【Confidential】

Subsidy Project of Decommissioning and Contaminated Water Management in the FY2018 Supplementary Budgets

R&D for Treatment and Disposal of Solid Radioactive Waste

Accomplishment Report for FY2019

December 2020

International Research Institute for Nuclear Decommissioning (IRID)

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1. Approach to Research & Development
- Background and Purpose of Research & Development -

Basic concept of waste management in the Mid-and-Long-Term Road-map

◆ The **characteristics** of solid waste, such as nuclide composition, radioactivity concentration, etc. **need to be understood** in order to study solid waste treatment and disposal.

◆ Generated solid waste is **stored and managed by means of safe and practical methods based on the characteristics of the waste.**

◆ To ensure safety of solid waste storage and management, **techniques for practically selecting treatment (preceding processing) methods** for waste stabilization and solidification **are established, and preceding processing methods are selected based on the established techniques** before determining the technical requirements for disposal.

◆ To promote efficient research and development (R&D) on solid waste treatment and disposal, close cooperation between R&D projects related to the characterization, treatment, and disposal of solid waste is required. R&D is promoted by **sharing research and issues among the R&D teams, taking an overview of all activities pertaining to solid waste management, and identifying required R&D tasks.**

By around FY2021,

Treatment and disposal measures, and their technical prospects pertaining to safety will be indicated.

*"Mid-and-Long-Term Road-map towards the Decommissioning of TEPCO HD's Fukushima Daiichi Nuclear Power Station (September 26, 2017)" 4-5 excerpts, partly reworde

1. Approach to Research & Development
Goals for achieving the mid-and-long-term road-map milestones

- The following specific goals for achieving milestones set for FY2021 are indicated in the strategic plan# of the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as NDF). R&D initiatives are undertaken to contribute to goals.

Specific goals related to technical prospects

1. Safe and practical disposal concepts should be established based on the properties and amount of solid waste generated at the Fukushima Daiichi Nuclear Power Station and the treatment technologies that can be used for that solid waste, and safety assessment techniques reflecting the characteristics of the disposal concept should be provided, based on examples from various foreign countries.
2. Analysis and evaluation techniques for characterization should be clearly specified.
3. Treatment technologies for stabilization and solidification considering disposal of various important waste streams such as secondary waste generated from contaminated water treatment, which are expected to be introduced in actual conditions, should be clearly specified.
4. Based on the above No. 3., before determining the technical requirements for disposal, techniques for practically selecting treatment (preceding processing) methods for stabilization and solidification should be established.
5. With respect to solid waste for which treatment technology that considers disposal is not clearly specified, establishment of a treatment and disposal plan using the series of techniques developed until FY2021 should be foreseeable.
6. The challenges pertaining to storage and management of solid waste until waste conditioning and corresponding measures should be clearly specified.

"Technical Strategic Plan 2019 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, September 09, 2019, 3.2.2.4.

1. Approach to Research & Development
- Goals (1/2) -

Item / Year	Second Term (Period until start of fuel debris retrieval)					
	2016	2017	2018	2019	2020	2021 onwards
Main events in the current mid-and-long-term road-map		△ Summarizing the basic concept related to treatment & disposal				Treatment & disposal plan and technical prospects pertaining to their safety △
[R&D related to treatment and disposal of solid waste] I. Storage and management 1. Study and evaluation of storage and management methods	Evaluation of the type and amount of waste resulting from debris retrieval			Evaluation of the type and amount of waste accompanying debris retrieval and revision based on the progress of studying retrieval		Evaluation study, study of measures in accordance with the on-site status
	Investigation of cases related to storage of high-level radioactive waste within Japan and overseas, study of applicability to 1F and consolidation of challenges			Study and presentation of storage and management methods including hydrogen measures		
2. Development of contamination evaluation technology for solid waste segregation	Investigation and study of the methods for measurement and evaluation of α contamination, etc.			Systematization for on-site application	Mock-up test	Technological development pertaining to the measurement and evaluation methods
II. Establishment of treatment and disposal concepts and development of safety assessment techniques 1. Establishment of techniques for selecting the preceding processing method	Technological investigation, testing, evaluation and presentation of candidate technologies		Acquisition and evaluation of required data on high temperature treatment technology and low temperature treatment technology, using engineering scale testing equipment			Identification of preceding processing method
			Collection and consolidation of items and information required for multi-faceted evaluation, and presentation of challenges		Identification of technology that can be applied to actual treatment (of some of the waste), from the technological perspective	
2. Presentation of disposal methods and development of safety assessment techniques	Investigation of disposal plans within Japan and overseas			Study of the disposal concepts and safety assessment techniques	Clear specification of the image of waste conditioning, consolidation of data required for the safety assessment technique for each disposal method	Preliminary safety assessment
	Investigation of cases related to materials with impact on disposal, study of analytical techniques			Acquisition of data for impact assessment related to the main materials with impact, improvement in the impact assessment techniques		

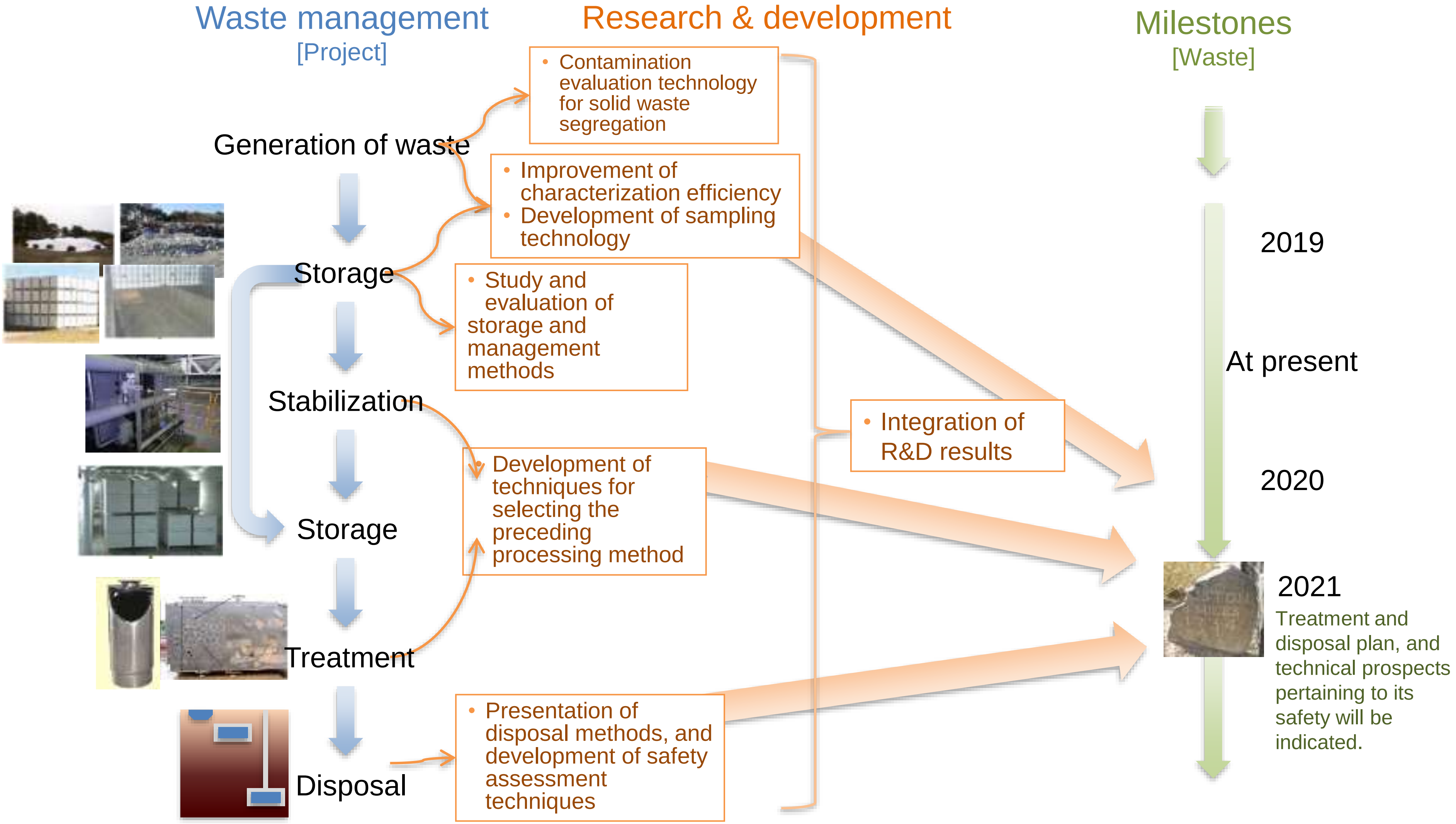
[Source] Created by extracting R&D items from P.16 of the “FY2019 Decommissioning R&D Plan” of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (63rd session, February 28, 2019)

