(The 1st) 1F Technical Meeting

Material 1-2

Supplementary explanation on conformity to the Items required for Measures which should be taken at Tokyo Electric Power Co., Inc.'s Fukushima Daiichi Nuclear Power Station in line with the Designation as the Specified Nuclear Facility
(Operation structure for the discharge of ALPS treated water into the sea and selection of nuclides to be measured and assessed)

November 2022

Tokyo Electric Power Company Holdings, Inc.

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The Japanese version shall prevail.

Chapter 1　Security of the Specified Nuclear Facility

1.1 Conformity to the items required for measures which should be taken for security of the Specified Nuclear Facility

Items required for Measures which should be taken at Tokyo Electric Power Co., Inc.'s Fukushima Daiichi Nuclear Power Station in line with the Designation as the Specified Nuclear Facility (November 7, 2012, Decision of NRA Commission)
(Hereinafter referred to as "items required for measures.")

III. Items concerning Measures Taken for Security of the Specified Nuclear Facility

By taking appropriate measures such as operation management, maintenance management, radiation control, radioactive waste management, emergency measure and on-site and off-site environmental radiation monitoring, etc., "II. Items concerning Measures to be taken for Design and Facilities" shall be ensured to be appropriately and reliably implemented, and workers' and on-site and off-site safety shall be ensured.
Particularly, with regard to emergency measures during accident or disaster, systems for communication with organizations concerned and medical care in emergency shall be developed in addition to responses to emergency situation.
In addition, education and training shall be appropriately conducted for employees and workers including those of contracted and subcontracted companies to maintain and improve their skill and capability.

1.1 Policy to ensure conformity to items required for measures

For ALPS treated water dilution/discharge facilities and related facilities, appropriate measures such as operation control, maintenance management, radiation control, radioactive waste management, emergency measures and on-site and off-site environmental radiation monitoring, etc., will be implemented appropriately and reliably to ensure "II. Items concerning Measures to be taken for Design and Facilities" and to secure the safety of workers in and outside the premises.

1.2 Response policy

1.2.1 Operation structure for the discharge of ALPS treated water into the sea

Among the duties for the security of the ALPS treated water dilution/discharge facilities and related facility, the FDNPS organization performs the following duties. The designing, construction, installation and maintenance to ensure integrity are performed based on the Facility Management Plan.

(1) The ALPS treated water Program Department performs duties on the planning and management of , and study for the operation method of facilities related to the discharge of the water which have been purified by Advance Liquid Processing System, etc., and whose sum of ratios to regulatory concentration limit of radioactive materials other than tritium is less than 1 (hereinafter, referred to as ALPS treated water), the planning of operation for ALPS treated water dilution/ discharge facility, and the duties on the design and construction/ installation of the mechanical and civil engineering SSCs related to those, among the safety assurance facilities of the Units 1 to 4. In addition, the Department performs duties on planning ALPS treated water analyses.

(2) The Electrical Engineering Group performs duties on the design of electrical SSCs (excluding the duties performed by the Power Distribution and Electrical Circuit Group Manager.).

(3) The Instrumentation Engineering Group performs duties on the design of instrumentation SSCs.

(4) The Architectural Construction Engineering Group performs duties on the design of new buildings.

(5) The Operation Shift Team (Water treatment System) performs duties on the operation management of contaminated water treatment facilities, buildings that store accumulated water, Advance Liquid Processing Systems, sub-drain etc. treatment facility (excluding groundwater drain collection facility,) and the ALPS treated water dilution/ discharge facility among the safety assurance facilities of the Units 1 to 4 (excluding the duties performed by the Operation Support Group Manager, the Work Management Group Manager and the Water Treatment Planning Group Manager.)

(6) The Operation Support Group performs duties on the part of the operation management, such as making manual and procedure and the facility management, of the common spent fuel pool facility and the radioactive solid management facility and related facility (excluding miscellaneous solid waste incineration facility and additional miscellaneous solid waste incineration facility) among the safety assurance facilities of the Units 1 to 4, the Units 5/6 and the others. In addition, the Group performs duties on the operation of water injection facility for RPV/ PCV (filtrate tanks, pure water tanks and raw water underground tanks) among the safety assurance facilities of the Units 1 to 4, and the radioactive solid management facility and related facility (miscellaneous solid waste incineration facility and additional miscellaneous solid waste incineration facility), large equipment decontamination facility and volume reduction facility among the safety assurance facilities of the others.

(7) The Water Storage Facility Group performs duties on the maintenance management of civil engineering SSCs of contaminated water treatment facilities (water storage facility) and mechanical SSCs of the ALPS treated water dilution/ discharge facility, and the construction/ installation and maintenance management of contaminated water treatment facilities (auxiliary facility of the water storage facility) and rain water treatment facility among the safety assurance facilities of the Units 1 to 4.

(8) The Electrical Maintenance Group performs duties on the maintenance management of electrical SSCs and operation and maintenance management of power supply vehicles (excluding the duties performed by the Power Distribution and Electrical Circuit Group Manager and the Electrical Facility Construction Group Manager.)

(9) The Electrical Facility Construction Group performs duties on the construction/ installation management of electrical SSCs (excluding the duties performed by the Power Distribution and Electrical Circuit Group Manager and the Electrical Facility Construction Group Manager.)

(10) The Water Treatment Instrumentation Group performs duties on the construction/ installation and maintenance management of instrumentation SSCs of contaminated water treatment facilities, buildings that store accumulated water, Advance Liquid Processing Systems, sub-drain etc. treatment facility, oil treatment facility, water intake facility from Unit 3 PCV and the ALPS treated water dilution/ discharge facility among the safety assurance facilities of the Units 1 to 4, temporary facilities for Units 5/6 (accumulated water storage facility) among the safety assurance facilities of the Units 5/6, and the radioactive solid management facility and related facility, radioactive material analysis/ research center laboratory-1, large equipment decontamination facility and volume reduction facility among the safety assurance facilities of the others.

(11) The Civil Infrastructure Group performs duties on the construction/ installation and maintenance management of civil engineering SSCs (excluding the duties performed by the general manager of each program department and group manager of each group other than the Civil Infrastructure Group Manager.).

(12) The Architectural Facility Maintenance Group performs duties on the maintenance management of buildings (excluding the duties performed by the general manager of each program department and group manager of each group other than the Architectural Facility Group Manager.) In addition, the group performs duties on the maintenance management of electrical SSCs of large equipment decontamination facility among the safety assurance facilities of the others.

(13) The Architectural Facility Construction Group performs duties on the construction/ installation management of buildings (excluding the duties performed by the general manager of each program department and group manager of each group other than the Architectural Facility Construction Group Manager.)

(14) The Release and Environment Monitoring Group performs duties on on-site and off-site land and sea area environmental monitoring among radiation control, and liquid waste discharge control and measurement and release management of gaseous waste from Units 1 to 4 reactors, and radioactive gaseous waste release management from Units 5 and 6 among radioactive waste management.

(15) The Chemical Analysis & Evaluation Group carries performs duties on the operation of analysis facilities, management of radiation and chemical analysis equipment, operation and maintenance management of radioactive material analysis/ research center laboratory-1, and analysis/data assessment.

1.2.2 Selection of nuclides to be measured and evaluated at the discharge of ALPS treated water to the sea

(1) Overview

With regard to radionuclides other than tritium in ALPS treated water, the result of the analysis of the radioactivity concentrations of the seven major nuclides* plus carbon 14 and technetium 99 in ALPS treated water, and the measured value of gross β shows no discrepancies that would raise suspicion regarding radionuclides except for radionuclides of the current 64 nuclides. In addition, some of the nuclides subject to removal by ALPS will be considered sufficiently decayed and become less abundant by the time of the discharge of ALPS treated water into the sea. Therefore, the sum of the ratios to regulatory concentration limits is considered to satisfy less than 1.

In order to ensure that the sum of the ratios to regulatory concentration limits is less than 1, target nuclides to be measured and assessed (hereinafter "nuclides to be measured and assessed") are selected after thorough verification whether they are significantly present in contaminated water based on domestic knowledge of decommissioning and disposal facilities.

Given that, in order to ensure the sum of the ratios to regulatory concentration limits of less than 1, thorough verifications will be performed, while taking into account previous studies on decommissioning and burial facilities in Japan, to check for significant presence of nuclides in the contaminated water. Then radionuclides to be measured and assessed (hereinafter referred to as nuclides to be measured and assessed) will be selected.

*: ALPS has a processing performance that can remove 62 nuclides until the sum of the ratios to regulatory concentration limits becomes below 1. Even so, since it would take a long time to analyze all of the 62 nuclides, it was necessary to select representative nuclides to confirm the performance of ALPS and to understand the concentration of nuclides contained in tanks without causing a delay in the decommissioning work. At that time, 62 nuclides in the treated water were analyzed, and the 7 nuclides that were detected at significant concentrations compared to the regulatory concentration limits are called major 7 nuclides (Cs-134, Cs-137, Sr-90, I-129, Co-60, Sb-125, Ru-106).

(2) Policy on the selection of nuclides to be measured and assessed

For verification of nuclides which have possibility to be significantly contained in contaminated water at FDNPS, nuclide analyses are conducted based on the domestic knowledge on decommissioning and disposal facilities, and inventory assessments are conducted.

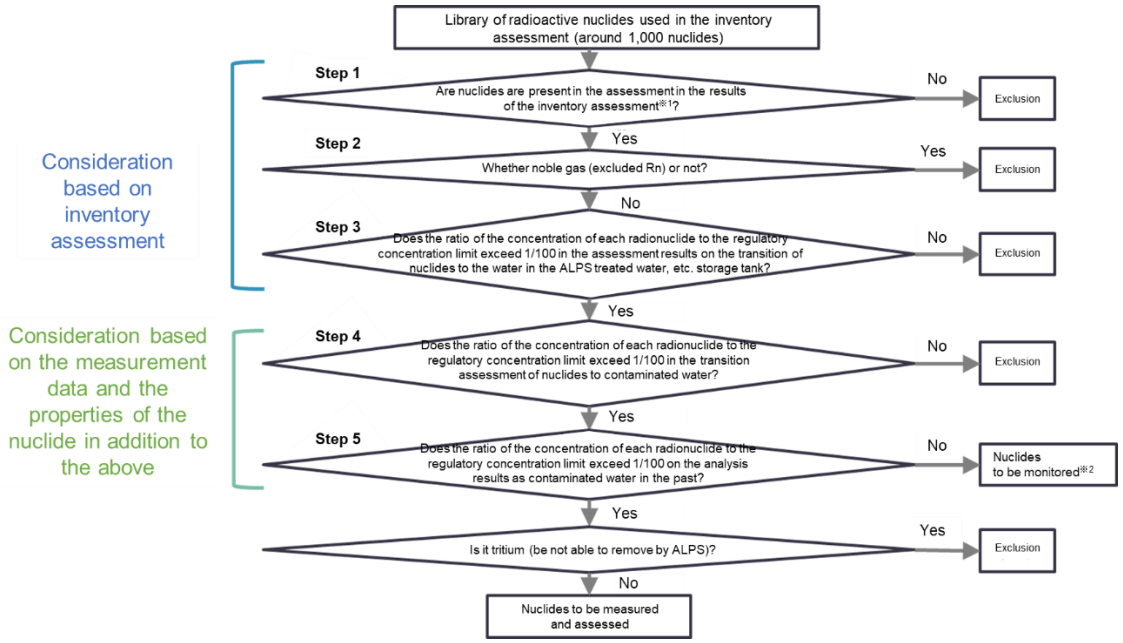
Nuclide analysis
Verify whether or not the nuclides to be assessed in the research on decommissioning and disposal facilities are also significantly present in contaminated water by actual analysis of water. Also verify the results of past nuclide analyses.
Inventory assessment
Assess an inventory of fission products in the same way as in the study of nuclides subject to removal by ALPS. Assess the inventory quantity generated by activation of such as structures in reactor pressure vessel based on the studies on decommissioning and disposal facilities. In the above assessments, taken into account the reduction of inventory quantity due to decay as the12 years have passed since the earthquake until discharge. Based on the above assessment results, verify the existence of nuclides that may be significantly contained in contaminated water, taking into account such as the ease of transfer to water.

Based on the results of nuclide analysis and inventory assessment, the nuclides to be measured and assessed are selected, taking into account the impacts on dose assessment.

(3) Selection of nuclides to be measured and assessed at the time of the discharge of ALPS treated water into the sea

a. Rational behind the selection of nuclides subject to be measured and assessed for discharge of ALPS treated water into the sea

Based on the results of nuclide analysis and inventory assessment in section (2), the nuclides to be measured and assessed are selected according to the flowchart, shown in Figure-1.1-1



*1: The decay period of the inventory evaluation is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))

*2: Nuclides were continuously confirmed whether are significantly presence in contaminated water.

Figure 1.1-1 Flow for selecting nuclides to be measured and evaluated at the discharge of ALPS treated water to the sea

b. Confirmation of discharge criterion

Before discharging ALPS treated water into the sea, it will be confirmed that the nuclides selected for measurement and assessment based on the flowchart in Figure-1.1-1 satisfy the discharge criteria (sum of the ratios to regulatory concentration limit of nuclides other than tritium is less than 1.)

c. Regular confirmation of nuclides to be measured and assessed

These nuclides to be measured and assessed are selected based on the flowchart in Figure-1.1-1. However, there is a possibility that the situation may change depending on the progress of the decommissioning work in the future. Therefore, the following methods are used to confirm that there are no significant nuclides other than the selected nuclides to be measured and assessed (hereinafter "other nuclides"). If it is confirmed that other nuclides are significantly present during this confirmation process, re-assessment of the nuclides to be measured and assessed will be performed. The decay of radionuclides will be also reflected in the selection flowchart.

(a) Confirmation of each discharge

When confirming that ALPS treated water meets the discharge limit, also confirm that no other nuclides are present significantly by measuring with gross α, gross β, and Ge semi-conductor detectors.

(b) Trend confirmation in contaminated water

Confirm that concentrations of radionuclides, regularly checked in contaminated water of downstream from the centralized radioactive waste building, are below the previously confirmed concentration and there is no change in the status of the transfer of radionuclides to contaminated water.

(c) Investigation analysis

The existence of other nuclides is investigated when the event with concern is confirmed in the sections (a) and (b). Even if such concerns are dispelled, check the presence of the nuclides subject to be monitored in contaminated water prior to ALPS treatment at a frequency of once a year in order to investigate the presence of other nuclides.

Attachment-1

Supplementary explanation on the change in operation system for the discharge of ALPS treated water into the sea

1. Overview

When the application for the change to the Implementation Plan concerning the establishment of the ALPS Treated Water Program Department was filed, it was planned to submit a separate application regarding the operation system for the running and maintenance of the ALPS treated water discharge. This time, the system has been concretized, and the details of the change are explained herein. Figure 1.1.1-1 shows the scope of the last application for the Implementation Plan and that of the application this time.

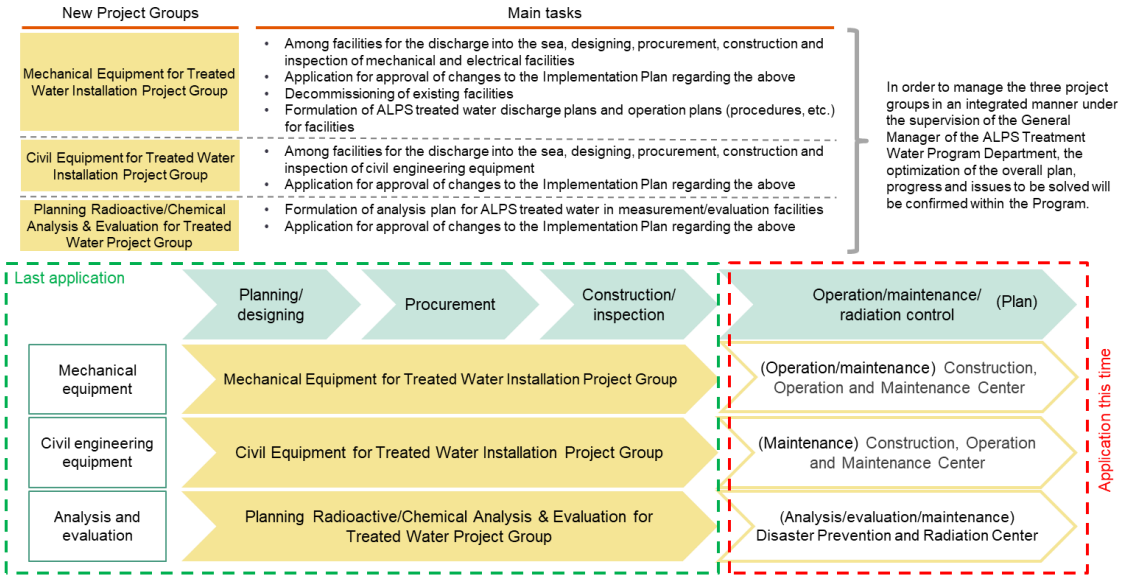


Figure 1.1.1-1 Organizations responsible for the discharge of ALPS treated water into the sea

2. Organizations responsible for the discharge of ALPS treated water into the sea

2.1 Designing, construction/installation, maintenance management system

As for designing, construction, and installation of the ALPS treated water dilution/discharge facilities and related facilities, the ALPS Treated Water Program Department had been in charge of the management of projects (process management, budgetary management, and risk management). The ALPS Treated Water Program Department had also been responsible for daily tasks associated with mechanical equipment and civil engineering equipment. Other daily tasks associated with electrical equipment, instrumentation and construction facilities had been entrusted to the Planning and Design Center and the Design, Operation and Maintenance Center.

After the start of operation, the maintenance management of facilities will be performed by the Design, Operation and Maintenance Center as shown in Table 1.1.1-1.

Table 1.1.1-1 Organizations responsible for the designing, construction/installation, and maintenance management of ALPS treated water dilution/discharge facilities and related facilities

Facilities	Last application		Application this time
	Designing	construction and installation	Maintenance management
Mechanical equipment	ALPS Treated Water Program Department		Water Storage Facility Group
Civil engineering equipment (including discharge facilities)	ALPS Treated Water Program Department		Civil Infrastructure Group
Electrical facilities	Electrical Engineering Group	Electrical Facility Construction Group	Electrical Maintenance Group
Instrumentation	Instrumentation Engineering Group	Water Treatment Instrumentation Group	Water Treatment Instrumentation Group
Construction facilities	Architectural Facility Engineering Group	Architectural Facility Construction Group	Architectural Facility Maintenance Group

*: The sections written in red are the changes to the Implementation Plan for which the application was filed this time.

2.2 Facility operation control system

As for the operation control of the ALPS treated water dilution/discharge facilities, the ALPS Treated Water Program Division reviews the operation method at present. Once the operation starts, the Design, Operation and Maintenance Center will take charge of the operation control as shown in Table 1.1.1-2 and the ALPS Treated Water Program Division the planning of operation.

Table 1.1.1-2 Organizations responsible for operation control of ALPS treated water dilution/discharge facilities

Tasks	Last application	Application this time
	Design stage	After the start of operation
Review of operation methods	ALPS Treated Water Program Department	
Operation control	-	Shift Team for Water Treatment
Among operation control tasks, tasks associated with manuals and procedures	-	Operation Support Group
Operation plan	-	ALPS Treated Water Program Department

*: The sections written in red are the changes to the Implementation Plan for which the application was filed this time.

2.3　Tasks associated with analyses for the discharge of ALPS treated water into the sea

As for tasks associated with analyses for the discharge of ALPS treated water into the sea, the ALPS Treated Water Program Division is in charge of planning of analyses at present. Once the operation starts, as is the case with tasks associated with other analyses, the Disaster Prevention and Radiation Center will take charge of the analysis/data evaluation, discharge control of liquid waste, etc. as shown in Table 1.1.1-3.

Table 1.1.1-3 Organizations responsible for the analysis of ALPS treated water

Tasks	Last application	Application this time
	Planning stage	After the start of operation
Analysis plan	ALPS Treated Water Program Department	
Analysis/data evaluation	-	Chemical Analysis & Evaluation Group
Discharge control of liquid waste, etc.	-	Release and Environment Monitoring Group

Attachment-2

Supplementary explanation on the nuclide analysis in the examination of nuclides to be measured and assessed at the discharge of ALPS treated water into the sea

1. Overview

In order to ensure that the sum of the ratios to regulatory concentration limits of radionuclides other than tritium in ALPS treated water is less than 1, thorough verifications will be performed, while taking into account previous studies on decommissioning and burial facilities in Japan, to check for significant presence of nuclides in the contaminated water. Then radionuclides to be measured and assessed (hereinafter referred to as nuclides to be measured and assessed) will be selected.
The examination will be carried out in accordance with the flow explained at the 9th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water (See Figure 1.1.2-1), and a nuclide analysis and inventory assessment are planned to be performed. This document supplements the explanation about the nuclide analysis.

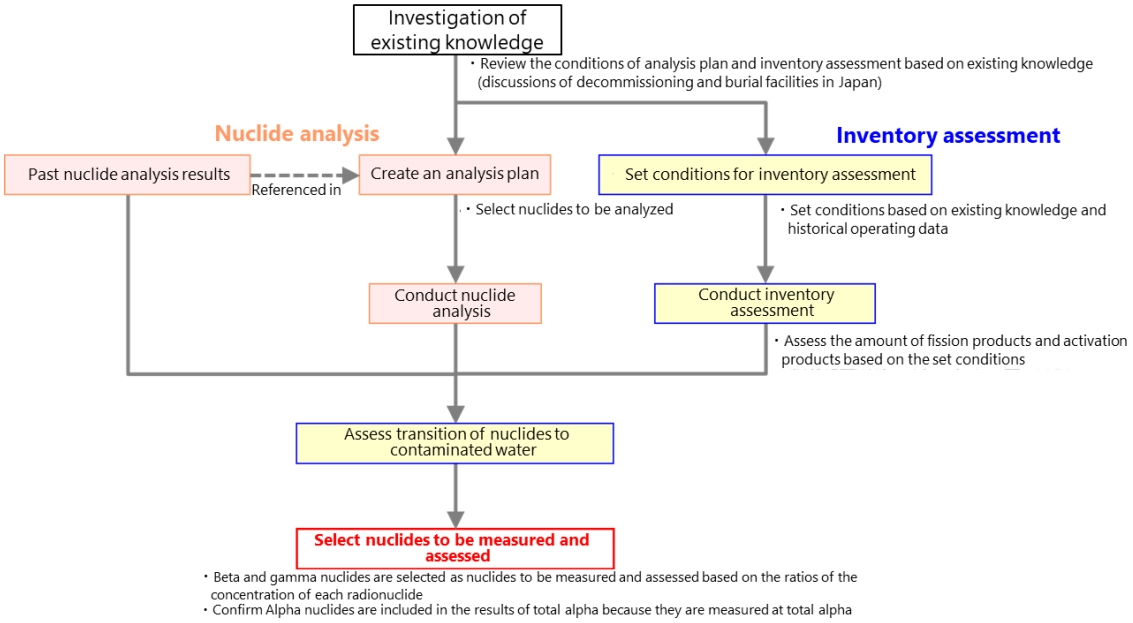


Figure 1.1.2-1 Overall procedure for examining the selection of the nuclides to be measured and evaluated
[Excerpt from a document for the 9th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water (partially revised)]

The Japanese version shall prevail.

