Tritiated Water Task Force Report

June 2016

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Tritiated Water Task Force Report (Outline)

As one of the countermeasures for treating contaminated water at Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station (hereafter referred to as "Fukushima Daiichi NPS"), various options underwent technical assessments meant to serve as basic data for determining how to handle, over a long period, water treated by multi-nuclide removal equipment, etc. (hereafter referred to as "tritiated water"). (This is not meant to reconcile the opinions of related parties or consolidate the options.)

○ Overview of Basic Information

In addition to organizing information on tritium, which is a radioactive isotope of hydrogen (hydrogen-3), and its physical properties, its environmental fate, and its impact on the environment and humans, the state of tritium at Fukushima Daiichi NPS, regulatory standards for tritium, and examples of handling it in Japan and abroad were compiled as basic information.

○ Options for Handling Tritiated Water and Option Assessment

Based on examples from other countries and the like, scenarios under assessment were established and technical assessments were carried out on the basis of conditions for treatment which were standardized in order to compare, side-by-side, 11 options consisting of five methods and pre-treatments.

- geosphere injection (no pre-treatment/ post-dilution/ post-separation)
- offshore release (post-dilution/ post-separation)
- vapor release (no pre-treatment/ post-dilution/ post-separation)
- hydrogen release (no pre-treatment/ post-separation)
- underground burial (no pre-treatment)

(Main Conditions) Volume to be Treated: 0.8 million m^3;
Volume to be Treated per Day: 400 m^3
Concentration in Raw Water: 4.2 million Bq/L or 0.5 million Bq/L
Concentration to be Treated: legally permitted concentration

Items for assessment were established for the assessment, with technical feasibility and regulatory feasibility established as the basic requirements, and the duration required for the treatment, the costs, the scale, secondary waste, radiation exposure of workers, and other conditions established as potentially restricting conditions. (The results of the estimations are approximations made under fixed hypothetical conditions and they are not guarantees of the details for the actual treatment.)

Also, based on the results from verification tests of tritium separation technologies, since isotopic separation was not found to be a technology which could be immediately utilized, the duration and costs required for separation are not addressed.

Contents

1. Introduction

A document entitled “Preventative and Multilayered Measures- Utilizing Enhanced Comprehensive Risk Management- for Contaminated Water Treatment at Tokyo Electric Power Company’s Fukushima Daiichi Nuclear Power Station” was compiled under the Committee on Countermeasures for Contaminated Water Treatment on December 10th, 2013. Therein, it became clear that even if the various countermeasures of “removing contamination sources,” “isolating water from contamination sources,” and “preventing leakage of contaminated water” were adopted, there would ultimately still be risks associated with storing water treated by multi-nuclide removal equipment, etc. (hereafter referred to as “tritiated water”). Thus, the “Tritiated Water Task Force” was established under the Committee on Countermeasures for Contaminated Water Treatment, with the goal of assessing the various options pertaining to handling tritiated water, and discussions commenced on December 25th, 2013.

At the recommendation of the IAEA (International Atomic Energy Agency) investigative committee to “examine all options” pertaining to handling tritiated water, the Nuclear Emergency Response Headquarters made a point, in the “Additional Measures for Decommissioning and Contaminated Water Issues at Tokyo Electric Power Company’s Fukushima Daiichi Nuclear Power Station” decided on December 20, 2013, about “contemplating countermeasures by urgently implementing a comprehensive assessment of all options pertaining to handling tritiated water, for which the large-volume storage thereof will still pose risks even after additional measures have been adopted.”

2. Goals and Assumptions of this Task Force

Amongst the contaminated water issues at Tokyo Electric Power Company Holdings’ Fukushima Daiichi Nuclear Power Station (hereafter referred to as “Fukushima Daiichi NPS”), the goal of this task force is to elicit various options, such as separation, storage, release, etc., which can serve as basic data for determining how to handle, over a long period, tritiated water in particular, and also to carry out technical assessments for each of those options regarding the technical feasibility, regulatory feasibility, and the duration and costs required for handling the water. (This is not meant to reconcile the opinions of related parties or consolidate the options.)

The assessments operate on the assumption that non-tritium isotopes will be removed separately by means of multi-nuclide removal equipment, etc.

3. Overview of Basic Information

(1) Physical Properties of Tritium (Reference Material 1)

- Tritium is an isotope of hydrogen (hydrogen-3) containing two neutrons in addition to a proton and electron.
- The half-life of tritium is 12.3 years. Tritium that enters the body is metabolized and half the amount is excreted from the body in approximately 10 days when it is in water and in approximately 40 days when it is in organic matter (biological half-life).
- Tritium has low energy beta rays (18.6 keV maximum), which can be shielded by a single sheet of paper.

(2) Environmental Fate and Impact of Tritium (Reference Materials 2–6)

(A) Environmental Fate of Tritium

- Tritium that is released into the atmosphere exhibits such behaviors as turbulent diffusion in the atmosphere, dry or wet deposition on the earth's surface, advection or diffusion underground, and evaporation from the earth's surface. Since the state of diffusion varies greatly depending on the meteorological conditions during release, a simple assessment is difficult.
- For tritium that is released offshore, although it depends on how and where it is released, the concentration decreases as it gains distance from the site where it was released. (It is estimated (taking into consideration only advection and diffusion due to oceanic currents) that the concentration decreases by approximately one digit at approximately 10 km downstream, decreases by approximately two digits at approximately 50 km downstream, and decreases by approximately three digits at approximately 100 km downstream.)
- Since approximately 7×10^{16} Bq of tritium is produced annually from cosmic rays, tritium also occurs naturally, and approximately 1 Bq/L is present in natural water, and approximately 100 Bq/person is present in the human body (of a 65 kg person). In the past, tritium originating from atmospheric nuclear tests (1945–1963) was present in the environment at approximately $1.8–2.4\times10^{20}$ Bq. As of 2010, the amount of tritium present in the environment was approximately $1.0–1.3\times10^{18}$ Bq.

(B) Environmental Impact of Tritium

- In organic matter, tritium is found as FWT (free water tritium) and OBT (organically bound tritium). Since OBT is easily absorbed by organisms and has a long biological half-life, it is important in terms of dose assessments.
- In aquatic environments, the FWT concentration in organisms and the tritium concentration in water rapidly reach equilibrium (becoming almost equivalent), and with bioaccumulation from water not being confirmed in certain organisms, the concentration factor of tritium (ratio of concentration in water to concentration in organisms) is considered to be one or less.
- Dose assessments on marine organisms are performed using typical organisms (for example marine organisms of different varieties such as flounder, trout, and crabs) as subjects. Dose assessments are generally calculated from the concentration (Bq/kg raw) (*1) of radioactive material, using a conversion factor. For example, supposing that in bottom-dwelling fish tritium is uniformly distributed throughout the bodies of the subject organisms, the concentration of tritium in the sea water is the legally permitted concentration of 60,000 Bq/L, and the concentration factor is one, then the absorbed dose rate would be 0.0048 mGy/day (*2). In assessments by the NCRP (United States National Council on Radiation Protection and Measurements) and the IAEA (International Atomic Energy Agency), aquatic organism populations were found to be sufficiently protected when chronic absorbed dose rates are 10 mGy/day or less. Accordingly, as long as considerably high concentrations of tritium are not continually present in aquatic environments, there is not considered to be significant impact on aquatic organisms.

(*1) This unit represents concentrations measured in a state in which the environmental samples have not been dried.

(*2) Absorbed doses represent the amount of energy from radiation absorbed by the affected body per unit mass, and the units are expressed in Gy (Gray). Note that dose equivalents are used when the type of radiation and affected tissue are taken into consideration in converting the absorbed doses to express the impact on the human body, and the units are expressed in Sv (Sieverts).

(C) Impact of Tritium on the Human Body

- Tritium is much less harmful, approximately 1/1000 as harmful, to the human body than radioactive cesium, which was used to establish the standard for radioactive material in food.

- Since tritium is a low-energy beta-ray radionuclide, external exposure is limited but ingesting tritium in the body is considered to result in internal exposure.
- As described above, tritium is found in organisms in two forms, FWT (free water tritium) and OBT (organically bound tritium), and according to the ICRP (International Commission on Radiological Protection) the half-life of tritium in organisms is considered to be approximately 10 days in the case of FWT, and approximately 40 days in the case of OBT.
- In terms of measurement data for the concentration of tritium in the surface seawater off the coast of Fukushima (at depths up to 200–300 meters deep), exploratory results (June 2011) revealed that the background tritium concentration level (0.07 Bq/L) increased to 0.15 Bq/L after the nuclear accident (an increase of 0.08 Bq per 1 liter of sea water). If the impact on the human body is estimated based on this value, supposing that fish took in the entire amount of tritium as OBT (0.15 Bq/kg) and a human ingested 60 kilograms of that fish a year, the annual exposure amount (subtracting background radiation exposure) would be approximately 2×10^{-7} mSv.

(3) State of Tritium at Fukushima Daiichi NPS (Reference Material 7)

- As of March 2016, there was approximately 820,000 m^3 of contaminated water in total being stored within the tanks, of which, 620,000 m^3 of water had undergone purification treatment by means of multi-nuclide removal equipment.
- The concentration of tritium in the water stored in the tanks differs according to the storage period, since it is gradually decreasing due to being diluted from groundwater inflowing to the building, but the concentration at the time of storage ranges from approximately 0.3–4.2 million Bq/L (September 2011–March 2016). Taking into account decay correction as of March 2016, the concentration is approximately 0.3–3.3 million Bq/L and the cumulative amount of tritium contained in the water stored in the tanks is approximately 7.6×10^{14} Bq (approximately 2.1g(*)) (as of March 24th, 2016).

  (*) This is the corresponding amount if the tritium was present as “T” (tritium atoms).

(4) Regulatory Standards for Tritium (Reference Material 8)

(A) Regulatory Standards for Normally Operating Nuclear Power Plants

- In the “Rules for Installation, Operation, etc. of Commercial Power Reactors” which were enacted on the basis of the “Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors” (hereinafter referred to as "Reactor Regulation Act"), it is required that when radioactive waste in gaseous form is being discharged using exhaust equipment, "the concentration of the radioactive material in the exhaust air coming from the exhaust outlet or the exhaust air monitoring equipment must be monitored such that the concentration of the radioactive material in the atmosphere beyond the exclusion zone does not exceed the concentration limit (*) declared by the Nuclear Regulation Authority." Moreover, when radioactive waste in liquid form is being discharged by means of wastewater equipment, it is required that "the concentration of the radioactive material in the wastewater coming from the wastewater outlet or the wastewater monitoring equipment must be monitored such that the concentration of the radioactive material in the water outside of the boundaries of exclusion zone does not exceed the concentration limit declared by the Nuclear Regulation Authority."

- Furthermore, in the "Notification for Radiation Dose Rate Limits, etc. Based on the Provisions of the Rules for Installation, Operation, etc. of Commercial Power Reactors" which was enacted on the basis of the abovementioned rules, it is required that the sum of the following is less than one: the fraction relative to an effective dose of 1 mSv/year from external exposure, the sum of the fractions relative to the concentration limits for radioactive materials in air, and sum of the fractions relative to the concentration limits for radioactive materials in water.

(*) This value accounts for an exposure dose of 1 mSv/year for only one type of isotope. If tritium is the only radioactive material, then the concentration limit for the concentration in the air is 5 Bq/L, when the radiation is in vapor form, and 70,000 Bq/L, when the radiation is in in hydrogen gas form, and the concentration limit for the concentration in water is 60,000 Bq/L.

(B) Regulatory Standards for Specified Nuclear Facility Fukushima Daiichi NPS

- In the "Rules Pertaining to the Safety of the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station Reactor Facilities and Protection Against Specified Nuclear Fuel Materials" enacted on the basis of the Reactor Regulation Act, it is required that when radioactive waste in gaseous form is being discharged using exhaust equipment, "the concentration of the radioactive material in the exhaust air coming from the exhaust outlet or the exhaust air monitoring equipment must be monitored such that the concentration of the radioactive material in the atmosphere beyond the exclusion zone does not exceed the concentration limit (*) declared by the Nuclear Regulation Authority.” Moreover, when radioactive waste in liquid form is being discharged by means of wastewater equipment, it is required that “the concentration of the radioactive material in the wastewater coming from the wastewater outlet or the wastewater monitoring equipment does not exceed the concentration limit declared by the Nuclear Regulation Authority.”

- Furthermore, in the “Notification for Vital Matters Pertaining to the Safety of the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station Reactor Facilities and Protection Against Specified Nuclear Fuel Materials” which was enacted on the basis of the abovementioned regulations, it is required that the sum of the following is less than one: the fraction relative to an effective dose of 1 mSv/year from external exposure, the sum of the fractions relative to the concentration limits for radioactive materials in air, and sum of the fractions relative to the concentration limits for radioactive materials in water.

  (*) This value accounts for an exposure dose of 1 mSv/year for only one type of isotope. If tritium is the only radioactive material, then the concentration limit for the concentration in the air is 5 Bq/L, when the radiation is in vapor form, and 70,000 Bq/L, when the radiation is in in hydrogen gas form, and the concentration limit for the concentration in water is 60,000 Bq/L.

(C) Regulatory Standards for Food

- When standard values pertaining to radioactive material in food were established in 2012, it was concluded that “it is difficult to conceive of the concentration of tritium in food reaching a dose that would require attention” (Report by the Working Group on Radioactive Materials Measures, Food Sanitation Subcommittee, Pharmaceutical Affairs and Food Sanitation Council, Ministry of Health, Labour, and Welfare), so no standard value was established for tritium.

(5) Examples of Handling Tritium in Japan and Abroad (Reference Materials 9–13)

(A) Example in America

- In the nuclear accident at Three Mile Island, approximately 2.43×10^{13} Bq (approximately 8,700 m^3) of tritium were disposed of by means of vapor release into the atmosphere.
- The NRC (United States Nuclear Regulatory Commission) assessed that nine

options out of 24 options had extremely low impact, and from those, vapor release was selected after the plant operator explained the options to stakeholders. After the accident, 10 years were required to initiate the disposal treatment, and another three years were required to conclude the disposal treatment. (At the Three Mile Island Nuclear Generating Station the volume of water increasing was minimal and there was sufficient storage capacity, so there was leeway for operating over a long period of time).

(B) Example in France

- The annual quantity of tritium released at the La Hague reprocessing plant is approximately 1.2×10^{16} Bq in liquid form, and approximately 7.0×10^{13} Bq in gaseous form. Although the total quantity of radioactive material released into the environment has been on the decrease in the last 20 years, the quantity of tritium released is not decreasing because tritium cannot be processed.
- Although tritium was internationally recognized as having minimal effects on health, since the necessity of assessing tritium in organic matter was recognized domestically, the ASN (Nuclear Safety Authority) compiled a report entitled “Tritium White Paper” in 2010. Technologies from around the world for removing tritium were explored in the process of compiling the report, but it was concluded that none of them could be adopted since none could resolve the problem at an acceptable cost, and consensus was also reached with stakeholders. After first compiling the report, the group in charge has regularly compiled and presented reports explaining the latest possibilities pertaining to tritium processing methods, and ASN has been scrutinizing these.

(C) Example in England

- At the EU’s Joint European Torus (JET), which was established at the Culham Center for Fusion Energy and which creates fuel from deuterium and tritium, there is a facility which uses electrolysis and cryogenic separation, etc., to collect tritium from coolants and the like containing high concentrations of tritium. This treatment method was selected through a preliminary review which narrowed 30 options total down to 10 options, followed by assessing 16 items total related to applicability/feasibility, economical efficiency, environmental impact, health/safety, and regulations/international relations.

(D) Example in Japan

- At nuclear power plants in Japan, tritium is discharged according to the regulatory standards in (4) (A) above.
- The volume of tritium released offshore per one nuclear power plant in Japan ranged from 2.2×10^{10} Bq–1.0×10^{14} Bq in the 2010 fiscal year (differs depending on power plant).

4. Options for Handling Tritiated Water and Option Assessment (Refer to "Appendix 1" for Details)

(1) Overview of Options

- Based on examples from other countries, five methods were chosen as methods for handling tritiated water over a long period, and these were organized into the following 11 options which resulted from combining each with either no pre-treatment process, with a dilution process, or with an isotopic separation process (*) (hereafter referred to as "separation").
  - geosphere injection (no pre-treatment/ post-dilution/ post-separation)
  - offshore release (post-dilution/ post-separation)
  - vapor release (no pre-treatment/ post-dilution/ post-separation)
  - hydrogen release (no pre-treatment/ post-separation)
  - underground burial (no pre-treatment)

(*) The depleted product after isotopic separation is treated.

(A) Dispose of by Injection into Geosphere (hereafter referred to as "geosphere injection")

- Utilizing a compressor, tritiated water which either undergoes no pre-treatment, or undergoes dilution or separation is injected into deep geosphere layers (2,500 m deep) through an underground pipeline, after safety has been ensured.

(B) Offshore Release

- Tritiated water which undergoes dilution or separation is released offshore, after safety has been ensured. Note that in the dilution scenario, the method for securing the diluent water may change depending on the dilution factor.

(C) Release as Vapor into Atmosphere (hereafter referred to as "vapor release")

- Tritiated water which either undergoes no pre-treatment, or undergoes dilution or separation, goes through evaporation processing, and a vapor containing tritium is sent to evaporation equipment and is released from an exhaust pipe into the atmosphere as a high-temperature vapor, after safety has been ensured.

(D) Reduce to Hydrogen and Release as Hydrogen Gas into Atmosphere (hereafter referred to as "hydrogen release")

- Tritiated water which either undergoes no pre-treatment or undergoes separation is reduced to hydrogen by means of electrolysis, and is released into the atmosphere, after safety has been ensured.

(E) Solidify or Gelify and Dispose of by Burial Underground (hereafter referred to as "underground burial")

- Tritiated water is mixed with a cement-based solidifying agent or the like, and is buried within the confines of a concrete pit or the like, after safety has been ensured.

(2) Items for Assessment

- The following were established as items for assessment so that all of the options listed in (1) could be compared side by side.

(A) Basic Requirements: items serving as grounds for determining whether or not option is feasible

- Technical Feasibility: technical feasibility of implementation, technical sophistication, whether or not track records exist
- Regulatory Feasibility: compatibility with existing regulations

(B) Potentially Restricting Conditions: items which could potentially be restricting conditions

- Duration: duration of time required for treatment (exploration, design/construction, treatment, dismantling, monitoring, etc.)
- Costs: costs required for treatment (exploration, design/construction, treatment, dismantling, monitoring, etc.)
- Scale: area (land, sea) required for treatment
- Secondary Waste: whether or not secondary waste is produced, type and quantity
- Radiation Exposure to Workers: whether workers would be exposed to excessive radiation in carrying out treatment
- Associated Conditions: other conditions which could potentially be restricting

(3) Conditions Established for Comparative Assessment

- The following three conditions were established as standardized conditions for comparing each option side by side.
- These conditions were established for the sake of convenience in order to conduct the comparative study. Accordingly, the volume to be treated, treatment capacity, and tritium concentration are subject to change in light of the period of implementation and the specific treatment method. The following conditions are not intended to be the conditions of the treatment.
    - Volume to be Treated: 0.8 million m^3
      This was set based on current total quantity of water in Unit 1–4 tanks (approximately 740,000 m^3, as of November 19, 2015)
    - Treatment Capacity: 400 m^3/day
      This is the treatment capacity which was established as a prerequisite in the separately implemented "Verification of Technologies for Contaminated Water Management (Demonstration Project for Verification Tests of Tritium Separation Technologies) Project." This was set such that the volume of increasing contaminated water (assessed value at that time) ≦ treatment capacity.
    - Tritium Concentration: permitted concentration or less
      From the perspective of standardizing the effects of radiation exposure, the tritium concentration was set at the upper limit of the permitted concentration which applies to each of the options. (In the event that the concentration does not reach the legally permitted amount, the treatment should simply be carried out on said concentration, without performing enrichment, etc.) Although regulations would not be met by setting only tritium at the legally permitted concentration, this condition was established simply for the purposes of the side-by-side comparison.
- Other points to consider are as follows
    - With respect to separation, since a separation factor of 100 or more was a basic requirement in the separately implemented "Verification of Technologies for Contaminated Water Management (Demonstration Project for Verification Tests of Tritium Separation Technologies) Project," a separation factor of 100 was also set as a prerequisite here.
    - For all options, consideration is given to reducing the radiation exposure of workers, and ensuring work safety in all processes from construction, to

treatment, and dismantling.

- The location where the treatment is performed shall not be designated. In the event that the treatment is performed offsite from Fukushima Daiichi NPS, transport would be necessary, yet such transport was excluded from the comparative assessment since it pertains equally to each option.
- For the legally permitted concentrations, please refer to the "Notification for Vital Matters Pertaining to the Safety of the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station Reactor Facilities and Protection Against Specified Nuclear Fuel Materials."

(4) Concrete Scenarios Established for Each Option (hereafter referred to as "scenarios under assessment")

- In establishing the scenarios under assessment, the 11 options indicated in (1) were rendered as the basic scenarios and organized in the following manner.
- Since the "post-dilution vapor release" scenario was determined to have no advantages over the "no pre-treatment vapor release" scenario based on the following reasons, it was excluded from the present assessment.
  - The concentration (Bq/L) of tritium in the atmosphere beyond the exclusion zone does not depend on the concentration (Bq/L) in the tritiated water undergoing evaporation treatment, but depends on the release rate (Bq/s)
  - If the volume to be treated per day is fixed, then the release rate (Bq/s) would be the same in both the "post-dilution" scenario and the "no pre-treatment" scenario, so there would be no particular point in carrying out dilution.
- For underground burial, the scenarios under assessment were subdivided into deep burial below groundwater level (hereafter referred to as "deep earth") and shallow burial above groundwater level (hereafter referred to as "shallow earth").
- For hydrogen release, keeping in mind that hydrogen is formed through the electrolysis of tritiated water, or the like, it must be noted that in the "(post-separation) hydrogen release" scenario, depending on the kind of separation technology, there are cases in which the depleted product (the product in which the concentration is reduced by means of separation) already contains hydrogen, and in such cases hydrogen release may be performed directly on the depleted product. Similarly, it must be noted that in the "(post-separation) vapor release" scenario, depending on the kind of separation technology, there are cases in which the depleted product already contains water vapor, and in such cases

vapor release may be performed directly on the depleted product.