1. Approach to Research & Development
- Goals (2/2) -

Item / Year	Second Term (Period until start of fuel debris retrieval)					
	2016	2017	2018	2019	2020	2021 onwards
Main events in the current mid-and-long-term road-map			△ Summarizing the basic concept related to treatment & disposal		Treatment & disposal plan and technical prospects pertaining to its safety △	
III. Characterization Characterization efficiency improvement (1) Establishment of the method of characterization by combining analysis data and evaluation data based on the migration models	Reflection of analysis data pertaining to secondary waste generated from contaminated water treatment, debris, felled trees and soil			Establishment of the method of characterization by combining analysis data and evaluation data based on the migration models, simplification and speeding up of analysis methods		Study on the applicability of techniques, reflection into the Okuma Analysis and Research Facility Building 1
(2) Simplification and speeding up of analysis methods				Acquisition, evaluation and management, etc. of analysis data, which would help in simplification and speeding up of analysis methods, study and proposal of techniques for providing manuals, overall needs of waste management or establishment of consistency		Reflection into the Okuma Analysis and Research Facility Building 1
2. Development of sampling technology	Development of technology for collecting cesium adsorbents and samples from inside the reactor building, and sampling of sludge from decontamination systems			Element tests and evaluation required for designing mock-up devices		Manufacturing and sampling test
IV. Integration of R & D results Study of waste streams	Creation of draft proposal, reflection of the outcome and revision			Integrated progress in R&D, consistency, challenge evaluation		Evaluation based on R&D progress

[Source] P.16 of the "FY2019 Decommissioning R&D Plan" of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (63rd session, February 28, 2019)

1. Approach to Research & Development
Reflection of results into the decommissioning of Fukushima Daiichi Nuclear Power Station



Waste management
[Project]

Generation of waste

Storage

Stabilization

Storage

Treatment

Disposal

Research & development

- Contamination evaluation technology for solid waste segregation

- Improvement of characterization efficiency
- Development of sampling technology

- Study and evaluation of storage and management methods

- Development of techniques for selecting the preceding processing method

- Presentation of disposal methods, and development of safety assessment techniques

- Integration of R&D results

Milestones
[Waste]

2019

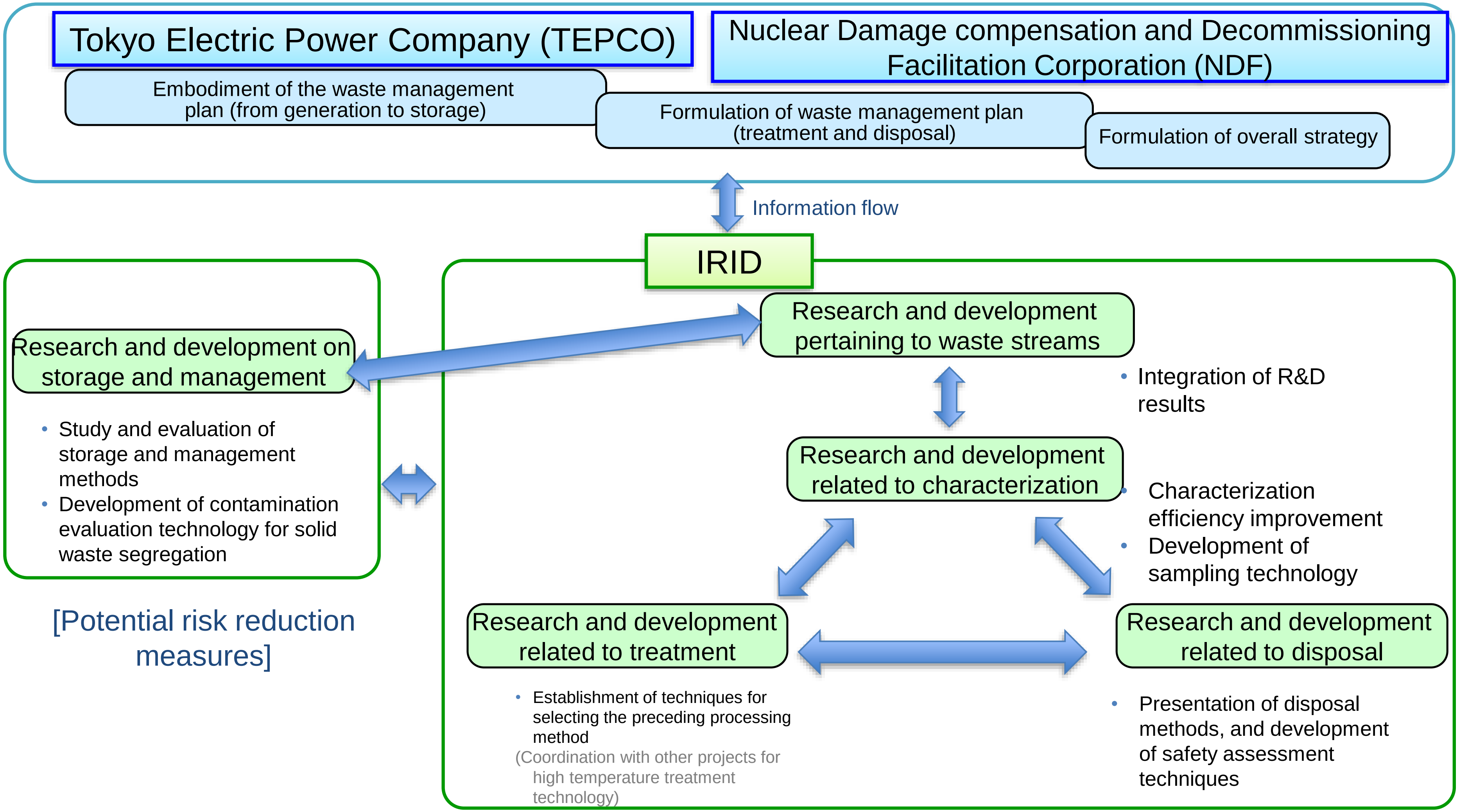
At present

2020

2021

Treatment and disposal plan, and technical prospects pertaining to its safety will be indicated.

