Subsidy Project of Decommissioning and Contaminated Water Management
in the FY2016 Supplementary Budgets

R&D for Treatment and Disposal of Solid Radioactive Waste

Accomplishment Report for FY2017

February 2019

International Research Institute for Nuclear Decommissioning (IRID)

Contents

1. Project Overview and Research Approach

General Overview

- Background and Purpose of the R&D -

- The project of decommissioning and the contaminated water management for the Fukushima Daiichi Nuclear Power Station(NPS) of Tokyo Electric Power Company Holdings, Inc. (hereinafter, TEPCO) are ongoing according to “The Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO’s Fukushima Daiichi NPS” (hereinafter, Mid-and-Long-Term Roadmap) and “The Progress Status and Future Challenges of the Mid-and-Long-Term Roadmap toward the Decommissioning of TEPCO's Fukushima Daiichi NPS*1.”

- Under such a circumstances, research and development (R&D) of technologies for solid radioactive waste treatment and disposal was performed for the nuclear decommissioning and contaminated water management according to “The Mid-and-Long-Term Roadmap and the Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi NPS of TEPCO Holdings, Inc. *2 “(hereinafter, Technical Strategic Plan 2017).

*1. The 39th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment/Secretariat Meeting (2017)
*2. Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., established by the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) in 2017

General Overview

- Mid-and-Long-Term Roadmap Policy

- The basic concept of waste management* (excerpts from description of research and development (R&D) , partly reworded)
  - The characteristics of solid radioactive waste, such as nuclide composition and activity concentration, need to be understood, to study solid waste treatment and disposal methods.
  - Generated solid waste shall be stored and managed by safe and streamline methods and procedures based on their characteristics.
  - A method to determine waste stabilization and solidification methods (pretreatment methods) on a rational basis shall be established, and pretreatment methods shall be determined by the established method before determining the technical requirements for disposal, in order to ensure the safety of solid waste storage and management.
  - To promote effective R&D on solid radioactive waste treatment and disposal, R&D projects related to the characterization, treatment, and disposal of solid waste work closely together. R&D is promoted by the sharing of research and issues among R&D teams, overviewing all activities of solid waste management, and identifying required R&D tasks.

The waste treatment and disposal measures, and their technical prospect of the safety shall be proposed by around FY2021.

*Revised on September 26, 2017

General Overview

- Policy of Technical Strategic Plan 2017 -

- Strategic proposals for solid radioactive waste treatment and disposal* (partly reworded)
  - Focusing on waste characterization, storage and management as predisposal management until the prospect of disposal can be obtained.

Item	R&D task
Promotion of characterization	• Establishment of a solid waste characterization method that complementarily combines evaluation data based on analysis data and migration models. • Optimization of analysis sample numbers, the simplification and speeding-up of analysis methods, etc.
Thorough storage and management	• Study on estimation methods and management of the volume of hydrogen gas production from the secondary wastes generated from contaminated water treatment during the storage and management of solid waste. • Study on methods to store and manage of solid wastes generated by fuel debris retrieval
Establishment of pretreatment selectionmethod considering the possibility of disposal	• Establishment of a method for selecting waste treatment based on safety evaluation results of in-process wastes for multiple waste treatment.
Promotion of effective R&D by overviewing all activities of solid waste management	• R&D is promoted by sharing research progress and issues among projects, overviewing all activities of solid waste management, and identifying required R&D tasks.

* Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., by Nuclear Damage Compensation and Decommissioning Facilitation Corporation

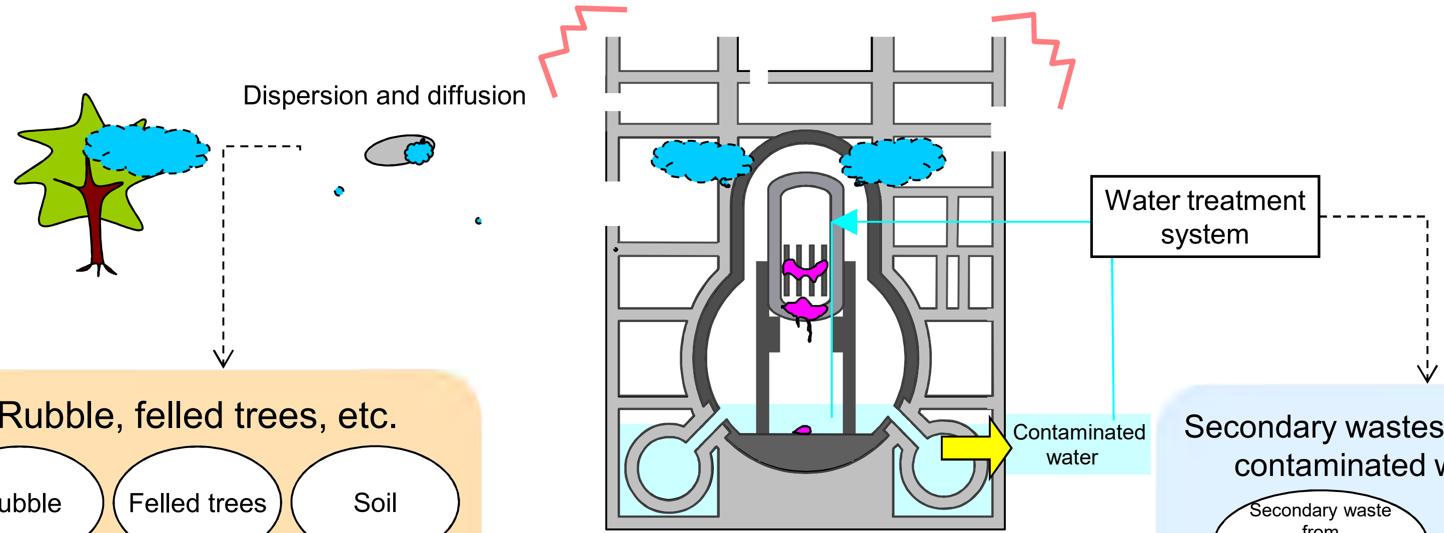
Approaches to R&D
- R&D Planning and Implementation -

- Specific plans were established for each of the following four main R&D items respectively: (1) Characterization of solid waste; (2) Predisposal management of solid waste (thorough storage and management); (3) Study of disposal strategy and safety assessment methods suitable for the characteristics of solid waste (establishment of pretreatment methods considering disposal strategy); and (4) Integration of R&D outcomes (the promotion of effective R&D by overviewing all activities of solid waste management).
  - The plans were developed based on the characteristics of waste.
  - The plans were created in reference to the process chart of the Technical Strategic Plan 2017 to ensure the steady implementation of the Plan and to achieve the goals.
  - The plans were implemented under appropriate role assignments and with active information exchange to enable the concurrent progress of R&D activities.
- Assessment indexes for achieving goals were established and implemented.

Approaches to R&D

- Estimated Characteristics of Waste Generated by the Fukushima Daiichi Accident for the Consideration of R&D Approaches -

- Waste generated out of control due to the accident
- Contamination originated from nuclear fuel in the reactor core of Unit 1 to Unit 3*
- The amount of produced waste will fluctuate with the varying status of decommissioning work.
- Currently only a limited amount of samples are available due to the access difficulty.



Rubble, felled trees, etc.

Rubble | Felled trees | Soil

- ○ Large volume, spreading into wide areas
- ○ Trees and soil a poor experience in treatment and disposal
- ○ Mainly surface contamination by dispersion and diffusion with some penetrating contamination by way of accumulated water

Generated waste from fuel debris retrieval

- ○ Large amount and high radioactivity
- ○ Currently some waste is difficult to sample due to the access difficulty.

Secondary wastes generated from contaminated water treatment

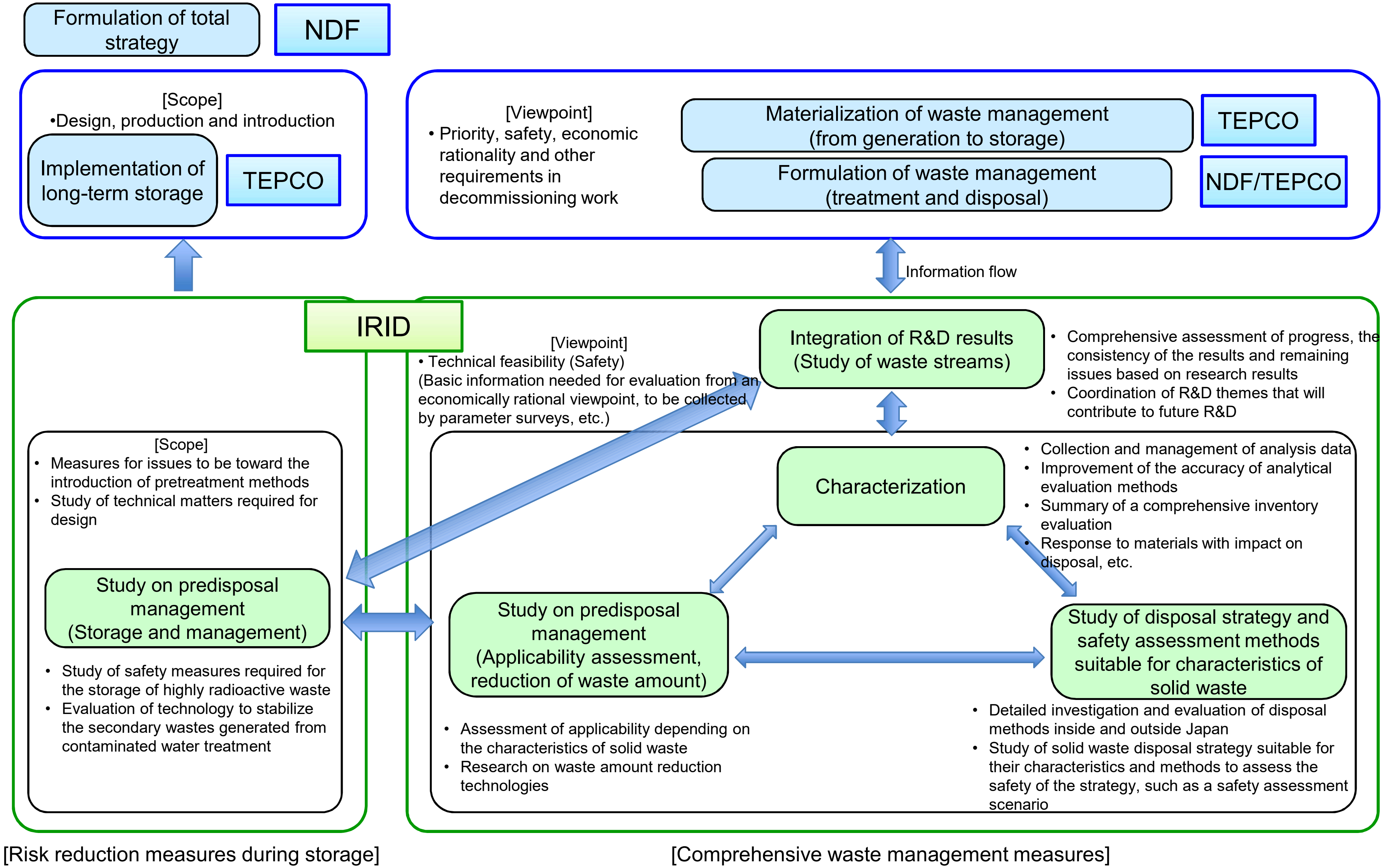
Secondary waste from contaminated water treatment | Replaced pipes, storage tanks, etc.

- ○ A poor experience in treatment and disposal
- ○ Some waste at the site is difficult to sample.
- ○ The amount of produced waste and nuclides can be partially estimated based on system features

*Contamination originated from activated materials and reactor operation waste may be included.

Approaches to R&D

Role-Sharing among Relevant Organizations, and Scope and Viewpoint of Study



2. Characterization

Contents of Report

(I) Collection and Management of Analysis Data
- a. Identification of contamination distribution
  - (a) Development of analysis plan
  - (b) Sampling and transportation
  - (c) Conducting analyses
  - (d) Study of waste classification based on analysis data
- b. Development of sampling technology
  - (a) Sampling of secondary wastes generated from contaminated water treatment, including sludge
  - (b) Study of sampling methods in the Reactor Buildings.
- c. Streamlining of analysis methods
  - (a) Study on the migration behavior and the contamination mechanism of radionuclides
  - (b) Study on the representativeness of analysis data
  - (c) Reselection of nuclides to be analyzed
  - (d) Study on more efficient and reasonable analysis methods
- d. Analysis data management
  - (a) Establishement of analysis database
  - (b) Organize and update waste data

(II) Accuracy Improvement of Analytical Evaluation Methods
"Comprehensive inventory evaluation" will be summarized in FY2018.

(III) Measures for Materials with Impact on Disposal

Correspondence of action plan with the Technical Strategic Plan 2017*

Item/FY	2nd period (the period until the start of fuel debris retrieval)					
	2014	2015	2016	2017	2018	2019/after
Main events planned in the current Roadmap	Summarizing basic concepts about treatment and disposal [C]					
I. Characterization 1.Collection and management of analysis data	Preparation for sampling rubble, ALPS, soil, incineration ash, and highly radioactive materials, as well as data release			Sampling of rubble, ALPS, soil, materials in the reactor building, incineration ash, and highly radioactive materials, the streamlining of sampling methods, and the creation of a database		Actions in response to progress of sampling and analysis
2. Accuracy improvement of analytical evaluation methods	Development of methods to evaluate the secondary wastes generated from contaminated water treatment, rubble, felled trees, and soil			Improvement of the accuracy of analytical inventory evaluation that takes into account the variation of analysis results		Upgrading of evaluation methods
3. Summary of comprehensive inventory evaluation	Development and update of analysis plan			Comprehensive assessment of analysis data and radioactive inventory estimates, inventory estimation, and the establishment of updating procedure		Preparation for analysis and evaluation of impact
4. Response to materials with impact on disposal, etc.				Collect and organize points of view pertaining to the provisional value of acceptable concentration in predisposal management and disposal facilities		

* Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (established by the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as NDF) in 2017.

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (a) Development of analysis plan

FY	Implementation plan	Goal achievement index
2017	• A mid- and long-term analysis plan will be developed based on the following information: the target schedule and the timings of judgment specified in the Mid-and-Long-Term Roadmap, analysis data accumulated to date and knowledge about various contamination behaviors, and the foreseeable availability of analysis samples. • The following samples will be collected in analysis targets: rubble, soil, incineration ash, secondary waste generated from contaminated water treatment, contaminated water stagnated at the basement of the building, etc. • An annual analysis plan will be developed.	• A mid- and long-term analysis planning • An annual analysis planning
2018	• An annual analysis plan will be developed.	• Annual analysis planning.

Implementation details	Legend Blue: Plan Red: Result	FY2017 4	5	6	7	8	9	10	11	12	1	2	3	Notes
I. Characterization														
(I) Collection and Management of Analysis Data														
a. Identification of contamination distribution - Development of analysis plan		Annual analysis planning		Mid- and long-term planning								Planning for next year		• A draft of next year's annual plan has already been developed.

*Analysis plans will be reviewed as necessary.

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (a) Development of analysis plan

- Analyses are tools to investigate methods for waste management (including storage, treatment and disposal). They provide information needed to classify waste at each stage of the waste management process. The functions of the individual stages of the waste management process were clarified, and needs required for analysis arising out of those functions were laid out.
- Analysis items vary with the individual stages of the waste management process. (Figure 1)
  - ○ Waste that may pose high risks during storage and treatment (waste conditioning and stabilization) have high priority.
  - ○ The procedure to determine disposal category and activity concentration acceptance criteria applied to waste bodies, requires the activity analysis of materials, including difficult-to-measure nuclides. In addition, not only radioactive materials but also chemically hazardous materials need to be detected by the analysis. Thus, the volume of analysis work is enormous. (Figure 2)

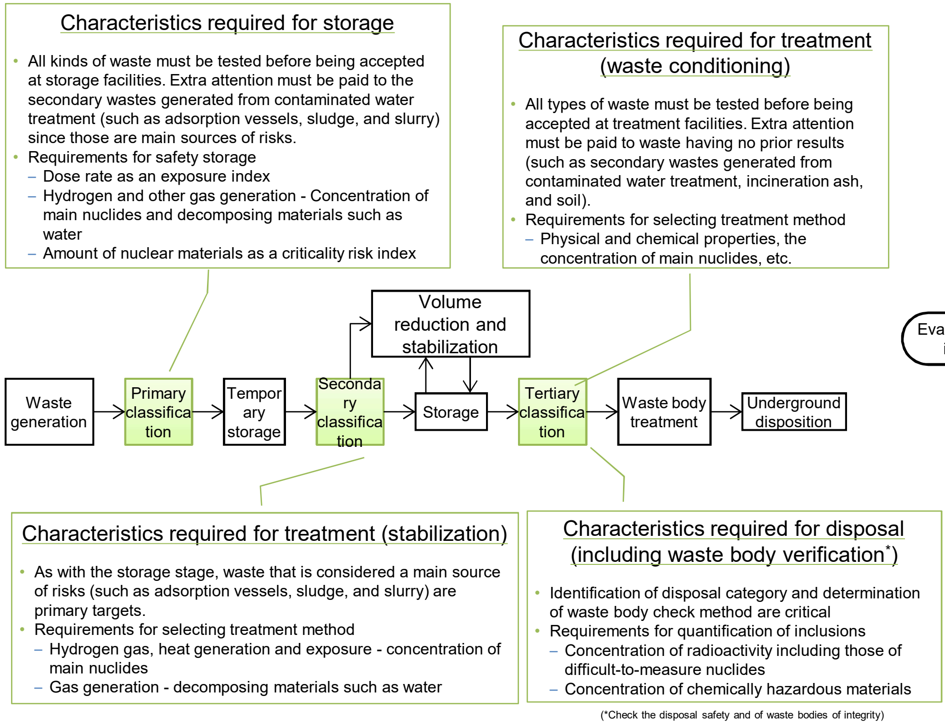


Figure 1. Issues of Characterization Required for Classification

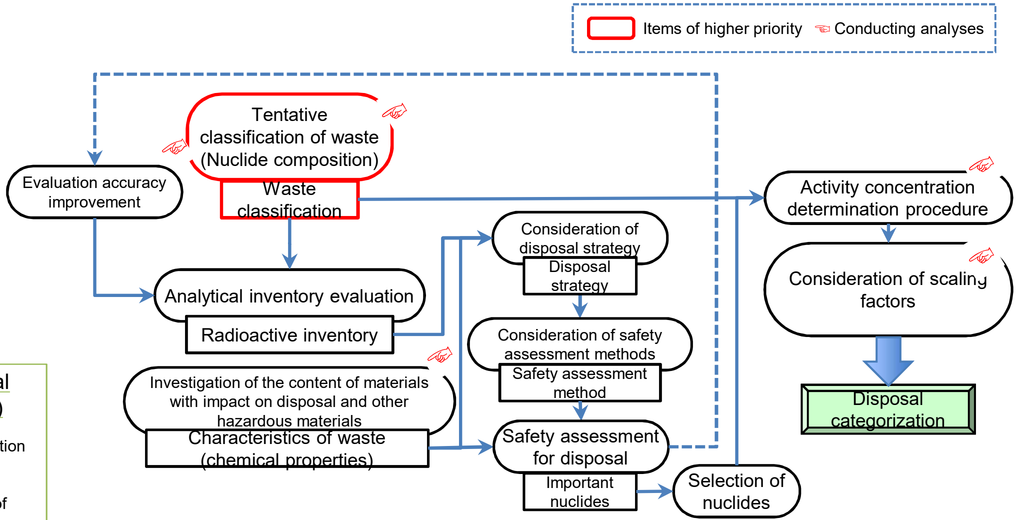


Figure 2. Illustrative diagram of activity concentration analyses in different stages in the context of the whole disposal process

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (a) Development of analysis plan

- Analyses that need to be performed with high priority in the mid-term period through 2021 were extracted based on the consideration of the purpose of analysis. (Table 1)
- Priority was quasi-quantitatively determined by assigning scores to each purpose, and analysis sample collection timing was presumed. Based on the preceding information, a table that summarizes the collection of samples and the implementation of analyses by year was created. (Table 2)

Table 1. Requirements for High-Priority Analysis in Mid-Term Range

Classification	Purpose	Target waste	Analysis item	Time limit for analysis implementation
Storage	Nuclear material amount (Criticality)	Fuel debris containing waste	Total α concentration	To be matched with the timing of the consideration and determination of storage methods
	Amount of radioactivity (Measure for hydrogen gas generation)	Slurry, sludge from decontamination systems, waste from fuel debris retrieval	Total α concentration and total β, γ concentration	
	Chemical form	All	Concentration of elements (when necessary)	
Treatment	Stabilization of sludge	Sludge from decontamination systems	Density, dry mass, particle size distribution, pH, chemical composition, main nuclide concentration, thermal conductivity, electrical conductivity, organic substances (TOC)	To be matched with the timing of the consideration and determination of treatment methods.
	Solidification of incineration ash	Incineration ash	Elemental composition, component analysis	
	Soil classification	Soil	Correlation between particle size distribution and the main concentration of radioactivity	
Disposal	Waste classification	Rubble, incineration ash, waste from dismantlement of structures and equipment outside the PCV, carbonate/iron coprecipitation slurry, sludge from decontamination systems, waste from debris retrieval, cesium adsorption vessel	Activity concentration by nuclide (distribution)	To be matched with the timing of the consideration and determination of disposal methods.

Table 2. Annual Analysis Plan

Classification	Target waste	Number of collected samples						Number of analyzed samples				
		2017*	2018	2019	2020	2021	Total	2018	2019	2020	2021	Total
Rubble	Already generated waste (cover soil storage vessels, etc.)	135	20	20	20		195	20	20	20	20	80
	Already generated (stored in containers)	10	10				20					0
	Metal and concrete inside the PCV (Lower portion)					5	5					0
	Metal and concrete outside the PCV (contacted with water)				20	40	60					0
	Vicinity of areas where materials extravasated out of the PCV are observed and other areas (no contact with water)	40	40				80	20	20	20	20	80
Secondary wastes generated from contaminated water treatment	Cesium adsorption apparatus (KURION and SARRY) and adsorbent				20	20	40					0
	Sludge from decontamination systems				20		20				10	10
	Multi-nuclide removal system (carbonate slurry)		20				20		10	10		20
	Multi-nuclide removal system (iron coprecipitation slurry)	3	3	15			21	3	3	5	10	21
	Multi-nuclide removal system (adsorbent)	5	5	5	5	5	25	5	5	5	5	20
Contaminated water (stagnant water)	Reactor building	In order to find the input amount to migrate into the said secondary waste, these analyses are performed according to the sampling/analysis result of secondary wastes generated from contaminated water treatment.										0
	Turbine building											0
	Centralized radiation waste treatment facility											0
Contaminated water (treated water)	Cesium adsorption apparatus	10					10					0
	Multi-nuclide removal system	40					40					0
Combustibles	Incineration ash (Tyvek, etc)	5					5					0
Soil	Soil (under atmosphere)	44					44					0
	Soil (contaminated water permeated)	6					6					0
Plants	Branches, leaves, etc.	31					31					0
	Total	329	98	40	85	70	622	48	58	60	65	231

* Includes existing preserved samples.

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (a) Development of analysis plan

- As a mid- and long-term analysis plan should be reviewed every few years, potential issues in development of the analysis plan were identified to be prepared for future plan revisions. (Table 3)
  - The table includes remaining issues to be solved (sample collection, the utilization of analysis resources and data) as wells as new issues to be addressed (analysis quality assurance).

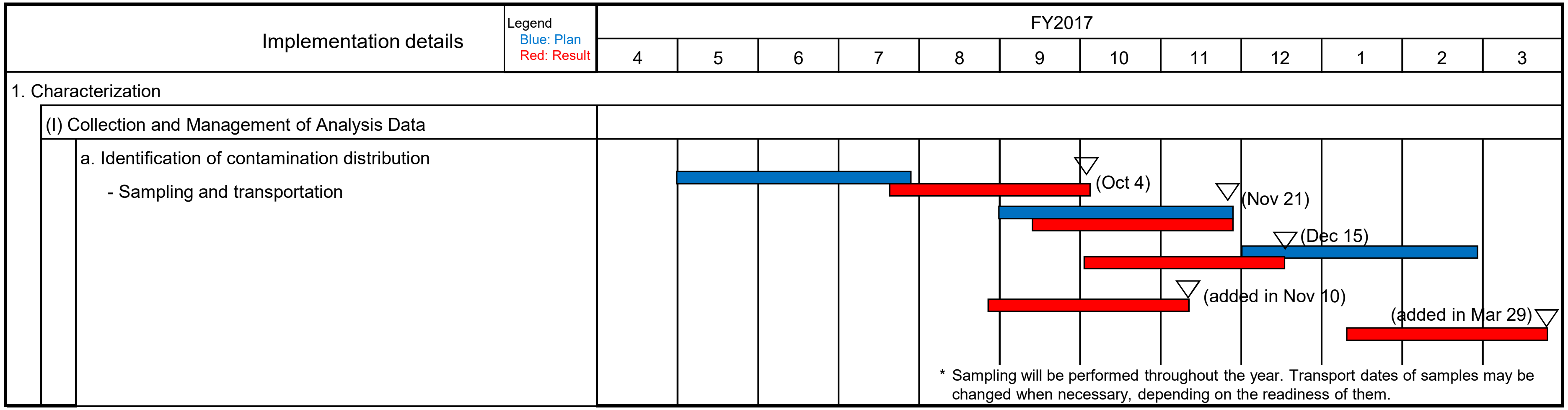
Table 3 Existing issues in conducting analyses and those that need to be addressed in future planning

Classification		Issues	Waste and samples concerned
Remaining issues to be solved	Sample collection	• Establishment of sample collection methods intended for areas with high radiation such as inside and outside the PCV and for highly radioactive objects such as cesium adsorption vessels.	• Sludge from decontamination systems, projected waste from planned debris removal work • Cesium adsorption vessel
		• Effective sample collection in cooperation with all decommissioning work and other projects.	• Samples collected in the project to identify the condition inside reactor and other projects • Projected waste from debris removal
		• Establishment of a method to estimate the radioactive inventory of waste concerned in consideration of the representativeness of analysis data obtained from a limited amount of samples. Also with the development of a sample collection plan that makes use of the method.	• All types of waste
		• Preparation of sample storage areas and methods before the Okuma Analysis and Research Center starts its operation.	• All types of waste
	Utilization of resources associated with analysis	• Reasonable use of existing facilities until the Okuma Analysis and Research Center starts its operation.	• All types of waste
	Utilization of analysis data	• Establishment of a database accessible for researchers and developers.	• All types of waste
New issues to be addressed	Analysis quality assurance	• Establishment of an analysis quality assurance system and the standardization of analysis methods based thereon with the aim of utilizing existing analysis data under a regulatory system	• All types of waste

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (b) Sampling and transportation

FY	Implementation plan	Goal achievement index
2017	• Regarding slurries and adsorbent produced by the operation of existing and expanded multi-nuclide removal systems and treated water produced by the operation of cesium adsorption apparatus, secondary cesium adsorption apparatus (SARRY), and existing and expanded multi-nuclide removal systems, sampling of them will be performed in sequence according to the analysis plan and depending on the status of readiness for the sampling at target locations, which is determined by considering the reliability of the sampling method and the estimate of exposure dose associated with the sampling. • Available samples are collected in cooperation with on-site operation and transported to analysis facilities.	• Samples are collected based on the annual analysis plan and transported to analysis facilities.
2018	• Regarding slurries and adsorbent produced by the operation of existing and expanded multi-nuclide removal systems and treated water produced by the operation of cesium adsorption apparatus, secondary cesium adsorption apparatus (SARRY), and existing and expanded multi-nuclide removal systems, sampling of them will be performed in sequence according to the analysis plan, subject to the confirmation of accessibility to them. • Available samples are collected in cooperation with on-site operation and transported to analysis facilities.	• Samples are collected based on the annual analysis plan and transported to analysis facilities.



(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (b) Sampling and transportation

Items in red text are samples collected in this project.