- Based on the above, the scenarios were organized into the following 11 scenarios under assessment.
  - ➢ geosphere injection (no pre-treatment (A1)/ post-dilution (B1)/ post-separation (C1))
  - ➢ offshore release (post-dilution (B2)/ post-separation (C2))
  - ➢ vapor release (no pre-treatment (A3)/ post-separation (C3))
  - ➢ hydrogen release (no pre-treatment (A4)/ post-separation (C4))
  - ➢ underground burial (no pre-treatment (deep earth) (A5a)/ no pre-treatment (shallow earth) A5b))
- Furthermore, for these scenarios under assessment, the concentration in the raw water and the volume of raw water were further subdivided into the following five scenarios, accounting for a total of 55 (=11x5) scenarios under assessment. (*)

  ① a scenario in which concentration in raw water is 4.2 million Bq/L, and raw water volume is 0.8 million m^3

  ② a scenario in which concentration in raw water is 0.5 million Bq/L, and raw water volume is 0.8 million m^3

  ③ a scenario in which concentration in raw water is 4.2 million Bq/L, and raw water volume is 0.4 million m^3

  ④ a scenario in which concentration in raw water is 0.5 million Bq/L, and raw water volume is 0.4 million m^3

  ⑤ a scenario of ③ + ④

  (*)The concentrations in raw water of 4.2 million Bq/L and 0.5 million Bq/L were adopted from the upper limit value and the lower limit value for tritiated water concentrations that were indicated in the Tritiated Water Task Force's "Summary of Previous Discussions" Reference Material No. 2–3 from the 12th meeting of the Committee on Countermeasures for Contaminated Water Treatment held on April 28, 2014.

(5) Conceptual Design for Each Scenario under Assessment

- Conceptual designs incorporating the following matters were implemented after concrete conditions based on the above conditions were established for each scenario under assessment.
- At that time, underground burial (Reference Materials 14 and 15) and geosphere injection (Reference Material 16) were discussed taking into account matters explained in the Task Force.

(Geosphere Injection)

A1: (No Pre-Treatment) Geosphere Injection

- The tritiated water is transferred from the water storage tank to a sampling tank, and after the concentration per tank is measured, the water is sent by means of an injection pump to a deep subterranean reservoir (2,500 m deep), and then entrapped in the geosphere.

B1: (Post-dilution) Geosphere Injection

- The tritiated water is transferred from the water storage tank to a sampling tank, and after the concentration per tank is measured, the water is diluted with sea water until the designated concentration (if the concentration in the raw water is 4.2 million Bq/L: dilution factor of 70; if it is 0.5 million Bq/L: dilution factor of approximately 8.3), and then the water is sent by means of an injection pump to a deep subterranean reservoir (2,500 m deep), and then entrapped in the geosphere.

C1: (Post-separation) Geosphere Injection

- The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and after the concentration per tank is measured, the water is sent by means of an injection pump to a deep subterranean reservoir (2,500 m deep), and then entrapped in the geosphere.

(Offshore Release)

B2: (Post-dilution) Offshore Release

- The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration is measured. Thereafter, the water is mixed and diluted with sea water using an intake water pump (if the concentration in the raw water is 4.2 million Bq/L: dilution factor of 70; if it is 0.5 million Bq/L: dilution factor of approximately 8.3), and discharged into the sea by pump.

C2: (Post-separation) Offshore Release

- The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and after the concentration per tank is measured, the water is discharged into the sea by pump.

(Vapor Release)

A3: (No Pre-treatment) Vapor Release

- The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration per tank is measured. The tritiated water in the sampling tank is directly vaporized at 900–1000℃, and the exhaust gas is diluted with air (in order to prevent deterioration to the equipment/machinery), and is released into the atmosphere at a height of 60 m above ground level.

C3: (Post-separation) Vapor Release

- The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and the concentration per tank is measured. The tritiated water in the sampling tank is directly vaporized at 900–1000℃, and the exhaust gas is diluted with air (in order to prevent deterioration to the equipment/machinery), and is released into the atmosphere at a height of 60 m above ground level.

(Hydrogen Release)

A4: (No Pre-treatment) Hydrogen Release

- The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration per tank is measured. The tritiated water from the sampling tank is electrolyzed into hydrogen and oxygen in an electrolyzer, and the produced hydrogen gas (which contains tritium gas) is released into the atmosphere at a height of 20 m above ground level.

C4: (Post-separation) Hydrogen Release

- The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and the concentration per tank is measured. The tritiated water from the sampling tank is electrolyzed into hydrogen and oxygen in an electrolyzer, and the produced hydrogen gas (which contains tritium gas) is released into the atmosphere at a height of 20 m above ground level.

(Underground Burial)

A5a, A5b: (No Pre-treatment) Underground Burial

- Underground excavation is carried out to construct a concrete pit. In order to deter groundwater inflow, and tritiated water seepage, soil mixed with bentonite is laid around the periphery of the concrete pit (having a thickness of 2 m if the concentration in the raw water is 4.2 million Bq/L, or a thickness of 1 m if the concentration in the raw water is 0.5 million Bq/L).

- A composition of tritiated water mixed together with a cement-based solidifying agent is poured into the finished concrete pit, to solidify together with the concrete formation.
- In order to deter the tritiated water from dissipating due to evaporation while being poured, a cover is installed on the top.
- After solidification, a top slab for the concrete formation is poured, and soil mixed with bentonite (having a thickness of 2 m if the concentration in the raw water is 4.2 million Bq/L, or a thickness of 1 m if the concentration in the raw water is 0.5 million Bq/L) is laid to further cover the installation.

(6) Assessment Results for Each Scenario under Assessment

- The assessment results for each scenario under assessment based on the conceptual designs listed in (5) are summarized in Appendix 2.
- Note that the assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.
- For scenarios having separation as the pre-treatment, the results of the "Demonstration Project for Verification Tests of Tritium Separation Technologies (Appendix 3)" implemented in the 2015 fiscal year were going to be used in the assessments. However, as "no technologies were verified to be at a stage which could be immediately applied" (Demonstration Project for Verification Tests of Tritium Separation Technologies Summary and Assessment (Appendix 4)), the technologies are difficult to analyze at this point, so the fields regarding duration and cost have been left blank.
- Other points to consider are as follows.
  - Assessments have been carried out without designating the location where the treatment is performed.
  - The following have not been taken into consideration in the assessment results for duration: transport in the event that treatment is performed offsite; simulations to assess environmental impact, etc.; uncertainties in terms of securing resources and required personnel.
  - The following have not been taken into consideration in the assessment results for costs: transport in the event that the treatment is performed offsite; simulations to assess environmental impact, etc.; uncertainties in terms of securing resources and required personnel; factors unique to the nuclear power plant site (additional personnel costs for work conducted under high doses,

additional construction costs to make the nuclear facilities safe against earthquakes, etc.); costs to acquire land; fixed property taxes; costs for disposing of demolition waste, secondary waste, or construction spoil; costs for third party monitoring.

5. Conclusion

This report is a compilation of the matters, including reports from experts (Reference Materials 1–18), that were deliberated under the Tritiated Water Task Force over a total of 15 meetings from December 25, 2013 to May 27, 2016, and it discusses the contaminated water issues at Fukushima Daiichi NPS, in particular the handling of tritiated water, from a technical perspective. It is hoped that this report will serve as basic data for future discussions.

Also, since handling tritiated water can largely influence rumors, it is hoped that future discussions about handling tritiated water will be advanced in a comprehensive manner, touching upon both technical perspectives, such as feasibility, economical efficiency, and duration, as well as social perspectives, such as damage caused by rumors.

As of May 27, 2016

Tritiated Water Task Force

Member List

Chief:	
Ichiro Yamamoto	Counselor/Emeritus Professor, Nagoya University; Professor, Nagoya University of Arts and Sciences (Member of Committee on Countermeasures for Contaminated Water Treatment)
Committee Members:	
Hideki Kakiuchi	Researcher, Department of Radioecology, Institute for Environmental Sciences
Yoshihisa Takakura	Director, Tohoku Radiological Science Center
Hideo Tatsuzaki	Director, Radiation Emergency Medicine Center, National Institute of Radiological Sciences, National Institutes for Quantum and Radiological Science and Technology
Hiroshi Tauchi	Professor (Biological Sciences), Faculty of Science, Ibaraki University
Shunkichi Nonaka	Managing Director, Co-op Fukushima
Takami Morita	Radioecology Group Leader, Radioecology Group, Research Center for Fisheries Oceanography & Marine Ecosystem, National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency
Toshihiko Yamanishi	Director, Department of Blanket Systems Research, Rokkasho Fusion Institute, Fusion Energy Research and Development Directorate, National Institutes for Quantum and Radiological Science and Technology
Tokuhiro Yamamoto	Director General, Nuclear Fuel Cycle Engineering Laboratories, Japan Atomic Energy Agency (JAEA) (Member of Committee on Countermeasures for Contaminated Water Treatment)
Regulatory Authority:	
Toshihiro Imai	Director, Office for accident measures of Fukushima-daiichi

	Nuclear power station, Nuclear Regulation Authority
Observers:	
Yuki Takeba	Director, Research and Technological Guidance Division, Resources Enhancement Promotion Department, Fisheries Agency
Ryosuke Murayama	Director for Decommissioning Technology Development, Atomic Energy Division, Research and Development Bureau, Ministry of Education, Culture, Sports, Science and Technology
Masato Usui	Director, International Nuclear Energy Cooperation Division, Disarmament, Non-Proliferation and Science Department, Ministry of Foreign Affairs
Hirotsugu Fujiwara	Director, International Research Institute for Nuclear Decommissioning
Masanori Imazu	General Manager, Technological Strategy Group, Nuclear Damage Compensation and Decommissioning Facilitation Corporation
Jun Matsumoto	Executive Vice President, Fukushima Daiichi Decontamination and Decommissioning Engineering Company, Tokyo Electric Power Company Holdings, Inc.
Nobuyuki Kanno	Director, Nuclear Power Safety Division, Risk Management Department, Fukushima Prefectural Government

Tritiated Water Task Force

Meeting Record

December 25, 2013 (1st Meeting)

- Tritiated Water Task Force Protocol
- Electing the Task Force Chief
- Debates under the Committee on Countermeasures for Contaminated Water Treatment, etc. (Explanation)
- Tritiated Water Task Force Approach (Discussion)

January 15, 2014 (2nd Meeting)

- State of Contaminated Water Treatment and Tritiated Water Storage at Fukushima Daiichi NPS
- Overview of Separation Technologies and Underground Storage
- Multiple Options and Items for Assessment

February 7, 2014 (3rd Meeting)

- Items for Assessment of Tritium (Beliefs about Environmental Fate/Impact)

February 27, 2014 (4th Meeting)

- Items for Assessment of Tritium (Diffusion into Environment, etc.)

March 13, 2014 (5th Meeting)

- Examples of Efforts Abroad

March 26, 2014 (6th Meeting)

- Examples of Efforts Abroad

April 9, 2014 (7th Meeting)

- Examples of Efforts Abroad

April 24, 2014 (8th Meeting)

- Summary of Previous Discussions

July 9, 2014 (9th Meeting)

- Toward Option Assessment (Discussion of Technical Feasibility of Options)

October 24, 2014 (10th Meeting)

- Shallow Earth Disposal of Tritiated Water
- Selection Results from the Demonstration Project for Verification Tests of Tritium Separation Technologies

January 21, 2015 (11th Meeting)

- Optimal State of Communications with Stakeholders
- Additional Request for Proposals for the Demonstration Project for Verification Tests of Tritium Separation Technologies

June 5, 2015 (12th Meeting)

- Discussion of All Options for Treating Tritiated Water

December 4, 2015 (13th Meeting)

- Discussion of Conceptual Designs for All Options

April 19, 2016 (14th Meeting)

- Assessment of All Options (Scenarios Under Assessment) for Handling Tritiated Water
- Demonstration Project for Verification Tests of Tritium Separation Technologies
- Tritiated Water Task Force Report Outline

May 27, 2016 (15th Meeting)

- Tritiated Water Task Force Report

Appendix 1

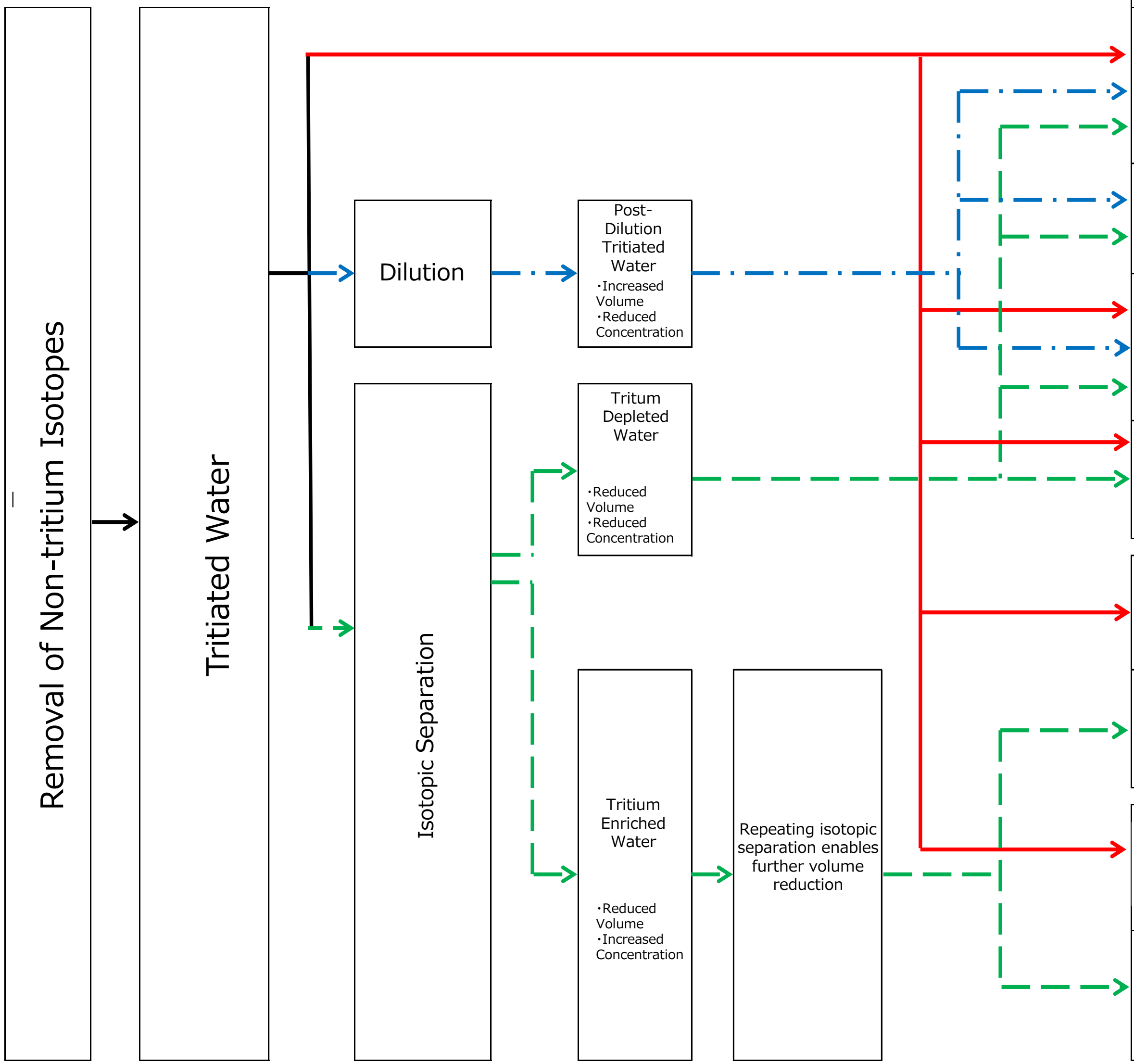
Assessment Results for All Options (Scenarios Under Assessment) For Handling Tritiated Water

Office of the Committee on Countermeasures for Contaminated Water Treatment

May 27, 2016

(1) Overview of Options

<PRE-TREATMENT>



<OPTIONS>

Treatment Method	Primary Tasks, etc.	Site of Treatment
Dispose of by Injection into Geosphere	○ Set parameters for underground injection (geosphere layer, injection speed, concentration, etc.) ○ Assess post-underground-injection diffusion behavior ○ Assess post-diffusion impact on humans, etc. ○ Develop a system for following post-injection behavior	under-ground
Release Offshore	○ Set parameters for offshore release (release site, release quantity, concentration, etc.) ○ Assess post-offshore-release diffusion behavior ○ Assess post-diffusion impact on humans, etc. ○ Develop a system for following post-offshore-release behavior	off-shore
Release as Vapor into Atmosphere	○ Set parameters for evaporation release (release speed, concentration, etc.) ○ Assess post-evaporation-release diffusion behavior ○ Assess post-diffusion impact on humans, etc. ○ Develop a system for following post-evaporation-release behavior	atmo-sphere
Reduce to Hydrogen & Release as Hydrogen Gas into Atmosphere	○ Set parameters for atmospheric release (release speed, concentration, etc.) ○ Assess post-atmospheric-release diffusion behavior ○ Assess post-diffusion impact on humans, etc. ○ Develop a system for following post-atmospheric-release behavior	
Solidify or Gelify & Dispose of by Burial Underground	○ Decide on burial site/burial method ○ Assess behavior of dissolution from concrete, etc. ○ Assess post-dissolution impact on humans, etc. ○ Develop a system for following post-dissolution behavior	under-ground
Dispose of Small Amounts of Highly Concentrated Tritiated Water	○ Select disposal method ○ Secure disposal site	
Store Tritiated Water	○ Assess storage risks ○ Establish method for safe, long-term storage ○ Establish method for permanent management ○ Secure storage sites and tanks	equip-ment
Store Small Amounts of Highly Concentrated Tritiated Water	○ Assess storage risks ○ Select storage method ○ Establish method for permanent management ○ Secure storage sites and tanks	

(1) Overview of Options

Pre-treatment		Treatment Method	Abbreviated Form	Code	Feasibility	Particular Points to Consider Regarding Feasibility
None		Dispose of by Injection into Geosphere	Geosphere Injection	A1		There are no pre-existing standards that can be applied (opinions exist that feasibility is low as it is difficult to verify safety)
		Release Offshore	Offshore Release	A2	×	Difficult to implement considering concentration limit (60Bq/cm3)
		Release as Vapor into Atmosphere	Vapor Release	A3		
		Reduce to Hydrogen & Release as Hydrogen Gas into Atmosphere	Hydrogen Release	A4		
		Solidfy or Gelify & Dispose of by Burial Underground	Underground Burial	A5		
		Store Tritiated Water	Storage	A6		This is ultimately a temporary measure, not a permanent solution
Dilution		Dispose of by Injection into Geosphere	Post-Dilution Geosphere Injection	B1		There are no pre-existing standards that can be applied (opinions exist that feasibility is low as it is difficult to verify safety)
		Release Offshore	Post-Dilution Offshore Release	B2		It is necessary to consider effective dilution method
		Release as Vapor into Atmosphere	Post-Dilution Vapor Release	B3		
		Reduce to Hydrogen & Release as Hydrogen Gas into Atmosphere	Post-Dilution Hydrogen Release	B4	×	Treatment becomes more challenging since the volume of water handled increases from dilution
		Solidfy or Gelify & Dispose of by Burial Underground	Post-Dilution Underground Burial	B5	×	Treatment and management become more challenging since the volume of water handled increases from dilution
		Store Tritiated Water	Post-Dilution Storage	B6	×	Treatment and management become more challenging since the volume of water handled increases from dilution
Isotopic Separation	Depletion	Dispose of by Injection into Geosphere	Post-Separation Geosphere Injection	C1		There are no pre-existing standards that can be applied (opinions exist that feasibility is low as it is difficult to verify safety)
		Release Offshore	Post-Separation Offshore Release	C2		
		Release as Vapor into Atmosphere	Post-Separation Vapor Release	C3		
		Reduce to Hydrogen & Release as Hydrogen Gas into Atmosphere	Post-Separation Hydrogen Release	C4		
		Solidfy or Gelify & Dispose of by Burial Underground	Post-Separation Underground Burial	C5	×	There is no merit to separation as long-term management would also be necessary after separation
		Store Tritiated Water	Post-Separation Storage	C6	×	There is no merit to separation as long-term management would also be necessary after separation
	Enrichment	Dispose of Small Amounts of Highly Concentrated Tritiated Water	Enrichment Disposal	C'a		It is necessary to consider disposal method
		Store Small Amounts of Highly Concentrated Tritiated Water	Enrichment Storage	C'b		This is ultimately a temporary measure, not a permanent solution (it is necessary to also consider methods for final disposal/utilization)

(2) Items for Assessment

- The following items for assessment were established in order to conduct a side-by-side comparison of each option.

Proposed Items for Assessment		Description
Basic Requirements		Items serving as grounds for determining whether or not option is feasible
	Technical Feasibility	Technical feasibility of implementation, technical sophistication, whether or not track records exist
	Regulatory Feasibility	Compatibility with existing regulations
Potentially Restricting Conditions		Items which could potentially be restricting conditions
	Duration	Duration of time required for treatment (exploration, design/construction, treatment, dismantling, monitoring, etc.)
	Costs	Costs required for treatment (exploration, design/construction, treatment, dismantling, monitoring, etc.)
	Scale	Area (land, sea) required for treatment
	Secondary Waste	Whether or not secondary waste is produced, type and quantity
	Radiation Exposure of Workers	Whether there would be excessive radiation exposure to workers in carrying out treatment
	Associated Conditions	Other conditions which could potentially be restricting

(3) Conditions Established for Comparative Assessment

- The following 3 conditions were established as standardized conditions for comparing each option side by side.

*These conditions were established for the sake of convenience in order to conduct the comparative study. The volume to be treated, treatment capacity, and concentration to be treated are subject to change in light of the period of implementation and the specific treatment method. The following conditions are not intended to be the conditions of the treatment.

1. Volume to be treated: 0.8 million m^3
   - This was set based on current total quantity of water in Unit 1–4 tanks (approximately 740,000m3, as of November 19, 2015).
2. Treatment capacity: 400m^3/day
   - This is the treatment capacity which was established as a prerequisite in the separately implemented “Verification of Technologies for Contaminated Water Management (Demonstration Project for Verification Tests of Tritium Separation Technologies) Project.”

   *This was set such that the volume of increasing contaminated water (assessed value at that time) ≦ treatment capacity.
3. Tritium concentration: permitted concentration or less
   - In order to standardize the effects of radiation exposure, the concentration to be treated was set at the upper limit of the permitted concentration which applies to each of the options. (In the event that the concentration does not reach the legally permitted amount, the treatment should simply be carried out on said concentration, without performing enrichment, etc.)
   - Although regulations would not be met by setting only tritium at the legally permitted concentration, this condition was established simply for the purposes of the side-by-side comparison.