2. Nuclide analysis

2.1 Survey of past analysis results

[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022)]

So far, JAEA and TEPCO have analyzed 20 nuclides except for the nuclides (62 nuclides) to be removed by ALPS, tritium, and C-14 as shown in Table 1.1.2-1.

A nuclide analysis plan has been laid out for examining the selection of nuclides to be measured and evaluated, and in developing this plan, the results of past analyses were taken into account as well as previous studies to select nuclides subject to the nuclide analysis (hereinafter referred to as "nuclides to be analyzed").

Table 1.1.2-1 List of nuclides analyzed in the past

Fission products (56 nuclides)						
Rb-86	Sr-89	Sr-90	Y-90	Y-91	Nb-95	Tc-99
Ru-103	Ru-106	Rh-103m	Rh-106	Ag-110m	Cd-113m	Cd-115m
Sn-119m	Sn-123	Sn-126	Sb-124	Sb-125	Te-123m	Te-125m
Te-127	Te-127m	Te-129	Te-129m	I-129	Cs-134	Cs-135
Cs-136	Cs-137	Ba-137m	Ba-140	Ce-141	Ce-144	Pr-144
Pr-144m	Pm-146	Pm-147	Pm-148	Pm-148m	Sm-151	Eu-152
Eu-154	Eu-155	Gd-153	Tb-160	Pu-238	Pu-239	Pu-240
Pu-241	Am-241	Am-242m	Am-243	Cm-242	Cm-243	Cm-244
Corrosion products (6 nuclides)						
Mn-54	Fe-59	Co-58	Co-60	Ni-63	Zn-65	
Nuclides other than the above (2 nuclides)						
H-3	C-14					
Nuclides other than the 64 nuclides (20 nuclides)						
Cl-36	Ca-41	Ni-59	Se-79	Nb-94	Mo-99	Tc-99m
Te-132	I-131	I-132	La-140	U-233	U-234	U-235
U-236	U-238	Np-237	Pu-242	Cm-245	Cm-246	

2.2 Previous studies used in developing the analysis plan

[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022)]

To develop the nuclide analysis plan, the nuclides to be analyzed were selected from the nuclides pointed out in previous studies, which are shown below, according to the following conditions.

- Nuclides that have not been analyzed in the past or have not been analyzed sufficiently
- Nuclides that were not studied at the time of selecting nuclides to be removed by ALPS
- β and γ nuclides which, according to previous studies, exist in reactor water as activation products at a concentration 1/100 or more of the concentration of Co-60 in stagnant water
- α nuclides except nuclides whose concentration can be evaluated by decay chain.

Even when nuclides fall under the above conditions, if they have a half-life of less than 1 year and reduced to about 1/1000 or less due to attenuation over 12 years up to discharge, those nuclides were excluded. On the other hand, even when nuclides do not fall under the above conditions, if it is possible to analyze them at external analysis organizations, some of them were included in the plan.

[Previous studies]

(1) Joint Electric Power Research Project "Study related to decommissioning of BWR nuclear reactor (Part 2)" (FY 1996)

(2) Tokai low-level radioactive waste burial facility, Type II waste disposal business license application "selection of major radioactive nuclides" (February 2018, Japan Atomic Power Company)

(3) Study data when JAEA examined nuclides to be analyzed to grasp 1F radioactive waste physical properties

- The upper three orders of magnitude for the nuclides with the highest relative importance D/C among the nuclides included in either the nuclear reactor waste or the cycle waste targeting trench disposal, pit disposal, and surplus depth disposal in "about the upper limit of activity concentration for burial disposal of low-level radioactive waste"
- Those selected as important nuclides in the "TRU waste disposal technology review report - second TRU waste disposal research and development report"
- Those selected as important nuclides in “technical reliability of geological disposal of high-level radioactive waste in Japan - second summary of research and development on geological disposal - general report”
- “Application for burying business license for Japan Nuclear Fuel Rokkasho low level radioactive waste storage center (near surface pit disposal) and JPDR (near surface trench disposal)”

2.3 Nuclides to be analyzed that have been identified based on previous studies (β and γ nuclides, etc.)

[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022) (The measuring method revised)]

Based on the previous studies in paragraph 2.2, β, γ and other nuclides to be analyzed were identified as shown in Table 1.1.2-2.
Since it is currently difficult for TEPCO to measure the identified nuclides on their own, the measurement is planned to be commissioned to an external organization.
Table 1.1.2-2 shows that the identified nuclides' energy is generally lower than that of the nuclides that are representative at Fukushima Daiichi NPS: Cs-137 (Ba-137 m), 0.662 MeV (γ-rays); Sr-90 (Y-90), 2.28 MeV (β-rays).

Table 1.1.2-2 Nuclides to be analyzed that have been identified based on previous studies (β and γ nuclides, etc.)

Candidate nuclides	Previous studies*1	Disintegration form	Energy [MeV]	Regulatory concentration limit [Bq/cm^3]	Measuring method	Remarks
Cl-36	[1] [2] [3]	β-	0.709550	9.0E-01	After pretreatment (separation, precipitation), a low-background β-ray spectrometer	Has ever been analyzed by an external organization
Se-79	[1][3]	β-	0.150630	2.0E-01	After pretreatment (separation, precipitation, and resolution), liquid scintillation counter	Has ever been analyzed by an external organization
Zr-93	[1] [2] [3]	β-	0.090800	1.0E+00	After pretreatment (separation), inductively coupled plasma mass spectrometer (ICP-MS)	—
Pd-107	[3]	β-	0.034000	2.0E+01		—
Ca-41	[1] [2] [3]	EC	0.003310	4.0E+00	After pretreatment (separation, precipitation, and resolution), Si (Li) detector	Has ever been analyzed by an external organization
Fe-55	[1][2]	EC	0.005900	2.0E+00	After pretreatment (separation), low-energy photon measuring device (LEPS)	—
Ni-59	[1] [2] [3]	EC	0.006930	1.0E+01		—
Nb-93m	[2]	IT	0.016615	7.0E+00		—
Mo-93	[1] [2] [3]	EC	0.016615	3.0E-01		—
Sn-121m	[3]*2	β- IT	0.359800 0.026359	2.0E+00		—
Ba-133	[1][2]	EC	0.356013	5.0E-01	Germanium semiconductor detector (Ge)	—

*1: Refer to the numbers in 2.2 "Previous studies."
*2: Selected because the study shows the nuclide is generated the most among Sn isotopes from zircaloy contained in cladding tubes, etc.

2.4 Nuclides to be analyzed that have been identified based on previous studies (α nuclides)

[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022) (Remarks revised)]

Based on the previous studies in paragraph 2.2, α nuclides to be analyzed were identified as shown in Table 1.1.2-3.

Since it is currently difficult for TEPCO to measure the identified nuclides on their own, the measurement is planned to be commissioned to an external organization.

The following nuclides were analyzed to identify α nuclides that may be contained in building stagnant water at significant concentrations.

Table 1.1.2-3 Nuclides to be analyzed that have been identified based on previous studies (α nuclides)

Candidate nuclides	Previous studies*1	Disintegration form	Energy [MeV]	Regulatory concentration limit [Bq/cm^3]	Half-life [y]	Measuring method	Remarks
U-233	[3]	α	4.824200	2.0E-02	1.6E+05	After pretreatment (separation), inductively coupled plasma mass spectrometer (ICP-MS)	Has ever been analyzed by an external organization
U-234	[1][3]	α	4.774600	2.0E-02	2.5E+05		Has ever been analyzed by an external organization
U-235	[1][3]	α	4.395400	2.0E-02	7.0E+08		Has ever been analyzed by an external organization
U-236	[1][3]	α	4.494000	2.0E-02	2.3E+07		Has ever been analyzed by an external organization
U-238	[1][3]	α	4.198000	2.0E-02	4.5E+09		Has ever been analyzed by an external organization
Np-237	[1][3]	α	4.788000	9.0E-03	2.1E+06		Has ever been analyzed by an external organization
Pu-238	[1] [2] [3]	α	5.499030	4.0E-03	8.8E+01	After pretreatment (separation), α-spectrometer	Pu-238 to Pu-241 are nuclides to be removed by ALPS. The concentration of Pu-241 was estimated using an isotope.
Pu-239	[1] [2] [3]	α	5.156590	4.0E-03	2.4E+04		
Pu-240	[1] [2] [3]	α	5.168170	4.0E-03	6.6E+03		
Pu-241	[1] [2] [3]	β-	0.020780	2.0E-01	1.4E+01	—	
Pu-242	[1][3]	α	4.902300	4.0E-03	3.8E+05	After pretreatment (separation), α-spectrometer	Has ever been analyzed by an external organization
Am-241	[1] [2] [3]	α	5.485560	5.0E-03	4.3E+02		Am-241 to Am-243 are nuclides to be removed by ALPS. The concentration of Am-242m was estimated using an isotope.
Am-242m	[1][3]	IT	0.018856	5.0E-03	1.4E+02	—	
Am-243	[1][3]	α	5.275300	5.0E-03	7.4E+03	After pretreatment (separation), α-spectrometer	
Cm-242	[3]	α	6.112720	6.0E-02	4.5E-01		Cm 242 to Cm-234 are nuclides to be removed by ALPS. Cm-243 and Cm-244, and Cm-245 and Cm-246 were measured as combined values as their energies are close to each other. Cm-245 and Cm-246 have ever been analyzed by an external organization.
Cm-243	[3]	α	5.785200	6.0E-03	2.9E+01		
Cm-244	[1][3]	α	5.804770	7.0E-03	1.8E+01		
Cm-245	[3]	α	5.361100	5.0E-03	8.4E+03		
Cm-246	[3]	α	5.386500	5.0E-03	4.7E+03		

*1: Refer to the numbers in 2.2 "Previous studies."

2.5　Analysis result of nuclides to be analyzed

The nuclides to be analyzed which have been identified in paragraph 2.3 through 2.4 were checked to see if they exist in building stagnant water, strontium treated water and ALPS treated water at significant concentrations.

As a result, some of them were detected in building stagnant water and water before treatment by ALPS, but nuclides (including α nuclides) pointed out in previous studies were not detected* in ALPS treated water.

*: Less than detection limit of 1/100 of the regulatory concentration limits; as uranium, natural uranium in the environment was detected.

(1)　ALPS treated water, etc. analysis results (β and γ nuclides, etc.)

Table 1.1.2-4 shows the analysis results of β and γ nuclides in ALPS treated water, etc.

Since the presence of suspended mattes was visually confirmed in the building stagnant water and strontium treated water before the treatment by ALPS, they were filtered with a 0.45 μm filter, and the filtrate and the residual were analyzed separately (for elements that are likely to be precipitated). Some of the ALPS treated water was also filtered and γ-rays of the used filter was measured. As a result, Cs-134, Cs-137, Co-60, which were found in filters for water up to ALPS treatment, were not detected. That shows that most of insoluble radionuclides have been removed through the ALPS treatment and that the filtering has no impacts.

The analysis of β and γ nuclides has confirmed that most nuclides were below the lower limit of detection, but Fe-55 and Ni-59 were detected in the building stagnant water, and Ni-59 in water before ALPS treatment at concentrations about 1/100, 1/1000, and 1/5000 of the regulatory concentration limits, respectively. In the analysis of Se-79 and Pd-107, Se-79 was detected at a concentration of about 1/20 of the regulatory concentration limit and Pd-107 at about 1/80000 of the regulatory concentration limit in building stagnant water and strontium treated water before ALPS treatment. On the other hand, in water after ALPS treatment, both were 1/100 or less of the regulatory limits and below the lower limit of detection.

Table 1.1.2-4 Results of nuclide analysis targeting nuclides to be analyzed (β and γ nuclides, etc.) (1/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
Fe-55	2.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 7, 2022	< 2.7E+00	Low-energy photon measuring device
		-	H4-B7 tank	Nov. 1, 2021		Apr. 14, 2022	< 2.3E+00	
		-	After treatment by added ALPS	Oct. 28, 2021		May. 17, 2022	< 3.0E+00	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 23, 2022	< 1.5E+01	
		Residue				Sep. 5, 2022	< 4.3E+00	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 22, 2022	< 4.1E+00	
		Residue				Sep. 15, 2022	1.7E+01	
Ni-59	1.00E+04	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 9, 2022	< 2.3E+00	
		-	H4-B7 tank	Nov. 1, 2021		Apr. 19, 2022	< 6.6E+00	
		-	After treatment by added ALPS	Oct. 28, 2021		May 23, 2022	< 2.3E+00	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 27, 2022	2.2E+00	
		Residue				Sep. 8, 2022	< 1.0E+00	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 26, 2022	9.4E+00	
		Residue				Sep. 26, 2022	3.5E+00	
Nb-93m	7.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 8, 2022	< 8.6E+00	
		-	H4-B7 tank	Nov. 1, 2021		May 10, 2022	< 1.5E+01	
		-	After treatment by added ALPS	Oct. 28, 2021		May 18, 2022	< 7.8E+00	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 13, 2022	< 5.6E+01	
		Residue				Sep. 26, 2022	< 5.2E+00	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 21, 2022	< 5.2E+01	
		Residue				Sep. 6, 2022	< 4.4E+00	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-4 Results of nuclide analysis targeting nuclides to be analyzed (β and γ nuclides, etc.) (2/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen*1	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
Mo-93	3.00E+02	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 10, 2022	< 1.1E+00	Low-energy photon measuring device
		-	H4-B7 tank	Nov. 1, 2021		Apr. 18, 2022	< 2.0E+00	
		-	After treatment by added ALPS	Oct. 28, 2021		May 19, 2022	< 1.0E+00	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 14, 2022	< 1.7E+00	
		Residue				Sep. 21, 2022	< 6.4E-01	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 25, 2022	< 1.2E+00	
		Residue				Sep. 7, 2022	< 1.4E+00	
Sn-121m	2.00E+03	-	K4-A10 tank	Nov. 1, 2021	(1)	Mar. 4, 2022	< 1.7E+00	
		-	H4-B7 tank	Nov. 1, 2021		Apr. 8, 2022	< 5.3E+00	
		-	After treatment by added ALPS	Oct. 28, 2021		May 20, 2022	< 2.0E+00	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 16, 2022	< 1.2E+01	
		Residue				Sep. 2, 2022	< 2.8E+00	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 28, 2022	< 9.2E+00	
		Residue				Sep. 22, 2022	< 1.2E+00	
Cl-36	9.00E+02	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 13, 2022	< 4.2E+00	Low-background β-ray spectrometer
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 30, 2022	< 5.5E+00	
		Filtrate	After treatment by added ALPS	Feb. 10, 2022		May 13, 2022	< 3.9E+00	
		Filtrate	Before treatment by added ALPS	Feb. 10, 2022		May. 17, 2022	< 3.7E+00	
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	May 23, 2022	< 4.3E+00	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-4 Results of nuclide analysis targeting nuclides to be analyzed (β and γ nuclides, etc.) (3/3)

Nuclide	Regulatory concentration limit [Bq/L]	Type of specimen	Sampling location	Date of collection	Sampling method[*1]	Base date	Analytical value [Bq/L]	Measuring instrument
Ca-41	4.00E+03	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	Jun. 3, 2022	< 7.9E+00	Si (Li) semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		Jun. 6, 2022	< 7.9E+00	
		Filtrate	After treatment by added ALPS	Feb. 10, 2022		Jun. 1, 2022	< 7.4E+00	
		Filtrate	Before treatment by added ALPS	Feb. 10, 2022		Jun. 14, 2022	< 1.9E+01	
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 13, 2022	< 1.4E+01	
Zr-93	1.00E+03	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	May 24, 2022	< 8.4E-01	Inductively coupled plasma mass spectrometer
		Filtrate	H4-B7 tank	Jan. 26, 2022		May 24, 2022	< 8.4E-01	
		Filtrate	After treatment by added ALPS	Feb. 10, 2022		May 24, 2022	< 8.4E-01	
		Filtrate	Before treatment by added ALPS	Feb. 10, 2022		May 24, 2022	< 8.4E-01	
		Residue				Jun. 7, 2022	< 1.3E+00	
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	May 24, 2022	< 8.4E-01	
		Residue				Jun. 7, 2022	< 1.3E+00	
Ba-133	5.00E+02	Filtrate	K4-A10 tank	Jan. 26, 2022	(1)	Apr. 23, 2022	< 7.3E-01	Ge semiconductor detector
		Filtrate	H4-B7 tank	Jan. 26, 2022		Apr. 22, 2022	< 7.0E-01	
		Filtrate	After treatment by added ALPS	Feb. 10, 2022		Apr. 24, 2022	< 7.0E-01	
		Filtrate	Before treatment by added ALPS	Feb. 10, 2022		Apr. 21, 2022	< 4.3E+00	
		Filtrate	Process Main Building	Feb. 4, 2022	(2)-a	Jun. 2, 2022	< 2.6E+00	
Se-79	2.00E+02	Filtrate	After treatment by added ALPS	Apr. 22, 2022	(1)	*2	< 1.5E+00	Liquid scintillation counter
		Filtrate	Before treatment by added ALPS	Apr. 22, 2022		*3	9.0E+00	
		Filtrate	Process Main Building	Apr. 21, 2022	(2)-b	*4	9.7E+00[*5]	
Pd-107	2.00E+04	Filtrate	After treatment by added ALPS	Apr. 22, 2022	(1)	Oct. 6, 2022	< 7.1E-02	Inductively coupled plasma mass spectrometer
		Filtrate	Before treatment by added ALPS	Apr. 22, 2022		Oct. 6, 2022	2.4E-01	
		Filtrate	Process Main Building	Apr. 21, 2022	(2)-b	Oct. 6, 2022	7.8E-02[*5]	

*1: Details are shown in Figure 1.1.2-2. *2: Sep.27, 2022; Sep. 27, 2022; Oct. 14, 2022 *3: Oct. 2, 2022; Oct. 14, 2022 *4: Sep. 21, 2022, Oct. 8, 2022

*5: The same specimen was analyzed three times, and the results were below the detection limit twice, and the value detected once was recorded. (In water before and after ALPS treatment, all of the three results were detected/below the detection limit, so the mean value was recorded)

(2) ALPS treated water, etc. analysis results (α nuclides)

Table 1.1.1-5 shows the analysis results of α nuclides in ALPS treated water, etc.

In order to identify α nuclides that are contained in the building stagnant water at significant concentrations, the measurement of them were tried up to 1/100 or less of the regulatory concentration limits. In ALPS treated water, most nuclides were 1/100 or less of the regulatory concentration limits and below the detection limits, but trace amounts of U-235 and U-238 were detected. However, considering that the mass ratio[*1] changed in the order of 1.8% (the ratio equivalent to spent fuel), 1.2% to 0.7% (the ratio of natural composition) in the process of treatment and based on other reasons[*2], they are considered to be natural uranium contained in ALPS treated water.

In this analysis too, suspended matter was visually confirmed in the building stagnant water and strontium treated water before ALPS treatment. So, they were filtered with a 0.45 μm filter, and then the filtrate and the residue were analyzed separately (for elements that are likely to be precipitated). As is the case with β, γ and other nuclides, some of the ALPS treated water was also filtered, and γ-rays of the used filter was measured. As a result, Cs-134, Cs-137, Co-60, which were found in filters for water up to ALPS treatment, were not detected. That shows that most of insoluble radionuclides have been removed through the ALPS treatment and that the filtering has no impacts.

*1: Calculated from $X = \lambda w/A \times N_A$ (X: radioactivity, λ: decay constant, w: mass, A: number of atoms, N_A: Avogadro constant)

*2: Within the range of uranium concentrations in Japanese rivers (excluding Okinawa), 0.47 to 488 ng/L [Natural level uranium concentration in Japanese rivers (Mochizuki et al.)] (approx. 6E-06 to 6E-03 Bq/L: U-238 equivalent), or U-236 derived from fuel was not detected.

