Cs-134	1.0E-11	8.2E-12	4.6E-12	
Te-125m	5.3E-12	3.9E-12	2.8E-12	
Y-90	7.6E-13	8.4E-13	8.5E-13	
Sm-151	6.6E-13	4.4E-13	2.4E-13	
Mn-54	1.4E-13	1.4E-13	8.8E-14	
Total	3.8E-07	2.0E-07	1.1E-07	

Table X-3-3 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (J1-G tank group), Average ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
C-14	1.2E-06	9.9E-07	5.7E-07	
Fe-55	4.7E-07	1.2E-06	2.2E-06	
I-129	3.4E-07	2.5E-07	1.1E-07	
Se-79	2.6E-07	8.4E-07	7.4E-07	
Am-241	5.0E-08	3.2E-08	1.8E-07	
Pu-239	4.8E-08	3.1E-08	1.6E-07	
Pu-240	4.8E-08	3.1E-08	1.6E-07	
Pu-238	4.2E-08	2.8E-08	1.4E-07	
H-3	3.2E-08	2.8E-08	2.3E-08	
Pu-241	2.9E-08	1.6E-08	6.6E-08	
Tc-99	2.4E-08	4.2E-08	7.3E-08	
Cm-244	1.9E-08	1.5E-08	8.8E-08	
Co-60	1.5E-08	3.8E-08	4.8E-08	
Ni-63	1.1E-08	1.7E-08	2.4E-08	
Cs-137	2.4E-09	8.8E-10	7.9E-10	
Ce-144	2.2E-09	4.0E-09	5.5E-09	
Eu-154	1.7E-09	2.8E-09	4.3E-09	
Ru-106	1.5E-09	2.6E-09	3.5E-09	
Np-237	1.2E-09	7.8E-10	4.4E-09	
Pm-147	1.0E-09	1.9E-09	2.8E-09	
Eu-155	3.9E-10	6.8E-10	1.1E-09	
Cs-134	3.4E-10	1.2E-10	9.5E-11	
Sb-125	2.7E-10	4.1E-10	5.5E-10	
Te-125m	2.1E-10	4.0E-10	6.5E-10	
Mn-54	2.0E-10	2.8E-10	3.1E-10	
U-234	1.7E-10	1.5E-10	2.5E-10	
U-238	1.6E-10	1.4E-10	2.3E-10	
Sr-90	2.7E-11	2.3E-11	4.5E-11	
Sm-151	9.8E-12	1.7E-11	3.0E-11	
Y-90	2.6E-12	4.9E-12	6.1E-12	
Total	2.6E-06	3.6E-06	4.6E-06	

Table X-3-4 Assessment result of internal exposure from ingestion of seafood (Source term based on measured values (J1-C tank group), More ingestion)

Nuclide	Exposure assessment result (mSv/year)			Remarks
	Adult	Children under school age	Infants	
C-14	4.4E-06	3.8E-06	2.1E-06	
Fe-55	2.5E-06	6.6E-06	1.1E-05	
I-129	1.6E-06	1.2E-06	5.1E-07	
Se-79	9.5E-07	3.2E-06	2.7E-06	
Pu-239	2.5E-07	1.6E-07	8.0E-07	
Pu-240	2.5E-07	1.6E-07	8.0E-07	
Am-241	2.4E-07	1.6E-07	8.5E-07	
Pu-238	2.2E-07	1.5E-07	7.3E-07	
Pu-241	1.5E-07	8.6E-08	3.4E-07	
H-3	1.2E-07	1.1E-07	8.7E-08	
Tc-99	1.2E-07	2.1E-07	3.5E-07	
Cm-244	9.1E-08	7.2E-08	4.2E-07	
Co-60	8.3E-08	2.1E-07	2.6E-07	
Ni-63	4.6E-08	7.2E-08	9.8E-08	
Ce-144	1.1E-08	2.1E-08	2.8E-08	
Eu-154	9.3E-09	1.5E-08	2.2E-08	
Cs-137	8.7E-09	3.3E-09	2.8E-09	
Ru-106	7.6E-09	1.4E-08	1.8E-08	
Np-237	7.2E-09	4.6E-09	2.5E-08	
Pm-147	5.4E-09	1.0E-08	1.5E-08	
Eu-155	2.1E-09	3.6E-09	5.5E-09	
Cs-134	1.2E-09	4.3E-10	3.4E-10	
Mn-54	1.2E-09	1.6E-09	1.7E-09	
Sb-125	9.4E-10	1.5E-09	1.9E-09	
U-234	8.5E-10	7.6E-10	1.2E-09	
U-238	7.8E-10	6.9E-10	1.1E-09	
Te-125m	7.4E-10	1.4E-09	2.3E-09	
Sr-90	1.2E-10	1.0E-10	2.0E-10	
Sm-151	5.3E-11	8.9E-11	1.6E-10	
Y-90	1.2E-11	2.2E-11	2.7E-11	
Total	1.1E-05	1.6E-05	2.2E-05	

X-2. Assessment result regarding environmental protection
For the following exposure assessments shown in chapter 7. “Assessment regarding environmental protection”, Tables X-4 to 6 show the assessment result of each nuclide.
As mentioned 4.(3), exposure from Am-241 in this assessment can be affected trough depletion and accumulation of Pu-241, up to 2 times greater than the values assessed. Considering that the effect of Am-241 is less than 1/100 of the total exposure and that the result of the exposure assessment is very small compared to the lower limit of the reference level for induction consideration, the effect of due to the accumulation of Am-241 is slight.

Source term based on measured values of 30 nuclides

i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

Table X-4 Assessment result of environmental protection (Source term based on measured values (K4 tank group))

Nuclide	Exposure assessment result (mGy/day)			Remarks
	Flatfish	Crab	Brown seaweed	
Co-60	4.4E-07	4.4E-07	4.8E-07	
C-14	5.4E-08	4.5E-08	3.6E-08	
Eu-154	5.3E-08	5.1E-08	5.4E-08	
Fe-55	4.7E-08	8.9E-08	1.4E-07	
Eu-155	4.8E-09	4.7E-09	4.8E-09	
H-3	4.7E-09	4.7E-09	1.8E-09	
Se-79	4.6E-09	4.6E-09	2.0E-10	
Cs-137	2.4E-09	2.3E-09	2.3E-09	
Ru-106	1.9E-09	1.9E-09	2.3E-09	
Ce-144	8.9E-10	5.2E-10	8.9E-10	
Mn-54	4.0E-10	3.7E-10	4.0E-10	
Sb-125	2.5E-10	2.3E-10	3.1E-10	
Cs-134	1.3E-10	1.2E-10	1.3E-10	
Am-241	8.4E-11	2.7E-10	8.6E-11	
Te-125m	6.8E-11	7.1E-11	6.0E-10	
Ni-63	5.9E-11	1.4E-09	4.3E-10	
Sr-90	5.1E-11	2.8E-10	4.9E-11	
Pu-238	5.0E-11	3.4E-11	8.1E-11	
Pu-240	4.9E-11	3.3E-11	8.0E-11	
Pu-239	4.9E-11	3.3E-11	8.0E-11	
Tc-99	3.4E-11	7.6E-09	2.2E-08	
Pm-147	3.1E-11	4.2E-10	2.9E-10	
I-129	1.5E-11	8.7E-09	3.8E-09	
Cm-244	4.5E-12	5.7E-10	2.2E-10	
Pu-241	1.8E-12	1.2E-12	2.9E-12	
Np-237	4.2E-13	7.8E-12	1.0E-12	
U-234	1.6E-13	6.3E-13	1.5E-12	
U-238	1.4E-13	5.7E-13	1.3E-12	
Sm-151	1.2E-13	2.5E-12	1.0E-12	
Y-90	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide Sr-90
Total	6.2E-07	6.6E-07	7.5E-07	

Table X-5 Assessment result of environmental protection (Source term based on measured values (J1-C tank group))

Nuclide	Exposure assessment result (mGy/day)			Remarks
	Flatfish	Crab	Brown seaweed	
Eu-154	1.3E-07	1.2E-07	1.3E-07	
Co-60	9.4E-08	9.4E-08	1.0E-07	
Ce-144	2.1E-08	1.2E-08	2.1E-08	
Eu-155	1.5E-08	1.4E-08	1.5E-08	
C-14	1.3E-08	1.1E-08	8.4E-09	
Fe-55	1.0E-08	2.0E-08	3.0E-08	
Mn-54	4.9E-09	4.4E-09	4.9E-09	
H-3	4.7E-09	4.7E-09	1.8E-09	
Ru-106	2.4E-09	2.4E-09	2.8E-09	
Se-79	9.0E-10	9.0E-10	3.9E-11	
Am-241	8.4E-10	2.7E-09	8.6E-10	
Pu-238	5.1E-10	3.5E-10	8.4E-10	
Pu-240	4.8E-10	3.3E-10	7.9E-10	
Pu-239	4.8E-10	3.3E-10	7.9E-10	
Cs-137	2.1E-10	2.0E-10	2.1E-10	
Cs-134	1.1E-10	1.1E-10	1.1E-10	
Sb-125	6.7E-11	6.3E-11	8.4E-11	
Pm-147	5.7E-11	7.6E-10	5.3E-10	
Cm-244	5.1E-11	6.6E-09	2.5E-09	
Ni-63	4.5E-11	1.1E-09	3.3E-10	
Te-125m	1.8E-11	1.9E-11	1.6E-10	
Pu-241	1.7E-11	1.2E-11	2.8E-11	
Tc-99	1.1E-11	2.5E-09	7.4E-09	
Np-237	4.2E-12	7.7E-11	1.0E-11	
Sr-90	1.8E-12	9.8E-12	1.7E-12	
I-129	1.7E-12	9.7E-10	4.2E-10	
U-234	1.6E-12	6.3E-12	1.5E-11	
U-238	1.4E-12	5.6E-12	1.3E-11	
Sm-151	2.9E-13	6.3E-12	2.6E-12	
Y-90	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide Sr-90
Total	2.9E-07	3.0E-07	3.3E-07	

Table X-6 Assessment result of environmental protection (Source term based on measured values (J1-G tank group))

Nuclide	Exposure assessment result (mGy/day)			Remarks
	Flatfish	Crab	Brown seaweed	
Eu-154	3.4E-07	3.2E-07	3.4E-07	
Co-60	2.0E-07	2.0E-07	2.2E-07	
Ce-144	6.3E-08	3.7E-08	6.4E-08	
C-14	3.4E-08	2.8E-08	2.2E-08	
Fe-55	3.1E-08	5.9E-08	9.1E-08	
Eu-155	2.2E-08	2.2E-08	2.2E-08	
Mn-54	1.5E-08	1.4E-08	1.5E-08	
H-3	4.7E-09	4.7E-09	1.8E-09	
Se-79	2.7E-09	2.7E-09	1.2E-10	
Ru-106	2.5E-09	2.5E-09	3.0E-09	
Am-241	2.2E-09	7.2E-09	2.3E-09	
Pu-238	1.3E-09	8.8E-10	2.1E-09	
Pu-240	1.3E-09	8.6E-10	2.1E-09	
Pu-239	1.3E-09	8.6E-10	2.1E-09	
Cs-137	1.2E-09	1.1E-09	1.1E-09	
Cs-134	3.0E-10	2.9E-10	3.0E-10	
Pm-147	1.5E-10	2.1E-09	1.4E-09	
Ni-63	1.4E-10	3.3E-09	1.0E-09	
Cm-244	1.3E-10	1.7E-08	6.4E-09	
Sb-125	1.3E-10	1.2E-10	1.6E-10	
Pu-241	4.1E-11	2.8E-11	6.8E-11	
Tc-99	3.6E-11	8.2E-09	2.4E-08	
Te-125m	3.5E-11	3.6E-11	3.0E-10	
Np-237	1.1E-11	2.0E-10	2.6E-11	
Sr-90	4.7E-12	2.6E-11	4.6E-12	
U-234	4.1E-12	1.6E-11	3.9E-11	
U-238	3.7E-12	1.5E-11	3.5E-11	
I-129	1.4E-12	8.0E-10	3.5E-10	
Sm-151	7.8E-13	1.7E-11	6.8E-12	
Y-90	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide Sr-90
Total	7.2E-07	7.3E-07	8.2E-07	

Attachment XI Conservativeness of the external exposure dose conversion factor

The dose conversion factor used for the dose assessment of external exposure is quoted from the Handbook for Determining Environmental Impacts of Decommissioning Work (hereinafter called “Decommissioning Handbook”). It has some defects: for example, its target is only the gamma radiation and conversion factors are not prepared for some of the nuclides subject to be assessed. For the unprepared conversion factors, conservativeness is secured by quoting the most conservative conversion factor for each of the βγ and α nuclides, Co-60 and Am-241, respectively. For verification, comparison was performed using the dose conversion factor of external exposure created overseas.

As the target of comparison, we used Federal Guidance Report No.15, “External Exposure to Radionuclides in Air, Water and Soil” (Environmental Protection Agency, 2019; hereinafter called “FGR15”) [XI-1] provided by the U.S. Environmental Protection Agency for radiation protection of U.S. citizens. FGR15 shows the dose conversion factor for the calculation of external exposure of humans from radioactive materials on the ground surface and in the soil, air, and water, and the target nuclides include all of the nuclides to be measured and assessed of ALPS treated water, so we attempted an assessment using the dose conversion factor shown in FGR15.

XI-1. Assessment method

Same as the exposure assessment method shown in the chapter 6-1. “Exposure assessment under normal conditions” and only the dose conversion factor is switched. However, external exposure from radioactive materials adhered to fishing nets are excluded from comparison targets because there is no appropriate dose conversion factor in FGR15. The following shows the assessment model and used parameters of each exposure pathway in FGR15.

(1) External exposure from the seawater surface

The effective dose conversion factor from radiation from seawater is calculated by multiplying the external dose conversion factor in immersion in water shown in Table 4-7. Reference person effective dose rate coefficients for water immersion. of FGR15 by the reduction factor of 0.5 considering that there is no radiation source (seawater) upward (Table XI-1). Figure XI-1 shows an image diagram of the assessment model. Shielding by hulls was ignored in the safe side.

Equation (XI-1) shows the calculation equation of the effective dose D_1(mSv/year) from radiation from the seawater surface.

$$\mathrm{D}_1 = 1000 \cdot 1000 \cdot 3600 \cdot \sum_i (K_1)_i \cdot (x_1)_i \cdot t_1 \qquad \text{(XI-1)}$$

where

$(K_1)_i$ is the effective dose conversion factor from radiation from nuclide *i* in immersion in water ((Sv/s)/(Bq/m^3))

$(x_1)_i$ is the concentration of nuclide i in seawater (Bq/L)

t_1 is the annual exposure time (h/year)

1000 is the factor of unit conversion (Sv to mSv) of the effective dose

1000 is the factor of unit conversion (Bq/L to Bq/m^3) of the concentration in seawater

3600 is the factor of unit conversion (h/year to s/year) of the annual exposure time

As in the chapter 6-1. “Exposure assessment under normal conditions”, the concentration of radioactive materials in seawater used for the assessment was the annual average concentration of the sea surface (top layer) within the 10 km × 10 km area around the power plant.

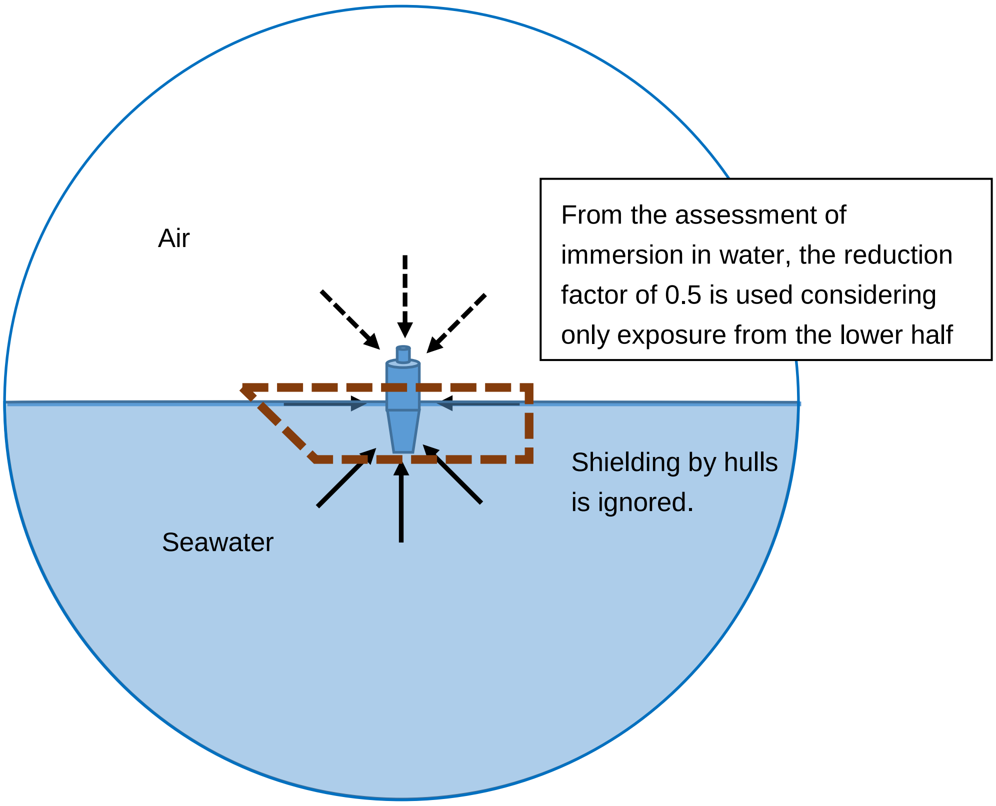


Figure XI-1 Conceptual diagram of the exposure assessment model from radioactive materials in seawater during work at sea

(2) External exposure from hulls

Assess the external radiation exposure from radioactive materials migrated from seawater to hulls during work at sea. The effective dose conversion factor from radiation from radioactive materials migrated from seawater to hulls is the external dose conversion factor in immersion in water shown in Table 4-1. Reference person effective dose rate coefficients for ground surface. of FGR15. (Table XI-2). Figure XI-2 shows an image diagram of the assessment model.

Equations (XI-2) and (XI-3) show the calculation equation of the effective dose D_2(mSv/year) from radioactive materials adhered to hulls.

$$\mathrm{D}_2 = 1000 \cdot 3600 \cdot \sum_i (K_2)_i \cdot (S_2)_i \cdot t_2 \qquad \text{(XI-2)}$$

$$(S_2)_i = (F_2)_i \cdot (x_2)_i \qquad \text{(XI-3)}$$

where

$(K_2)_i$	is the effective dose conversion factor from radiation from nuclide *i* from hulls ((Sv/s)/(Bq/m^2))
$(S_2)_i$	is the contamination density of nuclide *i* in hulls (Bq/m^2)
t_2	is the annual exposure time (h/year)
$(F_2)_i$	is the migration factor of nuclide *i* from seawater to hulls ((Bq/m^2)/(Bq/L))
$(x_2)_i$	is the concentration of nuclide *i* in seawater (Bq/L) at the assessment point
1000	is the factor of unit conversion (Sv to mSv) of the effective dose
3600	is the factor of unit conversion (h/year to s/year) of the annual exposure time

As in the chapter 6-1. “Exposure assessment under normal conditions”, the migration factor to hulls is 100((Bq/m^2)/(Bq/L)) from the Application for the Designation of Reprocessing Business at Rokkasho business facility.

As in the chapter 6-1. “Exposure assessment under normal conditions, the concentration of radioactive materials in seawater used for the assessment was the annual average concentration of the sea surface (top layer) within the 10 km × 10 km area around the power plant.

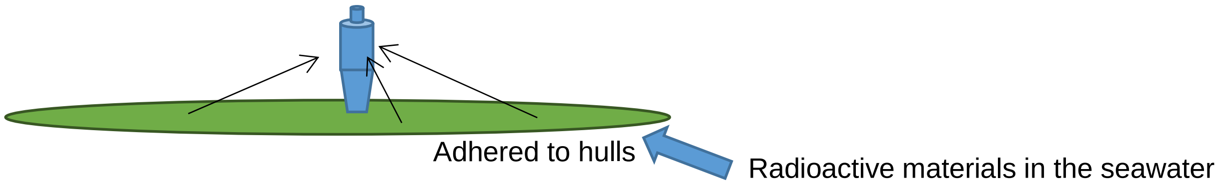


Figure XI-2 Conceptual diagram of the exposure assessment model from radioactive materials adhered to hulls during work at sea

(3) External exposure under water such as during swimming

Assess the external exposure from radioactive materials in the surrounding seawater during swimming and underwater work. The effective dose conversion factor from radiation from radioactive materials in seawater is the external dose conversion factor in immersion in water shown in Table 4-7. Reference person effective dose rate coefficients for water immersion. of FGR15 (Table XI-3). Figure XI-3 shows an image diagram of the assessment model.

Equation (XI-4) shows the calculation equation of the effective dose D_3 (mSv/year) from radiation during swimming and underwater work.

$$\mathrm{D}_3 = 1000 \cdot 1000 \cdot 3600 \cdot \sum_i (K_3)_i \cdot (x_3)_i \cdot t_3 \qquad \text{(XI-4)}$$

where

$(K_3)_i$	is the effective dose conversion factor from radiation from nuclide *i* from seawater ((Sv/s)/(Bq/m^3))
$(x_3)_i$	is the concentration of nuclide i in seawater (Bq/L)
t_3	is the annual exposure time (h/year)
1000	is the factor of unit conversion (Sv to mSv) of the effective dose
1000	is the factor of unit conversion (Bq/L to Bq/m^3) of the concentration in seawater
3600	is the factor of unit conversion (h/year to s/year) of the annual exposure time

As in the chapter 6-1. “Exposure assessment under normal conditions”, the concentration of radioactive materials in seawater used for the assessment site and for the assessment is the average concentration in sea water around the beach to the north of the power plant where the evacuation order has been lifted.

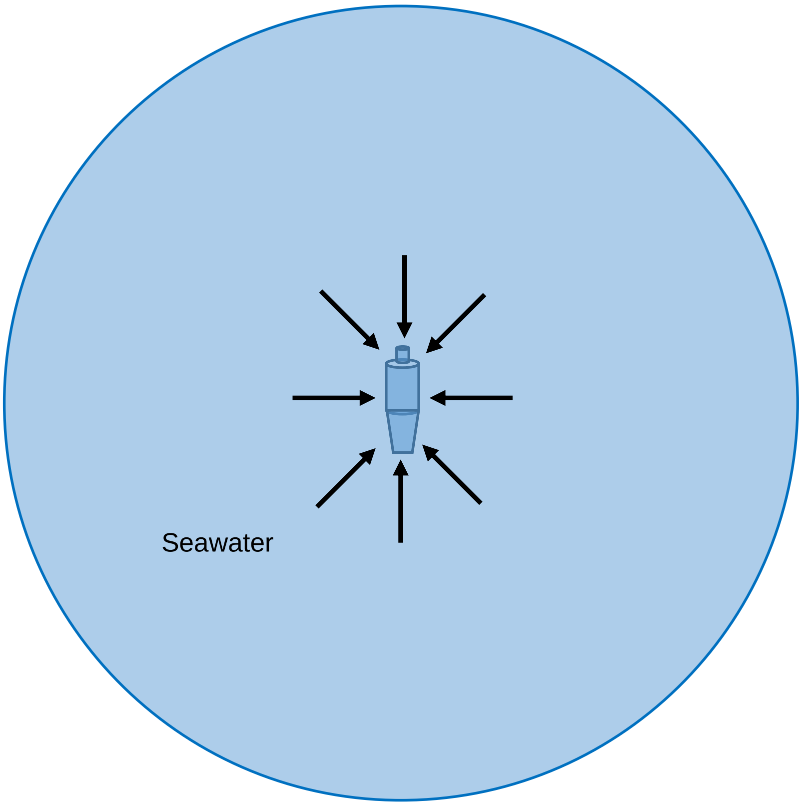


Figure XI-3 Conceptual diagram of the exposure assessment model from radioactive materials in seawater

(4) External exposure from beach sand

Assess the external exposure from radioactive materials migrated from seawater to beach sand while staying at a beach. The effective dose conversion factor from radiation from radioactive materials at a beach is the external dose conversion factor regarding exposure from radioactive materials in the soil shown in Table 4-5. Reference person effective dose rate coefficients for soil to infinite depth. of FGR15 (Table XI-4). Figure XI-4 shows an image diagram of the assessment model.

Equation (XI-5) shows the calculation equation of the effective dose D_4 (mSv/year) from the gamma radiation from beach sand.

$$\mathrm{D}_4 = 1000 \cdot 1600 \cdot 3600 \cdot \sum_i (K_4)_i \cdot (x_4)_i \cdot (F_4)_i \cdot t_4 \qquad \text{(XI-5)}$$

where

$(K_4)_i$ is the effective dose conversion factor from radiation from nuclide *i* from beach sand ((Sv/s)/(Bq/m^3))

$(x_4)_i$ is the concentration of nuclide i in seawater (Bq/L)

$(F_4)_i$ is the migration factor of nuclide i from seawater to beaches ((Bq/kg)/(Bq/L))

t_4 is the annual exposure time (h/year)

1000 is the factor of unit conversion (Sv to mSv) of the effective dose

1600 is the factor of unit conversion (Bq/kg to Bq/m^3) of the radioactive material concentration in the soil

3600 is the factor of unit conversion (h/year to s/year) of the annual exposure time

As with the chapter 6-1. “Exposure assessment under normal conditions”, the migration factor of nuclides to beaches is 1,000[(Bq/kg)/(Bq/L)] for all nuclides based on “Dose Assessment to the General Public in the Safety Review of Commercial Light Water Reactor Facilities.”

As in the chapter 6-1. “Exposure assessment under normal conditions”, the concentration of radioactive materials in seawater used for the assessment site and for the assessment is the average concentration in sea water around the beach to the north of the power plant where the evacuation order has been lifted.

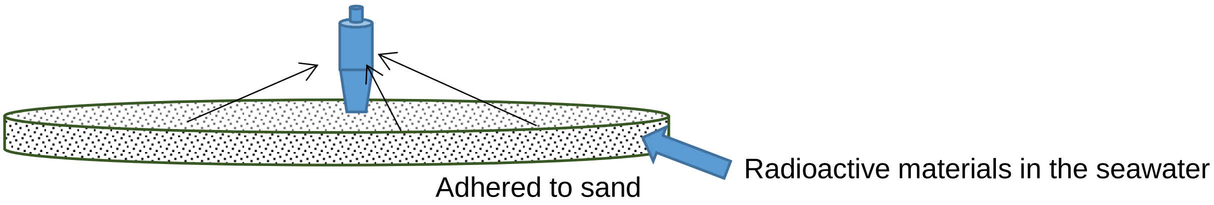


Figure XI-4 Conceptual diagram of the exposure assessment model from radioactive materials adhered to beach sand

XI-2. Setting of the representative person subject to the exposure assessment

The features of representative persons subject to the exposure assessment were the same as 6-2-5. as follows.

- Engage in fishing 120 days (2,880 hours) a year, of which 80 days (1,920 hours) are spent near fishing nets.
- Stay at the beach 500 hours a year and swim for 96 hours.

Table XI-1 Dose conversion factor for the effective dose from the radiation from the sea surface using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))	Remarks
H-3	3.1E-27	
C-14	1.4E-21	
Mn-54	4.0E-17	
Fe-55	6.2E-27	
Co-60	1.3E-16	
Ni-63	3.9E-24	
Se-79	1.7E-21	
Sr-90	5.4E-20	
Y-90	4.7E-19	
Tc-99	1.5E-20	
Ru-106	1.0E-17	The progeny nuclide Rh-106 is considered
Sb-125	1.9E-17	
Te-125m	3.0E-19	
I-129	2.6E-19	
Cs-134	7.3E-17	
Cs-137	2.8E-17	The progeny nuclide Ba-137 is considered
Ce-144	3.1E-18	The progeny nuclide Pr-144, Pr-144m are considered
Pm-147	4.7E-21	
Sm-151	3.1E-23	
Eu-154	6.1E-17	
Eu-155	2.0E-18	
U-234	5.8E-21	
U-238	1.5E-18	The progeny nuclide Th-234, Pa-234m are considered
Np-237	9.7E-18	The progeny nuclide Pa-233 is considered
Pu-238	3.3E-21	
Pu-239	3.6E-21	
Pu-240	3.2E-21	
Pu-241	5.7E-23	
Am-241	6.0E-19	
Cm-244	3.9E-21	

Table XI-2 Dose conversion factor for the effective dose from the radiation from hulls using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^2))	Remarks
H-3	6.7E-22	
C-14	6.1E-19	
Mn-54	5.3E-16	
Fe-55	9.0E-26	
Co-60	1.5E-15	
Ni-63	8.0E-20	
Se-79	6.8E-19	
Sr-90	6.5E-18	
Y-90	1.5E-16	
Tc-99	2.0E-18	
Ru-106	3.4E-16	The progeny nuclide Rh-106 is considered
Sb-125	2.7E-16	
Te-125m	4.1E-18	
I-129	4.4E-18	
Cs-134	1.0E-15	
Cs-137	4.0E-16	The progeny nuclide Ba-137 is considered
Ce-144	2.2E-16	The progeny nuclide Pr-144, Pr-144m are considered
Pm-147	9.4E-19	
Sm-151	1.1E-19	
Eu-154	7.9E-16	
Eu-155	3.1E-17	
U-234	6.4E-20	
U-238	1.4E-16	The progeny nuclide Th-234, Pa-234m are considered
Np-237	1.4E-16	The progeny nuclide Pa-233 is considered
Pu-238	2.1E-20	
Pu-239	4.2E-20	
Pu-240	2.2E-20	
Pu-241	1.7E-21	
Am-241	9.9E-18	
Cm-244	3.1E-20	

Table XI-3 Dose conversion factor for the effective dose from seawater during swimming and underwater work using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))	Remarks
H-3	6.2E-27	
C-14	2.8E-21	
Mn-54	8.0E-17	
Fe-55	1.2E-26	
Co-60	2.5E-16	
Ni-63	7.8E-24	
Se-79	3.3E-21	
Sr-90	1.1E-19	
Y-90	9.5E-19	
Tc-99	3.1E-20	
Ru-106	2.1E-17	The progeny nuclide Rh-106 is considered
Sb-125	3.8E-17	
Te-125m	6.0E-19	
I-129	5.1E-19	
Cs-134	1.5E-16	
Cs-137	5.6E-17	The progeny nuclide Ba-137 is considered
Ce-144	6.1E-18	The progeny nuclide Pr-144, Pr-144m are considered
Pm-147	9.4E-21	
Sm-151	6.1E-23	
Eu-154	1.2E-16	
Eu-155	3.9E-18	
U-234	1.2E-20	
U-238	2.9E-18	The progeny nuclide Th-234, Pa-234m are considered
Np-237	1.9E-17	The progeny nuclide Pa-233 is considered
Pu-238	6.6E-21	
Pu-239	7.3E-21	
Pu-240	6.5E-21	
Pu-241	1.1E-22	
Am-241	1.2E-18	
Cm-244	7.9E-21	

Table XI-4 Dose conversion factor for the effective dose from the radiation from beach sand using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))	Remarks
H-3	3.4E-23	
C-14	3.1E-20	
Mn-54	2.6E-17	
Fe-55	3.4E-27	
Co-60	8.3E-17	
Ni-63	4.1E-21	
Se-79	3.5E-20	
Sr-90	2.6E-19	
Y-90	2.3E-18	
Tc-99	1.0E-19	
Ru-106	1.0E-17	The progeny nuclide Rh-106 is considered
Sb-125	1.2E-17	
Te-125m	5.1E-20	
I-129	7.9E-20	
Cs-134	4.8E-17	
Cs-137	1.8E-17	The progeny nuclide Ba-137 is considered
Ce-144	4.7E-18	The progeny nuclide Pr-144, Pr-144m are considered
Pm-147	4.8E-20	
Sm-151	5.5E-21	
Eu-154	3.9E-17	
Eu-155	9.5E-19	
U-234	1.9E-21	
U-238	2.6E-18	The progeny nuclide Th-234, Pa-234m are considered
Np-237	5.8E-18	The progeny nuclide Pa-233 is considered
Pu-238	5.3E-22	
Pu-239	1.5E-21	
Pu-240	5.5E-22	
Pu-241	7.5E-23	
Am-241	2.2E-19	
Cm-244	1.0E-21	

XI-3. Exposure assessment result

Table XI-6 shows comparison with the assessment result of Table 6-1-22 in the results of the external exposure dose assessments of the following three cases.

Source term based on the composition of nuclides of the measured value

i. K4 tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.26)
ii. J1-C tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.21)
iii. J1-G tank group (Sum of the ratios to regulatory concentration limits of 29 nuclides other than tritium: 0.10)

Overall, the assessment using the conversion factor in the Decommissioning Handbook had similar results as those using the conversion factor in FGR15. This is thought to be due to the fact that the number of the nuclides for which conversion factors were not shown in the Decommissioning Handbook was reduced due to the selection of nuclides to be measured and assessed, and the use of conservative conversion factors such as Co-60 was reduced.

Table XI-6 Comparison with the external exposure dose assessment result using the dose conversion factor of FGR15

Source term	Source term based on measured values					
	i. K4 tank group		ii. J1-C tank group		iii. J1-G tank group	
Dose conversion factor	Decommissioning Handbook	FGR15	Decommissioning Handbook	FGR15	Decommissioning Handbook	FGR15
Seawater surface	4.6E-10	3.7E-10	1.7E-10	8.6E-11	3.7E-10	2.1E-10
Hull	4.9E-10	6.1E-10	1.8E-10	2.1E-10	3.7E-10	3.9E-10
Swimming	3.2E-10	1.8E-10	1.2E-10	4.2E-11	2.5E-10	1.0E-10
Beach sand	5.4E-07	3.2E-07	2.0E-07	7.5E-08	4.3E-07	1.8E-07

XI-4. Difference by age on external exposure assessment result

The Dose Conversion Factor for the Decommissioning Handbook used for the assessment of external exposure in the text does not provide a dose conversion factor by age, but a dose conversion factor by age is provided in FGR15.According to the results of the exposure assessment in the normal state shown in the figure 6-1-3, the exposure assessment results may not exceed 1mSv/year of the dose limit or 0.05mSv/year corresponding to dose constraint due to the difference in age. However, since child under school age and infants may also stay on the sandy beach at the same level as adults, external exposure at the sandy beach was estimated.