Table 4. Summary of Sample Transport in FY2017 and Analysis Status

Classification	Type	Sample	Number of samples	Transport			Analysis status
				Origin*1	Destination*1	Date	
Rubble	Floor	Cores samples obtained by the boring of concrete on the 1st to 5th floors of Unit 4 reactor building (R/B)	8	1F	NDC	Dec 15, 2017	In process
	Samples associated with decontamination tests	Materials used for decontaminating floors and walls in R/Bs of Unit 1 to Unit 3 R/B (flannel cloth, strippable paint, boring core, etc.)	22	JAEA, Oarai	JAEA, NSRI	Mar 29, 2018	Scheduled
	Rubble	Rubble of R/Bs, rubble of stored cover soil, sand gravel of turbine buildings(radioactivity distribution)	5	1F	JAEA, Oarai	Feb 27, 2017*2	Scheduled
Contaminated water	Stagnant water	Stagnant water in Unit 1 to Unit 3 R/Bs	8	1F	JAEA, NSRI	Oct 4, 2017	Reported (Mar 2018)
		Stagnant water in the R/Bs, the HTI building, and the RW building, treated water from KURION and SARRY, etc. (uranium analysis)	19	JAEA, NCL	NFD	Nov 10, 2017	Reporting planned
	Treated water	Treated water from existing ALPS	11	1F	JAEA, NSRI	Oct 4, 2017 Feb 27, 2017*2	In process
		Treated water from expanded ALPS	12	1F	NDC	Dec 15, 2017	In process
Secondary wastes generated from contaminated water treatment	Adsorbent	Cerium oxide, activated carbon and chelate resin 2 used in the existing ALPS	3	1F	JAEA, NCL	Oct 4, 2017	In process
		Chelate resin 1 and silver zeolite used in the existing ALPS	2	1F	JAEA, NCL	Nov 21, 2017	To be analyzed (stored)
	Sludge	Sludge from decontamination systems, clear supernatant liquid	2	1F	JAEA, NCL	Nov 21, 2017	Partly reported (Mar 2018)
		Sludge from decontamination systems (elemental analysis, etc.)	1	1F	NFD	Nov 21, 2017	In process
Soil		Surface layer of areas F, H, J and K, H4 tank area (measurement points A and B)	6	1F	NDC	Dec 15, 2017	In process
		Areas K and P, H4 tank area (measurement point A) (particle size vs activity concentration)	3	1F	JAEA, NSRI	Oct 4, 2017	In process

*1. 1F: Fukushima Daiichi Nuclear Power Station, JAEA: Japan Atomic Energy Agency, JAEA, NSRI: JAEA, Nuclear Science Research Institute, JAEA, NCL: JAEA, Nuclear Fuel Cycle Engineering Laboratories
JAEA, Oarai: JAEA, Oarai Research and Development Institute, NDC: Nuclear Development Corporation, NFD: Nippon Nuclear Fuel Development Co., Ltd.
*2 Transported during the FY2014 supplementary budgets project

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (c) Conducting analyses

FY	Implementation plan	Goal achievement index
2017 2018	• Sample analysis will be performed according to the analysis plan. • Besides activity concentration, other characteristics necessary for the storage and management of waste will be analyzed.	• Implementation of analysis and the reporting of analysis data in line with the annual analysis plan.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
1. Characterization													
(I) Collection and Management of Analysis Data													
a. Identification of contamination distribution - Conducting analyses													Reporting▽

* Analysis data will be reported at around the end of every quarter term. Reporting timing may be changed depending of the content of analysis data.

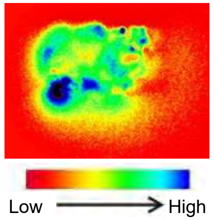
(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (c) Conducting analyses

- The analysis of core samples obtained by the boring of structures in the Unit 4 reactor building is underway.
- To evaluate representativeness of analysis samples, local contamination distribution within samples from various types of rubble is investigated using imaging plate (IP) autoradiography. (Figure 3 and 4)
  - An analysis of rubble (concrete) showed inhomogeneous contamination distribution in general, which suggests that a series of events that occurred in different parts of the unit during the accident had caused difference in contamination distribution.
  - It is necessary to take account of the representativeness of samples for the estimation of the amount of radioactivity because of the possibility of inhomogeneous contamination distribution.

(1) Sample

(2) IP-autoradiography



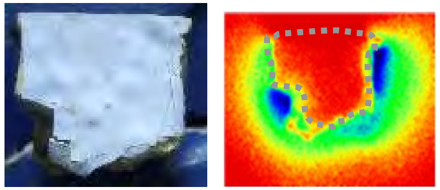
Dose rate

(3) IP-image sample

(4) Scene of sample surface grinding

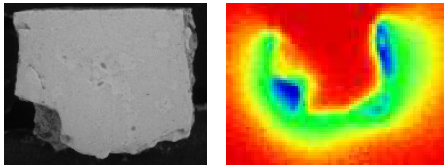
- Place a sample (1) on an imaging plate (2), and capture an image (3).
- The imaging plate changes the color of portions corresponding to the amount of received radiation dose. A profile in image is generally different from that of the sample because the image plate also senses radiation from part of the sample not in a direct contact with the plate.
- Repeat the imaging process by grinding the surface of the sample while maintaining its position same as that on the imaging plate (4) and then imaging a newly created cross-section surface.

Figure 3. Method of IP Analysis



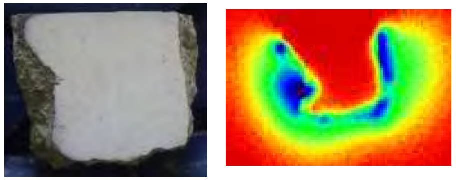
Surface (untreated)

- The contamination level of the light blue coating is low (The gray dotted line indicates the profile of the sample).
- Contamination on the side is shown in the image.



After 5 times of grinding

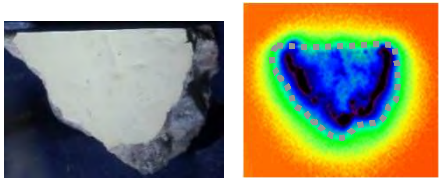
- No contamination is observed (and penetrated) in the interface between the coating and concrete.



After 10 times of grinding

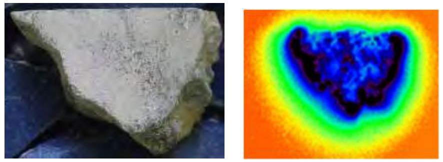
- No contamination was observed inside the sample. Similar images were obtained from the cross-section surfaces created by 11 or more trials of grinding.

Rubble collected around Unit 3
(Sample ID: 3U-01)



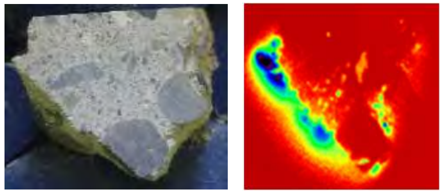
Surface (untreated)

- The white coating is obviously contaminated (The gray dotted line indicates the profile of the sample).



After 5 trials of grinding

- The IP-autoradiography results after 5 trials of grinding infers penetration of contamination into the interface.



After 10 trials of grinding

- No contamination was observed inside the sample. Similar images were obtained from the cross-section surfaces created by 11 or more trials of grinding.

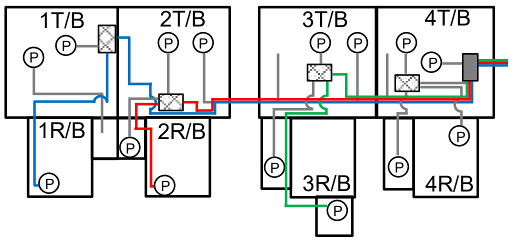
Rubble collected on operation floor of Unit 3
(Sample ID: 3RB-OP-C1)

Figure 4. Local Contamination Distribution of Rubble (Left photos: appearance, Right: IP images

(I) Collection and Management of Analysis Data

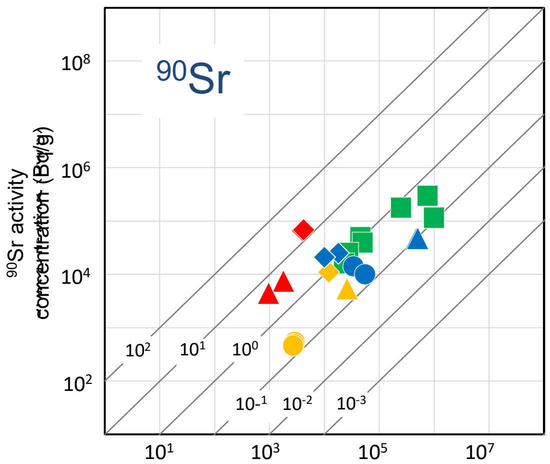
a. Understanding of contamination distribution - (c) Conducting analyses

- The analysis of water samples collected from stagnant water is underway.
- Samples taken from stagnant water Unit 1 to Unit 3 R/Bs (reactor buildings) were analyzed (Figures 5 and 6).
  - Stagnant water samples from Unit 1-3 reactor buildings show a single-digit variation in $^{90}Sr/^{137}Cs$ ratio (between around 10^{-1} and 10^{0}). The ratios are nearly equal to those of stagnant water in the turbine buildings. There seems no impact of the change in the amount of nuclear reactor water injection that was implemented around last March (2017).
  - Although the $^{238}Pu/^{137}Cs$ ratio is high on the stagnant water in primary containment vessels (PCV), there is no significant difference in this ratio among stagnant water samples from R/B, TB (turbine building) and centralized RW (centralized radwaste building). The ratios of stagnant water in Unit 1 and Unit 2 R/Bs are larger than that in Unit 3 R/B by about one digit.
  - Since different levels of activity concentration are detected depending on the type of nuclides, unit number, and the contaminated water flow path (reactor buildings are on the upstream side and the high temperature incinerator building is on the downstream side), it is important to investigate the migration of contamination on the upstream side continuously to estimate contamination by contact with contaminated water.



Stagnant water was sampled from the blue pipeline for Unit 1 R/B, the red pipeline for Unit 2 R/B, and the green pipeline for Unit 3 R/B respectively at the high temperature incinerator building. *1

Figure 5. R/B Stagnant Water Sampling



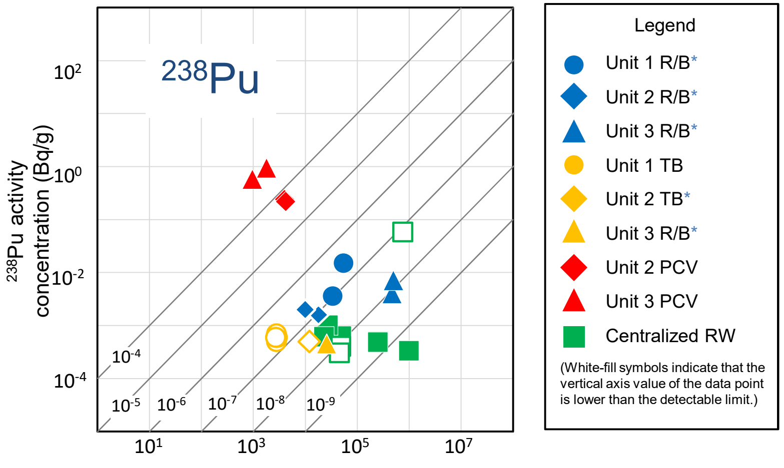


Figure 6. Concentration of ^{90}Sr and ^{238}Pu in Stagnant Water from different sources (correlation with the concentration of ^{137}Cs)

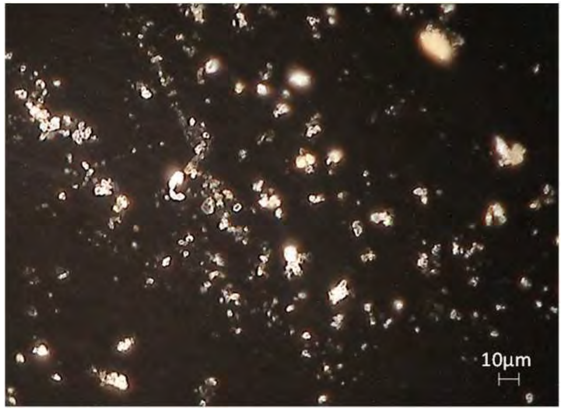
*1 This information is cited from the material 5 of the 53rd meeting of the Commission on Supervision and Evaluation of the Specified Nuclear Facilities (on May 22, 2017) in part with some additions.

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (c) Conducting analyses

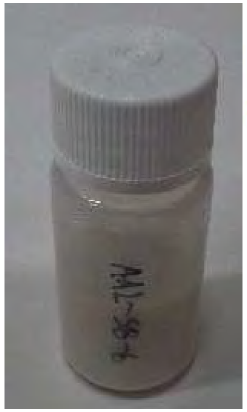
- The analysis of secondary waste generated from contaminated water treatment is underway.
- Sludge from decontamination systems was analyzed (Figure 7).
  - ○ The physical properties of sludge that were considered important for the determination of transport and treatment methods (such as density, ratio of solid content, particle size distribution, and fluidity) were analyzed as an initial action.
  - ○ Particles with a diameter of 5 μm or less amounted to about 90 percent of all particles contained. ^{90}Sr is considered to be a main nuclide as the source of radiation.
- Analyzed carbonate slurry generated by multi-nuclide removal systems (Figure 8).
  - ○ The analysis results suggested the influence of the characteristics of contaminated water that was treated by the systems, such as lower ^{90}Sr concentration compared with that of samples analyzed in the past[*1].

After left standstill

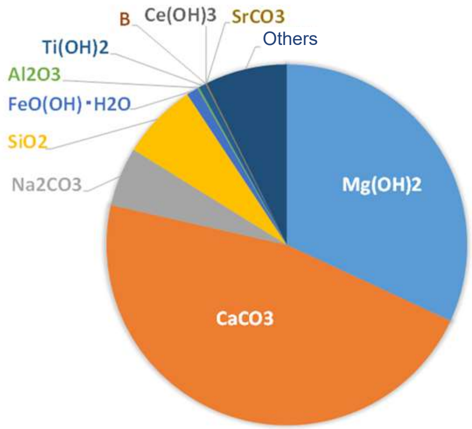


Appearance of dispersed particles

Figure 7. Analyzed sludge from decontamination systems
(Sample ID: LI-AR-SL1-3)



Appearance



Chemical composition [wt%]	
$Mg(OH)_2$	31.9
$CaCO_3$	46.6
Na_2CO_3	5.29
SiO_2	6.85
$FeO(OH) \cdot H_2O$	1.06
Al_2O_3	0.16
$Ti(OH)_2$	0.6
B	0.06
$Ce(OH)_3$	0.04
$SrCO_3$	0.03
Others	7.3

Estimated chemical composition

Figure 8. Analysis of Carbonate Slurry from Multi-nuclide Removal Systems
(Sample ID: AAL-S8-6)

*1 The 34th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment/Secretariat Meeting, held on September 29, 2016

(I) Collection and Management of Analysis Data

No.21

a. Understanding of contamination distribution - (d) Study of waste classification based on analysis data

FY	Implementation plan	Goal achievement index
2017	• Radionuclide compositions that determine the characteristics of waste will be identified. • Data analysis will proceed along the correlation between the concentrations of radionuclides and the amount of source term standardized by the composition of nuclides (transport rate) for the composition identification and the study of classification.	• Proposal of waste classification based on analyses data.
2018	• The results of classification will be reviewed as analysis data is accumulated.	• Proposal of waste classification based on analyses data.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
1. Characterization													
(I) Collection and Management of Analysis Data													
a. Identification of contamination distribution													
- Study of waste classification based on analysis data			Study	Summar									

*The study results are reflected in the study of analysis methods.

(I) Collection and Management of Analysis Data

a. Understanding of contamination distribution - (d) Study of waste classification based on analysis data

- Modeling work was started based on the element groups formulated by the U.S. Nuclear Regulatory Commission (NRC). The reconfiguration of the element groups was attempted by using accumulated analysis data to describe the state of contamination more accurately.
  - ○ The elimination and consolidation of the groups was considered using the frequency distribution of transport rate. Streamlining due to a decrease in groups to be examined, as well as the improvement of reliability due to an increase in the frequency of data, are expected for the future study by consolidating nuclides that have similar data distributions. (Figure 9)
  - ○ Newly formulated element groups intended for air and water contamination will be used for inventory estimation and other operations from this point forward. (Table 5)

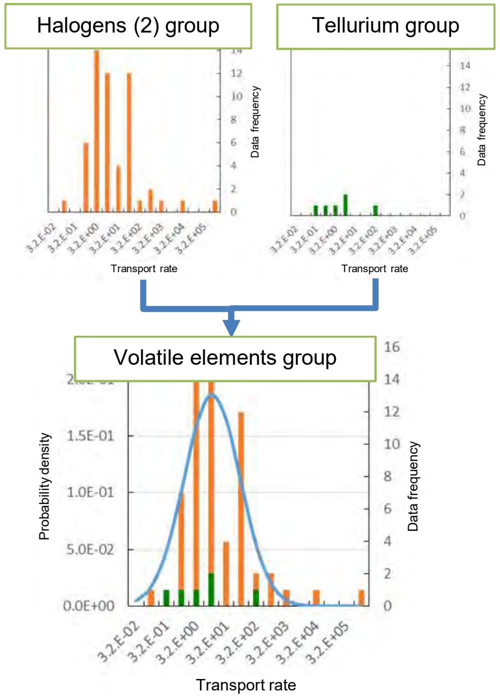


Table 9. Reformation of Element Groups based on Analysis Data

Table 5. Expedient Element Groups Formed based on Analysis Data

No	Contamination via air		Contamination via water	
1	Noble gases		Same as on the left	
2	Semivolatile Elements	H	Soluble Elements	H, **C, Cl, I**
3	Volatile Elements	**C, Cl, I**, S, Se, **Sb**, Te, **Ag**	Chalcogens	S, Se, Te
4	Alkali Metals	Na, K, Rb, Cs	Same as on the left	
5	Alkaline Earth Metals	Be, Ca, Sr, Cd, In, Ba, Ra	Alkaline Earth Metals	Be, Ca, Sr, **Ag**, Cd, In, **Sn**, Ba, Ra
6	Transition Metals	Mn, Fe, Co, Ni, Zn, Mo, Tc, Ru, Rh, Pd, **Sn**	Transition Metals	Mn, Fe, Co, Ni, Zn, Mo, Tc, Ru, Rh, Pd, **Sb**
7	Lanthanides, Actinides	Si, Zr, Nb, La, Nd, Pm, Sm, Eu, Gd, Tb, Ho, Tm, Lu, Hf, Ta, Re, Os, Ir, Pt, Tl, Pb, Bi, Po, Am, Cm, Cf, Ce, Ac, Th, Pa, U, Np, Pu	Same as on the left	

(Elements in red text are those that belong to either contamination via air or via water, not to both.)

(I) Collection and Management of Analysis Data

b. Development of sampling technology - (a) Sampling of secondary wastes generated from contaminated water treatment, including sludge

FY	Implementation plan	Goal achievement index
2017	i) Collection of cesium adsorbent, etc. • The issues that were clarified by the conceptual study in FY2016 (such as the adhesion of adsorbent) will be studied to substantiate a collection method. ii) Collection of sludge from decontamination systems • The site survey of D-pit will be conducted to substantiate a collection method to develop the design and production of waste sludge collection jigs and to create a construction plan.	i) Collection of cesium adsorbent, etc. • Show proposed absorbent sampling methods. ii) Collection of sludge from decontamination systems • Determine a sludge collection method and produce collection jigs.
2018	i) Collection of cesium adsorbent, etc. • Based on the results of detailed discussions in FY2017, development plan of sampling collection device will be developed to start designing a mockup device. ii) Collection of sludge from decontamination systems • Waste sludge from the D-pit will be collected using the produced collection jig.	i) Collection of cesium adsorbent, etc. • Formulation of a development plan, and the design of a mockup. ii) Collection of sludge from decontamination systems • Collect sludge from D-pit.

Implementation details	Legend Blue: Plan Red: Result	FY2017 4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
b. Development of sampling technology, etc.													
- Sampling of secondary wastes generated from contaminated water treatment, including sludge (Collection of cesium adsorbent, etc.)		Preoperational planning			Discuss specification of specific sampling device for adsorbent from the cesium adsorption vessel						Summary		
(Collection of sludge from decontamination systems)		Survey planning			Survey of periphery and inside of D-pit				Production of sampling jigs and formulation of construction plan				

(I) Collection and Management of Analysis Data

b. Development of sampling technology - (a) Sampling of secondary wastes generated from contaminated water treatment, including sludge

- Method to sample zeolite from the cesium adsorption vessel by remote control
  - The concept design of sampling system and the design of element test device to examine the performance and practicality of the sampling head were already implemented in projects last year or earlier.
  - Element test device was built (Figure 10), and tests were conducted with the combination of 9 conditions (boring speed, rotation speed, and tip shape) to evaluate the amount of collected samples. The shape of the sampling head should be reviewed for improvement because the amount of collected samples were still insufficient in the shallow part of the zeolite layer in all conditions, despite a good sampling performance shown by a flat-shaped sampling head.

- Method to sample slurry that was discharged from the multi-nuclide removal systems and stored in the HICs*1 from those HICs
  - The characteristics of slurry samples (dose rate, chlorine concentration, and the timing of generation) vary largely with their origin, and the generation is also large. For these reasons, samples with adequate representativeness were selected. (Figure 11)
  - A plan to focus on slurry in HICs stored in No. 2 and 3 storage facilities, and to collect 20 samples as a target number at No. 2 storage facility was developed. Sampling is performed effectively in cooperation with water draining work.

*1. HIC (high integrity container)

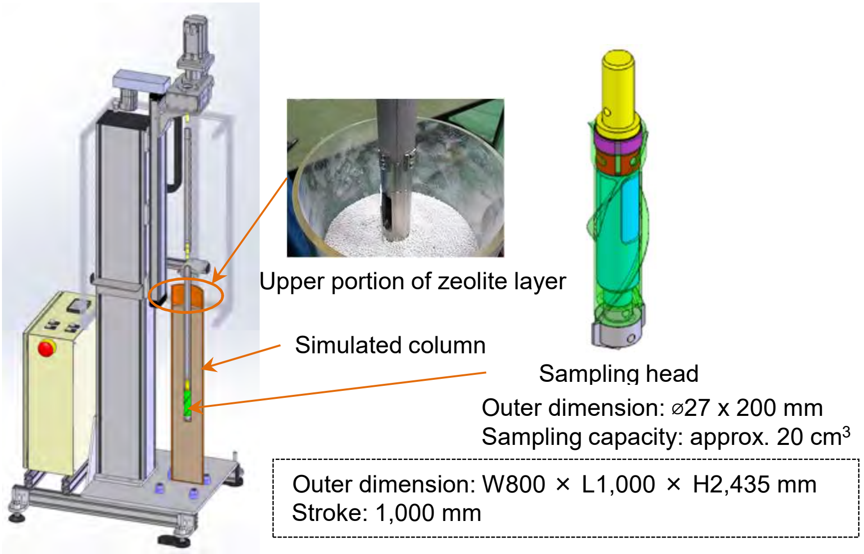


Figure 10. Element test device for the sampling of zeolite from cesium adsorption vessel

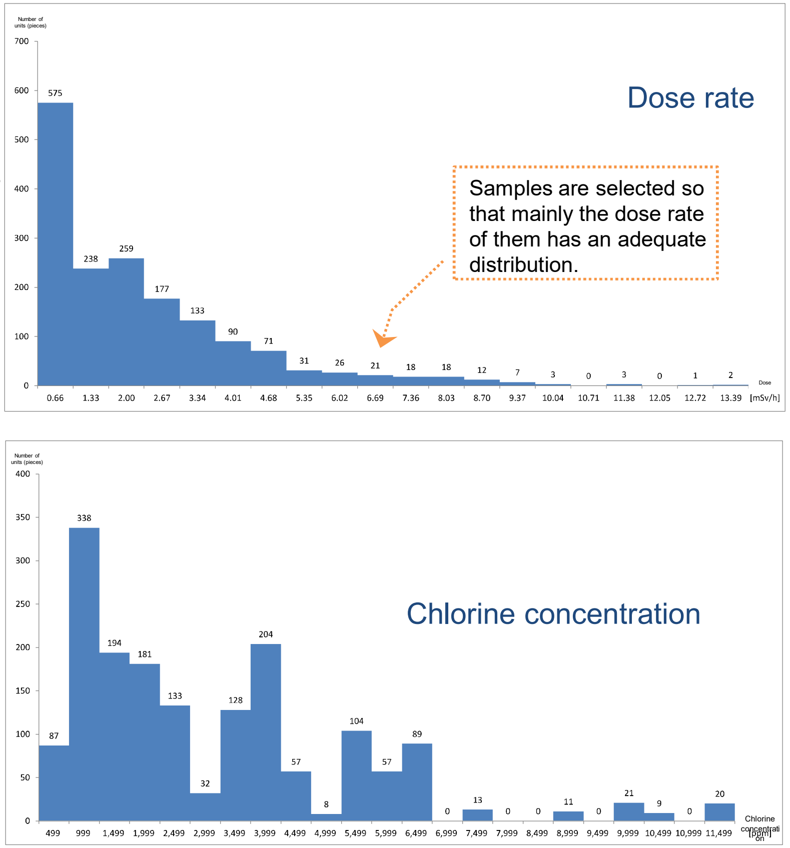


Figure 11. Frequency distribution of carbonate slurry (upper graph: dose rate, lower graph: chlorine concentration)

(I) Collection and Management of Analysis Data

b. Development of sampling technology - (a) Sampling of secondary wastes generated from contaminated water treatment, including sludge

- Method of collecting sludge from decontamination systems and the implementation of collection
  - As a site survey of the storage area (D-pit), an underwater camera was loaded for surveying the sludge sedimentation and separation status, the turbidity of clear supernatant water, etc. (Figure 12)
  - The image of the underwater camera (Figure 13) indicated that the thickness of accumulated sludge layer was about 40 cm. The volume was estimated to be just under about 37 m^3.
  - An investigation tool was made and inserted into the actual sludge layer at the site to investigate the degree of sludge consolidation as well as to sample the sludge. It is inferred that dense consolidation has not occurred in the sludge layer because the head of the investigation tool was confirmed to have reached the bottom of the D-pit. Sludge was collected into the vial container that was attached to the head of the investigation tool. (Figure 14)
  - The collected sludge sample was sent to JAEA, Nuclear Fuel Cycle Engineering Laboratories (JAEA, NCL) and Nippon Nuclear Fuel Development Co., Ltd. (NFD), and is being analyzed now. The target was achieved ahead of the original schedule (sampling in FY2018).