1. Approach to Research & Development
Role-sharing among relevant organizations, and correlation between study items



Tokyo Electric Power Company (TEPCO)

Nuclear Damage compensation and Decommissioning Facilitation Corporation (NDF)

Embodiment of the waste management plan (from generation to storage)

Formulation of waste management plan (treatment and disposal)

Formulation of overall strategy

Information flow

IRID

Research and development on storage and management

- Study and evaluation of storage and management methods
- Development of contamination evaluation technology for solid waste segregation

[Potential risk reduction measures]

Research and development pertaining to waste streams

- Integration of R&D results

Research and development related to characterization

- Characterization efficiency improvement
- Development of sampling technology

Research and development related to treatment

- Establishment of techniques for selecting the preceding processing method

(Coordination with other projects for high temperature treatment technology)

Research and development related to disposal

- Presentation of disposal methods, and development of safety assessment techniques

[Comprehensive waste management measures]

1. Approach to Research & Development
- Correlation with other research projects -

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[Input into this project]

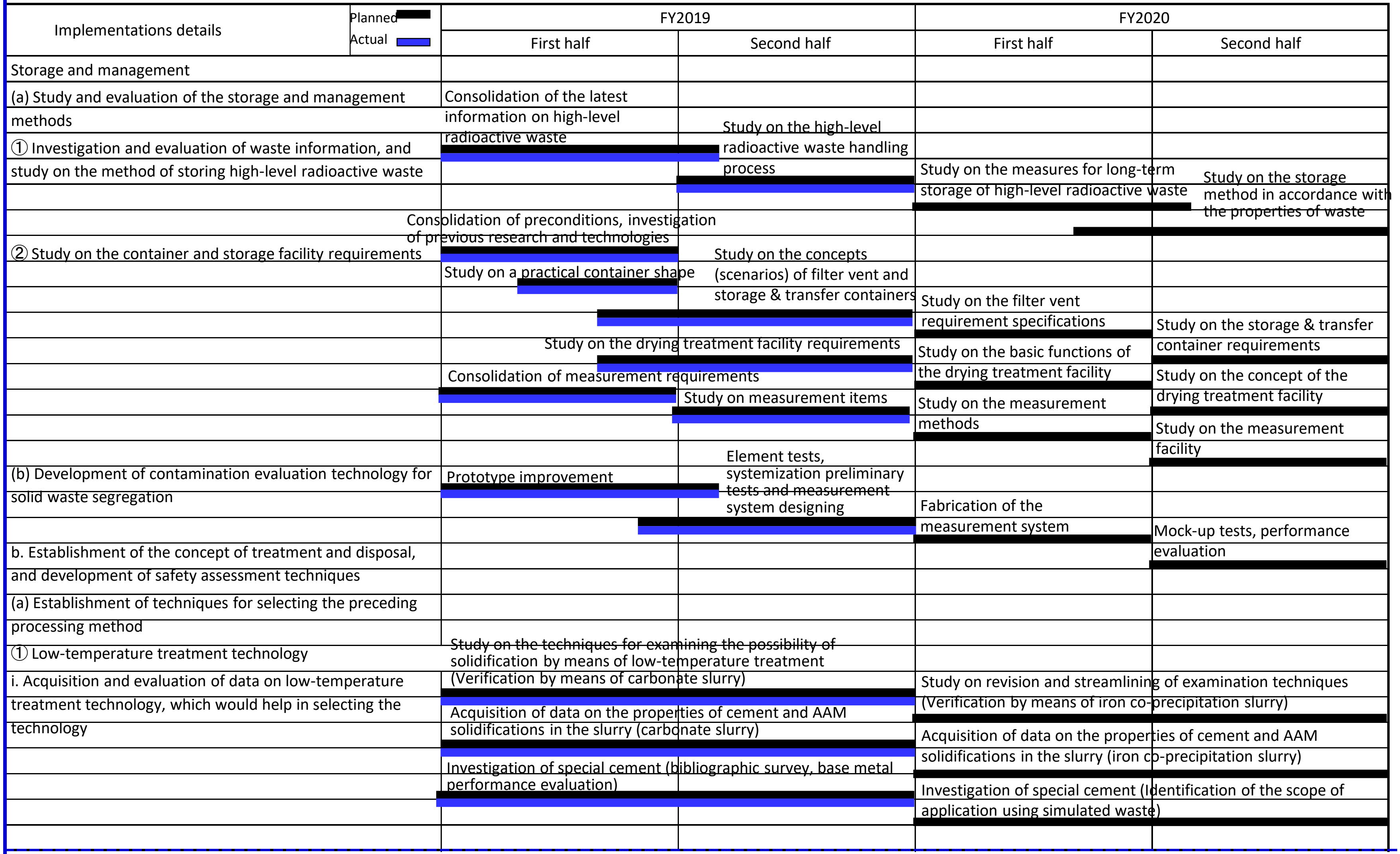
ID	Implementation Items and Specific Contents (Use of Information)	Required Information	Required Time	Source of Acquisition	Remarks
1	Understanding the storage conditions of high-level radioactive waste that will be studied under waste management	Specifications of the consumables in the equipment used for fuel debris retrieval and of the equipment used in the water treatment and air conditioning system, as well as specifications of the retrieval container	When required	Debris Retrieval project	Information exchange as necessary (4 times this year)
2	Understanding the storage conditions of high-level radioactive waste that will be studied under waste management	Specifications of equipment used for collection, transfer, and storage of fuel debris canisters	When required	Canister project	Information exchange as necessary (3 times this year)
3	Understanding the fundamental knowledge required for studying waste streams and for studying the approach for evaluating applicability of treatment technology	Information on high-temperature treatment technologies	When required	Some proposers	Coordinated via MRI

[Output from this project]

ID	Implementation Items and Output Details	Usage at Output Destination	Required Time	Destination	Remarks
1	Research results of subsidized projects so far	Understanding as fundamental data required for studying high-temperature treatment technologies	When required	Some proposers	Coordinated via MRI
2	Sharing the results of storage and management, and regulating the conditions for coordination	Confirmation of conformance with the debris retrieval process	When required	Debris Retrieval project	
3	Checking the conditions for evaluating amount of hydrogen generated	Comparison with evaluation of amount of hydrogen generated by fuel debris	When required	Canister project	

Note) Debris Retrieval project: Development of Technology for Further Increasing the Scale of Retrieval of Debris and Internal Structures project
Canister project: Development of Technology for Collection, Transfer and Storage of Fuel Debris project

1. Approach to Research & Development
- Implementation Schedule (1/4) -



Planned ▬ Actual 🟦

Implementations details	FY2019 First half	FY2019 Second half	FY2020 First half	FY2020 Second half
Storage and management				
(a) Study and evaluation of the storage and management methods				
① Investigation and evaluation of waste information, and study on the method of storing high-level radioactive waste	Consolidation of the latest information on high-level radioactive waste	Study on the high-level radioactive waste handling process	Study on the measures for long-term storage of high-level radioactive waste	Study on the storage method in accordance with the properties of waste
② Study on the container and storage facility requirements	Consolidation of preconditions, investigation of previous research and technologies Study on a practical container shape Consolidation of measurement requirements	Study on the concepts (scenarios) of filter vent and storage & transfer containers Study on the drying treatment facility requirements Study on measurement items	Study on the filter vent requirement specifications Study on the basic functions of the drying treatment facility Study on the measurement methods	Study on the storage & transfer container requirements Study on the concept of the drying treatment facility Study on the measurement facility
(b) Development of contamination evaluation technology for solid waste segregation	Prototype improvement	Element tests, systematization preliminary tests and measurement system designing	Fabrication of the measurement system	Mock-up tests, performance evaluation
b. Establishment of the concept of treatment and disposal, and development of safety assessment techniques				
(a) Establishment of techniques for selecting the preceding processing method				
① Low-temperature treatment technology				
i. Acquisition and evaluation of data on low-temperature treatment technology, which would help in selecting the technology	Study on the techniques for examining the possibility of solidification by means of low-temperature treatment (Verification by means of carbonate slurry) Acquisition of data on the properties of cement and AAM solidifications in the slurry (carbonate slurry) Investigation of special cement (bibliographic survey, base metal performance evaluation)		Study on revision and streamlining of examination techniques (Verification by means of iron co-precipitation slurry) Acquisition of data on the properties of cement and AAM solidifications in the slurry (iron co-precipitation slurry) Investigation of special cement (Identification of the scope of application using simulated waste)	