Table 1.1.2-5 Results of nuclide analysis targeting nuclides to be analyzed (α nuclides) (1/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
U-233	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 1.4E-02	Inductively coupled plasma mass spectrometer
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 1.3E-02	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	< 1.3E-02	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	< 1.3E-02	
		Residue				Sep. 27, 2022	< 2.4E-03	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	< 1.3E-02	
		Residue				Sep. 27, 2022	< 1.4E-03	
U-234	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 8.7E-03	
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 8.7E-03	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	< 8.7E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	< 8.7E-03	
		Residue				Sep. 27, 2022	< 1.6E-03	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	1.3E-01	
		Residue				Sep. 26, 2022	2.8E-02	
U-235	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	5.0E-05	
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	9.9E-06	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	8.8E-06	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	2.0E-05	
		Residue				Sep. 27, 2022	3.9E-06	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	3.7E-03	
		Residue				Sep. 26, 2022	6.0E-04	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-5 Results of nuclide analysis targeting nuclides to be analyzed (α nuclides) (2/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
U-236	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	< 9.1E-05	Inductively coupled plasma mass spectrometer
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	< 9.1E-05	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	< 9.0E-05	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	1.2E-04	
		Residue				Sep. 27, 2022	< 1.6E-05	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	2.2E-02	
		Residue				Sep. 26, 2022	3.8E-03	
U-238	2.00E+01	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 14, 2022	1.2E-03	
		-	H4-B7 tank	Nov. 1, 2021		Jul. 14, 2022	2.3E-04	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	2.1E-04	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 14, 2022	2.3E-04	
		Residue				Sep. 26, 2022	7.5E-05	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 14, 2022	3.1E-02	
		Residue				Sep. 26, 2022	5.5E-03	
Np-237	9.00E+00	-	K4-A10 tank	Nov. 1, 2021	(1)	Jul. 15, 2022	< 1.5E-03	
		-	H4-B7 tank	Nov. 1, 2021		Jul. 15, 2022	< 1.5E-03	
		-	After treatment by added ALPS	Oct. 28, 2021		Jul. 15, 2022	< 1.5E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jul. 15, 2022	1.2E-02	
		Residue				Sep. 26, 2022	8.0E-04	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jul. 15, 2022	2.1E-01	
		Residue				Sep. 27, 2022	8.5E-03	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-5 Results of nuclide analysis targeting nuclides to be analyzed (α nuclides) (3/5)

Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
Pu-238	4.00E+00	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.9E-03	Silicon surface barrier detector
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.9E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 2.5E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		May 31, 2022	2.8E-01	
		Residue				Jun. 30, 2022	4.1E-01	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 13, 2022	1.2E+00	
		Residue				Jul. 4, 2022	2.8E+00	
Pu-239+ Pu240	8.00E+00	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.9E-03	
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.9E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.9E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		May 31, 2022	9.1E-02	
		Residue				Jun. 30, 2022	1.4E-01	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 13, 2022	3.9E-01	
		Residue				Jul. 4, 2022	9.2E-01	
Pu-242	4.00E+00	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.9E-03	
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 2.2E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.9E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		May 31, 2022	< 4.4E-03	
		Residue				Jun. 30, 2022	< 6.1E-03	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 13, 2022	< 7.9E-03	
		Residue				Jul. 4, 2022	< 1.3E-02	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-5 Results of nuclide analysis targeting nuclides to be analyzed (α nuclides) (4/5)

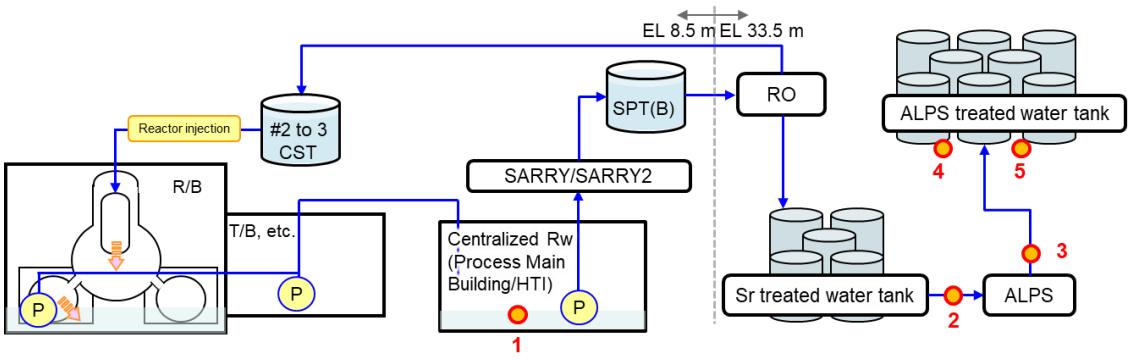
Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
Am-241	5.00E+00	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.8E-03	Silicon surface barrier detector
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.8E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.8E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 22, 2022	6.8E-02	
		Residue				Jun. 30, 2022	1.2E-01	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 28, 2022	4.0E-02	
		Residue				Jul. 4, 2022	5.7E-01	
Am-243	5.00E+00	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.5E-03	
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.5E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.5E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 22, 2022	< 7.7E-03	
		Residue				Jun. 30, 2022	< 5.5E-03	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 28, 2022	< 5.1E-03	
		Residue				Jul. 4, 2022	< 1.7E-02	
Cm-242	6.00E+01	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.5E-03	
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.5E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.6E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 22, 2022	< 1.6E-03	
		Residue				Jun. 30, 2022	5.5E-03	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 28, 2022	< 1.5E-03	
		Residue				Jul. 4, 2022	9.9E-03	

*1: Details are shown in Figure 1.1.2-2.

Table 1.1.2-5 Results of nuclide analysis targeting nuclides to be analyzed (α nuclides) (5/5)

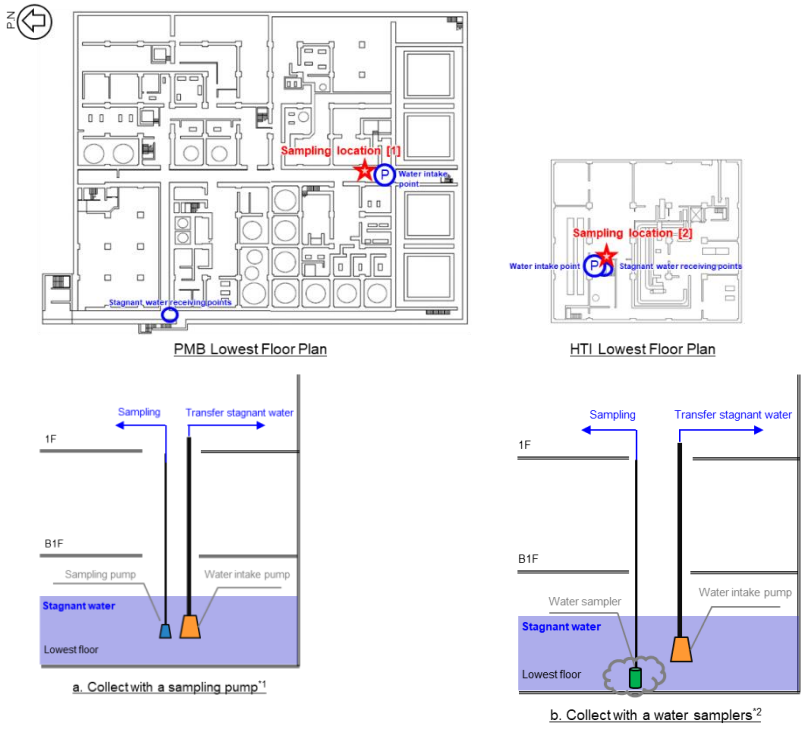
Nuclide	Regulatory concentration limit [Bq/L]	Type of sample	Sampling location	Date of collection	Sampling method*1	Base date	Analytical value [Bq/L]	Measuring instrument
Cm-243 +Cm-244	1.30E+01	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.5E-03	Silicon surface barrier detector
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 1.5E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.8E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 22, 2022	6.4E-02	
		Residue				Jun. 30, 2022	9.1E-02	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 28, 2022	2.7E-02	
		Residue				Jul. 4, 2022	4.4E-01	
Cm-244 +Cm-245	1.00E+01	Filtrate	K4-A10 tank	Nov. 1, 2021	(1)	May 27, 2022	< 1.5E-03	
		Filtrate	H4-B7 tank	Nov. 1, 2021		May 30, 2022	< 4.7E-03	
		Filtrate	After treatment by added ALPS	Oct. 28, 2021		May 27, 2022	< 1.5E-03	
		Filtrate	Before treatment by added ALPS	Oct. 28, 2021		Jun. 22, 2022	< 2.1E-02	
		Residue				Jun. 30, 2022	< 2.6E-02	
		Filtrate	Process Main Building	Nov. 2, 2021	(2)-a	Jun. 28, 2022	< 1.4E-02	
		Residue				Jul. 4, 2022	< 6.0E-02	

*1: Details are shown in Figure 1.1.2-2.



No.	Sampling location	Sampling method
1	Process Main Building	See (2).
2	Before treatment by ALPS	Collect from sampling rack installed at the inlet of ALPS
3	After treatment by ALPS	Collect from sampling rack installed at the outlet of ALPS
4	H4-B7 tank	Collected from the upper part of the tank using a water sampler.
5	K4-A10 tank	

(1) Sampling locations and methods for the nuclide analysis this time



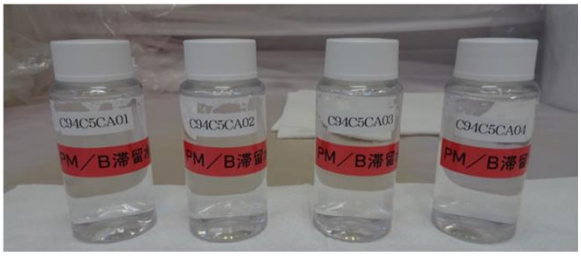
*1: The suction point of the sampling pump are set at the same height as that of the sampling pump.

*2: Since sediment on the bottom of the building was stirred up during sampling, samples collected contained more sludge than usual.

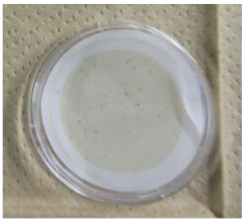
(2) Method for collecting samples from the Process Main Building

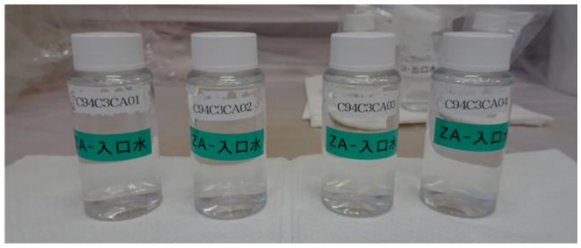
Figure 1.1.2-2 Sampling locations and methods for the nuclide analysis targeting nuclides to be analyzed

(Reference) Supplemental remarks on the analysis method for the additional analysis
In the analysis this time, suspended matter was visually confirmed in the stagnant water from the Process Main Building and in the strontium treated water before the ALPS treatment. Therefore, they were filtered with a 0.45 μm filter before analysis.
This analysis method has been adopted for light water reactors as a method to separate soluble from insoluble nuclides, and was used this time to identify which nuclides are insoluble and can be easily removed and which nuclides are dissolved in water and need to be removed by ALPS, etc.



Filtrate samples
(Stagnant water in Process Main Building)


Residue sample
(Stagnant water in Process Main Building)



Filtrate samples
(Strontium treated water before treatment by ALPS)


Residue sample
(Strontium treated water before treatment by ALPS)

Figure 1.1.2-3 Filtrate samples and residue samples from samples to be analyzed (stagnant water in Process Main Building and strontium treated water before ALPS treatment)

2.6 Summary of the nuclide analysis
This time, in examining the nuclides to be measured and evaluated at the discharge of ALPS treated water into the sea, among nuclides that have been the focus of studies about decommissioning and burial facilities, etc., excluding those with short half-lives, nuclides that have never been analyzed or have not been analyzed sufficiently so far were analyzed. As a result, they were not detected in the ALPS treated water, being 1/100 or less of the regulatory concentration limits.
The analysis have revealed that the nuclides that may exist in the ALPS treated water at significant concentrations are the major seven nuclides, carbon 14 and technetium 99.
In examining nuclides to be measured and evaluated at the discharge of ALPS treated water into the sea, nuclides will be selected based on the principle that nuclides that may exist in building stagnant water and strontium treated water before ALPS treatment at significant concentrations should be checked at discharge into the sea as well as the above mentioned nine nuclides in order to be conservative.

Attachment-3

Supplementary explanation on the inventory assessment in the examination of nuclides to be measured and assessed at the discharge of ALPS treated water into the sea

1. Overview

In order to ensure that the sum of the ratios to regulatory concentration limits of radionuclides other than tritium in ALPS treated water is less than 1, thorough verifications will be performed, while taking into account previous studies on decommissioning and disposal facilities in Japan, to check for significant presence of nuclides in the contaminated water. Then radionuclides to be measured and assessed (hereinafter referred to as nuclides to be measured and assessed) will be selected. The examination will be carried out in accordance with the flow explained at the 9th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water (See Figure 1.1.3-1), and a nuclide analysis and inventory assessment are planned to be performed. This document supplements the explanation about the inventory assessment.

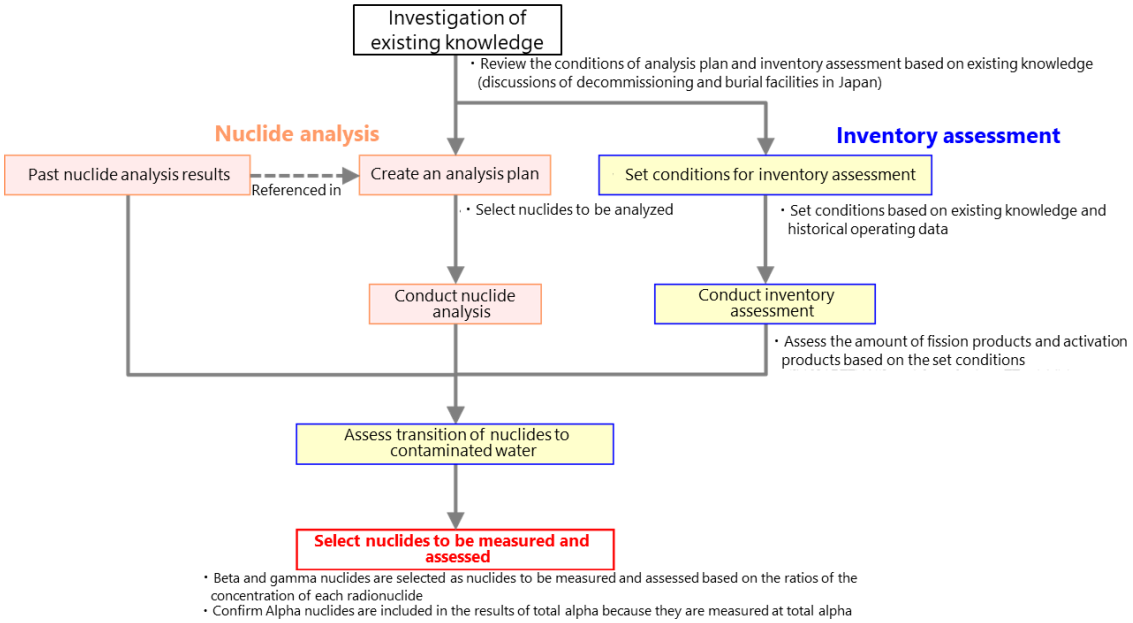


Figure 1.1.3-1 Overall procedure for examining the selection of the nuclides to be measured and assessed

[Excerpt from a document for the 9th Review Meeting on the Implementation Plan Regarding the Handling of ALPS Treated Water (partially revised)]

2. Inventory assessment

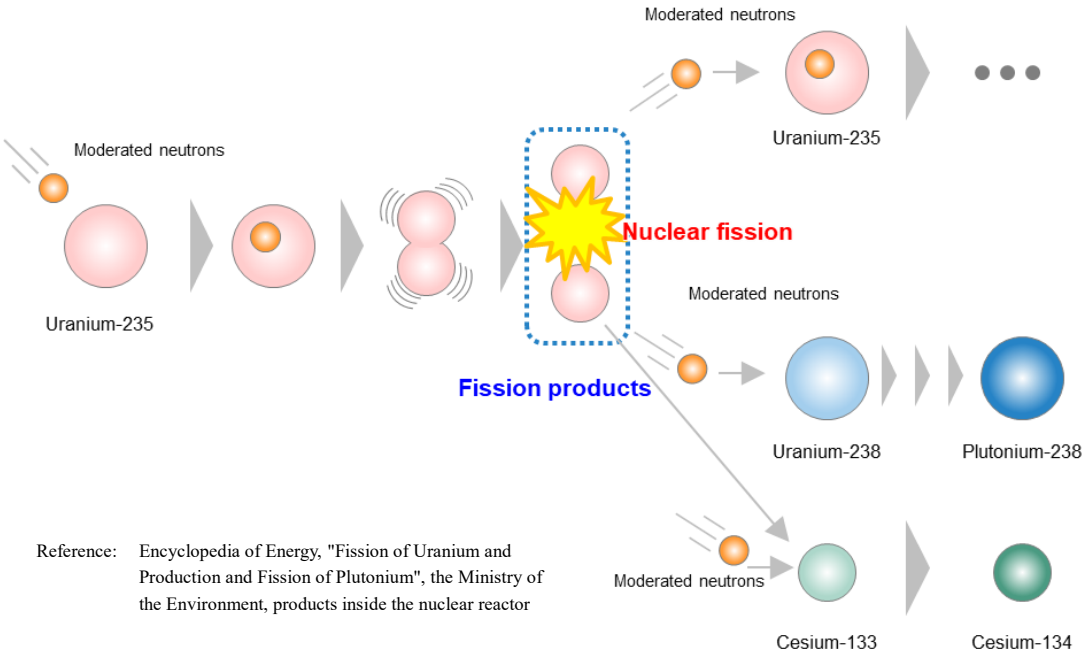
[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022)]

As the inventory assessment, fission products have been assessed in nuclear power plant safety assessments (used to examine nuclides to be removed by ALPS), while in studies regarding decommissioning and disposal facilities, activation of equipment in nuclear power plants has been calculated. In this examination, assessment of fission products and activation products will be performed while referring to the above assessments.
In both assessments, reduction in the inventory due to decay will also be assessed while taking into account that 12 years will have passed at the time of the discharge since the earthquake.
ORNL Isotope Generation and Depletion Code (ORIGEN: code system for calculating the generation, disintegration, and depletion of radioactive materials) will be used for the assessment as was the case with safety assessments, previous studies and other assessments so far.
Based on the result of ORIGEN assessment, the easiness of transfer into water will be taken into account, and then nuclides that may be contained at significant concentrations in building stagnant water will be identified.

2.1 Assessment of fission products

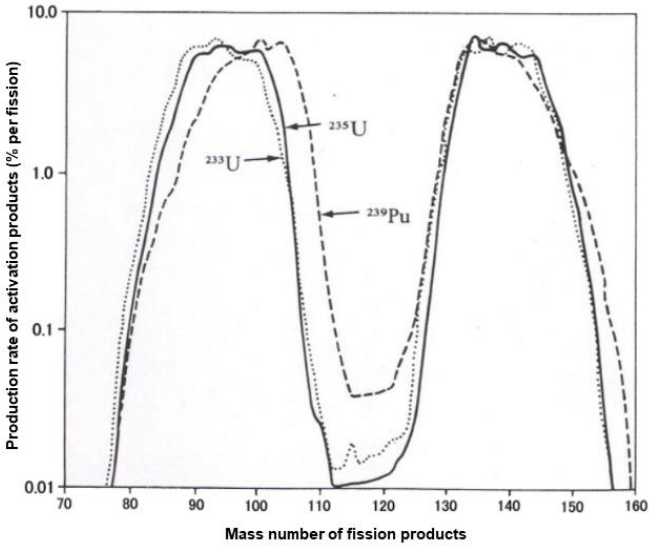
[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022)]

In the assessment of fission products, safety assessments at normal nuclear power plants will be referred to as they were in the examination of nuclides to be removed by ALPS, and the inventory as of March, 2011 will be assessed based on the condition of the fuel loaded in the Units 1 to 3 reactor pressure vessels at Fukushima Daiichi NPS as well as on the condition of the burnup assumed from the loading period of each piece of fuel. After March of 2011, the decrease in the inventory due to decay over 12 years will be calculated.
ORIGEN can assess inventories which are generated from nuclear fuel, disintegrated, and depleted. Regarding nuclear fission, it can assess that uranium 235 produces two nuclides mainly at peaks around mass numbers 95 and 140 in the process of fission. In addition, it is also capable of assess the generation of nuclides produced when uranium 238 absorbs neutrons, such as plutonium, as well as nuclides produced when fission products absorb neutrons, such as cesium 134.



Reference: Encyclopedia of Energy, "Fission of Uranium and Production and Fission of Plutonium", the Ministry of the Environment, products inside the nuclear reactor

Figure 1.1.3-2 Fission of uranium, and production and fission of plutonium



Based on the ATOMICA's "atomic mass number distribution of fission products."
Source: W. Marshall, ed.: Development of Reactor Technology (Vol.1), Shoukabou, p. 72

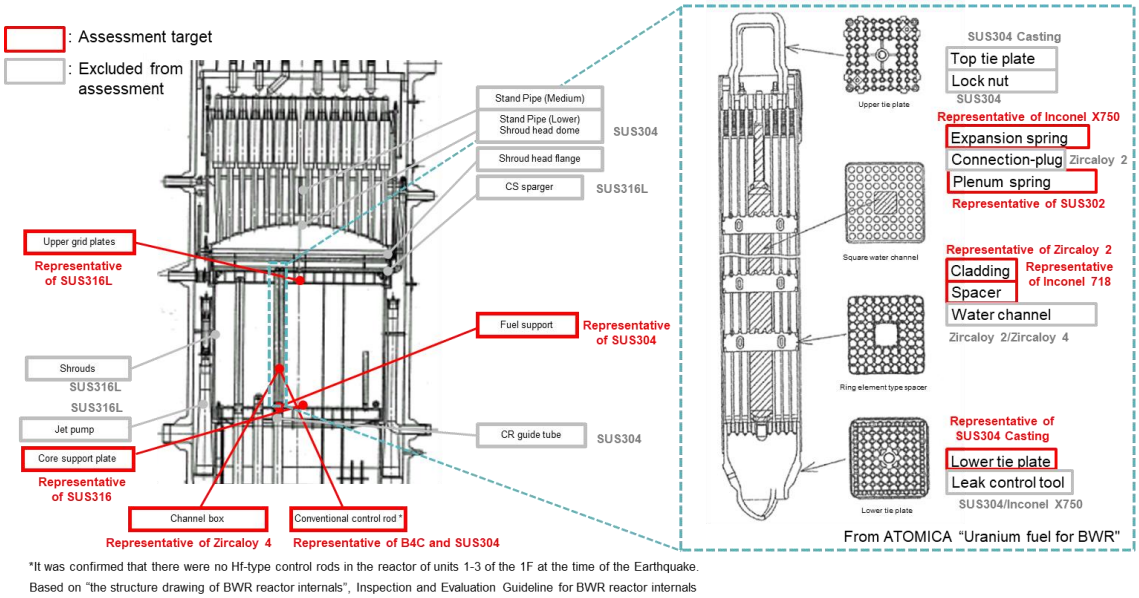
Figure 1.1.3-3 Distribution of mass numbers of fission products

2.2 Assessment of activation products

[Excerpt from the Supplementary Explanation of the Implementation Plan for the ALPS Treated Water Dilution/ Discharge Facilities and Related Facilities (July 2022)]

In the assessment of activation products, studies on decommissioning and disposal facilities will be used as a reference, and inventories as of March 2011 will be assessed, while taking into account the irradiation period from the core, for four kinds of equipment and structures: reactor internals, fuel assemblies (excluding nuclear fuel materials), pressure vessels, and pedestals, which exist in the reactor pressure vessels and lower part of them. In addition, inventories as of March of 2011 of corrosion products which will be produced as a result of corrosion and activation of materials comprising the equipment of the reactor coolant system will be assessed as well using water supply and metal data during operation, etc. In both of the assessments, for the period after March 2011, reduction in inventories due to decay over 12 years will be calculated.