【Other Points to Consider】

- With respect to separation, since a separation factor of 100 or more was a basic requirement in the separately implemented “Verification of Technologies for Contaminated Water Management (Demonstration Project for Verification Tests of Tritium Separation Technologies) Project” (meaning that the amount of radioactivity in the depleted product would be 1/100 or less of the original tritiated water), a separation factor of 100 was also set as a prerequisite for this assessment.
- For all options consideration is given to reducing the radiation exposure of workers, and ensuring work safety in all processes from construction, to treatment, and dismantling.
- The location where the treatment is performed shall not be designated. In the event that the treatment is performed offsite, transport would be necessary, yet such transport was excluded from the comparative assessment since it pertains equally to each option.
- For the legally permitted concentrations, please refer to the “Notification for Vital Matters Pertaining to the Safety of the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station Reactor Facilities and Protection Against Specified Nuclear Fuel Materials.”

(4) Concrete Scenarios (Scenarios Under Assessment) Established for Each Option

- The following 11 carefully-considered options were established as the basic scenarios to undergo assessment.
  - geosphere injection (no pre-treatment/ post-dilution/ post-separation)
  - offshore release (post-dilution/ post-separation)
  - vapor release (no pre-treatment/ post-dilution/ post-separation)
  - hydrogen release (no pre-treatment/ post-separation)
  - underground burial (no pre-treatment)

- Since the “post-dilution vapor release” scenario was determined to have no advantages over the “no pre-treatment vapor release” scenario based on the following reasons, it was excluded from the present assessment.
  - ✓ The concentration (Bq/L) of tritium in the atmosphere beyond the exclusion zone does not depend on the concentration (Bq/L) in tritiated water which would undergo evaporation treatment, but depends on the release rate (Bq/s).
  - ✓ As is described hereafter, if the volume to be treated per day is fixed, then the release rate (Bq/s) would be the same in both the “post dilution” scenario and the “no pre-treatment” scenario, so there would be no particular point in carrying out dilution.

- For underground burial, the scenarios under assessment were subdivided into:

  ① Deep burial below groundwater level (hereafter referred to as “deep earth”)

  ② Shallow burial above groundwater level (hereafter referred to as “shallow earth”)

(4) Concrete Scenarios (Scenarios Under Assessment) Established for Each Option

- For hydrogen release, keeping in mind that hydrogen is formed through the electrolysis of tritiated water, or the like, it must be noted that in the "(post-separation) hydrogen release" scenario, depending on the kind of separation technology (CECE process, etc.), there are cases in which the depleted product already contains hydrogen, and in such cases hydrogen release may be performed directly on the depleted product. Similarly, it must be noted that in the "(post-separation) vapor release" scenario, depending on the kind of separation technology, there are cases in which the depleted product already contains water vapor, and in such cases vapor release may be performed directly on the depleted product.

- For the abovementioned 11 scenarios under assessment, the concentration in the raw water and the volume of raw water were further subdivided into the following five scenarios, accounting for a total of 55 scenarios under assessment.

  ① a scenario in which concentration in raw water is 4.2 million Bq/L, and raw water volume is 0.8 million m^3

  ② a scenario in which concentration in raw water is 0.5 million Bq/L, and raw water volume is 0.8 million m^3

  ③ a scenario in which concentration in raw water is 4.2 million Bq/L, and raw water volume is 0.4 million m^3

  ④ a scenario in which concentration in raw water is 0.5 million Bq/L, and raw water volume is 0.4 million m^3

  ⑤ a scenario of ③＋④

*The concentrations in raw water of 4.2 million Bq/L and 0.5 million Bq/L were adopted from the upper limit value and the lower limit value for tritiated water concentrations that were indicated in the Tritiated Water Task Force's "Summary of Previous Discussions" (Reference Material No. 2-3 from the 12th meeting of the Committee on Countermeasures for Contaminated Water Treatment on 4/28/2014).

- A table listing the scenarios under assessment reflecting the above appears on the next page.

(4) Concrete Scenarios (Scenarios Under Assessment) Established for Each Option

Overview of Options at 8th Meeting

Code	Treatment Method	Pre-treatment
A1	geosphere injection	none
B1		dilution
C1		separation
B2	offshore release	dilution
C2		separation
A3	vapor release	none
B3		dilution
C3		separation
A4	hydrogen release	none
C4		separation
A5	underground burial	none

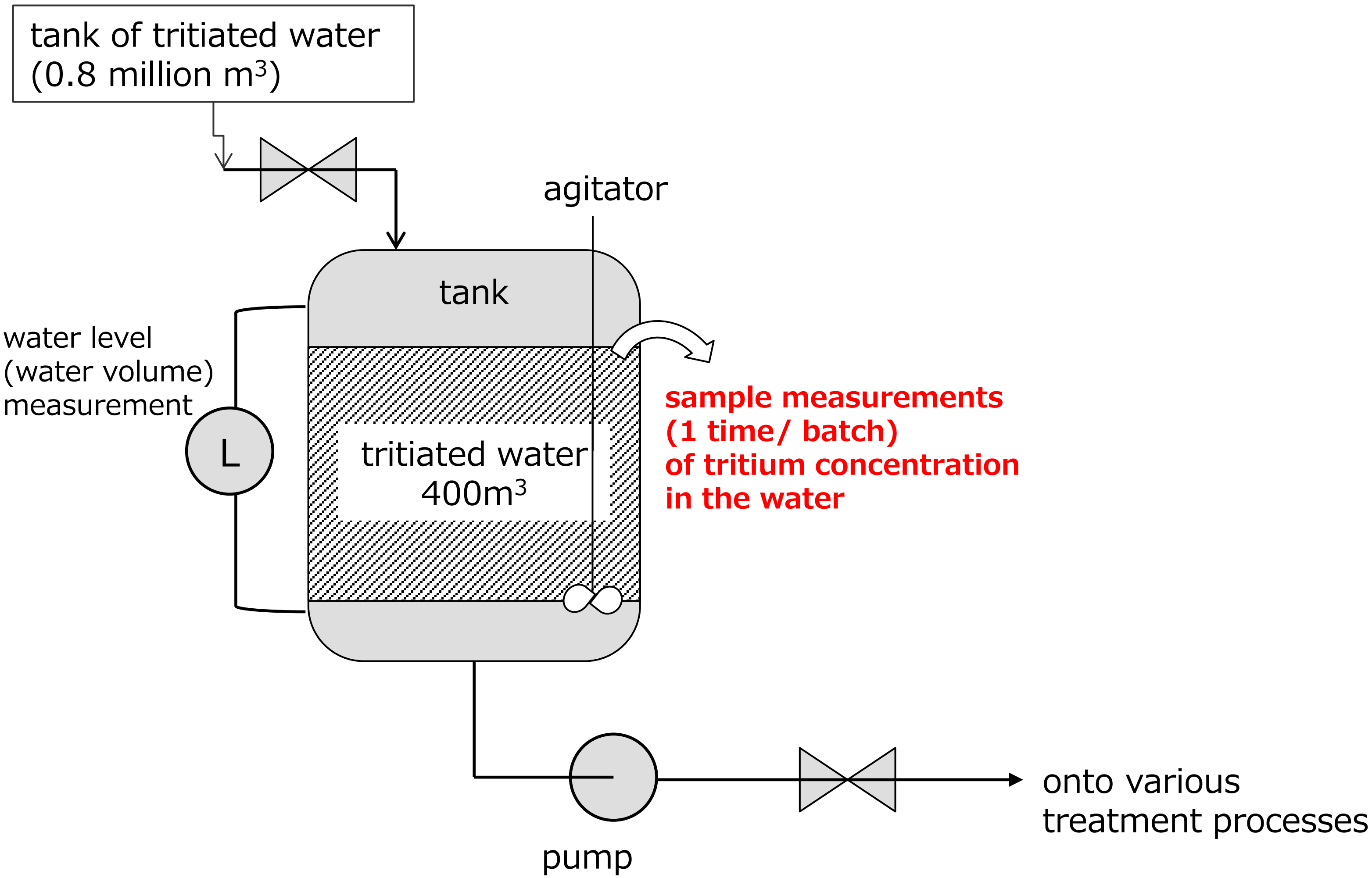
Scenarios Under Assessment in this Study

Code	Treatment Method	Pre-treatment
A1 ①–⑤	geosphere injection	none
B1 ①–⑤		dilution
C1 ①–⑤		separation
B2 ①–⑤	offshore release	dilution
C2 ①–⑤		separation
A3 ①–⑤	vapor release	none
C3 ①–⑤		separation
A4 ①–⑤	hydrogen release	none
C4 ①–⑤		separation
A5a ①–⑤	underground burial (deep earth)	none
A5b ①–⑤	underground burial (shallow earth)	none

*For ①–⑤, refer to previous section

(5) Conceptual Design for Each Scenario Under Assessment (Same for Each Option)

- The method for measuring the concentration in the raw tritiated water was established as per the following diagram, and is the same for each option.



(5) Conceptual Design for Each Scenario Under Assessment (Geosphere Injection)

- Same for All Geosphere Injection Options (A1, B1, C1)
  - Construction method & injection depth: established referencing CCS (carbon capture & storage) demonstration examples
    * Although there are other examples, such as an example of shallow earth injection at Hanford (USA), it is thought that a shallow earth injection would not be suitable in Japan where the groundwater level is shallow, so CCS examples are being referenced.
  - Reduction pace of raw tritiated water during injection operation: 400m^3/day

- A1: (No Pre-treatment) Geosphere Injection
  - Concentration: As there is no relevant legally permitted concentration, injection performed without set restriction, for the sake of convenience.
  - Volume treated: As there is no pre-treatment, 0.8 million m^3
  - The tritiated water is transferred from the water storage tank to a sampling tank, and after the concentration per tank is measured, the water is sent by means of an injection pump to a deep subterranean reservoir (2,500m deep), and then entrapped in the geosphere.

- B1: (Post-dilution) Geosphere Injection
  - Concentration: Using 60,000 Bq/L as a reference value, which is the permitted concentration for radioactive material coming from a discharge port, injection performed after dilution until a concentration of 60,000 Bq/L
  - Volume treated: The volume treated is increased according to the dilution rate for ensuring the above concentration.
  - The tritiated water is transferred from the water storage tank to a sampling tank, and after the concentration per tank is measured, the water is diluted with sea water until the designated concentration (if the concentration in the raw water is 4.2 million Bq/L: dilution factor of 70; if it is 0.5 million Bq/L: dilution factor of approximately 8.3), and then the water is sent by means of an injection pump to a deep subterranean reservoir (2,500m deep), and then entrapped in the geosphere.

- C1: (Post-separation) Geosphere Injection
  - Concentration: Injection performed at the concentration of the depleted product which was separated with a separation factor of 100.
  - Volume treated: Assuming that the quantity of the post-separation enriched product can be disregarded (the quantity of the depleted product unchanging), the volume treated shall be 0.8 million m^3.
  - State of tritiated water to be treated: The post-separation depleted product shall be in liquid form.
  - The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and after the concentration per tank is measured, the water is sent by means of an injection pump to a deep subterranean reservoir (2,500m deep), and then entrapped in the geosphere.

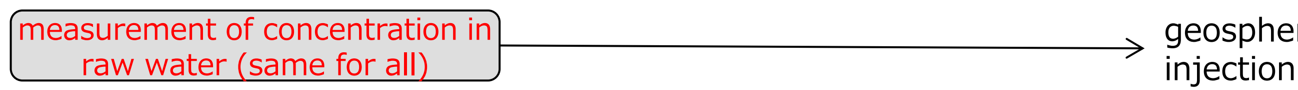
*These conditions were established for the sake of convenience in order to conduct the comparative study, and are not intended to be the actual conditions of the treatment.

(5) Conceptual Design for Each Scenario Under Assessment (Geosphere Injection)

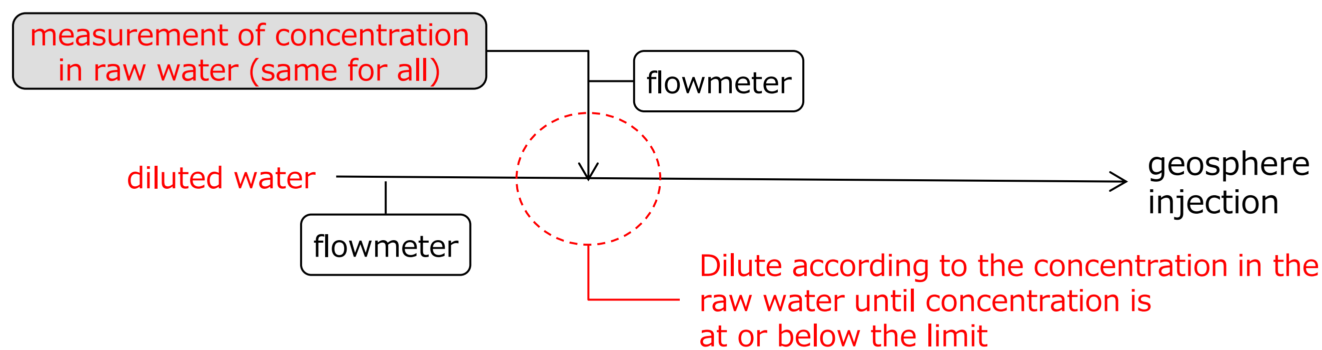
Monitoring Method

Regulation:
The concentration of the radioactive material in the wastewater coming from the wastewater outlet or the wastewater monitoring equipment must not exceed the concentration limit declared by the Nuclear Regulation Authority

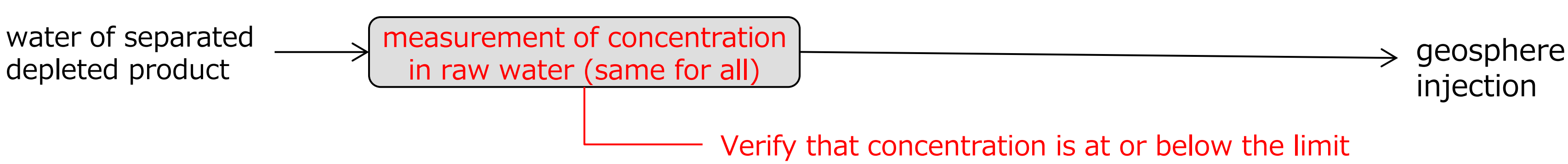
A1: (No Pre-treatment) Geosphere Injection



B1: (Post-dilution) Geosphere Injection

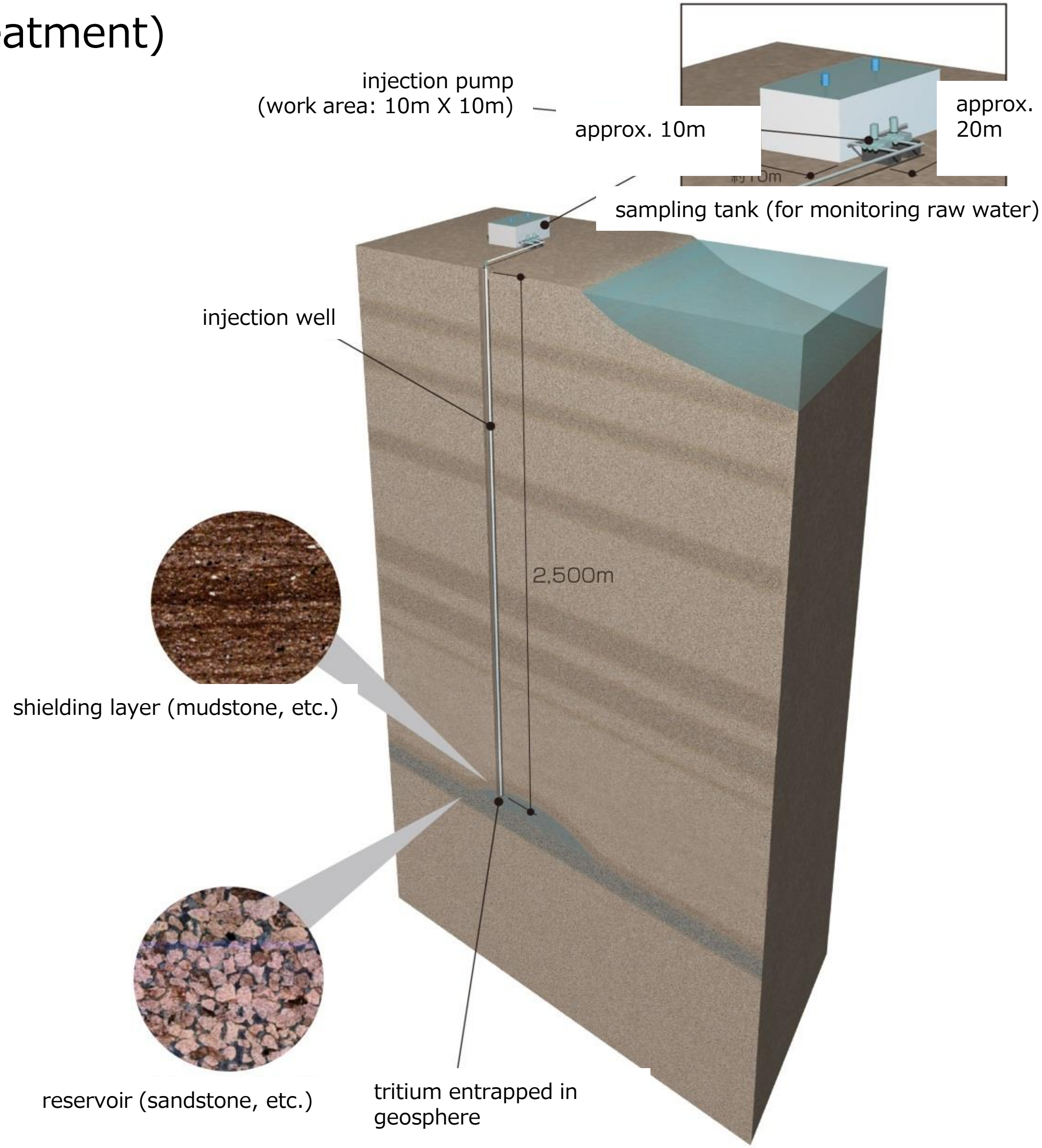


C1: (Post-separation) Geosphere Injection



(5) Conceptual Design for Each Scenario Under Assessment (Geosphere Injection)

- Conceptual Diagram: (No Pre-treatment) Geosphere Injection Example



(5) Conceptual Design for Each Scenario Under Assessment (Offshore Release)

- Same for All Offshore Release Options (B2, C2)
  - Reduction pace of raw tritiated water during rated release operation: 400m^3/day

- B2: (Post-dilution) Offshore Release
  - Concentration: Release performed after dilution until a concentration of 60,000 Bq/L, which is the permitted concentration for radioactive material coming from a discharge port.
  - Volume treated: The volume treated is increased according to the dilution rate for ensuring the above concentration.
  - The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration is measured. Thereafter, the water is mixed and diluted with sea water using an intake water pump (if the concentration in the raw water is 4.2 million Bq/L: dilution factor of 70; if it is 0.5 million Bq/L: dilution factor of approximately 8.3), and discharged into the sea by pump.

- C2: (Post-separation) Offshore Release
  - Concentration: Release performed directly since the concentration of the depleted product which was separated with a separation factor of 100 is less than 60,000 Bq/L.
  - Volume treated: Assuming that the quantity of the post-separation enriched product can be disregarded (the quantity of the depleted product unchanging), the volume treated shall be 0.8 million m^3.
  - State of tritiated water to be treated: The post-separation depleted product shall be in liquid form.
  - The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and after the concentration per tank is measured, the water is discharged into the sea by pump.

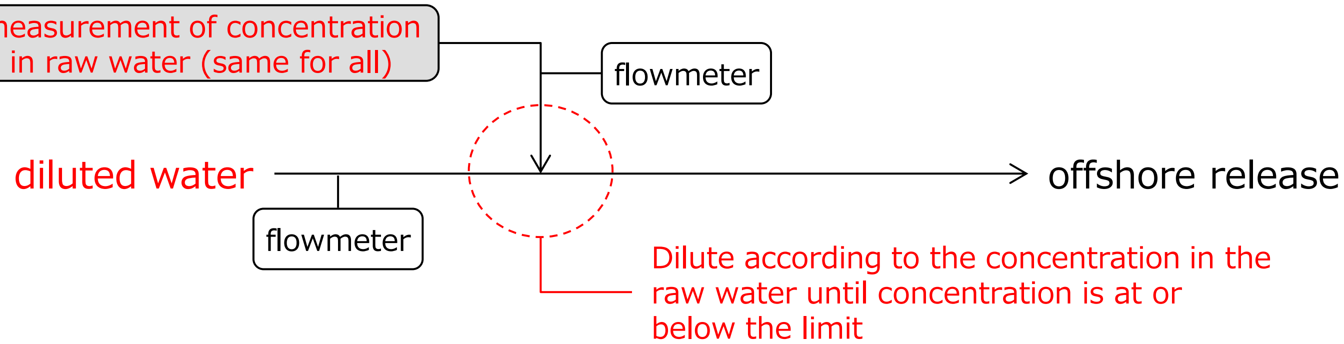
*These conditions were established for the sake of convenience in order to conduct the comparative study, and are not intended to be the actual conditions of the treatment.