The assessment method was as shown in XI-1, and with regard to life habits, child and infant's staying time at the sandy beach site is for 500 hours a year the same as adult and swimming hours of child was set for 96 hours. Dose conversion factors by age used are shown in Table XI-7,8.

As shown in XI-9, the results of the calculations show that the exposure of child and infant were about 1.5 times as high as those of adults. However, even if external exposure of a child or an infant is evaluated as 1.5 times as high as that of an adult, the results of the calculations do not affect the conclusion that the dose limit of 1mSv/year and dose constraint 0.05mSv/ year are sufficiently lower than the results of the calculations because the sum of external exposure is on the order of E-07 and is one to three orders of magnitude smaller than that of internal exposure (see Table 6-1-21).

Table XI-7 Effective dose conversion factor by age by radiation from sea water during swimming, seawater work using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))			Remarks
	Adult	Child under school age	Infant	
H-3	4.6E-26	2.4E-26	6.2E-27	
C-14	3.2E-21	2.9E-21	2.8E-21	
Mn-54	1.1E-16	9.3E-17	8.0E-17	
Fe-55	2.0E-26	1.5E-26	1.2E-26	
Co-60	3.4E-16	2.9E-16	2.5E-16	
Ni-63	2.6E-23	1.4E-23	7.8E-24	
Se-79	3.7E-21	3.4E-21	3.3E-21	
Sr-90	1.2E-19	1.1E-19	1.1E-19	
Y-90	1.1E-18	1.0E-18	9.5E-19	
Tc-99	3.3E-20	3.2E-20	3.1E-20	
Ru-106	2.8E-17	2.4E-17	2.1E-17	The progeny nuclide Rh-106 is considered
Sb-125	5.4E-17	4.5E-17	3.8E-17	
Te-125m	1.6E-18	8.9E-19	6.0E-19	
I-129	1.3E-18	7.6E-19	5.1E-19	
Cs-134	2.0E-16	1.7E-16	1.5E-16	
Cs-137	7.6E-17	6.5E-17	5.6E-17	The progeny nuclideBa-137 is considered

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))			Remarks
	Adult	Child under school age	Infant	
Ce-144	8.7E-18	7.1E-18	6.1E-18	The progeny nuclides Pr-144,Pr-144m are considered
Pm-147	1.0E-20	9.7E-21	9.4E-21	
Sm-151	2.1E-22	1.1E-22	6.1E-23	
Eu-154	1.6E-16	1.4E-16	1.2E-16	
Eu-155	6.9E-18	4.6E-18	3.9E-18	
U-234	3.3E-20	2.0E-20	1.2E-20	
U-238	4.1E-18	3.3E-18	2.9E-18	The progeny nuclides Th-234, Pa-234m are considered
Np-237	3.0E-17	2.3E-17	1.9E-17	The progeny nuclide Pa-233 is considered
Pu-238	2.6E-20	1.4E-20	6.6E-21	
Pu-239	1.8E-20	1.1E-20	7.3E-21	
Pu-240	2.5E-20	1.4E-20	6.5E-21	
Pu-241	1.9E-22	1.3E-22	1.1E-22	
Am-241	2.4E-18	1.5E-18	1.2E-18	
Cm-244	2.6E-20	1.5E-20	7.9E-21	

Table XI-8 Effective Dose Conversion Factor by Age by radiation from Beach Sand Using FGR15

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))			Remarks
	Adult	Child under school age	Infant	
H-3	3.4E-23	4.0E-23	4.6E-23	
C-14	3.1E-20	3.6E-20	4.2E-20	
Mn-54	2.6E-17	3.0E-17	3.5E-17	
Fe-55	3.4E-27	4.0E-27	4.7E-27	
Co-60	8.3E-17	9.5E-17	1.1E-16	
Ni-63	4.1E-21	4.8E-21	5.5E-21	
Se-79	3.5E-20	4.1E-20	4.7E-20	
Sr-90	2.6E-19	3.1E-19	3.5E-19	
Y-90	2.3E-18	2.6E-18	3.0E-18	
Tc-99	1.0E-19	1.2E-19	1.4E-19	
Ru-106	1.0E-17	1.2E-17	1.4E-17	The progeny nuclide Rh-106 is considered
Sb-125	1.2E-17	1.4E-17	1.7E-17	
Te-125m	5.1E-20	7.9E-20	1.4E-19	
I-129	7.9E-20	1.1E-19	1.7E-19	
Cs-134	4.8E-17	5.5E-17	6.4E-17	

Nuclide	Dose conversion factor for the effective dose ((Sv/s)/(Bq/m^3))			Remarks
	Adult	Child under school age	Infant	
Cs-137	1.8E-17	2.1E-17	2.5E-17	The progeny nuclide Ba-137 is considered
Ce-144	4.7E-18	5.4E-18	6.2E-18	The progeny nuclides Pr-144, Pr-144m are considered
Pm-147	4.8E-20	5.6E-20	6.4E-20	
Sm-151	5.5E-21	6.4E-21	7.4E-21	
Eu-154	3.9E-17	4.6E-17	5.3E-17	
Eu-155	9.5E-19	1.2E-18	1.4E-18	
U-234	1.9E-21	2.6E-21	3.5E-21	
U-238	2.6E-18	2.9E-18	3.4E-18	The progeny nuclide Th-234, Pa-234m are considered
Np-237	5.8E-18	6.9E-18	8.1E-18	The progeny nuclide Pa-233 is considered
Pu-238	5.3E-22	9.7E-22	1.6E-21	
Pu-239	1.5E-21	1.9E-21	2.4E-21	
Pu-240	5.5E-22	9.7E-22	1.6E-21	
Pu-241	7.5E-23	8.8E-23	1.0E-22	
Am-241	2.2E-19	2.9E-19	3.7E-19	
Cm-244	1.0E-21	1.5E-21	2.2E-21	

Table XI-9 External exposure at sand beach sites by age using FGR15 dose conversion factors

Assessed case	Source term	Source term based on measured values		
		i. K4 tank group	ii. J1-C tank group	iii. J1-G tank group
External exposure during swimming (mSv/year）	Adult	1.8E-10	4.2E-11	1.0E-10
	Child under school age	2.1E-10	4.8E-11	1.2E-10
	Infant	―	―	―
External exposure from beach sand (mSv/year）	Adult	3.2E-07	7.5E-08	1.8E-07
	Child under school age	3.7E-07	8.7E-08	2.1E-07
	Infant	4.3E-07	1.0E-07	2.5E-07

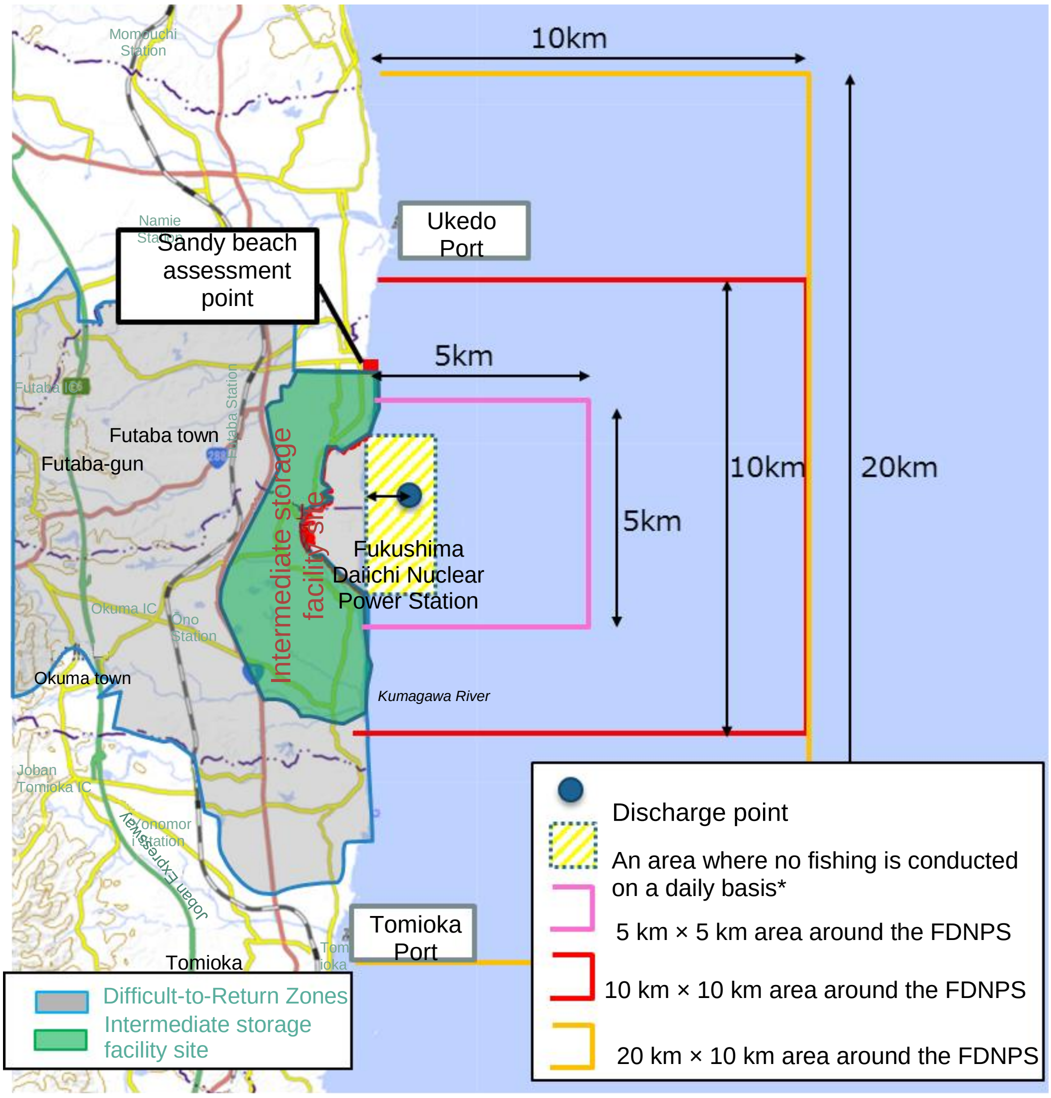
References

[XI-1] EPA, FEDERAL GUIDANCE REPORT NO.15 "EXTERNAL EXPOSURE TO RADIONUCLIDES IN AIR, WATER AND SOIL",2019

Attachment XII Impact of the assessment range of concentrations in seawater used for the assessment of exposures

In the chapter 6-1-2. (4) “Setting of the representative person subject to radiation exposure assessment”, for the concentration of the each nuclide in the seawater used for the exposure assessment, the average concentration within 10 km × 10 km around the FDNPS is used considering the distance from the nearby fishing port (about 6 km) because fishing is assumed as the feature of the representative person. However, since the actual behaviors of the representative person is uncertain, we changed the assessment target range from 5 km × 5 km to 20 km in the north-south direction × 10 km in the east-west direction to calculate exposure.

The target range of the sea area is set to 5 km × 5 km and 20 km × 10 km around the power plant as shown in Figure XII-1.



*Areas where common fishery rights are not established

Figure XII-1 Assessment range to confirm the impact of the range of concentrations in seawater used for the assessment of exposures

XII-1. Assessment method

We performed the same assessment as 6-1. Exposure assessment under normal conditions and changed the calculation range of the average concentration of tritium only for the concentration in the seawater used for the assessment.

Table XII-1 shows the annual average concentration within 5 km × 5 km and 20 km × 10 km around the FDNPS in the case of the annual discharge amount of 22 TBq (2.2E+13Bq) of tritium. We compared the concentrations in 2014 and 2019 and decided to use the concentration of 2019, which is higher, for the exposure assessment.

Tables XII-2 to 4 show this result and the radioactive material concentration in the seawater for the assessment calculated from the annual discharge amount of each nuclide shown in Tables 6-1-1 to 6-1-3 used for the assessment in each term. Since the sandy beach assessment point was the same, the concentration in the seawater used for the assessment of exposure from swimming, ingestion of water, inhalation of seawater spray, and beach sand was set to the same regardless of the assessment target range.

Table XII-1 Tritium concentration in the seawater in the case of the annual tritium discharge amount of 2.2E+13Bq

	Depth	Calculation result (Bq/L)			Concentration for assessment (Bq/L)
		Meteorological and oceanographic data of 2014	Meteorological and oceanographic data of 2019	Difference (%)	
Annual average concentration within 5 km × 5 km around the FDNPS	All layers	1.5E-01	1.7E-01	13	1.7E-01
	Top layer	2.1E-01	2.4E-01	14	2.4E-01
Annual average concentration within 20 km × 10 km around the FDNPS	All layers	4.1E-02	4.8E-02	17	4.8E-02
	Top layer	8.8E-02	1.1E-01	25	1.1E-01

Table XII-2 Concentration in the seawater used for the assessment (Source term based on measured values (K4 tank group))

Target nuclide	Annual volume of discharge (Bq)	Concentration in the seawater used for the assessment (Bq/L)			
		Average of all layers within 5km×5km	Average of the top layers within 5km×5km	Average of all layers within 20km×10km	Average of all layers within 5km×5km
H-3	2.2E+13	1.7E-01	2.4E-01	4.8E-02	1.1E-01
C-14	2.4E+09	1.8E-05	2.6E-05	5.1E-06	1.2E-05
Mn-54	1.3E+04	1.0E-10	1.5E-10	2.9E-11	6.7E-11
Fe-55	3.3E+08	2.6E-06	3.6E-06	7.2E-07	1.7E-06
Co-60	3.5E+07	2.7E-07	3.8E-07	7.5E-08	1.7E-07
Ni-63	3.3E+08	2.6E-06	3.6E-06	7.2E-07	1.7E-06
Se-79	2.4E+08	1.8E-06	2.6E-06	5.1E-07	1.2E-06
Sr-90	3.0E+07	2.3E-07	3.3E-07	6.5E-08	1.5E-07
Y-90	3.0E+07	2.3E-07	3.3E-07	6.5E-08	1.5E-07
Tc-99	1.1E+08	8.5E-07	1.2E-06	2.4E-07	5.5E-07
Ru-106	6.6E+06	5.1E-08	7.2E-08	1.4E-08	3.3E-08
Sb-125	1.4E+07	1.0E-07	1.5E-07	2.9E-08	6.8E-08
Te-125m	1.4E+07	1.0E-07	1.5E-07	2.9E-08	6.8E-08
I-129	3.3E+08	2.6E-06	3.6E-06	7.2E-07	1.7E-06
Cs-134	1.2E+06	9.0E-09	1.3E-08	2.5E-09	5.8E-09
Cs-137	5.8E+07	4.5E-07	6.3E-07	1.3E-07	2.9E-07
Ce-144	8.3E+04	6.4E-10	9.1E-10	1.8E-10	4.2E-10
Pm-147	7.1E+06	5.5E-08	7.7E-08	1.5E-08	3.5E-08
Sm-151	1.4E+05	1.0E-09	1.5E-09	2.9E-10	6.8E-10
Eu-154	1.2E+06	9.5E-09	1.3E-08	2.7E-09	6.1E-09
Eu-155	2.4E+06	1.8E-08	2.6E-08	5.1E-09	1.2E-08
U-234	9.9E+04	7.7E-10	1.1E-09	2.2E-10	5.0E-10
U-238	9.9E+04	7.7E-10	1.1E-09	2.2E-10	5.0E-10
Np-237	9.9E+04	7.7E-10	1.1E-09	2.2E-10	5.0E-10
Pu-238	9.4E+04	7.3E-10	1.0E-09	2.1E-10	4.7E-10
Pu-239	9.9E+04	7.7E-10	1.1E-09	2.2E-10	5.0E-10
Pu-240	9.9E+04	7.7E-10	1.1E-09	2.2E-10	5.0E-10
Pu-241	3.5E+06	2.7E-08	3.8E-08	7.5E-09	1.7E-08
Am-241	9.7E+04	7.5E-10	1.1E-09	2.1E-10	4.9E-10
Cm-244	8.0E+04	6.2E-10	8.7E-10	1.7E-10	4.0E-10
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	From fishing nets Ingestion of seafood	From sea surface From hulls

Table XII-3 Concentration in the seawater used for the assessment (Source term based on measured values (J1-C tank group))

Target nuclide	Annual volume of discharge （Bq)	Concentration in the seawater used for the assessment (Bq/L)			
		Average of all layers within 5km×5km	Average of the top layers within 5km×5km	Average of all layers within 20km×10km	Average of all layers within 5km×5km
H-3	2.2E+13	1.7E-01	2.4E-01	4.8E-02	1.1E-01
C-14	5.5E+08	4.3E-06	6.0E-06	1.2E-06	2.8E-06
Mn-54	1.6E+05	1.3E-09	1.8E-09	3.5E-10	8.1E-10
Fe-55	7.3E+07	5.7E-07	8.0E-07	1.6E-07	3.7E-07
Co-60	7.3E+06	5.7E-08	8.0E-08	1.6E-08	3.7E-08
Ni-63	2.5E+08	2.0E-06	2.8E-06	5.5E-07	1.3E-06
Se-79	4.6E+07	3.5E-07	5.0E-07	1.0E-07	2.3E-07
Sr-90	1.0E+06	8.0E-09	1.1E-08	2.3E-09	5.2E-09
Y-90	1.0E+06	8.0E-09	1.1E-08	2.3E-09	5.2E-09
Tc-99	3.7E+07	2.8E-07	4.0E-07	8.0E-08	1.8E-07
Ru-106	8.3E+06	6.4E-08	9.0E-08	1.8E-08	4.1E-08
Sb-125	3.7E+06	2.8E-08	4.0E-08	8.0E-09	1.8E-08
Te-125m	3.7E+06	2.8E-08	4.0E-08	8.0E-09	1.8E-08
I-129	3.7E+07	2.8E-07	4.0E-07	8.0E-08	1.8E-07
Cs-134	1.0E+06	7.8E-09	1.1E-08	2.2E-09	5.0E-09
Cs-137	5.2E+06	4.0E-08	5.7E-08	1.1E-08	2.6E-08
Ce-144	2.0E+06	1.5E-08	2.1E-08	4.3E-09	9.8E-09
Pm-147	1.3E+07	9.9E-08	1.4E-07	2.8E-08	6.4E-08
Sm-151	3.4E+05	2.6E-09	3.7E-09	7.3E-10	1.7E-09
Eu-154	2.9E+06	2.2E-08	3.1E-08	6.3E-09	1.4E-08
Eu-155	7.3E+06	5.7E-08	8.0E-08	1.6E-08	3.7E-08
U-234	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
U-238	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Np-237	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Pu-238	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Pu-239	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Pu-240	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Pu-241	3.4E+07	2.6E-07	3.7E-07	7.3E-08	1.7E-07
Am-241	9.8E+05	7.6E-09	1.1E-08	2.1E-09	4.9E-09
Cm-244	9.2E+05	7.1E-09	1.0E-08	2.0E-09	4.6E-09
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	From fishing nets Ingestion of seafood	From sea surface From hulls

Table XII-4 Concentration in the seawater used for the assessment (Source term based on measured value (J1-G tank group))

Target nuclide	Annual volume of discharge （Bq)	Concentration in the seawater used for the assessment (Bq/L)			
		Average of all layers within 5km×5km	Average of the top layers within 5km×5km	Average of all layers within 20km×10km	Average of all layers within 5km×5km
H-3	2.2E+13	1.7E-01	2.4E-01	4.8E-02	1.1E-01
C-14	1.5E+09	1.1E-05	1.6E-05	3.2E-06	7.3E-06
Mn-54	5.0E+05	3.8E-09	5.4E-09	1.1E-09	2.5E-09
Fe-55	2.2E+08	1.7E-06	2.4E-06	4.8E-07	1.1E-06
Co-60	1.6E+07	1.2E-07	1.7E-07	3.4E-08	7.8E-08
Ni-63	8.0E+08	6.2E-06	8.7E-06	1.7E-06	4.0E-06
Se-79	1.4E+08	1.1E-06	1.5E-06	3.0E-07	6.9E-07
Sr-90	2.8E+06	2.1E-08	3.0E-08	6.0E-09	1.4E-08
Y-90	2.8E+06	2.1E-08	3.0E-08	6.0E-09	1.4E-08
Tc-99	1.2E+08	9.2E-07	1.3E-06	2.6E-07	6.0E-07
Ru-106	8.6E+06	6.7E-08	9.4E-08	1.9E-08	4.3E-08
Sb-125	6.9E+06	5.3E-08	7.5E-08	1.5E-08	3.4E-08
Te-125m	6.9E+06	5.3E-08	7.5E-08	1.5E-08	3.4E-08
I-129	3.0E+07	2.3E-07	3.3E-07	6.6E-08	1.5E-07
Cs-134	2.8E+06	2.1E-08	3.0E-08	6.0E-09	1.4E-08
Cs-137	2.8E+07	2.2E-07	3.1E-07	6.2E-08	1.4E-07
Ce-144	6.0E+06	4.6E-08	6.5E-08	1.3E-08	3.0E-08
Pm-147	3.5E+07	2.7E-07	3.8E-07	7.6E-08	1.7E-07
Sm-151	9.0E+05	6.9E-09	9.8E-09	2.0E-09	4.5E-09
Eu-154	7.7E+06	6.0E-08	8.4E-08	1.7E-08	3.9E-08
Eu-155	1.1E+07	8.5E-08	1.2E-07	2.4E-08	5.5E-08
U-234	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
U-238	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
Np-237	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
Pu-238	2.5E+06	1.9E-08	2.7E-08	5.4E-09	1.2E-08
Pu-239	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
Pu-240	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
Pu-241	8.2E+07	6.3E-07	8.9E-07	1.8E-07	4.1E-07
Am-241	2.6E+06	2.0E-08	2.8E-08	5.6E-09	1.3E-08
Cm-244	2.4E+06	1.8E-08	2.6E-08	5.2E-09	1.2E-08
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	From fishing nets Ingestion of seafood	From sea surface From hulls

XII-2. Assessment results

Tables XII-5 to 10 show the assessment results. When the assessment result with the assessment area set to 10 km × 10 km, the assessment results are 0.000002 (2E-06) to 0.00003 (3E-05) mSv/year, when the assessment area is 5 km × 5 km, the value were 0.000005 (5E-06) to 0.00009 (9E-05) mSv/ year, which are about three times higher. Moreover, when the assessment area is set to 20 km × 10 km, the results ranged from 0.000002 (2E-06) to 0.00003 (3E-05) mSv/year, almost same as the case of 10 km × 10 km. In all cases, the results remained significantly smaller than the dose limit of 1 mSv/year for the general public and the dose target of 0.05 mSv/year for domestic nuclear power plants, which is equivalent to the dose constraint value.

Even for infants, whose effective dose factor and the assessment value of internal exposure are intended to high, the assessment result of internal exposure from ingestion of seafood is not exceeded value of adult and, 0.0000052 (5.2E-06) to 0.000097 (9.7E-05) mSv/year with the assessment area set to 5 km × 5 km, which is about 3 times higher 0.0000017 (1.7E-06) to 0.000032 (3.2E-05) than mSv/year with 10 km × 10 km.

Moreover, when the assessment area is set to 20 km × 10 km, the result is 0.0000015 (1.5E-06) to 0.000027 (2.7E-05) mSv/year, which is lower than that of 10 km × 10 km.

Table XII-5 Human exposure assessment result (Source term based on measured values (K4 tank group))

Assessed case	Assessment area of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
External exposure (mSv/year)	Sea surface	4.6E-10		9.2E-10		4.2E-10	
	Hull	4.9E-10		9.9E-10		4.5E-10	
	During swimming	3.2E-10		3.2E-10		3.2E-10	
	Beach sand	5.4E-07		5.4E-07		5.4E-07	
	Fishing net	1.1E-07		3.2E-07		9.0E-08	
Internal exposure (mSv/year)	Ingestion of water	3.4E-07		3.4E-07		3.4E-07	
	Inhalation of spray	9.2E-10		9.2E-08		9.2E-08	
	Ingestion of seafood	6.9E-06	3.1E-05	2.1E-05	9.3E-05	5.9E-06	2.6E-05
Total (mSv/year)		8E-06	3E-05	2E-05	9E-05	7E-06	3E-05

Table XII-6 Human exposure assessment result (Source term based on measured values (J1-C tank group))

Assessed case	Assessment area of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
External exposure (mSv/year)	Sea surface	1.7E-10		3.4E-10		1.6E-10	
	Hull	1.8E-10		3.5E-10		1.6E-10	
	During swimming	1.2E-10		1.2E-10		1.2E-10	
	Beach sand	2.0E-07		2.0E-07		2.0E-07	
	Fishing net	3.9E-08		1.2E-07		3.4E-08	
Internal exposure (mSv/year)	Ingestion of water	3.1E-07		3.1E-07		3.1E-07	
	Inhalation of spray	1.9E-07		1.9E-07		1.9E-07	
	Ingestion of seafood	1.2E-06	5.5E-06	3.8E-06	1.7E-05	1.1E-06	4.7E-06
Total (mSv/year)		2E-06	6E-06	5E-06	2E-05	2E-06	5E-06

Table XII-7 Human exposure assessment result (Source term based on measured values (J1-G tank group))

Assessed case	Assessment area of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
External exposure (mSv/year)	Sea surface	3.7E-10		7.3E-10		3.4E-10	
	Hull	3.7E-10		7.3E-10		3.4E-10	
	During swimming	2.5E-10		2.5E-10		2.5E-10	
	Beach sand	4.3E-07		4.3E-07		4.3E-07	
	Fishing net	8.3E-08		2.5E-07		7.1E-08	
Internal exposure (mSv/year)	Ingestion of water	3.1E-07		3.1E-07		3.1E-07	
	Inhalation of spray	3.8E-07		3.8E-07		3.8E-07	
	Ingestion of seafood	2.6E-06	1.1E-05	7.8E-06	3.4E-05	2.2E-06	9.5E-06
Total (mSv/year)		4E-06	1E-05	9E-06	4E-05	3E-06	1E-05

Table XII-8 Age-specific internal exposure assessment result (Source term based on measured values (K4 tank group))

Assessed case	Assessment range of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Internal exposure from ingestion of water (mSv/year)	Adult	3.4E-07		3.4E-07		3.4E-07	
	Child under school age	5.8E-07		5.8E-07		5.8E-07	
	Infant	-		-		-	
Internal exposure from inhalation of spray (mSv/year)	Adult	9.2E-08		9.2E-08		9.2E-08	
	Child under school age	6.0E-08		6.0E-08		6.0E-08	
	Infant	3.9E-08		3.9E-08		3.9E-08	
Internal exposure from ingestion of seafood (mSv/year)	Adult	6.9E-06	3.1E-05	2.1E-05	9.3E-05	5.9E-06	2.6E-05
	Child under school age	7.8E-06	3.6E-05	2.4E-05	1.1E-04	6.7E-06	3.1E-05
	Infants	6.9E-06	3.2E-05	2.1E-05	9.7E-05	5.9E-06	2.7E-05

Table XII-9 Age-specific internal exposure assessment result (Source term based on measured values (J1-C tank group))

Assessed case	Assessment range of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Internal exposure from ingestion of water (mSv/year)	Adult	3.1E-07		3.1E-07		3.1E-07	
	Child under school age	5.3E-07		5.3E-07		5.3E-07	
	Infant	-		-		-	
Internal exposure from inhalation of spray (mSv/year)	Adult	1.9E-07		1.9E-07		1.9E-07	
	Child under school age	1.1E-07		1.1E-07		1.1E-07	
	Infant	6.2E-08		6.2E-08		6.2E-08	
Internal exposure from ingestion of seafood (mSv/year)	Adult	1.2E-06	5.5E-06	3.8E-06	1.7E-05	1.1E-06	4.7E-06
	Child under school age	1.5E-06	6.8E-06	4.6E-06	2.1E-05	1.3E-06	5.9E-06
	Infants	1.7E-06	8.1E-06	5.2E-06	2.4E-05	1.5E-06	6.9E-06

Table XII-10 Age-specific internal exposure assessment result (Source term based on measured values (J1-G tank group))

Assessed case	Assessment range of the concentration	10 km × 10 km		5 km × 5 km		20 km × 10 km	
	Ingestion of seafood	Average	Large	Average	Large	Average	Large
Internal exposure from ingestion of water (mSv/year)	Adult	3.1E-07		3.1E-07		3.1E-07	
	Child under school age	5.4E-07		5.4E-07		5.4E-07	
	Infant	-		-		-	
Internal exposure from inhalation of spray (mSv/year)	Adult	3.8E-07		3.8E-07		3.8E-07	
	Child under school age	2.0E-07		2.0E-07		2.0E-07	
	Infant	1.1E-07		1.1E-07		1.1E-07	
Internal exposure from ingestion of seafood (mSv/year)	Adult	2.6E-06	1.1E-05	7.8E-06	3.4E-05	2.2E-06	9.5E-06
	Child under school age	3.6E-06	1.6E-05	1.1E-05	4.9E-05	3.1E-06	1.4E-05
	Infants	4.6E-06	2.2E-05	1.4E-05	6.6E-05	3.9E-06	1.9E-05

Attachment XIII Application of uncertainty in the analysis of ALPS treated water

ALPS treated water analysis includes analysis methods for gamma-ray emitting nuclides, which have been widely used in our power station, and other methods introduced after the 2011 off the Paciffic coast of Tohoku Earthquake in 2011, which have been developed by JAEA to confirm the radioactivity concentration of power plant waste and research facility waste, focusing on the change of nuclides in cooling water caused by contacts with fuel debris. Especially for methods that have been modified or newly adopted after the Earthquake, it is necessary to confirm that the intended analysis has been appropriately performed and obtained analytical values are appropriate.

Since the analytical value of ALPS treated water is used for the operational management of discharging ALPS-treated water and measuring the degree of environmental impact, it is necessary to manage and evaluate the analytical value after grasping the degree of variation. This degree of the variation was assessed by using "expanded uncertainty", which was obtained by grasping and evaluating individual features of the analytical process and sample preparation quantity, calibration and environment of analytical instruments for usage, and pretreatment. By introducing "expanded uncertainty" quantified into error bars, we also evaluated the uncertainty possessed by the analytical method, and we examined the method of matching with the analytical results by designated third party laboratories.

XIII-1 Process to assess uncertainties of measurements

The expanded uncertainty is assessed according to the following procedure [1].

Step 1: Development of a Measurement Model

Clarify the relationship between the radioactivity concentration of measured quantity and the input quantity (count measured by instrument, sample quantity, correction coefficients etc.).

Step 2: Identification of uncertainty sources

The measurement procedure is clarified, and potential factors of uncertainty are listed in Fishbone Diagrams and Tables of Source summary table.

Step 3: Quantification of uncertainty components

The magnitude of the components of uncertainty associated with the identified potential factors is estimated by using a budget sheet.

Step 4: Calculation of combined standard uncertainty

The magnitude of the contribution of uncertainty in each potential factor is expressed in standard deviations. Combined standard uncertainty is calculated based on general rules.

Step 5: Calculation of expanded uncertainty

The expanded uncertainty is calculated by multiplying the combined standard uncertainty by the coverage factor k. This result is also shown in the measurement results.

XIII-1-1 Step 1: Development of a Measurement Model

In this step, the relationship between the radioactivity concentration of measured quantity and the input quantity of the counting in the measuring instrument, the measured sample quantity, and half-life correction coefficient for each nuclide is clarified.

For example, for measuring gamma-ray emitting nuclides by Ge semiconductor detectors, the radioactivity concentration is expressed as a function of the input quantity, as shown below.

$$C_\gamma = f(x_1, x_2 \cdots) = f(X, Y, Z, E, V) = \frac{X \times Z}{(\frac{E}{100}) \times (\frac{Y}{100}) \times V}$$

$f(x_1, x_2 \cdots)$: Function of deriving the radioactivity concentration
X, Y, Z, E, V: Amount of input required to determine the radioactivity concentration

C_γ: Radioactivity concentration of gamma-ray emitting nuclide (Bq/L)
E: Peak efficiency of gamma ray of the relevant energy (%)
X: The net counting rate of the sample of the relevant peak (cps)
Y: The emission rate of gamma-ray of the relevant energy of the nuclide $(\%)$
Z: Half-life correction coefficient $(-)$
V: Sample dispensing volume (L)

XIII-1-2 Step 2: Identification of uncertainty sources

In this step, the measurement procedure of each measurement method is clarified, and the sources of possible uncertainty are summarized in the Fishbone Diagrams and Tables.

The Fishbone Diagrams were developed by referring to the uncertainty assessment of No.7 (gamma nuclide) of the Series of Environmental Radioactivity Measurement Method. The following figure and table show an example of gamma-ray emitting nuclides measured by Ge semiconductor detector.

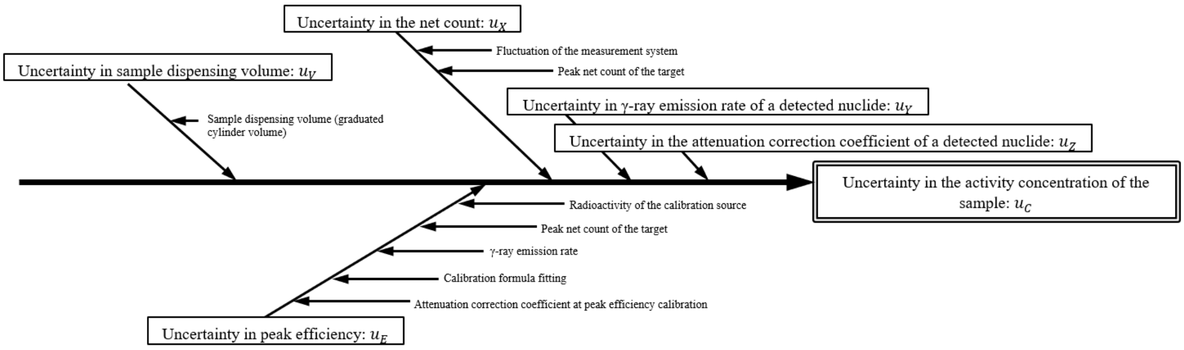


Figure XIII-1 Fishbone Diagram on Uncertainty of Gamma-Ray Emitting Nuclide Measured by Ge Semiconductor Detector

Table XIII-1 Summary of Uncertainty Souces for Gamma-Ray Emitting Nuclide measured by Ge Semiconductor Detectors

Major Source	Symbol	Breakdown of source
Sample dispensing volume	u_V	Sample dispensing volume (graduated cylinder volume)
Peak efficiency	u_E	Radioactivity of calibration source, peak net count of the calibration source, and gamma-ray emission rate of the calibration source Calibration formula fitting, attenuation correction coefficient at peak efficiency calibration
Net count	u_X	Fluctuation of the measurement system, peak net count of the target p
Gamma-ray emission rate	u_Y	Detected nuclide gamma-ray emission rate

Attenuation correction coefficient	u_Z	Half-life

XIII-1-3 Step 3: Quantification of uncertainty components

The uncertainty sources identified in Step 2 are quantitatively evaluated by using either Type A or Type B as below, and standard uncertainty for each uncertainty source is determined.