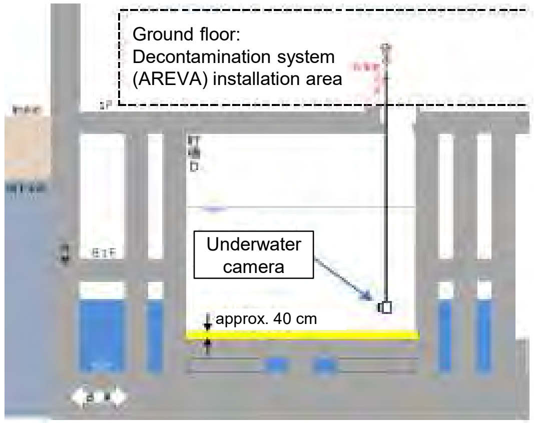


Figure 12. Schematic illustration of the Site (D-pit) Survey *

Figure 13. Condition of Sludge Sedimentation (yellow portion)*

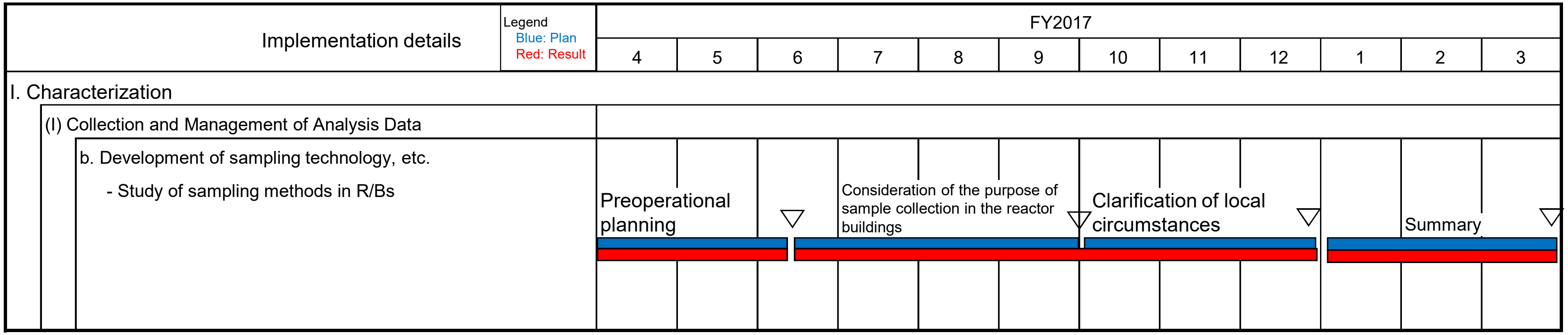
Figure 14. 10 mL Vial Container Setup (Right) and Collected Sludge (Left)*

*Material 2 of the 6th meeting of the Committee on Radioactive Waste Issues of the Specified Nuclear Facilities on July 25, 2017

(I) Collection and Management of Analysis Data

b. Development of sampling technology - (b) Study of sampling methods in R/Bs

FY	Implementation plan	Goal achievement index
2017	• Study on sampling technologies and target sampling locations depending on objectives and priorities will be conducted based on the outcomes of R&D activities in FY2016. • Samples will be collected accordingly at target sampling location based on the analysis plan.	• Proposal of target sampling locations according to objectives and priorities as well as technologies necessary to perform sampling • Implementation of sampling at locations for which a sampling method has been established
2018	• Study on target sampling locations and sampling technology will be continuously conducted in the same manner as FY2017. • Samples will be collected accordingly at target sampling location based on the analysis plan.	• Implementation of sampling at locations for which a sampling method has been established



(I) Collection and Management of Analysis Data

b. Development of sampling technology - (b) Study of sampling methods in R/Bs

- Methods for sampling in reactor buildings (R/Bs) by remote control
  - The feasibility of sampling in R/Bs was established using a sampling tool that was developed in consideration of applicability to remote operation during the last fiscal year project. (Figure 15)
  - The data of conditions inside the Unit 1 to Unit 3 R/Bs accumulated through past investigations (Figure 16) was scrutinized, and feasible access routes and sampling locations and exposure doses associated with the samplings were studied.
  - A prototype of remote sampling system was designed and produced. The sampling performance and remote operation performance of the prototype is being tested by mounting it on an existing robot (Packbot).

Figure 15. Sampling tool designed for remote operation (left) and a scene of concrete sampling in the Unit 4 reactor building (southwest corridor on 2F) (right)

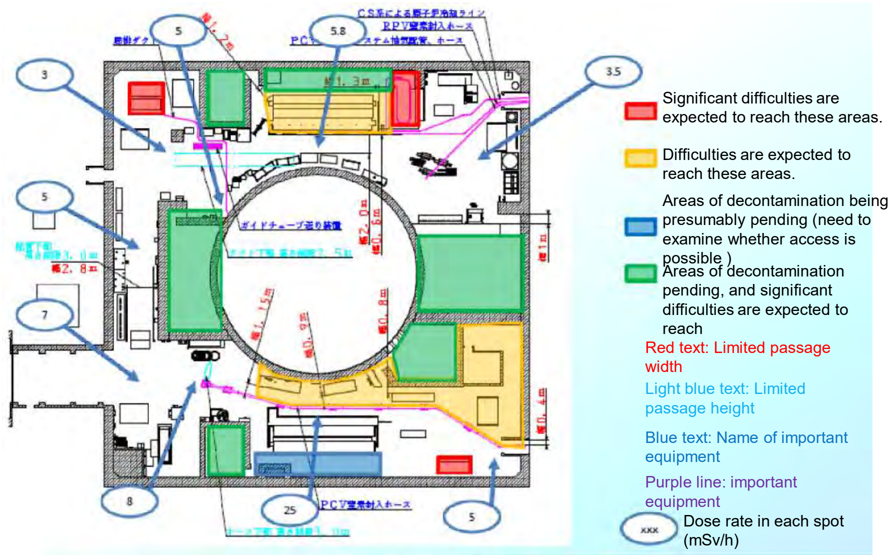


Figure 16. Reactor building illustration diagram with sampling locations

(I) Collection and Management of Analysis Data

No.28

c. Streamlining of analysis methods - (a) Study on migration behavior and the contamination mechanism of radionuclides

FY	Implementation plan	Goal achievement index
2017	• The contamination mechanism of radionuclides will be estimated in reference to information about the positions (locations) and processes where and how waste was contaminated and information about the development of the situation after the occurrence of the accident, as well as knowledge about the waste classification (composition of radionuclides that characterize the waste) studied in (I)-a.	• Presentation of the estimated contamination mechanism based on analysis data.
2018	• The results of classification will be reviewed as analysis data is accumulated.	• Presentation of the estimated contamination mechanism based on analysis data.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
c. Streamlining of analysis methods - Study on the migration behavior and the contamination mechanism of radionuclides					Study on contamination mechanisms						Summary		

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (a) Study on migration behavior and the contamination mechanism of radionuclides

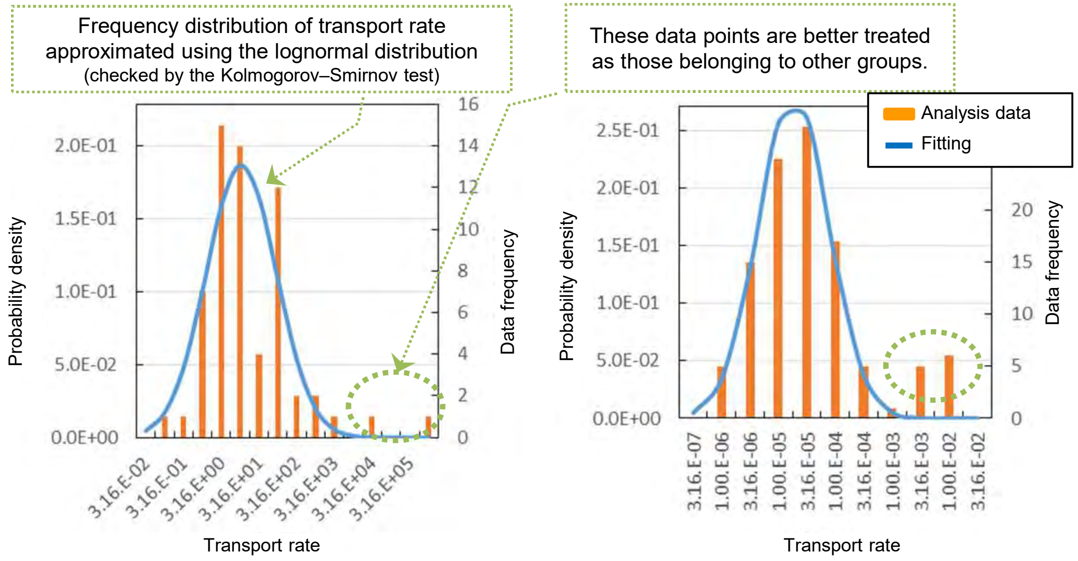
- The establishment of a model to describe contamination is needed for the estimation of the inventory of waste. It is important to gain knowledge about the types of radionuclide concentration distribution, to deal with the analysis data of radionuclide concentration.
  - The phenomena of contamination can often be described using the lognormal distribution assumption in general. The same is true for radioactive waste.
  - A transport rate is useful as an index because it makes it possible to deal with nuclides with similar chemical characteristics as one group.
- A good match to analysis data can often be obtained if the frequency distribution of transport rate is calculated based on a hypothetical contamination route and element group of similar chemical characteristics and approximated using the lognormal distribution. (Figure 17)
  - There is a possibility of different contamination behavior of elements if a good match is not obtained. Conversely, this result can be used to consider the grouping of contamination types.

Definition of transport rate *T*

- The transport rate of element X is calculated as a quotient of a ratio of X elements transported from the source term to the sample to the number of X elements in the source and the same ratio for the standard nuclide.

$$T_X = \frac{N_{X,\text{sample}} / N_{X,\text{source}}}{N_{\text{std,sample}} / N_{\text{std,source}}} = \frac{c_{X,\text{sample}} / c_{\text{std,sample}}}{A_{X,\text{source}} / A_{\text{std,source}}}$$

- *N* is the number of atoms, *c* is a concentration (Bq/g), *A* is an activity (Bq), X indicates the data of the nuclide concerned, and std indicates the data of the standard nuclide (^{137}Cs). *A* is applied after half-life period correction.
- It doesn't provide information in transient state during transport. The transport rate of Cs is 1 (one).



Volatile elements　　Rare earths, actinide elements

Figure17. Frequency distribution of transport rate and the suitability of lognormal distribution (Graphical presentation of analysis data on reactor building's internal contamination)

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (b) Study on representativeness of analysis data

FY	Implementation plan	Goal achievement index
2017 2018	• Study of assessment methods for the representativeness of analysis data will be conducted under the restriction conditions that the amount of the data and/or sampling locations are limited. Also, methods for estimating the distribution of waste contamination will be studied based on the assessment method established by the aforementioned study.	• Proposal of the assessment method for the representativeness of analysis data and the method for estimating contamination distribution.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
c. Streamlining of analysis methods													
- Study on the representativeness of analysis data								Study of data representativeness			Summary		

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (b) Study on representativeness of analysis data

- Waste is continuously generated, and sampling cannot cover all generated wasted due to the volume. It is conceivable that these facts make the establishment of clear and reliable waste classification, and the implementation of sampling in consideration of the representativeness of analysis data, difficult. (Figure 18)
- Based on the assumption that the destructive analysis of difficult-to-measure nuclides does not provide enough information about representativeness, inventory needs to be estimated.
- The non-destructive analysis and dose rate measurement of waste stored in storage containers are relatively easy and are expected to provide analysis and measurement data that assumes representativeness. For these reasons, a goal was set to establish a method that combines these two perspectives. (Figure 19)

○ A mid- and long-term analysis plan was considered based on the above viewpoint.

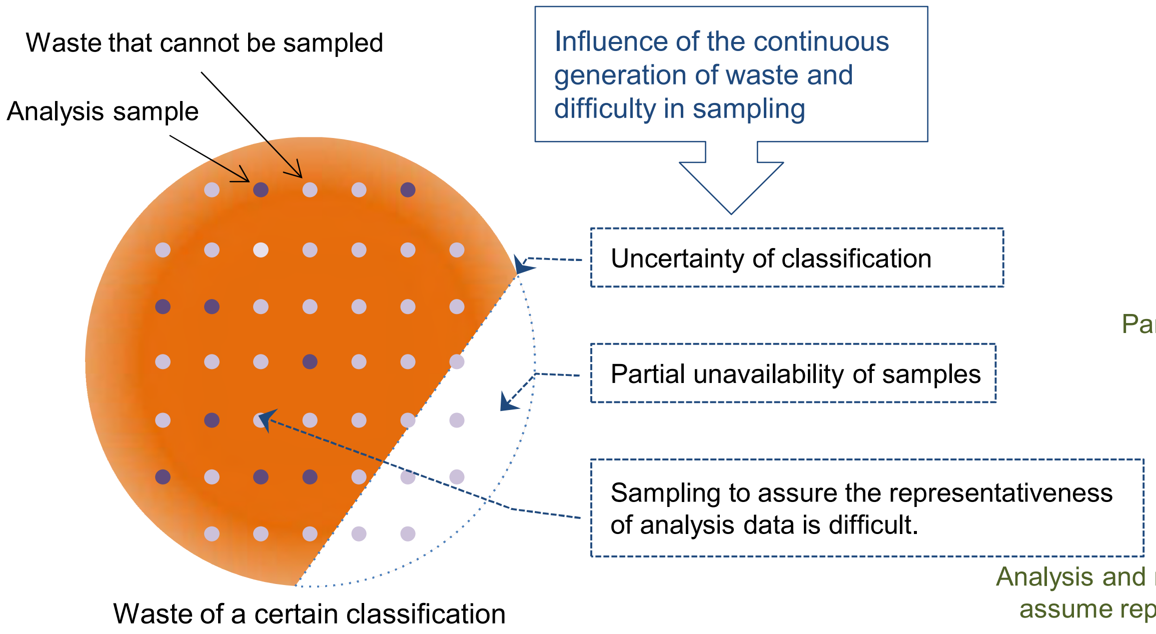


Figure 18. Illustration to explain difficulties in obtaining samples with representativeness

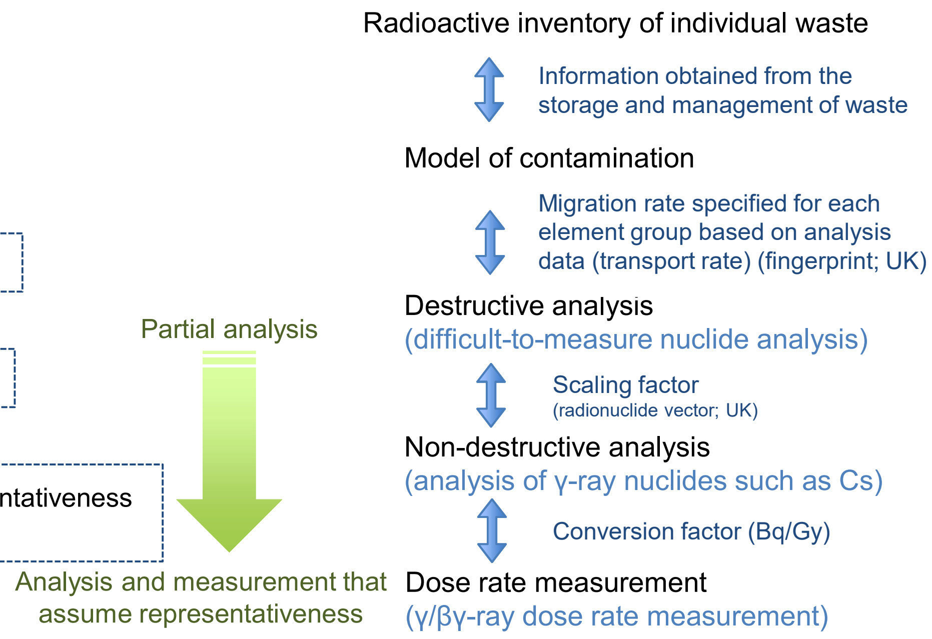


Figure 19 Relationship between the representativeness of analysis samples and inventory estimate

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (c) Reselection of nuclides to be analyzed

FY	Implementation plan	Goal achievement index
2017	• Radionuclides to be analyzed will be selected in consideration of the accumulated analysis data, limited capabilities of the analysis methods, and the importance in waste management. The result of the selection will be reflected in the analysis plan.	• Presentation of selected radionuclides to be analyzed.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
c. Streamlining of analysis methods - Reselection of nuclides to be analyzed		Selection of nuclides	▽ *Conduct a review and the analysis plan to reflect the result to the plan.										

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (c) Reselection of nuclides to be analyzed

- The method of difficult-to-measure nuclides analysis needs to be streamlined because it requires more resources (manpower, facility, and time) than that for typical nuclides. The list of nuclides to be analyzed was reviewed based on the accumulated analysis data to date and contamination behaviors (element groups) that were inferred by the analysis data.
- The concentration of some nuclides that weren't detected in the past (Table 6) can be estimated by the fuel consumption based-calculation, from the viewpoints of isotope and chemical similarity, not relying on analysis. In addition, the necessity of analysis and calculation was examined by taking into account the importance in disposal safety (Figure 20).
- Twenty-three (23) nuclides were listed as those whose concentration would be estimated by calculation, while the number of nuclides to be analyzed was reduced from 38 to 30. (Table 7)

Table6. List of undetected nuclides

Element	Detected	Not detected
H	^{3}H	
C	^{14}C	
Cl		^{36}Cl
Ca		^{41}Ca
Ni	^{63}Ni	^{59}Ni
Tc	^{99}Tc	
Cs	^{137}Cs	^{135}Cs
Eu	^{154}Eu	^{152}Eu
U	$^{234, 235, 236, 238}U$	
Np		^{237}Np
Pu	$^{238, 239+240}Pu$	$^{241, 242}Pu$
Am	^{241}Am	$^{242m, 243}Am$
Cm	^{244}Cm	$^{245, 246}Cm$

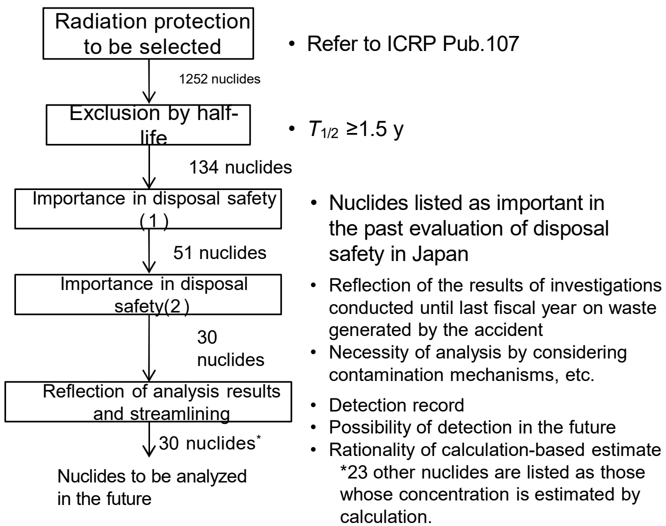


Figure20. Procedure to select nuclides to be analyzed considering the safety in disposal

Table 7. Nuclides Subject to Analysis and Calculation

Element	Nuclides to be analyzed	Nuclide subject to calculation
H	3	
C	14	
Cl	36	
Ca	41	
Co	60	
Ni	63	59
Se	79	
Sr	90	
Zr	93	
Nb	94	93m
Mo	93	
Tc	99	
Ru	106	
Pd	107	
Ag	108m	
Sn	126	
Sb	125	
I	129	
Cs	137	135
Sm		151
Eu	154	152
Pb		210
Po		210
Ra		226, 228
Ac		227
Th		228, 229, 230, 232
Pa		231, 233
U	234, 235, 236, 238	233
Np	237	
Pu	238, 239, 240	241, 242
Am	241	242m, 243
Cm	244	245, 246
Number of nuclides	30	23

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (d) Study on how to find more streamlined and reasonable analysis methods

FY	Implementation plan	Goal achievement index
2017	• Analysis methods that can be streamlined and improved in efficiency will be extracted based on the analysis plan.	• Listing analysis methods to be streamlined and improved in efficiency.
2018	• Applications of technologies expected to contribute to streamlining and improvement in efficiency will be studied.	• Presentation of the application scope of the listed analysis methods

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
c. Streamlining of analysis methods - Study on how to find more streamlined and rational analysis methods					Viewpoint of streamlining		▽	Study of streamlining analysis method		▽	Technical development plan discussed		▽

(I) Collection and Management of Analysis Data

c. Streamlining of analysis methods - (d) Study on more streamlined and reasonable analysis methods

- For the necessary high-level implementation of complex analysis, technologies expected to contribute to working out more efficient and rational analysis methods were listed from the viewpoint of cost reduction, worker exposure reduction and data quality assurance. (Figure 21)
- Promising R&D items were listed including the followings: change in measurement principle (from activity measurement to ICP-MS analysis), automation by introducing robots to automate chemical separation operation, and introducing a quality assurance system (Table 8). The realization of these themes was considered.

Table8. Evaluation of R&D Items Subject to Improvement in Efficiency and Reasonability

R&D items	Degree of effect	R&D resources		Degree of priority	Classification of theme
		Cost	Time		
Direct analysis of solid samples	Medium	High	Long	Medium	Fundamental
Sophisticated discrimination in detection	N/A	Low	Medium	Low	N/A
Change in measurement principle	Large	Medium	Short	High	Application
Concentration increase by chemical separation	Small	Medium	Long	Low	Fundamental
Integration of a series of steps	Medium	Medium	Medium	Medium	Fundamental
Chemical separation operation automated by robots	Large	High	Medium	High	Application
Introduction of quality assurance system	Large	Medium	Medium	High	Application

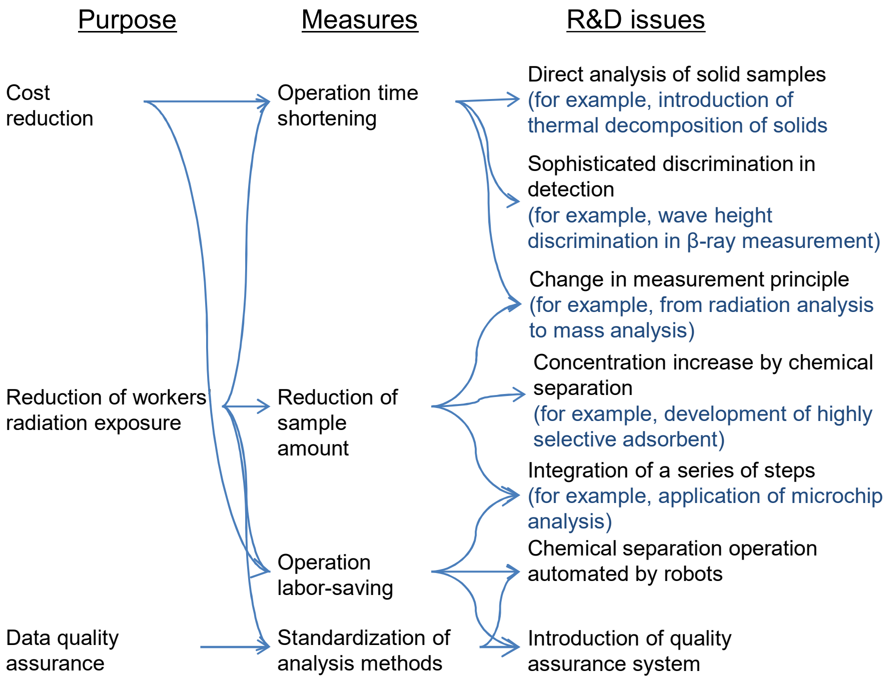


Figure 21. Required Improvements in Analysis and Required R&D Tasks

(I) Collection and Management of Analysis Data

d. Analysis data management

FY	Implementation plan	Goal achievement index
2017	i) Establishment of analysis database • A database through which all persons involved in analysis can share data will be established and used to streamline analysis work. • A database to be opened to the public will be created to utilize accumulated analysis data for decommissioning effectively. ii) Organize and update waste data • The latest waste analysis data will be collected and the data obtained in the FY2016 project will be re-organized. Additional data will be collected and updated accordingly.	i) Establishment of analysis database • Creation and utilization of the database ii) Organize and update waste data • Update of the waste list with the latest waste data and analysis results
2018	i) Establishment of analysis database • Issues for operation will be extracted to improve and upgrade functions. ii) Organize and update waste data • The latest waste analysis data will be collected and updated the data obtained in the FY2016 project. Additional data will be collected and updated accordingly.	i) Establishement of analysis database • Improvement of the database to solve issues identified during use ii) Organize and update waste data • Update of the waste list with the latest waste data and analysis results

Implementation details	Legend Blue: Plan Red: Result	FY2017 4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(I) Collection and Management of Analysis Data													
d. Analysis data management													
- Building of analysis database			Specification review	▽	Creation of database					▽	Operation and identification of issues		▽
- Organize and update waste data			Preoperational planning	▽	Consideration of data management and update policy, publication of updated data set					▽		Summary	▽

(I) Collection and Management of Analysis Data

d. Analysis data management - (a) Building of analysis database

- In the past, publicly released analysis data was included in a published report[*1]. Methods to publish analysis data on the internet were studied to improve the convenience of uses. In addition, methods to share data related to the management of samples and analysis work among relevant people were studied. (Figure 22)
- To secure the database, public data were extracted and released as public contents. (Figure 23)
  - ○ The contents built is currently being checked for vulnerability and will be released on the Internet with the announcement as soon as the check is complete[*2].
- The expansion of data coverage and English translation will be promoted.

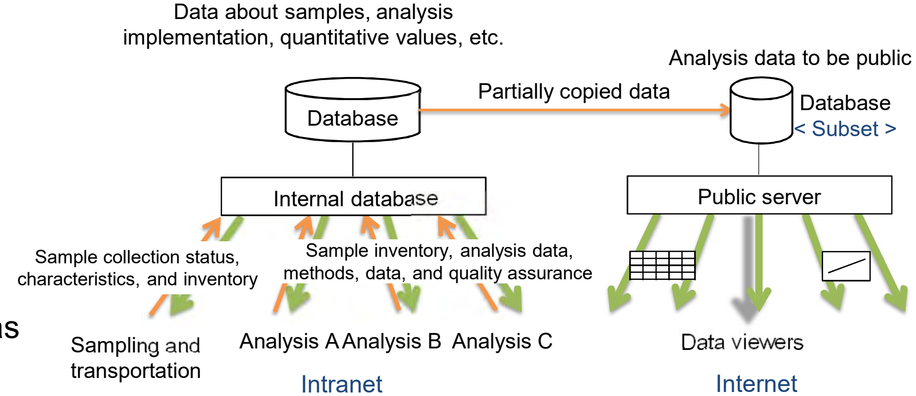


Figure 22. Analysis Database Structure

Top page | Graph view (change with time) | Table view (data downloadable)

Figure 23. Examples of Database Contents

*1 Analytical data on contaminated water, rubble and other debris collected at the Fukushima Daiichi Nuclear Power Station, JAEA-Data/Code 2017-001 (2017)
*2 https://frandli-db.jaea.go.jp/FRAnDLi/

(I) Collection and Management of Analysis Data

d. Analysis data management - (b) Organize and update waste data

- Information regarding stored waste is essential to the study of waste management. A control sheet has been created for every single waste generated and stored until now. However, paper-based management is not suitable for the utilization of waste information contained in a paper medium.. To cope with this issue, data items were considered and the information of the selected data items was computerized by input work, with the aim of making such information electronically accessible in a database.
  - Multiple types of control sheets have been created depending on the classification of waste and the time of use. A new database format was designed by carefully checking data items that form the basis of a new database in order not to miss any important items.
  - All the information of the selected items contained in about 47 thousand control sheets was input into the computer system. (Table9)
- The basic structure for the electronic data utilization was established by consolidating all waste volume and dose rate data contained in the control sheets. The following utilization methods are expected:
  - Reference for waste storage planning based on a macroscopic view over the characteristics of waste storage amount (volume) and dose rate. (Figures 24 and 25)
  - Identification of materials with impact on disposal
  - Utilization in reasonable storage and management planning.