(5) Conceptual Design for Each Scenario Under Assessment (Offshore Release)

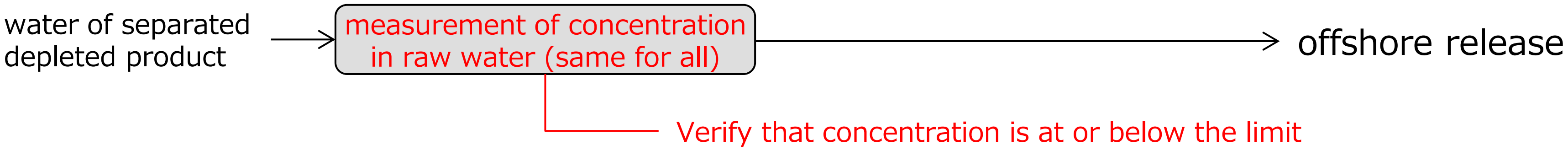
- Monitoring Method

Regulation:
The concentration of the radioactive material in the wastewater coming from the wastewater outlet or the wastewater monitoring equipment must not exceed the concentration limit declared by the Nuclear Regulation Authority

- B2: (Post-dilution) Offshore Release

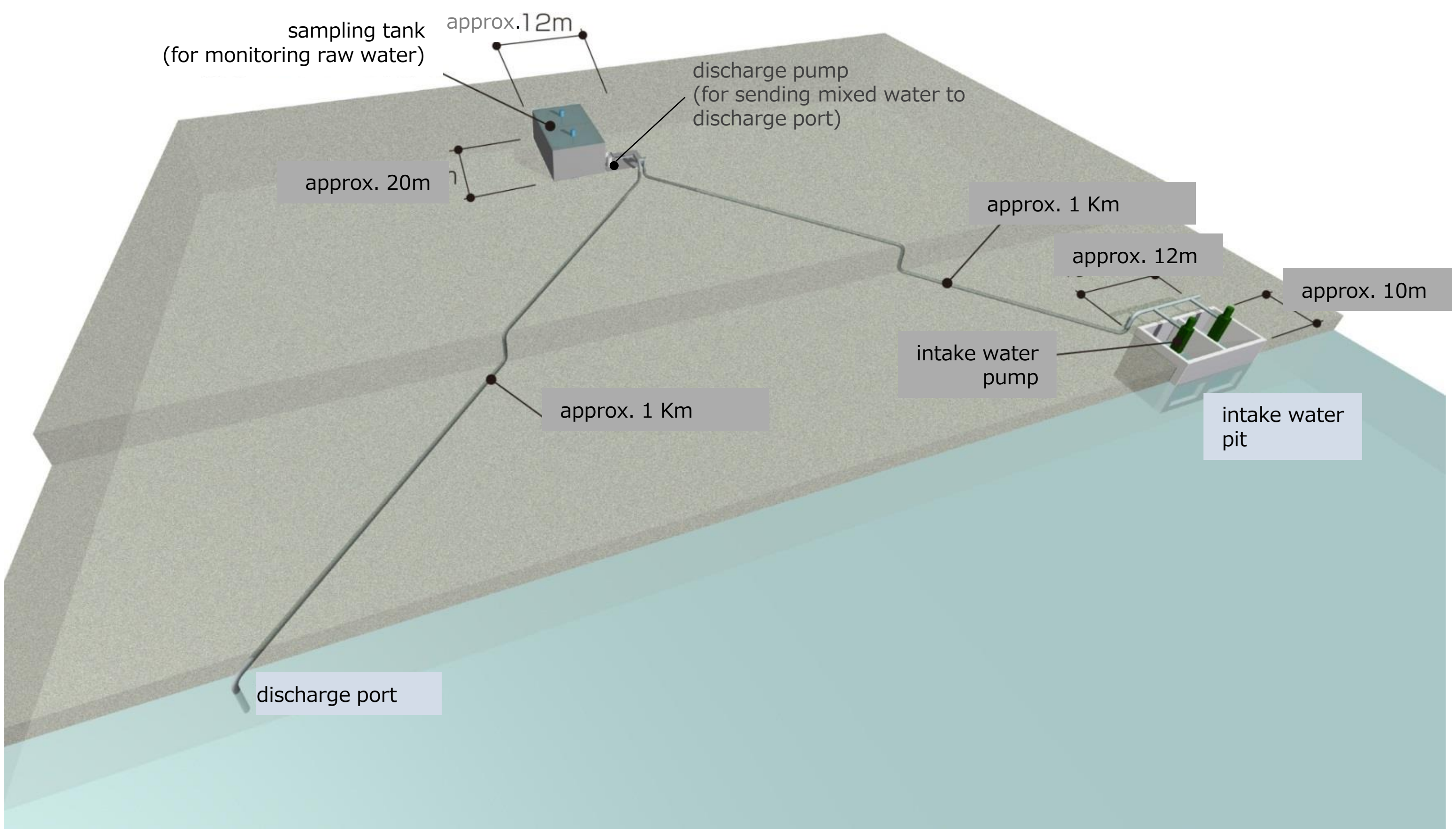


- C2: (Post-separation) Offshore Release



(5) Conceptual Design for Each Scenario Under Assessment (Offshore Release)

Conceptual Diagram: (Post-dilution) Offshore Release Example



* Must be devised such that discharged water is not directly taken in again.

- Here a measure is employed in which there is sufficient distance between the position of the intake water pit and the position of the discharge port.
- In terms of other measures, it is possible to conceive of a measure in which a divider, such as a quay wall, is used between the intake water pit and the discharge port, or a measure in which the discharge port is positioned further offshore.

(5) Conceptual Design for Each Scenario Under Assessment (Vapor Release)

- Same for All Vapor Release Options (A3, C3)
  - Reduction pace of raw tritiated water during release operation: 400m^3/day
  - Concentration: The concentration must be 5 Bq/L or less, which is the permitted concentration for radioactive material in the atmosphere beyond the exclusion zone.
  - Condensation (returning to liquid form) must not occur beyond the exhaust pipe outlet .

- A3: (No Pre-treatment) Vapor Release
  - Exhaust pipe height: The exhaust pipe height which enables the tritium concentration in the atmosphere beyond the exclusion zone to be 5 Bq/L or less was compared with the common exhaust pipe height utilized when there is direct contact with combustion equipment, and the taller exhaust pipe height (60m above ground level) was adopted.
  - Volume treated: As there is no pre-treatment, 0.8 million m^3
  - The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration per tank is measured. The tritiated water in the sampling tank is directly vaporized at 900–1000℃, and the exhaust gas is diluted with air (in order to prevent deterioration to the equipment/machinery), and is released into the atmosphere at a height of 60m above ground level.

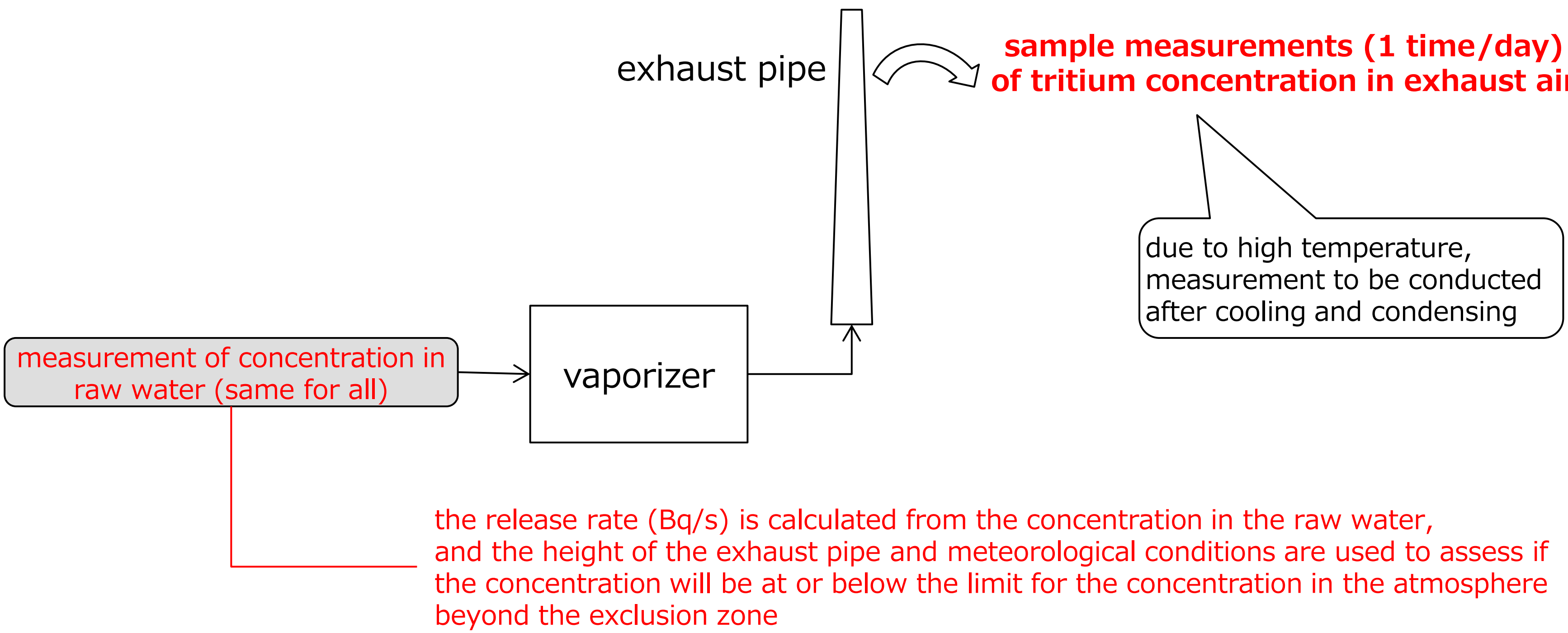
- C3: (Post-separation) Vapor Release
  - Exhaust pipe height: Same as height in “no pre-treatment” scenario
  - Volume treated: Assuming that the quantity of the post-separation enriched product can be disregarded (the quantity of the depleted product unchanging), the volume treated shall be 0.8 million m^3.
  - State of tritiated water to be treated: The post-separation depleted product shall be in liquid form.
  - The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and the concentration per tank is measured. The tritiated water in the sampling tank is directly vaporized at 900–1000℃, and the exhaust gas is diluted with air (in order to prevent deterioration to the equipment/machinery), and is released into the atmosphere at a height of 60m above ground level.

*These conditions were established for the sake of convenience in order to conduct the comparative study, and are not intended to be the actual conditions of the treatment.

(5) Conceptual Design for Each Scenario Under Assessment (Vapor Release)

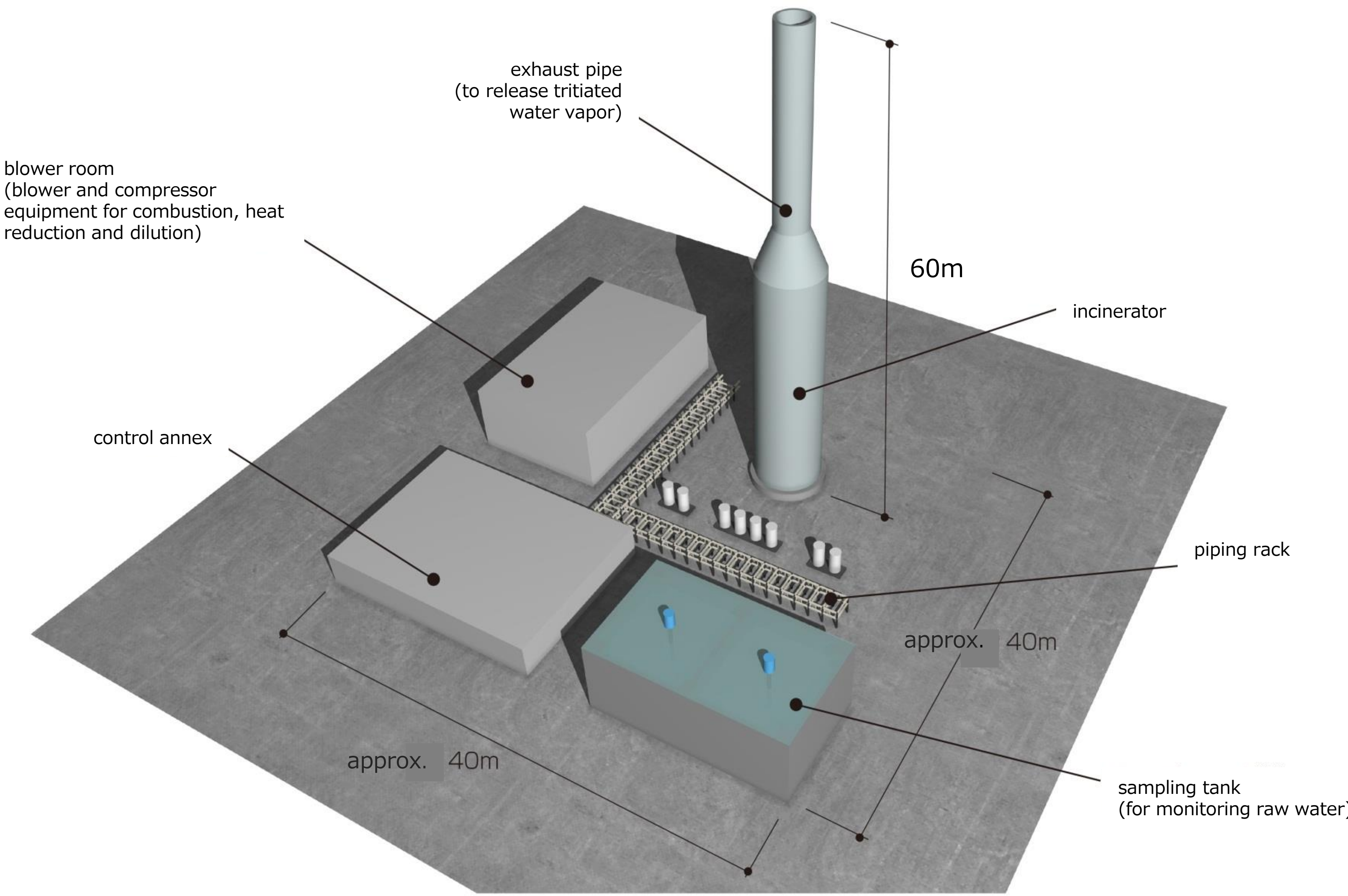
- Monitoring Method
  - A3: (No Pre-treatment) Vapor Release
  - C3: (Post-separation) Vapor Release

Regulation:
The concentration of the radioactive material in the exhaust air coming from the exhaust outlet or the exhaust air monitoring equipment must be monitored such that the concentration of the radioactive material in the atmosphere beyond the exclusion zone does not exceed the concentration limit declared by the Nuclear Regulation Authority



(5) Conceptual Design for Each Scenario Under Assessment (Vapor Release)

☐ Conceptual Diagram: (No Pre-Treatment) Vapor Release Example



(5) Conceptual Design for Each Scenario Under Assessment (Hydrogen Release)

- Same for All Hydrogen Release Options (A4, C4)
  - Reduction pace of raw tritiated water during release operation: 400m^3/day
  - Concentration: The concentration must be 70,000 Bq/L or less, which is the permitted concentration for radioactive material in the atmosphere beyond the exclusion zone.
  - At the exhaust pipe outlet, the concentration must be below the hydrogen-combustible concentration

- A4: (No Pre-treatment) Hydrogen Release
  - Exhaust pipe height: The exhaust pipe height which enables the tritium concentration in the atmosphere beyond the exclusion zone to be 70,000 Bq/L or less was compared with the exhaust pipe height for ensuring safety from an engineering standpoint, and the taller exhaust pipe height (20m above ground level) was adopted.
  - Volume treated: As there is no pre-treatment, 0.8 million m^3
  - The tritiated water is transferred from the water storage tank to a sampling tank, and the concentration per tank is measured. The tritiated water from the sampling tank is electrolyzed into hydrogen and oxygen in an electrolyzer, and the produced hydrogen gas (which contains tritium gas) is released into the atmosphere at a height of 20 m above ground level.

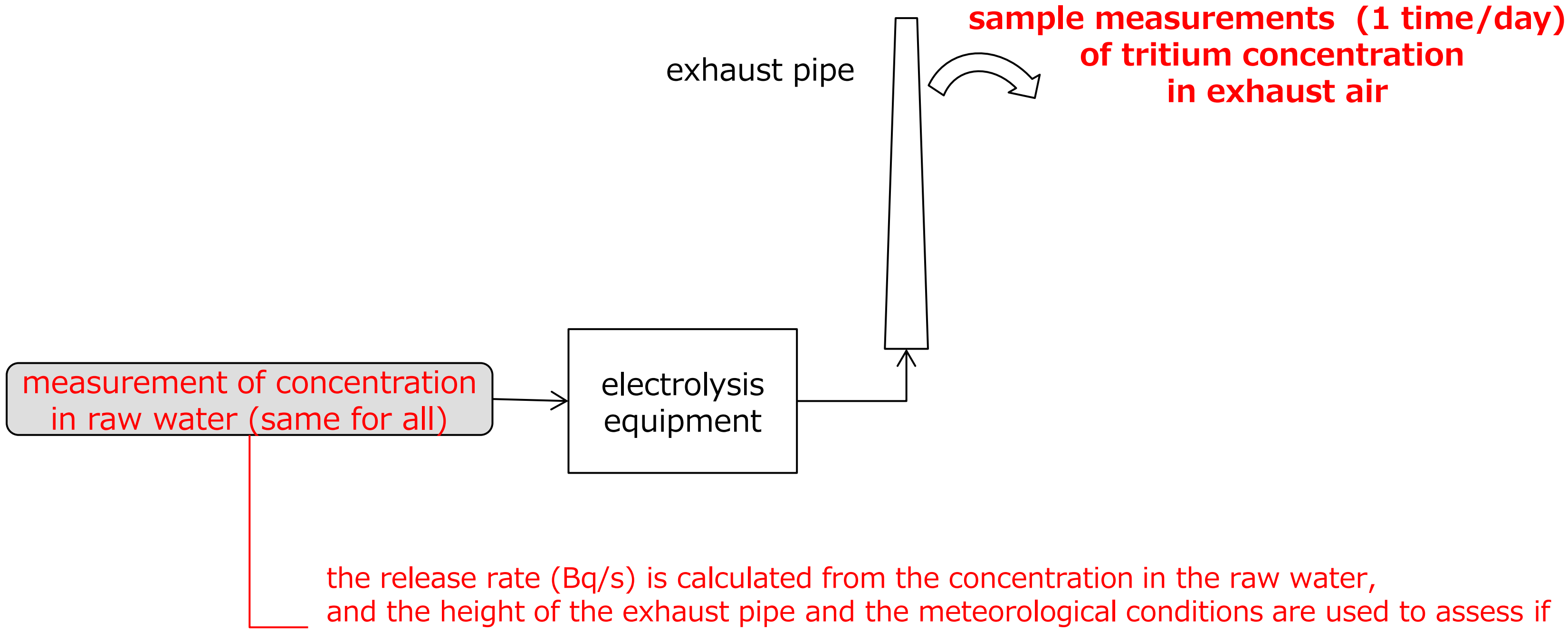
- C4: (Post-separation) Hydrogen Release
  - Exhaust pipe height: Same as height in “no pre-treatment” scenario
  - Volume treated: Assuming that the quantity of the post-separation enriched product can be disregarded (the quantity of the depleted product unchanging), the volume treated shall be 0.8 million m^3.
  - State of tritiated water to be treated: The post-separation depleted product shall be in liquid form.
  - The tritiated water is transferred from the separation processing (depleted product) water tank to a sampling tank, and the concentration per tank is measured. The tritiated water from the sampling tank is electrolyzed into hydrogen and oxygen in an electrolyzer, and the produced hydrogen gas (which contains tritium gas) is released into the atmosphere at a height of 20 m above ground level.

*These conditions were established for the sake of convenience in order to conduct the comparative study, and are not intended to be the actual conditions of the treatment.

(5) Conceptual Design for Each Scenario Under Assessment (Hydrogen Release)

- Monitoring Method
  - A4: (No Pre-treatment) Hydrogen Release
  - C4: (Post-separation) Hydrogen Release

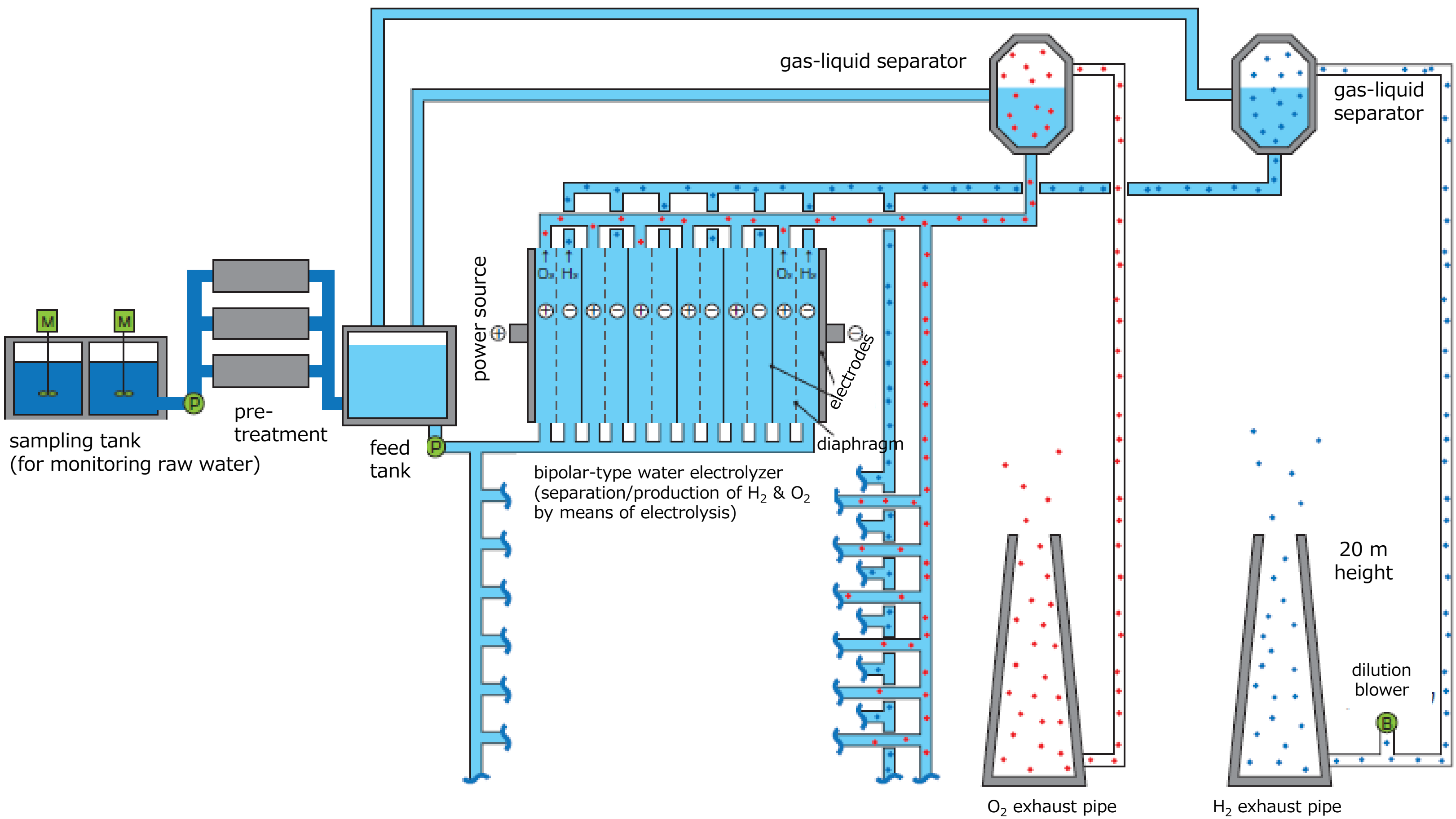
Regulation:
The concentration of the radioactive material in the exhaust air coming from the exhaust outlet or the exhaust air monitoring equipment must be monitored such that the concentration of the radioactive material in the atmosphere beyond the exclusion zone does not exceed the concentration limit declared by the Nuclear Regulation Authority



the release rate (Bq/s) is calculated from the concentration in the raw water, and the height of the exhaust pipe and the meteorological conditions are used to assess if the concentration will be at or below the limit for the concentration in the atmosphere beyond the exclusion zone

(5) Conceptual Design for Each Scenario Under Assessment (Hydrogen Release)

- Conceptual Diagram: (No Pre-treatment) Hydrogen Release Example



(5) Conceptual Design for Each Scenario Under Assessment (Underground Burial)

- A5: (No Pre-treatment) Underground Burial
  - Reduction pace of raw tritiated water during burial operation: 400 m^3/day
  - Construction method: Using a concrete disposal pit as the foundation, tritiated water and a cement-based solidifying agent are mixed together and poured directly within the confines of the pit, becoming integrally solidified with the installation. (*1)
  - Thickness of bentonite layer: the thickness of the man-made barrier (bentonite layer) is calculated such that the tritium concentration in any water seeping through the barrier becomes 60,000 Bq/L, which is the permitted concentration for radioactive material in water.
    - Example: approximately 2m (if the concentration in the raw water is 4.2 million Bq/L) or approximately 1m (if the concentration in the raw water is 0.5 million Bq/L)
  - Volume treated: As there is no pre-treatment, 0.8 million m^3
  - Underground excavation is carried out to construct the concrete pit. In order to deter groundwater inflow, or tritiated water seepage, soil mixed with bentonite is laid around the periphery of the concrete pit (having a thickness of 2m if the concentration in the raw water is 4.2 million Bq/L, or a thickness of 1m if the concentration in the raw water is 0.5 million Bq/L).
  - A composition of tritiated water mixed together with a cement-based solidifying agent is poured into the finished concrete pit, to solidify together with the concrete formation.
  - In order to deter the tritiated water from dissipating due to evaporation while being poured, a cover is installed on the top.
  - After solidification, a top slab for the concrete formation is poured, and the soil mixed with bentonite (having a thickness of 2m if the concentration in the raw water is 4.2 million Bq/L, or a thickness of 1m if the concentration in the raw water is 0.5 million Bq/L) is laid to further cover the installation.