Type A: Method in which measurements are performed repeatedly to actually obtain data, and the standard deviation is determined from the variation of the data.
Type B: Method of determining the standard deviation from available information, such as literature, the standard value specified by the manufacturer, calibration certificate, etc.

For example, the standard uncertainty of the sample dispensing volume u_V, was calculated through Type A with repetitive measurement and through Type B with the manufacturer's specification value, as shown below.

Table XIII-2 Quantification of Standard Uncertainty for Sample Dispensing Volume

Major Source	Uncertainty Source	Uncertainty Abbreviation	Type	Uncertainty assessment method
Uncertainty in sample dispensing volume		u_V	-	$u_V = \sqrt{u_{V1}^2 + u_{V2}^2}$
	Dispensing volume of the test sample (graduated cylinder) measured value	u_{V1}	B	Calculated based on the manufacturer's specifications
		u_{V2}	A	The standard deviation of repeated measurements

XIII-1-4 Step 4: Calculation of Combined Standard Uncertainty

Standard uncertainty of the measurement result is calculated by combining the standard uncertainties obtained through Steps 1 to 3 above in accordance with the propagation law of uncertainties.

The propagation law of uncertainties is given by the following equation.

$$u_C = \sqrt{\sum_{i=1}^{n} \left\{ \frac{\partial f}{\partial x_i} u(x_i) \right\}^2}$$

u_C: Combined standard uncertainty of radioactivity concentration
$u(x_i)$: Input quantity of standard uncertainty $x_1, x_2, \cdots, x_n$

For instance, in the case of gamma-ray emitting nuclides measured by Ge semiconductor detector, the standard uncertainties obtained up to Step 3 are combined by the propagation law of uncertainties, as follows.

$$u_Y = \sqrt{\left(\frac{\partial f}{\partial V} u_V\right)^2 + \left(\frac{\partial f}{\partial E} u_E\right)^2 + \left(\frac{\partial f}{\partial X} u_X\right)^2 + \left(\frac{\partial f}{\partial Y} u_Y\right)^2 + \left(\frac{\partial f}{\partial Z} u_Z\right)^2}$$

u_γ: Combined standard uncertainty of radioactive concentration for gamma-ray emitting nuclides

XIII-1-5 Step 5: Calculation of expanded uncertainty

In this step, the expanded uncertainty is obtained by multiplying the combined standard uncertainty obtained in Step 4 by the coverage factor "k" which reflects the level of confidence. This result is described in the measurement results.

For the coverage factor, k=2 is typically used when there is no particular requirement for confidence level (coverage factors are determined as appropriate when there is a special requirement).

The variation in the measurement results of the managed measurements is generally considered normally distributed in most cases [2]. In this case, when k=2 is used, the probability of confidence level is approximately 95% (i.e., 95% confidence interval). This means when the expanded uncertainty $U_C = 2u_C$ is obtained from the measurement result C, this measurement result has variation in the interval $[C - U_C, C + U_C]$ with the probability of about 95%.

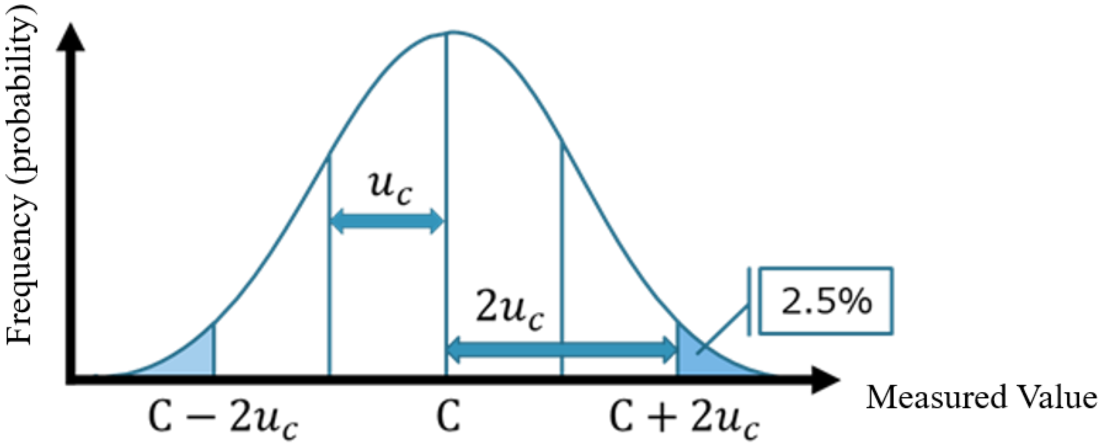


Figure XIII-2 Measured Value vs. Expanded Uncertainty

XIII-2 Evaluation Results of Expanded Uncertainty Sources

This chapter presents the assessment results for the uncertainty sources identified for ALPS treated water analytical methods. The uncertainty assessment was conducted for the radioactivity measurements of Ge semiconductor detector, liquid scintillation counting device, and alpha-ray automatic measurement device while using as a referrence the uncertainty assessment of Series-7 (gamma nuclide) of Environmental Radioactivity Measurement Methods. Further, the uncertainty assessment of the measurement for I-129 and Tc-99 by ICP-MS was carried out by referring to the uncertainty assessment using ICP-MS calibration curves for general metals.

With regard to the uncertainty assessment of undetected nuclides, it is estimated that measurement or evaluation values are within the range smaller than the lower limit of detection (0 to the lower limit of detection). Therefore, it is assumed that measurement value is in the vicinity of the lower limit of detection so that discharge control can be implemented conservatively.

The uncertainty sources of gamma-ray emitting nuclides determined by Ge semiconductor detector are shown in Figure XIII-1 and table XIII-1 above. Below are the uncertainty sources for other methods.

XIII-2-1 Uncertainty in Tritium Radioactivity Concentration Measurements by Liquid Scintillation Counter (LSC)

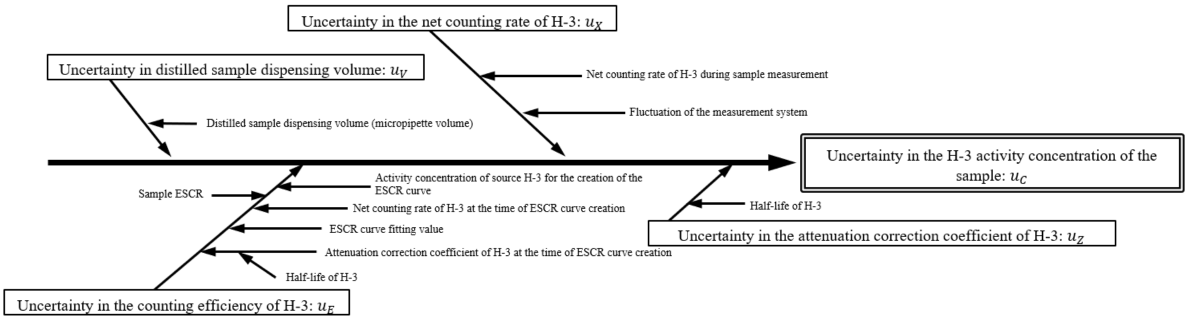
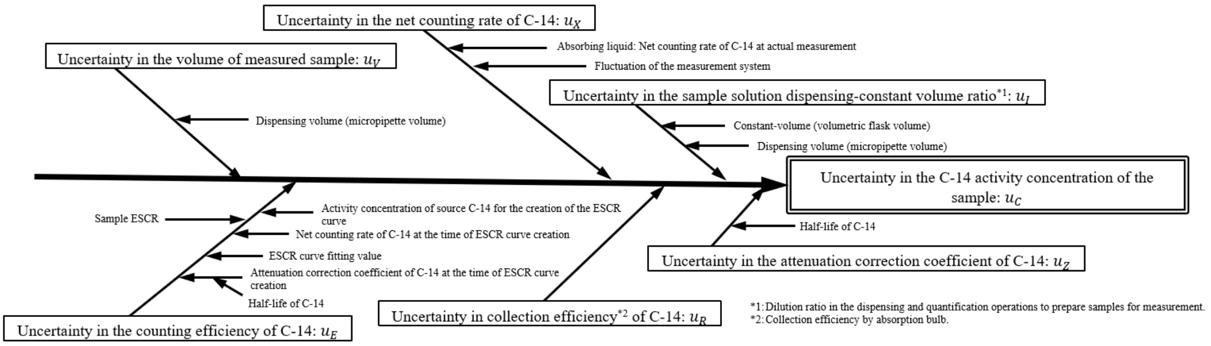


Figure XIII-3 Uncertainty Sources of Tritium Radioactivity Concentration Measurement by LSC

Table XIII-3 Summary of Uncertainty Sources of Tritium Radioactivity Concentration Measurement by LSC

Major Source	Symbol	Breakdown of source
Distilled sample dispensing volume	u_V	Distilled sample dispensing volume (micropipette volume)
H-3 counting efficiency	u_E	(at the time of created ESCR curve creation) H-3 activity concentration, H-3 net count, curve fitting value, H-3 attenuation correction
H-3 net count rate	u_X	Fluctuation of the measurement system, H-3 net counting
Attenuation correction coefficient of H-3	u_Z	Half-life

XIII-2-2 Uncertainty in Carbon-14 Radioactivity Concentration Measurement by Liquid Scintillation Counter (LSC)



*1: Dilution ratio in the dispensing and quantification operations to prepare samples for measurement.
*2: Collection efficiency by absorption bulb.

Figure XIII-4 Uncertainty Sources of C-14 Radioactivity Concentration Measurement by LSC

Table XIII-4 Summary of Uncertainty Sources of C-14 Radioactivity Concentration Measurement by LSC

Major Source	Symbol	Breakdown of source
Measured sample volume	u_V	Dispensing volume (micropipette volume)
C-14 counting efficiency	u_E	(at the time of ESCR curve creation) C-14 activity concentration, C-14 net count, curve fitting value, C-14 attenuation correction
C-14 net count rate	u_X	Variations in the measurement system, C-14 net counts
C-14 collection efficiency	u_R	C-14 Net Counting Rate (Collection bottle 1 and collection bottle 2)
Sample solution dispensing-constant volume ratio	u_I	Dispensing volume (Micro Pipette Volume), Constant Volume (Female Flask Volume)
Attenuation correction coefficient of C-14	u_Z	Half-life

XIII-2-3 Uncertainty in Nickel-63 Radioactivity Concentration Measurement by Liquid-scintillation Counter (LSC)

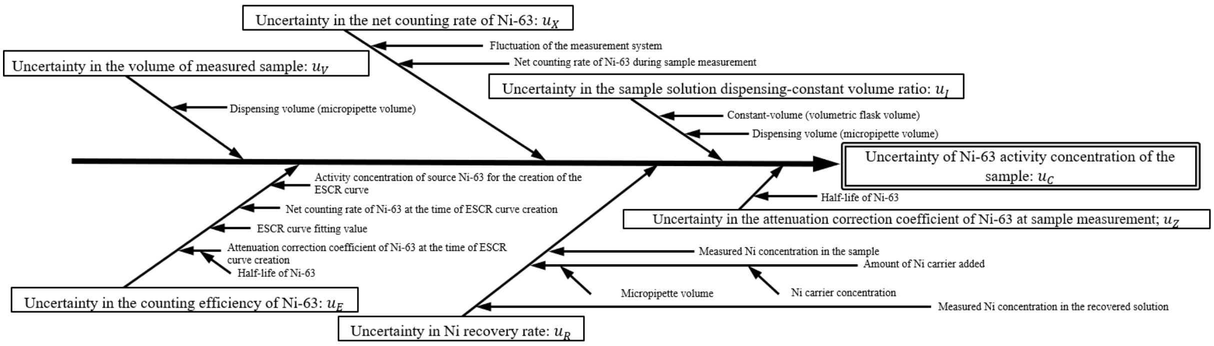


Figure XIII-5 Uncertainty Sources of Ni-63 Radioactivity Concentration Measurement by LSC

Table XIII-5 Summary of Uncertainty Sources of Ni-63 Radioactivity Concentration Measurement by LSC

Major Source	Symbol	Breakdown of source
Measured sample volume	u_V	Dispensing volume (micropipette volume)
Ni-63 counting efficiency	u_E	(at the time of ESCR curve-making) Ni-63 activity concentration, Ni-63 net count Curve-fitting value, Ni-63 attenuation correction
Ni-63 net count rate	u_X	Fluctuation of the measurement system, Ni-63 net counting
Ni recovery rate	u_R	Ni concentration in recovered solution, amount of Ni carrier added, Ni concentration in the sample
Sample solution dispensing-constant volume ratio	u_I	Dispensing volume (Micro Pipette Volume), Constant Volume (Female Flask Volume)
Attenuation correction coefficient of Ni-63	u_Z	Half-life

XIII-2-4 Uncertainty in Cadmium 113m Radioactivity Concentration Measurement by Liquid Scintillation Counter (LSC)

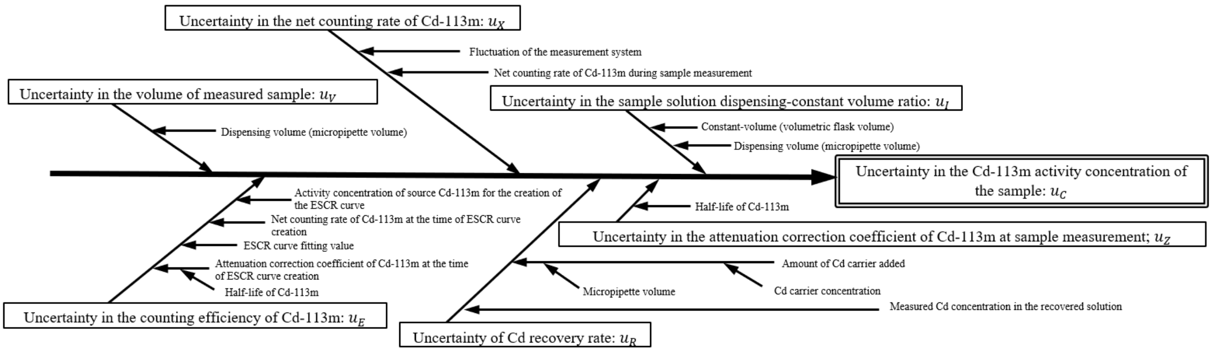


Figure XIII-6 Uncertainty Sources of Cd-113m Radioactivity Concentration Measurement by LSC

Table XIII-6 Summary of Uncertainty Sources of Cd-113m Radioactivity Concentration Measurement by LSC

Major Source	Symbol	Breakdown of source
Measured sample volume	u_V	Dispensing volume (micropipette volume)
Cd-113m counting efficiency	u_E	(at the time of ESCR curve creation) C-14 activity concentration, C-14 net count, curve fitting value, attenuation correction of C-14 (alternative estimation of Cd-113m calibration source)
Cd-113m net count rate	u_X	Fluctuation of the measurement system, Cd-113m net count
Cd recovery rate	u_R	Cd concentration in recovered solution, amount of Cd carrier added
Sample solution dispensing-constant volume ratio	u_I	Dispensing volume (Micropipette Volume), Constant Volume (Volumetric Flask Volume)
Attenuation correction coefficient of Cd-113m	u_Z	Half-life

XIII-2-5 Uncertainty in Iodine-129 Radioactivity Concentration Measurement by ICP-MS

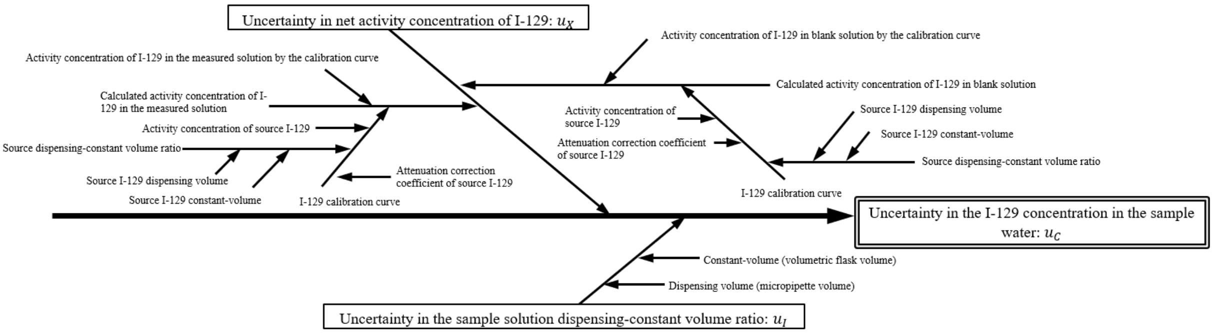


Figure XIII-6 Uncertainty Sources of I-129 Radioactivity Concentration Measurement by ICP-MS

Table XIII-6 Summary of Uncertainty Sources of I-129 Radioactivity Concentration Measurement by ICP-MS

Major Source	Symbol	Breakdown of source
I-129 net activity concentration in test solution	u_X	Calculated I-129 activity concentration in blank solution, calculated I-129 activity concentration in the test solution
Sample solution dispensing-constant volume ratio	u_I	Dispensing volume (Micropipette Volume), Constant Volume (Volumetric Flask Volume)

XIII-2-6: Uncertainty in Technetium-99 Radioactivity Concentration Measurement by ICP-MS

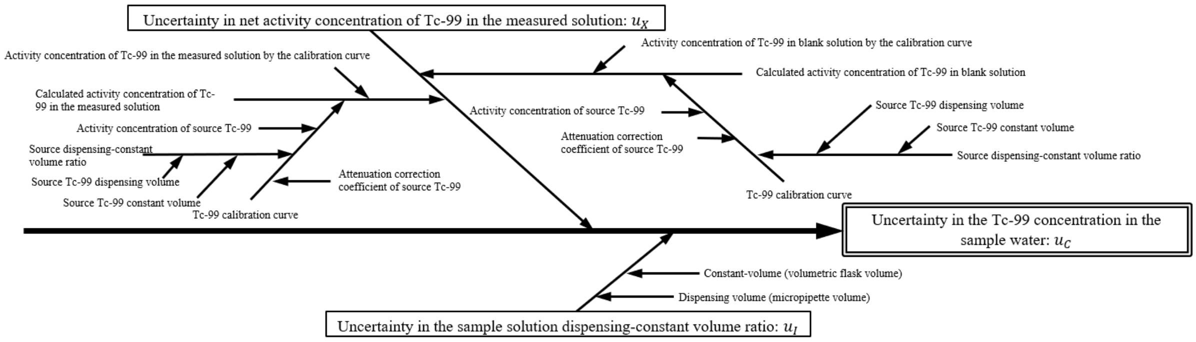


Figure XIII-7 Uncertainty Sources of Tc-99 Radioactivity Concentration Measurement by ICP-MS

Table XIII-7 Summary of Uncertainty Sources of Tc-99 Radioactivity Concentration Measurement by ICP-MS

Main source	Symbol	Breakdown of source
Net activity concentration of Tc-99 in the measured solution	u_X	Calculated Tc-99 activity concentration in blank solution, calculated Tc-99 activity concentration in the test solution
Sample solution dispensing-constant volume ratio	u_I	Dispensing volume (Micropipette Volume), Constant Volume (Volumetric Flask Volume)

XIII-2-7: Uncertainty in Strontium-89 and -90 Radioactivity Concentration Measurement by Beta Nuclide Analyzer

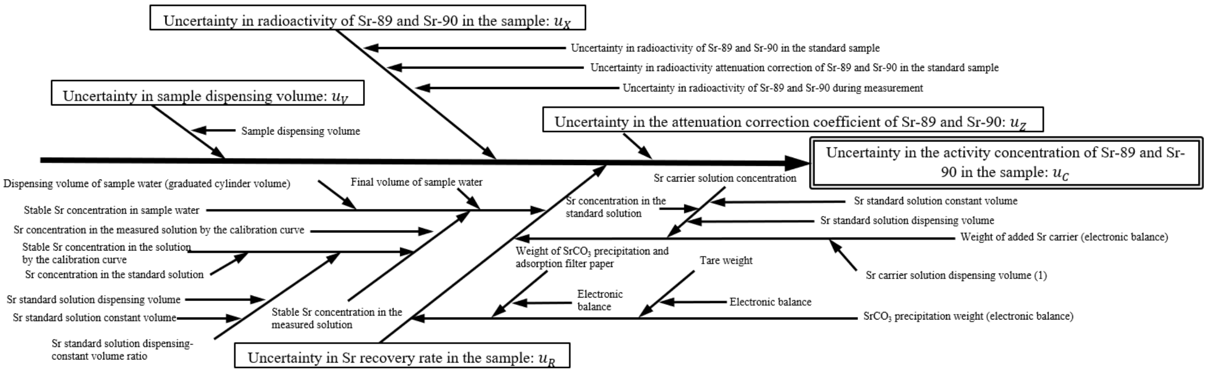


Figure XIII-8 Uncertainty Sources of Sr-89/90 Radioactivity Concentration Measurement by Beta-Nuclide Analyzer

Table XIII-8 Summary of Uncertainty Sources of Sr-89/90 Radioactivity Concentration Measurement by Beta-Nuclide Analyzer

Major source	Symbol	Breakdown of source
Sample dispensing volume	u_V	Sample dispensing volume (graduated cylinder volume)
Sr-89 and Sr-90 activity intensity in the sample	u_X	Sr-89, Sr-90 activity intensity in standard sample, Sr-89, Sr-90 activity attenuation correction, and Sr-89, Sr-90 activity intensity at measurement
Sample Sr recovery rate	u_R	Weight of SrCO3 precipitation, concentration of stable Sr in sample water, amount of Sr carrier added
Attenuation correction coefficient of Sr-89 and Sr-90	u_Z	Half-life

XIII-2-8: Uncertainty in Alpha-Ray Emitting Nuclides Radioactivity Concentration Measurement by Automatic Alpha-Ray Measuring Device

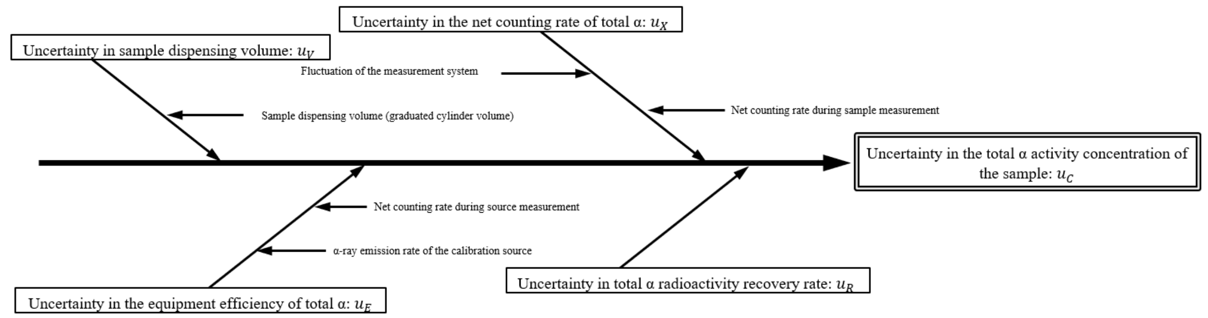


Figure XIII-9 Uncertainty Sources of Radioactivity Concentration of Alpha-Ray Emitting Nuclides by Automatic Alpha-Ray Measuring Device

Table XIII-9 Summary of Uncertainty Sources of Radioactivity Concentration of Alpha-Ray Emitted Nuclides by Automatic Alpha-Ray Measuring Device

Major source	Symbol	Breakdown of source
Sample dispensing volume	u_V	Sample dispensing volume (graduated cylinder volume)
Gross α Equipment Efficiency	u_E	Net count rate at measurement of the source, α-ray emission rate from the calibration source
Gross α Net Count	u_X	Fluctuations in the measurement system and the net count rate at sample measurement
Gross α radiation recovery rate	u_R	-

XIII-3 Evaluation results of expanded uncertainty

In this chapter, examples of expanded uncertainty calculated based on the radioactivity concentration measurement of J1-C tank group are shown for each measurement method. In all cases, the coverage factor is k=2.

Table XIII-10 Examples of Uncertainty in Gamma-Ray Emitting Nuclides Concentration Measurement by Ge semiconductor detector

Nuclide	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C	**Nuclide**	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C
	Units: Bq/L	Units: Bq/L		Units: Bq/L	Units: Bq/L
Ru-106	1.43E+00	3.7E-01	Ce-144	< 5.69E-01	4.0E-01
Cd-115m	< 2.70E+00	2.6E+00	Eu-154	< 1.14E-01	7.7E-02
Sb-125	2.26E-01	1.0E-01	Eu-155	< 3.36E-01	2.3E-01
Cs-134	< 7.60E-02	5.2E-02	Mn-54	< 3.83E-02	2.6E-02
Cs-137	1.85E-01	4.1E-02	Co-60	3.33E-01	6.1E-02

Table XIII-11 Examples of Uncertainty in Radioactivity Concentration Measurement by LSC

Nuclide	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C	**Nuclide**	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C
	Units: Bq/L	Units: Bq/L		Units: Bq/L	Units: Bq/L
H-3	8.22E+05	4.8E+04	Ni-63	< 8.45E+00	3.7E-01
C-14	1.76E+01	4.6E+00	Cd-113m	< 8.52E-02	3.8E-03

Table XIII-12 Examples of Uncertainty in Radioactivity Concentration Measurement by ICP-MS

Nuclide	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C	**Nuclide**	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C
	Units: Bq/L	Units: Bq/L		Units: Bq/L	Units: Bq/L
I-129	1.16E+00	1.8E-01	Tc-99	< 1.23E+00	1.6E-02

Table XIII-13 Examples of Uncertainty in Radioactivity Concentration Measurement by Beta-Nuclide Analyzer

Nuclide	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C	**Nuclide**	**Measurement results C** (J1-C tank group)	**Expanded uncertainty** u_C
	Units: Bq/L	Units: Bq/L		Units: Bq/L	Units: Bq/L
Sr-89	< 5.36E-02	9.7E-03	Sr-90	3.57E-02	1.1E-02

Table XIII-14 Example of Uncertainty in Radioactive Concentration Measurement by Automatic Alpha-Ray Measuring Device

Nuclide	**Measurement results C** (J1-C tank group)	**Extedded uncertainty** u_C
	Units: Bq/L	Units: Bq/L
Gross α radioactivity	< 3.25E-02	6.4E-03

XIII-4 Method to compare our analytical results with the analytical results of designated third party laboratories

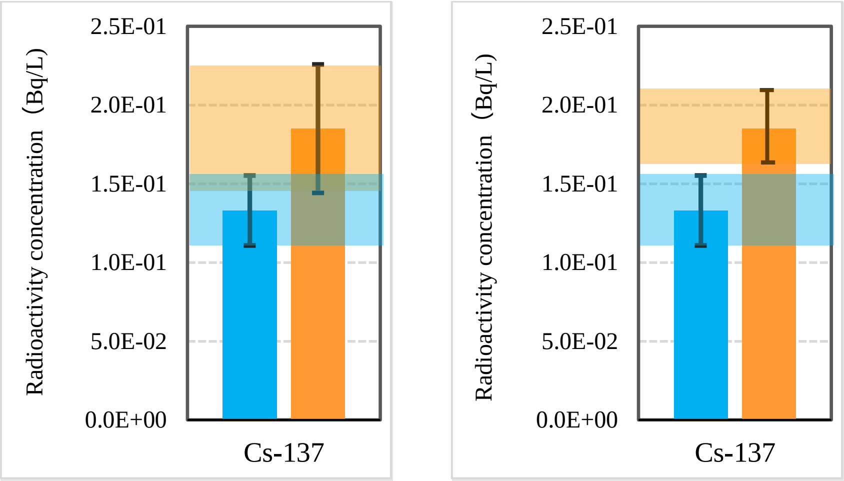
In the measurement of radioactivity concentration, even if the same sample is measured, the same radioactivity concentration is not necessarily obtained as a result because the disintegration of the radioactive nuclide to be measured (also called decay) is stochastic event and the analysis procedure and the equipment to be used are different.

Expanded uncertainty is used to compare the multiple measurement results with different measurement systems and evaluate the validity of the analytical results.

This is illustrated in Figure XIII-10 below. Our analysis results in orange and third-party analysis results in light blue are identical in both cases (a) and (b). However, the length of the error bars indicating expanded uncertainty are different.

Expanded uncertainty for each analytical result at each analytical organization is determined, using the coverage factor k=2. Then, confidence intervals are obtained usinig the expanded uncertainty added to and subtracted from the analytical result, and these intervals are usually indicated by error bars. If the error bars of the analytical results from diferrent organizations to be compared do overlap with each other, as in the case of (a), it is evaluated that the same results have been obtained.

On the other hand, even if the same measured values are obtained, when the error bars do not overlap as in the case of (b), the two evaluation results are considered as being inconsistent.



(a) (b)

Figure XIII-10 Comparison of our analysis results with third-party analysis results

Reference A Site boundary dose assessment of Fukushima Daiichi Nuclear Power Station and the regulatory concentration limit in the Japanese laws

In the Fukushima Daiichi Nuclear Power Station, which is a specific nuclear facility, it is required to take appropriate inhibition measures for radioactive materials discharged to the environment including air, sea, etc., to reduce the dose around the site as much as possible, and make the effective dose on the site boundary from debris, contaminated water, etc., generated and stored in the facility after the accident (assessment value of the effective dose including additional discharge of radioactive materials from the entire facility) less than 1 mSv/year.

In addition, to dispose of liquid waste including radioactive materials, it is required to reduce the concentration of radioactive materials in wastewater as much as possible by filtration, evaporation, adsorption by the ion exchange resin method, etc., attenuation of radioactivity over time, dilution with a large amount of water, etc., at the wastewater facility, and keep the concentration of radioactive materials in wastewater below the concentration limit set by the Nuclear Regulation Authority at drains and the wastewater surveillance facility.

In accordance with “public notice that stipulates the required matters regarding the safety of TEPCO Fukushima Daiichi Nuclear Power Station reactor facilities and the protection of specified nuclear fuel materials”, the concentration limit set by the Nuclear Regulation Authority is defined as the concentration set by Appended table 1 “Pronouncement which set the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials”, if only one type of a radioactive material is contained and the type of the radioactive material is identified. This concentration is called “regulatory concentration limit.”

This concentration is set so that the average dose from internal exposure of adults drinking 2L of the water every day for 70 years will be 1 mSv/year. In other words, the laws set a limit so that even if a person drinks water directly from a drain, the average does of 70 years will not exceed 1 mSv/year.

For example, the limits for tritium and Cs-137 are 60Bq/cm^3 (60,000Bq/L) and 0.09 Bq/cm^3 (90Bq/L), respectively. Therefore, if a person drinks 2L of water containing 60,000Bq/L of tritium alone or 90Bq/L of Cs-137 alone every day for 70 years, the average exposure of 70 years will be 1 mSv/year.

On the other hand, if liquid waste containing two or more types of radioactive materials is disposed of and a person drinks 2L of water containing the nuclides each of which reaches the regulatory concentration limit (e.g. water containing 60,000Bq/L of tritium and 90Bq/L of Cs-137) every day for 70 years, the exposure from each nuclide alone will reach 1 mSv/year, 2 mSv/year in total, thereby the overall exposure exceeding 1 mSv/year. Therefore, to not exceed 1 mSv/year, the regulatory concentration limits of nuclides are set in a way that the sum of their ratios does not exceed 1. In other words, it is set in a way that $\boldsymbol{R_n}$ in the following equation does not exceed 1.

$$R_n = \sum_{i=1}^{n} \frac{C_{i,measured}}{C_{i,limit}}$$

where

R_n Sum of the ratios to regulatory concentrations limits (dimensionless)
$C_{i,\ measured}$ Concentration of nuclide i in liquid waste to be discharged (Bq/cm^3)
$C_{i,\ limit}$ Regulatory concentration limit of nuclide i (Bq/cm^3)
n Number of types of nuclides contained in liquid waste to be discharged

For discharge of ALPS treated water into the sea we are currently planning, the following conditions are to be verified:

(1) The sum of the ratios to regulatory concentrations limits of nuclides excluding tritium falls below 1 in the facility for measurement and confirmation before dilution with seawater;
(2) The sum of the ratios to regulatory concentrations limits of nuclides excluding tritium falls below 1 in the discharge vertical shaft after dilution with seawater.

In (2), the water shall be diluted with seawater 100 or more times so that the tritium concentration falls below 1,500Bq/L. If the tritium concentration can be diluted by 100 times up to 1,500Bq/L, the sum of the ratios to regulatory concentrations limits of radioactive materials at the discharge vertical shaft will be up to

$$(Sum\ of\ the\ ratios\ to\ regulatory\ concentrations\ limits\ of\ nuclides\ other\ than\ tritium) + (Regulatory\ concentration\ ratio\ of\ tritium) = \frac{R_{(1)}}{100} + \frac{1{,}500}{60{,}000} = \frac{1}{100} + \frac{1}{40} = 0.035$$

because the sum of the ratios to regulatory concentrations limits of other than tritium before dilution is managed to be less than 1 in (1) and the concentration of tritium is 1,500Bq/L. Among the dose assessments on the site boundary mentioned at the beginning, the assessment of the contribution of the wastewater of liquid waste is also calculated according to this concept. If the sum of the ratios to regulatory concentrations limits is exactly 1, exposure of this discharge of ALPS treated water into the sea is assessed to be less than 0.035 mSv/ in this assessment method because the exposure dose on the site boundary (drain) is assessed to be 1 mSv/year.

Reference B Timeline of consideration of each disposal method of ALPS treated water

B1. Timeline of consideration

At the Committee on Countermeasures for Contaminated Water Treatment[1] on December 10, 2013, the risks associated with storage of water treated (hereinafter called “ALPS treated water”) with the advanced liquid processing system (hereinafter called “ALPS”), etc. at the TEPCO Fukushima Daiichi Nuclear Power Station (hereinafter called “FDNPS”) were clarified. On December 4, 2013, the review team of the International Atomic Energy Agency (hereinafter called “IAEA”) advised to “examine all options” for handling of ALPS treated water.