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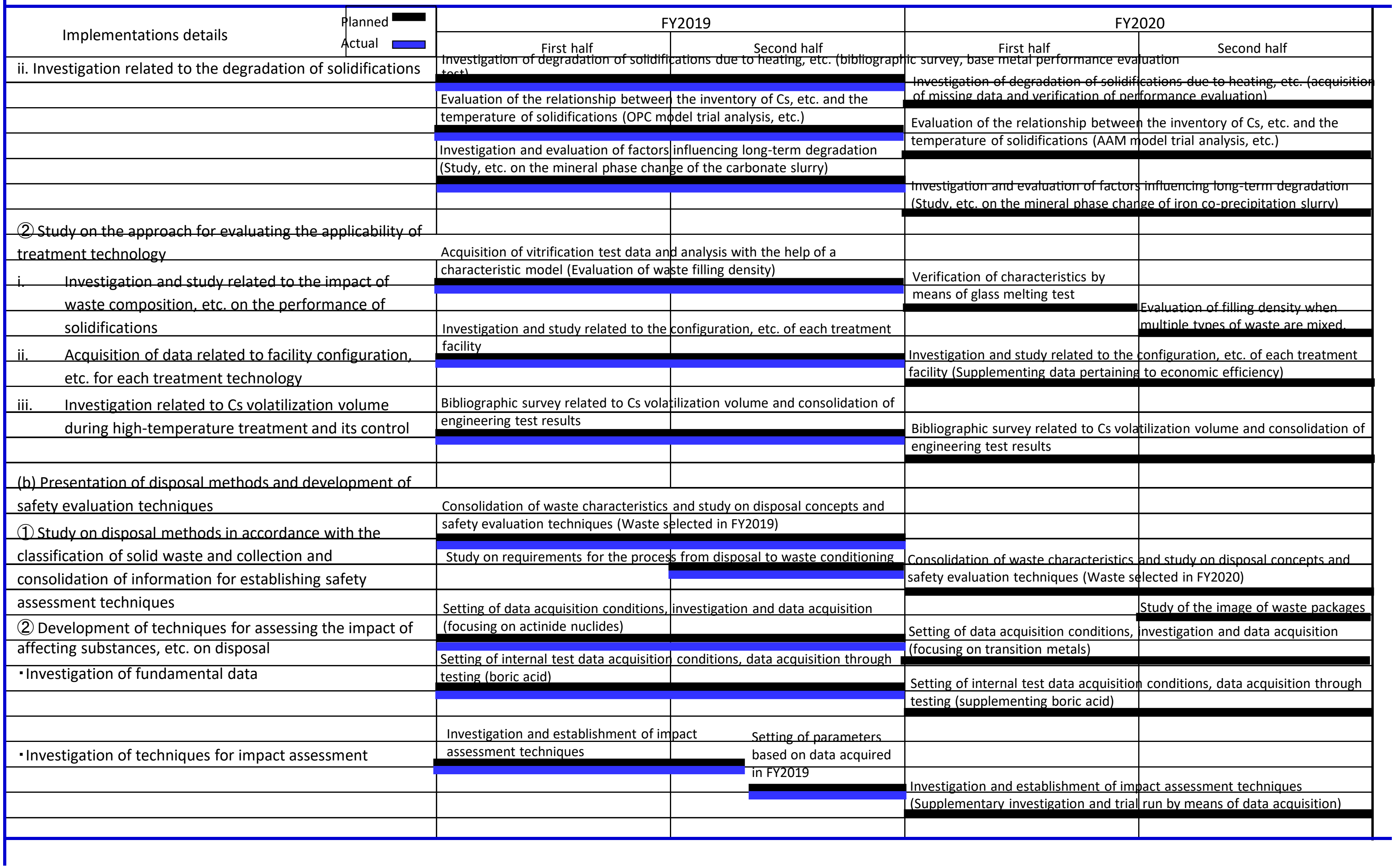
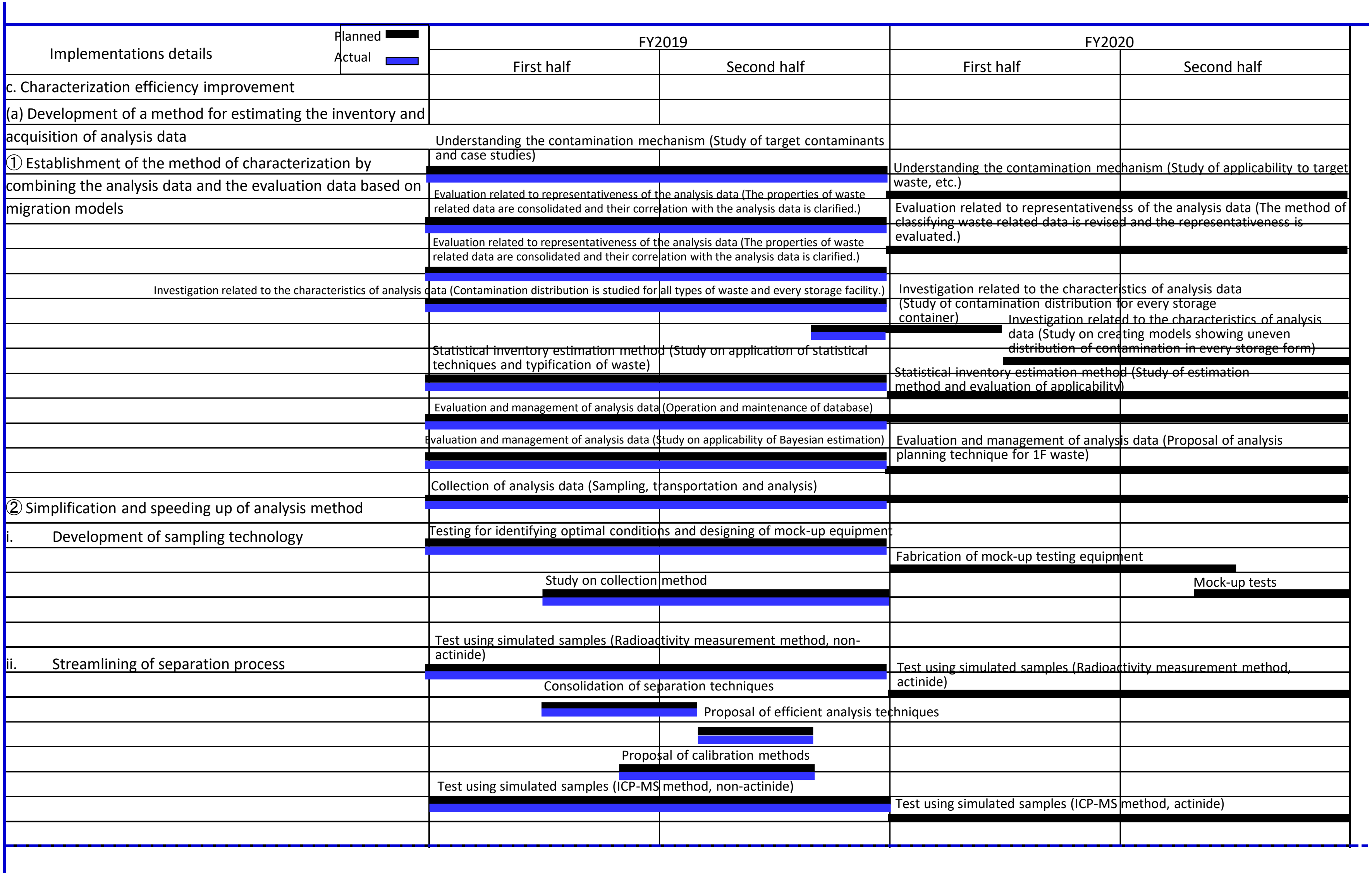
1. Approach to Research & Development
- Implementation Schedule (2/4) -