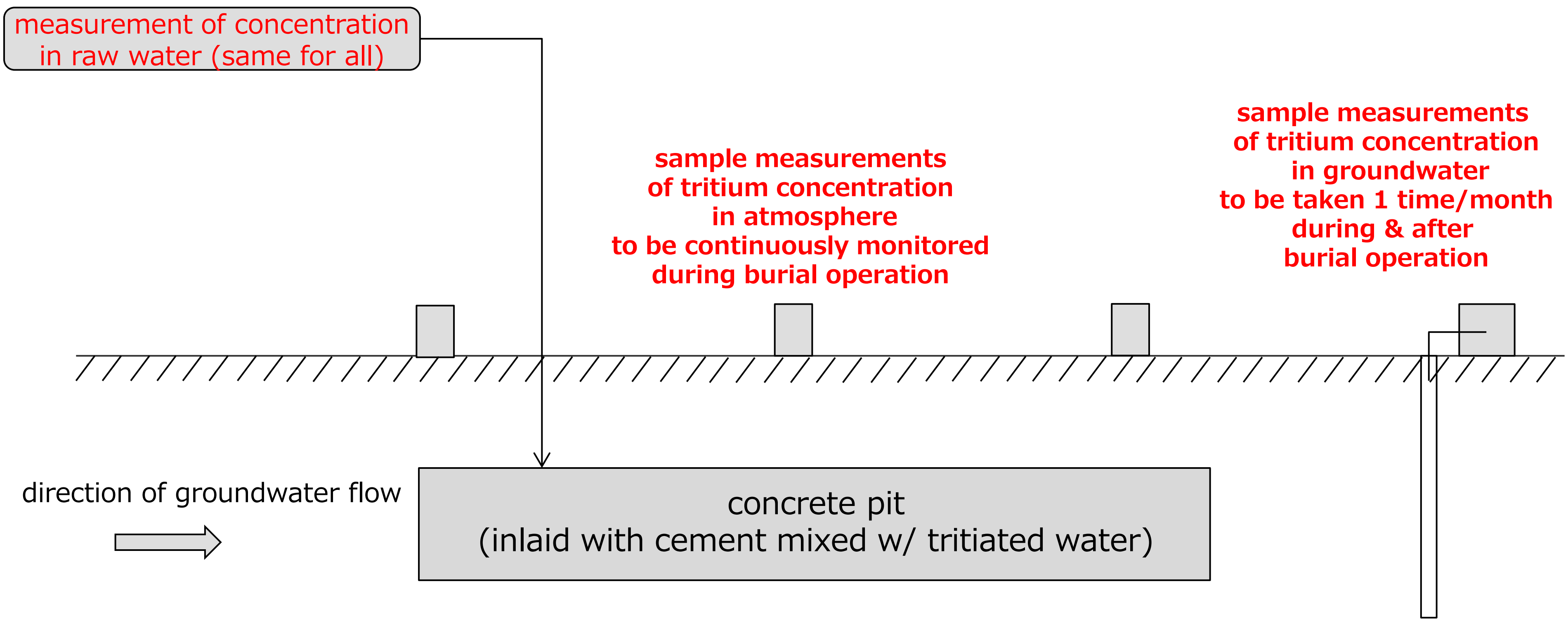
(*1) From the 10th Tritiated Water Task Force Meeting Reference Material No. 1 “Study Pertaining to Shallow Earth Disposal of Tritiated Water”

*These conditions were established for the sake of convenience in order to conduct the comparative study, and are not intended to be the actual conditions of the treatment.

(5) Conceptual Design for Each Scenario Under Assessment (Underground Burial)

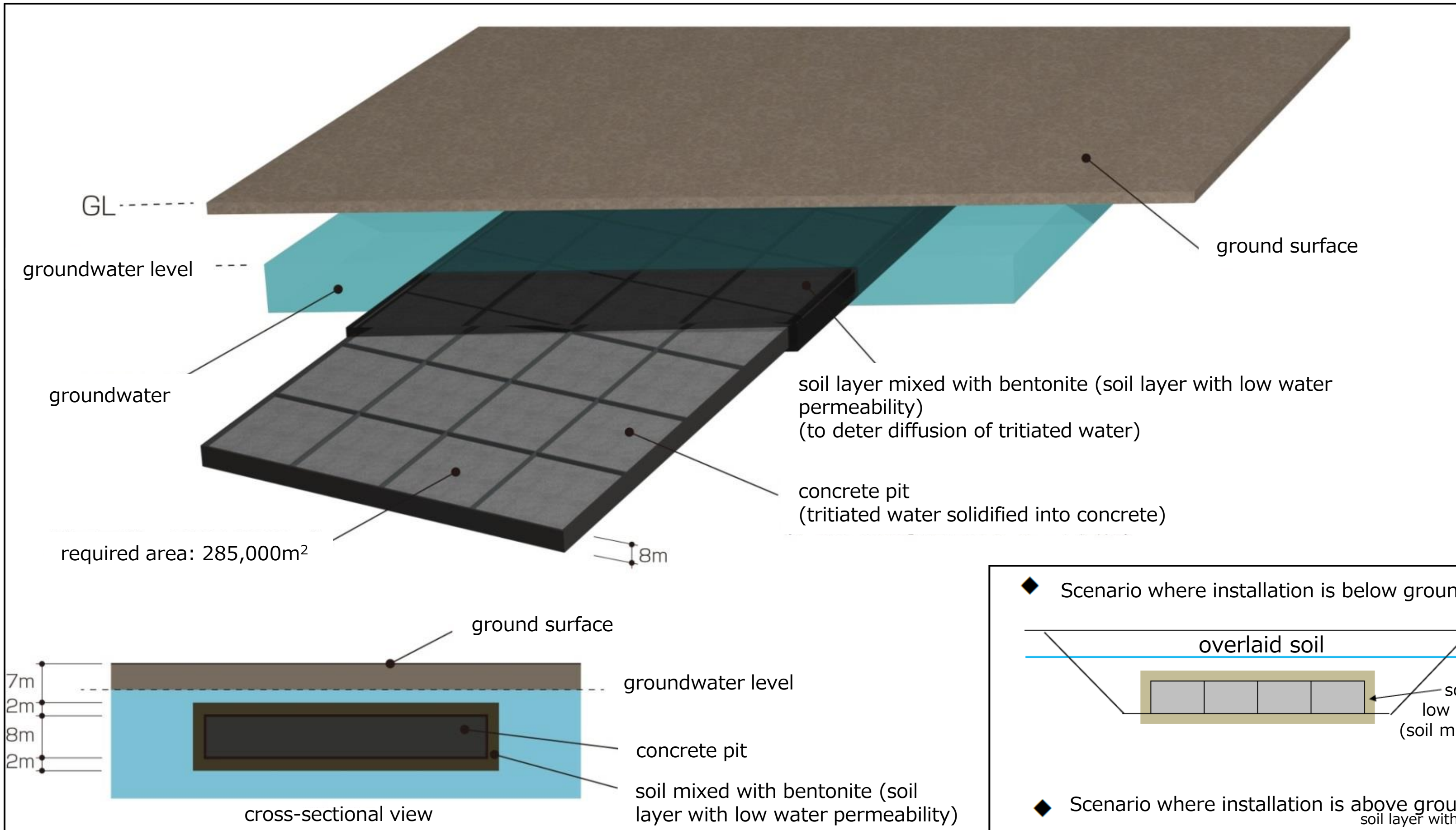
- Monitoring Method
  - A5: (No Pre-treatment) Underground Burial

In compliance with the "Rule for Disposal of Category 2 Waste Disposal of Nuclear Fuel Material or Material Contaminated with Nuclear Fuel Material"



(5) Conceptual Design for Each Scenario Under Assessment (Underground Burial)

◻ Conceptual Diagram: Example of Deep Burial Below Groundwater Level



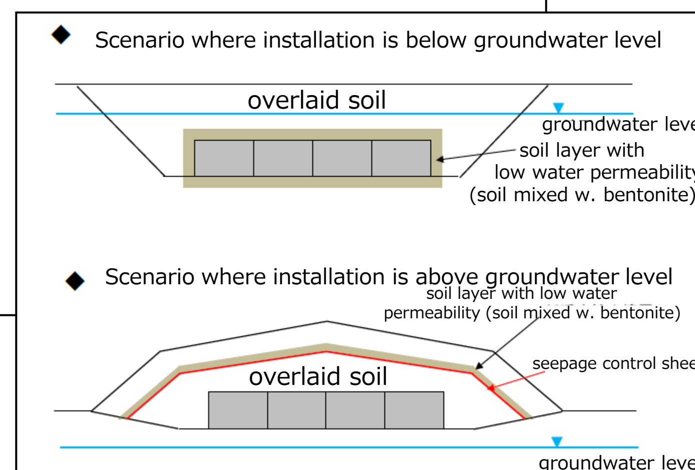


Diagram on Right: From the 10th Tritiated Water Task Force Meeting Reference Material No. 1 "Study Pertaining to Shallow Earth Disposal of Tritiated Water"

(6) Assessment Results for Each Scenario Under Assessment (Points to Consider)

- The assessment results based on the conceptual designs discussed in the previous section appear from page 28 and on.

- These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

- For the scenarios under assessment which have separation as the pre-treatment (C1, C3, C4), the duration and costs, etc., required for the separation process are added to the scenarios under assessment which have no pre-treatment (A1, A3, A4). Furthermore, the dilution process step in the “post-dilution offshore release” scenario (B2), is replaced with a separation process in the “post-separation offshore release” scenario (C2).

(6) Assessment Results for Each Scenario Under Assessment (Points to Consider)

- Other points to consider are as follows.
  - Assessments carried out without designating the location where the treatment is performed.
  - The following items have not been taken into consideration in the assessment results for duration:
    - ・Transport in the event that the treatment is performed offsite
    - ・Simulations to assess environmental impact, etc.
    - ・Uncertainties in terms of securing resources and required personnel
  - The following items have not been taken into consideration in the assessment results for costs:
    - ・Transport in the event that the treatment is performed offsite
    - ・Simulations to assess environmental impact, etc.
    - ・Uncertainties in terms of securing resources and required personnel
    - ・Factors unique to the nuclear power plant site (additional personnel costs for work conducted under high dosages, additional construction costs to make the nuclear facilities safe against earthquakes, etc.)
    - ・Costs to acquire land
    - ・Fixed property taxes
    - ・Costs for disposing of demolition waste, secondary waste, or construction spoil
    - ・Costs for 3rd party monitoring

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A1: (No Pre-treatment) Geosphere Injection [Basic Requirements])

- Technical Feasibility (same for all A1 scenarios)
  - CCS (carbon capture & storage) technologies are established, and pumping tritiated water into deep geosphere layers is considered to be possible.
  - However, the treatment cannot be initiated if a suitable geosphere layer cannot be found.
  - Moreover, a suitable method for long-term monitoring of deep geosphere layers has not yet been established.

- Regulatory Feasibility (same for all A1 scenarios)
  - If geosphere injection can be categorized as the “disposal of radioactive waste in liquid form,” then the concentration would exceed the concentration limit declared by the Nuclear Regulation Authority and would not be compliant.
  - The independent formulation of new regulations and standards pertaining to geosphere injection is necessary.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A1: (No Pre-treatment) Geosphere Injection [Duration])

- Duration of time until initiating treatment: **approx. "36 + 20n" months** (same for all A1 scenarios)
  - Approximately 20 months are required for exploring geosphere layers and conducting boring surveys, etc., at one location. In the event that the location does not have a suitable geosphere layer, then exploration of multiple locations will be required. This is expressed as "approx. 20 + 20n months." (where n=number of locations explored)
  - Designing and constructing injection wells (1 well) and injection equipment requires approximately 16 months. (design=approximately 6 months; rig preparation/coordination= approximately 4 months; excavation= approximately 6 months)
  - These durations remain constant for all scenarios ①–⑤ since they are determined by the prerequisite treatment capacity of 400m3/day.

- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for injection treatment depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 66 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Accordingly, the duration of time until concluding treatment is as follows. (n=number of locations explored)
    - scenarios ①, ② and ⑤: **approx. "102 + 20n" months,** for scenarios ③ and ④: **approx. "69 + 20n" months**

- Duration of time for dismantling: **approx. 2 months** (same for all A1 scenarios)
  - Dismantling the equipment and cementing the injection wells requires approximately 2 months.
  - This duration remains constant for all scenarios ①–⑤ since equipment/injection well numbers and size are determined by the prerequisite treatment capacity of 400m3/day.

- Duration of time for monitoring: (depends on scenario)
  - The duration of time for monitoring will depend on the tritium concentration in the raw water, as monitoring is to be conducted until the concentration in the raw water becomes the permitted concentration of 60,000 Bq/L, which is dependent upon the tritium half life.
    - For scenarios ①, ③ and ⑤: **approx. 912 months,** for scenarios ② and ④: **approx. 456 months**
  - However, it must be noted that this means the duration of time from when the tritium concentration in the raw water is measured, not the duration of time for monitoring after the treatment.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A1: (No Pre-treatment) Geosphere Injection [Costs])

- Exploration Costs: **approx. "6.5 + 6.5n" 100 million yen** (same for all A1 scenarios)
  - These are primarily the expenses required for boring surveys.
  - In the event that the location does not have a suitable geosphere layer, then exploration of multiple locations will be required, so "+ 6.5n" is added on. (where n=number of locations explored)
  - These costs remain constant for all scenarios ①–⑤ since they are influenced by equipment and injection well numbers/size, which are determined by the prerequisite treatment capacity of 400m^3/day.
- Design & Construction Costs: **approx. 16.2 billion yen** (same for all A1 scenarios)
  - These are primarily the expenses for site construction (approx. 15 billion yen), plus design expenses (approx. 80 million yen) and machinery expenses (approx. 11 billion yen).
  - These costs remain constant for all scenarios ①–⑤ since they are influenced by equipment/injection well numbers and size, which are determined by the prerequisite treatment capacity of 400m^3/day.
- Treatment Costs: (depends on scenario)
  - Treatment costs are composed of utility (electricity) expenses and personnel expenses.
  - These depend on the volume being treated and are as follows:
    - For scenarios ①, ② and ⑤: **approx. 500 million yen,** for scenarios ③ and ④: **approx. 300 million yen**
- Dismantling Costs: **approx. 600 million yen** (same for all A1 scenarios)
  - These are the expenses for shutting down the operation by dismantling the equipment and cementing the injection wells.
- Monitoring Costs: **"100m million yen"** (same for all A1 scenarios)
  - Since a suitable method for long-term monitoring has not yet been established, this must be newly developed. As the costs are unclear, this is expressed as "100m million yen."
- Total Costs: (depends on scenario) (n=number of locations explored) (m=monitoring costs)
  - For scenarios ①, ② and ⑤: **approx. "180+6.5n+m" 100 million yen,** for scenarios ③ and ④: **approx. "177+6.5n+m" 100 million yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A1: (No Pre-treatment) Geosphere Injection [Other])

- Scale (Area): Approximately **380m²** of land area (same for all A1 scenarios)

- Secondary Waste: (same for all A1 scenarios)
  - None in particular

- Worker Radiation Exposure: (same for all A1 scenarios)
  - No points to consider in particular

- Associated Conditions: (same for all A1 scenarios)
  - The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B1: (Post-dilution) Geosphere Injection [Basic Requirements])

- Technical Feasibility (same for all B1 scenarios)
  - CCS (carbon capture & storage) technologies are established, and pumping tritiated water into deep geosphere layers is considered to be possible.
  - However, the treatment cannot be initiated if a suitable geosphere layer cannot be found.

- Regulatory Feasibility (same for all B1 scenarios)
  - If geosphere injection can be categorized as the “disposal of radioactive waste in liquid form,” then the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B1: (Post-dilution) Geosphere Injection [Duration])

- Duration of time until initiating treatment: (depends on scenario)
  - The duration of time for exploring geosphere layers and conducting boring surveys, etc., is influenced by the number of injection wells* that will be installed, and the number of wells is influenced by the volume treated (dilution factor) per day.
    (*For scenarios ①, ③ and ⑤: simultaneous drilling of 48 wells/8 locations; for scenarios ② and ④: simultaneous drilling of 6 wells/ 2 locations)
  - Moreover, in the event that the location does not have a suitable geosphere layer, then exploration of multiple locations will be required, so "+ Xn" is added on. (where n=number of locations explored)
    - For scenarios ①, ③ and ⑤: **approx. "40 + 40n" months,** for scenarios ② and ④: **approx. "25+25n" months**
  - The duration of time for design and construction is also influenced by the number of injection wells, and is as follows.
    - For scenarios ①, ③ and ⑤: **approx. 50 months,** for scenarios ② and ④: **approx. 28 months**
  - Based on the above, the duration of time until initiating treatment is as follows. (n=number of locations explored)
    - For scenarios ①, ③ and ⑤: **approx. "90 + 40n" months,** for scenarios ② and ④: **approx. "53 + 25n" months**
- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for injection treatment depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 66 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Accordingly, the duration of time until concluding treatment is as follows. (n=number of locations explored)
    - For scenarios ① and ⑤: **approx. "156 + 40n" months,** for scenario ②: **approx. "119 + 25n" months**
      For scenario ③: **approx. "123 + 40n" months,** for scenario ④: **approx. "86 + 25n" months**
- Duration of time for dismantling: (depends on scenario)
  - Dismantling of equipment and cementing of injection wells will be carried out.
  - The duration of time required depends on the size of the equipment and the number of injection wells, and is as follows.
    - For scenarios ①, ③ and ⑤: **approx. 12 months,** for scenarios ② and ④: **approx. 6 months**
- Duration of time for monitoring: (same for all B1 scenarios)
  - Since the concentration in the treated water is the permitted concentration or less, monitoring will only be carried out during the treatment period.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B1: (Post-dilution) Geosphere Injection [Costs])

- Exploration Costs: (depends on scenario)
  - These are primarily the expenses required for boring surveys. These are influenced by the equipment and injection well numbers/size. In the event that the location does not have a suitable geosphere layer, then exploration of multiple locations will be required, so "+ Xn" is added on. (where n=number of locations explored)
    - For scenarios ①, ③ and ⑤: **approx. "110 + 110n" 100 million yen,** for scenarios ② and ④: **approx. "13 + 13n" 100 million yen**
- Design & Construction Costs: (depends on scenario)
  - These are primarily the expenses for site construction, and these are influenced by the equipment and injection well numbers/size.
    - For scenarios ①, ③ and ⑤: design expenses (approx. 980 million yen)+ machinery expenses (approx. 25 billion yen)+ site construction expenses (approx. 310 billion yen) = **approx. 336 billion yen,** for scenarios ② and ④: design expenses (approx. 200 million yen) + machinery expenses (approx. 4.2 billion yen) + site construction expenses (approx. 39 billion yen) =**approx. 43.4 billion yen**
- Treatment Costs: (depends on scenario)
  - Treatment costs are composed of utility (electricity) expenses and personnel expenses.
  - These depend on the volume being treated and the dilution factor, and are as follows:
    - For scenario ①: **approx. 21.5 billion yen,** for scenario ②: **approx. 3.4 billion yen,** for scenario ③: **approx. 10.7 billion yen,** for scenario ④: **approx. 1.7 billion yen,** for scenario ⑤: **approx. 12.3 billion yen**
- Dismantling Costs: (depends on scenario)
  - These are the expenses for shutting down the operation by dismantling the equipment and cementing the injection wells, and they are influenced by the equipment and injection well numbers/size.
    - For scenarios ①, ③ and ⑤: **approx. 29 billion yen,** for scenarios ② and ④: **approx. 3.6 billion yen**
- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water, and they depend upon the volume of raw water.
    - For scenarios ①, ② and ⑤: **approx. 102 million yen,** for scenarios ③ and ④: **approx. 91 million yen**
- Total Costs: (depends on scenario) (n=number of locations explored)
  - For scenario ①: **approx. "3976+110n" 100 million yen,** for scenario ②: **approx. "518+13n" 100 million yen,**
  - For scenario ③: **approx. "3868+110n" 100 million yen,** for scenario ④: **approx. "501+13n" 100 million yen,** for scenario ⑤: **approx. "3884+110n" 100 million yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B1: (Post-dilution) Geosphere Injection [Other])

- Scale (Area): (depends on scenario)
  - The required area depends on the dilution factor.
    - For scenarios ①, ③ and ⑤: approx. 2080m^2 of land area, and approx. 120m^2 of coastal area (**approx. 2200m^2** total)
    - For scenarios ② and ④: approx. 730m^2 of land area, and approx. 12m^2 of coastal area (**approx. 742m^2** total)

- Secondary Waste: (same for all B1 scenarios)
  - None in particular

- Worker Radiation Exposure: (same for all B1 scenarios)
  - No points to consider in particular

- Associated Conditions: (same for all B1 scenarios)
  - The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B2: (Post-dilution) Offshore Release [Basic Requirements])

- Technical Feasibility (same for all B2 scenarios)
  - There are examples of offshore release of liquid radioactive waste containing tritium at nuclear facilities, and it can be said to be an established method from a technical standpoint.