Table9. List of computerized control sheets

Classification	Period of paper-based control	Waste type	Number of created control sheets
Rubble and felled trees	From Apr to Jul 2012	No category	374
	From Jul 2012 to Jan 2014	8	5,282
	From Jan 1024 to Sep 2015	21	17,144
	From Sep 2015 to Nov 2017	19	23,830
	From Nov 2017	22	208
Waste from contaminated water treatment facilities	From Apr 2012 to Nov 2017	8	241

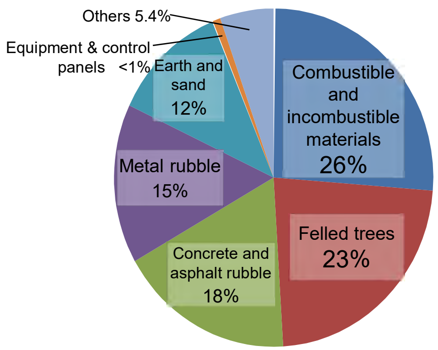


Figure 24. Percent of Waste Storage Amount (Volume) by Waste Type

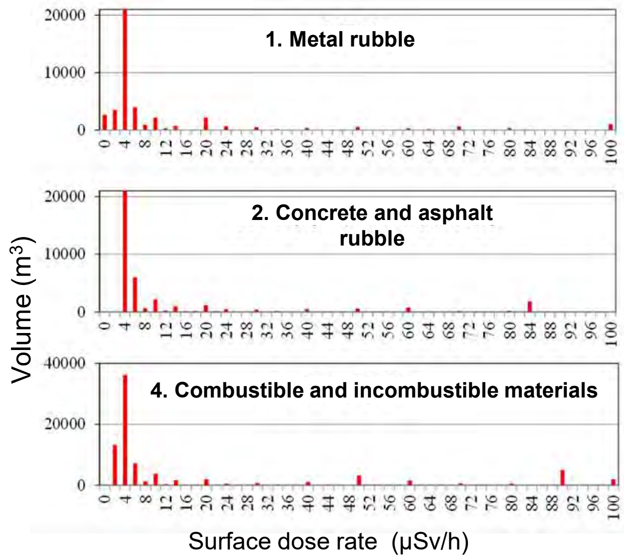


Figure 25. Relationship between Dose Rate and Storage Amount of Waste (Example)

(II) Accuracy Improvement of Analytical Evaluation Methods

No.39

a. Study of accuracy improvement methods, b. Study of data collection methods to improve accuracy, c. Establishment of analytical evaluation methods

FY	Implementation plan	Goal achievement index
2017 2018	i) Study of accuracy improvement methods • Methods necessary to improve the accuracy of inventory evaluation will be studied based on the results described in Section (I), including the classification of waste (composition of radionuclides that characterize the waste), the contamination mechanism of radionuclides, and the study results on the representativeness of analysis data. ii) Data collection for accuracy improvement • Necessary data will be collected based on the knowledge accumulated through studies and the knowledge obtained through the activities listed in Section (I). iii) Establishment of analytical evaluation methods • An environment for the analytical evaluation will be established which incorporates methods required for the improvement of inventory evaluation accuracy (including calculation tools).	i) Study of accuracy improvement methods • Indicate the measures for improving analytical evaluation accuracy. ii) Data collection for accuracy improvement • Collection of data that contributes to accuracy improvement. iii) Establishment of analytical evaluation methods • Preparation of analytical evaluation tools.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(II) Accuracy Improvement of Analytical Evaluation Methods - Study of accuracy improvement methods and establishment of analytical evaluation methods		Planning ▽			Accuracy improvement study and the establishment of methods ▽						Summary ▽		
- Collection of data for accuracy improvement		Planning ▽			Collection of basic experimental data ▽						Summary ▽		

(II) Accuracy Improvement of Analytical Evaluation Methods

- While the classification of waste is determined for the handling of them in storage, treatment, and disposal separately, the safety of them in disposal is closely related to the composition of nuclides. It was thought to be necessary to assess disposal safety and compare the result with a concentration equivalent to the standard dose rate for classification. (Figure 26)
- Although the contamination level of waste from dismantlement is not known, the setting of the parameters of nuclide migration to the waste was updated, considering the classification of waste generated by ordinary nuclear reactor decommissioning, contamination via air, and the process of secondary contamination caused by the contact with stagnant water and the adherence of fuel debris. (Figure 27)

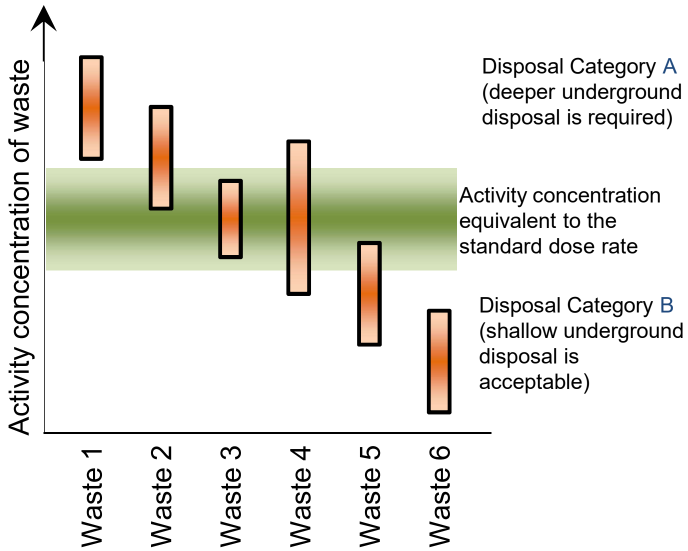


Figure 26. Comparison of the activity concentration of waste with a concentration equivalent to the standard dose rate of disposal safety for the classification of waste (concept illustration)

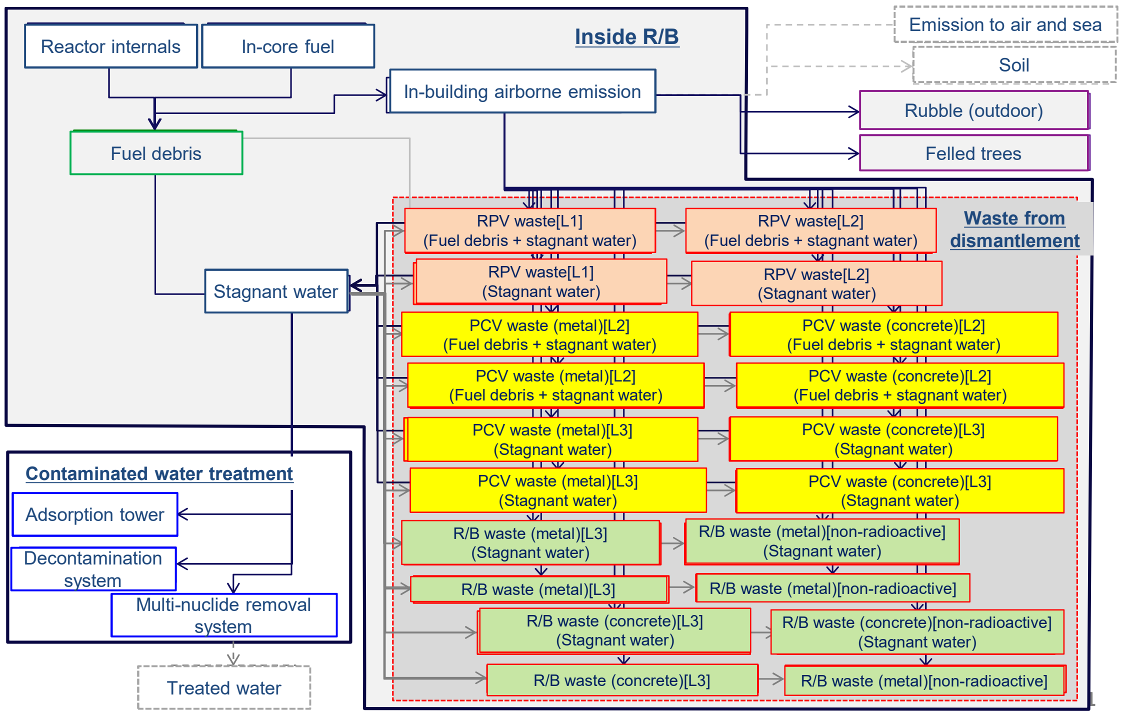


Figure 27. Contamination routes and classifications for the estimation of the inventory of waste from dismantlement

(III) Measures for Materials with Impact on Disposal

Implementation plan and goal achievement index

FY	Implementation plan	Goal achievement index
2017	• Case studies on acceptance criteria of waste inside and outside Japan will be surveyed, regarding not only radionuclides but also materials that influence treatment and disposal methods.	• Presentation of cases that address the acceptance standard of waste in terms of the content of influential materials to disposal concepts. • Proposal of quantitative evaluation indexes for the evaluation of barrier performance at the time of disposal and for the impact on nuclide migration.
2018	• Case studies on acceptance criteria of waste inside and outside Japan will be surveyed. • Based on the survey result, concepts of the acceptable concentration and content in materials with impact on disposal will be examined, which have risks of being contaminated in predisposal management and disposal facilities. • Methods of the quantitative evaluation will be studied for the impact of components that are known to have an impact on barrier performance (structural and nuclide migration-related chemical properties transformation) at the time of disposal and nuclide migration (nuclide migration-related chemical properties transformation).	• Indication of concepts about the acceptable concentration of materials exerting influence on disposal strategy and content of such materials in waste in Fukushima Daiichi Nuclear Power Station. • Proposal of quantitative evaluation indexes for the evaluation of barrier performance at the time of disposal and for the impact on nuclide migration.

Implementation details	Legend Blue: Plan Red: Result	FY2017											
		4	5	6	7	8	9	10	11	12	1	2	3
I. Characterization													
(III) Measures for Materials with Impact on Disposal													
- Case study inside and outside Japan			Planning				Research on cases					Summary	
- Investigation of impact on disposal safety			Planning		Study of indexes that can express impacts on performance and quantitative evaluation methods							Summary	

(III) Measures for Materials with Impact on Disposal

- The waste generated by the accidents may contain materials that are supposed to be separated and removed before disposal because of the restriction on the discharge of such materials into the environment. The same is true for materials with a potential adverse impact on the safety of treatment and disposal. Measures taken in Japan, the UK and the USA for dealing with such problems were surveyed. (Table 10)
- Typical materials with a potential adverse impact on the disposal and the solidification of waste were identified and listed. (Table 11)
  - ○ When examining the impact of a material on disposal, attention must be paid on the direct impact of the material on the migration of nuclides (deterioration of sorption performance due to complex formation, etc.) and indirect impact to cause change in the characteristics of the medium.
- It is necessary to examine whether there's anything to be reflected to the decommissioning process in parallel to the study on the impacts of such materials and their permissible concentrations.

Table10. Example of Waste Acceptance Standards in the UK (LLWR*1)

Category	Definition	Typical materials
Category 1	Requirement of control only without specific restrictions or sorting requirements The amount of the materials concerned needs to be recorded in the inventory.	Halogenated plastics, asphalt, copper, stainless steel, etc.
Category 2	Sorting required. Waste with the content of the materials concerned equal to or lower than criteria for acceptance can be accepted. The amount of the materials needs to be recorded in the inventory.	Arsenic, lead, mercury, electronic parts, etc.
Category 3	Materials classified as a hazardous material. Special management is required for these materials until disposal.	Asbestos, oil, solution, etc.

Table11. List of materials with a potential adverse impact on the disposal and the solidification of waste

Classification	Definition	Typical materials
Environmental toxins	Materials with a potential adverse impact on the environment	Lead (shielding material), boron
Materials with impact on disposal	Materials with a potential adverse impact on nuclide confinement performance	Organic material, boron, oxidizing material (nitric acid, etc.)
Materials with impact on solidification of waste	Materials that generate gases by corrosion during solidification	Aluminum, zinc (staging material, etc.)

*1. LLWR: a low-level radioactive waste disposal facility in the UK operated by Low Level Waste Repository Ltd.

3. Study on Predisposal Management

Contents of Report

(I) Applicability Assessment Based on Characteristics of Solid Waste

FY	Implementation plan	Goal achievement index
2017	• Characteristics wastes generated by the accident will be extracted for solidification technologies that have proven in the treatment of radioactive waste (such as cement solidification technology and high-temperature treatment technology). The applicability of the solidification technologies will be evaluated in consideration of the impact of dose rate and heat generation to identify issues to be addressed continuously.	• Clarification of issues in case of the application of conventional technologies to highly radioactive waste.
2018	• New solidification technologies will be investigated to evaluate the possibility of the solution for the identified issues. Expected effects by conducting tests will be evaluated and test the actual applicability when necessary.	• Proposal of a solidification technology that can solve the identified issues.

- Progress status
  - The applicability of solidification technologies to waste that possess unique characteristics attributable to the accident was examined by comparing those wastes with the existing classification of radioactive waste.
  - Six technologies that were considered in the fundamental tests performed until the end of FY2016 were grouped into the following two groups: technologies that have proven track records in pretreatment before disposal (waste conditioning) and technologies that can improve safety in storage (stabilization).
  - From the results of the applicability assessment of the conventional technologies to highly radioactive waste, the following issues were identified: the understanding of the relationship between the radioactivity amount of nuclides contained in the waste and decay heat that is generated in the waste and makes an impact on the material properties of solidified bodies, the development and adoption of an assessment index for the comparative assessment of applicable waste treatment technologies, and the collection and arrangement of data (data range) related to the developed index.
  - The necessity of considering approaches for refinement technologies applicable to pretreatment was also presented from the identified issues.
- Future plan
  - Develop an investigation and test plan toward solving identified issues, propose and implement it.

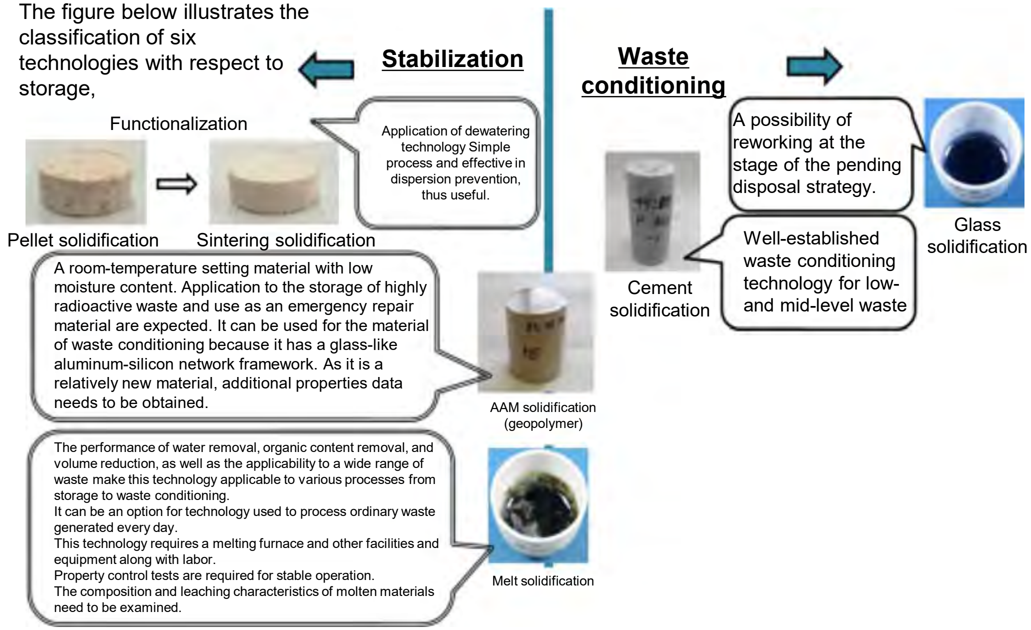


Figure 1. Classification of Six Technologies Subjected to Fundamental Tests Performed by FY2016

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

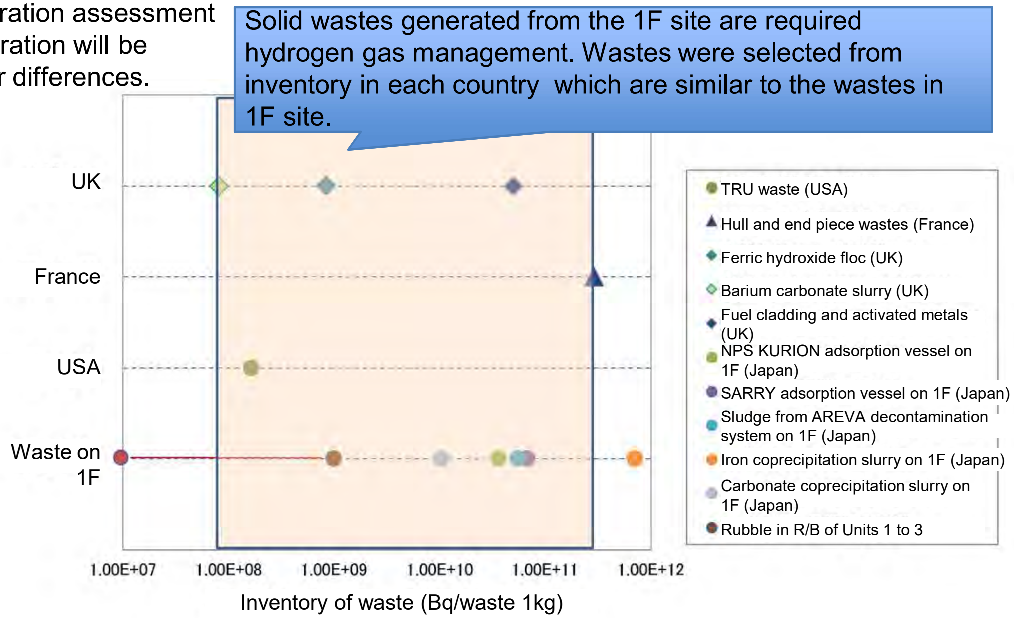
a. Study of safety measures required for the storage of highly radioactive waste
(a) Measures for hydrogen gas generation

FY	Implementation plan	which Goal achievement index
2017	• Expertise from overseas (the UK, the USA and France) and Japan will be surveyed about the hydrogen gas generation method during the storage of solid waste containing high radiation and water, and requirements for the storage container such as vents that hydrogen gas may generate..	• Presentation of knowledge concerning hydrogen gas generation assessment methods and requirements for the storage container such as vents
2018	• Based on the results of research on hydrogen gas generation conducted in FY 2017 which were collected from overseas and Japan, the applicability to 1F will be studied to clarify potential issues.	• Presentation of the 1F site applicability and issues

The survey on concepts of generated hydrogen gas, hydrogen gas generation assessment methods, container specifications, and measures for hydrogen gas generation will be conducted, focusing on differences from Japan and including reasons for differences.

[Survey items]

1. Survey on concepts of hydrogen gas generation in each country(regulations and technical requirements)
   - ➢ Concepts of hydrogen gas generation in each country(regulations and technical requirements) were surveyed in storage, treatment, disposal and transport phases.
2. Survey of evaluation methods for hydrogen gas generation
   - ➢ G-value settings and concepts were mainly investigated.
3. Investigation of required functions for a solid waste container
   - ➢ Types and materials of containers were broadly investigated, mainly measures for hydrogen gas generation.
4. Measures for hydrogen gas generation
   - ➢ Measures for reducing hydrogen gas generation were investigated.



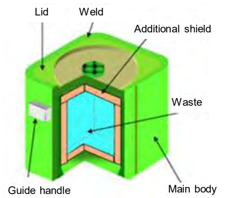
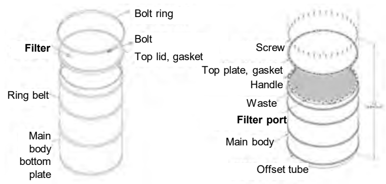
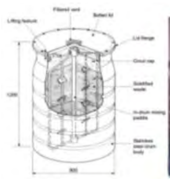
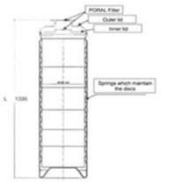
Source of 1F waste inventory data:
Appendix 4.4.3-1 titled "Inventory and nuclide migration parameters," of the research report (interim report) for "R&D for Treatment and Disposal of Solid Radioactive Waste" under Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budgets
Note that data of rubble in R/Bs of Unit 1 to Unit 3 are cited from the International Research Institute for Nuclear Decommissioning web site (2018).

No.47

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

a. Study of safety measures required for storage of highly radioactive waste
(a) Measures for hydrogen gas generation - Result overview

By the comparative investigation on cases in Japan and other countries, useful information on measures for hydrogen gas was obtained concerning:
(1) Reduction in free water volume, (2) Use of adequate G-values depending on materials and the type of rays, (3) Ventilated container.

	Japan	USA	UK	France
Waste to be investigated	Waste generated by power stations and reprocessing facilities, which can be accompanied by hydrogen gas generation • Activated metals • L1 waste, such as polymers • Waste from reprocessing facilities Waste from active facilities	Waste stored in disposal facility considering experience of waste acceptance • TRU waste (WIPP disposal facility) • Class C waste (WCS disposal facility)	ILW waste which hydrogen gas generation needs to be considered • Ferric hydroxide, barium carbonate • Oxide fuel cladding • Plutonium-contaminated material • Waste from Magnox fuel reprocessing • Mixed legacy waste	Waste with a risk of hydrogen gas generation and/or waste similar to that on 1F • Hull and end piece wastes (CSD-C) • Dry sludge from liquid waste treatment facilities (DSC)
Appearance of container (example)	 Activated metal waste	 Solid waste with a moisture content of 1 vol% or less	  Barium carbonate slurry waste	  CSD-C: Hull and end piece wastes
Hydrogen gas generation assessment	• Radiolytic water splitting G-value (H_2): γ-ray: 0.45	• Radiolytic water splitting G-value (H_2): α-ray: 1.6 βγ-ray: 0.5 • G-value for α-ray is determined depending on the characteristics of waste.	• Radiolytic water splitting G-value (H_2): βγ-ray: 0.4 • G-value of cement solidified material G-value (H_2): βγ-ray: 0.15	• Radiolytic water splitting G-value (H_2): α-ray: 0.044* γ-ray: 0.0021* *A value of the crystallization water of MoZr precipitate • Corrosive gas generation was assessed.
Measures for hydrogen gas generation	• Storing in a sealed container (Gas leakage prevention from the container) • Dewatering and drying	• Storing gas in a ventilated container (Stored in a sealed container during transport) • Moisture content ≤ 1%	• Storing gas in a ventilated container (Stored in a sealed container during transport)	• Storing gas in a ventilated container (Stored in a sealed container during transport) • Maintaining a hydrogen gas concentration of 1 vol% or less by ventilation

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

a. Study of safety measures required for storage of highly radioactive waste
(a) Measures for hydrogen gas generation - Result summary

Measures for hydrogen gas generation obtained from investigations in this fiscal year are summarized below from the aspect of reduction in free water volume, use of adequate G-values depending on materials and the type of rays, and storage using containers with vents.

Operators in all three countries determined the reasonable methods of treatment, storage, and disposal, and coordinated the methods to be approved by the regulatory authorities.

(1) Reduction in free water volume

- All three countries consider the reduction of free water volume by the drying or cement-solidification of waste because the decomposition of free water is basically dominant to estimate volume of hydrogen gas generation.
- The handling of free water and other water (ex. cement crystallization water) varies by country.
  Example)
  USA and UK: Volume of hydrogen gas generation is estimated depending on the volume decrease or state change of free water by cement solidification.
  France: G-value of crystallization water in MoZr precipitate was set to estimate volume of hydrogen gas generation.

(2) Use of adequate G-values depending on materials and the type of rays

- All three countries use different G-values in hydrogen gas generation volume estimation depending on the characteristics of waste (such as water state, the type of organic materials, and the type of radioactive rays).

(3) Storage in containers with vents

- All waste investigated in this research (ex. TRU waste in USA, ferric hydroxide waste in UK, and CSD-C waste in France) were stored in containers with vents, which were implemented hydrogen gas measures.
- Beside hydrogen gas, public radiation exposure from fission products (H-3, Kr-85, etc.)was also considered.

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

a. Study of measures for storing highly radioactive waste

(b) Measures for wastes generated by fuel debris retrieval (1/3)

FY	Implementation plan	Goal achievement index
2017	• The latest information on wastes generated by fuel debris retrieval work will be collected and organized the collected information based on study results from other projects conducted for fuel debris retrieval (such as the project of fuel debris retrieval, and containment, transport and storage of fuel debris). The proposed waste storage and management methods will be studied based on collected and organized information.	• Presentation of the latest information of projected wastes generated by fuel debris retrieval work based on study results from other projects conducted in relation to debris removal (such as the fuel debris retrieval project and the containment, transport and storage project).
2018	• The latest information will be collected and organized the collected information in cooperation with other projects conducted for fuel debris retrieval (such as the project of fuel debris retrieval and collecting, transferring and storing of fuel debris). All ideas of reasonable methods to store and manage wastes generated by fuel debris retrieval work will be reviewed and proposed recommendable methods in consideration of fuel debris retrieval process as well as the collected and organized information.	• Examine all ideas of reasonable methods to store and manage wastes generated by fuel debris retrieval work and propose recommendable methods among the ideas in consideration of fuel debris retrieval process, as well as the collected and organized information.

■ Progress status

○ Types and volume of wastes generated by fuel debris retrieval were estimated and the first version list (draft) of said waste was created based on the latest investigation results provided by the fuel debris retrieval project and the containment, transport and storage project. (Figure 2)

○ A list of the safety function requirements that will be required in each step for the storage and management of wastes generated by fuel debris retrieval was created. Several feasible process flows of storage and management (including a storage container case with filtered vent case) were developed.

■ Future plan

○ All reasonable and feasible methods to store and manage wastes generated by fuel debris retrieval work will be summarized and proposed recommendable methods among the methods.

Waste		Type	Weight (t)	Waste density (t/m^3)	Volume (m^3)	Dose rate (mSv/h)
Generated as waste	DSP slot plug	Concrete	Unknown	2.5	(>100)	4.0E+3
	Heat-retention material	Metal	Unknown	7.8	–	–
	PCV head	Metal	50	7.8	6.4	4.0E+3
	Shield plug	Concrete	600	2.5	240.0	4.0E+3
	RPV head	Metal	70	7.8	9.0	3.0E+4
	Dryer	Metal	28.0	7.8	3.6	4.0E+5
	Separator	Metal	17.2	7.8	2.2	2.0E+5
Generated as waste containing fuel debris	Top guide	Metal	3.4	7.8	0.4	1.0E+6
	Shroud	Metal	25.1	7.8	3.2	3.5E+5
	Core plate	Metal	4.0	7.8	0.5	3.5E+5
	CR guide tube	Metal	11.2	7.8	1.4	3.5E+5
	CRD	Metal	28.9	7.8	3.7	3.5E+5
	RPV bottom mirror	Metal	50.0	7.8	6.4	3.5E+5
Total		–	887.8	–	276.9	–

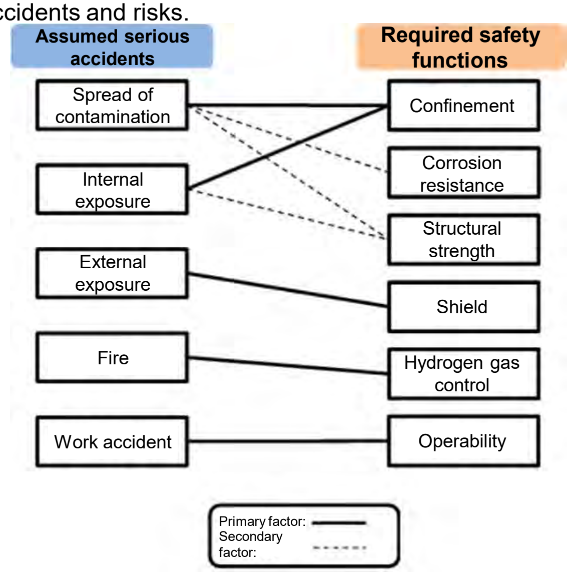
Figure 2. First version list (draft) of projected wastes generated by fuel debris retrieval (at Unit 1)

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

a. Study of measures for storing highly radioactive waste
(b) Measures for wastes generated by fuel debris retrieval (2/3)

"List of safety function requirements"

Potential serious accidents that could occur in each step of the handling of projected wastes generated by fuel debris retrieval, such as containment, transport, and storage, were considered along with risks posed in association with the accidents, as well as required safety functions to prevent accidents and risks.



Clarification of safety function requirements in individual work steps
⇒ Each of the confinement, transport, and storage steps

List of potential risks and safety function requirements during transport (partial listing for transport only)

	Serious accidents	Hypothetical accident scenarios	Risk		Measures according to required safety functions
During transport	Spread of contamination	• A transport cask falls and is damaged during transport, and the content spills out of the cask.	High	• The impact becomes serious when contamination spreads in the premise.	• Make the transport cask strong enough to withstand the impact of a fall and devise a secure sealing mechanism to prevent spillage or leakage even in case of a fall.
	Internal exposure	• α nuclides leak out of a container and a worker is exposed to internal radiation by inhaling them.	High	• There is a high risk of internal exposer if dusts that contains α nuclides leaks	• Make the transport cask strong and devise a high quality sealing mechanism.
	External exposure	• A worker near the transport cask is exposed to radiation from the cask directly.	High	• There is a high risk of external exposure unless the transport cask possess sufficient shielding performance.	• Make the shielding of the transport cask thicker to improve its shielding performance.
	Fire	• The inside of the transport container is filled with hydrogen gas and catches fire.	High	• There is a risk high of the occurrence of hydrogen concentration when moisture and α nuclides coexist inside the sealed container.	• Exercise time control to maintain hydrogen concentration below lower explosion limit.
	Work accident	• A worker is injured by a falling transport cask.	Low	• There is a similar risk of work accident to the transport of ordinary goods.	• Use fall prevention measures for transport casks.