Implementations details (Planned ▬ / Actual 🟦)	FY2019 First half	FY2019 Second half	FY2020 First half	FY2020 Second half
ii. Investigation related to the degradation of solidifications	Investigation of degradation of solidifications due to heating, etc. (bibliographic survey, base metal performance evaluation test)		Investigation of degradation of solidifications due to heating, etc. (acquisition of missing data and verification of performance evaluation)	
	Evaluation of the relationship between the inventory of Cs, etc. and the temperature of solidifications (OPC model trial analysis, etc.)		Evaluation of the relationship between the inventory of Cs, etc. and the temperature of solidifications (AAM model trial analysis, etc.)	
	Investigation and evaluation of factors influencing long-term degradation (Study, etc. on the mineral phase change of the carbonate slurry)		Investigation and evaluation of factors influencing long-term degradation (Study, etc. on the mineral phase change of iron co-precipitation slurry)	
② Study on the approach for evaluating the applicability of treatment technology				
i. Investigation and study related to the impact of waste composition, etc. on the performance of solidifications	Acquisition of vitrification test data and analysis with the help of a characteristic model (Evaluation of waste filling density)		Verification of characteristics by means of glass melting test	Evaluation of filling density when multiple types of waste are mixed.
ii. Acquisition of data related to facility configuration, etc. for each treatment technology	Investigation and study related to the configuration, etc. of each treatment facility		Investigation and study related to the configuration, etc. of each treatment facility (Supplementing data pertaining to economic efficiency)	
iii. Investigation related to Cs volatilization volume during high-temperature treatment and its control	Bibliographic survey related to Cs volatilization volume and consolidation of engineering test results		Bibliographic survey related to Cs volatilization volume and consolidation of engineering test results	
(b) Presentation of disposal methods and development of safety evaluation techniques				
① Study on disposal methods in accordance with the classification of solid waste and collection and consolidation of information for establishing safety assessment techniques	Consolidation of waste characteristics and study on disposal concepts and safety evaluation techniques (Waste selected in FY2019)		Consolidation of waste characteristics and study on disposal concepts and safety evaluation techniques (Waste selected in FY2020)	
		Study on requirements for the process from disposal to waste conditioning		Study of the image of waste packages
② Development of techniques for assessing the impact of affecting substances, etc. on disposal ・Investigation of fundamental data	Setting of data acquisition conditions, investigation and data acquisition (focusing on actinide nuclides)		Setting of data acquisition conditions, investigation and data acquisition (focusing on transition metals)	
	Setting of internal test data acquisition conditions, data acquisition through testing (boric acid)		Setting of internal test data acquisition conditions, data acquisition through testing (supplementing boric acid)	
・Investigation of techniques for impact assessment	Investigation and establishment of impact assessment techniques	Setting of parameters based on data acquired in FY2019	Investigation and establishment of impact assessment techniques (Supplementary investigation and trial run by means of data acquisition)	

1. Approach to Research & Development
- Implementation Schedule (3/4) -



Implementations details

Planned ■
Actual 🟦

FY2019: First half / Second half
FY2020: First half / Second half

c. Characterization efficiency improvement

(a) Development of a method for estimating the inventory and acquisition of analysis data

① Establishment of the method of characterization by combining the analysis data and the evaluation data based on migration models

Understanding the contamination mechanism (Study of target contaminants and case studies)

Understanding the contamination mechanism (Study of applicability to target waste, etc.)

Evaluation related to representativeness of the analysis data (The properties of waste related data are consolidated and their correlation with the analysis data is clarified.)

Evaluation related to representativeness of the analysis data (The method of classifying waste related data is revised and the representativeness is evaluated.)

Evaluation related to representativeness of the analysis data (The properties of waste related data are consolidated and their correlation with the analysis data is clarified.)

Investigation related to the characteristics of analysis data (Contamination distribution is studied for all types of waste and every storage facility.)

Investigation related to the characteristics of analysis data (Study of contamination distribution for every storage container)

Investigation related to the characteristics of analysis data (Study on creating models showing uneven distribution of contamination in every storage form)

Statistical inventory estimation method (Study on application of statistical techniques and typification of waste)

Statistical inventory estimation method (Study of estimation method and evaluation of applicability)

Evaluation and management of analysis data (Operation and maintenance of database)

Evaluation and management of analysis data (Study on applicability of Bayesian estimation)

Evaluation and management of analysis data (Proposal of analysis planning technique for 1F waste)

Collection of analysis data (Sampling, transportation and analysis)

② Simplification and speeding up of analysis method

i. Development of sampling technology

Testing for identifying optimal conditions and designing of mock-up equipment

Fabrication of mock-up testing equipment

Study on collection method

Mock-up tests

ii. Streamlining of separation process

Test using simulated samples (Radioactivity measurement method, non-actinide)

Test using simulated samples (Radioactivity measurement method, actinide)

Consolidation of separation techniques

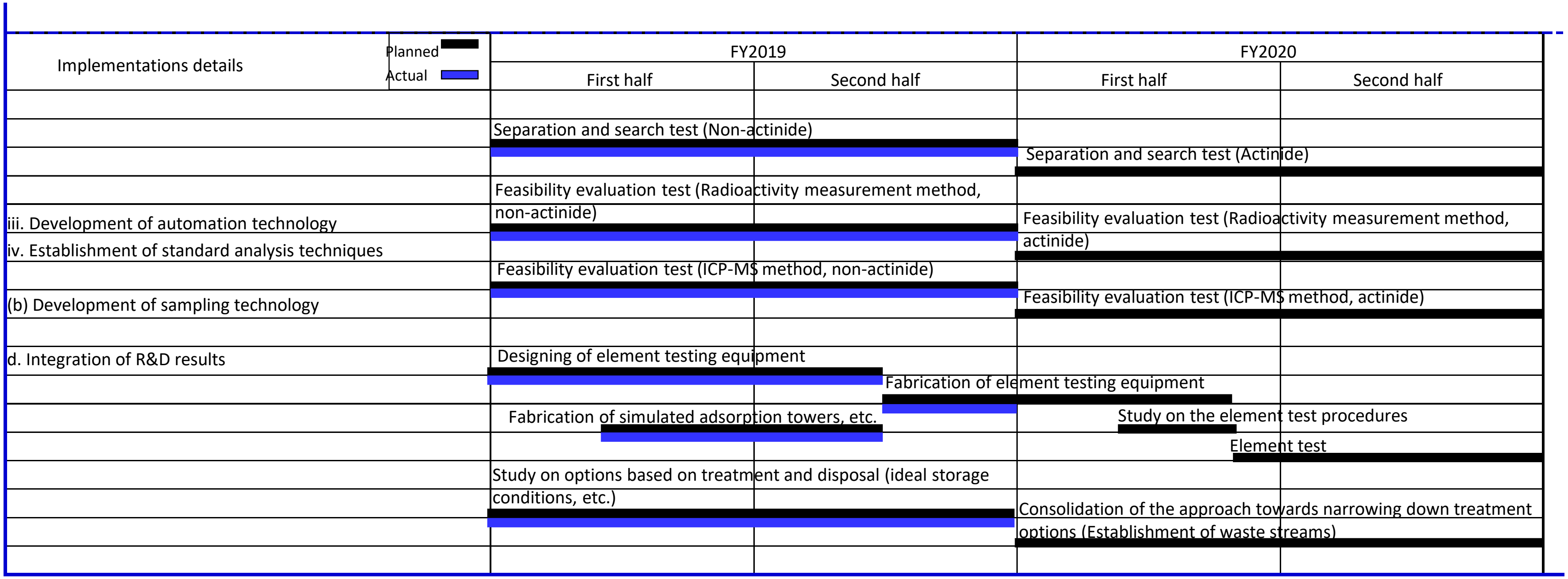
Proposal of efficient analysis techniques

Proposal of calibration methods

Test using simulated samples (ICP-MS method, non-actinide)

Test using simulated samples (ICP-MS method, actinide)

1. Approach to Research & Development
- Implementation Schedule (4/4) -



Implementations details

Planned ▬

Actual ▬

FY2019: First half, Second half

FY2020: First half, Second half

iii. Development of automation technology

iv. Establishment of standard analysis techniques

(b) Development of sampling technology

d. Integration of R&D results

Separation and search test (Non-actinide)

Separation and search test (Actinide)

Feasibility evaluation test (Radioactivity measurement method, non-actinide)

Feasibility evaluation test (Radioactivity measurement method, actinide)

Feasibility evaluation test (ICP-MS method, non-actinide)

Feasibility evaluation test (ICP-MS method, actinide)

Designing of element testing equipment

Fabrication of element testing equipment

Fabrication of simulated adsorption towers, etc.