Therefore, the government extracted all options from the neutral viewpoint as the basic material for the determination of long-term treatment of ALPS treated water, as well as set up the Tritiated Water Taskforce (hereinafter called “the Taskforce”) under the Committee on Countermeasures for Contaminated Water Treatment for the purpose of the technical assessment of each option (not for harmonizing views among stakeholders or unifying options) and has been proceeding with technical consideration for 2 years and 5 months.

After that, the government established the Subcommittee on Handling of the ALPS Treated Water (hereinafter called “the Subcommittee”) under the Committee on Countermeasures for Contaminated Water Treatment and have conducted comprehensive consideration for 38 months from the professional perspective, in terms of international best practices, options with the least adverse impact on human health and the environment, social impacts such as reputation damage, and technical feasibility in accordance with the knowledge summarized in the Taskforce report.

(1) Overview of consideration by the Taskforce

The Taskforce took place a total of 15 times from December 25, 2013 to May 27, 2016, with the participation of the Nuclear Regulation Authority and related ministries and agencies, in addition to nine members who are experts in the fields of nuclear energy, environmental science, radiation medicine, radiation biology, and fishery chemistry.

The Taskforce organized the basic knowledge as such on tritium regarding its property, dynamics in the atmospheric/geosphere/marine environment, and impacts on the environment and human body (radiation dose, biological concentration, in vivo half-life,

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[1] Committee set up under the ministerial meeting on measures for decommissioning/ contaminated water/ treated water. This committee was set up to totally examine the contaminated treatment measures of Fukushima Daiichi and consider the measures to radically solve the problems and to handle leakage accidents of contaminated water including tritium treatment measures.

etc.)[2] [3] [4], set the assessment cases based on the uniformed handling conditions for parallel comparison of 11 options combining five methods (geosphere injection, discharge into the sea, vapor release, hydrogen release, and underground burial) with the presence or absence of pretreatment such as dilution or isotope separation considering foreign cases, etc., and performed technical assessments.

For technical assessments, technical feasibility and regulatory feasibility were set as the basic requirements (items used as criteria to judge feasibility). As conditions which may be constraints on selection, the following evaluation items were set: time and cost required for disposal, scale (area required for disposal), whether any secondary waste is generated/its type and amount, the occurrence of excessive worker exposure from the disposal, and incidental conditions (other conditions which may be constraints).

(2) Overview of consideration by the Subcommittee

The Subcommittee met a total 17 times from November 11, 2016 to January 31, 2020, with the participations of 13 experts in the fields of nuclear power, geotechnical engineering, sociology, environmental science, agriculture, radiobiology, radiation science, and fishery chemistry, and related ministries. The Subcommittee had further discussions about the impact of tritium on organisms[5] [6] as well as comprehensively

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[2] Regarding the environment dynamics of tritium, it was reported that tritium discharged into air exhibited such behaviors such as turbulent dispersion in air, dry or wet deposition on the ground surface, underground advection and diffusion, and evaporation from the ground surface; that a simple assessment is difficult due to a big variation in the dispersion state depending on the weather conditions at the time of discharge; and that the concentration is reduced as it gets away from the location of discharge though it depends on the discharge method and discharge position (Summary of an explanation by Mr. Haruyasu Nagai at the 4th Taskforce, Pages 1 to 9 of the minutes).

[3] As for the environmental impact of tritium, it was explained that there were two types of tritium in organic substances, namely free water tritium (hereinafter called “FWT”) and organically bound tritium (hereinafter called “OBT”), OBT was easy to be absorbed by organisms and has long biological half-life, the in vivo FWT concentration and water tritium concentration counterweighed (becomes almost equal) immediately in the aquatic environment, the concentration factor of tritium (ratio of the in vivo concentration to the water concentration) is 1 or less, dose assessments of marine organisms were performed for “reference animals” (e.g. marine organisms with different shapes such as flatfish and crab), generally the calculation was performed from the radioactive material concentration (Bq/kg - raw organism), and there would be no significant impact on aquatic habitat unless an extremely high concentration of tritium is retained in the aquatic environment (Summary of an explanation by the Taskforce Member Mr. Hideki Kakiuchi at the 3rd meeting of the Taskforce, pp.2-10 of the minutes, Summary of an explanation by the Taskforce Member Takami Morita in the 3rd Taskforce, Pages 14 to 18 of the minutes).

[4] As for the impact of tritium on human bodies, it was explained that the impact of tritium on human bodies was much smaller than that of radioactive cesium set as the standard of radioactive materials in foods, about 1/1,000; tritium caused almost no external exposure, and internal exposure would be considered because it is radionuclide with low-energy beta rays; and tritium exists in two forms, namely FWT and OBT, in organisms and, according to ICRP (International Commission on Radiological Protection), the in vivo half-lives of FWT and OBT were about 10 days and 40 days, respectively (Summary of an explanation by the Taskforce Member Mr. Hideki Kakiuchi in the 3rd Taskforce, Pages 2 to 10 of the minutes; Summary of an explanation by the Taskforce Member Mr. Hideo Tatsuzaki at the 3rd Taskforce, Pages 21 to 25 of the minutes; Summary of an explanation by the Taskforce Member Mr. Hiroshi Tauchi at the 3rd Taskforce, Pages 26 to 33 of the minutes).

[5] It was explained that tritium just emits weak beta rays, the only exposure form with significant impact was internal exposure, it is said that there was almost no in-vivo concentration as characteristics, and it was passed out of the human body by metabolism about 10 days after entering the body since it was a kind of water (Summary of a statement by the Subcommittee Member Yamanishi at the 2nd Subcommittee, Page 34 of the minutes).

[6] It was explained that tritium was not concentrated on specific organisms or organs because molecules containing tritium had

considered the expansion of the tank storage capacity, the possibility to continue tank storage, etc., in addition to the technical viewpoints of the disposal methods and the advantages and disadvantages of the disposal methods taking into consideration the social and environmental impacts of disposal for each of the five disposal methods of ALPS treated water.

The proceedings of the meetings were open to the public, and those who applied and were registered in advance were able to listen to the proceedings at the venue as observers. All of the contents and materials from the discussion of each meeting are available on the website of METI[7]. The following shows the details of consideration at the Taskforce and the Subcommittee.

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the same properties as normal water molecules (Summary of an explanation by the Subcommittee Member Tauchi at the 11th Subcommittee, Page 19 to 24, 32 of the minutes). The following shows the discussion related to these:

(1) "For example, data from Sellafield Bay in the UK shows that the concentration of organically bound tritium in fish is higher than the concentration in seawater when measured at a certain point in time. However, this is because there was a very high concentration of tritiated water that was previously discharged into the sea. When that was taken in, the OBT remained because it has a longer half-life than water. The data shows that, as the years go by, the organic-bound form of the substance decreases rapidly when its concentration in seawater is almost undetectable. Therefore, this is not something that should be called bioaccumulation. Bioaccumulation means that substances in the environment accumulate and become more concentrated in living organisms. I hope you understand that this will not happen with tritium" (statement by the Subcommittee Member Tauchi at the 11th Subcommittee, Page 32 of the minutes).

(2) In response to the question "Have there been any examples of tritium concentrated in nature?" (statement by the Committee Member Mr. Tauchi at the 11th meeting of the Subcommittee, p.32 of the minutes), the answer was "As far as I know, there have been no such cases. If there had been, the tritiated water in the tank could be concentrated by living organisms and removed, but that is not the case" (statement by the Subcommittee Member Tauchi at the 11th Subcommittee, Pages 32 to 33 of the minutes).

(3) "As far as I know, there have been no cases where microorganisms have been cultured in tritiated water in so-called laboratory experiments, and where water-to-biological concentration has been observed. In addition, as Mr. Hiroshi Tauchi mentioned, the tritium concentration in living organisms can appear to be high in the environment. This is due to the fact that organic matter has been accidentally discharged from factories in the past. Because fish migrate, the opposite phenomenon is observed when fish grown in areas with low tritium concentrations go to areas with high concentrations. We have observed that living organisms grown in a place with high tritium concentration appear to be highly tritium-concentrated when they go to a place with low tritium concentration. This is the reality of the situation" (statement of the Subcommittee Member Kakiuchi at the 11th Subcommittee, Pages 33 to 34 of the minutes).

[7] https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/archive/task_force3.html
https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/archive/task_force4.html
https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku.html#osensuitaisaku_mt

B2. Discussion about each disposal method and result of the comparison

(1) Taskforce

The Taskforce set and evaluated the basic requirements (technical feasibility and regulatory feasibility) as well as conditions which may be constraints (time, cost, scale, secondary waste, worker exposure, etc.) as evaluation items for each case (as shown in the Table B-1) and prepared a report as a basic material for future consideration (“Tritiated Water Taskforce Report”[8]) in June 3, 2016 after the discussion and consideration on the technical point of view of each disposal method, environmental impacts, difficulty of monitoring, issues to secure the site, comparisons to precedents, increasing capacity of storage in tanks, and issues arising from storing water in tanks as mentioned below in footnotes of B2. (2) (ii), (3) and (4) using excerption of the discussions,

This report suggests that consideration should be proceeded with from comprehensive viewpoints including not only technical ones such as the feasibility, economy, required time, etc., as well as social ones such as reputation damage because the result may cause big impact on the reputation.

Table: Conditions which may be constraints

Disposal method	Geosphere injection	Discharge into the sea	Vapor release	Hydrogen release	Underground burial
Period[9]	104+20n months 912 months (for monitoring) (n=Number of survey points)	91 months	120 months	106 months	98 months 912 months (for monitoring)
Cost[10]	18+0.65n billion yen+Monitoring cost (n=Number of survey points)	3.4 billion yen	34.9 billion yen	100 billion yen	243.1 billion yen
Scale	380 m^2	400 m^2	2000 m^2	2.000 m^2	285.000 m^2

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[8] Available on the web site of the Ministry of Economy, Trade and Industry. https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20160915_01a.pdf

[9] The procedure is divided in to the plant construction phase and treatment phase, but depending on the method, technical development and some lead time may be required before plant construction (summary of a statement by the Taskforce Member Tokuhiro Yamamoto at the 12th meeting, Page 19 of the minutes)

[10] The following shows the related discussion in the Taskforce.

(1) It turned out that there is no realistic technology to solve the problem with the treatment method of tritium in France within the allowable range of costs. Such a technology may exist but will be too costly. Therefore, it was concluded that such technologies would not be feasible (Summary of a statement by Mr. Jean-Luc Lachaume, at the 7th Taskforce, Page 15 of the minutes).

(2) In France, not segregation but direct discharge of tritium into a river or the sea was adopted considering the cost, advantages, etc. (Summary of a statement by the Committee Member, Mr. Jean-Luc Lachaume, at the 7th Taskforce, Page 21 of the minutes).

Disposal method	**Geosphere injection**	**Discharge into the sea**	**Vapor release**	**Hydrogen release**	**Underground burial**
Secondary waste	N/A	N/A	Depending on the components of treated water, incineration ash may be generated.	Residues may be generated as secondary waste.	N/A
Radiation Exposure of Workers [11]	No points to consider in particular	No points to consider in particular	There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.	There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.	To prevent radiation exposure of workers during the burial operation, installing a cover etc. is needed.
Others	The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer.	In the case of using a divider between the intake water pit and the discharge port, the cost will increase.[12]	The duration may be extended, in case the release operation needs to be suspended due to precipitation.[13]	The duration may be extended, in case the release operation needs to be suspended due to precipitation.[14]	A large amount of concrete and bentonite will be needed. Construction spoil will be produced.[15]

(2) Subcommittee

On February 10, 2020, the Subcommittee prepared a report (“The Subcommittee on Handling of the ALPS Treated Water Report”[16]) considering the result of the Taskforce. The following shows the major contents of consideration.

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[11] “I believe the exposure of workers is quite important, and it should be taken into account. With regard to exposure of workers, if the workers to be deployed were changed rapidly, it would be possible to comply with laws and regulations, but I would like to keep this to a realistic level” (statement by the Taskforce Member Hideo Tatsuzaki at the 13th Taskforce, Page 14 of the minutes).

[12] “In the case of discharge into the sea, if tritium were released and the same water was taken in again, it would make no sense whatsoever. In order to deal with this, some methods of partitioning with wharves, etc. are described, but I’m wondering whether or not it is necessary to state this as an ancillary condition when the cost is calculated” (statement by the Taskforce Member Takami Morita at the 14th Taskforce, Page 13 of the minutes).

[13] “When it comes to implementation of vapor release or hydrogen release, I wonder if it is possible to do so in the midst of heavy snow or rain. If so, I believe the annual operating results, or the actual number of operations, may vary” (statement by the Taskforce Member Mr. Takami Morita at the 13th meeting of the Taskforce, p.13 of the minutes).

[14] Same as the above.

[15] “There is a problem of residual soil buried underground, which hardly arises when it is placed above the groundwater level. This makes me think that the story will be quite different depending on whether we build the plant above or below this groundwater level” (statement by the Taskforce Member Takami Morita at the 13th Taskforce, Page 13 of the minutes).

[16] Available on the web site of the Ministry of Economy, Trade and Industry.
https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/018_00_01.pdf

(i) Social impacts of each disposal method

As for social impacts, the impacts on life and economy (reputation damage) are assumed but it is difficult to comprehensively compare their significance.[17] Therefore, it was concluded that no matter which disposal method of discharge into the sea/vapor release is selected, it will be necessary to prepare for possible reputation damage after disposal considering the characteristics of each disposal method.

(ii) Technical viewpoints of each disposal method considering environmental and social impacts

The Subcommittee considered the realistic options considering in terms of environmental impacts including the continuation of tank storage (as shown in B2. (4) below) based on the technical viewpoint in accordance with the five disposal methods consideration results proposed at the Taskforce (geosphere injection, hydrogen release, underground burial, vapor release, and discharge into the sea.) As a result, for geosphere injection, there was an issue with securing of the site and also the method had not been established to monitor the behavior and effects of tritiated water after geosphere injection[18] [19]. For hydrogen release, further technical development

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[17] "I do not believe that the superiority of social impact is necessarily clear in our discussions so far, as to which has a greater or lesser social impact" (Summary of a statement by the Subcommittee Member Tokuhiro Yamamoto at the 16th Subcommittee, Page 25 of the minutes).

[18] As for geosphere injection, lack of knowledge of appropriate stratum, monitoring, etc. are difficult (Summary of our statement at the 14th Subcommittee, Page 37 of the minutes).

[19] The following shows the related matters discussed at the Subcommittee and then the Taskforce.

(1) If geosphere injection is performed other than at the site, thousands of trucks with water will drive on roads in the prefecture and even an accident of one of the truck will stop the entire process, which is risky (Summary of a statement by Mr. Chuck Negin at the 6th Taskforce, Page 36 of the minutes).
(2) The French regulations prohibit geosphere disposable of radioactive materials (Summary of a statement by Mr. Jean-Luc Lachaume, at the 7th Taskforce, Page 5 of the minutes).
(3) Of course, those without standards require much time and effort. Other one than discharge into the sea after dilution and vapor release after dilution are difficult to assess without knowing the details (Summary of a statement by the regulatory authorities (Chief Mr. Shinji Kinjo) at the 8th Taskforce, Page 35 of the minutes).
(4) It is very important how to explain the option of underground burial while there is a case in France. It cannot be assessed because no underground experiment has been conducted (Summary of a statement by the Taskforce Member Hiroshi Tauchi at the 8th Taskforce, Page 40 of the minutes).
(5) The current legal system does not assume burial disposal of fluid, so it is not an easy task (Summary of a statement by Taskforce Member Hideo Tatsuzaki at the 9th Taskforce, Page 27 of the minutes).
(6) Judging from the requirements of the international guidelines of IAEA and ICRP, direct injection of tritium water is not allowed globally (Summary of a statement by the regulatory authorities (Chief Shinji Kinjo) at the 12th Taskforce, Page 11 of the minutes).
(7) Especially as for geosphere injection, there is no precedent case, so there is no regulation. However, it is a waste of opportunity to abandon it due to the lack of regulatory standards. It would be appreciated if consideration could be made (Summary of a statement by Mr. Takasaka, an expert observer, at the 13th Taskforce, Page 17 of the minutes).
(8) For example, though the method is underground burial, the disposal site of even low-level radioactive waste is a great concern. There may be no candidate for the place of storage of tritium water. If so, the span of time up to construction will be massive (Summary of a statement by the Taskforce Member Yoshihisa Takakura at the 14th Taskforce, Page 16 of the minutes).

was required and there is the possibility of hydrogen explosion[20]. For underground burial, there was a risk of vapor release of tritium caused by heat generated by solidification, new legislation was required, and there was an issue of securing of the site[21] [22] [23]. In addition, the Subcommittee showed its view that there was no realistic model of assessment of environmental impacts of geosphere injection, hydrogen release, and underground burial. However, for vapor release and discharge into the

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[20] The following shows the related discussion in the Taskforce.

(1) With hydrogen distillation, even a small device can achieve a high segregation efficiency thanks to the large separation factor, which is an advantage, but it also has disadvantages: the cost is high due to the necessity for ancillary facilities for achieving a very low liquid hydrogen temperature of about 20 kelvin and it is necessary to consider safety measures for the issue of explosion protection of hydrogen gas, etc., due to high pressure caused by gasification of hydrogen when running out of the coolant and use of massive hydrogen gas (Summary of an explanation by the Taskforce Member Toshihiko Yamanishi at the 2nd Taskforce, Page 11 of the minutes).
(2) The electrolysis method consumes a lot of energy, so as of now electrolysis is rarely used alone for segregation (Summary of an explanation by the Taskforce Member Toshihiko Yamanishi at the 2nd Taskforce, Page 13 of the minutes).
(3) Though the concentration is low, it is significantly different from past research and development and actually operating plants in that extensive treatment is required. Water treatment in Fukushima is much different from that of the past plants and had no track record (Summary of an explanation by the Taskforce Member Toshihiko Yamanishi at the 2nd Taskforce, Page 16 of the minutes).
(4) The treatment amount is thousands of times greater than that of currently operating plants. Normally, in the engineering field, scale-up means making the scale 10 or less times greater, not applying a three-digit figure as it is. It is a difficult question whether the current technology is applicable (Summary of a statement by the Taskforce Member Toshihiko Yamanishi at the 2nd Taskforce, Page 17 of the minutes).

[21] The following shows the related discussion in the Taskforce.

(1) Currently, it is not assumed at all to dispose of liquid waste by injection in Japan. It is only assumed to dispose of solid waste. It is stipulated in the rules (Summary of an explanation by Mr. Yoshiaki Sakamoto at the 4th Taskforce, Page 22 of the minutes)
(2) Basically, the result of the safety assessment depends on the assumed extent of deterioration of concrete; based on it, the degree of leakage is assessed (Summary of an explanation by the Committee Member Yoshiaki Sakamoto at the 4th Taskforce, Page 24 of the minutes)
(3) “For the 800,000 cubic meters, we will need at least 300,000 square meters of land, which will be a very difficult situation” (Summary of an explanation by Mr. Yoshiaki Sakamoto at the 10th Taskforce, Page 7 of the minutes).
(4) In the case of tritium, some effects may appear due to combination of flow of water and dispersion (Summary of an explanation by Mr. Yoshiaki Sakamoto at the 10th Taskforce, Page 12 of the minutes).
(5) For treatment and disposal of radioactive waste, the current basic philosophy is that it should be disposed of in waste body. Cementation of tritium water is somewhat out of the course of this philosophy (Summary of a statement by the regulatory authorities (Chief Shinji Kinjo) at the 10th Taskforce, Page 14 of the minutes)
(6) “I think you are assuming concrete burial but this is only for solid waste from demolition. Also, it is clearly stated in the laws and regulations. However, there is nothing that allows to bury liquid waste as well” (Summary of a statement by the regulatory authorities (Chief Shinji Kinjo) at the 13th Taskforce, Page 19 of the minutes).
(7) For example, though the method is underground burial, the disposal site of even low-level radioactive waste is a great concern. There may be no candidate for the place of storage of tritium water. If so, the span of time up to construction will be massive (Summary of a statement by the Taskforce Member Yoshihisa Takakura at the 14th Taskforce, Page 16 of the minutes)

[22] As for underground burial, there is no track record of disposal, a larger land is required than continuation of storage because solidification makes the volume three or six times larger, and it was reported that solidification generates heat, which causes evaporation of moisture. For this report, no opinion was provided from the Committee (Summary of our report at the 14th Subcommittee, Page 22 of the minutes)

[23] Hydrogen release is the same as vapor release because even if waste is buried underground, tritium will move from the corresponding location, which makes monitoring difficult (Summary of an explanation by the Subcommittee Member Toshihiko Yamanishi at the 16th Subcommittee, Page 31 of the minutes)

sea, environmental impacts were assessed using the assessment model of public exposure in the event of exposure of radioactive nuclides to the environment set by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and all results were sufficiently lower than the annual exposure amount from the nature in Japan, 2.1 mSv (the environmental impact of discharge into the sea is half or less than that of vapor release)[24].

On one hand, since it is difficult to expect the time required to solve these issues and temporal constraints have to be considered, so geosphere injection, hydrogen discharge, and underground burial are associated with many issues from regulatory, technical, and temporal viewpoints. On the other hand, vapor release and discharge into the sea[25] were concluded as realistic options[26] [27].

(3) Advantages and disadvantages of vapor release and discharge into the sea

The Subcommittee compared the advantages and disadvantages of the realistic options, namely vapor release and discharge into the sea.

As a result, it was concluded that though vapor release had a precedent case of the accident reactor at Three Mile Island in the United States occurred in 1979 as well as actual cases of discharge at the time of ventilation even in normal reactors, the wastewater amount in the precedent case of Three Mile Island was significantly smaller than ALPS treated water and there was no domestic case of vaporizing liquid for vapor

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[24] Explanation by the Secretariat at the 15th Subcommittee, Pages 13 to 16 of the minutes. Even if all treated water stored in tanks is treated in one year, the environmental impact is about 0.052μSV to 0.62μSV per year and 1.3μSV per year in discharge into the sea and air, respectively. The following shows the discussion related to these:

(1) To the question of whether the impact is an order of magnitude smaller than exposure from natural radiation even under excessive assumption that the total amount stored in tanks, 860 trillion Bq, is discharged every year for 100 years (Summary of a statement by the Subcommittee Member Sakita at the 15 Subcommittee, Page 19 of the minutes), the answer was yes (Summary of the answer by the Secretariat at the 15th Subcommittee, Page 19 of the minutes).

(2) Even in the case of a heavy water moderated reactor in Canada, which discharges a lot of tritium, the impact of the concentration of tritium drops to a level close to the background in a location about 5 km away, so there was a statement that the simulation result based on UNSCEAR was appropriate as a simulation result of the impact on residents in locations about 5 km away from the facility (Summary of a statement by the Subcommittee Member Kakiuchi at the 15th Subcommittee, Pages 19 to 20 of the minutes).

[25] It was explained that tritium had been generated by domestic and foreign nuclear power plants, etc., associated with their operation and a part of such tritium had been discharged into the sea, rivers, lakes and marshes, and air according to the regulations in each country (Summary of an explanation by the Secretariat at the 8th Subcommittee, Pages 4 of the minutes).

[26] It is important to commit to perform the proven options, namely discharge into the sea and vapor release, among the five disposal methods (Summary of an explanation by the Subcommittee Member Yuko Sakita at the 16th Taskforce, Page 28 of the minutes).

[27] Among the five disposal methods, only discharge into the sea and vapor discharge are technically feasible (Summary of an explanation by the Subcommittee Member Toshihiko Yamanishi at the 16th Subcommittee, Page 31 of the minutes).

release for the purpose of disposal of liquid radioactive waste[28] [29]. In addition, prediction is difficult due to deposition on the ground surface and evaporation into the air after vapor release, and there will be demerit that the fluctuation of the monitoring result caused by the weather conditions is larger than discharge into the sea[30] [31]. Moreover, from social viewpoints, a wider range of industries are expected to be affected as compared to the case of discharge into the sea and reputation damage may occur in

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[28] The following shows the related discussion in the Taskforce.

(1) The amount of water handled at TMI (Note: Three Mile Island) is completely different from that of Fukushima, so naturally technical discussion will be different. It was reported that the amounts of contaminated water were about 10 thousand tons and the evaporated amount was about 8,400 tons. Therefore, naturally the technologies to be provided and the assessment will be different, but even TMI achieved the goal in more than 10 years (Summary of a statement by the regulatory authorities (Chief Shinji Kinjo) at the 1st Taskforce, Page 28 of the minutes).

(2) Though the concentration is low, it is significantly different from past research and development and actually operating plants in that extensive treatment is required. Water treatment in Fukushima is much different from that of the past plants and had no track record (Summary of an explanation by the Taskforce Member Toshihiko Yamanishi at the 2nd Taskforce, Page 16 of the minutes).

(3) The scales of Three Mile and Fukushima are completely different. In the case of Three Mile, an accident occurred in only one reactor and the condition has calmed down, but the condition of Fukushima has yet to calm down (Summary of a statement by the Taskforce Member Yoshihisa Takakura at the 6th Taskforce, Page 18 of the minutes).

(4) I understand that there is a big difference between the two accidents. And I also understand that the problem in Japan is much more significant than in TMI. In principle, we had no problem of accumulation. So we could wait and see. However, in the case of Fukushima, it is very important to solve the problem as soon as possible (Summary of a statement by Mr. Chuck Negin at the 6th Taskforce, Page 18 of the minutes).

(5) It is necessary to proceed with discussion understanding the similarity to and difference from TMI, but we must remember that although the concentration of the tritium is very close, the amount is much larger in Fukushima. In the case of TMI, in reality, the reactor is 160 km away from the coast, which would be almost equivalent to the case of a reactor at an inland site in the case of Japan, so the geographical environment seems to be much different (Summary of a statement by the Taskforce Member Tokuhiro Yamamoto at the 6th Taskforce, Page 21 of the minutes).

(6) In France, the amount of tritium discharged in liquid is much greater than that discharged into air. This is because tritium causes a greater impact on human body when released in gas than in liquid (Summary of an explanation by Mr. Jean-Luc Lachaume, at the 7th Taskforce, Page 7 of the minutes).

(7) In the case of Three Mile, it was possible because the amount was very limited, but it is too different from the case of Fukushima to be applicable (Summary of a statement by the Committee Member Yoshihisa Takakura at the 13th Taskforce, Page 11 of the minutes).

[29] In terms of the required time and cost, discharge into the sea is easier. The reason vapor release was performed in the case of the Three Mile accident is that the reactor was not adjacent to the sea (Summary of a statement by the Subcommittee Member Ichiro Yamamoto at the 14th Subcommittee, Page 39 of the minutes).

[30] It was reported that there was a problem with monitoring for vapor release because it is difficult to predict generation and dispersion of waste, especially salt, caused by evaporation of ALPS water. For this report, no opinion was provided from the Committee (Summary of our report at the 14th Subcommittee, Page 22 of the minutes).

[31] The following shows the related discussion in the Taskforce.

(1) As for atmospheric dispersion, the speed of especially redispersion of tritium is high. Tritium is much different from other radioactive materials in that most of it evaporates again and returns to the air (Summary of an explanation by Mr. Haruyasu Nagai at the 4th Taskforce, Page 2 of the minutes).

(2) The dispersion condition greatly depends on the weather conditions at the time of discharge. It also greatly varies within a day. As the weather condition varies from hour to hour, the conditions change from moment to moment, so the necessity for adjusting the assessment based on the conditions is a difficult point in atmospheric dispersion (Summary of an explanation by Mr. Haruyasu Nagai at the 4th Taskforce, Pages 2 and 3 of the minutes).

(3) We assessed the reduction of the concentration caused by marine dispersion from the viewpoint of the degree of dilution by advection and diffusion assuming discharge from a typical Pacific coast. The concentration of the lattice in the discharge position and 2 km lattice decreases by 1, 2, and 3 digits about 10 km, 50 km, and 100 km downstream. This is different from air. The current varies little, so prediction is easier (Summary of an explanation by Mr. Haruyasu Nagai at the 4th Taskforce, Page 8 of the minutes).

industries in Fukushima and the whole of the surrounding areas.

On the other hand, there are many actual cases of discharge into the sea as being implemented in domestic and foreign nuclear facilities on daily bases and about 31.6 billion to 83 trillion Bq/year (actual average of 3 years before the accident) per site is diluted and discharged into the sea, etc., from the domestic nuclear power plants. Therefore, the discharge into the sea was concluded to be possible within the proven range even considering the disposal amount. In addition, because the composition of the discharge facility is simpler than the composition of the vapor release facility, and knowhow on the design of the discharge system and its handling are known. Thus, it was concluded that it will be able to surely dispose the waster better than vapor release in knowledge of the facility and operation point of view. Moreover, in the case of discharge into the sea, the condition of dilution dispersion after discharge is relatively easy to predict because the variation in the current is smaller than the impacts of rain and wind direction in the case of vapor release, so it was easier to consider the construction of the surveillance framework by monitoring[32] [33] [34].

From social viewpoints, discharge into the sea may cause reputation damage in the fishing industry and tourism in Fukushima and the surrounding sea area. Especially, the catches of the fishing industry in Fukushima, which is now in test operation, are yet to be less than 20% of that before the earthquake and the Fukushima Daiichi accident. Considering these, it is necessary to consider countermeasures[35].

(4) Consideration of the expansion of the tank storage capacity and continuation of tank storage

The Subcommittee considered the measure to expand the tank storage capacity and continue tank storage without disposing of ALPS treated water as follows[36].

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[32] See footnote [31] (3)

[33] For our explanation that there is no technically difficult issue in discharge into the sea, no opinion was shown (Summary of our report at the 14th Subcommittee, Page 21 of the minutes).

[34] There are several methods of discharge into the sea including construction of a new pool or equalizing the concentration before discharge in a new tank, etc., and then rechecking them, which is not technically difficult up to construction (Summary of a statement by the Subcommittee Member Yoshihisa Takakura at the 16th Subcommittee, Page 37 of the minutes).

[35] It was explained that the social impacts of discharge in the sea widely affects areas outside Fukushima, but the impacts on land areas are limited and the directly affected parties are limited to the fishing industry and a part of tourism, such as sea bathing while vapor release widely affects up to areas outside Fukushima and may directly affects all products. There was no objection (Summary of an explanation by the Secretariat at the 12th Subcommittee, Pages 13 of the minutes).

[36] The following shows the related discussion in the Taskforce.

(1) “Even if it is stored, there is a possibility of sudden leakage.”, “Even if it is stored in tanks, is it enough to just store it? I think that some sort of tank maintenance will probably be necessary during that period, and depending on the endurance of the tanks, it may be necessary to transfer it from one tank to another, and so on, and the risk of accidents, including radiation exposure of workers, must be considered.” (Statement of the Taskforce Member Hideo Tatsuzaki at the 1st Taskforce, Pages 18 and 19 of the minutes).

(2) As long as a lot of tritium water is stored, the risk will not become zero. There must be some risks associated with

(i) Expansion of the tank storage capacity

The Subcommittee considered storage in large-capacity aboveground tanks and storage in underground and offshore tanks. As a result, it was concluded that the storage capacity of large-capacity aboveground and underground tanks is not significantly larger than that of the existing standard tanks but had issues such as much greater leakage amounts in the case of damage. Offshore tanks of the size adopted for oil storage bases are difficult to install because the water depth is shallow in the Fukushima Daiichi port. Moreover, it is difficult to collect leaked water before dilution. In accordance of those considerations, there was no advantage in installation of the large tanks, etc. at Fukushima Daiichi[37].

Though storage by transfer to outside of the site was also considered, in order to prevent leakage or accident caused by transfer of water before dilution, it takes much time to plan and prepare a method to transfer a lot of treated water due to the necessity for transfer facilities compliant with laws and regulations (e.g. nuclear material protection facility surrounding the piping for transfer (fence, etc.)) as well as getting approval from the local governments on the transfer route. In addition, it was concluded to take much time because proper facilities, diverse preliminary adjustments, and procedures for permission are required due to the necessity for permission as a radioactive waste storage facility since radioactive materials are handled[38].

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continuation of storage (Summary of a statement by the Taskforce Member Tokuhiro Yamamoto at the 1st Taskforce, Page 22 of the minutes).

(3) In reality, one 1,000-ton tank is prepared every two days, which is associated with concerns of leakage and human errors. Tritium must be handled smoothly, otherwise there will be so many tanks that management, etc., may be very difficult. If it continues for 30 or 40 years, we will run out of space for tanks (Summary of a statement by the Taskforce Member Yoshihisa Takakura at the 4th Taskforce, Page 28 of the minutes).

(4) For storage, it is necessary to consider the possibility of future relocation of the storage space; if we wait for the half-life, it will be unrealistic to wait for, for example, three half-lives because it is too long. In addition, we have to take some countermeasures against the risk of unexpected accidents during storage such as the risk of discharge of stored water (Summary of a statement by the Taskforce Member Hideo Tatsuzaki at the 4th Taskforce, Pages 32 and 33 of the minutes).

(5) “Of course, accidents can occur in the course of the construction of the tanks, and there is also the risk of massive leakage if the tanks are damaged. In that sense, we think it is riskier to keep the water in the tanks on the site” (Statement of the regulatory authorities (Chief Shinji Kinjo) at the 13th Taskforce, Page 22 of the minutes).

(6) “At present, for example, we have already built almost all the tanks in the areas that are relatively close to where contaminated water is generated and where tanks can be placed. If we build new tanks in the future, we would have to set up pipes to transfer the water over a long distance, and if we transfer the water over such a long distance, there would naturally be risks of leakage and other problems. Even if we manage to increase the capacity of the current area by replacing the tanks with new ones with a larger capacity, there is not much room left in the current area.” (Our statement at the 14th Taskforce, Pages 17 and 18 of the minutes).

[37] The advantages and disadvantages of each of the following methods assumed in the case of continuation of storage were explained: storage in large-capacity tanks, storage in large-capacity underground tanks, and storage in offshore tanks (Summary of our explanation at the 13th Subcommittee, Pages 34 and 35 of the minutes)

[38] It was explained that storage outside the site requires approval from the local governments on the transfer route in the case of transfer without dilution and transfer facilities, etc., compliant with laws and regulations were required, and there was no opinion to it (Summary of our explanation at the 13th Subcommittee, Page 35 of the minutes).

(ii) Continuation of tank storage

At the Subcommittee, the possibility of continuation of storage in tanks was also taken into consideration, however there is an issue pointed out as actual risk of handling of remaining ALPS treated water after storage, including the fracture of the tank due to the earthquake[39] [40]. In principle, it is important to proceed with reconstruction of Fukushima and decommissioning in parallel and it is necessary to finish disposal of ALPS treated water as a part of decommissioning in order to complete decommissioning of Fukushima Daiichi, so it was concluded that the water would have to be treated by the end of decommissioning even if storage was continued[41].