The most important challenge is to satisfy both of the following requirements.
- Ensure confinement performance
- Ensure measures for hydrogen gas

Conflicting safety requirements in case of hydrogen gas release

Development of a process flow that satisfied the above conflicting safety requirements and also meets all other safety function requirements.

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

a. Study of measures for storing highly radioactive waste
(b) Measures for wastes generated by fuel debris retrieval (3/3)

Allocation of safety functions that satisfies the prevention of nuclide dispersion (confinement) and measures for hydrogen gas (idea)

Formulation of ideas for reasonable storage and management process flow

- Use of transport casks
- Use of containers with filter
- Use of cask transporters with sealing function
- Adoption of dispersion prevention methods
- Drying pretreatment

:
:
:

The ideas to be narrowed down in FY2018

Roles of Safety functions for hydrogen gas confinement and reduction(idea)

Pretreatment	Roles of safety functions			
	During transport		Storage	
	Confinement	Hydrogen gas control	Confinement	Hydrogen gas control
N/A	Sealed transport cask	Time management	Storage building	Storage building
	Intra-premise cask transporter with sealing function	Time management	Storage building	Storage building
	Simple structure tunnel	Tunnel ventilation	Storage building	Storage building
	Sealing bag	Time management	Sealing bag	Periodic implementation
	Sealed storage container ventilated with high-performance filter		Sealed storage container ventilated with high-performance filter + Storage building	
Drying treatment	Sealed transport cask	Not required (due to drying treatment)	Storage building	Not required (due to drying treatment)
	Intra-premise cask transporter with sealing function		Storage building	
	Simple structure tunnel		Storage building	
	Sealing bag		Sealing bag	
	Sealed storage container		Sealed storage container	
Anti-scattering agent application/facing bag	Unnecessary (due to application of anti-scattering agent/packaging in facing bag)	Ventilated storage container	Unnecessary (due to application of anti-scattering agent/packaging in facing bag)	Ventilated storage container + Storage building
Drying treatment + Anti-scattering agent application/facing bag	Unnecessary (due to application of anti-scattering agent/packaging in facing bag)	Not required (due to drying treatment)	Unnecessary (due to application of anti-scattering agent/packaging in facing bag)	Not required (due to drying treatment)

11 storage and management flows were designed to evaluate the safety functions in each step.

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(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

b. Evaluation of stabilization technology for the secondary wastes generated from contaminated water treatment

(a) Applicability assessment of in-drum glass solidification technology

FY	Implementation plan	Goal achievement index
2017	• With the aim of clarifying glass solidification conditions, glass composition will be studied and crucible melting tests will be performed to obtain the data, such as treatment conditions, volume reduction ratio, and the physical properties of glass.	• Presentation of glass solidification conditions by studying glass composition and performing crucible melting tests.
2018	• Engineering-scale tests using the glass solidification conditions derived from the test results in FY2017 will be performed to investigate conditions for glass melting by joule heating, and to evaluate the impact of nuclides on the characteristics of solidified materials and off-gas systems. Additionally, the durability and maintenability of device will be confirmed.	• Presentation of the results of study on the impact of nuclides on the characteristics of solidified materials and off-gas systems and the results of the assessment on the durability and maintainability of equipment by performing engineering-scale joule heated glass melting tests.

■ Purpose

○ In-drum glass solidification technology (GeoMelt ICV) is focused on as a candidate stabilization technology for the pretreatment of secondary wastes generated from contaminated water treatment facilities from the aspect of the prevention of contamination spread and equipment size. The applicability of treatment which zeolite is used as the main component of the glass solidification agent to simultaneously melt slurries

○ Is studied and evaluated.

■ Progress status

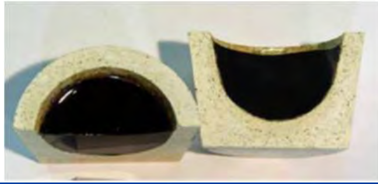
○ Basic tests (glass composition examination and crucible melting test)

- Crucible melting test (Figure 3)
  - ➢ Simulated waste: 20 types selected from the waste generated by the water processing facilities of Fukushima Daiichi NPS (Table 1)
  - ➢ Composition: Zeolite (main component), simulated waste, additives, and tracer were mixed with compositions determined based on analysis results (Total 40 kinds of mixing ratios).
  - ➢ Melting procedure: Remove volatile materials (such as water) at (700° C) first, heat the mixture to1250 °C while confirming the progress of melting, and anneal it at (500 °C).

Table 1 Simulated waste and tracer

Water treatment facility	Simulated waste*1)	Tracer
Decontamination system (AREVA)	Sludge (1 type)	Sr, Cs
Cesium adsorption apparatus (KURION)	Filter material (1 type) Adsorbent (4 types) *2)	Sr, Cs
Secondary cesium adsorption apparatus (SARRY)	Filter material (2 types)*3) Adsorbent (1 type) *4)	Sr, Cs
Multi-nuclide removal system	Slurry (2 types)	Sr, Cs
	Adsorbent (9 types)	Depending on adsorbent*5)

*1) Additives (such as B_2O_3, CaO, Na_2O) are mixed in simulated waste
*2) Types of absorbent include zeolite (two types), silver zeolite (one type), and silica titanate (one type)
*3) One of 2 types of filter materials contains zeolite
*4) Zeolite is used as adsorbent
*5) Sr, Cs, Co or Sb is used depending on the elements the adsorbent tries to remove.



Zeolite, sludge, and additive (such as B_2O_3) aremixed

Figure 3. Example of Glass Melted in Crucible

Results of glass observation and analysis

- **Fluidity**

  The fluidity of the mixture was visually observed at 1,150° C or higher temperature in all compositions.

- **Volume reduction ratio, waste filling rate**

  Volume reduction ratio (percentage of the volume of glass to the volume of simulated waste) is between 14% and 26%. Waste filling rate is between 70% and 80%.

- **Visual observation**

  The glass solidification was confirmed on both zeolite and other waste. Precipitates were observed in some solidified glass samples.

- **Analysis**

  Solidified glass samples with precipitates were sent to elemental analysis (7 samples to EDS) and crystallographic analysis (7 samples to XRD) to identify precipitated rutile from silicon titanate. As a result, it was found that homogeneous glass can be produced from the mixture of carbonate precipitates when the mixing ratio is between 16 to 21 wt%, and also from the mixture of iron coprecipitation with a mixing ratio of 11 to 12 wt%, both of which are kept a lot on 1F. In addition, the successful glass solidification of the mixture of carbonate precipitates (approx. 16 wt%) and iron coprecipitation (approx. 2 wt%) was confirmed when approx. 65 wt% zeolite was used.

  As to titanate, which is also kept a lot, the production of homogeneous glass from its mixture was confirmed when its mixing ratio was between 8 wt% and 18 wt%.

  Sludge may produce precipitates during glass solidification. However, glass without the layer of sulfate was produced from the mixture of sludge with a mixing ratio of 3-6 wet%.

- **Leach test** (Figure 4)

  Simulated waste samples were grouped into 7 groups and 15 types of mixtures each of which contains a simulated waste picked up from the 7 groups, with 1 to 3 different mixing ratios prepared. Glass samples were produced from those mixtures and subjected to leach tests (MCC-1, 28 days). As a result of the leach tests, the leaching amount $NL_{(B)}$ from the glass sample was found to be nearly equal to that of the P0798 glass developed by former Power Reactor and Nuclear Fuel Development Corporation (data is shown in Figure 4, indicated by ←) for all glass samples, and thus the high chemical durability of all glass was proved.

- **Tracer retention rate**

  The tracer retention rate in the glass samples was as follows regardless of the type and mixing ratio of simulated waste samples: Sr retention rate, 72 to 128%*; and Cs retention rate, 59 to 95%. Cs shows small volatilization suppressing effect in crucible melting.

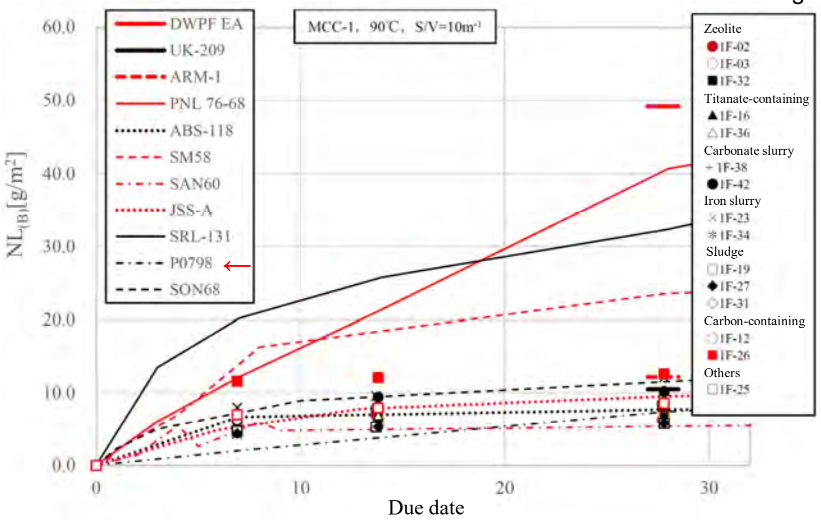


Figure 4. Comparison of leaching amount with international standard glass

* The analysis result of retention rate exceeded 100% due to analysis error.

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

b. Evaluation of stabilization technology for the secondary wastes generated from contaminated water treatment

(b) Study on sludge stabilization of decontamination systems (1/2)

FY	Implementation plan	Goal achievement index
2017	• Fluidity evaluation tests using simulated sludge samples will be performed to obtain basic data of fluidity properties for sludge concentration as a test parameter. In addition, a demonstration testing plan will be developed for FY2018.	• Collection of the basic data of fluidity and related properties and the formulation of a demonstration testing plan.
2018	• Sludge discharge methods will be verified by performing engineering-scale sludge collection, cleaning, and transferring tests that use simulated sludge samples and the simulated D-pit internal structure.	• Presentation of the feasibility of a sludge discharge method from the D-pit.

- Implementation details
  - Simulated sludge samples were produced according to the actual process and systems. A test plan was developed for the collection of basic data.
  - 3 types of simulated sludge samples were produced considering time deterioration of actual sludge (especially polymer sludge).
    - Sludge A: containing polymers
    - Sludge B: no polymer
    - Sludge C: irradiated sludge A
  - Collection of basic fluidity data using simulated sludge samples
  - Analysis results of actual sludge were compared and a verification testing plan was developed.
- Outcomes
  - A method for determining sludge discharge technology was established by producing simulated sludge considering time deterioration of sludge under actual conditions and understanding of fluidity properties necessary to design sludge collection and transfer methods in the combination of the results of the investigation of inside the D-pit.

Item		Test sample and concentration (g/L)		Test items (analysis items)	
(1)	Density	Sludge A Sludge B Sludge C	60	Wet density of sludge	
(2)	Particle size distribution		60	Particle size distribution of sludge	
(3)	Chemical composition		60	Sludge	Fe, Ni, Ba, Na, Si
					Cl
					Total C, Total S
				Clear supernatant water	Fe, Ni, Ba, Na, Si
					Free CN
					Cl, SO4
					TOC
(4)	Sedimentation property	Sludge A Sludge B Sludge C	60	Sedimentation behavior in water	
(5)	Viscosity	Sludge A	75 to 300	Viscosity variation with sludge concentration	
		Sludge B	2 concentrations		
		Sludge C	1 concentration		
(6)	Effectiveness of stirring	2 types	60	Effectiveness of bubbling stirring	

(II) Study and Evaluation of Waste Storage and Management Methods Appropriate for the Characteristics of Solid Waste

b. Evaluation of stabilization technology for the secondary wastes generated from contaminated water treatment

(b) Study on sludge stabilization of decontamination systems (2/2)

- Physical properties of simulated sludge (density, particle size, and chemical composition: Figure 5)
  - If all Ba atoms are assumed to exist in a form of barium sulfate, about 66% of sludge in weight is barium sulfate.
  - The particle size of sludge A is about 20 times larger than that of sludge B due to the aggregating effect of polymers.

	Wet density (g/cm^3)	Average particle size (volume basis) (μm)	Chemical composition of sludge (g/kg)							
			C	Na	Si	S	K	Fe	Ni	Ba
Sludge A	1.15	120	36.4	1.41	6.24	105	22.3	48.8	32.2	391
Sludge B	1.14	6.45	33.9	1.03	4.40	107	19.4	44.0	28.4	400
Sludge C	1.09	10.8	36.8	1.35	3.63	98	22.6	56.6	30.4	396
Actual sludge	1.18	8.89	–	20.5	13.2	108	16.2	107	32.6	461

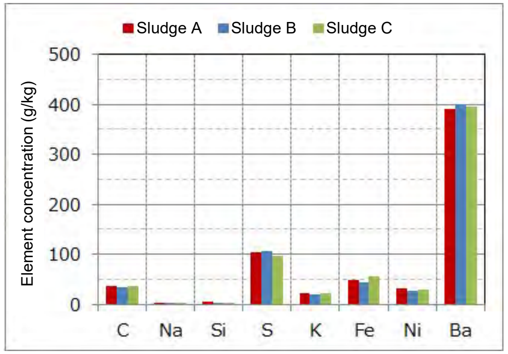


Figure 5. Chemical Composition of Simulated Sludge Samples

- Sedimentation property (Figure 6)
  - Sample sludge was stirred in a measuring cylinder and left standing to observe the occurrence of sedimentation (change in the height of sludge phase boundary).
  - Actual sludge showed sedimentation behavior that is like the even mixture of those of sludge A and B. Sludge C (irradiated sample) showed a similar behavior to that of actual sludge.
- Viscosity (Figure 7)
  - The viscosity of the sludge was measured with different concentrations to investigate the influence of the concentration.
  - The viscosity of the sludge decreased with an increase in the shear velocity in a high concentration range on both sludge samples A and B. Meanwhile, the sludge samples showed a near-constant viscosity in a low concentration range regardless of the shear velocity.

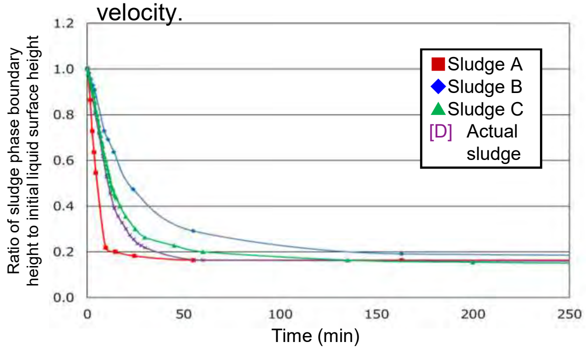


Figure 6. Sedimentation Property Test Result

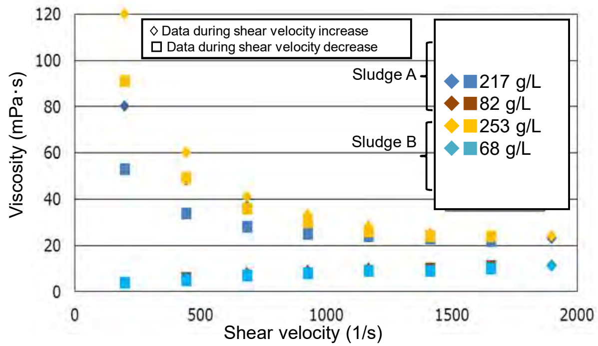
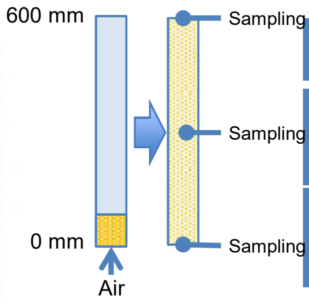


Figure 7. Result of viscosity measurement

- Effectiveness of stirring (Figure 8)
  - Sludge was put in a glass cylinder (Φ40 mm × 600 mm) and left standing for a week to cause sedimentation. Then air was injected from the bottom for stirring and the concentration of the sludge was measured at three different heights.
  - The measured sludge concentration was nearly equal to the initial value (60 g/L), which suggested that the homogeneous re-stirring and mixing of the sludge could be done.



	Sampling height (mm)	Concentration (g/L)
Sludge A	600	55
	300	56
	0	58
Sludge B	600	48
	300	49
	0	50

Figure 8. Stirring Verification Test result

Sludge A contains polymers, Sludge B contains no polymer and Sludge C is an irradiated sample

(III) Research on Technologies for Reducing Waste Production

FY	Implementation plan	Goal achievement index
2017	• Technologies applicable to the measurement and assessment of α-contamination in highly radioactive environments will be investigated and studied with the aim of applying them to waste sorting methods that can reduce waste amount and help realize waste categorization.	• Indicate technologies applicable to 1F.

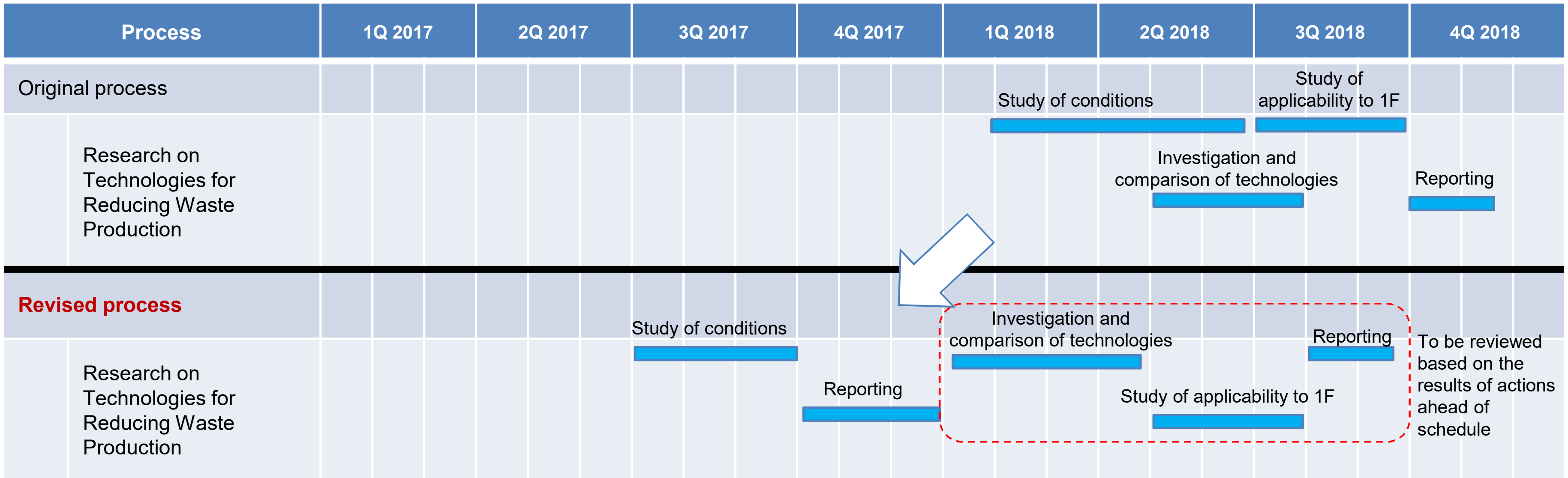
■ Progress status

○ The purpose of measurement, waste to be measured, and environmental conditions for measurement were studied, all of which were originally planned to be conducted in FY2018 but decided to do in this fiscal year by moving up the schedule by half a year.

■ Future plan

○ The purpose of measurement, waste to be measured, and environmental conditions for measurement will be studied in FY2017. Technologies applicable to the measurement and assessment of α-contamination will be investigated and studied by measuring principle, and promising technologies will be proposed in FY2018.

Original and Revised Schedule



(III) Research on Technologies for Reducing Waste Production

- Technical requirements for α nuclides measurement at 1F site -

- Technical requirements for α nuclides measurement were clarified from the following three viewpoints:
  - Measurement environment on 1F site (workspace, on-site dose rate, and influence of mixed βγ nuclides)
  - Operation of α nuclides measurement technology in the process of waste management (what and when to measure)

    The following timings were assumed to be feasible since the measurement of α nuclides contained in waste is difficult once they are stored in containers.
    - Before waste is detached from the structure/equipment (on-site measurement)
    - After waste is detached and before it is put into bags (such as vinyl bag)
    - After waste is detached and put into bags
      (Measurement from the outside of the bag or cutting a part of the bag)
  - Measurement performance (sensitivity, measurement time requirement, and ability to measure distribution)

Examples of requirements for α nuclides measurement

	Work space	On-site dose rate	Influence of mixed βγ nuclides	Measurement target	Sensitivity	Measurement time period	Contamination distribution measurement
Assumed measurement conditions and requirements	Width of corridors: approx. 1.5 m in R/Bs with possible presence of obstacles ⇒**Measurement should be possible even if obstacles exist in the corridor. (Contact measurement is not required)**	R/B 1F corridor: 1.9-36 mSv/h Unit 2 operation floor: max. 800 mSv/h ⇒**too highly radioactive for a worker to conduct measurements directly**	α/βγ = $1/10^{6\text{-}8}$ ⇒**Measurement should be done without the influence of βγ nuclide.**	Protection by vinyl sheet covers is assumed. ⇒**Measurement should be done over protection covers.**	Maximum permissible surface contamination density in the controlled area: 4 Bq/cm^2 (α) Material transfer standard: 0.4 Bq/cm^2 (α) ⇒**Set the above criteria as tentative targets.**	⇒**Shorter time requirement for measurement and setup is desirable from the viewpoint of worker exposure reduction.**	From the viewpoints of contamination spread prevention and waste amount reduction ⇒**The identification of hot spots and the measurement of contamination distribution should be possible.**

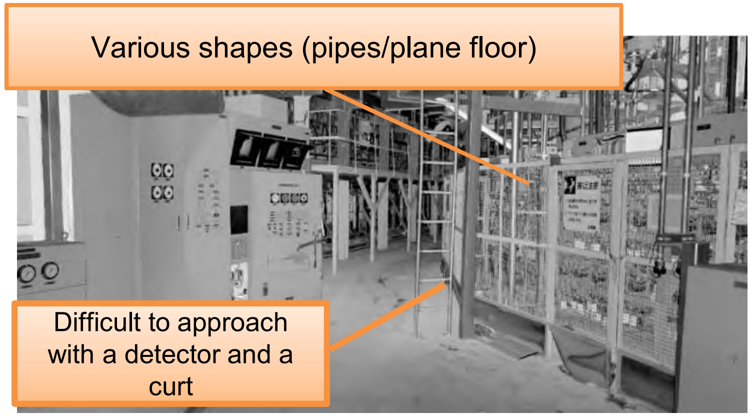
A comparison study on α nuclides measurement technologies' principle, in terms of their applicability, was conducted and applicable technologies were selected in light of the measurement environment and operation methods on 1F site.

(III) Research on Technologies for Reducing Waste Production

Reference information: Consideration of measurement environment and device operation method on 1F site

- **Estimated measurement conditions**
  - Direct measurement by workers is difficult due to high radiation.
  - Access by remote operation device is difficult due to the presence of obstacles
  - The shapes of measurement targets are very different, such as wall, pipes, and equipment.

[1] Quoted from the material for an IRID design review on Feb 14, 2017 of the "Development of Repair Technology for Leakage Points inside PCV" under Subsidy Project of Decommissioning and Contaminated Water Management in the FY2015 Supplementary Budgets



Environmental image inside R/B on 1F[1]

- **Idea of operation taking into consideration the measurement environment**

The following two equipment using methods were considered based on the assumption that measuring equipment is mounted on a remote controlled transporter to realize measurement in a highly radioactive environment:

- Device for a wide area: Traveling through corridors to collect information (see concept illustration in Figure 9 below)
- Device for narrow areas: Reaching difficult-to-access locations to collect information (see concept illustration in Figure 10 below)

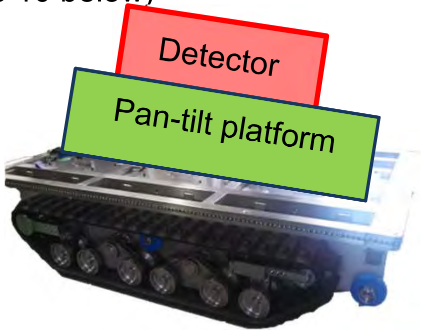


Figure 9. Detector Mounted on Relay Transporter (concept illustration)

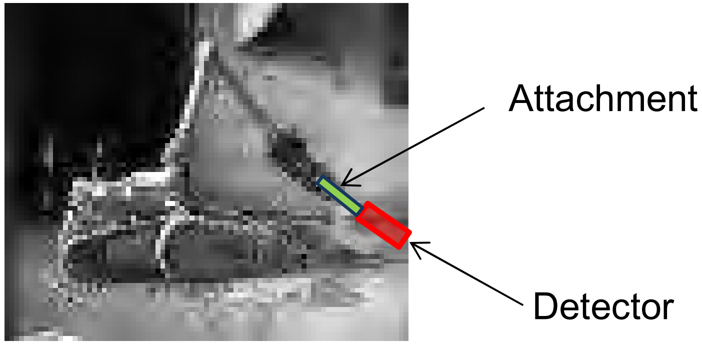
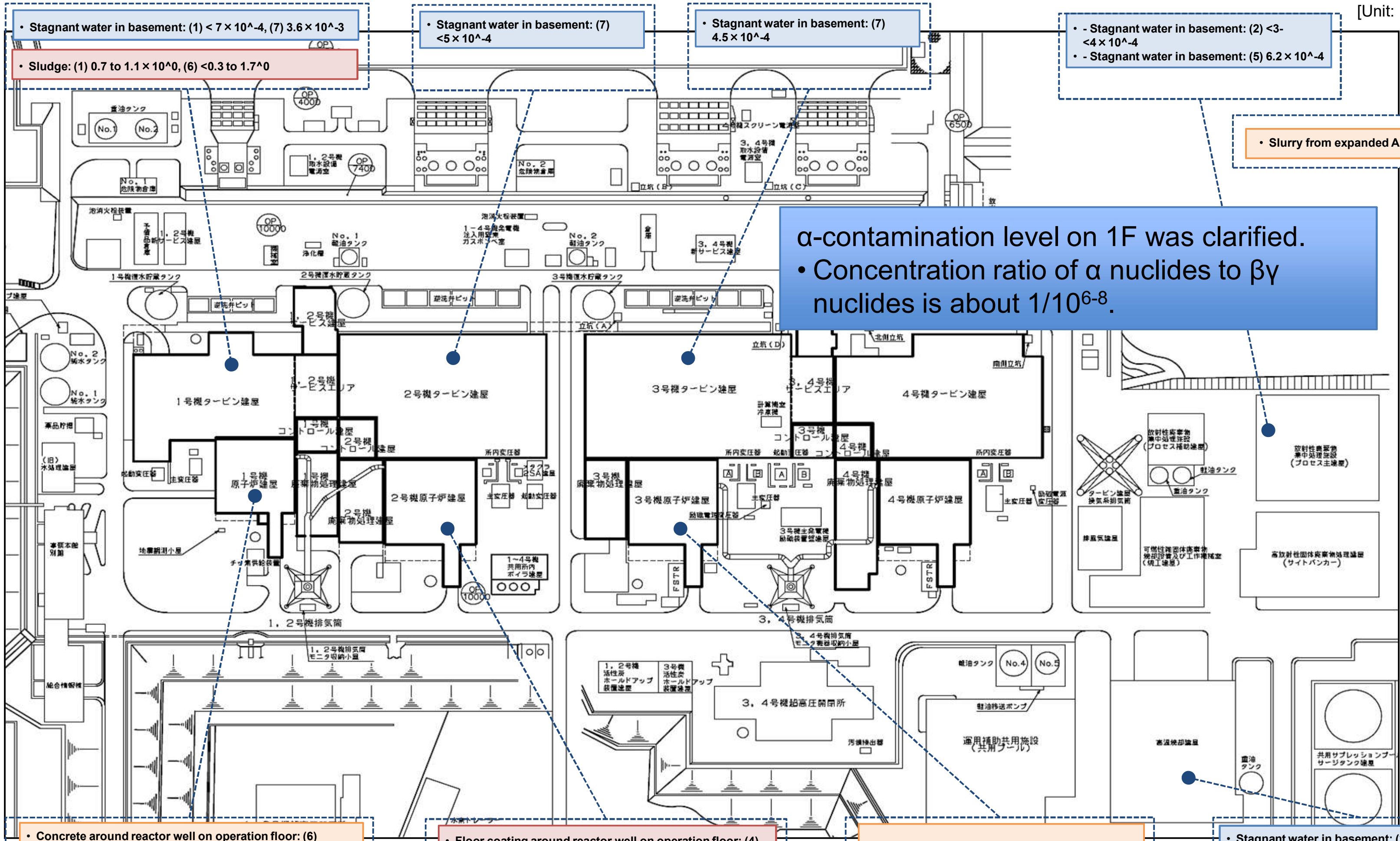


Figure 10. Detector Mounted on Kobra (concept illustration)

(III) Research on Technologies for Reducing Waste Production

Reference information: Identification of measurement environment on 1F site (α nuclides concentration)

[Unit: Bq/g]



- Stagnant water in basement: (1) < 7 × 10^-4, (7) 3.6 × 10^-3
- Sludge: (1) 0.7 to 1.1 × 10^0, (6) <0.3 to 1.7^0

- Stagnant water in basement: (7) <5 × 10^-4

- Stagnant water in basement: (7) 4.5 × 10^-4

- - Stagnant water in basement: (2) <3-<4 × 10^-4
- - Stagnant water in basement: (5) 6.2 × 10^-4

- Slurry from expanded ALPS: (6) 2.1 to 3.6 × 10^-1

α-contamination level on 1F was clarified.
- Concentration ratio of α nuclides to βγ nuclides is about 1/10$^{6\text{-}8}$.