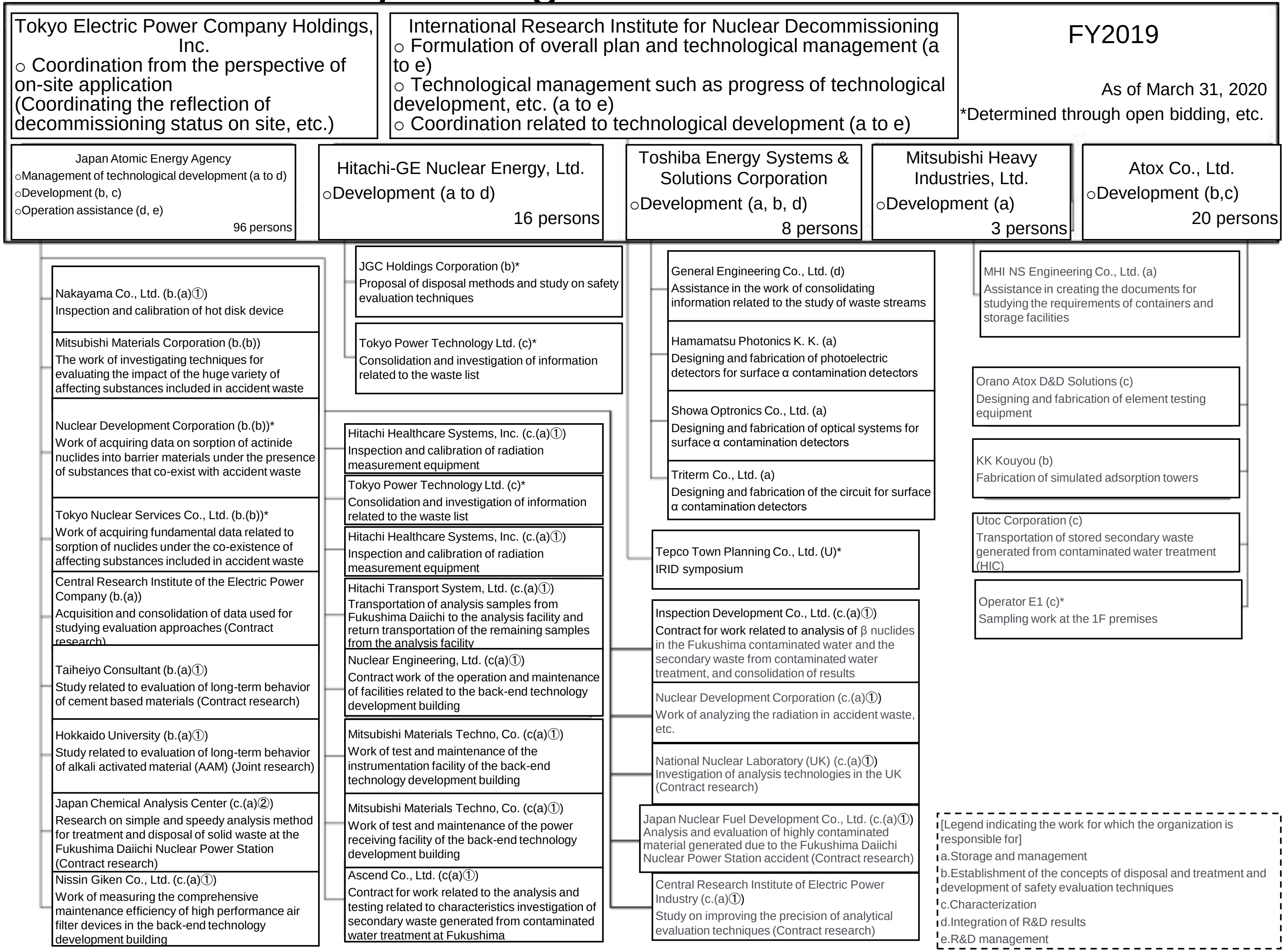
Study on the element test procedures

Element test

Study on options based on treatment and disposal (ideal storage conditions, etc.)

Consolidation of the approach towards narrowing down treatment options (Establishment of waste streams)

1. Approach to Research & Development
- Project Organization Chart -



Tokyo Electric Power Company Holdings, Inc.
○ Coordination from the perspective of on-site application
(Coordinating the reflection of decommissioning status on site, etc.)

International Research Institute for Nuclear Decommissioning
○ Formulation of overall plan and technological management (a to e)
○ Technological management such as progress of technological development, etc. (a to e)
○ Coordination related to technological development (a to e)

FY2019

As of March 31, 2020
*Determined through open bidding, etc.

Japan Atomic Energy Agency
○Management of technological development (a to d)
○Development (b, c)
○Operation assistance (d, e)
96 persons

Hitachi-GE Nuclear Energy, Ltd.
○Development (a to d)
16 persons

Toshiba Energy Systems & Solutions Corporation
○Development (a, b, d)
8 persons

Mitsubishi Heavy Industries, Ltd.
○Development (a)
3 persons

Atox Co., Ltd.
○Development (b,c)
20 persons

Nakayama Co., Ltd. (b.(a)①)
Inspection and calibration of hot disk device

Mitsubishi Materials Corporation (b.(b))
The work of investigating techniques for evaluating the impact of the huge variety of affecting substances included in accident waste

Nuclear Development Corporation (b.(b))*
Work of acquiring data on sorption of actinide nuclides into barrier materials under the presence of substances that co-exist with accident waste

Tokyo Nuclear Services Co., Ltd. (b.(b))*
Work of acquiring fundamental data related to sorption of nuclides under the co-existence of affecting substances included in accident waste

Central Research Institute of the Electric Power Company (b.(a))
Acquisition and consolidation of data used for studying evaluation approaches (Contract research)

Taiheiyo Consultant (b.(a)①)
Study related to evaluation of long-term behavior of cement based materials (Contract research)

Hokkaido University (b.(a)①)
Study related to evaluation of long-term behavior of alkali activated material (AAM) (Joint research)

Japan Chemical Analysis Center (c.(a)②)
Research on simple and speedy analysis method for treatment and disposal of solid waste at the Fukushima Daiichi Nuclear Power Station (Contract research)

Nissin Giken Co., Ltd. (c.(a)①)
Work of measuring the comprehensive maintenance efficiency of high performance air filter devices in the back-end technology development building

JGC Holdings Corporation (b)*
Proposal of disposal methods and study on safety evaluation techniques

Tokyo Power Technology Ltd. (c)*
Consolidation and investigation of information related to the waste list

Hitachi Healthcare Systems, Inc. (c.(a)①)
Inspection and calibration of radiation measurement equipment

Tokyo Power Technology Ltd. (c)*
Consolidation and investigation of information related to the waste list

Hitachi Healthcare Systems, Inc. (c.(a)①)
Inspection and calibration of radiation measurement equipment

Hitachi Transport System, Ltd. (c.(a)①)
Transportation of analysis samples from Fukushima Daiichi to the analysis facility and return transportation of the remaining samples from the analysis facility

Nuclear Engineering, Ltd. (c(a)①)
Contract work of the operation and maintenance of facilities related to the back-end technology development building