In addition, the Subcommittee concluded that transfer of radioactive waste to outside the site and expansion of the site to continue tank storage required understanding from the local governments, etc., of the area where the storage facility would be constructed and get permission as a radioactive waste storage facility, which would require so much adjustments and time up to implementation that the only possible method was to use standard tanks with improved installation efficiency at the site and the room for addition of more tanks than specified in the current plan was limited.

The Subcommittee pointed out that decommissioning required securing of places for construction of various facilities such temporary storage facilities for spent fuel and fuel debris, analysis facilities for various samples, storage facilities for fuel debris retrieval equipment, mock-up and training facilities for fuel debris retrieval, and waste recycling facilities[42].

B3. Assessment by IAEA

While the government had been proceeding with consideration, IAEA reviewed the disposal methods of ALPS treated water at all of the 4th peer review missions and recommended the Government of Japan to urgently determine how to dispose of ALPS treated water, which had been accumulated in the tanks at the Fukushima Daiichi site in the report of the 4th mission issued on January 31, 2019[43] [44].

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[39] Continuation of storage in tanks is associated with a fracture risk of tanks due to earthquake (Summary of a statement by the Subcommittee Member Hideki Kakiuchi at the 13th Subcommittee, Page 25 of the minutes).

[40] Even if we select continuation of storage, eventually it will be necessary to treat remaining tritium (Summary of a statement by the Subcommittee Member Hideki Kakiuchi at the 13th Subcommittee, Page 25 of the minutes)

[41] To the question “Will decommissioning continue as long as storage continues?” the Secretariat answered yes (Summary of a statement by the Subcommittee Member Takami Morita and summary of our statement at the 14th Subcommittee, Pages 24 and 25 of the minutes).

[42] Decommissioning required securing of areas in order not to hinder other operations (Summary of a statement by the Subcommittee Member Tokuhiro Yamamoto at the 13th Subcommittee, Page 26 of the minutes).

[43] 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 (Fourth Mission) Tokyo and Fukushima Daiichi NPS, Japan 5-13 November,” Page 8, etc.

[44] The IAEA also emphasized that the decision of the basic policy on handling of treated water by the Japanese government would encourage the whole procedure of decommissioning saying “The decision on ALPS treated water disposition path

Then, IAEA appraised the consideration result of the disposal methods of ALPS treated water by the government as mentioned above as follows in the report issued on April 2, 2020, in the review performed as follow-up for the 4th mission.

“Regarding the technical aspects, the IAEA Review Team considers that the recommendations made by the ALPS Subcommittee are based on a sufficiently comprehensive analysis and on a sound scientific and technical basis. The IAEA Review Team considers that the proposed objective of completing the disposition of the ALPS treated water by the time of the end of the decommissioning work is aligned with current international good practices. The IAEA Review Team considers the two options (namely controlled vapor release and controlled discharges into the sea, the latter of which is routinely used by operating nuclear power plants and fuel cycle facilities in Japan and worldwide) selected out of the initial five options are technically feasible and would allow the timeline objective to be achieved.

With the volume of ALPS treated water expected to reach the planned tank capacity of approximately 1.37 million m3 around the summer of 2022[45], s and taking into account that further treatment to meet regulatory standards for discharge before dilution and control of the stored water before disposition would be needed for implementation of any of the solutions considered by the Government of Japan, a decision on the disposition path should be taken urgently engaging all stakeholders."[46] [47]

B4. Summary

As described above, the Taskforce and Subcommittee discussed disposal of ALPS treated water, which had been an issue in decommissioning of Fukushima Daiichi, in detail for as long as six years, and considered the five disposal methods (geosphere injection, hydrogen release, underground burial, vapor release, and discharge into the sea) and continuation of tank storage from technical viewpoints. Based on the consideration result, the Subcommittee presented the conclusion that proven vapor release or discharge into the sea are the realistic options. Then the Subcommittee compared vapor release and discharge into the sea to present a view that discharge into the sea had more track records in terms of the relationship with the discharge disposal amount and was more reliable

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was an important advisory point of previous reviews, and it will facilitate the implementation of the whole decommissioning plan.” (Acknowledgement 2) in the 5th review mission report prepared after the policy was decided.

[45] The timing when the tanks are expected to be full is as of 2020 and may change depending on conditions.

[46] IAEA “Review Report IAEA Follow-up Review of Progress Made on Management of ALPS Treated Water and the Report of the Subcommittee on Handling of ALPS Treated water at TEPCO’s Fukushima Daiichi Nuclear Power Station,” Page 6.

[47] The Director General Grossi of IAEA also made a similar statement when the Japanese government decided the Basic Policy. “... Controlled water discharges into the sea are routinely used by operating nuclear power plants in the world and in the region under specific regulatory authorisations based on safety and environmental impact assessments.”, IAEA website dated April 13, 2021. https://www.iaea.org/newscenter/pressreleases/iaea-ready-to-support-japan-on-fukushima-water-disposal-director-general-grossi-says

including ease of handling of discharge facilities and monitoring methods.
The Subcommittee also presented a negative view on the continuation of storage in tanks considering the necessity for disposal of ALPS treated water for decommissioning of Fukushima Daiichi, the substantial need for the land required for future decommissioning due to the limited room for the additional tanks than specified in the current plan, and the risk factors such as the risk of leakage of treated water caused by a rupture of a tank.
Thus, the Subcommittee assessed disposal of ALPS treated water is appropriate based on the premise of the disadvantage of continuation of storage in tanks and the advantage of discharge, which has no issue with safety as long as discharge complies with the regulatory standard.
This consideration result of the government was appraised by IAEA.

Reference C Setting of previous management values and exposure assessment of hypothetical ALPS treated water

In discharge of ALPS treated water into the sea, sufficient safety is secured by verifying that the sum of the ratios to regulatory concentrations limits of nuclides other than tritium is less than 1 and diluting with seawater 100 or more times at the time of discharge so that the tritium concentration greatly falls below the regulatory concentration limit, but migration in the environment varies among nuclides, so the impact on exposure is different even among nuclides with the same regulatory concentrations limit. In the assessment of design stage, we proposed individual manage eight nuclides important for exposure in order to limit this uncertainty of the source term and reduce the impacts on the external environment further. On the other hand, in this assessment of construction stage, the source term was newly redefined with 30 nuclides. The management once have been set at the design stage will not adopt, because 7 nuclides out of the 8 nuclides were not determined as nuclideds to be measured and assessed due to their short half-lives, etc. We describe the consideration process of the selection of nuclides subject to management (hereinafter called as “nuclides subject to previous management”) and the management value for each nuclide (hereinafter called as “previous management value”) in the assessment of design stage for record in this Reference C.

The previous management values were set by the following procedure.

1. Selection of nuclides important in terms of exposure
2. Setting of the previous management values of the selected nuclides

If any concentration exceeding the set previous management value is detected, we did not discharge the water and transferred it to secondary treatment. However, these eight nuclides shall be reviewed as needed based on the review result of nuclides subject to measurement before future discharge.

C1. Selection of nuclides subject to previous management

Regulatory concentration limits are set so that the annual exposure does not exceed 1mSv even in the case of ingestion of radioactive materials contained in the liquid on a daily basis. Therefore, the annual exposure amount from direct ingestion is comparable among different nuclides as long as their regulatory concentration ratios are the same, and the annual exposure will not exceed 1 mSv and as long as the sum of the ratios to regulatory concentrations limits is less than 1 even if multiple nuclides are included.

On the other hand, the behavior varies among elements such as migration to organisms in the environment, so the impact on exposure varies among nuclides discharged even with the same regulator concentration limit.

Therefore, to verify the exposure impact of each nuclide discharged with the same regulator concentration limit, we assessed exposure from discharge of ALPS treated water containing the corresponding nuclides only at the regulatory concentration limits (the sum of the ratios to regulatory concentrations limits is 1) for one year, though it is unrealistic, and selected nuclides important in terms of exposure assessment.

a. Source term

Based on the following conditions, we set the source term of each nuclide (annual discharge amount) of each nuclide as shown in Table C-1.

- Set the tritium concentration used for assessment at 100,000 Bq/L, which is the lower than the ever since measured tritium concentration of about 150,000 Bq/L, to estimate larger annual discharge volume of water and annual discharge amount of the nuclides other than tritium which proportion to the annual discharge volume of water.
- Set the annual discharge amount by multiplying the regulatory concentration of each nuclide by the annual discharge volume of water.

b. Concentration of each nuclide used for the exposure assessment in the seawater

The concentration of each nuclide in the seawater used for exposure assessment was calculated from the ratio of tritium to the annual discharge amount of each nuclide based on the annual average concentration within 10 km × 10 km of the tritium concentration in the seawater (all layers) in Table 6-1-17. Table C-2 shows the concentration of each nuclide in the seawater used for the assessment.

c. Assessment targets

The assessment targets are internal exposure from beach sand, which is significantly affected by external exposure, internal exposure from ingestion of seafood, and exposure for environment protection.

The exposure assessment method is the same as 6-1-2. “Assessment method” and persons subject to the assessment evaluation are those who ingest a large amount of seafood.

d. Exposure assessment result and selection of nuclides subject to previous management

Table C-3 shows the assessment result of internal exposure of adults from each nuclide discharged at the regulatory concentration limit in descending order of the value. We selected the eight nuclides whose exposure amount exceeds 0.001 mSv/year when discharged at the regulatory concentration limit as nuclides subject to previous management, which are nuclides with significant impacts on the exposure assessment.

As for external exposure from beach sand, there are some nuclides whose exposure amount exceeds 0.001 mSv/year when discharged at the regulatory concentration limit, but as shown in Table C-4, the dose conversion factor of Co-60 is used for all of these nuclides and the actual impact on external exposure is much smaller than Co-60 considering the energy and discharge rate of photons discharged by each nuclide, so such nuclides are deemed not to be subject to previous management.

e. Confirmation regarding environmental protection

Consideration had focused on the impact of human exposure, but this time we confirmed whether there is any nuclide subject to previous management from the viewpoint of environmental protection.

Specifically, we assessed the impact of exposure of each nuclide on marine plants and animals by the assessment method shown in 7-2. “Assessment method” using the source term of a. Table C-5 shows the assessment results in descending order of the value.

The nuclide with the greatest impact of exposure is Fe-59, but it is lower than the lower limit value of the derived consideration reference level (DCRL). We judged that there was no nuclide to be added as a previous management target from the viewpoint of environmental protection because Fe-59 had been subject to previous management for reduction of human exposure and the assessment values of the other nuclides are an order of magnitude smaller than that of Fe-59.

Table C-1 Source term to verify the impacts of 63 nuclides other than tritium (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
H-3	1.0E+05	2.2E+08	2.2E+13	• For the annual discharge amount of tritium, the upper limit value is used. • The concentration of tritium is set to a lower value than the concentration of stored ALPS treated water, etc., because a relatively large annual discharge volume of water is set. • This source term is used for the assessment of the case of discharge of ALPS treated water containing only the corresponding nuclides at their regulatory concentration limits (the sum of the ratios to regulatory concentrations limits is 1) to verify the impact of exposure of each nuclide, and water of such quality will be never been discharged actually.
C-14	2.0E+03	2.2E+08	4.4E+11	
Mn-54	1.0E+03	2.2E+08	2.2E+11	
Fe-59	4.0E+02	2.2E+08	8.8E+10	
Co-58	1.0E+03	2.2E+08	2.2E+11	
Co-60	2.0E+02	2.2E+08	4.4E+10	
Ni-63	6.0E+03	2.2E+08	1.3E+12	
Zn-65	2.0E+02	2.2E+08	4.4E+10	
Rb-86	3.0E+02	2.2E+08	6.6E+10	
Sr-89	3.0E+02	2.2E+08	6.6E+10	
Sr-90	3.0E+01	2.2E+08	6.6E+09	
Y-90	3.0E+02	2.2E+08	6.6E+10	
Y-91	3.0E+02	2.2E+08	6.6E+10	
Nb-95	1.0E+03	2.2E+08	2.2E+11	
Tc-99	1.0E+03	2.2E+08	2.2E+11	
Ru-103	1.0E+03	2.2E+08	2.2E+11	
Ru-106	1.0E+02	2.2E+08	2.2E+10	
Rh-103m	2.0E+05	2.2E+08	4.4E+13	
Rh-106	3.0E+05	2.2E+08	6.6E+13	
Ag-110m	3.0E+02	2.2E+08	6.6E+10	
Cd-113m	4.0E+01	2.2E+08	8.8E+09	
Cd-115m	3.0E+02	2.2E+08	6.6E+10	
Sn-119m	2.0E+03	2.2E+08	4.4E+11	
Sn-123	4.0E+02	2.2E+08	8.8E+10	
Sn-126	2.0E+02	2.2E+08	4.4E+10	
Sb-124	3.0E+02	2.2E+08	6.6E+10	
Sb-125	8.0E+02	2.2E+08	1.8E+11	
Te-123m	6.0E+02	2.2E+08	1.3E+11	
Te-125m	9.0E+02	2.2E+08	2.0E+11	
Te-127	5.0E+03	2.2E+08	1.1E+12	
Te-127m	3.0E+02	2.2E+08	6.6E+10	
Te-129	1.0E+04	2.2E+08	2.2E+12	
Te-129m	3.0E+02	2.2E+08	6.6E+10	

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
I-129	9.0E+00	2.2E+08	2.0E+09	
Cs-134	6.0E+01	2.2E+08	1.3E+10	
Cs-135	6.0E+02	2.2E+08	1.3E+11	
Cs-136	3.0E+02	2.2E+08	6.6E+10	
Cs-137	9.0E+01	2.2E+08	2.0E+10	
Ba-137m	8.0E+05	2.2E+08	1.8E+14	
Ba-140	3.0E+02	2.2E+08	6.6E+10	
Ce-141	1.0E+03	2.2E+08	2.2E+11	
Ce-144	2.0E+02	2.2E+08	4.4E+10	
Pr-144	2.0E+04	2.2E+08	4.4E+12	
Pr-144m	4.0E+04	2.2E+08	8.8E+12	
Pm-146	9.0E+02	2.2E+08	2.0E+11	
Pm-147	3.0E+03	2.2E+08	6.6E+11	
Pm-148	3.0E+02	2.2E+08	6.6E+10	
Pm-148m	5.0E+02	2.2E+08	1.1E+11	
Sm-151	8.0E+03	2.2E+08	1.8E+12	
Eu-152	6.0E+02	2.2E+08	1.3E+11	
Eu-154	4.0E+02	2.2E+08	8.8E+10	
Eu-155	3.0E+03	2.2E+08	6.6E+11	
Gd-153	3.0E+03	2.2E+08	6.6E+11	
Tb-160	5.0E+02	2.2E+08	1.1E+11	
Pu-238	4.0E+00	2.2E+08	8.8E+08	
Pu-239	4.0E+00	2.2E+08	8.8E+08	
Pu-240	4.0E+00	2.2E+08	8.8E+08	
Pu-241	2.0E+02	2.2E+08	4.4E+10	
Am-241	5.0E+00	2.2E+08	1.1E+09	
Am-242m	5.0E+00	2.2E+08	1.1E+09	
Am-243	5.0E+00	2.2E+08	1.1E+09	
Cm-242	6.0E+01	2.2E+08	1.3E+10	
Cm-243	6.0E+00	2.2E+08	1.3E+09	
Cm-244	7.0E+00	2.2E+08	1.5E+09	

Table C-2 Concentration in the seawater used for the assessment

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)	Concentration in the seawater used for the assessment (Sandy beach assessment point)
		Mean concentration of all layers (Bq/L)	Mean concentration of all layers (Bq/L)
H-3	2.2E+13	5.6E-02	8.8E-01
C-14	4.4E+11	1.1E-03	1.8E-02
Mn-54	2.2E+11	5.6E-04	8.8E-03
Fe-59	8.8E+10	2.2E-04	3.5E-03
Co-58	2.2E+11	5.6E-04	8.8E-03
Co-60	4.4E+10	1.1E-04	1.8E-03
Ni-63	1.3E+12	3.4E-03	5.3E-02
Zn-65	4.4E+10	1.1E-04	1.8E-03
Rb-86	6.6E+10	1.7E-04	2.6E-03
Sr-89	6.6E+10	1.7E-04	2.6E-03
Sr-90	6.6E+09	1.7E-05	2.6E-04
Y-90	6.6E+10	1.7E-04	2.6E-04
Y-91	6.6E+10	1.7E-04	2.6E-03
Nb-95	2.2E+11	5.6E-04	8.8E-03
Tc-99	2.2E+11	5.6E-04	8.8E-03
Ru-103	2.2E+11	5.6E-04	8.8E-03
Ru-106	2.2E+10	5.6E-05	8.8E-04
Rh-103m	4.4E+13	1.1E-01	8.8E-03
Rh-106	6.6E+13	1.7E-01	8.8E-04
Ag-110m	6.6E+10	1.7E-04	2.6E-03
Cd-113m	8.8E+09	2.2E-05	3.5E-04
Cd-115m	6.6E+10	1.7E-04	2.6E-03
Sn-119m	4.4E+11	1.1E-03	1.8E-02
Sn-123	8.8E+10	2.2E-04	3.5E-03
Sn-126	4.4E+10	1.1E-04	1.8E-03
Sb-124	6.6E+10	1.7E-04	2.6E-03
Sb-125	1.8E+11	4.5E-04	7.0E-03
Te-123m	1.3E+11	3.4E-04	5.3E-03
Te-125m	2.0E+11	5.0E-04	7.9E-03
Te-127	1.1E+12	2.8E-03	4.4E-02
Te-127m	6.6E+10	1.7E-04	2.6E-03
Te-129	2.2E+12	5.6E-03	2.6E-03
Te-129m	6.6E+10	1.7E-04	2.6E-03

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (within 10 km × 10 km)	Concentration in the seawater used for the assessment (Sandy beach assessment point)
		Mean concentration of all layers (Bq/L)	Mean concentration of all layers (Bq/L)
I-129	2.0E+09	5.0E-06	7.9E-05
Cs-134	1.3E+10	3.4E-05	5.3E-04
Cs-135	1.3E+11	3.4E-04	5.3E-03
Cs-136	6.6E+10	1.7E-04	2.6E-03
Cs-137	2.0E+10	5.0E-05	7.9E-04
Ba-137m	1.8E+14	4.5E-01	7.9E-04
Ba-140	6.6E+10	1.7E-04	2.6E-03
Ce-141	2.2E+11	5.6E-04	8.8E-03
Ce-144	4.4E+10	1.1E-04	1.8E-03
Pr-144	4.4E+12	1.1E-02	1.8E-03
Pr-144m	8.8E+12	2.2E-02	1.8E-03
Pm-146	2.0E+11	5.0E-04	7.9E-03
Pm-147	6.6E+11	1.7E-03	2.6E-02
Pm-148	6.6E+10	1.7E-04	2.6E-03
Pm-148m	1.1E+11	2.8E-04	4.4E-03
Sm-151	1.8E+12	4.5E-03	7.0E-02
Eu-152	1.3E+11	3.4E-04	5.3E-03
Eu-154	8.8E+10	2.2E-04	3.5E-03
Eu-155	6.6E+11	1.7E-03	2.6E-02
Gd-153	6.6E+11	1.7E-03	2.6E-02
Tb-160	1.1E+11	2.8E-04	4.4E-03
Pu-238	8.8E+08	2.2E-06	3.5E-05
Pu-239	8.8E+08	2.2E-06	3.5E-05
Pu-240	8.8E+08	2.2E-06	3.5E-05
Pu-241	4.4E+10	1.1E-04	1.8E-03
Am-241	1.1E+09	2.8E-06	4.4E-05
Am-242m	1.1E+09	2.8E-06	4.4E-05
Am-243	1.1E+09	2.8E-06	4.4E-05
Cm-242	1.3E+10	3.4E-05	5.3E-04
Cm-243	1.3E+09	3.4E-06	5.3E-05
Cm-244	1.5E+09	3.9E-06	6.2E-05
Target exposure pathway		Ingestion of seafood	From beach sand

Reference C-7

Table C-3 Internal exposure assessment result from ingestion of seafood in the case of discharge of each nuclide at the regulatory concentration limit (adult) (Selected 8 nuclides exceeding 0.001 mSv/year as previous management targets)

No.	Target nuclide	Regulatory concentration limit (Bq/L)	Internal exposure dose from ingestion of seafood (mSv/year)	Remarks
1	Sn-126	6.0E+04	2.6E-02	Previous operation and management targets
2	Sn-123	2.0E+03	2.3E-02	Previous operation and management targets
3	Sn-119m	1.0E+03	1.9E-02	Previous operation and management targets
4	Fe-59	4.0E+02	5.6E-03	Previous operation and management targets
5	Cd-115m	1.0E+03	1.4E-03	Previous operation and management targets
6	C-14	2.0E+02	1.3E-03	Previous operation and management targets
7	Cd-113m	6.0E+03	1.3E-03	Previous operation and management targets
8	Ag-110m	2.0E+02	1.0E-03	Previous operation and management targets
9	Zn-65	3.0E+02	8.4E-04	
10	Mn-54	3.0E+02	5.2E-04	
11	Co-58	3.0E+01	2.5E-04	
12	Co-60	3.0E+02	2.3E-04	
13	Tc-99	3.0E+02	2.1E-04	
14	Te-129m	1.0E+03	1.4E-04	
15	Te-127	1.0E+03	1.3E-04	
16	Te-123m	1.0E+03	1.3E-04	
17	Eu-155	1.0E+02	1.3E-04	
18	Te-125m	2.0E+05	1.2E-04	
19	Pm-148m	3.0E+05	1.1E-04	
20	Eu-152	3.0E+02	1.1E-04	
21	Te-127m	4.0E+01	1.1E-04	
22	Gd-153	3.0E+02	1.1E-04	
23	Pm-146	2.0E+03	1.1E-04	
24	Pm-148	4.0E+02	1.1E-04	
25	Eu-154	2.0E+02	1.1E-04	
26	I-129	3.0E+02	1.1E-04	
27	Sm-151	8.0E+02	1.0E-04	
28	Pm-147	6.0E+02	1.0E-04	
29	Am-241	9.0E+02	1.0E-04	

No.	Target nuclide	Regulatory concentration limit (Bq/L)	Internal exposure dose from ingestion of seafood (mSv/year)	Remarks
30	Am-243	5.0E+03	1.0E-04	
31	Am-242m	3.0E+02	9.7E-05	
32	Pu-239	1.0E+04	8.4E-05	
33	Pu-240	3.0E+02	8.4E-05	
34	Ce-144	9.0E+00	8.4E-05	
35	Pu-241	6.0E+01	8.1E-05	
36	Pu-238	6.0E+02	7.8E-05	
37	Ni-63	3.0E+02	7.7E-05	
38	Cm-243	9.0E+01	6.3E-05	
39	Cm-244	8.0E+05	5.9E-05	
40	Ce-141	3.0E+02	5.7E-05	
41	Cm-242	1.0E+03	5.0E-05	
42	Tb-160	2.0E+02	4.9E-05	
43	Nb-95	2.0E+04	2.7E-05	
44	Sb-125	4.0E+04	2.4E-05	
45	Sb-124	9.0E+02	2.0E-05	
46	Ru-103	3.0E+03	2.0E-05	
47	Ru-106	3.0E+02	1.9E-05	
48	Y-91	5.0E+02	1.7E-05	
49	Cs-135	8.0E+03	6.2E-06	
50	Cs-137	6.0E+02	6.1E-06	
51	Cs-134	4.0E+02	5.9E-06	
52	Cs-136	3.0E+03	4.7E-06	
53	Te-129	3.0E+03	3.0E-06	
54	Y-90	5.0E+02	2.0E-06	
55	Ba-140	4.0E+00	9.8E-07	
56	Pr-144	4.0E+00	6.7E-07	
57	Rb-86	4.0E+00	6.3E-07	
58	Sr-90	2.0E+02	2.9E-07	
59	Sr-89	5.0E+00	2.7E-07	
60	Rh-103m	5.0E+00	1.8E-07	
61	H-3	5.0E+00	1.3E-07	
62	Rh-106	6.0E+01	0.0E+00	Assessed with the parent nuclide
63	Ba-137m	6.0E+00	0.0E+00	Assessed with the parent nuclide
64	Pr-144m	7.0E+00	0.0E+00	Assessed with the parent nuclide

Table C-4 Result of the external exposure assessment from beach sand in the case of discharge of each nuclide at the regulatory concentration limit

	Nuclide	Regulatory concentration limit (Bq/L)	Exposure from beach sand (mSv/year)	Remarks
1	Te-127	5.0E+03	1.0E-02	For the dose conversion factor, refer to the value of Co-60
2	Eu-155	3.0E+03	6.2E-03	For the dose conversion factor, refer to the value of Co-60
3	Gd-153	3.0E+03	6.2E-03	For the dose conversion factor, refer to the value of Co-60
4	Sn-119m	2.0E+03	4.1E-03	For the dose conversion factor, refer to the value of Co-60
5	Nb-95	1.0E+03	2.1E-03	For the dose conversion factor, refer to the value of Co-60
6	Ru-103	1.0E+03	2.1E-03	For the dose conversion factor, refer to the value of Co-60
7	Ce-141	1.0E+03	2.1E-03	For the dose conversion factor, refer to the value of Co-60
8	Pm-146	9.0E+02	1.9E-03	For the dose conversion factor, refer to the value of Co-60
9	Te-123m	6.0E+02	1.2E-03	For the dose conversion factor, refer to the value of Co-60
10	Cs-135	6.0E+02	1.2E-03	For the dose conversion factor, refer to the value of Co-60
11	Pm-148m	5.0E+02	1.0E-03	For the dose conversion factor, refer to the value of Co-60
12	Tb-160	5.0E+02	1.0E-03	For the dose conversion factor, refer to the value of Co-60
13	Co-58	1.0E+03	8.4E-04	For the dose conversion factor, refer to the value of Co-60
14	Sn-123	4.0E+02	8.3E-04	
15	Mn-54	1.0E+03	7.0E-04	
16	Rb-86	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
17	Sr-89	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
18	Y-91	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
19	Ag-110m	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
20	Cd-115m	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
21	Sb-124	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
22	Te-127m	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
23	Te-129m	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
24	Cs-136	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
25	Ba-140	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
26	Pm-148	3.0E+02	6.2E-04	For the dose conversion factor, refer to the value of Co-60
27	Eu-152	6.0E+02	5.5E-04	
28	Co-60	2.0E+02	4.1E-04	
29	Eu-154	4.0E+02	4.0E-04	
30	Sb-125	8.0E+02	2.9E-04	
31	Zn-65	2.0E+02	9.7E-05	
32	Cs-134	6.0E+01	8.2E-05	
33	Cs-137	9.0E+01	4.8E-05	
34	Ru-106	1.0E+02	1.9E-05	
35	Pu-241	2.0E+02	1.8E-05	

	Nuclide	Regulatory concentration limit (Bq/L)	Exposure from beach sand (mSv/year)	Remarks
36	Ce-144	2.0E+02	8.8E-06	
37	Te-125m	9.0E+02	7.5E-06	
38	Sn-126	2.0E+02	4.6E-06	
39	Cm-243	6.0E+00	8.2E-07	For the dose conversion factor, refer to the value of Am-243
40	Am-243	5.0E+00	6.8E-07	
41	Sr-90	3.0E+01	1.6E-07	
42	I-129	9.0E+00	5.1E-08	
43	Pm-147	3.0E+03	4.6E-08	
44	Am-242m	5.0E+00	4.4E-08	
45	Am-241	5.0E+00	3.7E-08	
46	Fe-59	4.0E+02	2.8E-08	
47	Tc-99	1.0E+03	2.8E-08	
48	Sm-151	8.0E+03	2.2E-08	
49	Cm-242	6.0E+01	9.8E-09	
50	Cd-113m	4.0E+01	7.2E-09	
51	Cm-244	7.0E+00	1.1E-09	
52	Pu-238	4.0E+00	6.3E-10	
53	Pu-240	4.0E+00	6.2E-10	
54	Pu-239	4.0E+00	3.7E-10	
55	H-3	6.0E+04	0.0E+00	
56	C-14	2.0E+03	0.0E+00	
57	Ni-63	6.0E+03	0.0E+00	
58	Y-90	3.0E+02	0.0E+00	Assessed with the parent nuclide
59	Rh-103m	2.0E+05	0.0E+00	Assessed with the parent nuclide
60	Rh-106	3.0E+05	0.0E+00	Assessed with the parent nuclide
61	Te-129	1.0E+04	0.0E+00	Assessed with the parent nuclide
62	Ba-137m	8.0E+05	0.0E+00	Assessed with the parent nuclide
63	Pr-144	2.0E+04	0.0E+00	Assessed with the parent nuclide
64	Pr-144m	4.0E+04	0.0E+00	Assessed with the parent nuclide

*Nuclides subject to previous management are hatched

Table C-5 Result of the environmental protection assessment in the case of discharge of each nuclide at the regulatory concentration limit

	Nuclide	Regulatory concentration limit (Bq/L)	Exposure assessment result (mGy/day)			Remarks
			Flatfish	Crab	Brown seaweed	
1	Fe-59	4.0E+02	5.4E-01	5.4E-01	5.8E-01	
2	Sn-126	2.0E+02	9.7E-03	9.3E-03	9.0E-03	
3	Pm-148m	5.0E+02	7.5E-03	7.2E-03	8.1E-03	
4	Mn-54	1.0E+03	6.6E-03	6.0E-03	6.6E-03	
5	Eu-152	6.0E+02	5.4E-03	5.1E-03	5.4E-03	
6	Pm-146	9.0E+02	5.1E-03	4.9E-03	5.4E-03	
7	Tb-160	5.0E+02	4.2E-03	4.2E-03	4.5E-03	
8	Eu-154	4.0E+02	3.8E-03	3.6E-03	3.8E-03	
9	Nb-95	1.0E+03	2.3E-03	2.3E-03	2.4E-03	
10	Gd-153	3.0E+03	2.2E-03	2.0E-03	2.5E-03	
11	Pm-148	3.0E+02	1.5E-03	1.4E-03	2.0E-03	
12	Eu-155	3.0E+03	1.3E-03	1.3E-03	1.3E-03	
13	Co-58	1.0E+03	1.1E-03	1.1E-03	1.1E-03	
14	Sn-123	4.0E+02	1.0E-03	9.7E-04	1.0E-03	
15	Sn-119m	2.0E+03	9.6E-04	9.1E-04	6.7E-04	
16	Ce-141	1.0E+03	8.6E-04	8.2E-04	8.9E-04	
17	Co-60	2.0E+02	5.6E-04	5.6E-04	6.1E-04	
18	Ce-144	2.0E+02	4.7E-04	2.7E-04	4.7E-04	
19	Ru-103	1.0E+03	7.4E-05	7.4E-05	7.6E-05	
20	Cd-115m	3.0E+02	4.4E-05	1.9E-04	8.3E-06	
21	Ag-110m	3.0E+02	4.1E-05	2.3E-04	3.5E-05	
22	Y-91	3.0E+02	3.6E-05	2.2E-05	1.6E-04	
23	Zn-65	2.0E+02	3.3E-05	6.6E-05	3.2E-05	
24	C-14	2.0E+03	1.0E-05	8.4E-06	6.7E-06	
25	Cs-136	3.0E+02	9.5E-06	9.4E-06	9.4E-06	
26	Te-127	5.0E+03	9.4E-06	9.4E-06	8.7E-05	
27	Am-243	5.0E+00	8.8E-06	1.1E-05	9.7E-06	
28	Ru-106	1.0E+02	6.4E-06	6.4E-06	7.6E-06	
29	Cm-243	6.0E+00	5.8E-06	1.5E-05	9.4E-06	
30	Ba-140	3.0E+02	5.6E-06	7.7E-06	1.0E-05	
31	Sb-124	3.0E+02	5.1E-06	4.8E-06	6.1E-06	
32	Sb-125	8.0E+02	3.2E-06	3.0E-06	4.0E-06	
33	Pm-147	3.0E+03	2.9E-06	3.9E-05	2.7E-05	
34	Cd-113m	4.0E+01	1.7E-06	7.8E-06	1.4E-07	
35	Te-129m	3.0E+02	1.6E-06	1.6E-06	1.5E-05	

	Nuclide	Regulatory concentration limit (Bq/L)	Exposure assessment result (mGy/day)			Remarks
			Flatfish	Crab	Brown seaweed	
36	Sm-151	8.0E+03	1.5E-06	3.3E-05	1.3E-05	
37	Cs-134	6.0E+01	1.5E-06	1.4E-06	1.5E-06	
38	Te-125m	9.0E+02	1.0E-06	1.0E-06	8.8E-06	
39	Am-241	5.0E+00	9.4E-07	3.1E-06	9.7E-07	
40	Te-123m	6.0E+02	9.0E-07	9.2E-07	5.4E-06	
41	Cs-137	9.0E+01	8.0E-07	7.7E-07	8.0E-07	
42	Rb-86	6.0E+01	7.8E-07	9.9E-05	3.7E-05	
43	Cm-242	3.0E+02	7.7E-07	7.7E-07	7.2E-06	
44	Te-127m	5.0E+00	7.2E-07	8.0E-07	1.3E-06	
45	Am-242m	3.0E+02	6.7E-07	5.3E-07	1.3E-06	
46	Pu-238	4.0E+00	4.6E-07	3.1E-07	7.6E-07	
47	Pu-240	4.0E+00	4.3E-07	2.9E-07	7.1E-07	
48	Pu-239	4.0E+00	4.3E-07	2.9E-07	7.1E-07	
49	Ni-63	6.0E+03	2.3E-07	5.5E-06	1.7E-06	
50	Cm-244	7.0E+00	8.6E-08	1.1E-05	4.2E-06	
51	Tc-99	1.0E+03	6.7E-08	1.5E-05	4.5E-05	
52	Sr-89	3.0E+02	6.1E-08	2.1E-07	6.0E-08	
53	Cs-135	6.0E+02	5.3E-08	2.9E-08	4.3E-08	
54	Pu-241	2.0E+02	2.2E-08	1.5E-08	3.7E-08	
55	Sr-90	3.0E+01	1.1E-08	4.1E-08	1.1E-08	
56	H-3	6.0E+04	4.7E-09	4.7E-09	1.8E-09	
57	I-129	9.0E+00	9.1E-11	5.2E-08	2.3E-08	
58	Y-90	3.0E+02	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
59	Rh-103m	2.0E+05	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
60	Rh-106	3.0E+05	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
61	Te-129	1.0E+04	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
62	Ba-137m	8.0E+05	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
63	Pr-144	2.0E+04	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide
64	Pr-144m	4.0E+04	0.0E+00	0.0E+00	0.0E+00	Assessed with the parent nuclide

* Nuclides subject to previous management are hatched

C2. Setting of previous management values

In the analysis results of tanks and ALPS outlet water, seven nuclides excluding C-14 were not detected among the nuclides subject to previous management. The management values of the undetected nuclides are obtained by rounding up 120% of the minimum detection limit (larger result of the two tank groups) in the secondary treatment performance test considering errors. That of C-14, which was detected, is obtained by rounding up the concentration twice as high as the maximum value.