Legend

- >10^0
- 10^-1 to 10^-0
- 10^-3–10^-1
- <10^-3

- Concrete around reactor well on operation floor: (6) 6.0 × 10^-1
- Paint of deck plate on the ceiling of the operation floor: (1) 9.4 × 10^-1
- - Heat-retention material on 1F: (3) 0.6 to 1.3 × 10^-1

- Concrete surface coating on 1F: (3) 8.2 × 10^-2

- Heat-retention material on 1F: (4) 8.2 × 10^-3
- Concrete on 1F: (4) 1.7 to 4.6^-3

- Floor coating around reactor well on operation floor: (4) 6.1 × 10^-1

- Stagnant water in PCV: (1) 2.2 to 2.4 × 10^-1

- Deck plate of the operation floor: (3) 1.4 to 2.3 × 10^-3

- - Stagnant water in PCV: (1) 5.8 to 9.4 × 10^-1
- - Concrete on 1st floor: (3) 1.7 × 10^-1
- - Heat-retention material on 1F: (3) 1.9 × 10^-1

- - Concrete on 1F: (4) 0.3 to 2.7 × 10^-2

- Stagnant water in basement: (2) <0.3 to 2.4 × 10^-3
- Stagnant water in basement: (5) 0.8 to 2.4 × 10^-3

Reference cited

(1) Analysis result of waste samples (stagnant water in Unit 2 & 3 PCVs, stagnant water including sludge in Unit 1 turbine building, core sample bored from the operating floor of Unit 1 reactor building) Feb. 23, 2017 JAEA

(2) Radioactivity analysis of stagnant water and treated water, Nov 28, 2013, JAEA

(3) Analysis of rubble collected in the premise of Fukushima Daiichi NPS, Apr 28, 2016, JAEA

(4) Radioactivity analysis of rubble collected in the reactor buildings of Fukushima Daiichi NPS, Oct 1, 2015, JAEA

(5) Analysis of supply water/discharged water to/from water treatment facilities for the radioactivity assessment of secondary waste generated from contaminated water treatment, Mar. 31, 2016, JAEA

(6) Analysis of waste samples (rubble on Unit 1 reactor building 5th floor, sludge in the 1st basement of Unit 1 turbine building, slurry from multi-nuclide removal equipment HIC) Feb 23, 2017, JAEA

(7) Analysis result of waste samples (stagnant water, treated water from water treatment facilities, etc.) Jul 27, 2017, JAEA

(III) Research on Technologies for Reducing Waste Production

- Summary of on-site applicability of α nuclides measurement technologies -

- Applicability of existing measurement technologies was assessed based on the results of study on requirements in light of measurement environment and operation method on 1F site.
- Remote measurement using excitation of nitrogen was selected as a highly applicable method because it does not require contact measurement and has a potential to locate hot spots and also enables contamination distribution measurement.
- The detail study of test device details will be necessary for the applicability of the 1F site.

Measurement technology	Total α-ray measurement			γ-ray spectrum measurement	Passive neutron measurement	Others	
	Direct measurement (automatic)		Remote measurement (automatic smearing)			Mass analysis (LA-ICP-MS)	Spectrometry (LIBS)
	Contact scanning	Remote measurement					
Principle	Direct measurement of α-ray from α nuclides	Measurement of the luminescence of α-ray excited nitrogen	Smear sampling by filter paper	Measurement of γ-ray from U-235 and nuclides contained in debris	Estimation based on the neutron generation rate from Cm-244 and the like	Mass analysis of isotopes suctioned after evaporated by laser	Elemental mass spectroscopy of surfaces from laser-induced plasmas
Width of work space is a few dozen cm or more	○ Limited access by remote operation device	◎:	○ Limited access by remote operation device	○ Limited access by remote operation device	○ Limited access by remote operation device	○ Limited access by remote operation device	○ Limited access by remote operation device
On-site dose rate (Max. 800 mSv/h)	◎:	◎:	◎:	○ Shielding required	◎:	◎:	◎:
Influence of mixed βγ nuclides (Ratio of α to βγ nuclides is the order of 10$^{-6 \text{ to } -8}$)	Normally ○ (To be assessed separately if concentration is high)	◎:	Normally ○ (To be assessed separately if concentration is high)	○ Impact on lower detection limit	◎:	◎:	◎:
Measurement target Covered by vinyl sheet, etc.	× (applicable only to special shapes)	◎: (α-ray range space required)	○ Not protectable	◎:	◎:	○ Not protectable	○ Not protectable
Sensitivity 0.4 Bq/cm^2 : Transfer standard 4Bq/cm^2: Density limit	◎:	○ (Possibility of sensitivity improvement)	◎:	○ Influence of measurement distance and γ-ray BG	× Low emission rate, low efficiency	◎:	× Insufficient sensitivity
Measurement time period	○ Contact scanning is required	◎:	○ Wiping is needed	○ Dependent on environmental dose rate	○ Scanning measurement is required	× Dependent on positioning accuracy, etc.	× Dependent on positioning accuracy, etc.
Contamination distribution measurement	○ Scanning is needed	◎: 2D distribution measurement is possible	○ Area segmentation is needed	○ Collimator and scanning are needed	○ Collimator and scanning are needed	○ Scanning is needed	○ Scanning is needed
Others		Dark environment is required					

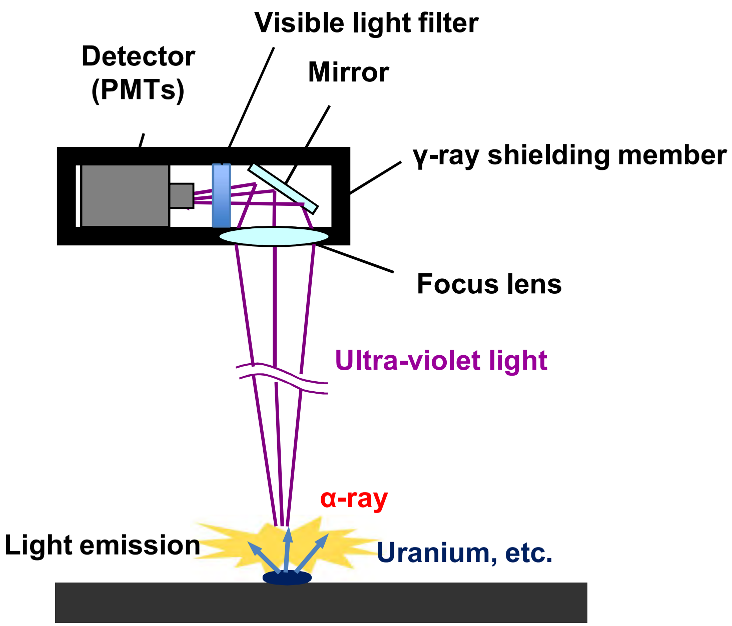
◎: Applicable
○: Limitedly applicable
×: Not applicable

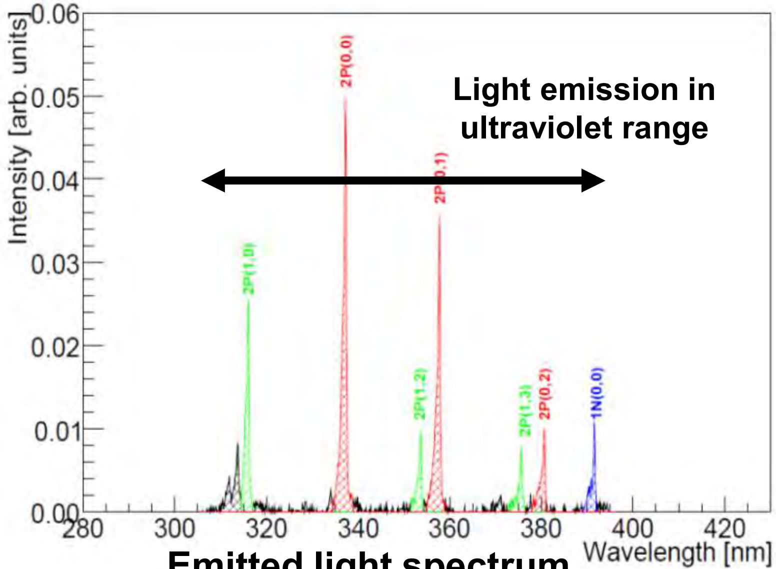
(III) Research on Technologies for Reducing Waste Production

Reference : Principle of selected α-contamination measurement technology

- Measurement principle
  (1) An α particle reacts with nitrogen in its flying distance (a few centimeters) and generates a few hundred photons of ultra-violet light.

  (2) The strength of α-ray is measured by collecting generated ultra-violet light through a lens and counting the number of photons using a photon counter.





Emitted light spectrum

Cited from J.Sand, *Remote Optical Detection of Alfa Radiation*, IAEA－CN-184/23

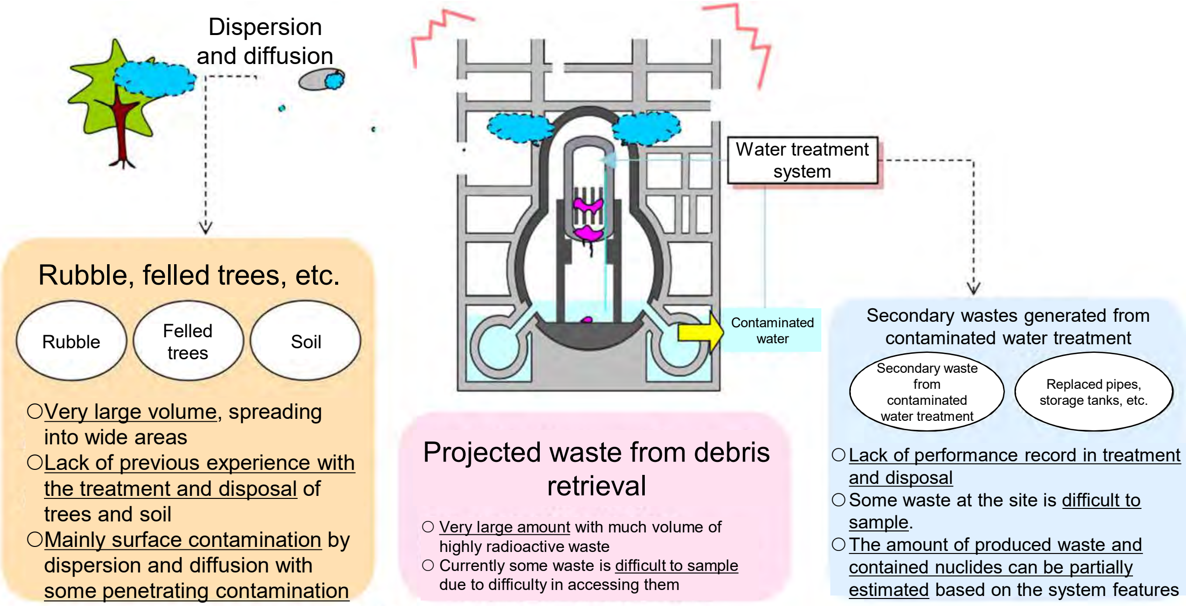
4. Study of Disposal Strategy and Safety Assessment Methods Applicable for Characteristics of Solid Waste

Contents of Report

- Characteristics of 1F solid waste
- Study of disposal strategy and safety assessment methods applicable for characteristics of solid waste on Fukushima Daiichi Nuclear Power Station (1F)
- Survey on disposal concepts and safety assessment methods
- Identification of important reference cases
    - List of important reference cases
    - Focused important reference cases and examples reflected to needs for Fukushima Daiichi NPS
- Investigation of background of important reference cases
- Summary of Survey Results
- Investigation and study plan until the end of FY2018

Characteristics of Solid Waste at Fukushima Daiichi Nuclear Power Station (1F)

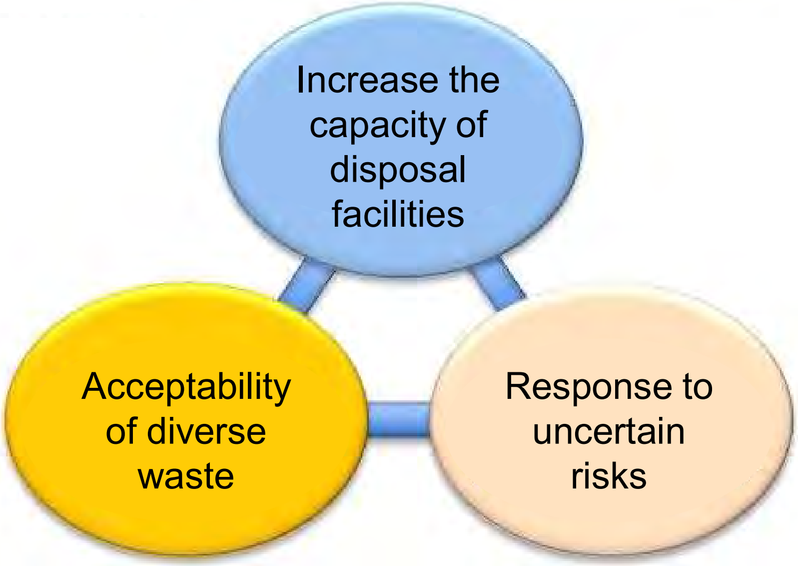
■ Characteristics of the 1 F solid waste



*: Contamination originated from activated materials or reactor operation waste may be included.

■ Needs required for safe and reasonable solid waste disposal, considering the characteristics of 1F solid waste

Investigations were conducted from three aspects shown on the right considering the characteristics of 1F solid waste



Study of solid waste disposal strategy suitable for the characteristics of 1F solid waste and methods to assess the safety of the strategy

Survey on disposal strategies and safety assessment methods in other countries

- Survey on establishment method of disposal concepts
- Survey on disposal concepts and safety assessment methods at disposal facilities

Detailed Information of international cases ↓

Research cycle

↑ Investigation on background and grounds for important reference case

Study based on survey results from Japan and other countries

- Organizing of information on waste disposal strategies and safety assessment methods applied in Japan
- Study on survey issues
- Extracting of important reference cases based on the survey results from other countries

Important reference cases
- Disposal concepts
- Safety assessment method
- Predisposal management

↓

The latest R&D outcomes related to the characterization and predisposal management of solid waste at the 1F

↓

Study on safe and reasonable disposal concepts and safety assessment methods

- Organizing of information on characteristics of 1F solid waste
- Study on applicability of important overseas cases in other countries
- Study on safe and reasonable disposal strategies and safety assessment methods

Survey on disposal concepts and safety assessment methods

Research on the waste disposal facilities in overseas which are available for various kinds of wastes and the detailed public data was conducted. *1

Drigg LLWR*2 (UK)

SFR*3 (Sweden)

WCS*4 (USA)

■ Contents of research

(1) Brief survey on disposal facilities
(2) Research on waste characteristics
(3) Research on waste pretreatment
(4) Research on waste containers
(5) Research on waste treatment
(6) Research on waste storage
(7) Research on acceptability of waste at disposal facilities
(8) Research on disposal strategies
(9) Survey on safety assessment methods
(10) Research on safety cases
(11) Research on cost optimization processes

Exhaustive research was conducted

■ Study on research result

- Comparison with previous cases in Japan
- Importance determined based on needs of 1F solid waste

Listing of important reference cases

*1. Quick research was conducted on cases at disposal facilities in Russia
*2. A low-level radioactive waste disposal facility in Drigg, UK operated by LLWR repository Ltd.
*3. A short-lived low- and intermediate-level radioactive waste disposal facility in Östhammar Municipality, Sweden, operated by SKB Sweden AB
*4. A low-level radioactive waste disposal facility in Texas, USA, operated by WCS

Identification of important reference cases

<List of important reference cases>

表 2.2-15 LLWR，SFR の合理的評価事例の検討

No.	合理的事例	適用	概略	合理的事例であることの理由	福島第一廃棄物処分との関連
1	Inventory records and management system	UK	廃棄物管理と処分のインフラ計画をサポートするために，UK 政府と NDA は公式のプロセス(原子力サイトが現時点のインベントリと将来発生する廃棄物を統一されたフォーマットを用いて報告する)を導入した。報告事項は，材料タイプ，放射能，化学的組成，体積(廃棄物体積と廃棄体体積)，発生時刻，発生場所である。 情報は国のインベントリ(UKRWI)で編集される。3 年に一度の更新がなされる。	・サイトを跨いだデータの編集や比較を可能にするために，標準フォーマットでデータがまとめられる。 ・廃棄物が生成された時にインフラが計画されることを可能にする。 ・廃棄物量に応じた処分場が設計されることを可能にする。 ・国レベルでのコスト低減効果(規模の経済)，効率の最適化 ・廃棄物の量と発生時刻の不確実性のよりよい試算が可能となること。	・1F の廃棄物体積の試算は不確実性を伴う。その為，インフラ要件を計画することは難しい。 ・よくまとまったインベントリ記録は，デコミと廃棄物管理の統合を可能にする。 ・大量の廃棄物が発生し，性状把握される前に，1F インベントリ管理システムを設計及び導入することは重要。
2	BPEO/BAT	UK	安全で，効率的で，費用対効果の高い廃棄物管理では，様々な要因のバランスを考えることが重要である。 BPEO は，代替的オプション（例：廃棄物の処理技術，処分概念設計）を考える為の系統的なアプローチとして UK 規制当局により導入された。 それは，主要な要因や主要な基準が意思決定において考慮されることを可能にしている。例えば，安全性，環境防護，技術実現性，規制の許可，ファイナンシアルコストが含まれる。 BAT は EU により導入された同様なプロセスであり，(安全性と技術及びコストをバランスしつつ) 安全性の最適化を推進することが意図されている。	・保守的な方法(defensible way)でコストと安全性がバランスすることを可能にする。そして，様々なサイトにおける決定は共通のアプローチでなされる。 ・放射線防護の最適化を支援する。 ・UK 規制当局は，BAT の適用は ALARA も達成できるということに同意している。 ・決定理由の正当化を含む，透明性があり監査可能なプロセス。それ故，長期のプロジェクトに対しては有効である。（往々にして決定理由が忘れられる） ・提案されている廃棄物管理や処分に対するアプローチの正当化を規制当局示す。	・1F の計画と意思決定プロセスは操業中サイトと関係し，廃止措置廃棄物管理や処分には適切ではない。 ・意思決定プロセスや計画プロセスへの規制当局の参加を必要とする。BPEO レポートにより，非公式に，情報が NRA に提出されることになる。 ・廃棄物管理と 1F の廃炉計画やコスト試算とを統合するのに役に立つ。 ・1F サイト全体に対する安全性/コスト決定に統一されたアプローチを提供する。
3	Sytematic process to achieve clearance	UK	・クリアランスと廃棄物管理と処分は関係する。基準値以下ならば非放射性として取り扱われる。 ・クリアランス基準値を満足するかどうかを測定により証明することは難しい。UK では，廃棄物を統計的に特性把握するための実務的方法(code of practice)を用いてクリアランスを達成するための系統的アプローチを開発した。 ・この方法を廃棄物に適用し，規制からの事前許可なしで廃棄物を処分している。	・放射性廃棄物の物量を減少する。このことにより，全体的な効率を向上させ，コストを低減させる。(非放射性廃棄物の処分はコスト小である) ・Code of practice は産業界により開発されたが規制当局により承認されている。 ・IAEA ガイダンスとも整合的 ・性状把握プロセスの不確実性を除去。Code of practice は単純なフローチャートと指示で構成されている。	・1F の大部分の廃棄物はレベルの低い廃棄物であり，規制上，非放射性である可能性がある。 ・クリアランスはこれらの廃棄物が通常の産業廃棄物として処分されることを許す。潜在的には，処分場のキャップ構成材として利用されてもよい。 ・プロセスが単純であれば，規制当局の指示を得やすく，導入も早く進む。
4	LLW management strategy	UK	UK 政策/NDA 戦略では，LLWR は LLW の高い側の処分場として利用される。 ・低い側の廃棄物は，VLLW として産業 landfill 施設に送られる。	・処分への Graded Approach を可能にする。少ない人工バリアで，費用対効果のよい施設を VLLW に用いる。 ・LLWR サイトの利用，放射能的容量，寿命を最	・1F 廃棄物の大部分は VLLW である。そして，規制を満足するための人工バリアシステムを必要としない。 ・VLLW 処分場はコスト小であり，建

Additional survey was conducted on the important reference cases from the following view points:

- Background and evidences
- Advantages
- Disadvantages and restrictions

Sorted listed cases to find how to reflect needs of solid waste at Fukushima Daiichi Nuclear Power Station (1F)

⇒ Study of important reference cases from the viewpoints of outlines, advantages, and the assumption of effects for the applicability of the 1F site.

List of Important Reference Cases at LLWR and SFR (1/3)

No.	Important reference cases	Applied in	General description
1	Inventory records and management system	UK	An inventory management system developed by the UK government and NDA (UKRWI). Updated every three years. It serves as a reference for waste management and disposal planning.
2	BPEO/BAT	UK	A systematic approach to decision making based on factors such as safety, environmental protection, technology feasibility, regulatory approval and financial costs It is intended to promote waste management optimization while balancing safety with technology and costs.
3	Systematic process to achieve clearance	UK	A practical method (code of practice) for the statistical characterization of difficult to measure waste and a systematic approach for achieving clearance using this method. The same method enables waste disposal without prior approval from regulatory bodies.
4	LLW management strategy	UK	The UK government's waste management strategy to reduce the load on LLWR by making most of the waste that was conventionally disposed of by LLWR very low level waste (VLLW) and applying the same disposal procedures as general industrial waste to them.
5	Disposability Assessment (DA)	UK	Evaluation to confirm whether waste and waste bodies meet waste acceptance criteria It can be an indicator to determine the treatment requirements for waste from operation and waste from decommissioning.
6	Limitation of short-lived nuclides	LLWR and SFR	Waste categorization considering half-life in addition to total radioactivity Based on this categorization, some cases outside Japan show short half-life ILW shallow land disposal on the premise of long-term institutional control.
7	Development of WAC including for hazardous materials	LLWR and SFR	Waste acceptance criteria that serve as criteria for the restriction of radioactive materials as well as chemicals that may affect the environment or disposal..

List of Important Reference Cases at LLWR and SFR (2/3)

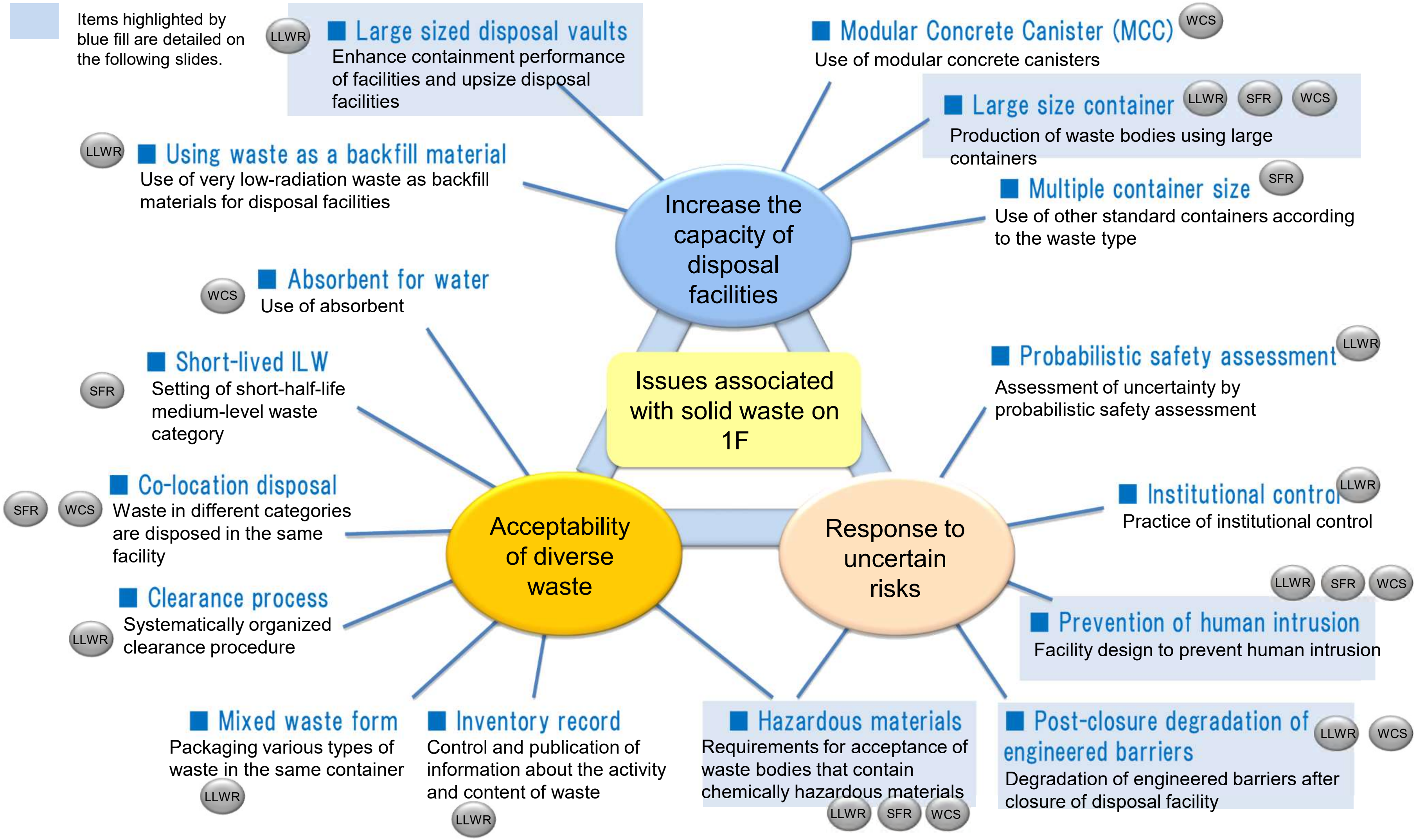
No.	Important reference cases	Applied in	General description
8	Large size container	LLWR	At LLWR, ISO containers are used to store waste, and waste bodies are produced by applying grouting solidification to the containers that store waste. The use of ISO containers is superior in terms of transport efficiency, handling at the disposal facility, and cost.
9	Overpacking of super-compacted waste drums	LLWR	At LLWR, drums compressed by a super compressor are stored in ISO containers. The use of a super compressor can significantly reduce waste volume.
10	Using waste as a backfill material	LLWR	The use of extremely low level radioactive waste as backfill materials for disposal facilities is recommended. Although reduction in the final waste volume is expected, there is no cases of such use in the UK due to the variation of waste characteristics and the complexity of the process.
11	Multiple Container sizes	SFR	Waste containers with different shapes used at SFR for the purpose of enhancing the volumetric utilization efficiency of cylindrical silos.
12	Disposal of large items	LLWR and SFR	A method to bury large-size waste at disposal facilities without using a container by directly solidifying them on site when the waste is too large to put into a container.
13	Large sized disposal vaults	LLWR	A large-scale vault type disposal facility with a multilayer barrier structure.. An increase in disposal capacity and an improvement in disposal efficiency are expected.
14	Prevention of human intrusion by capping	LLWR	Multi-layered barrier cap with a bio-intrusion layer on the bed of rocks. Reduction of intruder's exposure to radiation is expected, which needs to be assessed according to the human intrusion scenario in the safety assessment protocol.
15	Prevention of human intrusion by location undersea	SFR	Reduction in the risk of accidental human intrusion by constructing a disposal facility under the sea floor.