Regarding reactor internals and fuel assemblies, rather than assessing all pieces of equipment, when same materials are used, those that are closer to the core (larger activation amount) will be selected for assessment to be conservative.



Reactor internals

Fuel assembly (excluding nuclear fuel materials)

Figure 1.1.3-4 Targets of the inventory assessment, such as reactor internals

2.3 Inventory assessment results

Tables 1.1.3.1 to 3 show the results of the inventory assessment performed under the conditions described in paragraphs 2.1 and 2.2.

In the assessment of fission products, all of the inventories produced from fuel are taken into account. When assessing the inventories of fission products, only inventories produced from fuel are taken into account and the presence of combustible poisons is not considered as is the case with normal nuclear power plant safety assessments and in the examination of nuclides to be removed by ALPS.

In the assessment of activation products, all of the radioactivity produced through activation of equipment which exist in the core while the reactor is in operation and assumed to have melted through past investigations and accident analyses are taken into account. Those equipment are upper grid plates, channel box, fuel assembly (all components), conventional control rods, fuel support, core support plate. In addition, as for reactor pressure vessels, 25% of the total weight is taken into account given the damage on the bottom, and for the concrete on the lower part of PCVs, the inventory is calculated from the amount of concrete contained in the fuel debris in IRID subsidized project “Advanced understanding of status in reactors through accident progress analysis and actual equipment data, etc.” (approx. 160 tons for each of Units 1 to 3). The activation of each piece of equipment are assessed based on operation records and conditions (element composition*, neutron flux) for waste subject to subsurface disposal (L1), high-concentration radioactive waste (glassified waste) and hull and end piece wastes, which have been studied by the Electric Technology Research Association.

In the assessment of inventories using ORIGEN, as is the case with past safety assessments and research of decommissioning, the inventories for the fuel, channel box, fuel assembly, and conventional control rods, which can be assessed by point kinetics of neutron flux in reactors, are assessed by ORIGEN2, while upper grid, core support plate, fuel support, reactor pressure vessel and concrete, whose neutron spectrum is different from that of fuel, are assessed by SCALE5.1/ORIGEN-S. The data embedded in JENDL4.0 and SCALE5.1 are used as nuclear data respectively.

*: Among the elements with atomic numbers from 1 to 103 of the element periodic table, 83 elements, excluding radioactive elements except for Bi, Th and U (20 elements), were selected as being subject to the setting. In this assessment, conditions of elements, except rare gas, were input to conduct analysis.

Table 1.1.3-1 Inventory assessment results: Unit 1 (1/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	4.8E+14	Nb-94	1.9E+11	Te-123m	1.5E+04
Be-10	8.4E+08	Mo-93	2.4E+11	Te-125m	2.9E+14
C-14	5.4E+12	Tc-97	2.9E+06	Te-127	7.8E+03
Na-22	3.6E+07	Tc-98	9.6E+06	Te-127m	8.0E+03
Si-32	7.1E+05	Tc-99	2.7E+13	I-129	4.9E+10
P-32	7.1E+05	Ru-106	2.1E+14	Cs-134	6.9E+15
Cl-36	5.1E+09	Rh-101	1.1E+05	Cs-135	1.1E+12
Ar-39	1.7E+11	Rh-102	7.1E+06	Cs-137	1.5E+17
Ar-42	4.9E+03	Rh-102m	1.6E+07	Ba-133	5.0E+10
K-40	1.6E+08	Rh-106	2.1E+14	Ba-137m	1.5E+17
K-42	4.9E+03	Pd-107	1.9E+11	La-137	1.4E+07
Ca-41	3.5E+09	Ag-108	3.3E+09	La-138	3.1E+04
Ca-45	4.8E+06	Ag-108m	3.8E+10	Ce-139	5.4E+03
Sc-46	3.7E+01	Ag-109m	8.8E+09	Ce-142	5.3E+07
V-49	2.3E+04	Ag-110	3.5E+08	Ce-144	4.1E+13
Mn-54	4.1E+11	Ag-110m	2.6E+10	Pr-144	4.1E+13
Fe-55	2.6E+15	Cd-109	8.8E+09	Pr-144m	6.2E+11
Co-60	8.1E+15	Cd-113m	2.5E+13	Nd-144	3.3E+03
Ni-59	1.4E+13	In-113m	1.7E+04	Pm-144	2.8E+01
Ni-63	1.6E+15	In-115	4.5E+03	Pm-145	1.8E+10
Zn-65	9.9E+08	Sn-113	1.7E+04	Pm-146	1.0E+12
Se-75	1.0E+03	Sn-119m	1.6E+10	Pm-147	1.5E+16
Se-79	1.1E+11	Sn-121	2.1E+13	Sm-145	3.1E+07
Kr-81	1.1E+10	Sn-121m	2.7E+13	Sm-146	2.3E+05
Kr-85	9.2E+15	Sn-123	1.1E+05	Sm-147	1.3E+07
Rb-87	9.4E+07	Sn-126	4.8E+11	Sm-148	8.2E+01
Sr-90	1.1E+17	Sb-125	7.9E+14	Sm-149	1.5E+00
Y-90	1.1E+17	Sb-126	6.8E+10	Sm-151	5.7E+14
Zr-93	3.9E+12	Sb-126m	4.8E+11	Eu-150	3.9E+07
Nb-91	1.0E+05	Te-121	6.1E+02	Eu-152	2.8E+12
Nb-92	1.7E+06	Te-121m	6.1E+02	Eu-154	3.8E+15
Nb-93m	1.8E+12	Te-123	1.3E+04	Eu-155	1.1E+15

Table 1.1.3-1 Inventory assessment results: Unit 1 (2/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Gd-152	4.3E+00	Pb-212	3.8E+10	Th-228	3.8E+10
Gd-153	3.2E+08	Pb-214	5.2E+06	Th-229	4.6E+05
Tb-157	6.8E+08	Bi-208	6.5E+05	Th-230	6.8E+08
Tb-158	6.9E+08	Bi-210	1.8E+06	Th-231	8.4E+10
Dy-159	1.9E+01	Bi-210m	1.7E+05	Th-232	6.3E+06
Ho-163	1.5E+07	Bi-211	2.2E+07	Th-234	8.0E+11
Ho-166m	6.9E+09	Bi-212	3.8E+10	Pa-231	7.6E+07
Tm-170	5.0E+05	Bi-213	4.6E+05	Pa-233	5.0E+11
Tm-171	1.4E+12	Bi-214	5.2E+06	Pa-234	1.0E+09
Lu-176	5.1E+05	Po-210	1.8E+06	Pa-234m	8.0E+11
Lu-177	4.7E+05	Po-211	6.2E+04	U-232	3.9E+10
Lu-177m	2.0E+06	Po-212	2.4E+10	U-233	1.1E+08
Hf-182	2.1E+06	Po-213	4.6E+05	U-234	3.4E+12
Ta-182	2.2E+06	Po-214	5.2E+06	U-235	8.4E+10
W-181	8.3E+02	Po-215	2.2E+07	U-236	5.6E+11
Re-187	1.4E+06	Po-216	3.8E+10	U-237	3.0E+12
Os-194	1.4E+08	Po-218	5.2E+06	U-238	8.0E+11
Ir-192	5.7E+06	At-217	4.6E+05	U-240	5.7E+05
Ir-192m	5.7E+06	Rn-219	2.2E+07	Np-235	2.2E+06
Ir-194	1.4E+08	Rn-220	3.8E+10	Np-236	7.6E+06
Ir-194m	3.6E+03	Rn-222	5.2E+06	Np-237	5.0E+11
Pt-190	2.2E+03	Fr-221	4.6E+05	Np-238	7.9E+10
Pt-193	2.5E+12	Fr-223	3.1E+05	Np-239	2.7E+13
Tl-204	3.6E+12	Ra-223	2.2E+07	Np-240m	5.7E+05
Tl-206	1.7E+05	Ra-224	3.8E+10	Pu-236	3.3E+10
Tl-207	2.2E+07	Ra-225	4.6E+05	Pu-238	4.4E+15
Tl-208	1.4E+10	Ra-226	5.2E+06	Pu-239	6.7E+14
Tl-209	1.0E+04	Ra-228	6.2E+06	Pu-240	8.7E+14
Pb-205	5.1E+05	Ac-225	4.6E+05	Pu-241	1.2E+17
Pb-209	4.6E+05	Ac-227	2.2E+07	Pu-242	3.2E+12
Pb-210	1.8E+06	Ac-228	6.2E+06	Pu-243	2.2E+05
Pb-211	2.2E+07	Th-227	2.2E+07	Pu-244	5.7E+05

Table 1.1.3-1 Inventory assessment results: Unit 1 (3/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Am-241	3.5E+15	Cm-243	2.3E+13	Bk-249	1.8E+05
Am-242	1.6E+13	Cm-244	2.3E+15	Cf-249	5.4E+06
Am-242m	1.6E+13	Cm-245	4.0E+11	Cf-250	3.0E+07
Am-243	2.7E+13	Cm-246	6.9E+10	Cf-251	3.1E+05
Am-245	2.6E+00	Cm-247	2.2E+05	Cf-252	4.3E+06
Cm-242	1.3E+13	Cm-248	5.9E+05		

Table 1.1.3-2 Inventory assessment results: Unit 2 (1/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	6.1E+14	Nb-93m	2.3E+12	Te-123	1.2E+04
Be-10	1.1E+09	Nb-94	3.6E+11	Te-123m	2.0E+04
C-14	9.8E+12	Mo-93	6.0E+11	Te-125m	3.9E+14
Na-22	5.0E+07	Tc-97	4.1E+06	Te-127	1.2E+04
Si-32	1.5E+06	Tc-98	1.1E+07	Te-127m	1.2E+04
P-32	1.5E+06	Tc-99	3.4E+13	I-129	5.9E+10
Cl-36	1.3E+10	Ru-106	2.8E+14	Cs-134	9.1E+15
Ar-39	2.4E+11	Rh-101	1.5E+05	Cs-135	1.2E+12
Ar-42	1.3E+04	Rh-102	9.7E+06	Cs-137	1.9E+17
K-40	1.5E+08	Rh-102m	2.1E+07	Ba-133	6.0E+10
K-42	1.3E+04	Rh-106	2.8E+14	Ba-137m	1.8E+17
Ca-41	6.8E+09	Pd-107	2.2E+11	La-137	1.7E+07
Ca-45	6.8E+06	Ag-108	5.8E+09	La-138	4.1E+04
Sc-46	5.2E+01	Ag-108m	6.7E+10	Ce-139	7.5E+03
V-49	3.8E+04	Ag-109m	1.3E+10	Ce-142	6.7E+07
Mn-54	5.8E+11	Ag-110	4.5E+08	Ce-144	6.4E+13
Fe-55	4.2E+15	Ag-110m	3.3E+10	Pr-144	6.4E+13
Co-60	1.4E+16	Cd-109	1.3E+10	Pr-144m	9.7E+11
Ni-59	2.9E+13	Cd-113m	2.9E+13	Nd-144	4.1E+03
Ni-63	3.4E+15	In-113m	2.4E+04	Pm-144	3.8E+01
Zn-65	1.5E+09	In-115	4.9E+03	Pm-145	3.0E+10
Se-75	1.5E+03	Sn-113	2.4E+04	Pm-146	1.3E+12
Se-79	1.3E+11	Sn-119m	2.2E+10	Pm-147	2.1E+16
Kr-81	1.7E+10	Sn-121	2.6E+13	Sm-145	4.4E+07
Kr-85	1.2E+16	Sn-121m	3.3E+13	Sm-146	2.5E+05
Rb-87	1.1E+08	Sn-123	1.6E+05	Sm-147	1.7E+07
Sr-90	1.5E+17	Sn-126	5.8E+11	Sm-148	9.4E+01
Y-88	1.1E+00	Sb-125	1.1E+15	Sm-149	2.3E+00
Y-90	1.5E+17	Sb-126	8.1E+10	Sm-151	7.8E+14
Zr-93	4.9E+12	Sb-126m	5.8E+11	Eu-150	4.1E+07
Nb-91	4.1E+05	Te-121	9.3E+02	Eu-152	3.1E+12
Nb-92	3.8E+06	Te-121m	9.3E+02	Eu-154	4.6E+15

Table 1.1.3-2 Inventory assessment results: Unit 2 (2/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Eu-155	1.4E+15	Pb-211	2.5E+07	Th-227	2.5E+07
Gd-152	4.7E+00	Pb-212	4.2E+10	Th-228	4.2E+10
Gd-153	3.8E+08	Pb-214	5.5E+06	Th-229	4.4E+05
Tb-157	9.5E+08	Bi-208	9.1E+05	Th-230	8.7E+08
Tb-158	7.6E+08	Bi-210	1.7E+06	Th-231	1.4E+11
Dy-159	2.5E+01	Bi-210m	2.4E+05	Th-232	5.9E+06
Ho-163	2.2E+07	Bi-211	2.5E+07	Th-234	1.1E+12
Ho-166m	9.5E+09	Bi-212	4.2E+10	Pa-231	9.4E+07
Tm-170	7.0E+05	Bi-213	4.4E+05	Pa-233	6.2E+11
Tm-171	1.9E+12	Bi-214	5.5E+06	Pa-234	1.5E+09
Lu-176	7.2E+05	Po-210	1.7E+06	Pa-234m	1.1E+12
Lu-177	6.5E+05	Po-211	7.1E+04	U-232	4.4E+10
Lu-177m	2.8E+06	Po-212	2.7E+10	U-233	1.5E+08
Hf-182	2.9E+06	Po-213	4.3E+05	U-234	5.1E+12
Ta-182	3.0E+06	Po-214	5.5E+06	U-235	1.4E+11
W-181	1.2E+03	Po-215	2.5E+07	U-236	7.3E+11
Re-187	2.2E+06	Po-216	4.2E+10	U-237	3.6E+12
Os-194	2.0E+08	Po-218	5.5E+06	U-238	1.1E+12
Ir-192	6.9E+06	At-217	4.4E+05	U-240	6.1E+05
Ir-192m	6.9E+06	Rn-219	2.5E+07	Np-235	2.8E+06
Ir-194	2.0E+08	Rn-220	4.2E+10	Np-236	9.4E+06
Ir-194m	4.4E+03	Rn-222	5.5E+06	Np-237	6.2E+11
Pt-190	2.1E+03	Fr-221	4.4E+05	Np-238	7.7E+10
Pt-193	3.6E+12	Fr-223	3.5E+05	Np-239	2.8E+13
Tl-204	5.4E+12	Ra-223	2.5E+07	Np-240m	6.1E+05
Tl-206	2.4E+05	Ra-224	4.2E+10	Pu-236	4.0E+10
Tl-207	2.5E+07	Ra-225	4.4E+05	Pu-238	4.8E+15
Tl-208	1.5E+10	Ra-226	5.5E+06	Pu-239	8.7E+14
Tl-209	9.5E+03	Ra-228	5.8E+06	Pu-240	1.1E+15
Pb-205	1.2E+06	Ac-225	4.4E+05	Pu-241	1.5E+17
Pb-209	4.4E+05	Ac-227	2.5E+07	Pu-242	3.4E+12
Pb-210	1.7E+06	Ac-228	5.8E+06	Pu-243	1.9E+05

Table 1.1.3-2 Inventory assessment results: Unit 2 (3/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Pu-244	6.1E+05	Cm-242	1.3E+13	Cm-248	4.8E+05
Am-241	4.1E+15	Cm-243	2.3E+13	Bk-249	1.5E+05
Am-242	1.5E+13	Cm-244	2.2E+15	Cf-249	4.5E+06
Am-242m	1.5E+13	Cm-245	3.9E+11	Cf-250	2.5E+07
Am-243	2.8E+13	Cm-246	6.1E+10	Cf-251	2.5E+05
Am-245	2.2E+00	Cm-247	1.9E+05	Cf-252	3.3E+06

Table 1.1.3-3 Inventory assessment results: Unit 3 (1/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
H-3	5.7E+14	Nb-93m	2.2E+12	Te-123	1.2E+04
Be-10	1.1E+09	Nb-94	3.6E+11	Te-123m	2.0E+04
C-14	9.8E+12	Mo-93	6.1E+11	Te-125m	3.8E+14
Na-22	5.0E+07	Tc-97	4.1E+06	Te-127	1.2E+04
Si-32	1.5E+06	Tc-98	1.0E+07	Te-127m	1.2E+04
P-32	1.5E+06	Tc-99	3.2E+13	I-129	5.6E+10
Cl-36	1.3E+10	Ru-106	2.7E+14	Cs-134	8.6E+15
Ar-39	2.4E+11	Rh-101	1.5E+05	Cs-135	1.2E+12
Ar-42	1.3E+04	Rh-102	9.4E+06	Cs-137	1.8E+17
K-40	1.5E+08	Rh-102m	2.0E+07	Ba-133	5.6E+10
K-42	1.3E+04	Rh-106	2.7E+14	Ba-137m	1.7E+17
Ca-41	6.8E+09	Pd-107	2.0E+11	La-137	1.6E+07
Ca-45	6.8E+06	Ag-108	5.8E+09	La-138	4.1E+04
Sc-46	5.2E+01	Ag-108m	6.7E+10	Ce-139	6.9E+03
V-49	3.8E+04	Ag-109m	1.3E+10	Ce-142	6.3E+07
Mn-54	6.1E+11	Ag-110	4.1E+08	Ce-144	6.2E+13
Fe-55	4.4E+15	Ag-110m	3.0E+10	Pr-144	6.2E+13
Co-60	1.4E+16	Cd-109	1.3E+10	Pr-144m	9.4E+11
Ni-59	3.0E+13	Cd-113m	2.8E+13	Nd-144	3.9E+03
Ni-63	3.4E+15	In-113m	2.4E+04	Pm-144	3.7E+01
Zn-65	1.5E+09	In-115	4.9E+03	Pm-145	3.0E+10
Se-75	1.5E+03	Sn-113	2.4E+04	Pm-146	1.2E+12
Se-79	1.3E+11	Sn-119m	2.2E+10	Pm-147	2.0E+16
Kr-81	1.7E+10	Sn-121	2.4E+13	Sm-145	4.4E+07
Kr-85	1.1E+16	Sn-121m	3.1E+13	Sm-146	2.3E+05
Rb-87	1.1E+08	Sn-123	1.7E+05	Sm-147	1.6E+07
Sr-90	1.4E+17	Sn-126	5.5E+11	Sm-148	8.6E+01
Y-88	1.0E+00	Sb-125	1.0E+15	Sm-149	2.3E+00
Y-90	1.4E+17	Sb-126	7.7E+10	Sm-151	8.0E+14
Zr-93	4.7E+12	Sb-126m	5.5E+11	Eu-150	3.8E+07
Nb-91	4.1E+05	Te-121	9.3E+02	Eu-152	3.1E+12
Nb-92	3.9E+06	Te-121m	9.3E+02	Eu-154	4.2E+15

Table 1.1.3-3 Inventory assessment results: Unit 3 (2/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Eu-155	1.3E+15	Pb-211	2.4E+07	Th-227	2.4E+07
Gd-152	4.6E+00	Pb-212	3.8E+10	Th-228	3.8E+10
Gd-153	3.6E+08	Pb-214	5.5E+06	Th-229	4.0E+05
Tb-157	9.5E+08	Bi-208	9.1E+05	Th-230	8.6E+08
Tb-158	6.8E+08	Bi-210	1.8E+06	Th-231	1.4E+11
Dy-159	2.5E+01	Bi-210m	2.4E+05	Th-232	5.9E+06
Ho-163	2.2E+07	Bi-211	2.4E+07	Th-234	1.1E+12
Ho-166m	9.2E+09	Bi-212	3.8E+10	Pa-231	9.0E+07
Tm-170	7.0E+05	Bi-213	4.0E+05	Pa-233	5.8E+11
Tm-171	1.9E+12	Bi-214	5.5E+06	Pa-234	1.4E+09
Lu-176	7.2E+05	Po-210	1.8E+06	Pa-234m	1.1E+12
Lu-177	6.5E+05	Po-211	6.8E+04	U-232	3.9E+10
Lu-177m	2.8E+06	Po-212	2.4E+10	U-233	1.4E+08
Hf-182	2.9E+06	Po-213	3.9E+05	U-234	5.1E+12
Ta-182	3.0E+06	Po-214	5.5E+06	U-235	1.4E+11
W-181	1.2E+03	Po-215	2.4E+07	U-236	7.0E+11
Re-187	2.2E+06	Po-216	3.8E+10	U-237	4.0E+12
Os-194	2.0E+08	Po-218	5.5E+06	U-238	1.1E+12
Ir-192	6.9E+06	At-217	4.0E+05	U-240	5.5E+05
Ir-192m	6.9E+06	Rn-219	2.4E+07	Np-235	2.5E+06
Ir-194	2.0E+08	Rn-220	3.8E+10	Np-236	8.6E+06
Ir-194m	4.4E+03	Rn-222	5.5E+06	Np-237	5.8E+11
Pt-190	2.1E+03	Fr-221	4.0E+05	Np-238	3.0E+11
Pt-193	3.6E+12	Fr-223	3.4E+05	Np-239	2.9E+13
Tl-204	5.4E+12	Ra-223	2.4E+07	Np-240m	5.5E+05
Tl-206	2.4E+05	Ra-224	3.8E+10	Pu-236	3.6E+10
Tl-207	2.4E+07	Ra-225	4.0E+05	Pu-238	6.7E+15
Tl-208	1.4E+10	Ra-226	5.5E+06	Pu-239	1.1E+15
Tl-209	8.6E+03	Ra-228	5.9E+06	Pu-240	1.4E+15
Pb-205	1.2E+06	Ac-225	4.0E+05	Pu-241	1.6E+17
Pb-209	4.0E+05	Ac-227	2.4E+07	Pu-242	4.6E+12
Pb-210	1.8E+06	Ac-228	5.9E+06	Pu-243	1.3E+05

Table 1.1.3-3 Inventory assessment results: Unit 3 (3/3)

Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]	Nuclide	Radioactivity [Bq]
Pu-244	5.5E+05	Cm-242	4.9E+13	Cm-248	3.3E+05
Am-241	5.6E+15	Cm-243	2.9E+13	Bk-249	1.0E+05
Am-242	5.9E+13	Cm-244	1.9E+15	Cf-249	3.0E+06
Am-242m	5.9E+13	Cm-245	3.1E+11	Cf-250	1.6E+07
Am-243	2.9E+13	Cm-246	4.6E+10	Cf-251	1.6E+05
Am-245	1.5E+00	Cm-247	1.3E+05	Cf-252	2.0E+06

Code used for inventory calculations (ORIGEN-2)

1. Overview

ORIGEN-2 is a burn-up calculation code based on point kinetics of neutron flux in reactors which was developed by Oak Ridge National Laboratory (ORNL). ORIGEN-2 is a versatile analysis code and is widely used for the calculation of decay heat of transportation casks, etc.