- Regulatory Feasibility (same for all B2 scenarios)
  - This corresponds to the "disposal of radioactive waste in liquid form," and the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B2: (Post-dilution) Offshore Release [Duration])

- Duration of time until initiating treatment: (depends on scenario)
  - Approximately 3 months are required for ground/topography exploration in order to install machinery, equipment, piping, and intake water ports, etc.
  - Procurement of large-scale water circulation pumps, and work to lay several kilometers of piping are required, and these durations depend on the dilution factor.
    - For scenarios ①, ③ and ⑤: approx. 19 months
    - For scenarios ② and ④: approx. 16 months
  - According to the above, the duration of time until initiating treatment is as follows.
    - For scenarios ①, ③ and ⑤: **approx. 22 months**
    - For scenarios ② and ④: **approx. 19 months**
- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for release treatment depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 66 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Accordingly, the duration of time until concluding treatment is as follows.
    - For scenarios ① and ⑤: **approx. 88 months**
    - For scenario ②: **approx. 85 months**
    - For scenario ③: **approx. 55 months**
    - For scenario ④: **approx. 52 months**
- Duration of time for dismantling: **approx. 3 months** (same for all B2 scenarios)
  - Approximately 3 months are required for dismantling the equipment and abandoning the underground piping.
- Duration of time for monitoring: (same for all B2 scenarios)
  - Since the concentration in the treated water is the permitted concentration or less, monitoring will only be carried out during the treatment period.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B2: (Post-dilution) Offshore Release [Costs])

- Exploration Costs: **approx. 40 million yen** (same for all B2 scenarios)
  - These are the expenses required for ground/topography exploration in order to install machinery, equipment, piping, and intake water ports, etc.
- Design & Construction Costs: (depends on scenario)
  - These are primarily the expenses for site construction, and these are influenced by the dilution factor.
    - For scenarios ①, ③ and ⑤: design expenses (approx. 88 million yen) + machinery expenses (approx. 790 million yen) + site construction expenses (approx. 1.4 billion yen) = **approx. 2.3 billion yen**
    - For scenarios ② and ④: design expenses (approx. 60 million yen) + machinery expenses (approx. 230 million yen) + site construction expenses (approx. 790 million yen) = **approx. 1.1 billion yen**
- Treatment Costs: (depends on scenario)
  - Treatment costs are composed of utility (electricity) expenses and personnel expenses.
  - These depend on the volume being treated and the dilution factor, and are as follows.
    - For scenarios ① and ⑤: **approx. 500 million yen,** for scenarios ② and ③: **approx. 300 million yen,** for scenario ④: **approx. 100 million yen**
- Dismantling Costs: (depends on scenario)
  - These are the expenses for dismantling the equipment and abandoning the underground piping, and they depend on the dilution factor.
    - For scenarios ①, ③ and ⑤: **approx. 470 million yen,** for scenarios ② and ④: **approx. 340 million yen**
- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water, and they depend upon the volume of raw water.
    - For scenarios ①, ② and ⑤: **approx. 102 million yen,** for scenarios ③ and ④: **approx. 91 million yen**
- Total Costs: (depends on scenario)
  - For scenario ①: **approx. 3.4 billion yen,** for scenario ②: **approx. 1.8 billion yen,** for scenario ③ **approx. 3.1 billion yen**
  - For scenario ④: **approx. 1.7 billion yen,** for scenario ⑤: **approx. 3.4 billion yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (B2: (Post-dilution) Offshore Release [Other])

- Scale (Area): (depends on scenario)
  - The required area depends on the dilution factor.
    - For scenarios ①, ③ and ⑤: approx. 280m² of land area, and approx. 120m² of coastal area (**approx. 400m²** total)
    - For scenarios ② and ④: approx. 280m² of land area, and approx. 12m² of coastal area (**approx. 292m²** total)

- Secondary Waste: (same for all B2 scenarios)
  - None in particular

- Worker Radiation Exposure: (same for all B2 scenarios)
  - No points to consider in particular

- Associated Conditions: (same for all B2 scenarios)
  - None in particular

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A3: (No Pre-treatment) Vapor Release [Basic Requirements])

- Technical Feasibility (same for all A3 scenarios)
  - Track records exist for evaporating water in a combustion furnace. (There is an example from TMI-2 of an evaporation method using a boiler.)

- Regulatory Feasibility (same for all A3 scenarios)
  - If vapor release can be categorized as the “disposal of radioactive waste in gaseous form,” then the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A3: (No Pre-treatment) Vapor Release [Duration])

- Duration of time until initiating treatment: **approx. 35 months** (same for all A3 scenarios)
  - Approximately 12 months are required as the duration of time for ground/topography exploration in order to install machinery, equipment, and piping, etc., and as the duration of time for obtaining meteorological conditions over a 1 year span.
  - However, in the event that meteorological conditions over a 1 year span are already able to be obtained, this duration may become shorter than 12 months.
  - Approximately 23 months are required for equipment design and construction. This primarily accounts for the duration of time for procuring a combustion furnace and installing it onsite.
  - These durations remain constant for all scenarios ①–⑤ since they are determined by the prerequisite treatment capacity of 400m3/day.
- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for release treatment depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 80 months, and scenarios ③ and ④ require approximately 40 months. (volume treated ÷ treatment capacity) (assuming that the combustion furnace operates for 300 days a year)
  - Accordingly, the duration of time until concluding treatment is as follows.
    - For scenarios ①, ② and ⑤: **approx. 115 months**
    - For scenarios ③ and ④: **approx. 75 months**
  - Note that the release operation may need to be suspended due to precipitation, so the duration may be extended.
- Duration of time for dismantling: **approx. 5 months** (same for all A3 scenarios)
  - Approximately 5 months are required for dismantling the combustion furnace.
- Duration of time for monitoring: (same for all A3 scenarios)
  - Since the atmospheric release will be performed so as to meet the legally permitted concentration, monitoring will only be carried out during the treatment period.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A3: (No Pre-treatment) Vapor Release [Costs])

- Exploration Costs: **approx. 40 million yen** (same for all A3 scenarios)
  - These are the expenses for ground/topography exploration in order to install machinery, equipment, and piping, etc., and the expenses for obtaining meteorological conditions over a 1 year span.

- Design & Construction Costs: **approx. 8 billion yen** (same for all A3 scenarios)
  - These are primarily the expenses for site construction (approx. 5.8 billion yen), plus design expenses (approx. 230 million yen) and machinery expenses (approx. 2 billion yen).

- Treatment Costs: (depends on scenario)
  - Treatment costs are composed of utility (fuel) expenses and personnel expenses.
  - These depend on the volume being treated, and are as follows.
    - For scenarios ①, ② and ⑤: **approx. 24.3 billion yen**
    - For scenarios ③ and ④: **approx. 12.1 billion yen**

- Dismantling Costs: **approx. 2.4 billion yen** (same for all A3 scenarios)
  - These are primarily the expenses for dismantling the combustion furnace.

- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water and the expenses for measuring the concentration in the exhaust pipe, and they depend upon the volume of raw water.
    - For scenarios ①, ② and ⑤: **approx. 156 million yen**
    - For scenarios ③ and ④: **approx. 138 million yen**

- Total Costs: (depends on scenario)
  - For scenarios ①, ② and ⑤: **approx. 34.9 billion yen**
  - For scenarios ③ and ④: **approx. 22.7 billion yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A3: (No Pre-treatment) Vapor Release [Other])

- Scale (Area): (same for all A3 scenarios)
  - Approximately **2000 m^2** of land area

- Secondary Waste: (same for all A3 scenarios)
  - Incinerator ash may be produced depending on components in the tritiated water.

- Worker Radiation Exposure: (same for all A3 scenarios)
  - There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.

- Associated Conditions: (same for all A3 scenarios)
  - None in particular

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A4: (No Pre-treatment) Hydrogen Release [Basic Requirements])

□ Technical Feasibility (same for all A4 scenarios)

- Electrolyzing water and reducing it to hydrogen is possible from a technical standpoint.
- However, R&D concerning pre-treatment and scale enlargement, etc., may be necessary when the process involves actual tritiated water.

□ Regulatory Feasibility (same for all A4 scenarios)

- If hydrogen release can be categorized as the "disposal of radioactive waste in gaseous form," then the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A4: (No Pre-treatment) Hydrogen Release [Duration])

- Duration of time until initiating treatment: **approx. 35 months** (same for all A4 scenarios)
  - Approximately 12 months are required as the duration of time for ground/topography exploration in order to install machinery, equipment, and piping, etc., and as the duration of time for obtaining meteorological conditions over a 1 year span.
  - However, in the event that meteorological conditions over a 1 year span are already able to be obtained, this duration may become shorter than 12 months.
  - Approximately 23 months are required for equipment design and construction. This primarily accounts for the duration of time for procuring electrolysis equipment and installing it onsite.
  - These durations remain constant for all scenarios ①–⑤ since they are determined by the prerequisite treatment capacity of 400m3/day.
- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for release treatment depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 66 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Accordingly, the duration of time until concluding treatment is as follows.
    - For scenarios ①, ② and ⑤: **approx. 101 months**
    - For scenarios ③ and ④: **approx. 68 months**
  - Note that the release operation may need to be suspended due to precipitation, so the duration may be extended.
- Duration of time for dismantling: **approx. 5 months** (same for all A4 scenarios)
  - Approximately 5 months are required for dismantling the electrolysis equipment.
- Duration of time for monitoring: (same for all A4 scenarios)
  - Since the atmospheric release will be performed so as to meet the legally permitted concentration, monitoring will only be carried out during the treatment period.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A4: (No Pre-treatment) Hydrogen Release [Costs])

- Exploration Costs: **approx. 40 million yen** (same for all A4 scenarios)
  - These are the expenses for ground/topography exploration in order to install machinery, equipment, and piping, etc., and the expenses for obtaining meteorological conditions over a 1 year span.

- Design & Construction Costs: **approx. 13 billion yen** (same for all A4 scenarios)
  - This is an estimation based on documentation.

- Treatment Costs: (depends on scenario)
  - Treatment costs are composed of utility (electricity) expenses and personnel expenses.
  - These depend on the volume being treated, and are as follows.
    - For scenarios ①, ② and ⑤: **approx. 83.1 billion yen**
    - For scenarios ③ and ④: **approx. 43.1 billion yen**

- Dismantling Costs: **approx. 3.7 billion yen** (same for all A4 scenarios)
  - These are primarily the expenses for dismantling the electrolysis equipment

- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water and the expenses for measuring the concentration in the exhaust pipe, and they depend upon the volume of raw water.
    - For scenarios ①, ② and ⑤: **approx. 136 million yen**
    - For scenarios ③ and ④: **approx. 123 million yen**

- Total Costs: (depends on scenario)
  - For scenarios ①, ② and ⑤: **approx. 100 billion yen**
  - For scenarios ③ and ④: **approx. 60 billion yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A4: (No Pre-treatment) Hydrogen Release [Other])

- Scale (Area): (same for all A4 scenarios)
  - Approximately **2000 m²** of land area

- Secondary Waste: (same for all A4 scenarios)
  - Secondary waste in the form of residue may be produced in the electrolysis pre-treatment step.

- Worker Radiation Exposure: (same for all A4 scenarios)
  - There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.

- Associated Conditions: (same for all A4 scenarios)
  - None in particular

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5a: (No Pre-treatment) Underground Burial (Deep Earth) [Basic Requirements])

□ Technical Feasibility (same for all A5 scenarios)

- Track records exist for concrete pit disposal sites and isolated-type disposal sites.

□ Regulatory Feasibility (same for all A5 scenarios)

- Since the waste is not entrapped or solidified in a container, it cannot be categorized as the “waste substance” in the “Rule for Disposal of Category 2 Waste Disposal of Nuclear Fuel Material or Material Contaminated with Nuclear Fuel Material.”
- If the solidification which is a mixture of tritiated water and cement can be categorized as the “waste such as concrete” in the abovementioned regulations, it may be necessary to independently formulate new standards since there are no examples of using a pit to dispose of tritiated water in the form of a concrete solidification.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5a: (No Pre-treatment) Underground Burial (Deep Earth) [Duration])

- Duration of time until initiating treatment: **approx. 26 months** (same for all A5 scenarios)
  - Approximately 12 months are required as the duration of time for ground/topography exploration in order to install the concrete pits, and as the duration of time for obtaining information on underground environmental conditions over a 1 year span.
  - However, in the event that information on underground environmental conditions over a 1 year span is already able to be obtained, this duration may become shorter than 12 months.
  - Approximately 8 months are required for equipment design. In terms of equipment construction, rather than constructing all of the concrete pits and initiating pouring, the process is expected to be one in which the concrete pits are constructed in installments, and the mixture is poured into the completed pits while the other pits are sequentially constructed in parallel. 6 months are required in order to construct the first installment of pits. (14 months are required until initiating treatment.)
  - These durations remain constant for all scenarios ①–⑤ since they are determined by the prerequisite treatment capacity of 400m3/day.

- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for burial disposal depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 66 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Furthermore, upon completing the burial, time is required for installing the top slab and overlaying soil, etc. (likewise 6 months and 3 months).
  - Accordingly, the duration of time until concluding treatment is as follows.
    - For scenarios ①, ② and ⑤: **approx. 98 months,** and for scenarios ③ and ④: **approx. 62 months**

- Duration of time for monitoring: (depends on scenario)
  - The duration of time for monitoring will depend on the tritium concentration in the raw water, if monitoring is to be conducted until the concentration in the raw water becomes the permitted concentration of 60,000 Bq/L, which is dependent upon the tritium half life.
    - For scenarios ①, ③ and ⑤: **approx. 912 months,** for scenarios ② and ④: **approx. 456 months**
  - However, it must be noted that this means the duration of time from when the tritium concentration in the raw water is measured, not the duration of time for monitoring after the treatment.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5a: (No Pre-treatment) Underground Burial (Deep Earth) [Costs])

- Exploration Costs: **approx. 100 million yen** (same for all A5 scenarios)
  - These are the expenses for ground/topography exploration in order to install the concrete pits, and the expenses for obtaining information on underground environmental conditions over a 1 year span.

- Design & Construction Costs: (depends on scenario) (includes treatment costs)
  - These are primarily the expenses for site construction, and these are influenced by the concentration in the raw water, and the volume treated.
    - For scenario ①: **approx. 252.9 billion yen**
    - For scenario ②: **approx. 222.6 billion yen**
    - For scenario ③: **approx. 131.7 billion yen**
    - For scenario ④: **approx. 121.6 billion yen**
    - For scenario ⑤: **approx. 242.7 billion yen**

- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water, and the expenses for measuring the concentration in the atmosphere and in the groundwater during and after burial, and these are influenced by the volume of raw water and the concentration in the raw water (during monitoring).
    - For scenarios ① and ⑤: **approx. 220 million yen**
    - For scenario ②: **approx. 184 million yen**
    - For scenario ③: **approx. 209 million yen**
    - For scenario ④: **approx. 173 million yen**

- Total Costs: (depends on scenario)
  - For scenario ①: **approx. 253.3 billion yen**
  - For scenario ②: **approx. 222.9 billion yen**
  - For scenario ③: **approx. 132.0 billion yen**
  - For scenario ④: **approx. 121.9 billion yen**
  - For scenario ⑤: **approx. 243.1 billion yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5a: (No Pre-treatment) Underground Burial (Deep Earth) [Other])

- Scale (Area): (depends on scenario)
  - For scenarios ①, ② and ⑤: **approx. 285,000 m^2** of land area
    - ✓ this is equivalent to approximately 8% of the area of the Fukushima Daiichi Nuclear Power Station site
  - For scenarios ③ and ④: **approx. 144,000 m^2** of land area
- Secondary Waste: (same for all A5 scenarios)
  - None in particular
- Worker Radiation Exposure: (same for all A5 scenarios)
  - Measures will be implemented to prevent radiation exposure to workers during the burial operation, such as installing a cover to deter tritiated water from evaporating from the cement.
- Associated Conditions: (depends on scenario)
  - **Required amount of concrete and cement-based solidifying agent:**
    - For scenarios ①, ② and ⑤: approx. 420,000 m^3 of concrete + approx. 1.6 million tons of cement-based solidifying agent
      - ✓ the above amount is equivalent to approximately 5% of Japan's annual cement consumption amount
    - For scenarios ③ and ④: approx. 230,000 m^3 of concrete + approx. 800,000 tons of cement-based solidifying agent
  - **Required amount of bentonite:**
    - For scenario ①: approx. 1.23 million m^3
      - ✓ the above amount is equivalent to approximately 8% of the global annual production amount, and equivalent to Japan's production amount over approximately 3 years
    - For scenario ②: approx. 610,000 m^3, for scenario ③: approx. 630,000 m^3, for scenario ④: approx. 310,000m^3, for scenario ⑤: approx. 920,000 m^3
  - **Produced amount of construction spoil:**
    - For scenario ①: approx. 3.48 million m^3
      - ✓ this is equivalent to approximately 3 times the area of Tokyo Dome, and equivalent to approximately 1/5 the area of the Fukushima Interim Storage Facility
      - ✓ if the construction spoil was hypothetically piled 5m high, an area of approximately 700,000 m^2 would be required for the construction spoil site (equivalent to approximately 20% of the area of the Fukushima Daiichi Nuclear Power Station site)
    - For scenario ②: approx. 2.86 million m^3, for scenario ③: approx. 1.78 million m^3, for scenario ④: approx. 1.46 million m^3, for scenario ⑤: approx. 3.18 million m^3

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5b: (No Pre-treatment) Underground Burial (Shallow Earth) [Basic Requirements])

- Technical Feasibility (same for all A5 scenarios)
  - Track records exist for concrete pit disposal sites and isolated-type disposal sites.

- Regulatory Feasibility (same for all A5 scenarios)
  - Since the waste is not entrapped or solidified in a container, it cannot be categorized as the "waste substance" in the "Rule for Disposal of Category 2 Waste Disposal of Nuclear Fuel Material or Material Contaminated with Nuclear Fuel Material."
  - If the solidification which is a mixture of tritiated water and cement can be categorized as the "waste such as concrete" in the abovementioned regulations, it may be necessary to independently formulate new standards since there are no examples of using a pit to dispose of tritiated water in the form of a concrete solidification.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5b: (No Pre-treatment) Underground Burial (Shallow Earth) [Duration])

- Duration of time until initiating treatment: **approx. 26 months** (same for all A5 scenarios)
  - Approximately 12 months are required as the duration of time for ground/topography exploration in order to install the concrete pits, and as the duration of time for obtaining information on underground environmental conditions over a 1 year span.
  - However, in the event that information on underground environmental conditions over a 1 year span is already able to be obtained, this duration may become shorter than 12 months.
  - Approximately 8 months are required for equipment design. In terms of equipment construction, rather than constructing all of the concrete pits and initiating pouring, the process is expected to be one in which the concrete pits are constructed in installments, and the mixture is poured into the completed pits while the other pits are sequentially constructed in parallel. 6 months are required in order to construct the first installment of pits. (14 months are required until initiating treatment.)
  - These durations remain constant for all scenarios ①–⑤ since they are determined by the prerequisite treatment capacity of 400m3/day.
- Duration of time until concluding treatment: (depends on scenario)
  - The duration required for burial disposal depends on the volume being treated. Scenarios ①, ② and ⑤ require approximately 64 months, and scenarios ③ and ④ require approximately 33 months. (volume treated ÷ treatment capacity)
  - Furthermore, upon completing the burial, time is required for installing the top slab and overlaying soil, etc. (likewise 6 months and 3 months).
  - Accordingly, the duration of time until concluding treatment is as follows.
    - For scenarios ①, ② and ⑤: **approx. 98 months,** and for scenarios ③ and ④: **approx. 62 months**
- Duration of time for monitoring: (depends on scenario)
  - The duration of time for monitoring will depend on the tritium concentration in the raw water, if monitoring is to be conducted until the concentration in the raw water becomes the permitted concentration of 60,000 Bq/L, which is dependent upon the tritium half life.
    - For scenarios ①, ③ and ⑤: **approx. 912 months,** for scenarios ② and ④: **approx. 456 months**
  - However, it must be noted that this means the duration of time from when the tritium concentration in the raw water is measured, not the duration of time for monitoring after the treatment.

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5b: (No Pre-treatment) Underground Burial (Shallow Earth) [Costs])

- Exploration Costs: **approx. 100 million yen** (same for all A5 scenarios)
  - These are the expenses for ground/topography exploration in order to install the concrete pits, and the expenses for obtaining information on underground environmental conditions over a 1 year span.
- Design & Construction Costs: (depends on scenario) (includes treatment costs)
  - These are primarily the expenses for site construction, and these are influenced by the concentration in the raw water, and the volume treated.
    - For scenario ①: **approx. 162 billion yen**
    - For scenario ②: **approx. 151.9 billion yen**
    - For scenario ③: **approx. 80.2 billion yen**
    - For scenario ④: **approx. 74.2 billion yen**
    - For scenario ⑤: **approx. 151.9 billion yen**
- Monitoring Costs: (depends on scenario)
  - These are the expenses for measuring the concentration in the raw water, and the expenses for measuring the concentration in the atmosphere and in the groundwater during and after burial, and these are influenced by the volume of raw water and the concentration in the raw water (during monitoring).
    - For scenarios ① and ⑤: **approx. 220 million yen**
    - For scenario ②: **approx. 184 million yen**
    - For scenario ③: **approx. 209 million yen**
    - For scenario ④: **approx. 173 million yen**
- Total Costs: (depends on scenario)
  - For scenario ①: **approx. 162.4 billion yen**
  - For scenario ②: **approx. 152.2 billion yen**
  - For scenario ③: **approx. 80.5 billion yen**
  - For scenario ④: **approx. 74.5 billion yen**
  - For scenario ⑤: **approx. 152.3 billion yen**

* These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.