List of Important Reference Cases at LLWR and SFR (3/3)

No.	Important reference cases	Applied in	General description
16	Co-location of disposal concepts	SFR	Waste disposal strategy to dispose of VLLW and short half-life ILW at a single site by constructing both a land disposal facility and a vault type facility together.. Construction costs can be reduced by sharing the same site and infrastructure.
17	Institutional control	LLWR and SFR	Institutional control consisting of the prevention of intrusion into the facility and performance guarantee by monitoring the disposal system. The prevention of human intrusion over a long period of time and reduction in the activity of short half-life nuclides are expected by long-term institutional control.
18	Process by agreement	UK	The phased process of consensus-based regulatory approval in the UK , which includes early phase dialogue with regulatory agencies prior to a formal disposition application
19	Generic disposal safety case	UK geological repository	Comprehensive and general safety cases before the identification by the site , which are referred to for the extraction of R&D themes and the evaluation of the possibility of disposal.
20	Insight modelling	UK	A predictive and simplified safety assessment model for sensitivity analysis and bounding analysis, which is used to identify important parameters for disposal.
21	Long-term climate change modelling	LLWR and SFR	The assessment of the impact of long-term climate change, including the quantification of coastal erosion impacts on shallow land disposal, which is used for the safety assessment of sites where significant climate change is expected..
22	Post-closure degradation of engineered barriers	LLWR and SFR	Safety assessment using time-dependent parameters, taking into account the deterioration of the engineered barrier, which is expected to be effective for the prevention of an overly conservative forecast by suggesting a risk of instantaneous loss of barrier performance after the end of the institutional management period, for example.

Identification of important reference cases

<Focused important reference cases and examples of those reflected to 1F needs>



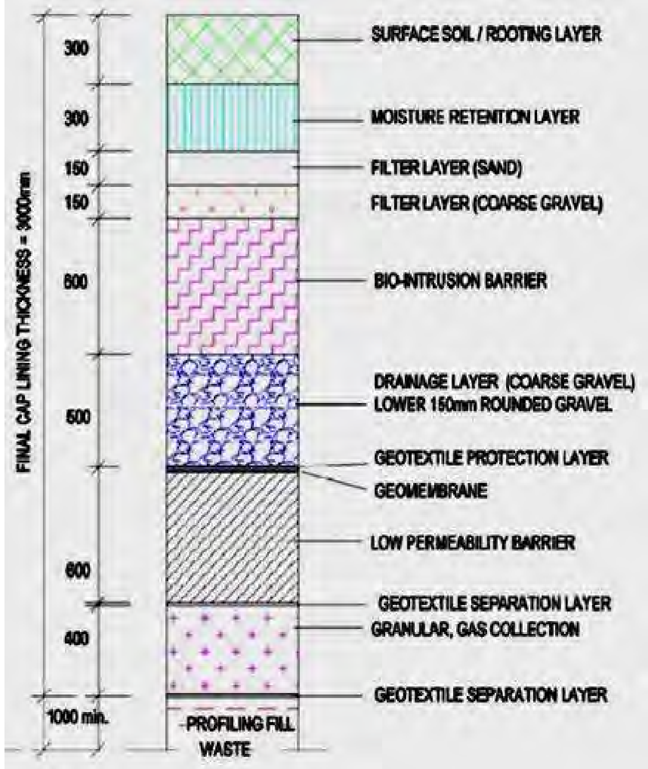
Investigation of background of important reference cases

■ Large sized disposal vaults

Enhance containment performance of facilities and upsize disposal facilities

LLWR

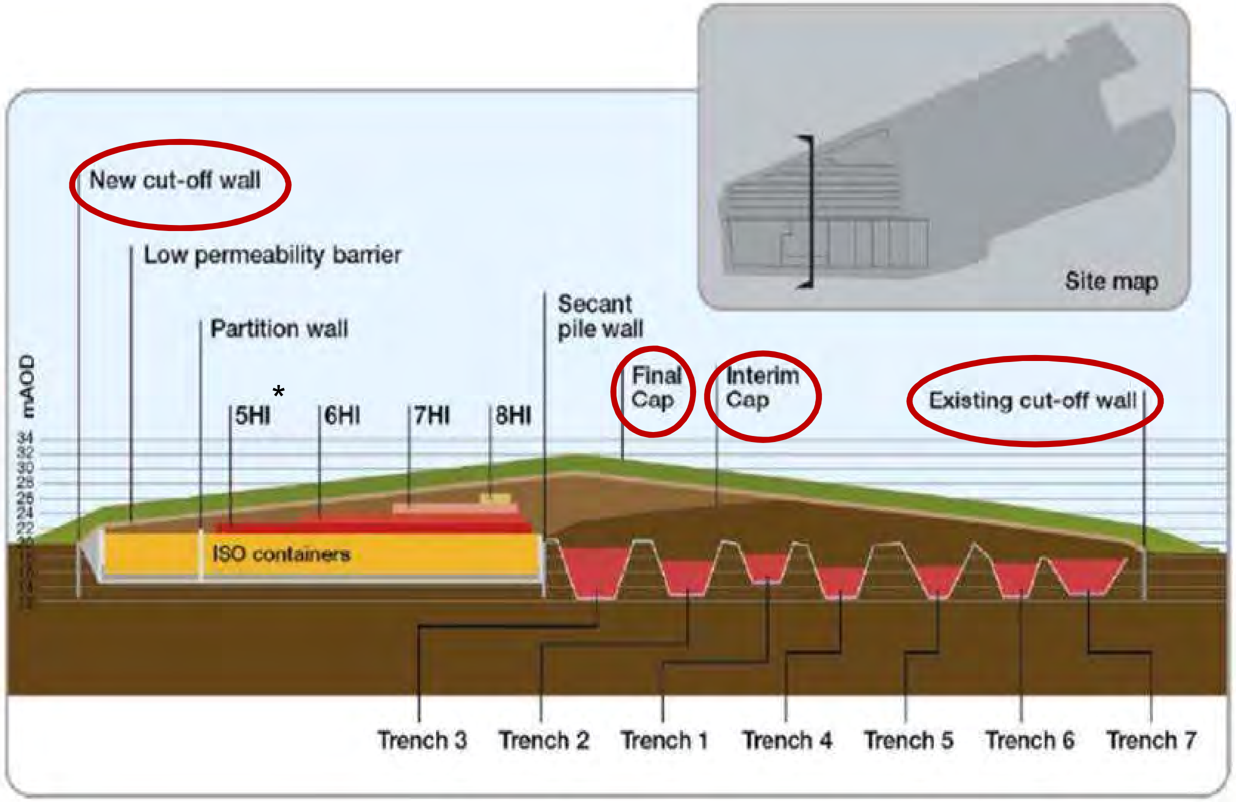
Cap system structure



Appearance of geomembrane (asphalt sheet)

Overall structure

- Cap (prevention of water permeation from the upper area and human intrusion)
- Wall (prevention of lateral water permeation within the facility)
- Bottom plate (prevention of upward water permeation from under the facility)



*HI: Number of stacked level of ISO containers

Figure 4.7: The preliminary design of the final cap for the LLWR at closure.

Investigation of background of important reference cases

■ Prevention of human intrusion
Facility design to prevent human intrusion

LLWR | SFR | WCS

LLWR in UK

- A cap with a bio-intrusion barrier built on a bed of round rocks with a diameter of 600 mm is employed as a measure to enhance protection against human intrusion by excavation.

WCS in USA

- Class C waste is buried at a depth of 5m or more from the surface to protect unintended intruders according to the Texas State Code.
- The modular concrete canister (MCC) used at WCS has a structural strength that prevents human intrusion to Class C waste.

SFR in Sweden

- The coastal submarine location prevents human intrusion.
- Assuming an uplift over a 1,000-year period, the disposal facility was built at a depth of 60 m from the seafloor so that it will remain below the seafloor after the uplift.

■ Large size container

Production of waste bodies using large containers

LLWR SFR WCS

Improvement of waste disposal efficiency by the scale-up of disposal facilities and the use of large-sized containers

	LLWR	SFR	WCS
Appearance	 ISO container or half height ISO (HHISO) container	 • Drum • Mold • Concrete tank • ISO container	 Modular concrete canisters (MCC)
Dimensions	H1.32 m × W2.5 m × L6.06 m (HHISO)	Various dimensions	Inner diameter 2 m × inner height 2.8 m
Strength	9-level stack is assumed	Up to 42-level stack is assumed	34.5 MPa (up to 6-level stack)
Solidification agent	Superplasticizer-containing PFA + Portland cement	Asphalt Concrete	High-strength grout (compressive strength after 28 days ≥ 2,000 psi)
Notes	A HHISO container is used more often because of its handleability.	Containers are put in a silo and cement-grouted.	A layer of sand or soil is added in between every stacked MCCs.

Background study of important reference cases

■ Large size container

Production of waste bodies using large containers

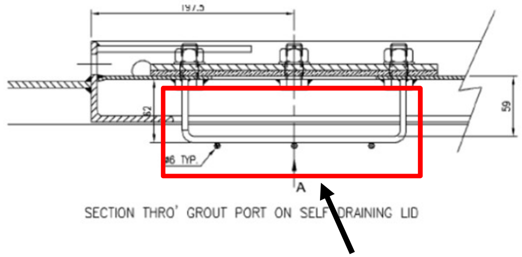
LLWR | SFR | WCS

No.75

- The homogeneity of grouted waste in a container is secured by using a grout injection port with a flow straightener disposed at its lower part and inclining the container in the container solidifying process.
- Voids (small-bores) may be generated in the inside of pipes because grout may not go into the pipes.
- Waste bodies are made of a mixture of waste with different characteristics but their inventory is known as each waste is managed under UKRWI (UK Radioactive Waste Inventory) from the initial stage of generation.

Cutting a solidified container

Grout injection port

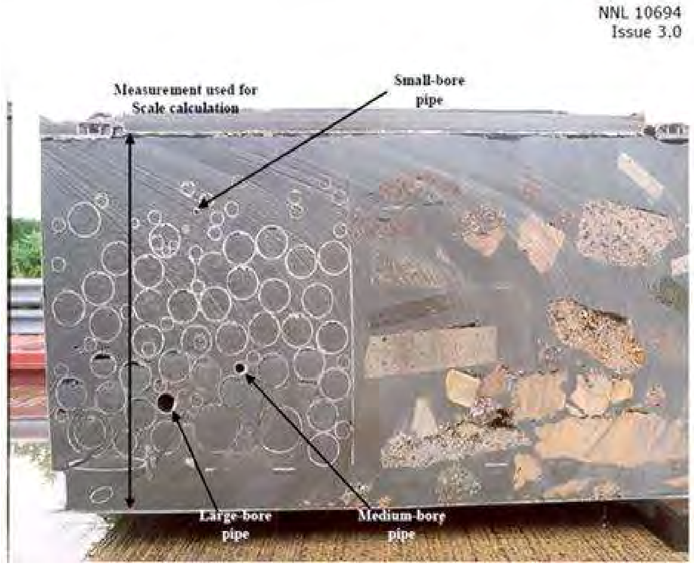


Flow straightener (baffle)

- When using a large-sized container, difficulty in homogeneous solidification and technical issues to overcome it are expected in comparison to the use of a small-sized container.
- In addition, measurement using a measuring device for a small waste body that is mainly used domestically at present and the method of determining the inventory based on such measurement cannot be applied to a large-sized waste directly.

The use of a large-sized container requires the following technology and method:

- **Technology to realize the homogeneous solidification of waste in the container**
- **Method to determine inventory of waste body**



Cut cross-section of a solidified container containing pipes

■ Post-closure degradation of engineered barriers

Degradation of engineered barriers after closure of disposal facility

LLWR WCS

- An overly conservative assessment of uncertainty is avoided by considering degradation.
- In many safety cases, the degradation of engineered barrier's confinement performance after the end of the institutional control period is considered in the safety assessment.
  (Those safety cases presume that engineered barrier's confinement performance will be maintained during the institutional control period because serious defects or deterioration of the barrier will be repaired during institutional control.)
- Note that such assessment method varies greatly depending on the country.
- LLWR and SFR estimate gradual degradation in engineered barrier's confinement performance.

Comparison of assessment for the degradation of engineered barrier's confinement performance between Japan and other countries

Japan (actual case)	UK	Sweden	USA
• The assessment is based on the hypothesis that the water permeation prevention performance of the existing facility deteriorates to a level of that of sand immediately after burying.	• The assessment is performed through probabilistic evaluation taking into account change over time after defining the probability distribution function (pdf) of hydraulic parameters.	• The aim of assessment is to ensure a 1,000 year long confinement after facility closure. • A deterministic assessment is performed using different parameters taking into account change over time.	• Although the structure of the concrete container is expected to be maintained for 300 years, it is still shorter than the requirement from the long-term (50,000-year) safety assessment. Therefore, the long-term safety assessment does not rely on the concrete confinement performance.

■ Post-closure degradation of engineered barriers
Degradation of engineered barriers after closure of disposal facility

LLWR WCS

Probabilistic hydraulic parameters of the engineered barrier used at LLWR in UK (2011ESC)

Hydraulic parameter	Point of time (A.D.)	Percentile					
		0	5	15	50	95	100
Hydraulic conductivity of container (m/s)	During installation	10^{-9}			10^{-6}		10^{-4}
Hydraulic conductivity of a gap between containers (m/s)	During installation	10^{-5}			10^{-4}		10^{-3}
Hydraulic conductivity of vault (m/s)	Year 7000	10^{-9}			10^{-6}		10^{-4}
Hydraulic conductivity of cap (mm/yr)	During construction	0.0003	0.3		1		3
	Year 2180	0.003	3		10	30	50
	Year 3180	3		90	200	450	750
Hydraulic conductivity of impermeable wall (m/s)	During construction and year 2180	10^{-10}			10^{-9}		10^{-8}
	Year 3180	10^{-9}			3×10^{-8}		10^{-6}
	Year 7000	10^{-8}			10^{-7}		10^{-5}

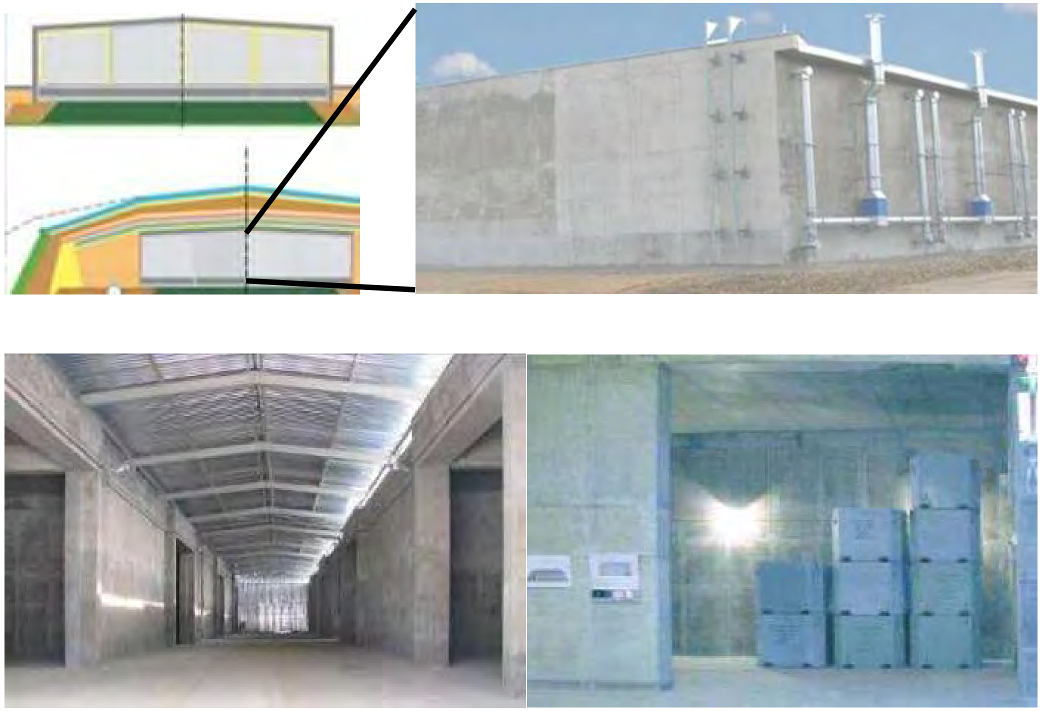
- These parameters were derived from expert elicitation in UK.
- Many barriers are comprised of multiple components.
  For example, the base of a vault is constructed with geomembrane, bentonite, and concrete.

Materials with impact on disposal inside and outside Japan

Issues	Japan	UK	USA
(1) Substances that affect nuclide migration	• Chelating agent • Organic materials (cellulose) • Rubber	• Inorganic phosphate • Organic phosphate • Carboxylic acid and polycarboxylic acid • Amino polycarboxylic acid (EDTA, NTA, DTPA)	• Liquid (Limited to 1% of container capacity)
(2) Materials affecting barrier performance	• Soluble salts $NaCl$, Na_2SO_4, $NaNO_3$	• Under investigation	• Organic materials (Total organic material content is limited to 5%. There is no restriction when putting in MCC.)
Notes	Sulfates: React with cement or other hydration products and reduce its confinement performance. Salts: Increase the hydraulic conductivity of bentonite.	According to the latest findings, it is concluded that the influence of iso-saccharic acid, etc., is small. (The soil environment of LLWR is pH 11 so that organic materials are decomposed by microbial activity.)	Solidification or adding absorbent 2 times as much as the liquid in volume in the container is required for liquid.

<Case study> - Case of Disposal facility in Russia (NZK-type disposal facility*1) -

- A new-type near-surface disposal facility for low-level solid waste and short-lived intermediate-level solid waste, currently planned in Russia.
- The facility is divided into 20 independent modules that can store waste for a long time (50 years) with the ability to retrieve the buried waste.
- Waste is put in long-durability reinforced concrete containers (NZK-150-1.5P) and solidified airtightly with a special non-shrink concrete mixture.
- Multilayer protective coatings used for the final cap include biological barriers and anti-filtration screens made of concrete, crushed stone, clay, geotextile, geomembrane, silt, sand, and topsoil.



Plan of a new-type near-surface disposal facility (NZK-type)

Disposal facilities in Russia will be investigated in detail in FY2018.

*1. A new-type near-surface disposal facility currently under planning

Summary of Survey Results

- Case studies were conducted on three international disposal facilities
  ⇒ Exhaustive research was done on 11 items.

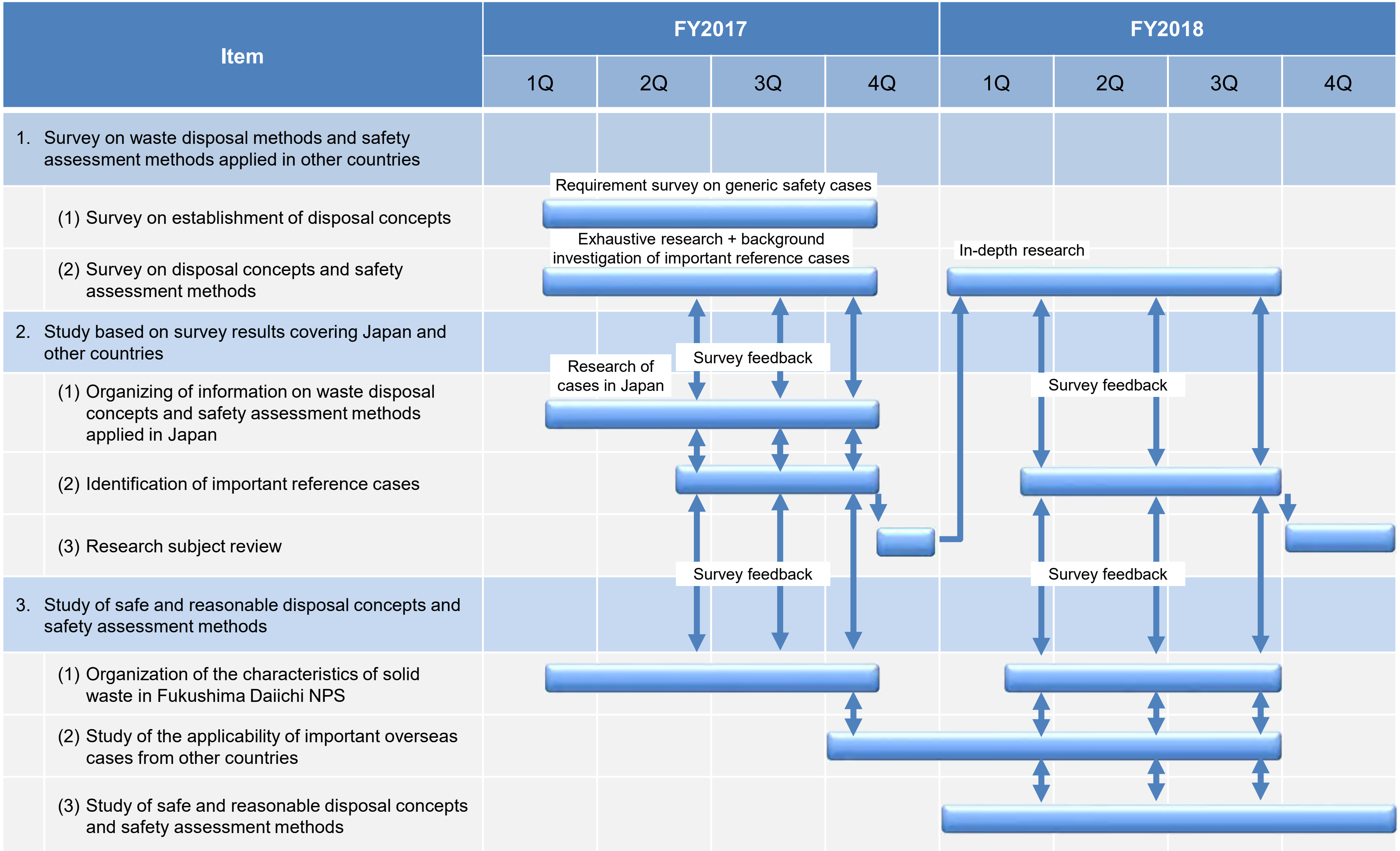
- Important reference cases were listed through comparison with actual cases in Japan and in consideration of needs associated with waste at Fukushima Daiichi Nuclear Power Station (1F).

  ⇒ A list of 22 cases was created.

- Backgrounds of important reference cases are surveyed along with consideration of how to reflect these case studies to the needs of the1F

  ⇒ Applicability of important reference cases to the 1F will be examined in FY2018

Investigation and study plan until the end of FY2018



5. Integration of R&D Results
(Study on Waste Stream)

Contents of Report

- Summary of Implementation Plan and Results
- Reflection of Research Results
  - ➢ Example and Effect of Waste-Specific Input Information Management Sheet
  - ➢ Example of Refined Treatment Flow
- Result of Integration into Waste Stream
- Summary of Waste Stream Study

Summary of Implementation Plan and Results

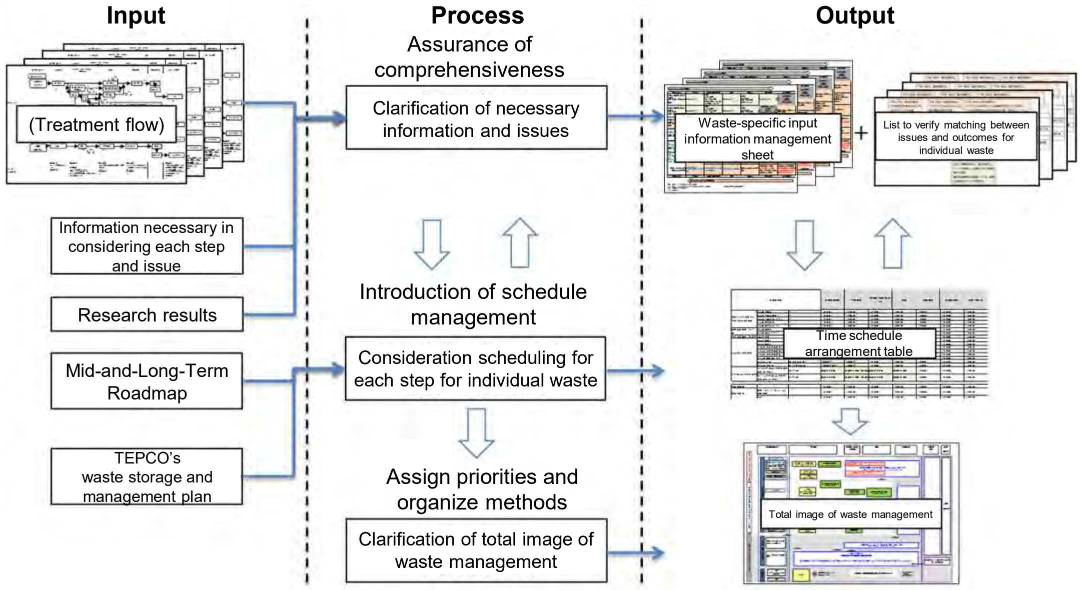
FY	Implementation plan	Goal achievement index
2017	• The promising waste streams presented in FY2016 will be comprehensively evaluated with respect to the progress, consistency of the outcomes, and remaining issues by reflecting the latest results obtained in previous research.	• Presentation of the progress, the consistency of the outcomes, and remaining issues
2018	• The waste streams will be repeatedly examined by reflecting issues and research results obtained in FY2017, and present evaluation results based on it.	• Establishment of comprehensive methods to evaluate progress, consistency, and issues and the presentation of evaluation results based on them

■ Summary of results

○ Methods to comprehensively manage the progress and issues in R&D were designed and tried (Figure).

- In order to ensure the comprehensiveness of target waste, necessary information and issues were identified using the classification of treatment flows created, based on the list that enumerates all types of waste on 1F (waste list), and a waste-specific input information management sheet and a list to verify matching between issues and outcomes were created.
- In order to introduce schedule management, consideration time schedules were set for each step of waste management process for individual waste based on the Mid-and-Long-Term Roadmap and the storage and management plan, and a time schedule arrangement table was created.
- In order to assign priorities and organize methods, the total image of waste management is clarified from the result of organization as listed above and flows are integrated into the form of a waste stream.

○ The progress, the consistency of the outcomes, and remaining issues were clarified using the established method.