2. Functions

ORIGEN-2 has the following functions for burn-up analysis.

[1] It can calculate decay heat, radioactive intensity, radioactivity of nuclides according to the cooling period by calculating burn-up of fuel in reactors and calculating decay after removal from reactors.
[2] It allows free selection from the built-in cross section libraries for reactor type-fuel combinations which have been weighted in accordance with the difference in neutron energy spectrum.
[3] Calculation results to be output are classified into activation products, actinoids, fission products.
[4] Regarding radionuclide data (decay heat, energy distribution of gamma rays, neutron source intensity generated by spontaneous fission and (alpha, n) reactions, etc.) necessary for burn-up calculation, libraries exclusive to ORIGEN-2 are available and used for calculation.

3. Calculation flow

Figure 1.1.3-5 shows the calculation flow of ORIGEN-2.

4. Application record

ORIGEN-2 is widely used for the calculation of decay heat of transportation casks and fuel facilities.

5. Verification method

It has been confirmed that the introduction of the versatile code has been evaluated[*1]. It has been confirmed that a verification[*2] has been conducted through large-scale experiments and benchmark tests.

*1: A.G.Croff, “ORIGEN2 Isotope Generation and Depletion Code MATRIX EXPONETIAL METHOD”, CCC-371(1987)
*2: Atomic Energy Society of Japan "Reactor decay heat and its recommended values" August 1989.

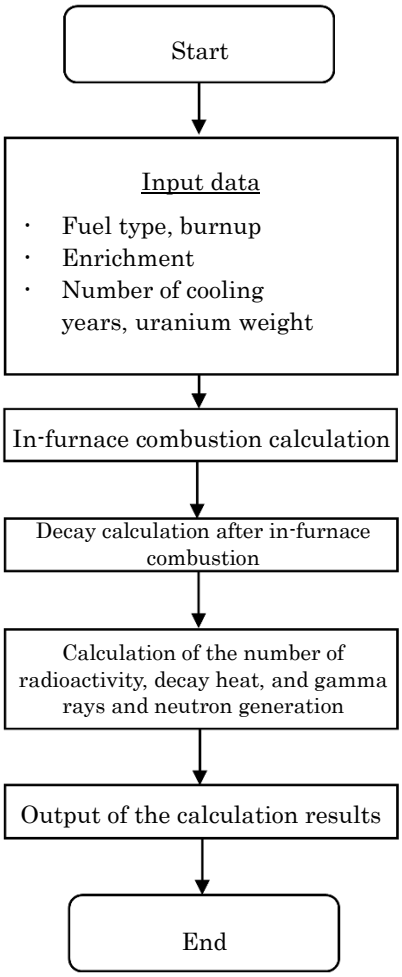


Figure 1.1.3-5 Calculation flow of ORIGEN-2

End

Reference-2

The code used for inventory calculations (ORIGEN-S)

1. Overview

SCALE 5.1/ORIGEN-S (hereinafter, ORIGEN-S) is an activation calculation code developed by Oak Ridge National Laboratory (ORNL) in the United States, which can use three groups of spectra—fast neutron, epithermal neutron and thermal neutron. ORIGEN-S is a versatile analysis code and is widely used for the calculation of activation of reactor internals and for decommissioning of reactor facilities, etc.

2. Functions

ORIGEN-S is capable of calculating the following.

[1] Calculates the radioactivity of nuclides, number of neutrons and gamma rays produced, production of fission products and actinoids by inputting fuel nuclide composition (weight), irradiation period (operation pattern), neutron flux or specific power of the reactor.

[2] Calculates activation activity of structure materials by inputting the material composition, neutron flux and irradiation record of the structure material to be assessed.

[3] Calculates energy deposition of radionuclides to be obtained by production and annihilation calculation by inputting the material composition, neutron flux and irradiation record of the material composition to be assessed.

3. Calculation flow

Figure 1.1.3-6 shows the calculation flow of ORIGEN-S.

4. Application record

The ORIGEN-S is widely used for the activation calculation of reactor structures whose neutron spectrum is different from that of the fuel, and for the activation calculation of reactor pressure vessels and biological shielding materials for the purpose of decommissioning of reactor facilities.

5. Verification method

It has been confirmed that the introduction of the versatile code has been evaluated[*1]. It has been confirmed that a verification[*2] has been conducted through large-scale experiments and benchmark tests.

*1: SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation,ORNL/TM-2005/39, Version 5.1, Vols.I–III,November (2006)

*2: K.Tanaka et al., “Radioactivity evaluation for Main Steam Line and Suppression Chamber of small type BWR”, Progress in Nuclear Science and Technology Volume 4 (2014) pp.836-839

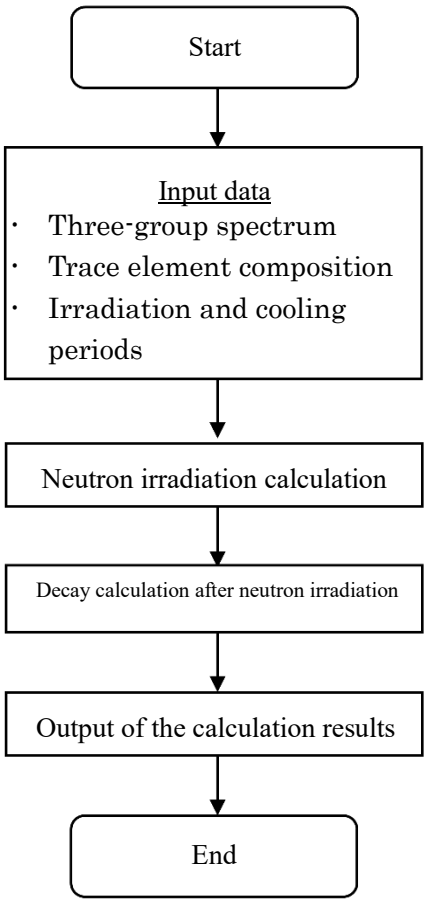


Figure 1.1.3-6 Calculation flow of ORIGEN-S

Attachment-4

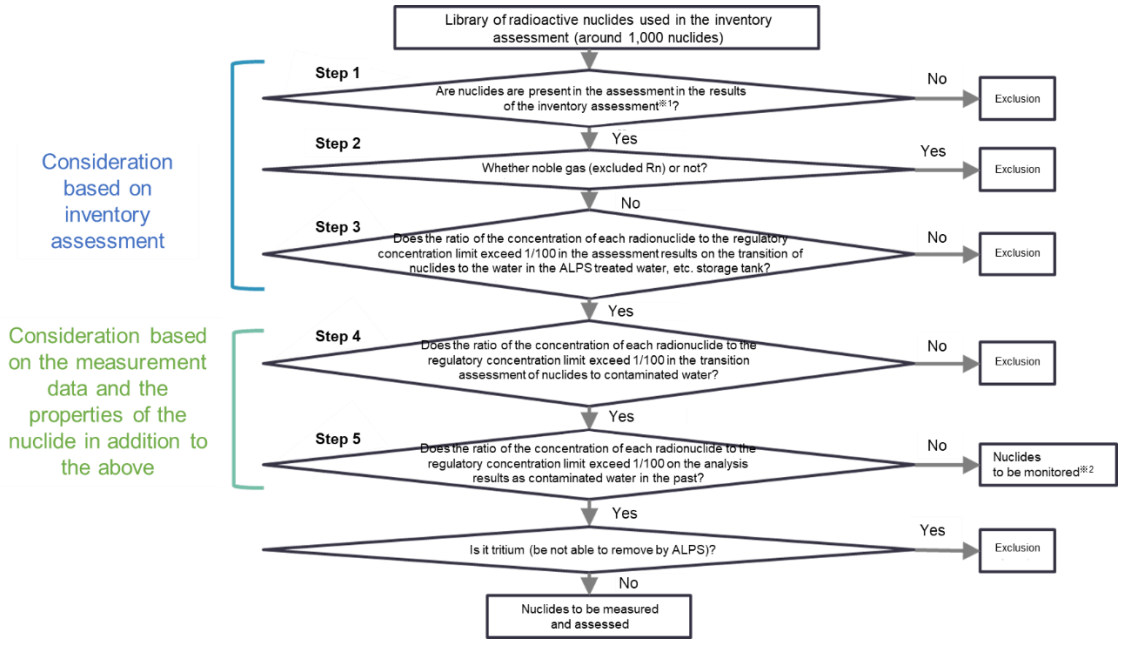
Supplementary explanation on the selection of nuclides in the examination of nuclides to be measured and assessed at the discharge of ALPS treated water into the sea

1. Overview

Attachments-2 and 3 provide supplementary explanations on the nuclide analysis and inventory assessment which are performed in order to ensure that the sum of the ratios to regulatory concentration limits of radionuclides other than tritium in ALPS treated water is less than 1 while taking into account previous studies on decommissioning and disposal facilities in Japan.
This document supplements the explanation about how to select nuclides to be measured and assessed at the discharge of ALPS treated water into the sea based on the results obtained through the nuclide analysis and inventory assessment.

2. How to select nuclides to be measured and assessed

The nuclides to be measured and assessed at the discharge of ALPS treated water into the sea will be selected in accordance with the flow shown in Figure 1.1.4-1. This section gives supplementary explanations about each steps of the procedures.



*1: The decay period of the inventory assessment is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))

*2: Nuclides were continuously confirmed whether are significantly presence in contaminated water.

Figure 1.1.4-1 Flowchart for selection of nuclides to be measured and assessed for discharge of ALPS treated water into the sea

2.1 Step 1

In Step 1 “Are nuclides are present in the assessment in the results of the inventory assessment? ,” nuclides will be evaluated by the criteria that if they were found to exist through the inventory assessment (if 1 Bq or more of the nuclide exists in each core of Units 1 to 3), and nuclides that were found not to exist through the assessment will be excluded.

In the selection flow, it is stated that the decay period for the inventory assessment will be set appropriately. In the assessment this time, the decay period was set to March 2023, 12 years after the earthquake when the discharge of ALPS treated water into the sea starts.

As a result, the 210 nuclides that are shown in Table 1.1.4-1 were found to exist (See Attachment-3 for details about the inventory assessment).

Table 1.1.4-1 Nuclides that were found to exist through Step 1 (1/2)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*21*	Zn-65	*41*	Rh-102	*61*	Sb-126	*81*	Pr-144
2	Be-10	*22*	Se-75	*42*	Rh-102m	*62*	Sb-126m	*82*	Pr-144m
3	C-14	*23*	Se-79	*43*	Rh-106	*63*	Te-121	*83*	Nd-144
4	Na-22	*24*	Kr-81	*44*	Pd-107	*64*	Te-121m	*84*	Pm-144
5	Si-32	*25*	Kr-85	*45*	Ag-108	*65*	Te-123	*85*	Pm-145
6	P-32	*26*	Rb-87	*46*	Ag-108m	*66*	Te-123m	*86*	Pm-146
7	Cl-36	*27*	Sr-90	*47*	Ag-109m	*67*	Te-125m	*87*	Pm-147
8	Ar-39	*28*	Y-88	*48*	Ag-110	*68*	Te-127	*88*	Sm-145
9	Ar-42	*29*	Y-90	*49*	Ag-110m	*69*	Te-127m	*89*	Sm-146
10	K-40	*30*	Zr-93	*50*	Cd-109	*70*	I-129	*90*	Sm-147
11	K-42	*31*	Nb-91	*51*	Cd-113m	*71*	Cs-134	*91*	Sm-148
12	Ca-41	*32*	Nb-92	*52*	In-113m	*72*	Cs-135	*92*	Sm-149
13	Ca-45	*33*	Nb-93m	*53*	In-115	*73*	Cs-137	*93*	Sm-151
14	Sc-46	*34*	Nb-94	*54*	Sn-113	*74*	Ba-133	*94*	Eu-150
15	V-49	*35*	Mo-93	*55*	Sn-119m	*75*	Ba-137m	*95*	Eu-152
16	Mn-54	*36*	Tc-97	*56*	Sn-121	*76*	La-137	*96*	Eu-154
17	Fe-55	*37*	Tc-98	*57*	Sn-121m	*77*	La-138	*97*	Eu-155
18	Co-60	*38*	Tc-99	*58*	Sn-123	*78*	Ce-139	*98*	Gd-152
19	Ni-59	*39*	Ru-106	*59*	Sn-126	*79*	Ce-142	*99*	Gd-153
20	Ni-63	*40*	Rh-101	*60*	Sb-125	*80*	Ce-144	*100*	Tb-157

Table 1.1.4-1 Nuclides that were found to exist through Step 1 (2/2)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
101	Tb-158	*123*	Tl-207	*145*	Po-216	*167*	Th-234	*189*	Pu-240
102	Dy-159	*124*	Tl-208	*146*	Po-218	*168*	Pa-231	*190*	Pu-241
103	Ho-163	*125*	Tl-209	*147*	At-217	*169*	Pa-233	*191*	Pu-242
104	Ho-166m	*126*	Pb-205	*148*	Rn-219	*170*	Pa-234	*192*	Pu-243
105	Tm-170	*127*	Pb-209	*149*	Rn-220	*171*	Pa-234m	*193*	Pu-244
106	Tm-171	*128*	Pb-210	*150*	Rn-222	*172*	U-232	*194*	Am-241
107	Lu-176	*129*	Pb-211	*151*	Fr-221	*173*	U-233	*195*	Am-242
108	Lu-177	*130*	Pb-212	*152*	Fr-223	*174*	U-234	*196*	Am-242m
109	Lu-177m	*131*	Pb-214	*153*	Ra-223	*175*	U-235	*197*	Am-243
110	Hf-182	*132*	Bi-208	*154*	Ra-224	*176*	U-236	*198*	Am-245
111	Ta-182	*133*	Bi-210	*155*	Ra-225	*177*	U-237	*199*	Cm-242
112	W-181	*134*	Bi-210m	*156*	Ra-226	*178*	U-238	*200*	Cm-243
113	Re-187	*135*	Bi-211	*157*	Ra-228	*179*	U-240	*201*	Cm-244
114	Os-194	*136*	Bi-212	*158*	Ac-225	*180*	Np-235	*202*	Cm-245
115	Ir-192	*137*	Bi-213	*159*	Ac-227	*181*	Np-236	*203*	Cm-246
116	Ir-192m	*138*	Bi-214	*160*	Ac-228	*182*	Np-237	*204*	Cm-247
117	Ir-194	*139*	Po-210	*161*	Th-227	*183*	Np-238	*205*	Cm-248
118	Ir-194m	*140*	Po-211	*162*	Th-228	*184*	Np-239	*206*	Bk-249
119	Pt-190	*141*	Po-212	*163*	Th-229	*185*	Np-240m	*207*	Cf-249
120	Pt-193	*142*	Po-213	*164*	Th-230	*186*	Pu-236	*208*	Cf-250
121	Tl-204	*143*	Po-214	*165*	Th-231	*187*	Pu-238	*209*	Cf-251
122	Tl-206	*144*	Po-215	*166*	Th-232	*188*	Pu-239	*210*	Cf-252

2.2 Step 2

In Step 2 "Whether noble gas (excluded Rn) or not?," given that rare gas nuclides generated while the reactor is in operation are not considered to exist in the core in 12 years after the earthquake and that, even if they exists, rare gas are stable elements and therefore insoluble in the contaminated water, they were judged not to fall within the scope of nuclides to be measured and assessed at the discharge of ALPS treated water into the sea and excluded. On the other hand, Rn is considered to still exist in the core due to the decay chains of uranium, neptunium, etc. Therefore, even though it is rare gas, it was not excluded in this step.

The rare gas nuclides identified in this step, except for Rn, are the following four nuclides, and Table 1.1.4-2 shows their half-lives and biosynthetic pathways which have been confirmed as well.

Table 1.1.4-2 Nuclides excluded in Step 2 and their biosynthetic pathways

Nuclides (rare gas)	Half-life [y]	Major biosynthetic pathway
Ar-39	2.7E+02	Produced by activation of trace component (K) in structural materials
Ar-42	3.3E+01	Produced by activation of trace component (K, Ca, etc.) in structural materials
Kr-81	2.3E+05	Produced by fission of fuel Produced by activation of trace component (Br) in structural materials
Kr-85	1.1E+02	Produced by fission of fuel

2.3 Step 3

In Step 3 "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the assessment results on the transition of nuclides to the water in the ALPS treated water, etc. storage tank?," nuclides are evaluated to see if their impacts on the dose assessment are sufficiently small or not (1/100 or less of the regulatory concentration limit), and if the concentration of a nuclide exceeds the limit, it will proceed to the next step. This evaluation is performed under the assumption that all of the inventory existing in the PCV will have been dissolved in ALPS treated water, etc. tanks (prediction) as of March 2023*. Therefore, given the current status confirmed through the PCV inside investigation, an adequate level of conservativeness is secured under this assumption.

*: The same timing as for the inventory assessment will be adopted.

$$\text{Concentration of nuclide i} = \text{Inventory of nuclide i (Bq)} \div \underbrace{\text{Amount of ALPS treated water, etc. stored (m}^3\text{)}}_{\text{1.33 million m}^3\text{ (estimated value) as of March 2023}} < \text{Regulatory concentration limit of nuclide i} \times 0.01\ (\text{Bq/cm}^3)$$

In addition, since the inventory generated in the reactor will be divided by 1.33 million m^3 in Step 3, the easiness of transfer to contaminated water is equal to that of alkali earth metals (Sr-90, etc.) in Step 4, which means, for most of the nuclides to be removed in this step (transition metals, lanthanoids, actinoids, etc.), the set criterion is 100 times or more as conservative as their actual easiness of transfer. Together with the regulatory concentration limit of less than 1/100, the actual concentration will be less than 1/10,000 of the regulatory concentration limit. Therefore, the criterion set in this step is sufficiently conservative.

As a result, 93 nuclides will proceed to Step 4, while 113 nuclides will be removed.

Table 1.1.4-3 Nuclides that proceed to Step 4 (93 nuclides)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*46*	Ag-108m	*81*	Pr-144	*159*	Ac-227	*189*	Pu-240
3	C-14	*49*	Ag-110m	*82*	Pr-144m	*162*	Th-228	*190*	Pu-241
7	Cl-36	*50*	Cd-109	*86*	Pm-146	*164*	Th-230	*191*	Pu-242
16	Mn-54	*51*	Cd-113m	*87*	Pm-147	*165*	Th-231	*194*	Am-241
17	Fe-55	*55*	Sn-119m	*93*	Sm-151	*167*	Th-234	*195*	Am-242
18	Co-60	*56*	Sn-121	*95*	Eu-152	*168*	Pa-231	*196*	Am-242m
19	Ni-59	*57*	Sn-121m	*96*	Eu-154	*169*	Pa-233	*197*	Am-243
20	Ni-63	*59*	Sn-126	*97*	Eu-155	*172*	U-232	*199*	Cm-242
21	Zn-65	*60*	Sb-125	*104*	Ho-166m	*173*	U-233	*200*	Cm-243
23	Se-79	*61*	Sb-126	*106*	Tm-171	*174*	U-234	*201*	Cm-244
27	Sr-90	*62*	Sb-126m	*120*	Pt-193	*175*	U-235	*202*	Cm-245
29	Y-90	*67*	Te-125m	*121*	Tl-204	*176*	U-236	*203*	Cm-246
30	Zr-93	*70*	I-129	*130*	Pb-212	*177*	U-237	*208*	Cf-250
33	Nb-93m	*71*	Cs-134	*136*	Bi-212	*178*	U-238		
34	Nb-94	*72*	Cs-135	*141*	Po-212	*182*	Np-237		
35	Mo-93	*73*	Cs-137	*145*	Po-216	*183*	Np-238		
38	Tc-99	*74*	Ba-133	*149*	Rn-220	*184*	Np-239		
39	Ru-106	*75*	Ba-137m	*153*	Ra-223	*186*	Pu-236		
43	Rh-106	*79*	Ce-142	*154*	Ra-224	*187*	Pu-238		
44	Pd-107	*80*	Ce-144	*157*	Ra-228	*188*	Pu-239		

2.4 Step 4

2.4.1 Overview of evaluation of transfer to contaminated water

In Step 4 "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the transition assessment of nuclides to contaminated water?," an “evaluation of transfer to contaminated water” is performed using actual analysis results to check if the impact on the dose assessment is sufficiently small (1/100 or less of the regulatory concentration limit). Then, nuclides whose results are above the criterion will proceed to the next step.

In this step, nuclides which have proceeded to Step 4 are divided into groups according to radioactive equilibrium, isotopes, similarity in characteristics of nuclides, and based on the results of actual analysis of individual groups, the easiness of transfer into water is calculated by radionuclide (hereinafter, “transfer coefficient”). Concentrations of individual radionuclides are evaluated using the coefficient. Concretely, the following equation is used for the evaluation.

The reason behind the set criterion of 1/100 or less of the regulatory concentration limit is that the impact on the dose assessment is sufficiently small and that the target to be evaluated here is building stagnant water and strontium treated water before the inlet of ALPS. Given the subsequent ALPS treatment, the criterion is sufficiently conservative.

Evaluated concentration of radionuclides in contaminated water (Bq/L) = inventory*1 (Bq) × transfer coefficient*2 (1/L)

*1: In consideration of the timing when ALPS treated water is to be discharged into the sea, the evaluation result in 12 years after the earthquake is used.
*2: Calculated by the equation of Analysis result of contaminated water (Bq/L) ÷ Inventory (Bq). Results obtained with the base date set to March 11, 2011 are used.