(6) Assessment Results for Each Scenario Under Assessment (A5b: (No Pre-treatment) Underground Burial (Shallow Earth) [Other])

- Scale (Area): (depends on scenario)
  - For scenarios ①, ② and ⑤: **approx. 285,000 m^2** of land area
  - For scenarios ③ and ④: **approx. 144,000 m^2** of land area

- Secondary Waste: (same for all A5 scenarios)
  - None in particular.
- Worker Radiation Exposure: (same for all A5 scenarios)
  - Since tritiated water may evaporate from the cement during the burial operation, which would create a tritium atmosphere in the work environment and pose the risk of radiation exposure via inhalation, evaporation will be deterred by installing a cover, etc.
- Associated Conditions: (depends on scenario)
  - **Required amount of concrete and cement-based solidifying agent:**
    - For scenarios ①, ② and ⑤: approx. 420,000 m^3 of concrete + approx. 1.6 million tons of cement-based solidifying agent
    - For scenarios ③ and ④: approx. 240,000 m^3 of concrete + approx. 800,000 tons of cement-based solidifying agent
  - **Required amount of bentonite:**
    - For scenario ①: approx. 690,000 m^3
    - For scenario ②: approx. 350,000 m^3
    - For scenario ③: approx. 360,000 m^3
    - For scenario ④: approx. 180,000 m^3
    - For scenario ⑤: approx. 520,000 m^3
  - **Produced amount of construction spoil:**
    - None in particular

(Reference 1) Vapor Release & Hydrogen Release: Calculation for the Exhaust Pipe Height

- In the vapor release and hydrogen release scenarios, the concentration beyond the boundaries of the site must be below 5 Bq/L and 70,000 Bq/L, respectively.
- The concentration of radioactivity at certain points is calculated using the method defined in the "Meteorological Guidelines for the Safe Analysis of Power Generating Nuclear Facilities."
- As seen in the equation, the concentration of radioactivity (Bq/L) at certain points does not depend on the concentration of radioactivity (Bq/L) at the outlet of the exhaust pipe, but depends on the released volume (Bq/s) (also depends on the exhaust pipe height and meteorological conditions).

$$\chi = \sum_{S=A}^{F} \left[\frac{Q}{\pi \cdot \sigma_{yS} \cdot \sigma_{zS} \cdot U_{S1}} \cdot \exp\left(-\frac{{H_1}^2}{2{\sigma_{zS}}^2}\right) \cdot F_{S1} + \frac{Q}{\pi \cdot \sigma_{yS} \cdot \sigma_{zS} \cdot U_{S2}} \exp\left(-\frac{{H_2}^2}{2{\sigma_{zS}}^2}\right) \cdot F_{S2} + \frac{Q}{\pi \cdot \sigma_{yS} \cdot \sigma_{zS} \cdot U_{S3}} \exp\left(-\frac{{H_3}^2}{2{\sigma_{zS}}^2}\right) \cdot F_{S3} \right] \quad \cdots (2)$$

Meaning of Symbols in the equation

$\chi(x, y, 0)$: concentration (Bq/m^3) of radioactive material at points (x, y, 0)
Q: release rate (Bq/s)
σ_{yS}, σ_{zS}: σ_y, σ_z (m) during atmospheric stability (S)
σ_y : spread parameter (m) for distribution of concentration in y direction
σ_z : spread parameter (m) for distribution of concentration in z direction
U_{S1}: wind speed (m/s) at target orientation during atmospheric stability (S)
U_{S2}, U_{S3}: wind speed (m/s) at proximal orientations during atmospheric stability (S)
H_1: Effective height (m) of source of release with respect to target orientation
H_2, H_3: Effective height (m) of source of release with respect to proximal orientations
F_1: Averaged coefficient (m) of concentration at target orientation during atmospheric stability (S)
F_2, F_3: Averaged coefficient (m) of concentration at proximal orientations during atmospheric stability (S)

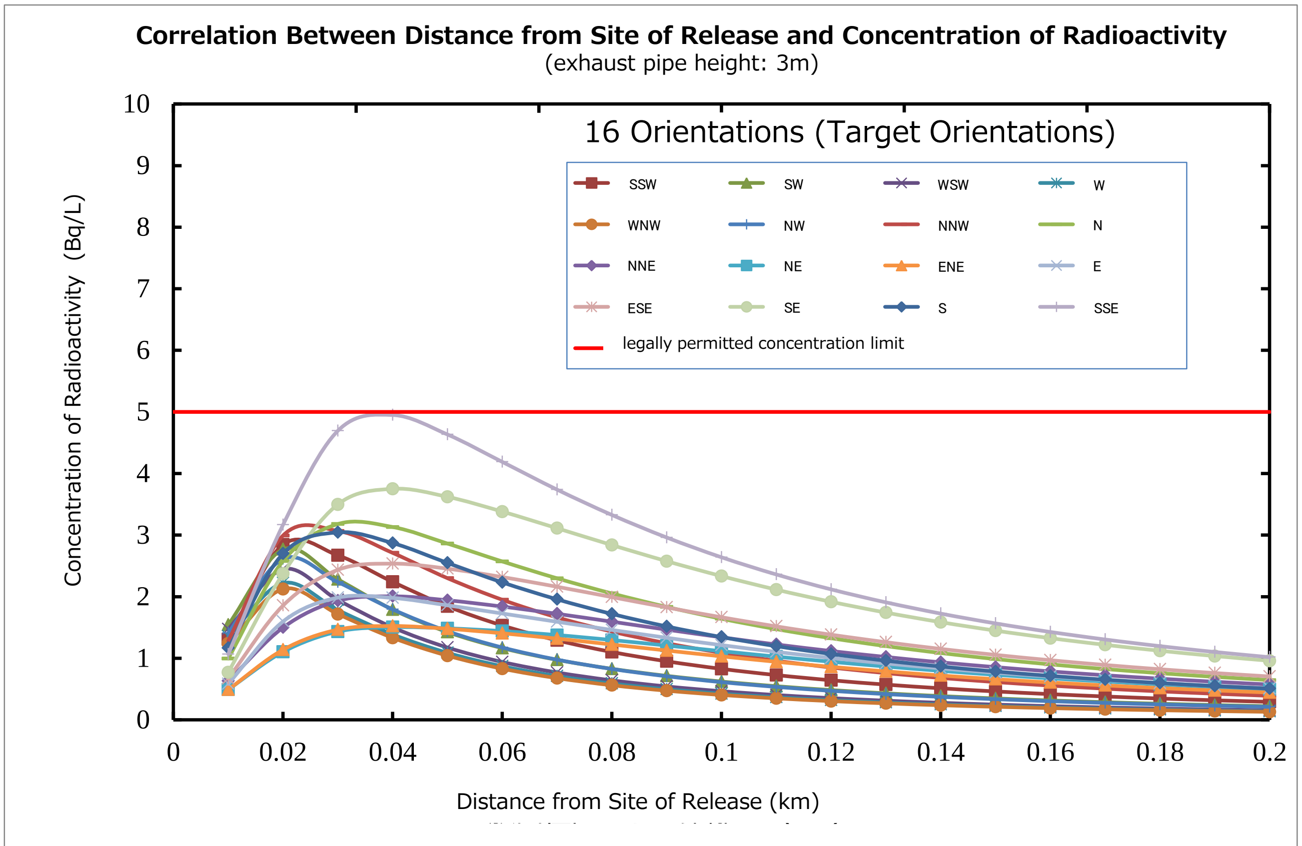
$$\chi_{cont,\,S} = Q_{cont} \cdot \overline{\chi_S} \cdot \frac{1}{N_t} \cdot S_d \quad \cdots (8)$$

$X_{cont,\,S}$: Continuous annual average concentration (Bq/m^3) during atmospheric stability (S)
Q_{cont}: release rate (Bq/s) when continuous radiation dosage is continuously released uniformly for 1 year
$\overline{Xs}$: Average value (Bq/m^3) of concentration in surface air at one orientation during per-unit release rate (1Bq/s) and per-unit wind speed (1m/s)
Nt: total observation frequency (8,760 times)
S_d: Sum of wind speed reciprocals (s/m) for wind direction and atmospheric stability

Excerpt from the "Meteorological Guidelines for the Safe Analysis of Power Generating Nuclear Facilities."

(Reference 1) Vapor Release & Hydrogen Release: Calculation for the Exhaust Pipe Height

- Using parameters provided by Tokyo Electric, below shows an example of the calculation results for the exhaust pipe height needed so that the permitted concentration is not exceeded beyond the boundaries of the site.
  - In order to treat 400 m^3 per day of tritiated water with a concentration of radioactivity of 4.2 million Bq/L, the release rate (Q) was set to approximately 1.95×10^7 Bq/s.
  - After researching the exhaust pipe height which would enable the maximal concentration of radioactivity to become 5Bq/L, which is the legally permitted maximal concentration for water vapor, it was assessed that with an exhaust pipe height of 3m, the maximal concentration of radioactivity would become 5 Bq/L at a point approximately 40m from the site of release.
  - Below shows the calculation results for the concentration of radioactivity depending on the distance from the site of release, hypothesizing that the meteorological conditions at the elevation of 132m, which is in the documentation from Tokyo Electric, also apply to the exhaust pipe height of 3m.



(Reference 2) Underground Burial: Calculation for the Thickness of the Bentonite Layer

- The thickness of the bentonite layer, the outermost man-made layer in the underground burial scenario, is calculated so as to enable the tritium concentration in any water seeping through said layer to become 60,000 Bq/L or less.
- In order to assess the concentration of radioactivity in water seeping though the bentonite layer, it is necessary to set the permeability coefficient for the concrete layer and its diffusion coefficient, the permeability coefficient for the bentonite layer and its diffusion coefficient, as well as the hydraulic gradient of the groundwater. Below shows the settings for those values and their validity.
  - ✓ permeability coefficient for the concrete layer: $1.0 \times 10^{-6}\ \mathrm{m/s}$
    - Referenced data on cement mortar permeability coefficients in the "Second Progress Report on Research and Development for TRU Waste Disposal in Japan – Repository Design, Safety Assessment and Means of Implementation in the Generic Phase –" (*1)
    - When there are no cracks in the cement mortar: 5×10^{-11}, when there are cracks: 4×10^{-6}
  - ✓ diffusion coefficient for the concrete layer: $3 \times 10^{-10}\ \mathrm{m^2/s}$
    - Referenced data on cement mortar diffusion coefficients in the "Second Progress Report on Research and Development for TRU Waste Disposal in Japan – Repository Design, Safety Assessment and Means of Implementation in the Generic Phase –"
  - ✓ permeability coefficient for the bentonite layer: $1.0 \times 10^{-9}\ \mathrm{m/s}$
    - Referenced data on various permeability coefficients for bentonite in the "Second Progress Report on Research and Development for TRU Waste Disposal in Japan – Repository Design, Safety Assessment and Means of Implementation in the Generic Phase –," and set conservatively.
  - ✓ diffusion coefficient for the bentonite layer: $3.0 \times 10^{-10}\ \mathrm{m^2/s}$
    - Referenced the "Atomic Energy Society of Japan Standards for Safe Assessment Methods for Shallow Earth Pit Disposal" (*2)
  - ✓ hydraulic gradient of the groundwater: 0.5%
    - Referenced the Ministry of the Environment resource material indicating the common hydraulic gradient of groundwater (*3)

*1 Japan Atomic Energy Agency "Second Progress Report on Research and Development for TRU Waste Disposal in Japan – Repository Design, Safety Assessment and Means of Implementation in the Generic Phase –"
*2 Atomic Energy Society of Japan "Safe Assessment Methods for Shallow Earth Pit Disposal"
*3 Ministry of the Environment "Guideline on the Investigation and Countermeasure Based on the Soil Contamination Countermeasures Act (Revised 2nd Edition) – Framework for the Fixed Limits that Groundwater Containing Specified Hazardous Substances May Reach"

(Reference 2) Underground Burial: Calculation for the Thickness of the Bentonite Layer

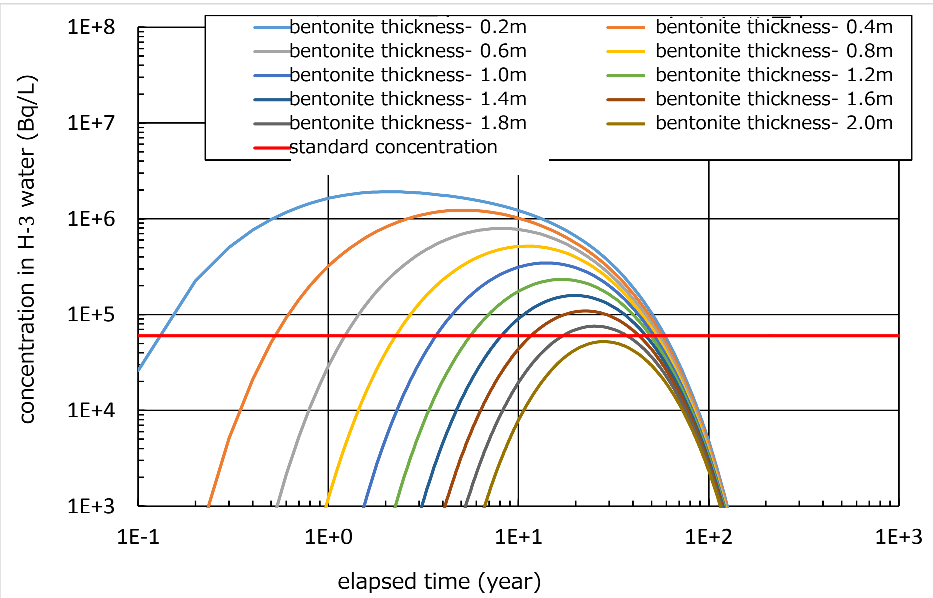


Diagram 1 Time dependence of tritium concentration in water (scenario in which concentration is 4.2 million Bq/L prior to solidification)

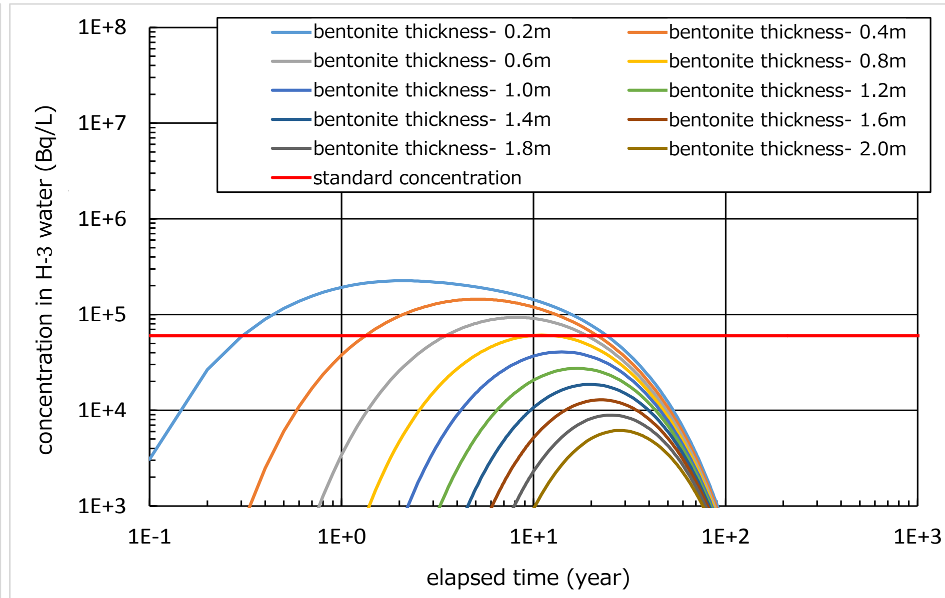


Diagram 2 Time dependence of tritium concentration in water (scenario in which concentration is 0.5 million Bq/L prior to solidification)

bentonite layer thickness calculated as 2m

bentonite layer thickness calculated as 1m

(Reference 3) Other Prerequisites

[Geosphere Injection]

- No Pre-treatment
  - ① The water storage tank (0.8 million m^3) shall be in proximal distance (100m) to the plant.
  - ② Elevation of plant installation site: O.P.+10.0m
  - ③ A sufficient amount of electric power shall be supplied using the required voltage. (transformers and the like are out of range)
  - ④ The geosphere layer which enables the injected tritiated water to remain stably submerged over a long period of time shall be within an excavatable range.
  - ⑤ Referencing CCS (carbon capture & storage) demonstration examples, the depth of the geosphere layer that is suitable for geosphere injection shall be 2,500m deep.
  - ⑥ There shall be no restrictions based on the work environment (radioactive contamination, etc.).

- Dilution
  - ① The tritium concentration in the sea water shall be so low upon dilution that it can be disregarded.
  - ② Prerequisites ①–⑥ for geosphere injection (no pre-treatment) also apply here.

[Offshore Release]

- Dilution
  - ① The water storage tank (0.8 million m^3) shall be in proximal distance (100m) to the plant.
  - ② Elevation of plant installation site: O.P.+10.0m
  - ③ Elevation proximal to sea level: O.P.+4.0m (tide level: O.P.+0.2m to +2.0m)
  - ④ A sufficient amount of electric power shall be supplied using the required voltage. (transformers and the like are out of range)
  - ⑤ The distance from the plant to the coast (to the intake water ports and discharge pipe ports) shall be 1,000m.
  - ⑥ No access point will be provided for the underground piping.
  - ⑦ There shall be no restrictions based on the work environment (radioactive contamination, etc.).
  - ⑧ The tritium concentration in the sea water shall be so low upon dilution that it can be disregarded.

(Reference 3) Other Prerequisites

[Vapor Release]

- No Pre-treatment
  - ① The water storage tank (0.8 million m^3) shall be in proximal distance (100m) to the plant.
  - ② Elevation of plant installation site: O.P.+10.0m
  - ③ Combustion equipment and associated equipment shall be installed outside.
  - ④ A sufficient amount of electric power shall be supplied using the required voltage. (transformers and the like are out of range)
  - ⑤ The work conditions for construction and operation shall be the same as those under the existing provisional incinerator.
  - ⑥ There shall be no restrictions based on the work environment (radioactive contamination, etc.).
  - ⑦ The fact that the release operation may need to be suspended due to precipitation has not been taken into consideration in the calculation.

[Hydrogen Release]

- No Pre-treatment
  - ① The water storage tank (0.8 million m^3) shall be in proximal distance (100m) to the plant.
  - ② Elevation of plant installation site: O.P.+10.0m
  - ③ A sufficient amount of electric power shall be supplied using the required voltage. (transformers and the like are out of range)
  - ④ The matters of a facility for pre-treatment, and treating produced residues shall be considered in research and development.
  - ⑤ There shall be no restrictions based on the work environment (radioactive contamination, etc.).
  - ⑥ The fact that the release operation may need to be suspended due to precipitation has not been taken into consideration in the calculation.

[Underground Burial]

- No Pre-treatment
  - ① Design and construction shall be carried out on the basis of the "Study Pertaining to Shallow Earth Disposal of Tritiated Water"(*)
  - ② First a bottom slab and walls will be constructed for the concrete pit formation, and then a top slab will be constructed after solidification of the concrete mixed with the pertinent raw water.
  - ③ Removal of existing structures and structures buried underground at the construction site has not been taken into consideration.
  - ④ Disposal of construction spoil has not been taken into consideration.
  - ⑤ Even supposing contaminated soil is produced, the decontamination thereof has not been taken into consideration.
  - ⑥ There shall be no restrictions based on the work environment (radioactive contamination, etc.).

*From the 10th Tritiated Water Task Force Meeting on 10/24/2014 Reference Material No. 1 "Study Pertaining to Shallow Earth Disposal of Tritiated Water"

Table of Assessment Results for Each Scenario Under Assessment

Appendix 2

(*These assessment results are estimations based on approximations of the established hypothetical conditions, and they are not guarantees of the costs, etc., required for the treatment.)