Figure C-1 and Table C-6 show the setting flow of previous management values and the set previous management values, respectively.

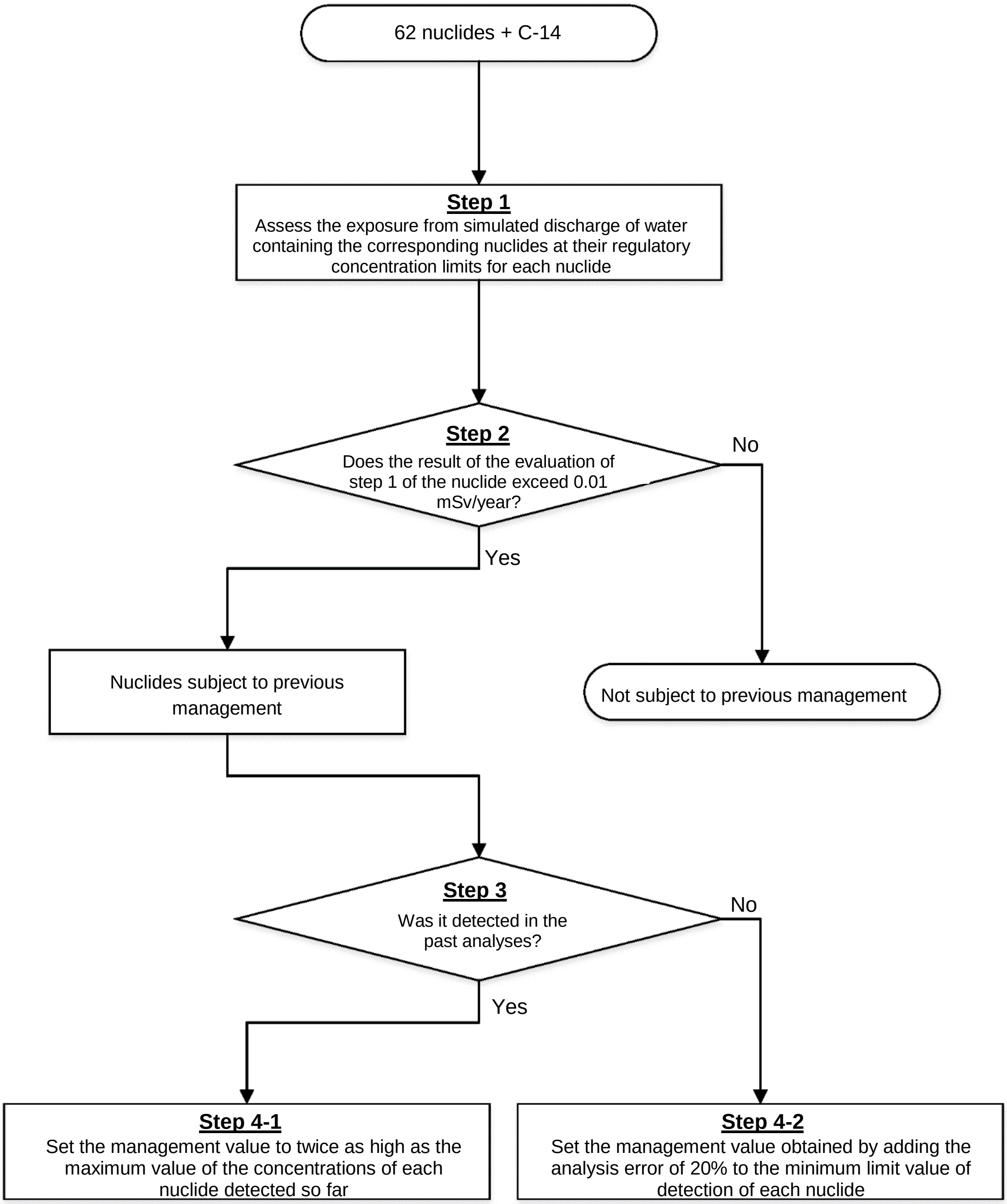

Figure C-1 Flow of setting of previous management values

Table C-6 Setting of previous management values

	Nuclide	Regulatory concentration limit (Bq/L)	Minimum detection limit (Bq/L)	Minimum detection limit ×1.2 (Bq/L)	Previous operation and management value (Bq/L)	Ratio to regulatory concentration limit
Undetected nuclide	Fe-59	4.0E+02	8.66E-02	1.04E-01	2E-01	5.0E-04
	Ag-110m	3.0E+02	4.26E-02	5.11E-02	6E-02	2.0E-04
	Cd-113m	4.0E+01	8.55E-02	1.03E-01	2E-01	5.0E-03
	Cd-115m	3.0E+02	2.70E+00	3.24E+00	4E+00	1.3E-02
	Sn-119m	2.0E+03	4.24E+01	5.09E+01	6E+01	3.0E-02
	Sn-123	4.0E+02	6.59E+00	7.91E+00	8E+00	2.0E-02
	Sn-126	2.0E+02	2.92E-01	3.50E-01	4E-01	2.0E-03
Detected nuclide	Nuclide	Regulatory concentration limit (Bq/L)	Maximum detected value (Bq/L)	Maximum detected value×2 (Bq/L)	Previous operation and management value (Bq/L)	Ratio to regulatory concentration limit
	C-14	2.0E+03	2.15E+02	4.30E+02	5E+02	2.5E-01
	Total of regulatory concentration ratios					3.2E-01

C3. Simulation assessment of human exposure from ALPS treated water

To verify that the previous management values set in C2. reduce the risk caused by the uncertainty of the source term, we assessed the exposure from continuous discharge of simulated ALPS treated water containing only nuclides with relatively great impacts of exposure such as the nuclides subject to previous management as a very conservative assessment, though such ALPS treated water cannot exist in reality.

a. Setting of the source terms

Based on the following steps, we set the source term of each nuclide (annual discharge amount) of each nuclide as shown in Table C-7.

- The annual discharge amount of tritium shall be the upper limit: 22 TBq (2.2E+13Bq).
- The annual discharge volume of ALPS treated water is conservatively estimated as 220 million L (2.2E+08L) by setting a low tritium concentration of ALPS treated water used for the assessment to 100 thousand Bq/L below the minimum concentration of tritium confirmed so far (about 150 thousand Bq/L). Because of this, the annual discharge amount of nuclides other than tritium is conservatively estimated.
- Among 63 nuclides other than tritium, the previous management value, which is the upper limit, is set to the concentrations of 8 nuclides with relatively great impacts on exposure. The sum of the ratios to regulatory concentrations limits of the 8 nuclides is 0.32.
- For the other 55 nuclides, Zn-65, whose impact on exposure is relatively great following the 8 nuclides subject to previous management, shall be assessed, and the concentration of Zn-65 is set to 140Bq/L, which is equivalent to the regulatory concentration ratio of 0.68. Because of this, the sum of the ratios to regulatory concentrations limits of 63 nuclides other than tritium becomes 1, which is the upper limit value in discharge management.
- Set the annual discharge amount of 9 nuclides by multiplying the concentrations of the 8 nuclides subject to previous management and Zn-65 by the annual discharge volume of water of 220 million L.

b. Concentration of each nuclide used for the exposure assessment in the seawater

For the concentration of each nuclide in the seawater used for exposure assessment, the concentration of the other nuclides was calculated from the ratio of tritium to the annual discharge amount of the other nuclides in the source term based on the annual average concentration within 10 km × 10 km and the annual average concentration of the sandy beach assessment point in the tritium concentration in the seawater (all layers) in Table 6-1-17. Table C-8 shows the concentration of each nuclide in the seawater used for the assessment.

c. Exposure assessment method

The migration pathway, the exposure pathway, exposure assessment method, and the setting of the representative person are the same as those of 6-1. “Exposure assessment under normal conditions”.

d. Exposure assessment result

Table C-9 shows the result of the exposure assessment using the source term with simulated ALPS treated water containing only the nuclides with relatively great impacts on exposure. Even if the source term that seems to be the most conservative in terms of discharge management is used, the results were much smaller than the dose limit of 1 mSv/year for the general public and the dose target of 0.05 mSv/year, which is equivalent to the dose constraint value.

Table C-7 Source term using hypothetical ALPS treated water (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual discharge amount (Bq)	Remarks
H-3	1.0E+05	2.2E+08	2.2E+13	• For the annual discharge amount of tritium, the upper limit value is used. • In actual discharge, the water is diluted with seawater 100 or more times so that the tritium concentration will become less than 1,500Bq/L, so the Sum of the ratios to regulatory concentrations limits of 63 nuclides other than tritium in the discharged water will be less than 0.01.
C-14	5.0E+02		1.1E+11	
Fe-59	2.0E-01		4.4E+07	
Zn-65	1.4E+02		3.1E+10	
Ag-110m	6.0E-02		1.3E+07	
Cd-113m	2.0E-01		4.4E+07	
Cd-115m	4.0E+00		8.8E+08	
Sn-119m	6.0E+01		1.3E+10	
Sn-123	8.0E+00		1.8E+09	
Sn-126	4.0E-01		8.8E+07	

Table C-8 Concentration in the seawater used for the assessment (Source term using hypothetical ALPS treated water)

Target nuclide	Annual discharge amount (Bq)	Concentration in the seawater used for the assessment (Bq/L)		
		Average of all layers within 10×10 km	Average of the top layers within 10×10 km	Average of all layers of the sandy beach assessment point
H-3	2.2E+13	5.6E-02	1.2E-01	8.8E-01
C-14	1.3E+09	2.8E-04	6.0E-04	4.4E-03
Fe-59	5.9E+06	1.1E-07	2.4E-07	1.8E-06
Zn-65	6.5E+06	7.8E-05	1.7E-04	1.2E-03
Ag-110m	3.3E+06	3.4E-08	7.2E-08	5.3E-07
Cd-113m	7.0E+06	1.1E-07	2.4E-07	1.8E-06
Cd-115m	1.9E+08	2.2E-06	4.8E-06	3.5E-05
Sn-119m	3.3E+09	3.4E-05	7.2E-05	5.3E-04
Sn-123	5.1E+08	4.5E-06	9.6E-06	7.0E-05
Sn-126	1.2E+07	2.2E-07	4.8E-07	3.5E-06
Target exposure assessment		From fishing nets Ingestion of seafood	From sea surface From hulls	During swimming From beach sand Ingestion of seawater Inhalation of seawater spray

Table C-9 Human exposure assessment result (Assessment area: 10 km × 10 km)

Assessed case	Source term	Source term using hypothetical ALPS treated water	
	Ingestion of seafood	Average	Large
External exposure (mSv/year)	Sea surface	1.8E-07	
	Hull	1.4E-07	
	During swimming	1.2E-07	
	Beach sand	2.2E-04	
	Fishing net	4.5E-05	
Internal exposure (mSv/year)	Ingestion of water	4.6E-07	
	Inhalation of spray	2.1E-07	
	Ingestion of seafood	4.8E-04	2.0E-03
Total (mSv/year)		7E-04	2E-03

Table C-10 Assessment result of internal exposure from ingestion of seafood by age (10 km × 10 km)

Assessed case	Source term	Source term using hypothetical ALPS treated water	
	Ingestion of seafood	Average	Large
Internal exposure from ingestion of seawater (mSv/year)	Adult	4.6E-07	
	Child under school age	8.7E-07	
	Infant	-	
Internal exposure from inhalation of seawater spray (mSv/year)	Adult	2.1E-07	
	Child under school age	1.6E-07	
	Infant	1.0E-07	
Internal exposure from ingestion of seafood (mSv/year)	Adult	4.8E-04	2.0E-03
	Child under school age	7.5E-04	3.1E-03
	Infant	9.4E-04	3.9E-03

C4. Assessment of environmental protection with ALPS treated water

As with the human exposure assessment, we assessed exposure of animals and plants in the case of continuous discharge of simulated ALPS treated water.

a. Setting of the source terms

As with C3. a. Setting of the source term, based on the following steps, we set the source term of each nuclide (annual discharge amount) of each nuclide as shown in Table C-11.

- The annual discharge amount of tritium shall be the upper limit: 22 TBq (2.2E+13Bq).
- The annual discharge volume of ALPS treated water is conservatively estimated as 220 million L (2.2E+08L) by setting a low tritium concentration of ALPS treated water used for the assessment to 100 thousand Bq/L below the minimum concentration of tritium confirmed so far (about 150 thousand Bq/L). Because of this, the annual discharge amount of nuclides other than tritium is conservatively estimated.
- Among 63 nuclides other than tritium, the previous management value, which is the upper limit, is set to the concentrations of 2 nuclides with relatively great impacts on exposure. The sum of the ratios to regulatory concentrations limits of the 2 nuclides (Fe-59 and Sn-126) is 0.0025 (2.5E-03).
- For the other 61 nuclides, Pm-148m, whose impact on exposure is relatively great following the 2 nuclides subject to previous management, shall be assessed, and the concentration of Pm-148m is set to 499Bq/L, which is equivalent to the regulatory concentration ratio of 0.9975 (9.975E-01)). Because of this, the sum of the ratios to regulatory concentrations limits of 63 nuclides other than tritium becomes 1, which is the upper limit value in discharge management.
- Set the annual discharge amount of 3 nuclides by multiplying the concentrations of the 2 nuclides subject to management and Pm-148m by the annual discharge volume of water of 220 million L.

b. Concentration of each nuclide used for the exposure assessment in the seawater

For the concentration of each nuclide in the seawater used for exposure assessment, the concentration of the other nuclides was calculated from the ratio of tritium to the annual discharge amount of the other nuclides in the source term based on the tritium concentration in the seawater (bottom layer) in Table 7-3-1. Table C-12 shows the concentration of each nuclide in the seawater used for the assessment.

c. Exposure assessment method

The migration pathway, the exposure pathway, exposure assessment method, and the setting of the representative person are the same as those of 7. Assessment of environmental protection.

d. Exposure assessment result

Table C-13 shows the result of the exposure assessment of the standard animals and plants using the source term with simulated ALPS treated water containing only the nuclides with relatively great impacts on exposure. Even if the source term, which seems to be the most conservative in terms of discharge management, is used, the dose rate is much lower than the lower limit value of derived consideration reference level (DCRL)

Table C-11 Source term using hypothetical ALPS treated water (annual discharge amount)

Target nuclide	Nuclide concentration (Bq/L)	Annual discharge volume of water (L)	Annual volume of discharge (Bq)	Remarks
H-3	1.0E+05	2.2E+08	2.2E+13	• For the annual discharge amount of tritium, the upper limit value is used. • In actual discharge, the water is diluted with seawater 100 or more times so that the tritium concentration will become less than 1,500Bq/L, so the Sum of the ratios to regulatory concentrations limits of 63 nuclides other than tritium in the discharged water will be less than 0.01.
Fe-59	2.0E-01		4.4E+07	
Sn-126	4.0E-01		8.8E+07	
Pm-148m	5.0E+02		1.1E+11	

Table C-12 Concentration in the seawater used for the assessment (Source term using hypothetical ALPS treated water)

Target nuclide	Annual volume of discharge (Bq)	Concentration in the seawater used for the assessment (Bq/L)
		Within 10 × 10 km Average of the bottom layer
H-3	2.2E+13	5.6E-02
Fe-59	4.4E+07	1.2E-07
Sn-126	8.8E+07	2.4E-07
Pm-148m	1.1E+11	3.0E-04
Target exposure assessment		Environmental protection

Table C-13 Assessment result regarding environmental protection

Assessed case		Source term using hypothetical ALPS treated water
Exposure (mGy/day)	Flatfish	7.8E-03
	Crab	7.5E-03
	Brown seaweed	8.4E-03
derived consideration reference level (DCRL) Flatfish: 1-10 mGy/day Crab: 10-100 mGy/day Brown seaweed: 1-10 mGy/day		

Reference D Assessment result of environmental impacts including other elements than radiation related to discharge of ALPS treated water

We have assessed non-radiological environmental impacts associated with the discharge of ALPS treated water into the sea. This document presents the result of our review of whether non-radiological factors associated with the presence and operation of facilities and its construction related to the discharge of ALPS treated water into the sea “could cause substantial pollution or significant and harmful changes in the marine environment.” In conclusion, we have assessed that none of such element was associated with such risks.
First, we analyzed the measurement items specified in the Water Pollution Prevention Law and related ordinances of Fukushima Prefecture other than radioactive materials contained in the stored ALPS treated water. The analysis result is described in Attachment II “Properties of ALPS treated water,” with which we verified that all measurement items are below the standard values and that even if these water are discharged into the water, any significant or harmful changes will not occur in the marine environment due to non-radioactive substances contained in these water in the case of discharge into the sea.
Moreover, we also assessed the possibility for non-radiological environmental impacts from discharge of ALPS treated water into the sea or its method. Tables D-1 and D-2 show the systems subject to the assessment and their overview, and the overview of the assessment result, respectively. We considered the following two factors as those which may cause an impact:

a. Presence or operation of the facilities related to discharge of ALPS treated water into the sea (facilities related to measurement/confirmation, transfer, dilution, and discharge) (middle column);
b. Implementation of installation or operation of the facilities (right column).

We assessed the possible impacts of these influencing factors on the components of various environment such as air quality, water quality, geology, terrain, soil, and ecosystem. We also included the impacts of the radioactivity which already exist in the environment as the targets of the assessment. As a result, the expected effects on these components of the environment were evaluated to be either none or sufficiently small to be negligible.
The targets are the same conditions as those of discharge of ALPS treated water into the sea, impacts of discharge of contents, and impacts of construction of the related facilities assumed in the radiation impact assessment handled in this report.

Table D-1 Facilities related to discharge of ALPS treated water into the sea

Classification of facilities	Facilities	Specifications
Measurement /confirmation facilities	Measurement/confirmation tanks	For measurement and confirmation, reuse 30 out of 35 current units (about 34 thousand m^3) installed in the K 4 area as facilities
	Circulation pump	160 m^3/h/unit × 2 units
	Stirring equipment	One unit per tank, A total of 30 units
	Piping, valve, etc.	Connecting tube (nominal diameter of the pressure hose equivalent to 200A or steel pipe 100A) Duplicate boundary valves in series to prevent water mixing among tank groups
Transfer facilities	ALPS treated water transfer pump	30 m^3/h/unit × 2 units (1 reserve)
	Emergency isolation valve	Install two valves with different operating principles and installation locations in series for multiplexing and diversification
	Flowmeter	
	Other valves, piping, etc.	
Dilution facilities	Water intake channel	Reuse the Unit 5 facility
	Seawater transfer pump	7,086 m^3/h × 3 units
	Flowmeter	
	Seawater pipe header	Nominal diameters of 2200A and 1800A
	Discharge vertical shaft (upper-stream storage)	1 reinforced concrete storage, Height about 37 m × Width about 18 m × Depth about 7 m, Capacity about 2,000 m^3
	Other valves, piping, etc.	
Related facilities	Discharge vertical shaft (down-stream storage)	1 reinforced concrete storage, Height about 7 m × Width about 12m × Depth about 18 m, Capacity about 800 m^3
	Discharge tunnel	Shield tunnel, Inner diameter about 3 m, Overall length about 1 km
	Discharge outlet	Discharge outlet caisson: W about 9 m × D about 12 m × H about 10 m (Discharge outlet: 3 m in four directions, Height 2 m) Backfill the upper base about 40 m × about 40 m, lower base about 16 m × about 16 m, and depth about 11 m in the surrounding with anti-washout underwater concrete, etc.

For the allocation, installation, and operation of these facilities, we made the following considerations in order to reduce the impacts on the environment as much as possible.

- We made considerations to prevent new terrain modifications by reusing 30 tanks out of a total of 35 tank of the existing K4 area tank group (about 34,000 m^3) for facilities for measurement and confirmation (the other 5 tanks continue to be used as ALPS treated water storage) as facilities related to discharge of ALPS treated water into the sea.
- The dilution facilities to be newly installed shall be installed in the existing development area in the FDNPS to prevent new terrain modifications excluding discharge vertical shafts and tunnel outlets.
- For the water intake channel, the existing Unit 5 water intake channel is reused to avoid new terrain modifications.
- Discharge is designed to minimize the impacts of the presence, operation, and construction of facilities by the undersea tunnel method, which affects no impact to the terrain such as seabed surface by drilling bedrock, for maximum environmental protection.

Table D-2 shows the details of the consideration of the items of environmental impact assessments of other elements than radiation based on the plan reflecting these design considerations. All of them were judged to have no impact on the environment.

Table D-2 TEPCO's consideration result of the non-radiological environmental impact assessment of nuclides contained in the ALPS treated water[1]

Impact factors / Environmental elements	Presence and operation of the facilities	Implementation of construction
	Presence of facilities related to discharge of ALPS treated water into the sea - Discharge of ALPS treated water using the facilities	Construction of facilities related to discharge of ALPS treated water into the sea
Atmosphere environment (Air quality and noise/vibration)	The motor operation method or pneumatic method shall be adopted for the power to drive active components such as pumps or valves and no facility to emit air pollutants shall be installed. In addition, the total flow rate of 3 seawater dilution pumps in normal operation for discharge of ALPS treated water and 1 ALPS treated water transfer pump (maximum daily amount: about 510 thousand m^3) is smaller than that in normal operation of the circulation water pump of a general nuclear power plant (about 9 times as large daily amount in Unit 1, which is the smallest, if FDNPS before the accident is used as an example: about 4.25 million m^3). The area surrounding the FDNPS is used as an intermediate storage facility	The ships used for construction are 1 dredger, 2 crane barges, and 1 concrete plant vessel (not operated simultaneously). Heavy equipment is up to about 20 units/day. The shield machine (diameter of about 3m) is one unit. Material transportation is up to about 30 units/day. Only the installation of the intake and discharge facilities is construction out of the site and most of the installation of the intake and discharge facilities is construction of the undersea tunnel. The construction is limited to the inside of the FDNPS and the area where no fishing is conducted on a daily basis and the surrounding area of the FDNPS within about 2 km from the place of construction are used for the

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[1] Based on table 1.1 in "Environmental Impact Assessment Technical Guide" p.6.

Impact factors Environmental elements	Presence and operation of the facilities	Implementation of construction
	Presence of facilities related to discharge of ALPS treated water into the sea - Discharge of ALPS treated water using the facilities	Construction of facilities related to discharge of ALPS treated water into the sea
	completely surrounding the land side of the FDNPS, and the closest place in the outside Difficult-to-Return Zone is at least 1 km away from the site boundary of FDNPS and about 2 km away from the place assumed to be the construction site (seaside area of Unit 5). Therefore, there is no target whose impact on the life environment should be assessed within the possible range of noise, vibration, etc.	intermediate storage facilities, so there is no target whose impact on the life environment should be assessed within the range where noise, vibration, etc., caused by the construction may cause any impact.
Water environment (Water quality/Water temperature/Flow velocity)* Other than radioactive materials	ALPS treated water is contaminated water with the contained radioactive materials eliminated by coagulating sedimentation, absorbents, filters, etc. Heavy metal, infusible suspended substances, organic substances, etc., are eliminated. No treatment to increase the pollution load, which causes an increase in COD, etc., is performed. It was verified in past measurement[2] that the water quality of ALPS treated water sufficiently meets the wastewater standard. Moreover, in actual discharge of ALPS treated water, the water to be discharged shall be verified to meet the wastewater standard. In addition, seawater to be taken and discharged is only used for dilution of ALPS treated water and is not heated. The temperature of ALPS treated water stored on land may change due to the ambient temperature. However, it is not in an equilibrium state with the seawater temperature and discharged after diluted 100 or more times with seawater, so there is almost no difference between the temperatures of wastewater and seawater. The discharge flow velocity from the discharge outlet is as slow as about 1m/s even in the case of the maximum flow rate with the three seawater dilution pumps in operation. Water is discharged straight up from the seabed with a water depth of about 12 m. Therefore, changes	There is no target to be assessed because occurrence of water turbidity caused by the construction is deemed to be limited because the construction of the intake facilities is performed in the port, most of the discharge facilities is constructed by the shield method as undersea tunnels, and a rocky shore is selected as the site for tunnel outlets.

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[2] December 28, 2018 “Analysis of chemical substances in ALPS treated water tanks” https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/012_04_01.pdf

Impact factors Environmental elements	Presence and operation of the facilities	Implementation of construction
	Presence of facilities related to discharge of ALPS treated water into the sea - Discharge of ALPS treated water using the facilities	Construction of facilities related to discharge of ALPS treated water into the sea
	in the flow velocity are limited to near the discharge outlet.	
Other environments (terrain/geology, subgrade, and soil)	The discharge flow velocity from the discharge outlet is as slow as about 1m/s even in the case of the maximum flow rate with the three seawater dilution pumps in operation. Water is discharged straight up from the seabed. The protrusion from the seabed height is limited to a height of about 2 m within about 3 m in the four directions. The square area of about 40 m around the discharge outlet (about 1,600 m^2) is backfilled. Therefore, changes in the flow velocity are limited to near the discharge outlet, and there is no risk of scouring. Pumping of groundwater, which causes ground subsidence, shall not be performed and it is planned not to use any substance which causes soil contamination.	Terrain modifications are limited to very small areas, namely the discharge vertical shaft (upper-stream storage of about 670 m^2, down-stream storage of about 80 m^2, a total of about 750 m^2) and the outlet of the undersea tunnel (about 1,600 m^2) by avoiding new terrain modifications by reuse of the existing facilities, installation of the undersea tunnel by the shield method which gives very low change to terrain drilling bedrock.
Animals, plants, and ecosystem	Most of the facilities are installed in places where site preparation has been completed within the site of the FDNPS. The facility for discharge is an undersea tunnel and requires the minimum necessary area of about 40 m x about 40 m (about 1,600 m^2) near the outlet. The impact of discharge of ALPS treated water on tidal currents, etc., is small and there is almost no impact of the operation of the facility on organisms, because of ALPS treated water being diluted 100 or more times with the seawater of the adjacent sea and the low discharge flow velocity of about 1 m/s.	New terrain modifications are avoided by reuse of the existing facilities, installation of the undersea tunnel by the shield method, etc. No important species, habitat, etc., have been found in the sea area where construction is to be performed.
Rich natural environment (landscape, etc.)	There is no item to be assessed because the existing facilities are reused and the scale of the facilities to be newly installed is small.	Since the scales of the facilities to be installed are small, the traffic of vehicles for transportation of materials, etc., is assumed to be up to 20 vehicles/day, which is limited.
Environmental loads (waste, emission of greenhouse gas, etc.)	Discharge of ALPS treated water does not generate any new waste. In addition, the motor operation method or pneumatic method shall be adopted for the power to drive active components such as pumps or valves used for the facilities for discharging ALPS treated	Construction waste soil is generated (about 40 thousand m^3) associated with excavation of the undersea tunnel, but the generated amount is small and it is disposed of at the existing soil disposal site in the premises without transfer to outside.

Reference D-5

Impact factors Environmental elements	Presence and operation of the facilities	Implementation of construction
	Presence of facilities related to discharge of ALPS treated water into the sea - Discharge of ALPS treated water using the facilities	Construction of facilities related to discharge of ALPS treated water into the sea
	water into the sea, so no greenhouse gas including that generated by combustion of fossil fuel is emitted. Therefore, there is no item to be assessed.	Therefore, there is no item to be assessed.
Radioactive materials already exist in environment	The planned discharge outlet is installed in a rocky shore outside the port, the surrounding square area of 40 m is backfilled with concrete, etc., and water is discharge straight up at a low flow velocity of about 1 m per second, so discharge of treated water does not swirl marine sediment or disperse radioactive materials. The seawater for diluting the ALPS treated water is planned to be drawn from the outside of the port (north side of the Unit 5/6 discharge outlet) by blocking the intake path opening channel with partition weir (rubble mound and sheet) from the port of the Unit 1-4 side considering that the concentration of radioactive materials is slightly higher than that of the seawater in the surrounding sea area and that it may swirl marine sediment, etc., in the port. As shown in attachment V "Impacts of intake and discharge of diluted water on outside," the result of the assessment of exposure considering the impact of the radioactive materials, which may be contained in drawn seawater in the case of intake of seawater outside this port is 9.6E-05 mSv/year, which is much lower than 0.05mSv/year.	It is considered that construction in the port has almost no impact such as dispersion of radioactive materials, etc., thanks to installation of contamination prevention fences for construction, careful work at slower construction speed than usual, etc., in order to reduce sedimentation sand swirled in the port. It was confirmed that the concentration of radioactive materials in the seawater did not vary significantly during similar construction performed in the port (pouring materials such as riprap into the sea by using working crafts and backhoes) in the past three years[3]. Actually, the concentration of radioactive materials in the seawater in the port is below the domestic regulatory standard even inside the intake path opening channel of Units 1 to 4, in which the concentrations are relatively high (Cs-137 1E+00Bq/L order, Sr-90 1E+00Bq/L order, 10E+2Bq/L as of 2021)[4]. In addition, it is considered that the tunnel outlet construction outside the port has almost no impact, such as swirling of the seabed sediment, because a rocky shore is selected for the construction area, the excavation area is as small as about 40 m × 40 m, the concentration of radioactive materials contained the marine sediment is low[5] according to the investigation result of the surrounding sea area, and measures such as temporarily

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[3] 9th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water Material 1-1, pp. 39 -40
https://www.tepco.co.jp/en/hd/decommission/information/committee/pdf/2022/alps_22021501-e.pdf

[4] 35th Environmental Monitoring and Evaluation Sub-committee of the Safety Monitoring Council on Decommissioning of the Nuclear Power Station of Fukushima Prefecture Material 2-1, p.1
https://www.pref.fukushima.lg.jp/uploaded/attachment/495913.pdf

[5] The Nuclear Regulation Authority "Change of the radioactivity concentration of the sediment in sea area close to Fukushima Daiichi NPS / coastal sea area"
https://radioactivity.nsr.go.jp/en/contents/8000/7747/24/engan_soil.pdf

Impact factors / Environmental elements	Presence and operation of the facilities	Implementation of construction
	Presence of facilities related to discharge of ALPS treated water into the sea - Discharge of ALPS treated water using the facilities	Construction of facilities related to discharge of ALPS treated water into the sea
		suspending the construction will be taken if a significant change in the turbidity of seawater is observed during the construction period. Therefore, we assessed that there is almost no impact of construction such as dispersion of radioactive materials, etc.

Reference D-7

Reference E State of consultation with domestic and foreign stakeholders

The Basic Policy of the government on the handling of ALPS treated water states that “every effort will be made to foster understanding among the public and international community” and we are proactively working with the government to promote risk communication.

E1. Activities toward steady implementation of the Basic Policy

On April 16, 2021, the government established “the Council of Relevant Cabinet Ministers for Steady Implementation of the Basic Policy on the Handling of ALPS Treated Water,” and decided to speedily and steadily take countermeasures stipulated in the Basic Policy as a united government, and to listen carefully voices of stakeholders and those who concern about the impact, and to take necessary additional measures in a flexible countermeasures to dispel their concerns.

Specifically, a working group of the Council was held in various regions including Fukushima, Miyagi, and Ibaraki, and opinions were exchanged with local governments, those who are engaged in agriculture, forestry, fisheries, commerce and tourism etc. The Council also developed the “Immediate Measures Associated with the handling of ALPS Treated Water at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (Decision at the 2nd Ministerial Council on Measures for Steady Implementation of the Basic Policy on the Handling of ALPS treated water, August 2021)”[1] and “Action plan for Steady Implementation of the Basic Policy for the Handling of ALPS Treated Water (Decision at the 3rd Ministerial Council on Measures for Steady Implementation of the Basic Policy on the Handling of ALPS Treated Water, December 2021)”[2].

In the abovementioned action plan, the results of the assessment of the radiation impacts on humans and the environment and the result of the ocean diffusion simulation shall be explained and disseminated by preparing easy-to-understand materials as part of efforts over the next one year. The results of the assessment will be revised and enhanced based on the review by the IAEA, review by the Nuclear Regulatory Commission, and opinions from the public, and will be verified over the medium to long term based on the latest status and actual discharge data to confirm that no impact has occurred.

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[1] Web site of the Cabinet Secretariat (August 24, 2021) “List of materials distributed at the ministerial meeting on measures for steady implementation of the basic policy on handling of ALPS treated water (2nd)” Material 3 https://www.kantei.go.jp/jp/singi/hairo_osensui/alps_shorisui/dai2/index.html

[2] Web site of the Cabinet Secretariat (December 28, 2021) “List of materials distributed at the ministerial meeting on measures for steady implementation of the basic policy on handling of ALPS treated water (3rd)” Material 1 https://www.kantei.go.jp/jp/singi/hairo_osensui/alps_shorisui/dai3/index.html

E2. Responses to public comments regarding the Radiological Environmental Impact Assessment Report

After the publication of this report on November 17, 2021, we received 400 or more opinions from both inside and outside of Japan in response to our Public Comment Procedure. For the purpose of further enhancing the report, TEPCO solicited public comments both in Japanese and English for a month. We have revised the contents of the report in April 2022, by taking into account the public comments we received through this procedure[3]. Table E-1 shows examples of the items reflected in the revision, based on the results of soliciting comments.