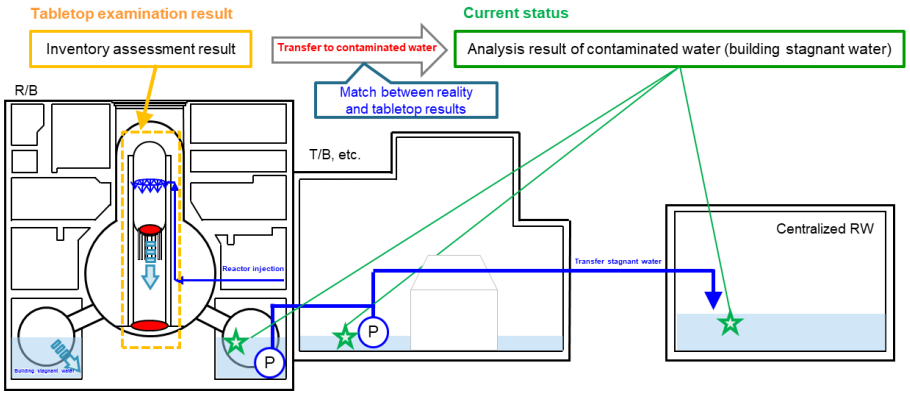


Figure 1.1.4-2 Image of the evaluation of transfer to contaminated water

2.4.2 Analysis results to be used for the evaluation of transfer to contaminated water

As shown in Table 1.1.4-4 and Figure 1.1.4-3, the analysis results to be used in the calculation of the transfer coefficient were classified and summarized into four types.

Since all contaminated water is collected in Centralized Rw (Process Main Building (PMB), High Temperature Incinerator Building (HTI)) and then treated with cesium adsorption system (SARRY/SARRY2), and this water finally becomes ALPS treated water. Therefore, the analysis results of Centralized Rw will be used in principle. However, only with the analysis results of Centralized Rw, it is impossible to obtain data on all radionuclides, and due to the reason that detection limits are high for building stagnant water because Cs concentration is high, available data on some nuclides is not enough. Therefore, as for those nuclides, analysis results of Units 1 to 4 building stagnant water, etc. and water before ALPS treatment will be used to complement the data.

Table 1.1.4-4 Classification of analysis results

No.	Classification of analyses	Details
[1]	Stagnant water in Unit 1 to 4 buildings	Analysis results of stagnant water in Unit 1 to 4 PCVs and buildings
[2]	Stagnant water in Centralized Rw building	Analysis results of water in Centralized Rw (PMB/HTI), at the inlet of SARRY, etc.
[3]	Cesium adsorption system - inlet of ALPS	Analysis results of water from the outlet of cesium adsorption system to the inlet of ALPS
[4]	Outlet of ALPS	Analysis results of water after ALPS treatment

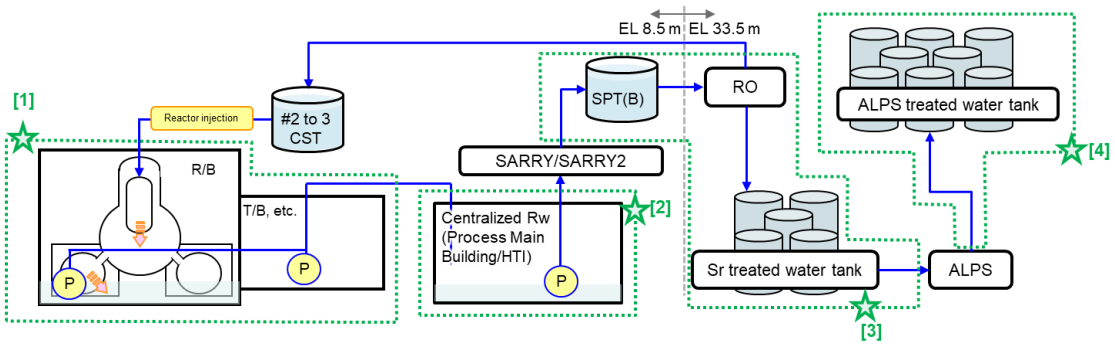
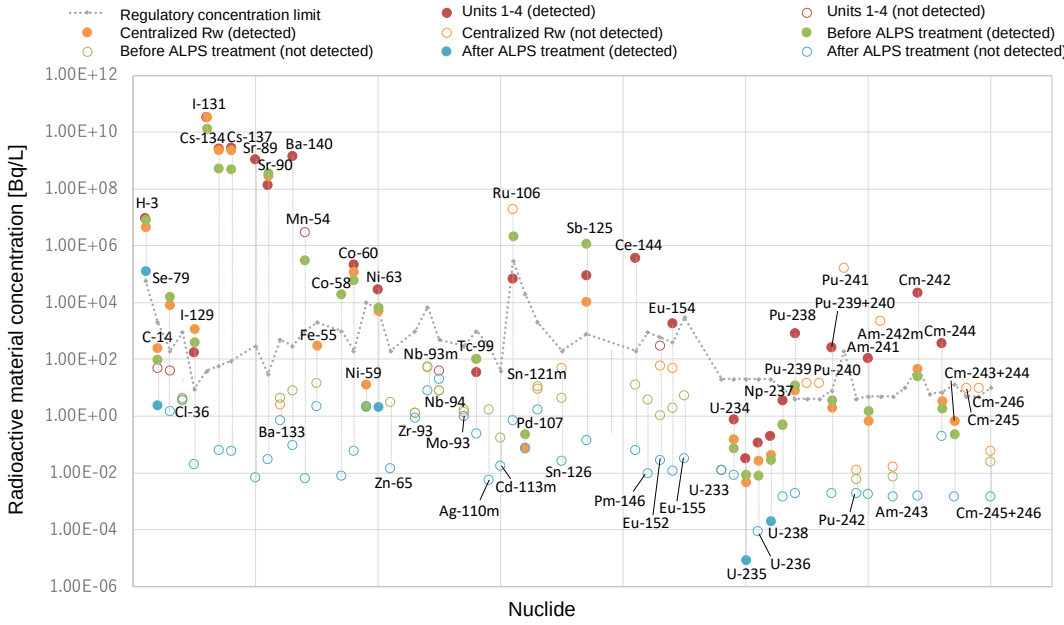


Figure 1.1.4-3 Classification of analysis results to be used for the evaluation of transfer

The data was classified according to the sampling locations shown in Table 1.1.4-4, and analysis results of the radionuclides which have proceeded to Step 4 (including detected values of isotopes with a short half-life) was summarized in Figure 1.1.4-4. In Figure 1.1.4-4, the detected values for No.1 to 3 in Table 1.1.4-4 are the maximum values which have been decay corrected until March 11, 2011, while non-detected values are minimum values of the analytical data. The values for No.4 are minimum values of the analysis results.
This figure shows the concentration ranges of individual radionuclides throughout the process from building stagnant water to ALPS treated water. It shows regulatory concentration limits as well to enable the comparison of the analysis results with regulatory limits.



*1: The results show that Sr-89 was detected at the inlet of existing ALPS during the period from 2013 to 2014, but it was excluded from the evaluation because it is a pseudo detection.

*2: For the FRAnDLi data on Pu-238, Am-241, and Cm-242, the analyzed values were simply decay corrected up to March 11, 2011. However, given that those nuclides are produced from parent nuclides, decay correction that takes into account the production of the parent nuclides was performed.

Figure 1.1.4-4 Summary of analysis results

Figure 1.1.4-4 was developed using the following data: FRAnDLi data published by JAEA that are available as of September 2022 (including data published by TEPCO), analyses of 62 nuclides at the time of ALPS performance confirmation, etc. (FY 2013 to 2022), data of water before and after ALPS treatment which is available on the treated water portal, data of ALPS treated water, etc. tanks, etc. When using data on detection limits, only data which shows detection limit values was included in the aggregation, while data which only shows “N.D.” was excluded. Table 1.1.4-5 shows the number of pieces of analytical data for each radionuclide.

Table 1.1.4-5 Number of analyzed data (1/2)

Nuclide	[1] Units 1 - 4	[2] Centralized Rw	[3] Before ALPS treatment	[4] After ALPS treatment
	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)
H-3	22(22)	28(28)	310(310)	486(486)
C-14	5(0)	15(1)	25(13)	341(341)
Cl-36	0(0)	10(0)	12(0)	3(0)
Mn-54	2(0)	0(0)	1194(290)	1893(14)
Fe-55	0(0)	1(1)	1(0)	3(0)
Co-58	0(0)	0(0)	26(5)	42(0)
Co-60	40(20)	41(27)	1568(1404)	2330(2187)
Ni-59	0(0)	3(1)	12(1)	3(0)
Ni-63	13(10)	21(16)	92(48)	55(1)
Zn-65	0(0)	0(0)	21(0)	42(0)
Se-79	10(0)	15(9)	47(12)	5(0)
Sr-89	4(3)	0(0)	65(17※1)	128(0)
Sr-90	41(40)	40(40)	844(833)	1782(775)
Zr-93	0(0)	1(0)	1(0)	3(0)
Nb-93m	0(0)	1(0)	1(0)	3(0)
Nb-94	36(0)	38(0)	67(0)	2(0)
Mo-93	0(0)	1(0)	1(0)	3(0)
Tc-99	5(2)	21(7)	246(221)	898(105)
Ru-106	6(1)	2(0)	1255(972)	2376(1431)
Pd-107	0(0)	1(1)	1(1)	1(0)
Ag-110m	0(0)	0(0)	21(0)	42(0)
Cd-113m	0(0)	0(0)	21(0)	42(0)
Sn-121m	0(0)	1(0)	1(0)	3(0)
Sn-126	0(0)	2(0)	32(0)	44(0)
Sb-125	27(9)	14(10)	1618(1605)	2378(1589)
I-129	22(4)	30(10)	449(380)	1840(1550)
I-131	4(0)	16(2)	43(22)	0(0)

*1: The results show that Sr-89 was detected at the inlet of existing ALPS during the period from 2013 to 2014, but it was excluded from the evaluation because it is a pseudo detection.

*2: Although it has not proceeded to Step 4, Te-123m (half-life of 119 days) was detected on September 9, 2019 at the outlet of added ALPS (B) at 1.1E - 01 Bq/L, which is less than 1/100 of the regulatory concentration limit (6.0E + 01 Bq/L) (The detection limit is 0.9E - 01 Bq/L).

Table 1.1.4-5 Number of analyzed data (2/2)

Nuclide	[1] Units 1 - 4	[2] Centralized Rw	[3] Before ALPS treatment	[4] After ALPS treatment
	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)	Number of data items (of which, number of items detected)
Cs-134	190(190)	260(260)	1502(1261)	2384(364)
Cs-137	224(224)	300(300)	1745(1699)	2391(1512)
Ba-133	0(0)	1(0)	1(0)	3(0)
Ba-140	4(2)	0(0)	21(0)	42(0)
Ce-144	3(3)	0(0)	21(0)	42(0)
Pm-146	0(0)	0(0)	21(0)	42(0)
Eu-152	36(0)	40(0)	92(0)	44(0)
Eu-154	38(2)	40(0)	113(0)	47(0)
Eu-155	0(0)	0(0)	21(0)	42(0)
U-233	0(0)	3(0)	8(0)	3(0)
U-234	25(7)	23(11)	22(7)	3(0)
U-235	26(19)	23(14)	44(14)	6(3※1)
U-236	20(7)	23(12)	22(8)	3(0)
U-238	31(26)	23(18)	44(20)	6(3※1)
Np-237	9(9)	13(9)	16(7)	3(0)
Pu-238	38(17)	41(22)	73(16)	8(0)
Pu-239	0(0)	1(0)	0(0)	0(0)
Pu-240	0(0)	1(0)	0(0)	0(0)
Pu-239+240	38(12)	40(12)	73(10)	8(0)
Pu-241	0(0)	1(0)	0(0)	0(0)
Pu-242	0(0)	4(0)	8(0)	3(0)
Am-241	37(11)	41(6)	62(3)	7(0)
Am-242m	0(0)	1(0)	0(0)	0(0)
Am-243	0(0)	3(0)	8(0)	3(0)
Cm-242	7(2)	1(1)	2(1)	3(0)
Cm-244	37(7)	40(2)	61(6)	4(0)
Cm-243+244	0(0)	1(1)	1(1)	3(0)
Cm-245	0(0)	1(0)	0(0)	0(0)
Cm-246	0(0)	1(0)	0(0)	0(0)

*1: Natural uranium contained in ALPS treated water was detected (See Attachment-2)

2.4.3 Grouping of nuclides

2.4.3.1 Concept behind the grouping of nuclides

(1) Progeny nuclides in radioactive equilibrium

Among the nuclides which have proceeded to Step 4, nuclides that exist in the radioactive equilibrium are shown in Tables 1.1.4-6 and 1.1.4-7. The progeny nuclides shown in Table 1.1.4-6 have short half-lives, and in 12 years after the earthquake when ALPS treated water is set to be discharged into the sea, they exist only as nuclides produced by decay of parent nuclides. Therefore, in the evaluation of transfer to contaminated water, they are assumed to behave together with the parent nuclides. On the other hand, the half-lives of the progeny nuclides shown in Table 1.1.4-7 are long, and they have not reached the radioactive equilibrium even as of 2022. Therefore, the progeny nuclides will be evaluated separately from the parent nuclides.

Table 1.1.4-6 Progeny nuclides that are in radioactive equilibrium and assumed to behave together with the parent

No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Sr-90	2.88E+01 [y]	Y-90	2.67 [d]
2	Ru-106	1.02E+00 [y]	Rh-106	30.07 [s]
3	Sn-121m	4.39E+01 [y]	Sn-121	1.13 [d]
4	Sn-126	2.30E+05 [y]	Sb-126 Sb-126m	12.35 [d] 19.15 [m]
5	Sb-125	2.76E+00 [y]	Te-125m	57.40 [d]
6	Cs-137	3.01E+01 [y]	Ba-137m	2.552 [m]
7	Ce-144	7.81E-01 [y]	Pr-144 Pr-144m	17.28 [m] 7.2 [m]
8	Pu-241	1.43E+01 [y]	U-237	6.752 [d]
9	Am-242m	1.41E+02 [y]	Np238	2.112 [d]
10	Am-242m	1.41E+02 [y]	Am-242 Cm-242	16.02 [h] 162.8 [d]
11	Am-243	7.37E+03 [y]	Np-239	2.356 [d]

Table 1.1.4-7 Progeny nuclides that are in radioactive equilibrium but assumed to behave differently with the parent

No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Zr-93	1.61E+06 [y]	Nb-93m	1.61E+01 [y]

(2) Nuclides produced from decay chains of uranium, neptunium, etc.

Among the nuclides which have proceeded to Step 4, the nuclides shown in red frames in Figure 1.1.4-5 are nuclides produced from decay chains of uranium, neptunium, etc. In the evaluation of transfer to contaminated water, those nuclides will be evaluated under assumption that they are behaving together with the parent nuclides (neptunium and uranium).

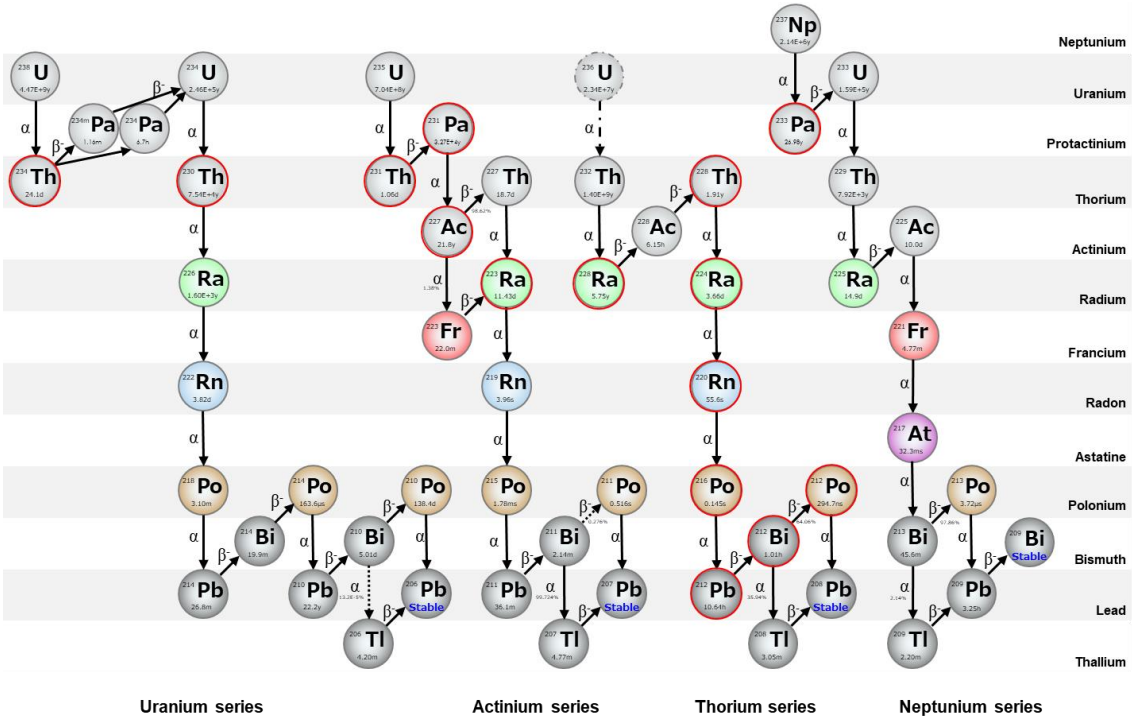


Figure 1.1.4-5 Nuclides produced from decay chains of uranium, neptunium, etc.

(3) Nuclides showing similarities in characteristics underwater

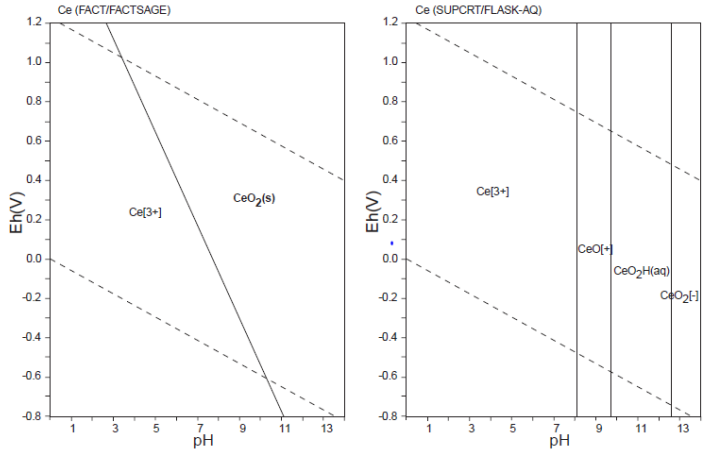
In addition to nuclides in (1) and (2), there are nuclides for which there is no available analytical data because analytical techniques have not been established as of 2022, because it is difficult to analyze individually, or for other reasons. For those nuclides, the similarities of their chemical forms underwater, ion diameter, etc. will be checked, and if it is confirmed that they have similarities, they will be evaluated while assuming that they are likely to transfer to water as easily as the similar nuclides with available analytical data. When confirming the similarities, the chemical form underwater will be checked with Eh-pH diagrams, etc., and in addition to that, the ion diameter and adsorption performance in the water treatment will also be considered.

(1) Lanthanoids (Pm, Sm, Ho, Tm)

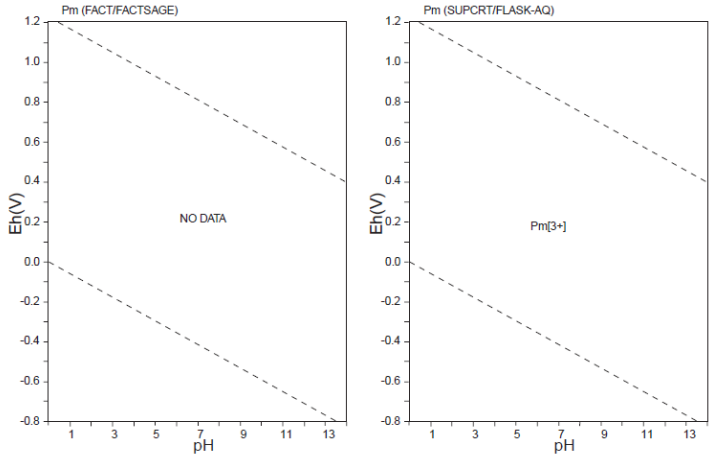
As lanthanoids to be removed by ALPS, Ce-141, Ce-144, Pm-146, Pm-148, Pm-148m, Eu-152, Eu-154, Eu-155, Gd-153, Tb-160 are analyzed and assessed. However, they have never been detected in the analyses of water before ALPS treatment. Eu-152 and Eu-154 in building stagnant water have not been detected neither through the approximately 80 analyses performed in the past. On the other hand, Ce-144 and Eu-154 have been detected in samples of PCV stagnant water which were collected during past investigations in Units 2 and 3 PCVs.

This data on Ce-144 and Eu-154, which were detected in the PCVs, will be used for this evaluation of transfer to contaminated water for other lanthanoids, too. Therefore, the validity was checked with Eh-pH diagrams (See Figure 1.1.4-6).

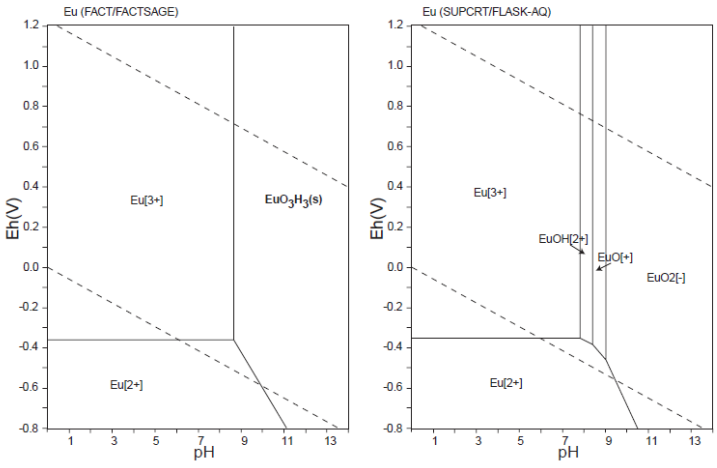
The verification has revealed that lanthanoids have a similarity in that they are stable trivalent cation at hydrogen-ion exponents (pH) of 6 to 8, pH range in reactor injection water and building stagnant water. In addition, lanthanoids are well known for their similarity in properties. Considering the verification results obtained this time, it is adequate to evaluate all lanthanoids as one group.