Mitsubishi Materials Techno, Co. (c(a)①)
Work of test and maintenance of the instrumentation facility of the back-end technology development building

Mitsubishi Materials Techno, Co. (c(a)①)
Work of test and maintenance of the power receiving facility of the back-end technology development building

Ascend Co., Ltd. (c(a)①)
Contract for work related to the analysis and testing related to characteristics investigation of secondary waste generated from contaminated water treatment at Fukushima

General Engineering Co., Ltd. (d)
Assistance in the work of consolidating information related to the study of waste streams

Hamamatsu Photonics K. K. (a)
Designing and fabrication of photoelectric detectors for surface α contamination detectors

Showa Optronics Co., Ltd. (a)
Designing and fabrication of optical systems for surface α contamination detectors

Triterm Co., Ltd. (a)
Designing and fabrication of the circuit for surface α contamination detectors

Tepco Town Planning Co., Ltd. (U)*
IRID symposium

Inspection Development Co., Ltd. (c.(a)①)
Contract for work related to analysis of β nuclides in the Fukushima contaminated water and the secondary waste from contaminated water treatment, and consolidation of results

Nuclear Development Corporation (c.(a)①)
Work of analyzing the radiation in accident waste, etc.

National Nuclear Laboratory (UK) (c.(a)①)
Investigation of analysis technologies in the UK (Contract research)

Japan Nuclear Fuel Development Co., Ltd. (c.(a)①)
Analysis and evaluation of highly contaminated material generated due to the Fukushima Daiichi Nuclear Power Station accident (Contract research)

Central Research Institute of Electric Power Industry (c.(a)①)
Study on improving the precision of analytical evaluation techniques (Contract research)

MHI NS Engineering Co., Ltd. (a)
Assistance in creating the documents for studying the requirements of containers and storage facilities

Orano Atox D&D Solutions (c)
Designing and fabrication of element testing equipment

KK Kouyou (b)
Fabrication of simulated adsorption towers

Utoc Corporation (c)
Transportation of stored secondary waste generated from contaminated water treatment (HIC)

Operator E1 (c)*
Sampling work at the 1F premises

[Legend indicating the work for which the organization is responsible for]
a.Storage and management
b.Establishment of the concepts of disposal and treatment and development of safety evaluation techniques
c.Characterization
d.Integration of R&D results
e.R&D management

2. Project Details

a. Storage and Management

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

② Study on container and storage facility requirements

(b) Development of contamination evaluation technology for solid waste segregation

Status of the study on high-level radioactive waste generated by fuel debris retrieval

(a) Study and evaluation of storage and management methods

The FY2017 study was started.

Preconditions for the study were determined.

- Waste related information
- Process requirements

The collection, transfer and storage flow was studied based on the safety function requirements and the primary proposal was presented.
(Refer to the FY2018 Final Report)
→The primary proposal on the scenarios is considered as the starting point of this study.

The FY2019 Subsidy Project started.

The prerequisites were reset based on the latest information.

- The latest findings were collected from other projects and waste information was updated.

Specifics on the concepts of equipment and facilities

- Inner container
- Storage container with filter vent
- Transport cask
- Drying equipment
- Measuring device

Identified through studies up to last year

Updating and study on the collection, transfer and storage flow

- Resetting the prerequisites and reflecting the specifics on the concepts of equipment and facilities
- Verifying consistency throughout the process

GOAL

To list down multiple possible scenarios in the handling process of high-level radioactive waste (waste generated by fuel debris retrieval) based on the latest waste information.

Examples of input required for study

Waste related information

- Information on waste properties → No direct information
- Range of fuel debris / waste → Under discussion
- Cutting method, size → multiple options are being studied

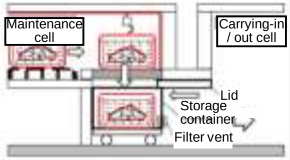
⋮

Process requirements

- Requirements for transfer inside the premises → TBD
- Requirements of waste storage vault for receiving waste → TBD
- Material accounting and management policy → TBD
- Sorting → Under examination

⋮

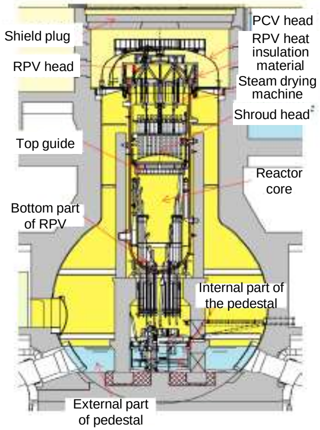
Study on last year's process (example of lid closing and transfer inside the premises)

Work		3. Storage of inner container inside storage container, and lid closing			6. Transfer inside the premises			
Workflow								
Specifications		. Preventing the contamination of carrying-in / out cell To prevent the contamination of carrying-in / out cell using the double door system between the maintenance cell and carrying-in / out cell . Storage container specifications . Has shielding functionality . Has filter vent functionality . Capable of transferring into the transport cask using remote operations . Capable of tightening the lid using remote operations . Is corrosion resistant (during storage) . The transfer of waste storage container inside the carrying-in / out cell is done using cart or conveyor belts (details under discussion)			.Transfer inside the premises . Has fall prevention function and structural strength that prevents the leakage of contents of the waste container in case it falls . Carrier . Has a function that prevents the storage container from tipping over			
		Safety function	Equipment and facilities		Safety function	Equipment and facilities		
			Storage container	Maintenance cell / Carrying –in/out cell		Storage container	Transport cask	Transport vehicle
Major events	Spread of contamination / internal exposure	Confinement	• Confinement of fine particles using anti-dispersing agent + filter vent	• Maintains the confinement function • Controls the exhaust using HEPA filter	Structural strength	-	• Has a structural strength that prevents transport cask from getting damaged in case it falls.	-
					Confinement	• Has a containment function that prevents the spilling of contents	• Has sealing function	-
	External radiation	Shielding	• Has a shielding function using thick shielding	-	Shielding	-	• Maintains shielding function using the shielding thickness	• Unmanned transportation for high-dose items
	Fire	Hydrogen measures	• Has a filter vent function	• Ventilated	Hydrogen measures	-	• Performs time management to prevent the hydrogen concentration from exceeding the explosion limit	-
	Industrial accidents	Operability	• Has operability such that it can be handled easily and safely	-	Operability	-	• Has a fall prevention function	• Has a fall prevention function
Issues		• Storage of cask using remote operations • Tightening of lid using remote operations • Prevention of contamination in carrying in/out cell by means of the double door system • Development of filter vent			• Increase in the throughput of unmanned operations			

(a) Study and evaluation of storage and management methods

<Results of studies so far ①　An example of setting the prerequisite；waste information>

Example of an existing study



Waste[#5]	Classification[#1]
Shield plug	Solid radioactive wastes
PCV head	Solid radioactive wastes
RPV heat insulation material	Solid radioactive wastes
RPV head	Solid radioactive wastes
Steam drying machine	Solid radioactive wastes
Shroud head	Solid radioactive wastes
Top guide	Fuel debris
Shroud	Fuel debris
Jet pump	Fuel debris
Fuel debris inside the reactor core	Fuel debris
Fuel debris at the bottom of RPV	Fuel debris
Fuel debris adhering to lower part of RPV / CRD housing	Fuel debris
Internal structures of pedestal	Fuel debris
CRD exchanger	Fuel debris
Fuel debris inside the pedestal	Fuel debris
External structures of pedestal	Solid radioactive wastes
Fuel debris outside the pedestal	Fuel debris

Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary Budgets
Project for Advancement of Retrieval Method and System of Fuel Debris

Studied by carrying out discussions (conducted 23 times in FY2017-2019) with related projects, with the existing study as the starting point.