Table E-1 : Examples of the items to be reflected in the Radiological Environmental Impact Assessment Report, based on the results of public comments on the Report

	Examples of reflected content in the Radiological Environmental Impact Assessment Report
Assessment addition/revision	■ Addition of exposure pathways (Ingestion of water while swimming and inhalation of seawater spray) ■ Review of potential assessment methods ■ Consideration of the effects of organically bound tritium ■ Effects of radioactive materials already released into the environment ■ Consideration of effects outside the model due to specific concentrations at model boundaries ■ Case study of sea water concentrations used in the assessment
Enhanced description	■ Addition of a chapter and references on the process of selecting a disposal method ■ Added description of nuclide accumulation in the environment ■ Addition of the model used in the simulation and the assessed conditions. ■ Reflecting the progress of the review by the Nuclear Regulation Authority and the review after the publication of the report. ■ Transcription of information from previously published documents (e.g., consideration of discharge period) ■ Assessment results for environmental effects other than radiation
Appropriate description	■ Review of difficult-to-understand expressions ■ Improvement of translation quality of English translation ■ Correction of errors

In addition, we explained the contents of the radiological impact assessment in various occasions. For example, on December 6, 2021 and January 19, 2022, we explained the contents of the Radiation Impact Assessment at the Environmental Monitoring and Evaluation Sub-committee of the Safety Monitoring Council on Decommissioning of the Nuclear Power Station of Fukushima Prefecture. Moreover, we have also provided about 3,000 explanations to those who are engaged in fishery, seafood processing and distribution industry, agriculture, commerce and industry and tourism, local governments, civil groups, etc. respectively (result of FY 2021).

E3. Transmission to and consultation with the international community

(1) Cooperation with the IAEA

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[3] With regard to the major opinions collected through the call for opinions and our responded, please refer to our reply issues at the same time of the revised report.

On the day following the announcement of the Basic Policy, then Minister of Economy, Trade and Industry, Kajiyama (hereinafter called “Minister Kajiyama”), had a teleconference with Rafael Mariano Grossi, the Director General of IAEA. The Minister Kajiyama requested the IAEA to disseminate information on IAEA's assessment of the safety related aspects of ALPS treated water with the international community as well as Japan based on their scientific knowledge. Also, he made a formal request in the following areas: (1) dispatch of review missions, (2) support to environmental monitoring, and (3) ensuring transparency towards the international community. Director General Grossi welcomed the announcement of the Basic Policy, responded positively to the request made by Minister Kajiyama, and will cooperate and work together with Japan in a highly transparent manner in each stage of the process, before, during and after the discharge[4]. In addition, the Director General Grossi said in the statement announced by IAEA in response to the Basic Policy “The Japanese Government’s decision is in line with practice globally, even though the large amount of water at the Fukushima plant makes it a unique and complex case,” “Nuclear safety is a national responsibility and it was for the Government of Japan to decide how to address the critical issue of water management. I’m confident that the Government will continue to interact with all parties in a transparent and open way as it works to implement today’s decision,” and “Our cooperation and our presence will help build confidence – in Japan and beyond – that the water disposal is carried out without an adverse impact on human health and the environment.” [5]

Based on the communication between the leaders of the government and the IAEA, both parties accelerated preparation for cooperation, and the Terms of Reference (TOR) for the Cooperation Framework for ALPS treated water was signed in July 2021. Following this TOR, IAEA decided to conduct a review regarding safety and other aspects of the handling of ALPS treated water including the assessment of the radiation impact on human and environment in accordance with IAEA safety standards[6].

Based on the TOR, the review mission of safety aspects of ALPS treated water was conducted from February 14 to 18 in 2022. IAEA members and international experts visited the FDNPS and had discussions with the Ministry of Economy, Trade and Industry. In addition, they also saw and reviewed the ALPS, the K4 tank groups to be reused for measurement and confirmation of the concentration of radioactive materials contained in the treated water before dilution and discharge, and the harbor area which is being considered

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[4] Web site of the Ministry of Economy, Trade and Industry (April 14, 2021) “Minister Kajiyama met with IAEA Director General Grossi”
https://www.meti.go.jp/english/press/2021/0414_001.html

[5] Web site of IAEA (April 13, 2021) "IAEA Ready to Support Japan on Fukushima Water Disposal, Director General Grossi Says"
https://www.iaea.org/newscenter/pressreleases/iaea-ready-to-support-japan-on-fukushima-water-disposal-director-general-grossi-says

[6] This report was reviewed by IAEA as a part of the review of the safety of ALPS treated water based on TOR mentioned above.

for the installation of facilities for dilution and discharge of the treated water[7]. The contents of discussions with the IAEA were also reflected in the review of this report. Main examples of reflected in the report are shown in Table E-2.

Table E-2 Main examples of areas reflected in the report based on the findings of the IAEA review

No.	IAEA Comments	Our Response	Reflection point
1	Considering that 12 years have passed since the accident, the source term should be realistic, even if sufficiently conservative.	It is noted that the target nuclide to be assessed will be scrutinized in the future, including whether there are any Nuclides that should be added, and that this assessment will be reviewed as necessary.	Main text 6-1-2(1) Source Term
2	Even if the ALPS-treated water to be discharged contains little or no organically bound tritium (OBT), the assessment should take OBT into account and be included in the monitoring program to verify the validity of the Assessment.	Assessed a conservative assumption of 10% of tritium to be ingested as OBT along with the ingestion of seafood. In addition, a monitoring plan including OBT measurement for seafood was included in the report.	Main text 4. (2) Tritium Main text 9-3-1. Sea area monitoring around the Fukushima Daiichi Nuclear Power Station by TEPCO Appendix III Impact of the organically bound tritium in the exposure assessment of tritium
3	The rationale for setting the Assessment Target area as 10 km x 10 km around the power plant should be documented.	The sea area to be assessed for fisheries is conservatively described as 5 km north and south of the power plant and 10 km offshore (10 km x 10 km around the power plant), as the distance from the power plant to the nearest fishing port is at least 5 km away and fishing operations are conducted mainly around the fishing port. The impact on the assessment due to the difference in the sea area to be assessed is discussed as "Uncertainty depending on the range of the sea area to be assessed (epistemic uncertainty)".	Main text 6-1-2(4) (2) Characteristics of the representative person Main text 8-4-3. Uncertainty depending on the range of the sea area to be assessed (epistemic uncertainty) Appendix XII Impact of the assessment range of concentrations in seawater used for the assessment of exposures

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[7] Web site of the Ministry of Economy, Trade and Industry (February 18, 2022) “IAEA conducted a review of the safety of ALPS treated water at TEPCO's Fukushima Daiichi Nuclear Power Station.”
https://www.meti.go.jp/english/press/2022/0218_001.html

No.	IAEA Comments	Our Response	Reflection point
4	The establishment of a representative person's lifestyle and the location of where they receive exposure should be considered for the future as well.	In the section "Situation around the FDNPS" of "Setting of the representative person subject to the exposure assessment," it is stated that "in the area around the FDNPS, measures to prevent the general public from living in the area are taken by setting Difficult-to-Return Zones set in response to the accident, installing intermediate storage facilities surrounding the land side of the FDNPS, etc." and "an assessment shall be performed using the data used for the safety review of the existing reactor facilities, etc." The first nuclear power plant is surrounded by a difficult-to-return zone and an interim storage facility on the land side of the plant, and therefore, the public cannot live there. On the other hand, as the assessed point of exposure by staying on the beach (external exposure during swimming and from beach sand, internal exposure from ingestion of water, and inhalation of seawater spray), the nearest habitable beach to the north of the site was selected.	Main text 6-1-2(4) (1) Situation around the FDNPS, and (2) Characteristics of representative person
5	It should be indicated that the expected exposure pathway is taken into account, even if the contribution is small.	Assessments were also conducted for pathways that were thought to have a small contribution, and relatively small effects on exposure were found. "Ingestion of water due to swimming, etc." and "inhalation of seawater spray " were added to the assessed results.	Main text 6-1-2(3) Setting of exposure pathways Attachment VI Transfer pathways and exposure pathways other than the assessment targets
6	Potential exposure scenarios should consider uncontrolled releases due to External events. Assessed should include all exposure pathways and the source term should consider all radioactive nuclides.	The previous evaluation was limited to external exposure and was assessed using a conservative source term, which is not possible in reality and includes a large amount of only Nuclide, which has a large exposure.	Main text 6-2. Potential exposure assessment
7	Evidence should be provided that tritium and other nuclides behave the same way as cesium in the ocean.	Clearly describe the rationale.	Main text 4(3) Assessment of migration and accumulation of nuclides other than tritium
8	Considering that the discharge period will continue for about 30 years, the accumulation of radioactive materials in the environment should be taken into account and assessed to maximize exposure.	In the assessment of diffusion, the decrease in seawater concentration due to adsorption to seabed soil, etc., is not considered, while adsorption to seabed soil and concentration in organisms are evaluated by conservatively assuming that they are in equilibrium.	Main text 4(3) Assessment of migration and accumulation of nuclides other than tritium
9	The impact on neighboring countries should be assessed in order to respond to the interests of the international community.	At the boundary of the calculation area of the diffusion simulation (approximately 490 km north-south and 270 km east-west) with meteorological and oceanographic data from 2014 to 2020 years, the report states that the maximum value of annual average is 0.00026 Bq/L and the maximum value of day average is 0.014 Bq/L, which is sufficiently low compared to the tritium concentration in sea water (about 0.1 Bq/L) in the sea area around the main island on the day of the report.	Main text 6-1-3(1) Diffusion simulation results Appendix VII Validity of the diffusion simulation

No.	IAEA Comments	Our Response	Reflection point
10	In the consideration of uncertainty, sensitivity analysis (e.g., sorting out the effects of changing parameters) is recommended.	Uncertainty is broadly classified into "aleatory uncertainty" and "epistemic uncertainty," and sensitivity analysis is performed for those that are possible, and the discussion is described in terms of these two types of uncertainty.	Main text 8. Discussion about the uncertainty of the assessment
11	The dose constraint value should be used as an input to the Radiological Impact Assessment Report to indicate that the tritium discharge limit is appropriate and to confirm the discharge limit for other nuclides, if necessary.	On February 16, 2022, the Nuclear Regulation Authority of Japan (NRA) announced the concept and guideline for the confirmation of radiological impact assessment, which is to confirm that "the exposure result for a representative person is sufficiently small compared to the range of variation in the exposure dose between years of a person due to the region and living environment, etc., i.e., the exposure dose is less than 50 μSv/year. 50 μSv/year is the dose target applicable to light water reactors for power generation during normal operation and corresponds to the dose constraint value in the IAEA safety standards. Assessed by treating 50 μSv/year = 0.05 mSv/year as the dose constraint value.	Main text 4(1) Dose constraints Main text 6-1-2(5) Dose assessment method Main text 6-1-3(3) Exposure assessment results

(2) Briefing for diplomats and bilateral exchange of opinions

In addition to providing explanations to domestic parties, we also attended the Video Conference briefing session for diplomats in Tokyo held on November 18, 2021, the day after the publication of the first edition of the report, and the Video Conference briefing session for the Government of Republic of Korea held on December 3, 2021, both in the presence of government officials, to provide detailed explanation of the contents of the report. In addition, we also provided individual explanation to interested countries and regions together with the relevant Ministries of the government.

At these Video Conference briefing sessions, we explained that the result of the assessment of the radiation impacts on humans and environment in accordance with the internationally recognized methods was significantly lower than the dose limit of the public, etc. and that it would take measures according to the international standards and practices, with maximum consideration given to the impacts on the health and safety of environment and humans. We also carefully answered the questions from foreign governments during the question-and-answer session.

The Government of Japan has provided explanations to foreign governments through Embassies, Consulates and Permanent Missions of Japan overseas as well as explanations to diplomats in Tokyo, and we also have provided the necessary information including technical contents at request.

Through these activities, the Government of Japan and we have been engaged in mutual communication with not only domestic parties but also the international community, and in revising this report, we have taken into consideration the opinions provided through these communications.

Reference F Rationale behind the selection of nuclides subject to removal by ALPS

F-1. Selection of nuclides subject to removal

It is assumed that the water to be treated in the advanced liquid processing system (fresh water, RO concentrated salt water, and treatment device outlet water) contains radioactive materials derived from the fuel in the Units 1 to 3 reactors (hereinafter called “FP nuclide”) and radioactive materials derived from corrosion products contained in the water retained during plant operation (hereinafter called “CP nuclide”). In order to reduce the risk of radiation exposure to the surrounding public area in the event of leakage of the water to be treated into the environment, it is necessary to estimate the nuclides present at high concentrations so that they can be removed by the advanced liquid processing system among FP nuclides and CP nuclides contained in the water to be treated.

Therefore, in estimating the concentration of radioactive materials contained in the water to be treated, for FP nuclides, nuclides assumed to exist at significant concentrations were selected based on the assessment results of the core inventory; for nuclides for which measurement of radioactive materials was carried out in March 2011, the concentration in the stagnant water was estimated from the measurement results; and for nuclides for which measurement was not carried out, the concentration in the stagnant water was estimated from the assessment results of the core inventory.

The concentration of CP nuclides in the stagnant water was estimated using the measurement results of CP nuclides in the water retained in the reactor and the concentrated waste liquid tank during plant operation, because nuclides contained in the water retained in the reactor during plant operation were transferred to the stagnant water, and it is considered that nuclides contained in the water retained in the concentrated waste liquid tank were mixed when the stagnant water was transferred to the high-temperature incinerator building.

The operation of the advanced liquid processing system was assumed to be started 1 year (365 days) after reactor shutdown for both FP and CP nuclides, so the concentration in the stagnant water was estimated by decay correction 365 days after reactor shutdown considering the half-life. Comparing the estimated concentration obtained by decay correction at 365 days after reactor shutdown and nuclides over 1/100 of the regulatory concentration limit were selected as nuclides subject to removal by the advanced liquid processing system assuming that they exist at significant concentrations in the stagnant water. The sum of the ratio of the estimated concentration to the regulatory concentration limit of nuclides which are excluded because they are below 1/100 of the regulatory concentration limit is about 0.05 at maximum. Therefore the concentration of the excluded nuclides is considered to be sufficiently low.

F-2. Selection method and selection result of nuclides subject to removal

(1) Selection method and selection result of nuclides subject to removal from FP nuclides

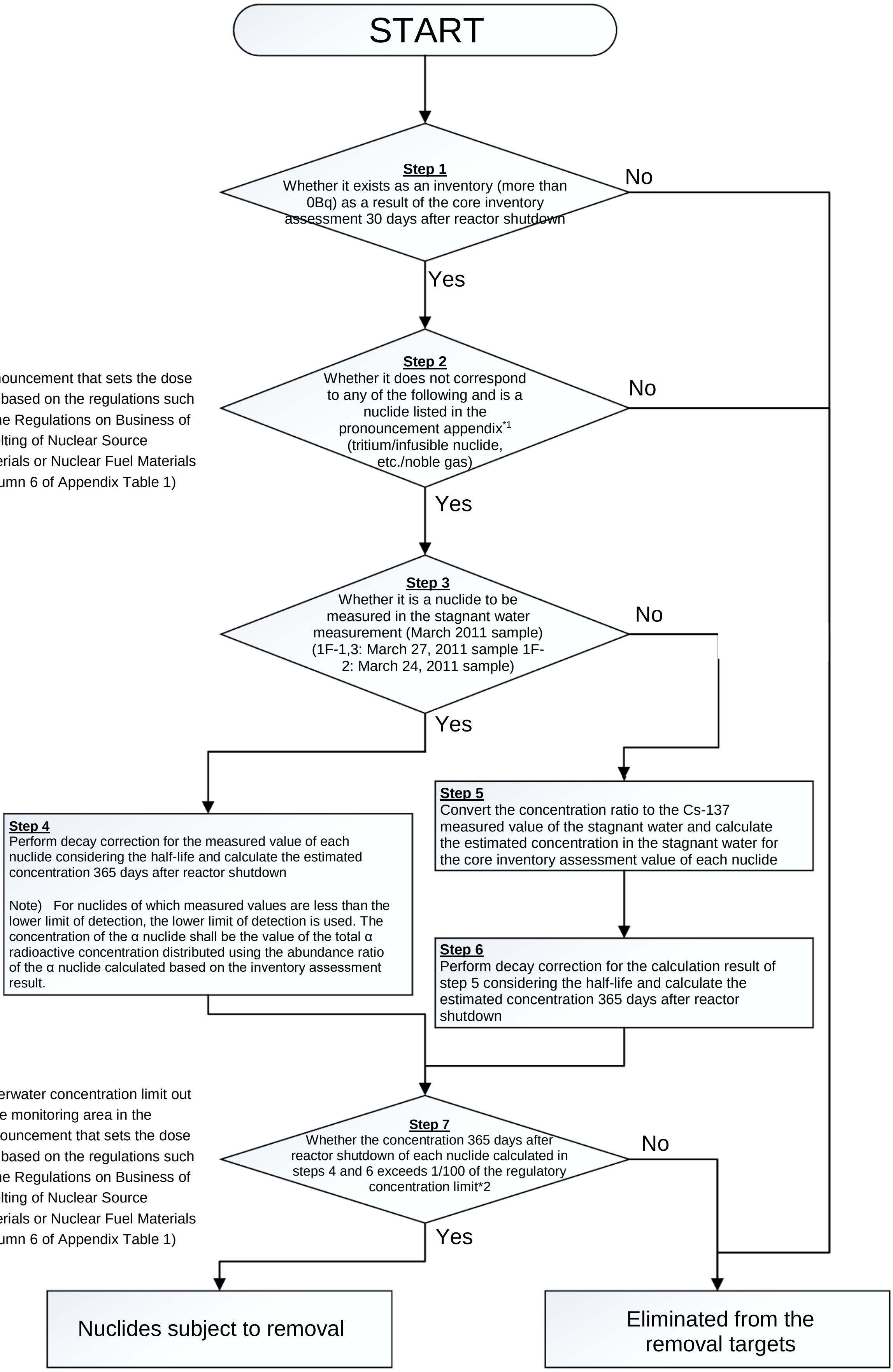
Nuclides subject to removal from FP nuclides were selected according to the flow of Figure F-1. As a result, 56 nuclides were selected as nuclides subject to removal.

(2) Selection method and selection result of nuclides subject to removal from CP nuclides

Nuclides subject to removal from CP nuclides were selected according to the flow of Figure F-2. As a result, 6 nuclides were selected as nuclides subject to removal.

(3) Summary of the selection result of nuclides subject to removal

A total of 62 nuclides were selected: 56 nuclides selected from FP nuclides and 6 nuclides selected from CP nuclides (See Table F-1).



Step 1
Whether it exists as an inventory (more than 0Bq) as a result of the core inventory assessment 30 days after reactor shutdown

Step 2
Whether it does not correspond to any of the following and is a nuclide listed in the pronouncement appendix[*1] (tritium/infusible nuclide, etc./noble gas)

Step 3
Whether it is a nuclide to be measured in the stagnant water measurement (March 2011 sample) (1F-1,3: March 27, 2011 sample 1F-2: March 24, 2011 sample)

Step 4
Perform decay correction for the measured value of each nuclide considering the half-life and calculate the estimated concentration 365 days after reactor shutdown

Note) For nuclides of which measured values are less than the lower limit of detection, the lower limit of detection is used. The concentration of the α nuclide shall be the value of the total α radioactive concentration distributed using the abundance ratio of the α nuclide calculated based on the inventory assessment result.

Step 5
Convert the concentration ratio to the Cs-137 measured value of the stagnant water and calculate the estimated concentration in the stagnant water for the core inventory assessment value of each nuclide

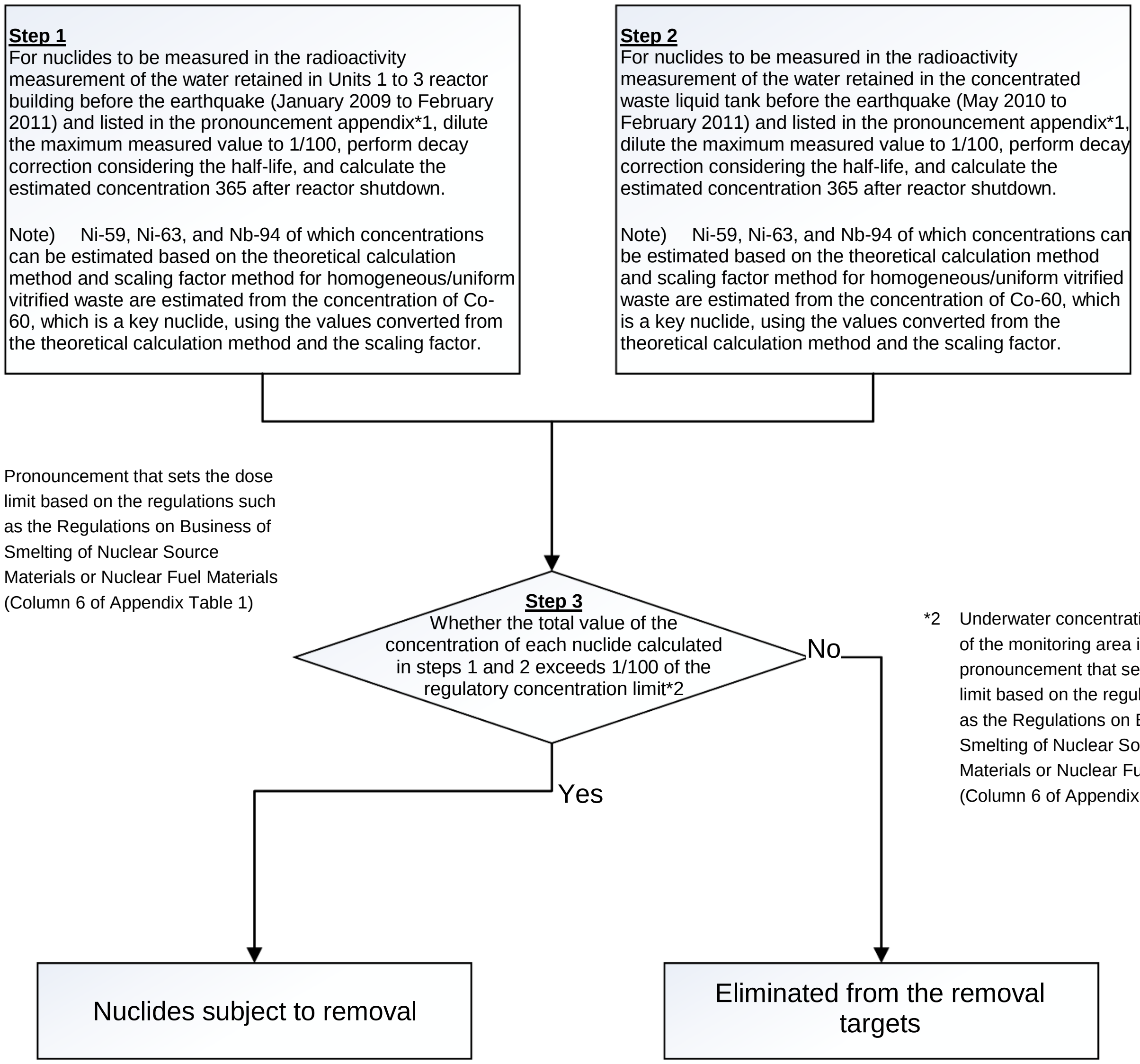
Step 6
Perform decay correction for the calculation result of step 5 considering the half-life and calculate the estimated concentration 365 days after reactor shutdown

Step 7
Whether the concentration 365 days after reactor shutdown of each nuclide calculated in steps 4 and 6 exceeds 1/100 of the regulatory concentration limit*2

*1 Pronouncement that sets the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials (Column 6 of Appendix Table 1)

*2 Underwater concentration limit out of the monitoring area in the pronouncement that sets the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials (Column 6 of Appendix Table 1)

Figure F-1: Flow to select the nuclides subject to removal in FP nuclides



Step 1
For nuclides to be measured in the radioactivity measurement of the water retained in Units 1 to 3 reactor building before the earthquake (January 2009 to February 2011) and listed in the pronouncement appendix*1, dilute the maximum measured value to 1/100, perform decay correction considering the half-life, and calculate the estimated concentration 365 after reactor shutdown.

Note) Ni-59, Ni-63, and Nb-94 of which concentrations can be estimated based on the theoretical calculation method and scaling factor method for homogeneous/uniform vitrified waste are estimated from the concentration of Co-60, which is a key nuclide, using the values converted from the theoretical calculation method and the scaling factor.

Step 2
For nuclides to be measured in the radioactivity measurement of the water retained in the concentrated waste liquid tank before the earthquake (May 2010 to February 2011) and listed in the pronouncement appendix*1, dilute the maximum measured value to 1/100, perform decay correction considering the half-life, and calculate the estimated concentration 365 after reactor shutdown.

Note) Ni-59, Ni-63, and Nb-94 of which concentrations can be estimated based on the theoretical calculation method and scaling factor method for homogeneous/uniform vitrified waste are estimated from the concentration of Co-60, which is a key nuclide, using the values converted from the theoretical calculation method and the scaling factor.

Step 3
Whether the total value of the concentration of each nuclide calculated in steps 1 and 2 exceeds 1/100 of the regulatory concentration limit*2

*1 Pronouncement that sets the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials (Column 6 of Appendix Table 1)

*2 Underwater concentration limit out of the monitoring area in the pronouncement that sets the dose limit based on the regulations such as the Regulations on Business of Smelting of Nuclear Source Materials or Nuclear Fuel Materials (Column 6 of Appendix Table 1)

Figure F-2 Flow to select the nuclides subject to removal in CP nuclides

Table F-1 List of the nuclides subject to removal

No.	Nuclide	Physical half-life	Radiation type	No	Nuclide	Physical half-life	Radiation type
1	Mn-54	310d	γ	32	I-129	1.6E+07y	βγ
2	Fe-59	44 d	γ	33	Cs-134	2.1y	βγ
3	Co-58	71d	γ	34	Cs-135	2.3E+06y	β
4	Co-60	5.3y	βγ	35	Cs-136	13d	βγ
5	Ni-63	100y	β	36	Cs-137	30y	βγ
6	Zn-65	240d	βγ	37	Ba-137m	2.6m	γ
7	Rb-86	19d	βγ	38	Ba-140	13d	βγ
8	Sr-89	51d	β	39	Ce-141	33d	βγ
9	Sr-90	29y	β	40	Ce-144	280d	βγ
10	Y-90	64h	β	41	Pr-144	17m	βγ
11	Y-91	59d	βγ	42	Pr-144m	7.2m	γ
12	Nb-95	35d	βγ	43	Pm-146	5.5y	βγ
13	Tc-99	2.1E+05y	β	44	Pm-147	2.6y	βγ
14	Ru-103	39d	βγ	45	Pm-148	5.4d	βγ
15	Ru-106	370d	β	46	Pm-148m	41d	γ
16	Rh-103m	56m	βγ	47	Sm-151	90y	βγ
17	Rh-106	30s	γ	48	Eu-152	14y	βγ
18	Ag-110m	250d	βγ	49	Eu-154	8.6y	βγ
19	Cd-113m	14 y	γ	50	Eu-155	4.8y	βγ
20	Cd-115m	45d	βγ	51	Gd-153	240d	γ
21	Sn-119m	290d	γ	52	Tb-160	72d	βγ
22	Sn-123	130d	βγ	53	Pu-238	88y	α
23	Sn-126	2.3E+05y	βγ	54	Pu-239	2.4E+04y	α
24	Sb-124	60d	βγ	55	Pu-240	6.6E+03y	α
25	Sb-125	2.8y	βγ	56	Pu-241	14y	β
26	Te-123m	120d	γ	57	Am-241	430y	α
27	Te-125m	57d	γ	58	Am-242m	140y	α
28	Te-127	9.4h	βγ	59	Am-243	7.4E+03y	α
29	Te-127m	110d	βγ	60	Cm-242	160d	α
30	Te-129	70m	βγ	61	Cm-243	29y	α
31	Te-129m	34d	βγ	62	Cm-244	18y	α

Reference G Results of upper annual discharge limit of each nuclide based on the dose constraint and optimization

According to IAEA GSR Part3 and GSG-9, when a need for approval of discharge arises, the following steps should be followed: (See IAEA GSG-9, Para 5.13)

1) The regulatory body should specify the relevant dose constraint for the facility or activity under consideration.
2) In order to assess adequately the exposure of the representative person, the applicant should characterise the discharge and the main exposure pathways.
3) The applicant should present the measures to be used for the optimization of protection and safety of the public, having given consideration to measures for keeping the exposures due to discharges as low as reasonably achievable and having taken into account all relevant factors.
4) The applicant should assess the doses to the representative person.
5) The applicant should submit the results of the assessment to the regulatory body. The regulatory body should evaluate whether the models and assumptions used by the applicant are appropriate, should compare the results of the assessment with dose limits and dose constraints, and should evaluate whether the assessed doses are in accordance with the need to provide optimized protection of the public.

The steps are as described in the Fig. G-1.

Dose constraints are set separately for each source under control and they serve as boundary conditions in defining the range of options for the purposes of optimization of protection and safety (GSR Part 3, Para 1.22). Therefore, optimization of protection and safety related to discharge ALPS treated water into the sea is conducted within the dose, which was determined to to dose constraints, in other words it is conducted up to the discharge amount of radioactive material that the representative person is exposed.

In the current plan on the discharge of ALPS treated water, some studies on the discharge methods had been conducted as a part of the process until the compilation of the Japanese government’s Basic Policy, however TEPCO have basically conducted optimization studies in accordance with the above-mentioned process in the design activities. The results are summarized in this Reference G.

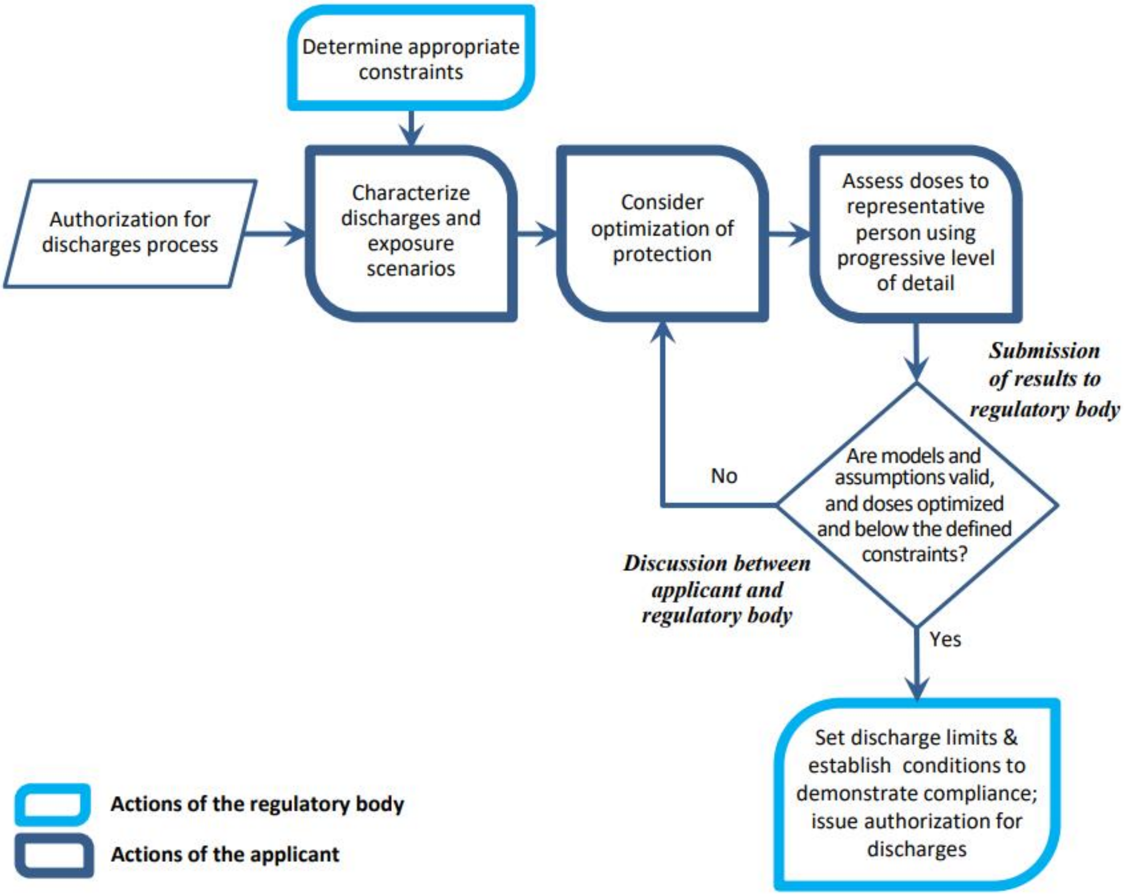


Fig. G-1: Steps in setting discharge limits by IAEA GSG-9 (IAEA GSG-9 FIG.3)

G1. D&D Works in Fukushima Daiichi Nuclear Power Station and Optimization of Radiological Protection

The decontamination and the decommissioning (D&D) works at Fukushima Daiichi Nuclear Power Station are the works to remove the hazard by radioactive materials that had already prevailed due to the severe accident. This work needs to be steadily progressed. The discharge of the ALPS treated water must also be carried out steadily so as not to affect the progress of the entire decommissioning furnace.

On the other hand, in individual D&D works, it is necessary to proceed with so-called optimization of radiological protection considering the balance between the reduction of risk due to radiation and the risks caused by factors other than radiation, while preventing excessive radiation risk. For the disposal of the ALPS treated water, as detailed in the Reference B, the Japanese government set up Tritiated Water Task Force and the Subcommittee on Handling of the ALPS Treated Water from the stage of the examination of the disposal methods, and the investigation of the optimization based on not only the technical aspect but also the environmental and social impact was carried out, and the government’s Basic Policy (hereafter “Basic Policy”) was presented in April, 2021 based on the examination. TEPCO has sought further optimization based on the Basic Policy[1].

On February 16, 2022, the Nuclear Regulation Authority confirmed that the evaluation results of representative person shall be sufficiently smaller than the range of annual exposure to a person caused by area and living environments, i.e. less than 50 μSv/year. 50 μSv/year is the target dose to be applied to light water power reactors in normal operation, and corresponds to dose constraint in IAEA safety standards. Therefore, the examination of optimization of radiological protection was carried out within the range of less than 50 μSv. On the other hand, since paragraph 5.32 of IAEA GSG-9 states that "When the projected doses to members of the public are of the order of 10 μSv per year or below, a process for optimization should not normally be required, on the basis that the efforts for further dose reduction would generally not fulfil the requirement for optimization.", this clause was used as a standard for judging the need for further optimization.