(1) Cerium (Ce)



(2) Promethium (Pm)

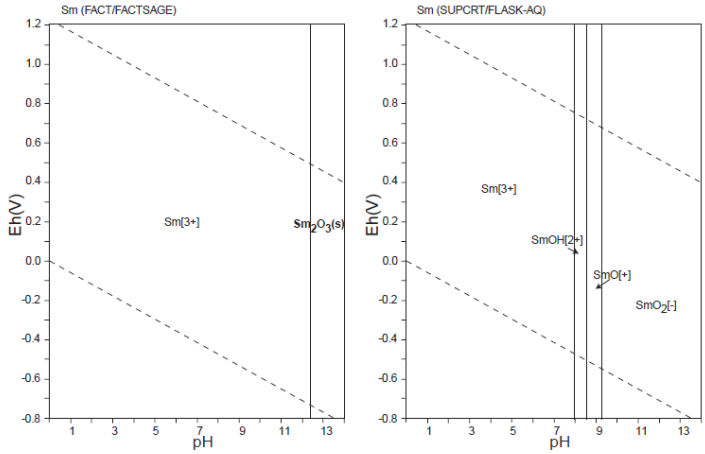


(3) Europium (Eu)

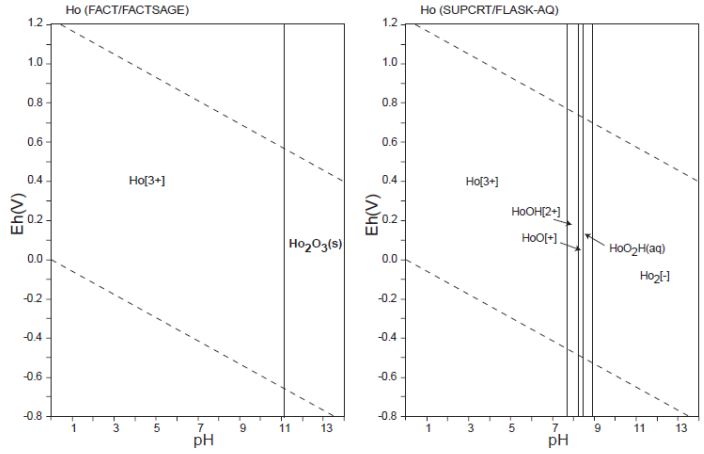
* Fact: Database attached to FactSage 5.2, GTT-Technologies software
Supcrt: Database used in software developed by LLNL researchers SUPCRT92

Excerpt from “Atlas of Eh-pH diagrams - Intercomparison of themodynamic databases”
(National Institute of Advanced Industrial Science and Technology)

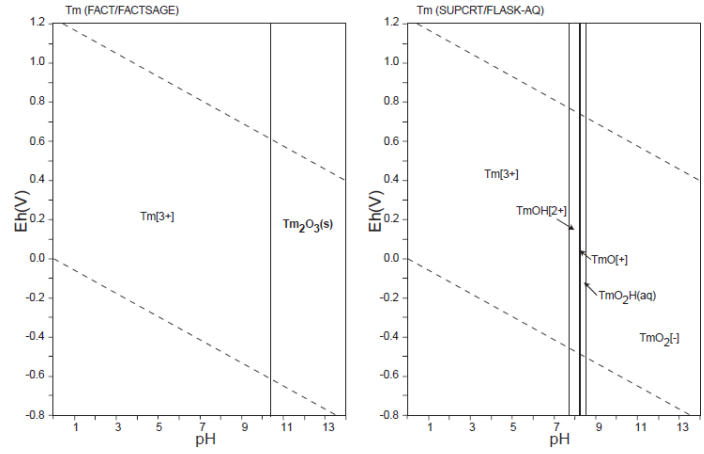
Figure 1.1.4-6 Comparison among lanthanoids (1/2)



(4) Samarium (Sm)



(5) Holmium (Ho)



(6) Thulium (Tm)

* Fact: Database attached to FactSage 5.2, GTT-Technologies software
Supcrt: Database used in software developed by LLNL researchers SUPCRT92
Excerpt from "Atlas of Eh-pH diagrams - Intercomparison of themodynamic databases"
(National Institute of Advanced Industrial Science and Technology)

Figure 1.1.4-6 Comparison among lanthanoids (2/2)

(2) Platinum group (Ru, Pd, Pt)

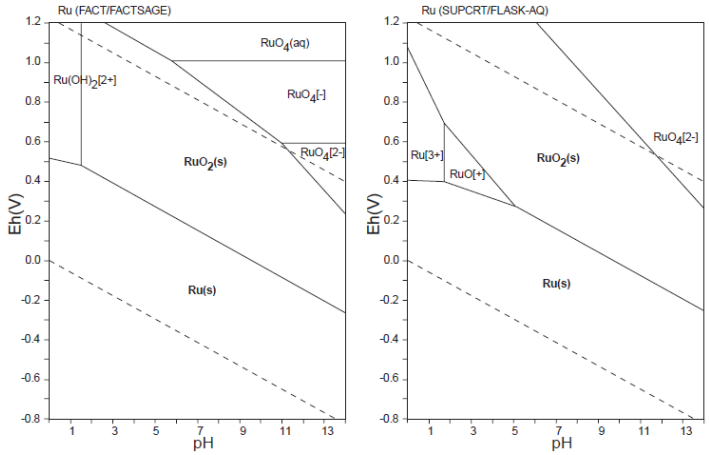
As for platinum group, Ru-103 (Rh-103m) and Ru-106 (Rh-106) have been analyzed as nuclides to be removed by ALPS, and Ru-106 (Rh -106) has been detected so far (Both of the Rh are produced from decay of Ru). Ru-106 is a representative nuclide to be evaluated to check the performance of ALPS, being among the major seven nuclides. In addition, Pd was analyzed through the nuclide analysis which was performed additionally this time, and it was found to exist at a very low concentration in building stagnant water and strontium treated water before ALPS treatment. As for Pt-193, although it has proceeded to Step 4, it has not been analyzed so far due to the lack of measurement method that can measure the nuclide independently.

Therefore, when evaluating the transfer of Pt to contaminated water based on the analysis results of Ru-106 and Pd-107, the validity was checked with Eh-pH diagrams, etc. (See Figure 1.1.4-7).

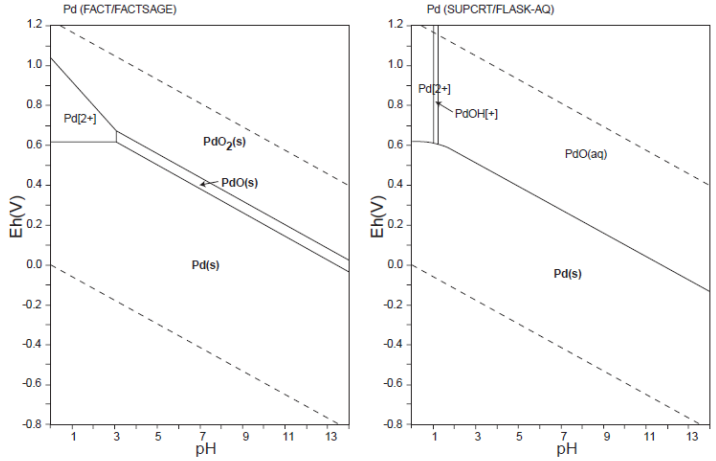
The verification has revealed that platinum group exists in solid state at hydrogen-ion exponents (pH) of 6 to 8, pH range in reactor injection water and building stagnant water. Ru was found to exist as a single metal or solid of oxides, and Pd and Pt as solid of single metal; the their solubility in water was found to be very small as follows: 2.0E-10 mol/L[*1] for Ru (single metal), 6.0E-10 mol/L[*1] for RU (oxides), 1.0E-09 mol/L[*2] for Pd, 4.1E-10 mol/L[*1] for Pt (The solubility of Ru (oxides) was calculated based on values mentioned in reference documents and from the solubility of anhydrous compounds, which is the most conservative solubility). Given that physical and chemical properties of platinum group elements are generally similar to one another and that they do not react with water and are not easily affected by acids and bases, it is appropriate to handle Pt together with Ru-106 and Pd-107 as one group in evaluating the transfer to contaminated water.

*1: Excerpt from “The International Platinum Group Metals Association, “Safe Use of Platinum Group Metals in the Workplace”, Chapter 2 PHYSICAL AND CHEMICAL PROPERTIES OF PLATINUM GROUP METALS (2017)”

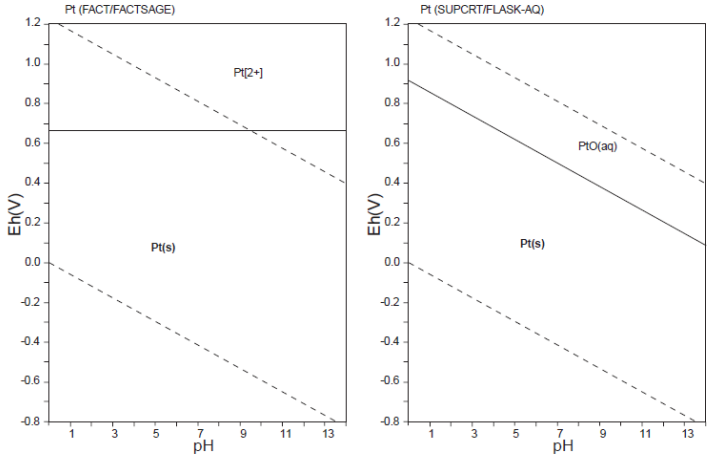
*2: Excerpt from “Technical reliability of geological disposal of high-level radioactive waste in Japan - second summary of research and development on geological disposal -” (2000 Report)



(1) Ruthenium (Ru)



(2) Palladium (Pd)



(3) Platinum (Pt)

* Fact: Database attached to FactSage 5.2, GTT-Technologies software
Supcrt: Database used in software developed by LLNL researchers SUPCRT92
Excerpt from "Atlas of Eh-pH diagrams - Intercomparison of themodynamic databases"
(National Institute of Advanced Industrial Science and Technology)

Figure 1.1.4-7 Comparison among platinum group elements

(3) Thallium (Tl)

As for thallium, although Tl-204 has proceeded to Step 4, it has not been analyzed so far due to the lack of measurement method that can measure the nuclide independently. However, this nuclide generally emits beta particles when disintegrating, and the energy is as high as about 760 keV. Considering that there is no deviation between the result of total beta analysis in ALPS treated water and the analysis of the major seven nuclides plus Tc-99 and C-14, it is reasonable to conclude that the nuclide does not exists in ALPS treated water at a significant concentration.

On the other hand, through the survey performed at the time of the evaluation of transfer to contaminated water this time, thallium was found to have properties similar to alkali metal (Cs). Therefore, the validity will be explained with Eh-pH diagrams, ion diameter, and adsorption performance during treatment.

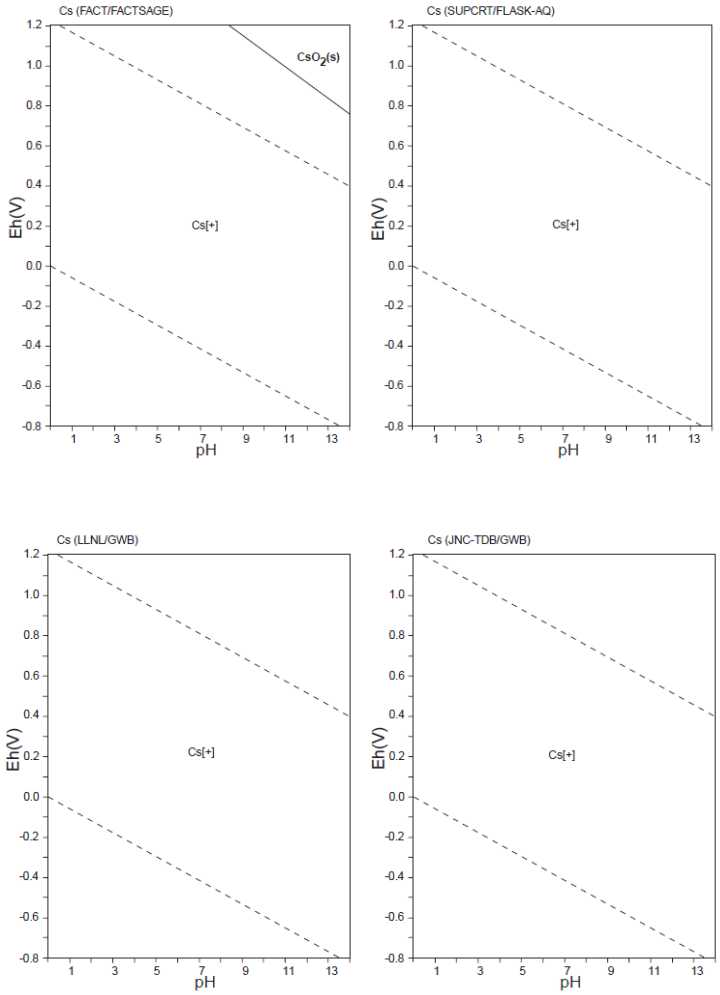
Checking with Eh-pH diagrams has revealed that Tl, which is element 13, is a stable monovalent cation at hydrogen-ion exponents (pH) of 6 to 8, pH range in reactor injection water and building stagnant water (See Figure 1.1.4-8). In addition, the diameter of TI ion, which is 1.64 Å (6-coordinate) and 1.73 Å (8-coordinate), is in the middle between the diameter of alkali metal Cs ion, 1.81 Å (6-coordinate) and 1.81 Å (8-coordinate), and that of K ion, 1.51 Å (4-coordinate), 1.52Å (6-coordinate), and 1.65 Å (8-coordinate); the selectivity of positive ions using zeolite has been evaluated as equal to that of K ions[*1]. It is also known[*2] that TI ions in waste liquid generated in mines are adsorbed to ferrocyanide compounds, activated carbon, titanic acid and clay minerals in the same way as Cs ions, and a report[*3] says they have the same level of adsorption performance to soil as Cs.

Given the above, it is reasonable to evaluate thallium together with alkali metals as the same group while assuming that it will behave in the same way throughout the process from the transfer to contaminated water to water treatment.

*1: Nitta and Aomura, "Study on the Site Selectivity of Exchangeable Cation in Synthetic Zeolite A"

*2: Hariyin Xu, Yuanling Luo, et al.“Removal of thallium in water-wastewater”, 2019-Water Research
Juan Liu, Xuwen Luo, et al.“hallium pollution in China and removal technologies for waters”, 2019-Environment International
L.G.Twidwell, C. Williams-Beam, “Potential Technologies for Removing Thallium from Mine and Process Wastewater”, Twidwell2002
Kobayashi, Yamamoto, and Akashi, “Prussian Blue as an Agent for Decontamination of 137Cs in Radiation Accidents”

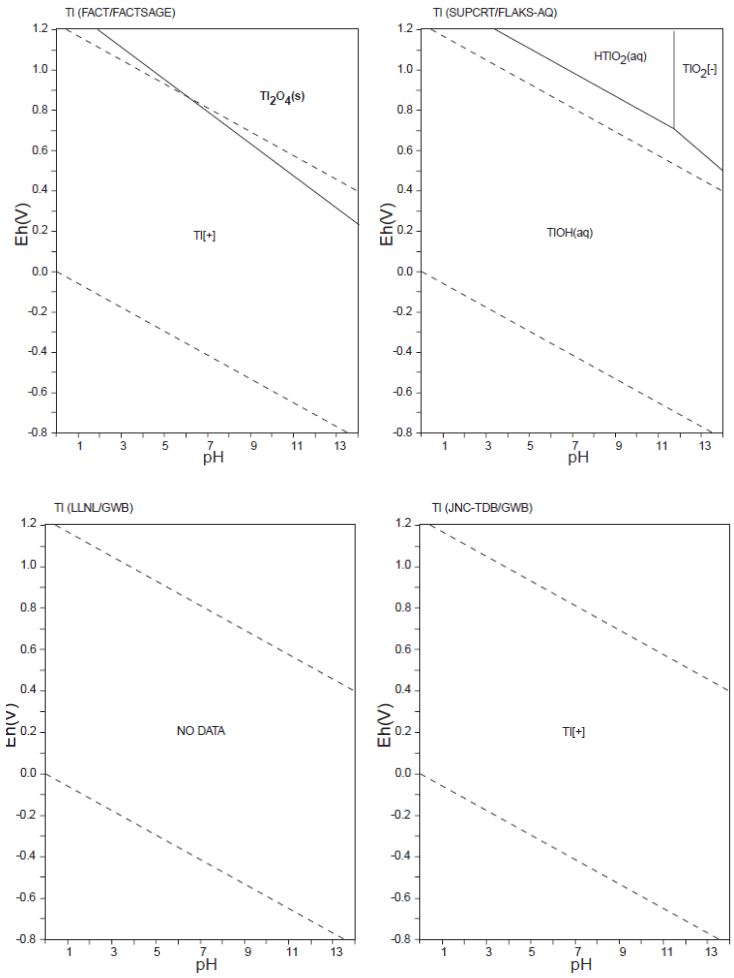
*3: John E. Till, Helen A. Grogan, "Radiobiological Risk Assessment and Environmental Analysis" Oxford University Press (2008).



(1) Cesium (Cs)

* Fact: Database attached to FactSage 5.2, GTT-Technologies software
Supcrt: Database used in software developed by LLNL researchers SUPCRT92
LLNL: Database that normally attached to software developed by the University of Illinois
JNC-TDB: Database developed by the former Japan Nuclear Cycle Development Institute
Excerpt from "Atlas of Eh-pH diagrams - Intercomparison of themodynamic databases"
(National Institute of Advanced Industrial Science and Technology)

Figure 1.1.4-8 Comparison between thallium and cesium (1/2)



(2) Thallium (Tl)

* Fact: Database attached to FactSage 5.2, GTT-Technologies software
Supcrt: Database used in software developed by LLNL researchers SUPCRT92
LLNL: Database that normally attached to software developed by the University of Illinois
JNC-TDB: Database developed by the former Japan Nuclear Cycle Development Institute
Excerpt from "Atlas of Eh-pH diagrams - Intercomparison of themodynamic databases"
(National Institute of Advanced Industrial Science and Technology)

Figure 1.1.4-8 Comparison between thallium and cesium (2/2)

(4) Californium (Cf)

As for californium, although Cf-250 has proceeded to Step 4, no analysis has been performed. However, this nuclide emits alpha particles when disintegrating. Considering that the result of the total α analysis was not detected in the ALPS treated water, it is reasonable to conclude that the nuclide does not exist in ALPS treated water at a significant concentration.

On the other hand, in the evaluation of transfer to contaminated water this time, Cf was evaluated to have properties similar to those of Am and Cm. Therefore, its chemical form underwater and ion diameters were confirmed to explain the validity.

For californium, although it was impossible to check the validity with Eh-pH diagrams, there is a description that it is a stable trivalent cation in solution and that its chemical behavior is very similar to that of trivalent superplutonium elements (Am, Cm)[*1]. It has also been confirmed that the trivalent cations, Am, Cm and Cf, have almost the same diameters: 1.12 Å (6-coordinate), 1.11 Å (6-coordinate), and 1.09 Å (6-coordinate)[*2] respectively.

Given the above, it is reasonable to evaluate the transfer of Cf to contaminated water together with Am and Cm as one group.

*1: Laster R.Morss, Norman M.Edelstein, Jean Fuger, "The Chemistry of The Actinide And Transactinide Elements_4thEd"

*2: R.D.Shannon, "Revised Effective Ionic Radii and Systematic Studies of Interatomic Distances in Halides and Chalcogenides"

2.4.3.2 Results of the grouping of nuclides

Tables 1.1.4-8 to 1.1.4-19 show the nuclide groups obtained as a result of the grouping in Step 4 based on the concept behind the grouping of nuclides which are shown in paragraph 2.4.3.1. The nuclides in one group will be evaluated while assuming that they will behave in the same way throughout the process up to ALPS treatment.

Nuclides that have been classified into a group will be compared with the representative nuclide that has the largest impact on the dose assessment among the nuclides in the group. If the relative ratio of a nuclide to the representative one is 1/100 or less, it will be excluded. This is based on the following concept: Because nuclides in one group behave in the same way, the inventory ratio will be maintained throughout the treatment. Considering the dose assessment of ALPS treated water in which the ratio to the regulatory concentration limits is less than 1, it is reasonable to conclude that the impact on the dose assessment of nuclides whose relative ratio is 1/100 or less is negligible if the representative nuclide has been removed adequately.

Table 1.1.4-8 Group 1 (Ni isotopes)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ni-59	7.60E+04 [y]	7.3E+13	1.0E+04	0.0052	*Excluded*
Ni-63	1.01E+02 [y]	8.5E+15	6.0E+03	1	Representative nuclide

Table 1.1.4-9 Group 2 (Sr-90 radioactive equilibrium)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sr-90	2.88E+01 [y]	3.9E+17	3.0E+01	1	Representative nuclide
Y-90	2.67 [d]	3.9E+17	3.0E+02	0.10	

Table 1.1.4-10 Group 3 (Nb isotopes)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Nb-93m	1.61E+01 [y]	6.3E+12	7.0E+03	0.50	
Nb-94	2.03E+04 [y]	9.0E+11	5.0E+02	1	Representative nuclide

*In the future, Nb-93 m will be in radioactive equilibrium with Zr-93, so the evaluation is tentative.