								Basic Requirements		Potentially Restricting Conditions																							
								Technical Feasibility	Regulatory Feasibility	Duration (Months)								Costs (100 million yen)												Scale (Area) (m2)	Secondary Waste	Worker Radiation Exposure	Associated Conditions
										Duration Until Completion						Dismantling	Monitoring	Separation	Exploration	Design & Construction				Treatment			Dismantling	Monitoring					
										Duration Until Initiation				Treatment	Total																		
Treatment Method	No.	Pre-treatment	Concentration in Raw Water	Treated Raw Water Volume	Dilution Factor	Top: Total Volume Treated Bottom: Treatment Capacity	Treated Concentration			Separation	Exploration	Design + Construction	Total							Design	Machinery Expenses	Site Construction Expenses	Subtotal	Utilities	Personnel and Other Expenses, etc.	Subtotal			Total				
geosphere injection	A1-①	none	4.2 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	4.2 million Bq/L	・CCS (carbon capture & storage) technologies are established, and pumping tritiated water into deep geosphere layers is itself considered to be possible. ・However, the treatment cannot be initiated if a suitable geosphere layer cannot be found. ・Moreover, a suitable method for long-term monitoring of deep geosphere layers has not yet been established. (m= monitoring costs)	・If geosphere injection can be categorized as the "disposal of radioactive waste in liquid form," then the concentration would exceed the concentration limit declared by the Nuclear Regulation Authority and would not be compliant.	–	#####	16	36 +20n	66	102 +20n	2	912	–	6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	m	180 +6.5n +m	land area: 380	・None in particular	・No points to consider in particular	・The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer. (n=number of times geosphere exploration is implemented)
	A1-②		0.5 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	0.5 million Bq/L			–	#####	16	36 +20n	66	102 +20n	2	456	–	6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	m	180 +6.5n +m				
	A1-③		4.2 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	4.2 million Bq/L			–	#####	16	36 +20n	33	69 +20n	2	912	–	6.5 +6.5n	0.8	11	150	162	0.62	2.1	2.7	6	m	177 +6.5n +m				
	A1-④		0.5 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	0.5 million Bq/L			–	#####	16	36 +20n	33	69 +20n	2	456	–	6.5 +6.5n	0.8	11	150	162	0.62	2.1	2.7	6	m	177 +6.5n +m				
	A1-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	4.2 million Bq/L 0.5 million Bq/L			–	#####	16	36 +20n	66	102 +20n	2	912	–	6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	m	180 +6.5n +m				
	B1-①	dilution	4.2 million Bq/L	0.8 million m3	70	56 million m3 28,000m3/day	60,000 Bq/L	・CCS (carbon capture & storage) technologies are established, and pumping tritiated water into deep geosphere layers is itself considered to be possible. ・However, the treatment cannot be initiated if a suitable geosphere layer cannot be found.	・If geosphere injection can be categorized as the "disposal of radioactive waste in liquid form," then the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.	–	#####	50	90 +40n	66	156 +40n	12	during treatment period	–	110 +110n	9.8	250	3,100	3,360	85	130	215	290	1.02	3976 +110n	sea area: 120 land area: 2080	・None in particular	・No points to consider in particular	・The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer. (n=number of times geosphere exploration is implemented)
	B1-②		0.5 million Bq/L	0.8 million m3	8.33	6.66 million m3 3,340m3/day	60,000 Bq/L			–	#####	28	53 +25n	66	119 +25n	6	during treatment period	–	13 +13n	2.0	42	390	434	13	21	34	36	1.02	518 +13n	sea area: 12 land area: 730			
	B1-③		4.2 million Bq/L	0.4 million m3	70	28 million m3 28,000m3/day	60,000 Bq/L			–	#####	50	90 +40n	33	123 +40n	12	during treatment period	–	110 +110n	9.8	250	3,100	3,360	43	64	107	290	0.91	3868 +110n	sea area: 120 land area: 2080			
	B1-④		0.5 million Bq/L	0.4 million m3	8.33	3.33 million m3 3,340m3/day	60,000 Bq/L			–	#####	28	53 +25n	33	86 +25n	6	during treatment period	–	13 +13n	2.0	42	390	434	6.3	11	17	36	0.91	501 +13n	sea area: 12 land area: 730			
	B1-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		70 8.33	28 million m3 28,000m3/day 3.33 million m3 3,340m3/day	60,000 Bq/L			–	#####	50	90 +40n	66	156 +40n	12	during treatment period	–	110 +110n	9.8	250	3,100	3,360	49	74	123	290	1.02	3884 +110n	sea area: 120 land area: 2080			
	C1-①	separation	42,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	42,000 Bq/L	・CCS (carbon capture & storage) technologies are established, and pumping tritiated water into deep geosphere layers is itself considered to be possible. ・However, the treatment cannot be initiated if a suitable geosphere layer cannot be found.			#####	16	36+20n or duration for initiating separation	66	until initiating treatment +66	2	during treatment period		6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	1.02	separation costs +181+6.5n	land area: 380+area for separation	・Secondary waste may be produced depending on the separation technology.	・No points to consider in particular	・The costs and duration of the exploration will increase in the event that it is difficult to find a suitable geosphere layer. (n=number of times geosphere exploration is implemented)
	C1-②		5,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	5,000 Bq/L				#####	16	36+20n or duration for initiating separation	66	until initiating treatment +66	2	during treatment period		6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	1.02	separation costs +181+6.5n				
	C1-③		42,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	42,000 Bq/L				#####	16	36+20n or duration for initiating separation	33	until initiating treatment +33	2	during treatment period		6.5 +6.5n	0.8	11	150	162	0.62	2.1	2.7	6	0.91	separation costs +178 +6.5n				
	C1-④		5,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	5,000 Bq/L				#####	16	36+20n or duration for initiating separation	33	until initiating treatment +33	2	during treatment period		6.5 +6.5n	0.8	11	150	162	0.62	2.1	2.7	6	0.91	separation costs +178 +6.5n				
	C1-⑤		42,000 Bq/L × 0.4 million m3 +5,000 Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	42,000 Bq/L 5,000 Bq/L				#####	16	36+20n or duration for initiating separation	66	until initiating treatment +66	2	during treatment period		6.5 +6.5n	0.8	11	150	162	1.3	4.0	5.3	6	1.02	separation costs +181+6.5n				

Treatment Method	No.	Pre-treatment	Concentration in Raw Water	Treated Raw Water Volume	Dilution Factor	Top: Total Volume Treated Bottom: Treatment Capacity	Treated Concentration	Basic Requirements: Technical Feasibility	Basic Requirements: Regulatory Feasibility
offshore release	B2-①	dilution	4.2 million Bq/L	0.8 million m3	70	56 million m3 28,000m3/day	60,000 Bq/L	・There are examples of offshore release of liquid radioactive waste containing tritium at nuclear facilities.	・This corresponds to the "disposal of radioactive waste in liquid form," and the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.
	B2-②		0.5 million Bq/L	0.8 million m3	8.33	6.66 million m3 3,332m3/day	60,000 Bq/L		
	B2-③		4.2 million Bq/L	0.4 million m3	70	28 million m3 28,000m3/day	60,000 Bq/L		
	B2-④		0.5 million Bq/L	0.4 million m3	8.33	3.33 million m3 3,340m3/day	60,000 Bq/L		
	B2-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		70 8.33	28 million m3 28,000m3/day 3.33 million m3	60,000 Bq/L		
	C2-①	separation	42,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	42,000 Bq/L	・There are examples of offshore release of liquid radioactive waste containing tritium at nuclear facilities.	・This corresponds to the "disposal of radioactive waste in liquid form," and the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.
	C2-②		5,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	5,000 Bq/L		
	C2-③		42,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	42,000 Bq/L		
	C2-④		5,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	5,000 Bq/L		
	C2-⑤		42,000 Bq/L × 0.4 million m3 +5,000 Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	42,000 Bq/L 5,000 Bq/L		

Potentially Restricting Conditions

No.	Duration (Months): Duration Until Completion: Duration Until Initiation: Separation	Exploration	Design + Construction	Total	Treatment	Total	Dismantling	Monitoring
B2-①	–	3	19	22	66	88	3	during treatment
B2-②	–	3	16	19	66	85	3	during treatment
B2-③	–	3	19	22	33	55	3	during treatment
B2-④	–	3	16	19	33	52	3	during treatment
B2-⑤	–	3	19	22	66	88	3	during treatment
C2-①		2	14	16 or duration for initiating separation	66	until initiating treatment +66	2	during treatment
C2-②		2	14	16 or duration for initiating separation	66	until initiating treatment +66	2	during treatment
C2-③		2	14	16 or duration for initiating separation	33	until initiating treatment +33	2	during treatment
C2-④		2	14	16 or duration for initiating separation	33	until initiating treatment +33	2	during treatment
C2-⑤		2	14	16 or duration for initiating separation	66	until initiating treatment +66	2	during treatment

No.	Costs (100 million yen): Separation	Exploration	Design & Construction: Design	Machinery Expenses	Site Construction Expenses	Subtotal	Treatment: Utilities	Personnel and Other Expenses, etc.	Subtotal	Dismantling	Monitoring	Total
B2-①	–	0.4	0.88	7.9	14	23	0.71	4.5	5.2	4.7	1.02	34
B2-②	–	0.4	0.6	2.3	7.9	11	0.13	2.6	2.7	3.4	1.02	18
B2-③	–	0.4	0.88	7.9	14	23	0.36	2.3	2.7	4.7	0.91	31
B2-④	–	0.4	0.6	2.3	7.9	11	0.07	1.3	1.4	3.4	0.91	17
B2-⑤	–	0.4	0.88	7.9	14	23	0.64	4.5	5.1	4.7	1.02	34
C2-①		0.2	0.22	0.91	4.7	6	0.05	1.8	1.9	2.2	1.02	separation costs +11
C2-②		0.2	0.22	0.91	4.7	6	0.05	1.8	1.9	2.2	1.02	separation costs +11
C2-③		0.2	0.22	0.91	4.7	6	0.03	0.9	0.9	2.2	0.91	separation costs +10
C2-④		0.2	0.22	0.91	4.7	6	0.03	0.9	0.9	2.2	0.91	separation costs +10
C2-⑤		0.2	0.22	0.91	4.7	6	0.05	1.8	1.9	2.2	1.02	separation costs +11

No.	Scale (Area) (m2)	Secondary Waste	Worker Radiation Exposure	Associated Conditions
B2-①	sea area: 120 land area: 280	・None in particular	・No points to consider in particular	・Costs will increase in the event that a divider, such as a quay wall, is used between the intake water pit and the discharge port so as to deter discharged water from being directly taken in again.
B2-②	sea area: 12 land area: 280			
B2-③	sea area: 120 land area: 280			
B2-④	sea area: 12 land area: 280			
B2-⑤	sea area: 120 land area: 280			
C2-①	land area: 280+area for separation	・Secondary waste may be produced depending on the separation technology.	・No points to consider in particular	・Costs will increase in the event that a divider, such as a quay wall, is used between the intake water pit and the discharge port so as to deter discharged water from being directly taken in again.
C2-②				
C2-③				
C2-④				
C2-⑤				

								Basic Requirements		Potentially Restricting Conditions																							
										Duration (Months)								Costs (100 million yen)												Scale (Area) (m2)	Secondary Waste	Worker Radiation Exposure	Associated Conditions
										Duration Until Completion										Design & Construction				Treatment									
										Duration Until Initiation																							
Treatment Method	No.	Pre-treatment	Concentration in Raw Water	Treated Raw Water Volume	Dilution Factor	Top: Total Volume Treated Bottom: Treatment Capacity	Treated Concentration	Technical Feasibility	Regulatory Feasibility	Separation	Exploration	Design + Construction	Total	Treatment	Total	Dismantling	Monitoring	Separation	Exploration	Design	Machinery Expenses	Site Construction Expenses	Subtotal	Utilities	Personnel and Other Expenses, etc.	Subtotal	Dismantling	Monitoring	Total				
vapor release	A3-①	none	4.2 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	4.2 million Bq/L	·Track records exist for evaporating water in a combustion furnace. (There is an example from TMI-2 of an evaporation method using a boiler.)	·If vapor release can be categorized as the "disposal of radioactive waste in gaseous form," then the concentration would be below the concentration limit declared by the Nuclear Regulation Authority.	–	12	23	35	80	115	5	during treatment	–	0.4	2.3	20	58	80	180	63	243	24	1.56	349	land area: 2000	·Incinerator ash may be produced depending on components in the tritiated water.	·There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.	·The duration may be extended slightly since the release operation may need to be suspended due to precipitation.
	A3-②		0.5 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	0.5 million Bq/L			–	12	23	35	80	115	5	during treatment	–	0.4	2.3	20	58	80	180	63	243	24	1.56	349				
	A3-③		4.2 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	4.2 million Bq/L			–	12	23	35	40	75	5	during treatment	–	0.4	2.3	20	58	80	89	32	121	24	1.38	227				
	A3-④		0.5 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	0.5 million Bq/L			–	12	23	35	40	75	5	during treatment	–	0.4	2.3	20	58	80	89	32	121	24	1.38	227				
	A3-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	4.2 million Bq/L 0.5			–	12	23	35	80	115	5	during treatment	–	0.4	2.3	20	58	80	180	63	243	24	1.56	349				
	C3-①	separation	42,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	42,000 Bq/L	·Track records exist for evaporating water in a combustion furnace. (There is an example from TMI-2 of an evaporation method using a boiler.)			12	23	35 or duration for initiating separation	80	until initiating separation +80	5	during treatment		0.4	2.3	20	58	80	180	63	243	24	1.56	separation costs +349	land area: 2000+area for separation	·Incinerator ash may be produced depending on components in the tritiated water. ·Secondary waste may be produced depending on the separation technology.	·There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.	·The duration may be extended slightly since the release operation may need to be suspended due to precipitation.
	C3-②		5,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	5,000 Bq/L				12	23	35 or duration for initiating separation	80	until initiating separation +80	5	during treatment		0.4	2.3	20	58	80	180	63	243	24	1.56	separation costs +349				
	C3-③		42,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	42,000 Bq/L				12	23	35 or duration for initiating separation	40	until initiating separation +40	5	during treatment		0.4	2.3	20	58	80	89	32	121	24	1.38	separation costs +227				
	C3-④		5,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	5,000 Bq/L				12	23	35 or duration for initiating separation	40	until initiating separation +40	5	during treatment		0.4	2.3	20	58	80	89	32	121	24	1.38	separation costs +227				
	C3-⑤		42,000 Bq/L × 0.4 million m3 +5,000 Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	42,000 Bq/L 5,000 Bq/L				12	23	35 or duration for initiating separation	80	until initiating separation +80	5	during treatment		0.4	2.3	20	58	80	180	63	243	24	1.56	separation costs +349				
											12				0		during treatment						0			0		検討中					・降水条件によっては放出を停止しなければならない可能性があり、多少期間が延びる可能性がある。
											12				0		during treatment						0			0		検討中					
											12				0		during treatment						0			0		検討中					
											12				0		during treatment						0			0		検討中					
											12				0		during treatment						0			0		検討中					
hydrogen release	A4-①	none	4.2 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	4.2 million Bq/L	·Electrolyzing water and reducing it to hydrogen is possible from a technical standpoint. ·However, R&D concerning pre-treatment and scale enlargement, etc., may be necessary when the process involves actual tritiated water.	·If hydrogen release can be categorized as the "disposal of radioactive waste in gaseous form," then the concentration would be below the concentration limit declared by the Nuclear Regulation	–	12	23	35	66	101	5	during treatment	–	0.4	130			130	770	61	831	37	1.36	1,000	land area: 2000	·Secondary waste in the form of residue may be produced in the electrolysis pre-treatment step.	·There are no points to consider in particular since the height of the exhaust pipe will be sufficiently high.	·The duration may be extended slightly since the release operation may need to be suspended due to precipitation.
	A4-②		0.5 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	0.5 million Bq/L			–	12	23	35	66	101	5	during treatment	–	0.4	130			130	770	61	831	37	1.36	1,000				
	A4-③		4.2 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	4.2 million Bq/L			–	12	23	35	33	68	5	during treatment	–	0.4	130			130	400	31	431	37	1.23	600				
	A4-④		0.5 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	0.5 million Bq/L			–	12	23	35	33	68	5	during treatment	–	0.4	130			130	400	31	431	37	1.23	600				
	A4-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	4.2 million Bq/L 0.5			–	12	23	35	66	101	5	during treatment	–	0.4	130			130	770	61	831	37	1.36	1,000				
	C4-①		42,000 Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	42,000 Bq/L	·Electrolyzing water and reducing it to hydrogen is possible from a technical			12	23	35 or duration for initiating separation	66	until initiating separation +66	5	during treatment		0.4	130			130	770	61	831	37	1.36	separation costs +1000		·Secondary waste in the	·There are no points to consider in	
	C4-②		5,000 Bq/L	0.8 million m3	—	0.8 million m 400m3/day	5,000 Bq/L				12	23	35 or duration for initiating separation	66	until initiating separation +66	5	during treatment		0.4	130			130	770	61	831	37	1.36	separation costs +1000				

Treatment Method	No.	Pre-treatment	Concentration in Raw Water	Treated Raw Water Volume	Dilution Factor	Top: Total Volume Treated Bottom: Treatment Capacity	Treated Concentration	Basic Requirements: Technical Feasibility	Basic Requirements: Regulatory Feasibility	Duration (Months) – Duration Until Completion – Duration Until Initiation: Separation	Duration Until Initiation: Exploration	Duration Until Initiation: Design + Construction	Duration Until Initiation: Total	Treatment	Duration Until Completion: Total	Dismantling	Monitoring	Costs (100 million yen): Separation	Exploration	Design & Construction: Design	Design & Construction: Machinery Expenses	Design & Construction: Site Construction Expenses	Design & Construction: Subtotal	Treatment: Utilities	Treatment: Personnel and Other Expenses, etc.	Treatment: Subtotal	Dismantling	Monitoring	Total	Scale (Area) (m2)	Secondary Waste	Worker Radiation Exposure	Associated Conditions
	C4-③	separation	42,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	42,000 Bq/L	standpoint. ・However, R&D concerning pre-treatment and scale enlargement, etc., may be necessary when the process involves actual tritiated water.	Authority.		12	23	35 or duration for initiating separation	33	until initiating separation +33	5	during treatment		0.4	130			130	400	31	431	37	1.23	separation costs +600	land area: 2000+area for separation	form of residue may be produced in the electrolysis pre-treatment step.	particular since the height of the exhaust pipe will be sufficiently high.	・The duration may be extended slightly since the release operation may need to be suspended due to precipitation.
	C4-④		5,000 Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	5,000 Bq/L				12	23	35 or duration for initiating separation	33	until initiating separation +33	5	during treatment		0.4	130			130	400	31	431	37	1.23	separation costs +600				
	C4-⑤		42,000 Bq/L × 0.4 million m3 +5,000 Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	42,000 Bq/L 5,000 Bq/L				12	23	35 or duration for initiating separation	66	until initiating separation +66	5	during treatment		0.4	130			130	770	61	831	37	1.36	separation costs +1000				

Treatment Method	No.	Pre-treatment	Concentration in Raw Water	Treated Raw Water Volume	Dilution Factor	Top: Total Volume Treated Bottom: Treatment Capacity	Treated Concentration	Basic Requirements: Technical Feasibility	Basic Requirements: Regulatory Feasibility
under-ground burial (below ground-water level)	A5a-①	none	4.2 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	4.2 million Bq/L	･Track records exist for concrete pit disposal sites and isolated-type disposal sites.	･Since the waste is not entrapped or solidified in a container, it cannot be categorized as the “waste substance” in the “Rule for Disposal of Category 2 Waste Disposal of Nuclear Fuel Material or Material Contaminated with Nuclear Fuel Material.” ･If the solidification which is a mixture of tritiated water and cement can be categorized as the “waste such as concrete” in the abovementioned regulations, it may be necessary to independently formulate new standards since there are no examples of using a pit to dispose of tritiated water in the form of a concrete
	A5a-②		0.5 million Bq/L	0.8 million m3	—	0.8 million m 400m3/day	0.5 million Bq/L		
	A5a-③		4.2 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	4.2 million Bq/L		
	A5a-④		0.5 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	0.5 million Bq/L		
	A5a-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	4.2 million Bq/L 0.5		
under-ground burial (above ground-water level)	A5b-①	none	4.2 million Bq/L	0.8 million m3	—	0.8 million m3 400m3/day	4.2 million Bq/L		
	A5b-②		0.5 million Bq/L	0.8 million m3	—	0.8 million m 400m3/day	0.5 million Bq/L		
	A5b-③		4.2 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	4.2 million Bq/L		
	A5b-④		0.5 million Bq/L	0.4 million m3	—	0.4 million m3 400m3/day	0.5 million Bq/L		
	A5b-⑤		4.2 million Bq/L × 0.4 million m3 +0.5 million Bq/L × 0.4 million m3		—	0.8 million m3 400m3/day	4.2 million Bq/L 0.5		

No.	Potentially Restricting Conditions: Duration (Months)								Costs (100 million yen)											
	Duration Until Completion						Dismantling	Monitoring	Separation	Exploration	Design & Construction				Treatment			Dismantling	Monitoring	Total
	Duration Until Initiation				Treatment	Total					Design	Machinery Expenses	Site Construction Expenses	Subtotal	Utilities	Personnel and Other Expenses, etc.	Subtotal			
	Separation	Exploration	Design + Construction	Total																
A5a-①	–	12	14	26	72	98	0	912	–	1	25	4.3	2,500	2,529	included in construction expenses			0	2.20	2,533
A5a-②	–	12	14	26	72	98	0	456	–	1	22	4.3	2,200	2,226				0	1.84	2,229
A5a-③	–	12	14	26	36	62	0	912	–	1	13	4.3	1,300	1,317				0	2.09	1,320
A5a-④	–	12	14	26	36	62	0	456	–	1	12	4.3	1,200	1,216				0	1.73	1,219
A5a-⑤	–	12	14	26	72	98	0	912	–	1	23	4.3	2,400	2,427				0	2.20	2,431
A5b-①	–	12	14	26	72	98	0	912	–	1	16	4.3	1,600	1,620	included in construction expenses			0	2.20	1,624
A5b-②	–	12	14	26	72	98	0	456	–	1	15	4.3	1,500	1,519				0	1.84	1,522
A5b-③	–	12	14	26	36	62	0	912	–	1	8.1	4.3	790	802				0	2.09	805
A5b-④	–	12	14	26	36	62	0	456	–	1	7.6	4.3	730	742				0	1.73	745
A5b-⑤	–	12	14	26	72	98	0	912	–	1	15	4.3	1,500	1,519				0	2.20	1,523

No.	Scale (Area) (m2)	Secondary Waste	Worker Radiation Exposure	Associated Conditions	
A5a-①	land area: 285,000	･None in particular	･Since tritiated water may evaporate from the cement during the burial operation, which would create a tritium atmosphere in the work environment and pose the risk of radiation exposure via inhalation, evaporation will be deterred by installing a cover, etc.	･The concrete and bentonite listed in the cell on the right are required. ･The construction spoil listed in the cell on the right will be produced.	concrete: 420,000m3 bentonite: 1.23 million m3 construction spoil: 3.48 million m3 cement-based solidifying agent: 1.6 million t
A5a-②	land area: 285,000				concrete: 420,000m3 bentonite: 610,000m3 construction spoil: 2.86 million m3 cement-based solidifying agent: 1.6 million t
A5a-③	land area: 144,000				concrete: 230,000m3 bentonite: 630,000m3 construction spoil: 1.78 million m3 cement-based solidifying agent: 0.8 million t
A5a-④	land area: 144,000				concrete: 230,000m3 bentonite: 310,000m3 construction spoil: 1.46 million m3 cement-based solidifying agent: 0.8 million t
A5a-⑤	land area: 285,000				concrete: 420,000m3 bentonite: 920,000m3 construction spoil: 3.18 million m3 cement-based solidifying agent: 1.6 million t
A5b-①	land area: 285,000			･The concrete and bentonite listed in the cell on the right are required.	concrete: 420,000m3 bentonite: 690,000m3 cement-based solidifying agent: 1.6 million t
A5b-②	land area: 285,000				concrete: 420,000m3 bentonite: 350,000m3 cement-based solidifying agent: 1.6 million t
A5b-③	land area: 144,000				concrete: 240,000m3 bentonite: 360,000 m3 cement-based solidifying agent: 0.8 million t
A5b-④	land area: 144,000				concrete: 240,000m3 bentonite: 180,000m3 cement-based solidifying agent: 0.8 million t
A5b-⑤	land area: 285,000				concrete: 420,000m3 bentonite: 520,000m3 cement-based solidifying agent: 1.6 million t

*1: In light of the assessment from Appendix 4, the fields regarding separation technology have been left blank since the technologies are difficult to analyze.
*2: It must be noted that costs associated with on-site work (exploration, site construction expenses, personnel and other expenses, and dismantling) may increase due to the work environment (spatial radiation dosage ratios, work space, and coordination between associated construction works, etc.)
*3: It must be noted that the durations and costs were calculated on the grounds that work would be done off site from the nuclear power plant, and factors unique to the nuclear power plant site have not been taken into consideration.
*4: It must be noted that the costs for decontaminating and disposing of waste from dismantling are not included in the dismantling costs.
*5: In the treatment costs, the treated raw water volume of 0.8 million m3 was calculated using the annual running costs x 5.5 years (800,000 ÷ 400 ÷ 365). The treated raw water volume of 0.4 million m3 was calculated using the annual running costs x 2.8 years (400,000 ÷ 400 ÷ 365).
The vapor release scenario is formulated on the assumption of operating 300 days per year. The treated raw water volume of 0.8 million m3 was calculated using the annual running costs x 6.7 years (800,000 ÷ 400 ÷ 300), and the treated raw water volume of 0.4 million m3 was calculated using the annual running costs x 3.4 years (400,000 ÷ 400 ÷