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[1] Basic Policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings’ Fukushima Daiichi Nuclear Power Station

G2. Assessment of the Upper Annual Discharge Limits Corresponding to the Dose Constraint

As mentioned above, the Nuclear Regulation Authority has regarded the annual 0.05mSv, as a dose corresponding to dose constraint in IAEA Safety Standards. Dose constraint is upper limit of exposure set for each radiation source that causes the exposure so that individuals exposed from multiple sources shall never exceed the dose limit for the public, 1mSv/ year. It corresponds to the starting point of the optimization (IAEA GSG-9, Para 5.15). In IAEA Safety Standards, dose constraints are set separately for each source under control and they serve as boundary conditions in defining the range of options for the purposes of optimization of protection and safety (GSR Part 3, Para 1.22). IAEA Safety Standards require to optimize the protection by balancing between dose reduction and various factors such as time, cost and social impact (IAEA GSG-9, Para 5.26 - 31). Therefore, optimization of radiological protection and safety related to discharge ALPS treated water into the sea is conducted within the dose, which was determined to the dose constraints, which means it is conducted up to the discharge amount of radioactive material that the representative person is exposed. As a start-up of the optimization process, annual inventories to be discharged when the representative person receives 0.05mSv/ year, equivalent to dose constraint, was calculated by the following equation.

$$A_{DC,S,N} = \frac{D_C \times A_{E,S,N}}{D_{E,S}} \qquad \text{(G-1)}$$

Where,

$A_{DC,S,N}$: Annual inventory of nuclide *N* when the representative person is exposed to the dose equivalent to the dose constraint (= 0.05mSv/ year) by discharging a source term of the same nuclide composition profile as source term ***S*** (Bq/year)

D_C: Dose constraint (= 0.05mSv/ year)

$A_{E,S,N}$: Annual inventory of nuclide *N* discharged into the environment by discharging Source Term *S* (Bq/ year)

$D_{E,S}$: Dose assessed to be received by the representative person by the dischage of source term *S* (mSv/year)[2]

Tables G-1-1～G-1-3 show the results of calculations for each nuclide contained in each source term.

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[2] The total values with a large amount of marine product ingestion in the human exposure assessment results shown in Table 6-1-21 is used.

Table G-1-1: Upper annual discharge limits for each nuclide (source term with the composition of the K4 tank group)

Nuclide	Concentration (Bq/L)	Annual discharge inventory by calculation (Bq)	Annual discharge corresponding to dose constraint(Bq)
H-3	1.4E+05	2.2E+13	3.7E+16
C-14	1.5E+01	2.4E+09	3.9E+12
Mn-54	8.5E-05	1.3E+04	2.2E+07
Fe-55	2.1E+00	3.3E+08	5.5E+11
Co-60	2.2E-01	3.5E+07	5.8E+10
Ni-63	2.1E+00	3.3E+08	5.5E+11
Se-79	1.5E+00	2.4E+08	3.9E+11
Sr-90	1.9E-01	3.0E+07	5.0E+10
Y-90	1.9E-01	3.0E+07	5.0E+10
Tc-99	7.0E-01	1.1E+08	1.8E+11
Ru-106	4.2E-02	6.6E+06	1.1E+10
Sb-125	8.6E-02	1.4E+07	2.3E+10
Te-125m	8.6E-02	1.4E+07	2.3E+10
I-129	2.1E+00	3.3E+08	5.5E+11
Cs-134	7.4E-03	1.2E+06	1.9E+09
Cs-137	3.7E-01	5.8E+07	9.7E+10
Ce-144	5.3E-04	8.3E+04	1.4E+08
Pm-147	4.5E-02	7.1E+06	1.2E+10
Sm-151	8.6E-04	1.4E+05	2.3E+08
Eu-154	7.8E-03	1.2E+06	2.0E+09
Eu-155	1.5E-02	2.4E+06	3.9E+09
U-234	6.3E-04	9.9E+04	1.7E+08
U-238	6.3E-04	9.9E+04	1.7E+08
Np-237	6.3E-04	9.9E+04	1.7E+08
Pu-238	6.3E-04	9.9E+04	1.6E+08
Pu-239	6.3E-04	9.9E+04	1.7E+08
Pu-240	6.3E-04	9.9E+04	1.7E+08
Pu-241	2.2E-02	3.5E+06	5.8E+09
Am-241	6.2E-04	9.7E+04	1.6E+08
Cm-244	5.1E-04	8.0E+04	1.3E+08
Calculation method of discharge inventory		The case thta K4 tank water is discharged until tritium reaches 22 TBq	The case the water in K4 tank group has been discharged until the exposure estimate reaches dose constraint

Table G-1-2: Upper annual discharge limits for each nuclide (source term with the composition of J1-C tank group)

Nuclide	Concentration (Bq/L)	Annual discharge inventory by calculation (Bq)	Annual discharge corresponding to dose constraint (Bq)
H-3	7.2E+05	2.2E+13	1.8E+17
C-14	1.8E+01	5.5E+08	4.6E+12
Mn-54	5.3E-03	1.6E+05	1.3E+09
Fe-55	2.4E+00	7.3E+07	6.1E+11
Co-60	2.4E-01	7.3E+06	6.1E+10
Ni-63	8.3E+00	2.5E+08	2.1E+12
Se-79	1.5E+00	4.6E+07	3.8E+11
Sr-90	3.4E-02	1.0E+06	8.7E+09
Y-90	3.4E-02	1.0E+06	8.7E+09
Tc-99	1.2E+00	3.7E+07	3.1E+11
Ru-106	2.7E-01	8.3E+06	6.9E+10
Sb-125	1.2E-01	3.7E+06	3.1E+10
Te-125m	1.2E-01	3.7E+06	3.1E+10
I-129	1.2E+00	3.7E+07	3.1E+11
Cs-134	3.3E-02	1.0E+06	8.4E+09
Cs-137	1.7E-01	5.2E+06	4.3E+10
Ce-144	6.4E-02	2.0E+06	1.6E+10
Pm-147	4.2E-01	1.3E+07	1.1E+11
Sm-151	1.1E-02	3.4E+05	2.8E+09
Eu-154	9.4E-02	2.9E+06	2.4E+10
Eu-155	2.4E-01	7.3E+06	6.1E+10
U-234	3.2E-02	9.8E+05	8.1E+09
U-238	3.2E-02	9.8E+05	8.1E+09
Np-237	3.2E-02	9.8E+05	8.1E+09
Pu-238	3.2E-02	9.8E+05	8.1E+09
Pu-239	3.2E-02	9.8E+05	8.1E+09
Pu-240	3.2E-02	9.8E+05	8.1E+09
Pu-241	1.1E+00	3.4E+07	2.8E+11
Am-241	3.2E-02	9.8E+05	8.1E+09
Cm-244	3.0E-02	9.2E+05	7.6E+09
Calculation method of discharge inventory		The case that J1-C tank water is discharged until tritium reaches 22 TBq	The case the water in J1-C tank group has been discharged until the exposure estimate reaches dose constraint

Table G-1-3: Upper annual discharge limits for each nuclide (source term with the composition of J1-G tank group)

Nuclide	Nuclide concentration (Bq/L)	In the evaluation annual emission (Bq)	Annual emissions (Bq) equivalent to dose constraint
H-3	2.4E+05	2.2E+13	1.1E+17
C-14	1.6E+01	1.5E+09	7.3E+12
Mn-54	5.4E-03	5.0E+05	2.5E+09
Fe-55	2.4E+00	2.2E+08	1.1E+12
Co-60	1.7E-01	1.6E+07	7.8E+10
Ni-63	8.7E+00	8.0E+08	4.0E+12
Se-79	1.5E+00	1.4E+08	6.9E+11
Sr-90	3.0E-02	2.8E+06	1.4E+10
Y-90	3.0E-02	2.8E+06	1.4E+10
Tc-99	1.3E+00	1.2E+08	6.0E+11
Ru-106	9.4E-02	8.6E+06	4.3E+10
Sb-125	7.5E-02	6.9E+06	3.4E+10
Te-125m	7.5E-02	6.9E+06	3.4E+10
I-129	3.3E-01	3.0E+07	1.5E+11
Cs-134	3.0E-02	2.8E+06	1.4E+10
Cs-137	3.1E-01	2.8E+07	1.4E+11
Ce-144	6.5E-02	6.0E+06	3.0E+10
Pm-147	3.8E-01	3.5E+07	1.7E+11
Sm-151	9.8E-03	9.0E+05	4.5E+09
Eu-154	8.4E-02	7.7E+06	3.9E+10
Eu-155	1.2E-01	1.1E+07	5.5E+10
U-234	2.8E-02	2.6E+06	1.3E+10
U-238	2.8E-02	2.6E+06	1.3E+10
Np-237	2.8E-02	2.6E+06	1.3E+10
Pu-238	2.7E-02	2.5E+06	1.2E+10
Pu-239	2.8E-02	2.6E+06	1.3E+10
Pu-240	2.8E-02	2.6E+06	1.3E+10
Pu-241	8.9E-01	8.2E+07	4.1E+11
Am-241	2.8E-02	2.6E+06	1.3E+10
Cm-244	2.6E-02	2.4E+06	1.2E+10
Calculation method of discharge inventory		The case that J1-G tank water is discharged until tritium reaches 22 TBq	The case the water in J1-G tank group has been discharged until the exposure estimate reaches dose constraint

G3. Upper Discharge Limits Based on the Basic Policy by the Japanese Government

Regarding the discharge of ALPS treated water into the sea, the Basic Policy dated on April 13, 2021 states the requirement to TEPCO as a policy of the government on the disposal as follows:

- Discharge of the ALPS treated water into the sea will be implemented from Fukushima Daiichi Nuclear Power Station as the discharge method based on the premise of complying the rigorous regulatory standards.
- Make sure that the water is purified until the level of radioactive materials other than tritium satisfies the regulatory standards for safety will be confirmed and disclosed.[3]
- To allay the concerns of the consumers, the target concentration of tritium, which is difficult to remove, should be the same as the operational target (less than 1,500Bq/Liter-water) for the currently implemented discharge of water pumped up via sub-drains, at FDNPS.
- The total annual amount of tritium to be discharged will be at a level below the operational target value for tritium discharge of the FDNPS before the accident (22 TBq/ year). The amount will be reviewed periodically.

The government set the above condition for discharge of ALPS treated water into the sea.Therefore, it was decided to carry out the following examination of the optimization on a basis of the above-mentioned policy.

In addition, as described above, in the Basic Policy, although the amount will be reviewed periodically, optimization should be considered as an upper limit on the discharge amount of radioactive material $A_{DC,S,N}$ leading to dose constraints as IAEA GSG Part 3 Para 1.22 describes “Dose constraints are set separately for each source under control and they serve as boundary conditions in defining the range of options for the purposes of optimization of protection and safety”,.

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[3] For radioactive materials other than tritium, concentrations shall be to be lower than the standards for the safe discharge of liquid radioactive waste only into the enviroment as stipulated in the announcement based on Reactor Regulation Act prior to dilution.

G4. Options for Optimization

Based on the Basic Policy, TEPCO considered the following as options for optimization:

G4-1. Outlet Position

As options, a plan to use existing facilities (Units 5 and 6 discharge outlet) and a plan to install a new discharge outlet offshore were considered. The use of existing Unit 5 and 6 discharge outlet has advantages in terms of environmental impact and duration of construction, however the option to install a new discharge outlet offshore is advantageous for dispersion of radionuclides after the discharge. In selecting the offshore discharge outlet position, it was considered that a stable rock mass suitable for the installation of the facilities was exposed on the sea floor, and that it was within the area where the joint fishing rights were not established in consideration of the impacts on fisheries.

G4-2. Discharge Rate of the ALPS Treated Water

Discharge rate of ALPS reated water can directly affect radionuclide concentrations in sea areas and thus affect exposure to the representative person. For radiation protection, therefore, it is better if the rate is as small as possible, but in order to steadily promote D&D works, it is necessary to discharge as much as possible to secure the site and reduce the risk of tank storage.

Contaminated water is still being generated as much as a daily 130m^3. In order to reduce the amount of ALPS treated water stored in the power plant, the discharge rate must be set at a flow rate exceeding this and, also needs to be determined so that the discharge of ALPS treated water will be completed by the completion of decommissioning.

G4-3. Capacity of Dilution Facility by the Sea Water

Although the Basic Policy states that the tritium concentration at the time of discharge should be less than 1,500Bq/L, it may be discharged at lower concentrations by increasing flow rate of the sea water. In particular, changes in the dilution ratio may not be meaningful if the discharged radioactivity is the same from the macroscopic view. However, by keeping the concentration in very vicinity area around discharge outlet where dispersion dilution by oceanic currents is not sufficiently carried out, the impact around discharge outlet can be reduced and impact on reputations can be suppressed.

G4-4. Discharge Sequence based on Tritium Concentration in ALPS Treated Water to be Discharged

Even in the case the same 22 TBq of tritium is discharged, the lower tritium-concentration results in higher discharge volume of ALPS treated water, as described in Section 6-1-2. (1) of the main body. Consideration of the impact of tritium concentration, including the viewpoint from other evaluation factors, will be given.

G5. Optimization

Evaluate the options considered in the above G4. from the following perspectives.

- Exposure to the general public (the representative person) and the environment
- Risk of health effects other than exposure to the general public and the environment
- Exposure (occupational exposure) to persons working at FDNPS
- Impact on the progress of D&D in the FDNPS
- Impacts on the environment other than radiation
    - Atmospheric environment (air quality, noise/vibration)
    - Water environment (water quality, water temperature, flow velocity, other than radioactive materials)
    - Other environments (terrain/geology, subgrade, soil)
    - Animals, plants, and ecosystems
    - Rich natural environment (landscape, etc.)
    - Environmental load (waste, greenhouse gas emissions, etc.)
- Energy consumption
- Impacts of radioactive materials already in the environment
- Public interest

G5-1. Outlet Position

The optimization study for discharge outlet position is shown in Table G-2.

Discharge outlet for Units 5 and 6 are advantageous because they do not require any additional construction. However, they can be overcome only by appropriately setting the size of the facilities to be installed in 1km offshore plan, and they are advantageous in terms of public exposure, the impacts of environmental radioactive materials, and social concerns. Therefore, they decided to adopt the option of 1km offshore.

Table G-2: Result of Outlet Position Optimization Considerations

Evaluation viewpoint		Discharge outlet for Units 5 and 6	1km offshore
Exposure to the public and the environment (Examined by simulation results of tritium concentration)		(-) Although it is sufficiently small in number, the concentration of nuclides in the seawater are higher in the coastal area near discharge outlet than the option of discharge offshore, and the exposure in the area is larger.	(+) While there is no significant difference in dispersion over a wider area, it can be said to be somewhat advantageous from the viewpoint of dispersion.
Occupational exposure		(±) There is no clear difference between the two options.	(±) Same as left
Impact on decommissioning		(±) Since there are few new facilities to be installed, discharge can be started promptly, but this alone does not necessarily contribute to the progress of D&D works.	(-) Soil disposal area for excavated soil is required on the premises. (-) The larger the scale of the facility, the longer the process and the need for additional tank installation, which may affect the progress of decommissioning.
Impacts on the environment other than radiation (see Reference D)	Atmospheric environment (air quality, noise/vibration)	(±) No particular impact.	(±) No particular impact.
	Water environment (water quality, water temperature, flow velocity, other than radioactive materials)	(±) No particular impact.	(±) No particular impact.
	Other environment (terrain/geology, subgrade, soil)	(±) No particular impact.	(±) It involves new topographical modifications, but is very limited.
	Animals, plants, and ecosystems	(±) No particular impact.	(±) No particular impact.
Energy consumption		(±) No particular impact.	(-) Energy input is required for the construction of the facility, but not for the operation of the facility.
Impact of radioactive materials already in the environment (refer to Attachment V)		(-) Although it has been confirmed that the impact is sufficiently small, the impact on the general public and the environment becomes relatively large by drawing in sea water of which radioactive material concentration in the harbor is a little high and discharging it to the outside of the harbor.	(±) Since discharge outlet is offshore, it draws in clean seawater on the north side of the port and discharges it outside the port, so there is no impact.
Public interest		(-) It is the position of the existing discharge port, and the flow rate is about 1/10 of the circulating water pump which was in operation before. However, as it can be visually confirmed the discharge, there is a possibility that the reputational impact may be caused.	(±) It is difficult to receive unnecessary attention because the discharge point cannot be visually confirmed directly above the water.
Overall evaluation		(--)	(-)

G5-2. Discharge Rate of the ALPS Treated Water

Table G-3 shows the results of optimization study on discharged flow rate of the ALPS treated water.

The results of the study indicated that the discharge flow rate of the ALPS treated water should be as high as possible in order to minimize the impact on the D&D works, but at the same time, as there is concern about the reputational impact, this balance should be taken into consideration.

Since ALPS treated water, etc. already stored on the site exceeds about 1.3 million m^3, even if the discharge begins in the spring of 2023, it will need to be discharged at least daily $123m^3$ in simple-calculation to complete the discharge by 2051. In addition, it becomes about daily $154m^3$ if calculated with 80% of facility utilization factor, considering unavailable period for maintenance of the facility. When the new generation of contaminated water is added to this, the discharge rate of the ALPS treated water needs to be at least as $300m^3$ as the daily discharge rate.

On the other hand, in order to promote D&D works, it is better to take a larger amount of discharged treated water and proceed with the dismantling of the tanks as soon as possible. However, according to the Basic Policy, the total amount of tritium discharged shall be limited to be 22 TBq per year. Since the annual discharge of the ALPS treated water is inversely proportional to the concentration of tritium in the water to be discharged by the equation shown in 6-1-2. (1) The maximum flow rate is the flow rate when annual 22 TBq of tritium is discharged at the lowest concentration of tritium among the tank groups storing ALPS treated water at present (about 150,000 Bq/L), and the amount is approximately the daily volume $500m^3$ (2.2E+13Bq/ year ÷ (365 days/year × 0.8) ÷ 150,000 Bq/L ÷ 1,000 L/m^3=$500m^3$ per day). In the future, it will be possible to increase the discharge flow rate even further when the tritium concentration decreases due to the natural decay. However, it is difficult to assume a situation where a higher flow rate is required for the discharge for the time being. Therefore, the maximum flow rate for the discharge facility is set to be the required $500m^3$.

When the annual discharge water volume by the three source terms used for the dose evaluations is converted into the daily flow rate, the annual discharge of K4 tank group source term is about $410m^3$ as the largest and the estimated dose is 2E-05mSv/ year (= 0.02 μSv/year), which is much lower than the judgment criterion of 10 μSv/year whether further optimization is required or not.

In order to steadily proceed with decommissioning, it is necessary to construct facilities to reduce the risk of fuel debris, spent fuel, and radioactive waste. In addition, it is our policy to locate the storage sites for high-dose materials such as spent fuel and fuel debris as far away from the site boundary as possible, in order to reduce exposure of the public around the site. In principle, ALPS treated water will be discharged in the order of low level of tritium concentration.Based on the above, the following year's discharge plan should be prepared at the end of each fiscal year based on the latest information, and the discharge should be carried out in accordance with the plan, so that the optimum discharge can be carried out.

Table G-3: Optimization Study of ALPS Treated Water Discharge Flow Rate

Evaluation viewpoint		Low flow rate	High flow rate
Exposure to the public and the environment (Examined by simulation results of tritium concentration)		(±) The smaller the discharge inventory, the smaller the exposure, but in any case the impact is very small.	(-) Although the impact is extremely small, the exposure is relatively large because of the larger discharge inventory. (+) Since the site can be operated with sufficient margin, the facilities to be constructed in the future will also be able to be installed in the optimum location for radiation exposure management.
Occupational exposure		(-) Though the dose rate is sufficiently low, exposure by direct ray and skyshines from the tank for storing treated water, etc., which requires secondary treatment in the power plant, will be prolonged. (±) Since the period to discharge completion is extended, the number of inspections of the equipment is expected to increase, but the equipment is installed in low-dose areas, and the impact is small.	(+) Treated water and other tanks, one of the radiation sources on the premises of the power station, are quickly reduced. (+) Since the site can be operated with sufficient margin, the facilities to be constructed in the future will also be able to be installed in the optimum location for radiation exposure management.
Impact on decommissioning		(---) If the discharge rate is too low, it will be difficult to install facilities necessary for D&D works by the time when they is necessary in the future, which will seriously affect the progress of D&D works leading to the management of radioactive materials with much higher risks.	(++) If allowance in site operation is available, it will be easy to install facilities in the optimal location along the purpose of the facility in the future, and it will be possible to efficiently proceed with D&D works.
Impacts on the environment other than radiation (see Reference D)	Atmospheric environment (air quality, noise/vibration)	(±) If the dynamic equipment to be installed is small enough, the noise and vibration generated are also small enough, and there is no particular effect.	(-) The larger the dynamic equipment to be installed, the greater the noise and vibration generated.
	Water environment (other than water quality, water temperature, flow velocity, and radioactive materials)	(±) No particular impact.	(±) No particular impact.
	Other environment (topography, geology, ground, soil)	(±) Due to the smaller size of equipment, it is possible to minimize the modification of the terrain.	(-) The higher the discharge rate, the larger the equipment and the larger the scale such as the modification of the terrein necessary for the installation.
	Animals, plants, and ecosystems	(±) No particular impact.	(±) No particular impact.
Energy consumption		(-) Energy input is required to establish and operate new facilities.	(-) As the facility to be installed becomes larger, the energy required for installation becomes larger, while the operation period becomes shorter, so there is no

Evaluation viewpoint	Low flow rate	High flow rate
		significant difference in the energy input to perform the operation.
Impact of radioactive materials already in the environment (refer to Attachment V)	(±) No particular impact.	(±) No particular impact.
Public interest	(-) It can give the impression that the reconstruction is stagnant by the tanks remaining persistently in the NPS.	(--) Releasing treated water at larger rate could result in reputational impact on fisheries and other industries.
Overall evaluation	(--)	(+)

For radionuclides other than tritium, the concentrations of those radionuclides at the time of discharge shall not exceed regulatory concentration limits specified for each nuclide, since the concentrations of radionuclides other than tritium shall be less than the standard for discharge of liquid radioactive waste based on Reactor Regulation Act before dilution , that is, the ALPS treated water shall not be discharged if the sum of ratios to regulatory concentration limits of the radionuclides other than tritium in ALPS treated water exceeds 1 before dilution. Therefore, using the following equation, the total inventory of each radionuclide at the concentration equal to the regulatory standard in treated water discharged for 365 consecutive days at the full capacity (=500 m^3/day) of ALPS treated water transfer pump in the ALPS treated water discharge facilities.

$$A_{CL,N} = CL_N \times V_E \qquad \text{(G-2)}$$

Where,

$A_{CL,N}$: Maximum annual discharged inventory of nuclide ***N*** calculated by the product of the maximum annual discharge volume of ALPS treated water and regulatory concentration limit (Bq/ year)
CL_N: Regulatory concentration limit (Bq/L) of nuclide ***N***
V_E: Max. annual discharge volume based on the capacity of an ALPS treated water transfer pump (1.8E+08 L/year, = 500 m^3 per day × 365 days per year × 1,000 L/m^3)

In comparison of the upper limit of annual discharge corresponding to dose constraint $A_{DC,S,N}$ with the upper limit of annual discharge by regulatory standard for each nuclide $A_{CL,N}$, the smaller value is the actual upper limit of annual discharge. Therefore, the smallest value is shown in Table G-4 as the nuclide N's upper limit $A_{Limit,N}$ of annual discharged inventory. Therefore,

$$A_{Limit,N} = \min\left(A_{DC,K4,N},\ A_{DC,J1-C,N},\ A_{DC,J1-G,N},\ A_{CL,N}\right) \qquad \text{(G-3)}$$

Table G-4: Upper limit of annual inventory discharged for each radionuclide (Bq/year)

Nuclide	Annual discharged inventory based on the dose constraint $A_{DC,S,N}$			Upper limit by regulatory standard $A_{CL,N}$	Upper limit of annual discharged inventory $A_{Limit,N}$
	K4 $A_{DC,K4,N}$	J1-C $A_{DC,J1-C,N}$	J1-G $A_{DC,J1-G,N}$		
H-3	3.7E+16	1.8E+17	1.1E+17	—	2.2E+13
C-14	3.9E+12	4.6E+12	7.3E+12	3.7E+11	3.7E+11
Mn-54	2.2E+07	1.3E+09	2.5E+09	1.8E+11	2.2E+07
Fe-55	5.5E+11	6.1E+11	1.1E+12	3.7E+11	3.7E+11
Co-60	5.8E+10	6.1E+10	7.8E+10	3.7E+10	3.7E+10
Ni-63	5.5E+11	2.1E+12	4.0E+12	1.1E+12	1.1E+11
Se-79	3.9E+11	3.8E+11	6.9E+11	3.7E+10	3.7E+10
Sr-90	5.0E+10	8.7E+09	1.4E+10	5.5E+09	5.5E+09
Y-90	5.0E+10	8.7E+09	1.4E+10	5.5E+10	8.7E+09
Tc-99	1.8E+11	3.1E+11	6.0E+11	1.8E+11	1.8E+11
Ru-106	1.1E+10	6.9E+10	4.3E+10	1.8E+10	1.1E+10
Sb-125	2.3E+10	3.1E+10	3.4E+10	1.6E+11	2.3E+10
Te-125m	2.3E+10	3.1E+10	3.4E+10	1.6E+11	2.3E+10
I-129	5.5E+11	3.1E+11	1.5E+11	1.6E+09	1.6E+09
Cs-134	1.9E+09	8.4E+09	1.4E+10	1.1E+10	1.1E+10
Cs-137	9.7E+10	4.3E+10	1.4E+11	1.6E+10	1.6E+10
Ce-144	1.4E+08	1.6E+10	3.0E+10	3.7E+10	1.4E+08
Pm-147	1.2E+10	1.1E+11	1.7E+11	5.5E+11	1.2E+10
Sm-151	2.3E+08	2.8E+09	4.5E+09	1.5E+12	2.3E+08
Eu-154	2.0E+09	2.4E+10	3.9E+10	7.3E+10	2.0E+09
Eu-155	3.9E+09	6.1E+10	5.5E+10	5.5E+11	3.9E+09
U-234	1.7E+08	8.1E+09	1.3E+10	3.7E+09	1.7E+08
U-238	1.7E+08	8.1E+09	1.3E+10	3.7E+09	1.7E+08
Np-237	1.7E+08	8.1E+09	1.3E+10	1.6E+09	1.7E+08
Pu-238	1.6E+08	8.1E+09	1.2E+10	7.3E+08	1.7E+08
Pu-239	1.7E+08	8.1E+09	1.3E+10	7.3E+08	1.7E+08
Pu-240	1.7E+08	8.1E+09	1.3E+10	7.3E+08	1.7E+08
Pu-241	5.8E+09	2.8E+11	4.1E+11	3.7E+10	5.8E+09
Am-241	1.6E+08	8.1E+09	1.3E+10	9.1E+08	1.6E+08
Cm-244	1.3E+08	7.6E+09	1.2E+10	1.3E+09	1.3E+08

G5-3. Capacity of Dilution Facility by the Sea Water

Table G-5 shows the result of the optimization regarding capacity of dilution facility by the sea water.

The flow rate on ALPS treated water side to be diluted was set to a maximum of 500 m^3 per day based on the discussion of G5-2, but the Basic Policy only states that the concentration after dilution should be less than 1,500 Bq/L, and there is no description regarding the dilution facility. Therefore, optimization of the capacity of the dilution facility in the case of the maximum flow rate on ALPS treated water side was conducted in this section.

Based on the results of the study, the overall evaluation was that a smaller capacity of dilution facility is preferable mainly from the perspective of impact on decommissioning and environmental impact, however, individual evaluation shows, a larger capacity of dilution facility is preferable from the perspective of social impact, such as suppression of reputation. Through the assessment in the design stage, it is confirmed that the tiritum concentration after dilution does not exceed 1,500Bq/L even if the error of the flow meters and the uncertainty of the mixing condition for dilution in seawater pipes are considered, by setting the seawater flow rate to about 330,000 m^3 per day[4], which includes 1.5 times as a safety factor added to the required seawater flow rate for the case that the ALPS treated water with the highest tritium concentration confirmed so far must be discharged at the rate of the equivalent amount of contaminated water generated on a daily basis as a risk scenario, and by setting the upper limit of tritium concentration in the treated water discharged to 1 million Bq/L.[5]

Therefore, it was decided to install three pumps of 170,000 m^3 per day, which can cover the above-mentioned required flow rate by two pumps, for sea water pumps for dilution. As a result, even if one pump is supposed to be a standby, the dilution ratio becomes about 680 times or more (two pumps are in operation). When the ALPS treated water with a relatively high tritium concentration is discharged at the maximum flow rate of 500m^3 per day, the tritium concentration in discharged water can be reduced to less than 1,500Bq/L. On the other hand, when a higher dilution ratio is required in terms of social impact, the concentration in discharged water can be reduced by operating all the three sea water pumps.

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[4] The 5th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water Document 1 pp.6-8

[5] The 13th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water Ref.1-1 pp.31-33

Table G-5: Optimization regarding Capacity of Dilution Faclitiy by the Sea Water

Evaluation viewpoint		Low capacity of dilution facility	High capacity of dilution facility
Exposure to the public and the environment (Examined by simulation results of tritium concentration)		(±) The same inventory discharged per unit time would result in the same evaluated dose except in the close vicinity of the outlet, so the capacity of dilution facility does not affect the dose assessment.	(±) Same as left
Occupational exposure		(±) Less than 1,500Bq/L at discharge is sufficiently low, and occupational exposure is not an issue.	(±) Same as left
Impact on decommissioning		(-) If the capacity is too small, there will be restrictions on the amount of ALPS treated water with high tritium concentration to be discharged, which may affect the decommissioning process due to the time required for discharge. Therefore, the necessary capacity must be secured.	(-) If a pump with too large capacity is installed, the delivery date and installation period of the equipment could be extended, which may affect the D&D process. Therefore, it is necessary to select the optimum pump size. (-) As the diameter of the undersea tunnel for discharge increases, there is a possibility of further tightness of the land use, such as the necessity of a new soil disposal site, by generating a large amount of construction waste soil accompanied by the large-scale terrein modification, in addition to the extension of the construction period.
Impacts on the environment other than radiation (see Reference D)	Atmospheric environment (air quality, noise/vibration)	(±) If the dynamic equipment to be installed is small enough, the noise and vibration generated are also small enough, and there is no particular effect.	(-) The larger the dynamic equipment to be installed, the greater the noise and vibration generated.
	Water environment (other than water quality, water temperature, flow velocity, and radioactive materials)	(±) The flow velocity at the outlet can be suppressed to a sufficiently low speed.	(-) If the diameter of the undersea tunnel or the size of discharge outlet is not changed, the higher the flow rate, the higher the flow velocity at the discharge outlet. In the case of an upward flow, the flow velocity affects the vessels underway in the surrounding area by the jet, and in the case of a horizontal flow, erosion of the seabed, etc. may become a problem.
	Other environment (topography, geology, ground, soil)	(±) Because of the small equipment, it is possible to minimize the modification of the terrain caused by the installation.	(-) The higher the flow rate, the larger the equipment and the larger the scale such as the modification of the terrein by the installation.
	Animals, plants, and ecosystems	(±) Small equipment can minimize the impacts on animals, plants, and ecosystems associated with both installation and operation.	(-) The higher the flow rate, the greater the capacity and the greater the impact on animals, plants and ecosystems associated with installation and operation.
Energy consumption		(-) Energy input associated with the installation and operation of the facility is required.	(--) The larger the scale of the facility to be installed, the greater the energy consumption associated

Evaluation viewpoint	Low capacity of dilution facility	High capacity of dilution facility
		with the installation and its operation.
Impact of radioactive materials already in the environment (refer to Attachment V)	(±) No particular effect.	(±) No particular effect.
Public interest	(--) There is a risk of reputational impact because the concentration in the vicinity of the outlet becomes relatively higher.	(±) It is expected that the risk of reputational impact can be suppressed to some extent by sufficiently diluting with a large amount of seawater.
Overall evaluation	(-)	(--)

G5-4. Discharge Sequence based on Tritium Concentration in ALPS Treated Water

Table G-6 shows the results of optimization studies on tritium concentration in ALPS treated water to be discharged.

ALPS treated water, etc. contains tritium at concentrations ranging from approximately 100,000 Bq/L at low levels to over 2 million Bq/L at high levels, and the concentrations are not constant. On the other hand, if the annual discharge amount is assumed to be constant at 22 trillion Bq, the lower concentration is advantageous from the viewpoint of securing the site for decommissioning work because more ALPS treated water can be discharged. But the discharge inventory of nuclides other than tritium tends to increase with the larger amount of water discharged. As K4 tank group used as the source term in this assessment had the lowest tritium concentration measured so far, the value in this assessment can be regarded as the upper limit of the tritium discharge inventory.

Based on the results of the following study, it is decided to preferentially discharge treated water with low-tiritum-concentration.

Table G-6: Optimization Study regarding Discharge Sequence based on Tritium Concentration in ALPS Treated Water

Evaluation viewpoint		Prioritize low concentration	Prioritize high concentration
Exposure to the public and the environment (Examined by simulation results of tritium concentration)		(-) At lower concentrations of tritium in ALPS treated water discharged, discharge of radionuclides other than tritium would be relatively higher, but even the evaluation result of the lowest tritium concentrations of K4 indicated the minimal impact.	(±) Although the discharge inventory of nuclides other than tritium is relatively small, there is no change in the conclusion that the impact is extremely small.
Occupational exposure		(±) The concentration of tritium in ALPS treated water and other nuclides are not found to be associated with each other and have no particular effect.	(±) Same as left
Impact on decommissioning		(++) Since there is a difference of about 10 times in tritium concentration ratio, it is possible to discharge a relatively large amount of treated water, and it will be possible to quickly secure the site necessary for D&D works.	(+) Empty tanks come out by the discharge, but the amount of the discharge is limited, so there is less significant progress in securing the site.
Impacts on the environment other than radiation (see Reference D)	Atmospheric environment (air quality, noise/vibration)	(±) No particular effect.	(±) No particular effect.
	Water environment (other than water quality, water temperature, flow velocity, and radioactive materials)	(±) No particular effect.	(±) No particular effect.
	Other environment (topography, geology, ground, soil)	(±) No particular effect.	(±) No particular effect.
	Animals, plants, and ecosystems	(±) No particular effect.	(±) No particular effect.
Energy consumption		(±) No particular effect.	(±) No particular effect.
Impact of radioactive materials already in the environment (refer to Attachment V)		(±) No particular effect.	(±) No particular effect.
Public interest		(-) The lower the tritium concentration in the discharged ALPS treated water, the smaller the social impact, which is advantageous for the countermeasure against rumors.	(---) Higher concentration results in greater impact.
Overall evaluation		(-)	(---)

G5-5. Optimization result

Based on the considered design as described above, the assessment result on exposure dose to a representative person shows the value that is satisfactly below 10μSv (see Table 6-1-21.) We have determined it had been properly optimized, however, further optimization studies will be considered as needed like when status changes in the future.