Table 1.1.4-11 Group 4 (Ru-106 radioactive equilibrium)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ru-106	1.02E+00 [y]	7.5E+14	1.0E+02	1	Representative nuclide
Rh-106	30.07 [s]	7.6E+14	3.0E+05	0.00033	*Excluded*

Table 1.1.4-12 Group 5 (Sn isotopes, Sn-126 radioactive equilibrium)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sn-119m	293.1 [d]	5.9E+10	2.0E+03	0.00065	*Excluded*
Sn-121	1.13 [d]	7.1E+13	4.0E+03	0.39	
Sn-121m	4.39E+01 [y]	9.1E+13	2.0E+03	1	Representative nuclide
Sn-126	2.30E+05 [y]	1.6E+12	2.0E+02	0.18	
Sb-126	12.35 [d]	2.3E+11	4.0E+02	0.012	
Sb-126m	19.15 [m]	1.6E+12	2.0E+04	0.0018	*Excluded*

Table 1.1.4-13 Group 6 (Sb-125 radioactive equilibrium)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Sb-125	2.76E+00 [y]	2.9E+15	8.0E+02	1	Representative nuclide
Te-125m	57.40 [d]	1.1E+15	9.0E+02	0.33	

Table 1.1.4-14 Group 7 (Cs isotopes, Cs-137 radioactive equilibrium, Tl-204)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Cs-134	2.06E+00 [y]	2.5E+16	6.0E+01	0.070	
Cs-135	2.30E+06 [y]	3.5E+12	6.0E+02	0.00000099	*Excluded*
Cs-137	3.01E+01 [y]	5.3E+17	9.0E+01	1	Representative nuclide
Ba-137m	2.552 [m]	5.0E+17	8.0E+05	0.00011	*Excluded*
Tl-204	3.78E+00 [y]	1.4E+13	7.0E+02	0.0000035	*Excluded*

Table 1.1.4-15 Group 8 (Lanthanoids)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Ce-142	5.00E+16 [y]	1.8E+08	7.0E-01	0.0000082	*Excluded*
Ce-144	284.91 [d]	1.7E+14	2.0E+02	0.027	
Pr-144	17.28 [m]	1.7E+14	2.0E+04	0.00027	*Excluded*
Pr-144m	7.2 [m]	2.5E+12	4.0E+04	0.000002	*Excluded*
Pm-146	5.53E+00 [y]	3.6E+12	9.0E+02	0.00013	*Excluded*
Pm-147	2.62E+00 [y]	5.6E+16	3.0E+03	0.59	
Sm-151	9.00E+01 [y]	2.2E+15	8.0E+03	0.0085	*
Eu-152	1.35E+01 [y]	9.0E+12	6.0E+02	0.00048	*Excluded*
Eu-154	8.60E+00 [y]	1.3E+16	4.0E+02	1	Representative nuclide
Eu-155	4.75E+00 [y]	3.8E+15	3.0E+03	0.04	
Ho-166m	1.20E+03 [y]	2.6E+10	4.0E+02	0.000002	*Excluded*
Tm-171	1.92E+00 [y]	5.3E+12	7.0E+03	0.000024	*Excluded*

*: It is not excluded because it has a longer half-life than the representative nuclide Eu-154 and the relative ratio exceeds 0.01 during the discharge period.

Table 1.1.4-16 Group 9 (U isotopes)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
U-232	6.89E+02 [y]	1.2E+11	3.0E+00	0.06	
U-233	1.59E+05 [y]	4.0E+08	2.0E+01	0.000030	*Excluded*
U-234	2.45E+05 [y]	1.4E+13	2.0E+01	1	Representative nuclide
U-235	7.04E+08 [y]	3.7E+11	2.0E+01	0.027	
U-236	2.34E+07 [y]	2.0E+12	2.0E+01	0.15	
U-238	4.47E+09 [y]	3.0E+12	2.0E+01	0.22	

Table 1.1.4-17 Group 10 (Pu isotopes)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Pu-236	2.86E+00 [y]	1.1E+11	1.0E+01	0.0000027	*Excluded*
Pu-238	8.77E+01 [y]	1.6E+16	4.0E+00	1	Representative nuclide
Pu-239	2.41E+04 [y]	2.6E+15	4.0E+00	0.17	
Pu-240	6.56E+03 [y]	3.3E+15	4.0E+00	0.21	
Pu-241	1.43E+01 [y]	4.3E+17	2.0E+02	0.55	
U-237	6.752 [d]	1.1E+13	1.0E+03	0.0000027	*Excluded*

Table 1.1.4-18 Group 11 (Am isotopes, Am242m/Am-243 radioactive equilibrium)

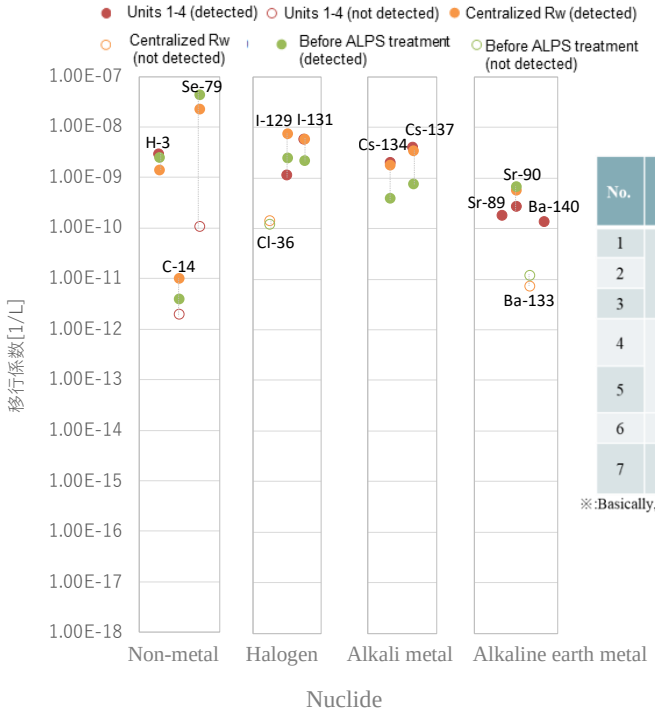
Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Am-241	4.33E+02 [y]	1.3E+16	5.0E+00	1	Representative nuclide
Am-242	16.02 [h]	9.0E+13	3.0E+03	0.000011	*Excluded*
Am-242m	1.41E+02 [y]	9.0E+13	5.0E+00	0.0069	*Excluded*
Am-243	7.37E+03 [y]	8.5E+13	5.0E+00	0.0065	*Excluded*
Np-238	2.112 [d]	4.5E+11	9.0E+02	0.00000019	*Excluded*
Np-239	2.356 [d]	8.5E+13	1.0E+03	0.000032	*Excluded*
Cm-242	162.8 [d]	7.4E+13	6.0E+01	0.00047	*Excluded*

Table 1.1.4-19 Group 12 (Cm isotopes, Cf-250)

Nuclide	Half-life	Inventory (in 12 years) [Bq]	Regulatory concentration limit [Bq/L]	Relative ratio to the representative nuclide	Evaluation result
Cm-243	2.91E+01 [y]	7.5E+13	6.0E+00	0.014	
Cm-244	1.81E+01 [y]	6.5E+15	7.0E+00	1	Representative nuclide
Cm-245	8.42E+03 [y]	1.1E+12	5.0E+00	0.00024	*Excluded*
Cm-246	4.76E+03 [y]	1.8E+12	5.0E+00	0.000038	*Excluded*

2.4.3 Evaluation of transfer coefficients

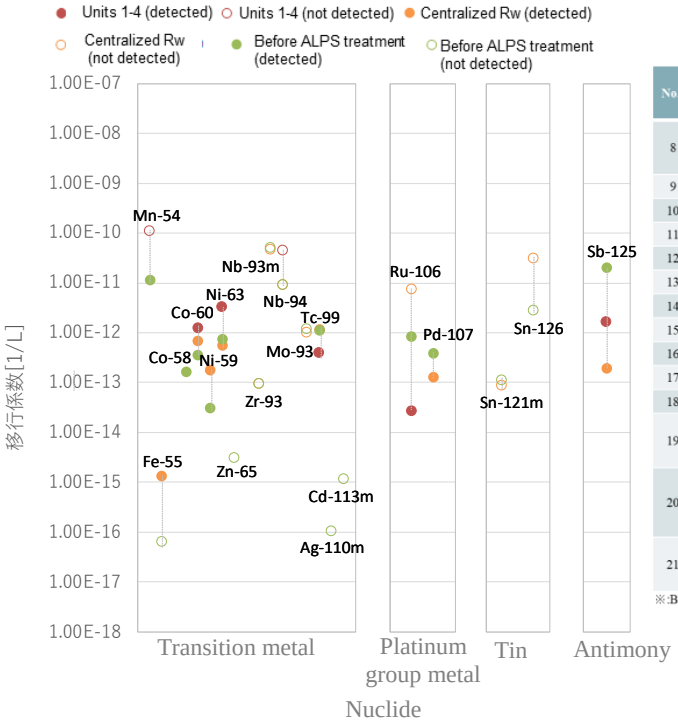
The transfer coefficients for the groups set in paragraph 2.4.2 and other individual nuclides are calculated using the results of the inventory assessment on March 11, 2011 based on the analytical data shown in Figure 1.1.4-4. As described previously, the maximum value among the result of the Centralized Rw is basically used for the evaluation of transfer coefficients, and the transfer coefficients rounded up to a higher level are used for the evaluation in consideration of the variation in the analytical values.



No.	Group		Transfer coefficient ※ [1/L]	Application Element	Remarks
1	Non-metals	Tritium	1.0E-08	H	
2		Carbon	1.0E-10	C	
3		Selenium	1.0E-07	Se	
4	Halogen	Chlorine	1.0E-09	Cl	
5		Iodine	1.0E-08	I	
6	Alkali metal		1.0E-08	Cs	
7	Alkali-earth metal		1.0E-09	Sr, Ba	

※:Basically, the value of the upward digit of the max. value of the central Rw is indicated.

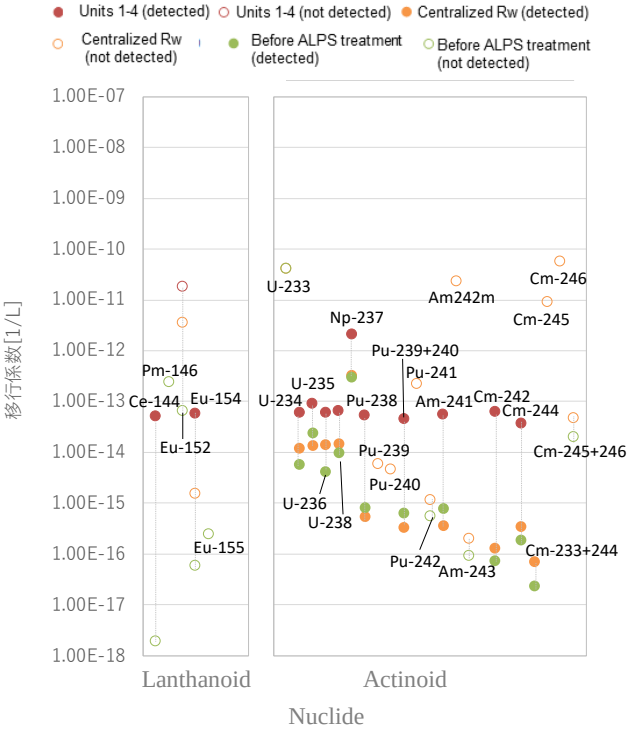
Figure 1.1.4-9 Transfer coefficients (1/3)



No.	Group		Transfer coefficient ※ [1/L]	Application Element	Remarks
8	Transition metal	Manganese	1.0E-10	Mn	Use the detected data before ALPS treatment
9		Iron	1.0E-14	Fe	Solid (residue)
10		Cobalt	1.0E-12	Co	From Co-60 data
11		Nickel	1.0E-12	Ni	From Ni-63 data
12		Zinc	1.0E-14	Zn	No detected value
13		Zirconium	1.0E-13	Zr	No detected value
14		Niobium	1.0E-10	Nb	No detected value
15		Molybdenum	1.0E-11	Mo	No detected value
16		Technetium	1.0E-11	Tc	
17		Silver	1.0E-15	Ag	No detected value
18		Cadmium	1.0E-14	Cd	No detected value
19	Platinum group metal		1.0E-12	Ru, Pd, Pt	Use before ALPS treatment for Ru and Pd
20	Tin		1.0E-13	Sn	Since there is no detected value, use the lower detection limit of Sn-121m.
21	Antimony		1.0E-10	Sb	Use data before ALPS treatment with many data

※:Basically, the value of the upward digit of the max. value of the central Rw is indicated.

Figure 1.1.4-9 Transfer coefficients (2/3)



No.	Group		Transfer coefficient ※ [1/L]	Application Element	Remarks
22	Lanthanod		1.0E-13	Ce, Pm, Sm, Eu, Ho, Tm	Since there is no detected value after the central Rw, use the largest value among detected values of Ce-144, Eu-154 (within PCV of Unit 3) that has been confirmed .
23	Actinoid	Uranium	1.0E-13	U	
24		Neptunium	1.0E-12	Np	
25		Plutonium	1.0E-15	Pu	
26		Trans-plutonium	1.0E-15	Am, Cm, Cf	

※:Basically, the value of the upward digit of the max. value of the central Rw is indicated.

Figure 1.1.4-9 Transfer coefficients (3/3)

2.4.4 Results of the evaluation of transfer to contaminated water

As a result of the evaluation of transfer performed with the transfer coefficients obtained in paragraph 2.4.3, the number of nuclides that are to proceed to Step 5 is 37 nuclides, while 56 nuclides are to be excluded.

Table 1.1.4-20 Nuclides to proceed to Step 5 (37 nuclides)

No.	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide	*No.*	Nuclide
1	H-3	*27*	Sr-90	*60*	Sb-125	*93*	Sm-151	*189*	Pu-240
3	C-14	*29*	Y-90	*67*	Te-125m	*96*	Eu-154	*190*	Pu-241
7	Cl-36	*33*	Nb-93m	*70*	I-129	*97*	Eu-155	*194*	Am-241
16	Mn-54	*34*	Nb-94	*71*	Cs-134	*174*	U-234	*200*	Cm-243
17	Fe-55	*35*	Mo-93	*73*	Cs-137	*178*	U-238	*201*	Cm-244
18	Co-60	*38*	Tc-99	*74*	Ba-133	*182*	Np-237		
20	Ni-63	*39*	Ru-106	*80*	Ce-144	*187*	Pu-238		
23	Se-79	*51*	Cd-113m	*87*	Pm-147	*188*	Pu-239		

2.5 Step 5

In Step 5, the nuclides that have proceeded to this step will be checked if they have been detected at significant concentrations (1/100 or more of the regulatory concentration limit) in past analyses of contaminated water. Then, nuclides which have been detected at a concentration exceeding the criterion will proceed to the next step, while nuclides whose concentration was below the criterion will be classified as nuclides to be monitored.

The purpose of Step 5 is as follows. In the evaluation of transfer to contaminated water in Step 4, detection limit values are included in the evaluation, which caused some nuclides to remain without being excluded. In addition, like Fe-55, there are nuclides whose concentration in the contaminated water is less than 1/100 of the regulatory concentration limits that have found to exist in insoluble state, which can be removed easily. Considering that those nuclides are unlikely to be contained in ALPS treated water, selecting them as nuclides to be measured and assessed at each discharge is excessively conservative. Even so, given that they have proceeded to Step 5 (with relatively large inventories) and that their half-lives are long, the situation may change depending on the progress of decommissioning even though they have not been found to exist at significant concentrations so far. Therefore, those nuclides will be classified as nuclides that are not to be measured at each discharge but to be monitored constantly to check for significant presence in contaminated water. As analytical data will be collected through periodical checking of nuclides to be measures and assessed, which will be described later, the nuclides to be measured and assessed will be reviewed as necessary in accordance with the selection flow based on the obtained data.

Table 1.1.4-21 shows the nuclides to be monitored which have been selected this time.

Table 1.1.4-21 Nuclides to be monitored

Nuclide	Number of analyses (Numbers in parentheses are number of detections)			Analysis result [Bq/L]	Regulatory concentration limit [Bq/L]
	(1) Units 1 to 4	(2) Centralized Rw	(3) Before treatment by ALPS		
Cl-36	0(0)	10(0)	12(0)	< 4.3E+00	9.0E+02
Fe-55	0(0)	1(1)	1(1)	1.7E+01	2.0E+03
Nb-93m	0(0)	1(0)	1(0)	< 5.2E+01	7.0E+03
Nb-94	36(0)	38(0)	67(0)	< 1.0E+01	5.0E+02
Mo-93	0(0)	1(0)	1(0)	< 1.4E+00	3.0E+02
Ba-133	0(0)	1(0)	1(0)	< 2.6E+00	3.0E+02

Although the numbers of analyses for four of the six nuclides are small, given that the water used for the injection to reactors is RO plain water and that the quality standard specified by the Technical Specifications for the water to be used for injection, which is 40 mS/m or less at 25°C (in cases where this value is exceeded, chloride ion concentration of 100 ppm or less), has been satisfied constantly, the environment in reactors and transition status of radionuclides are unlikely to change. Therefore, this selection is reasonably considered as appropriate.

2.6 Results of the selection

Table 1.1.4-22 shows the 30 nuclides to be measured and assessed that have been selected in accordance with the flow shown in Figure 1.1.4-1. The table also shows quantification methods that are currently planned for these nuclides. In addition to the 30 nuclides shown in the table below, H-3 concentration will also be measured before discharge into the sea in order to set dilution ratio.

Table 1.1.4-22 Nuclides to be measured and assessed and quantification methods

No.	Nuclide	Quantification method	*No.*	Nuclide	Quantification method
1	C-14	After chemical separation, measure β-rays	*16*	Ce-144	γ-ray nuclide analysis
2	Mn-54	γ-ray nuclide analysis	*17*	Pm-147	Assessed from the activity concentration of representative nuclide (Eu-154)
3	Co-60	γ-ray nuclide analysis	*18*	Sm-151	
4	Ni-63	After chemical separation, measure β-rays	*19*	Eu-154	γ-ray nuclide analysis
5	Se-79	After chemical separation, measure β-rays	*20*	Eu-155	γ-ray nuclide analysis
6	Sr-90	After chemical separation, measure β-rays	*21*	U-234	Assessed as included in the total α radioactivity
7	Y-90	Radioactive equilibrium with Sr-90	*22*	U-238	
8	Tc-99	ICP-MS	*23*	Np-237	
9	Ru-106	γ-ray nuclide analysis	*24*	Pu-238	
10	Cd-113m	After chemical separation, measure β-rays	*25*	Pu-239	
11	Sb-125	γ-ray nuclide analysis	*26*	Pu-240	
12	Te-125m	Radioactive equilibrium with Sb-125	*27*	Pu-241	Assessed from the activity concentration of representative nuclide (Pu-238)
13	I-129	ICP-MS	*28*	Am-241	Assessed as included in the total α radioactivity
14	Cs-134	γ-ray nuclide analysis	*29*	Cm-243	
15	Cs-137	γ-ray nuclide analysis	*30*	Cm-244	

3. Periodical checking of nuclides to be measured and assessed

The nuclides to be measured and assessed which were identified in paragraph 2 were selected based on the results of past analyses. However, the situation may change depending on the progress of future decommissioning work. Therefore, the following checking will be performed to make sure that nuclides other than the selected nuclides to be measured and assessed (hereinafter referred to as "other nuclides") do not exist at significant concentrations. If other nuclides are found to exist at significant concentrations through the checking, the nuclides to be measured and assessed will be reassessed. The decay of radionuclides will also be taken into account in the selection flow.

3.1 Checking before each discharge

When ensuring the discharge criteria before discharge into the sea, the measurement shown in table below will be performed to make sure that other nuclides do not exist at significant concentrations.

Table 1.1.4-23 Confirmation method at each discharge

Nuclide type	Confirmation method
α nuclides	Check the total α value to make sure that the value is below the lower limit of detection, which is 1/100 order or less of the regulatory concentration limit (4 Bq/L).
β nuclides	Check the total β value to make sure that nuclides other than the nuclides to be measured and assessed do not exist at significant concentrations.
γ nuclides	Check with gamma spectrum of Ge semiconductor detector for significant peaks derived from contaminated water aside from the nuclides to be measured and assessed.

3.2 Checking trend in the contaminated water

The concentrations of radionuclides in contaminated water after the Centralized Rw which have been checked at a frequency of once a month or more while facilities are in operation will be inspected to make sure that they are below the concentrations recorded in the past, and thus ensure that the transfer status of radionuclides to contaminated water will not change. This is because if any change occurs in the transfer status of radionuclides to water, it is hard to believe that the status of a single nuclide will change. In that case, the status of nuclides that are currently measured periodically will probably change as well. Therefore, the presence of changes in the transfer status into water will be judged not based on the result of one radionuclide analysis but based on the results of several analyses or analyses of nuclides having similar properties.

Furthermore, there is a plan to install α nuclide removal facilities in the downstream from the Cs adsorption system because increases in α nuclide concentration have been confirmed as the treatment of building stagnant water progresses. Considering that, even if the α nuclide concentration in stagnant water in Centralized Rw building rises, that will not have direct impact on the nuclides to be measured and assessed at the discharge of ALPS treated water into the sea. Therefore, principally, radioactive concentrations in contaminated water before ALPS treatment will be inspected in this checking, although the stagnant water in the Centralized Rw building is also used as a reference.

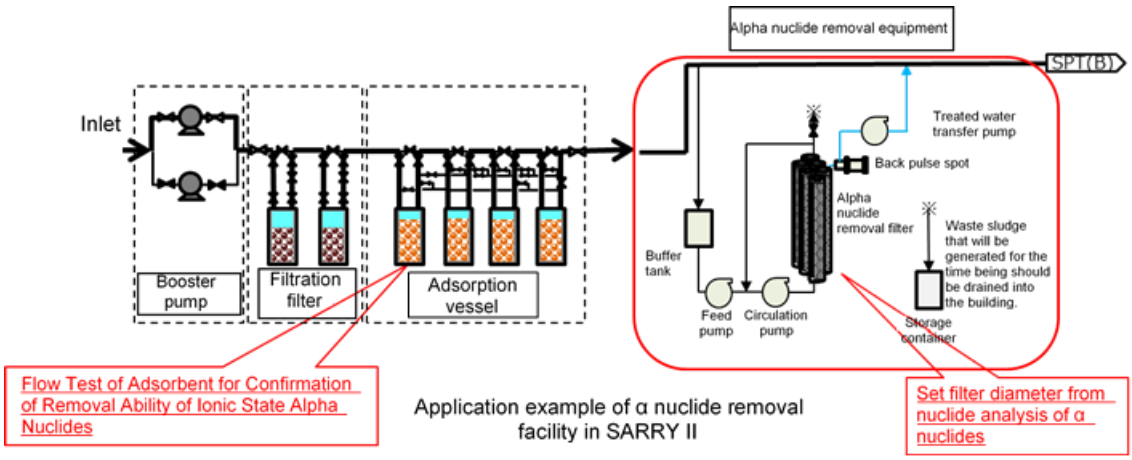


Figure 1.1.4-10 Application example of α nuclide removal facilities

3.3 Survey analysis

When an event that raises concerns is found in paragraph 3.1 or 3.2, a survey analysis will be performed in order to identify the other nuclides. Even if such an event does not occur, nuclides to be monitored will be checked once a year to make sure that they do not exist in significant concentration in contaminated water before ALPS treatment in order to survey the presence of other nuclides. As described in paragraph 2.5, the nuclides to be monitored and assessed will be reviewed as necessary in accordance with the selection flow based on analytical data obtained.