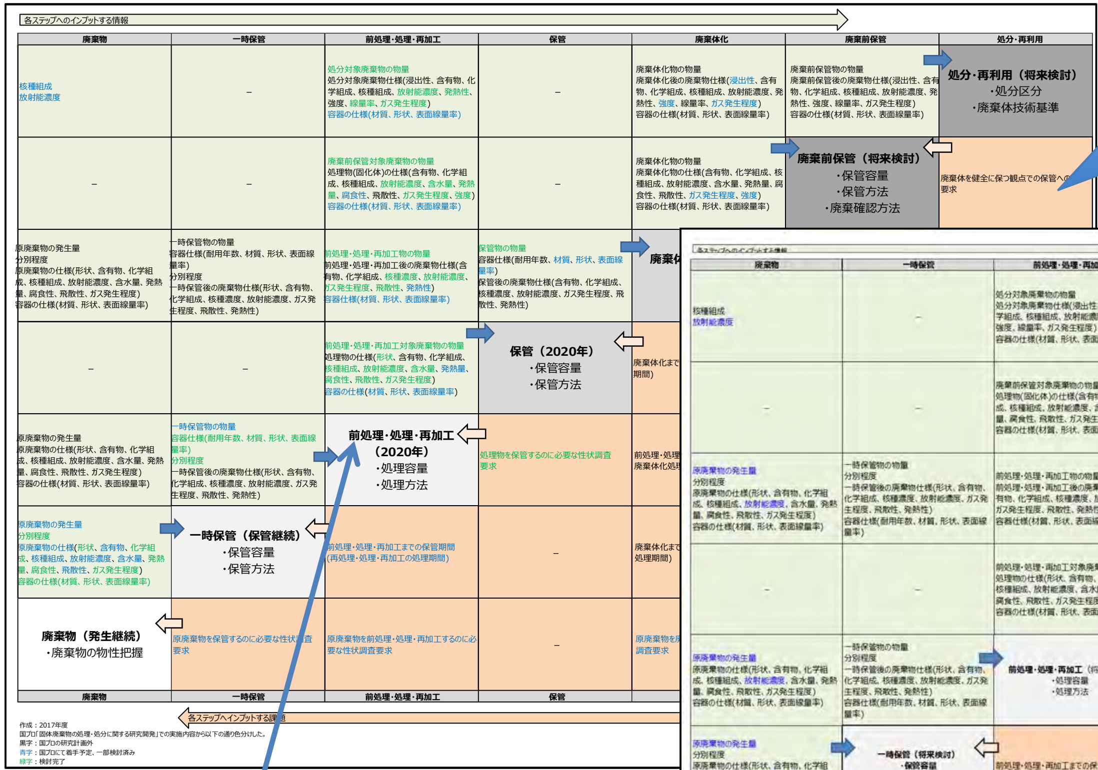


Total Image of Waste Stream Development

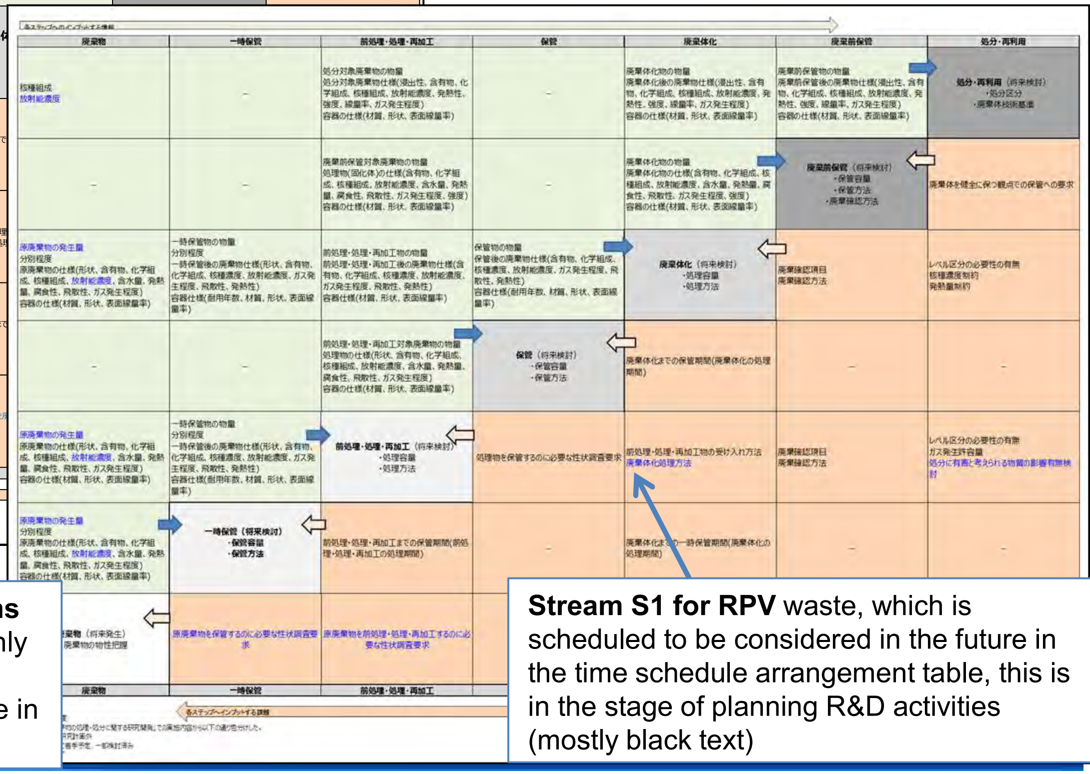
Reflection of Research Results

< Example and Effect of Waste-Specific Input Information Management Sheet >

R&D progress status is indicated by colored text, and the consistency of results and remaining issues can be clarified.



Progress can be understood visually for each waste type, such as good progress or still in the planning stage



Stream S10 Slurry from multi-nuclide removal systems shows good progress in the collection of information mainly on waste (characteristics), pretreatment, treatment, and reprocessing with the aim of achieving the start of storage in 2020 (mostly blue and green text).

Stream S1 for RPV waste, which is scheduled to be considered in the future in the time schedule arrangement table, this is in the stage of planning R&D activities (mostly black text)

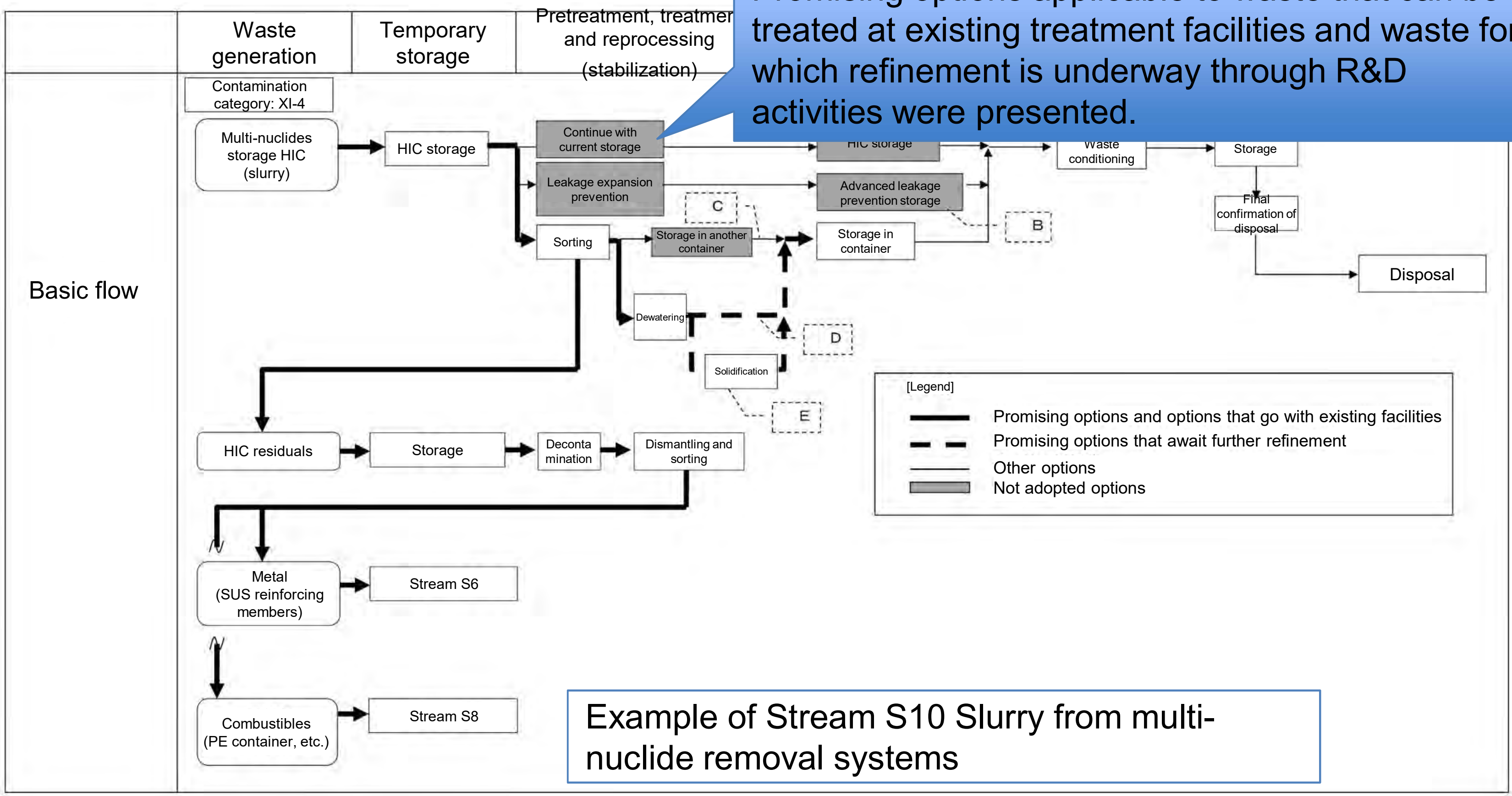
Green text: Consideration completed; Blue text: Planned under a subsidized program, or consideration partly completed;
Black text: Not included in R&D plan under subsidized programs (Color coding will be further reviewed)
Stream S1 RPV shows the flow from installation of RPVs in each Unit of Fukushima Daiichi NPS to disposal of such RPVs.
Stream S10 Slurry from multi-nuclide removal systems shows the flow from generation of radioactive sludge waste in the pretreatment process of multi-nuclide removal systems to disposal of such waste.

Reflection of Research Results

< Example of Refined Treatment Flow >

To clarify necessary information and issues, the progress of refinement is confirmed based on the input information management sheet.

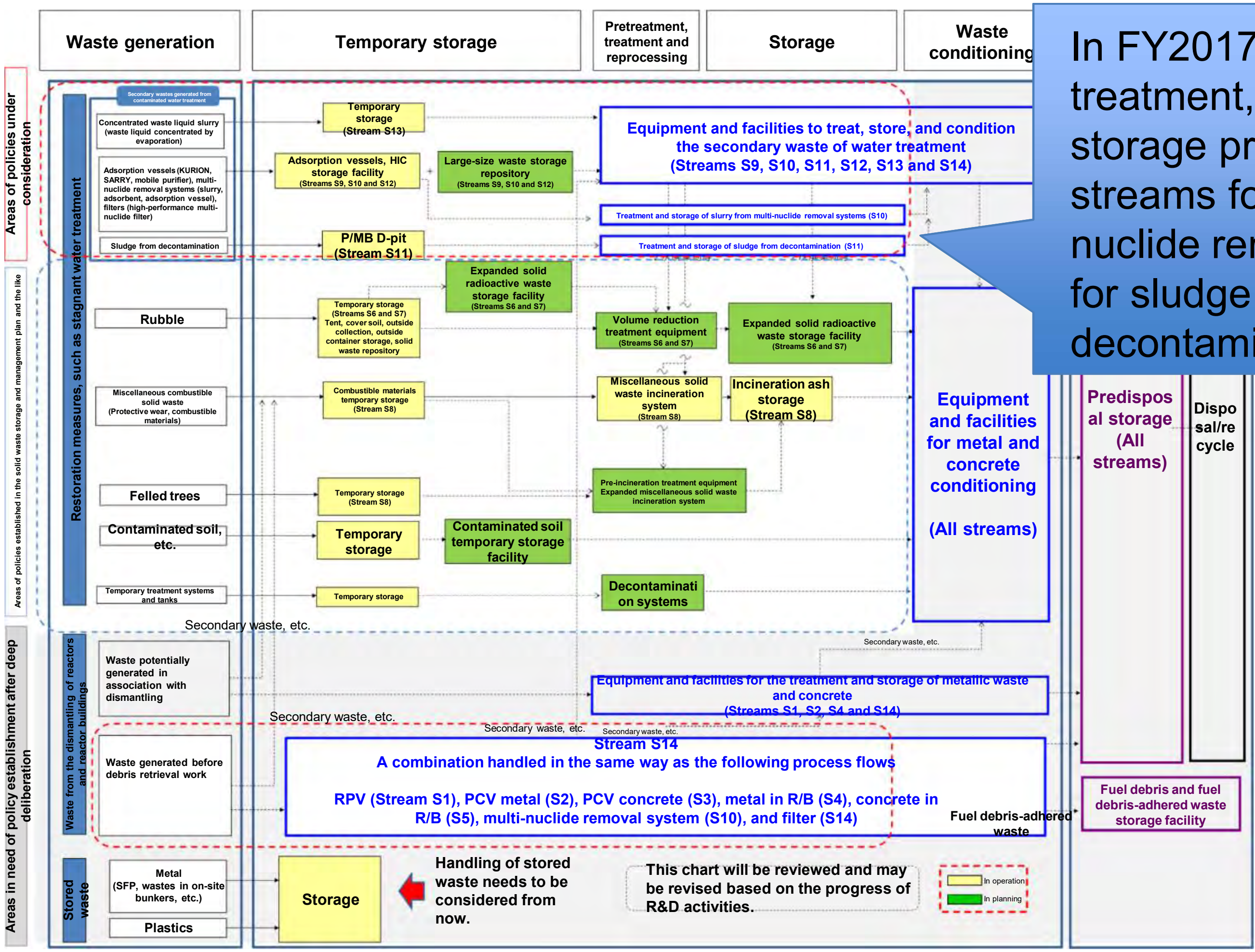
Promising options applicable to waste that can be treated at existing treatment facilities and waste for which refinement is underway through R&D activities were presented.



Example of Stream S10 Slurry from multi-nuclide removal systems

Result of Integration into Waste Stream

In order to clarify the total image of waste management, refined treatment process flows are integrated into waste streams



In FY2017, the pretreatment, treatment, reprocessing, and storage processes of the streams for slurry from multi-nuclide removal systems and for sludge from decontamination were updated

Summary of Waste Stream Study

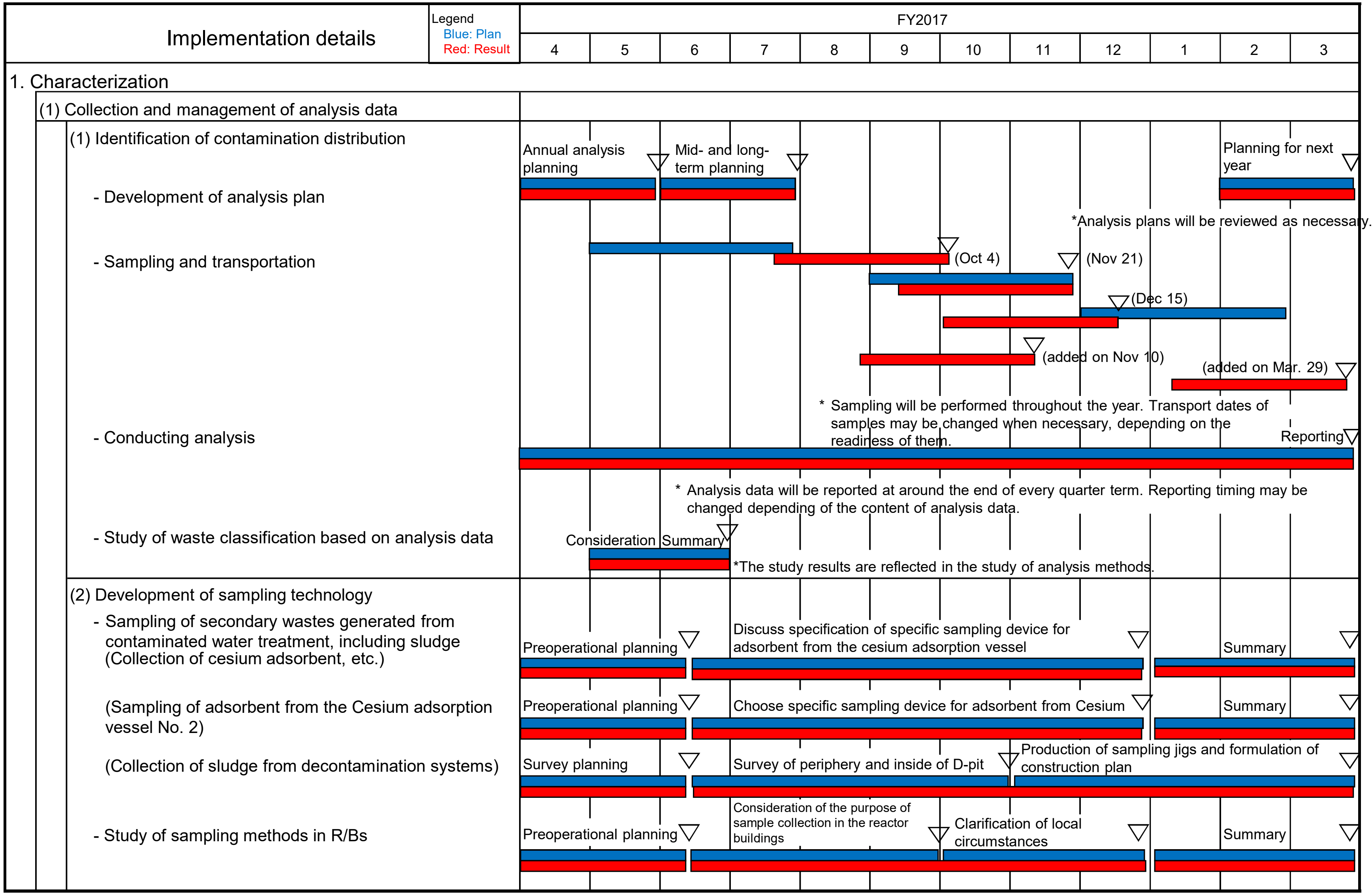
Waste		
Stream S1	Reactor pressure vessel (RPV)	原廃棄物の仕様(デブ 一時保管容器の仕様 る必要がある。
Stream S2	Metal of primary containment vessel (PCV metal)	原廃棄物の仕様(デブ 一時保管容器の仕様 る必要がある。
Stream S3	Concrete of primary containment vessel (PCV)	原廃棄物の仕様(デ や一時保管容器の
Stream S4	Metal in reactor building	Pretreatment, treatment and reprocessing methods (decontamination, volume reduction, and reprocessing methods) need to be considered based on the characteristics of nuclear waste (such as content, radiation concentration, and the shape of waste dependent on the dismantling method) and the specifications of temporary storage containers.
Stream S5	Concrete in reactor building	Treatment methods (decontamination, volume reduction, and reprocessing methods) need to be considered based on the characteristics of waste at the site (such as content, radiation concentration, and the shape of waste dependent on the dismantling method) and the specifications of temporary storage containers.
Stream S6	Metal rubble	Volume reduction by shredding is planned.
Stream S7	Concrete rubble	Volume reduction by crushing is planned.
Stream S8	Combustibles	Felled trees undergo a volume reduction process. Protective wear is incinerated.

The waste-specific R&D status and refinement were confirmed.
Study on waste streams will be repeated by reflecting issues identified and research results obtained through R&D activities, and the evaluation results based on such reviews will be presented

6. Schedule and Project Organization

Planned and Actual Schedule (1/3)

Schedule of FY2017 “R&D for Treatment and Disposal of Solid Radioactive Waste”



Planned and Actual Schedule (2/3)

Legend: Blue: Plan / Red: Result

Implementation details	FY2017: 4	5	6	7	8	9	10	11	12	1	2	3
(3) Streamlining of analysis methods												
- Study on the migration behavior and the contamination mechanism of radionuclides				Consideration of contamination mechanisms						Summary		
- Study on the representativeness of analysis data							Study of data representativeness			Summary		
- Reselection of nuclides to be analyzed	Selection of nuclides		*Conduct a review in line with the analysis plan and reflect the result to the plan.									
- Streamlined analysis method				Viewpoint of streamlining			Viewpoint of streamlining analysis method			Technical development plan discussed		
(4) Analysis data management												
- Building of analysis database		Specification review		Database creation						Operation and identification of issues		
- Organize and update waste data		Preoperational planning		Consideration of data management and update policy, publication of updated data set						Summary		
ii) Improvement of the accuracy of analytical evaluation methods												
- Analytical evaluation methods		Planning		Accuracy improvement study and the establishment of methods						Summary		
- Collection of basic data		Planning		Collection of basic experimental data						Summary		
iii) Summary of comprehensive inventory evaluation	Not included in FY2017 R&D plan											
iv) Response to materials with impact on disposal, etc.												
- Case study inside and outside Japan		Planning		Research on cases						Summary		
- Investigation of impact on disposal safety		Planning		Study of indexes that can express impacts on performance and quantitative evaluation methods						Summary		

Planned and Actual Schedule (3/3)

Implementation details	Legend Blue: Plan Red: Result	FY2017 4	5	6	7	8	9	10	11	12	1	2	3
2. Study on Predisposal Management													
i) Assessment of applicability depending on the characteristics of solid waste			Planning		Consideration of applicability of existing technologies			Issues in applying to waste generated by the accident				Summary	
ii) Consideration and evaluation of waste storage and management methods taking into account the characteristics of solid waste													
(1) Study of measures for storing highly radioactive waste													
- Measures for hydrogen gas generation (case study outside Japan)			Planning		Research on the international know-how ledge of hydrogen gas control in storage							Summary	
- Measures for projected wastes generated by fuel debris retrieval			Planning		Research on projected rubble from planned fuel debris retrieval							Summary	
- Management method of waste originated from cesium adsorption vessels (JAEA)			Test condition consideration and preparation				Tests with full-scale simulated waste samples				Consideration of management methods, conclusion		
(2) Evaluation of technology to stabilize the secondary wastes generated from contaminated water treatment													
- Applicability assessment of in-drum glass solidification technology		Test			Fundamental test on glass solidification							Summary	
- How to stabilize sludge from decontamination systems		Test			Fundamental test on fluidity						Planning of demonstration tests		
iii) Research on Technologies for Reducing Waste Production						Research on α-contamination measurement and assessment technologies*1 Note 1)						Summary	
3. Study of Disposal Strategy and Safety Assessment Methods Suitable for Characteristics of Solid Waste		Preoperational planning			Searching for target disposal facilities			Investigation and evaluation of disposal regulations				Summary	
4. Integration of R&D Results (Waste Stream)		Preoperational planning			Comprehensive evaluation of progress, consistency of outcomes, and remaining issues							Summary	

Note 1) This was originally scheduled in FY2018 but completed ahead of schedule.

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Project Organization Chart (FY2017)

*Participation by a public invitation

Tokyo Electric Power Company Holdings, Inc. (TEPCO)
○Development coordination (1) to (4)

R&D liaison department of TEPCO
- Waste Management Group, Project Planning Department, Fukushima Daiichi Decontamination and Decommissioning (D&D) Engineering Company

International Research Institute for Nuclear Decommissioning (IRID)
o Formulation of overall plan and technical integration (1) to (5)
o Technical management such as technical development progress management (1) to (5)
o Coordination concerning technical development (1) to (5)

Japan Atomic Energy Agency (JAEA)
○Summary of technical development (1) to (3)
○Development (1) to (4)
○Operational assistance (5)

- **Hitachi, Ltd. (1)*** Inspection and calibration of radiation monitoring instruments
- **Chiyoda Technol Corporation (1)*** APD inspection and calibration
- **Hitachi, Ltd. (1)*** Inspection and calibration of GM counters
- **Hitachi Transport System, Ltd. (1)*** Transport of analysis samples from Fukushima Daiichi NPS to analysis laboratories
- **Hitachi Transport System, Ltd. (1)*** Transport of analysis samples collected at Fukushima Daiichi NPS
- **Asima Co., Ltd. (1)*** Commissioned operation and maintenance of equipment and facilities related to backend technology development buildings
- **Mitsubishi Materials Techno Corporation (1)*** Inspection and maintenance of power receiving equipment in backend technology development buildings
- **Mitsubishi Materials Techno Corporation (1)*** Inspection and maintenance of instrumentation equipment in backend technology development buildings
- **NISSIN GIKEN CO., LTD (1)*** General maintenance/repair and efficiency measurement of high-performance air filtration systems in backend technology development buildings
- **Ascend Co., Ltd. (1)*** Commissioned research on analysis and tests associated with the characterization of the secondary waste from contaminated water treatment systems in Fukushima Daiichi NPS
- **Inspection Development Company Ltd. (1)*** Commissioned research on the analysis of β-nuclides in contaminated water and secondary waste from contaminated water treatment systems in Fukushima Daiichi NPS as well as subsequent organizing and interpretation of the analysis data
- **Art Kagaku Co., Ltd. (1)*** Anemometer calibration
- **Nippon Nuclear Fuel Development Co., Ltd. (1)*** Analysis of contaminated water and secondary wastes generated from contaminated water treatment
- **E&E Techno Service Co, Ltd. (1)*** Tests concerning the contamination distribution analysis of waste samples from Fukushima Daiichi NPS
- **SynchroSoft Co.,Ltd. (1)*** Design and prototyping of database for the analysis of waste in Fukushima Daiichi NPS
- **Central Research Institute of Electric Power Industry (1)** Study on accuracy improvement of analytical evaluation methods
- **Mitsubishi Materials Corporation (1)*** Collection of data concerning nuclide sorption behavior to support the inventory estimation of waste zeolite
- **Tokyo Nuclear Services Co., Ltd. (1)*** Collection of basic data concerning nuclide sorption on adsorbent in liquids with different characteristics
- **Mitsubishi Materials Corporation (1)*** Research on influencing factors and influence propagation of waste generated by the accident as well as nuclide migration parameter settings (II)
- **National Nuclear Laboratory, UK (2)** Study on waste management (hydrogen gas generation)
- **Ascend Co., Ltd. (2)*** Full-scale tests to examine salt concentration behavior using SARRY test samples

Hitachi-GE Nuclear Energy, Ltd.
○ Development (1) to (4)

- **Tokyo Power Technology Ltd. (1)*** Support of information handling operations for waste list update
- **JGC Corporation (1) and (3)*** Case study in other countries concerning acceptance criteria of waste including influential materials to disposal strategy
  - Support of survey on reasonable disposal methods applied in other countries

Toshiba Energy Systems & Solutions Corporation
○ Development (1) to (4)

- **AECOM E&C UK Limited (2) and (3)***
  - Survey on hydrogen gas evaluation methods and storage in other countries (UK., USA, etc.)
  - Survey on international know-how of waste disposal strategies and safety assessment methods (in UK, USA, etc.)

KOKUYO Co.,Ltd. (5) Organization of documents and data

Mitsubishi Heavy Industries, Ltd.
○ Development (1), (2) and (4)

- **Kanden Engineering Co. (1)*** Sampling tools design and manufacturing
- **MHI NS Engineering Co., Ltd. (1)** Mock-up test support
- **TAIHEI DENGYO KAISHA, LTD. (1)** On-site investigation support
- **ANADEC (2)** Sludge fluidity test

ATOX Co., Ltd.
○ Development (1), (2) and (3)

- **Orano ATOX D&D SOLUTIONS Co., Ltd. (1)** Study of methods for sampling secondary waste generated from high radiation water treatment
- **Orano ATOX D&D SOLUTIONS Co., Ltd. (2)** Detailed study on methods to estimate hydrogen gas generation and requirements for hydrogen gas venting system
- **Kurion Japan, KK (2)** Fundamental test on glass solidification

[Types of operations]
(1) Characterization
(2) Study on predisposal management
(3) Study of disposal strategy and safety assessment methods suitable for characteristics of solid waste
(4) Integration of R&D results
(5) R&D management, etc.