Basic concept of what is treated as waste (provisional)

① Removed items
Above the fuel loading position (shroud head - shield plug) and external structure of the pedestal

② Other waste
Waste that retains its original form and is not likely to have criticality

Waste information is identified from the study results of related Pjs and consolidated.

Consolidation of waste information (processed based on the FY2018 Final Report)

Waste classification	Generated waste	Estimated generation volume (Per reactor)	Estimated dose
Removed items (Core internals, etc.)	Shield plug and PCV head RPV insulating material and RPV head Steam dryer and separator Etc.	・Top access debris retrieval: 670 t ・Side access debris retrieval: 67 t	3.4E+12 -1E+16 Bq/t
Retrieval equipment	Drills, manipulator, camera, etc.	TBD (Depends on the retrieval method)	–
Air-conditioning and water treatment system waste	HEPA filter and water treatment filter Waste adsorbent Etc.	–	–

Needs to be updated along with the progress of study of related projects

In this subsidy project, the waste information is updated based on the report on the latest techniques.

Examples of other prerequisites (temporarily set based on the current waste handling information from 1F site)

① Requirements for transfer inside the premises
・Surface dose of transport cask　30 mSv/h or less
　・・・Set with reference to the current waste transfer within 1F[#] site premises
・Transport cask should be a sealed type cask
　・・・From the viewpoint of preventing the spread of α contamination

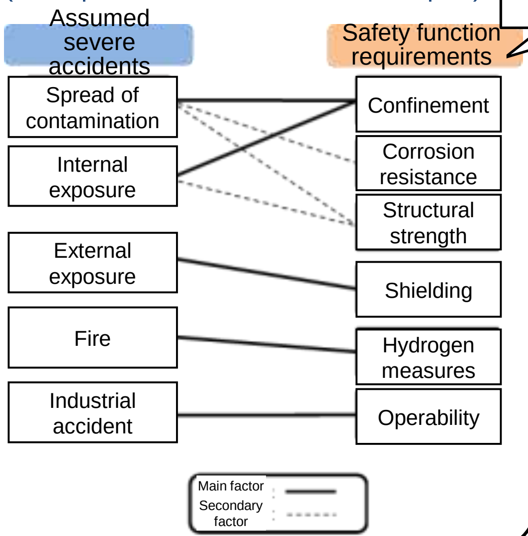
②Requirements for receiving water at the storage vault
・Surface dose of storage container　10 Sv/h or less
　・・・Set with reference to the operation of the solid waste storage building No. 9
・Storage container weight (including shield and contents) 7.5 tons or less
　・・・Set with reference to the operation of the solid waste storage building No. 9

(# In the following slides, “1F" refers to "Fukushima Daiichi Nuclear Power Station“.)

<Results of studies so far ② Study on safety functions / hydrogen measures>

Study on safety functions

(Excerpts from the FY2018 Final Report)



Assumed severe accidents

Safety function requirements

- Spread of contamination
- Internal exposure
- External exposure
- Fire
- Industrial accident

- Confinement
- Corrosion resistance
- Structural strength
- Shielding
- Hydrogen measures
- Operability

Main factor	———
Secondary factor	- - - -

Safety functions are studied based on the prerequisites.

Identification of the main issues

・Prevention of nuclide dispersion (ensuring **sealability**)

These are conflicting safety function requirements. Measures to make these requirements compatible are required.

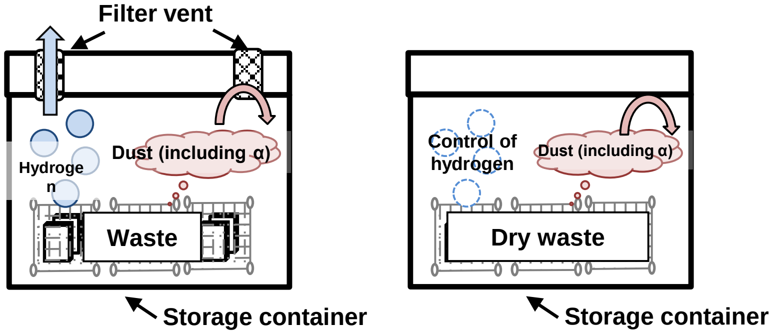
・Release of hydrogen gas (ensuring **permeability**)

Investigation on the cases of storing high-level radioactive wastes within Japan and overseas (processed based on the FY2018 Final Report)

Storage method	Hydrogen measures	Examples of main application	Issues while applying
Dry type / Without vent	Dry + sealed storage container	・Zion (USA)	・Development of drying technology ・Scale of drying equipment and drying time
Dry type / With vent#	Exhaust through filter vent	・TMI-2 (USA)	・Development of suitable filter vent
Wet type / Without vent	Full of water + open storage container	・Shroud replacement work, etc. (within Japan)	・Contamination of the pool ・Requires securing the pool and a water treatment system
Wet type / With vent	Vent pipe / Compensator	・Paks-2 (Hungary)	・Development of vent pipe ・Securing the pool

Focusing on dry storage that does not require the securing and management of pools, and based on the results of overseas case studies on filter vents, the "dry type / without vent" and "dry type / with vent" storage methods were selected as candidates.

Illustration of storage method (left: dry type/ with vent, right: dry type / without vent)



When transporting inside the premises, it is over-packed with sealed transport casks and the amount of hydrogen generation is time controlled.

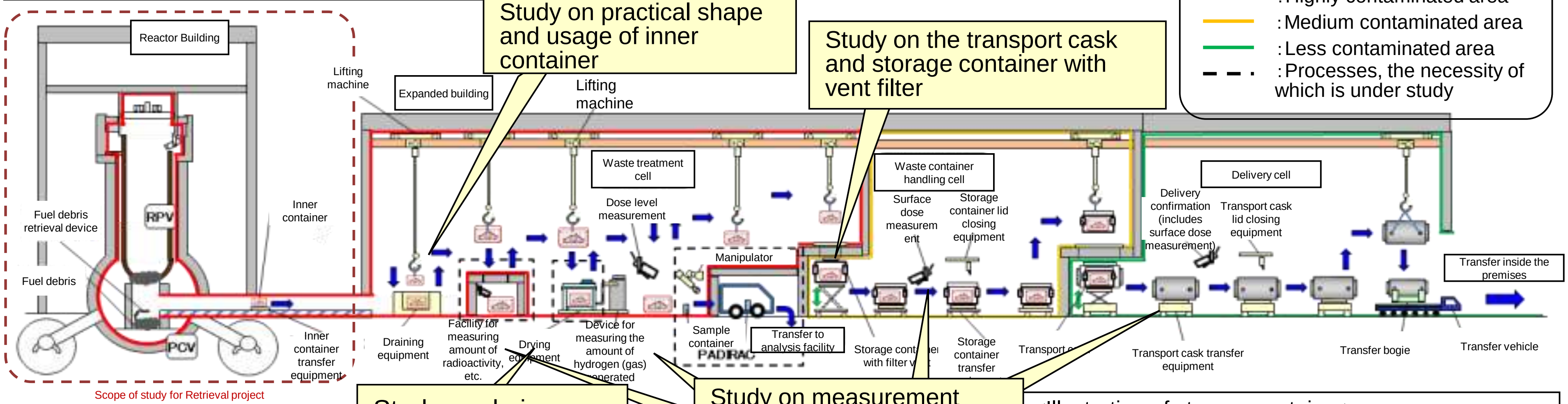
In this subsidy project, the specifics of the concept of filter vent system and drying methods suitable for fuel debris retrieval waste will be studied.

<Results of studies so far ③ Study on collection, transfer and storage flow>

Collection, transfer and storage flow of waste generated by fuel debris retrieval (Example of implementing hydrogen measures using a container with a vent filter in side-access retrieval method PLAN-B)

(Studied based on the FY2018 Final Report)

Retrieval - Storage in container - delivery - transfer inside premises



Study on practical shape and usage of inner container

Study on the transport cask and storage container with vent filter

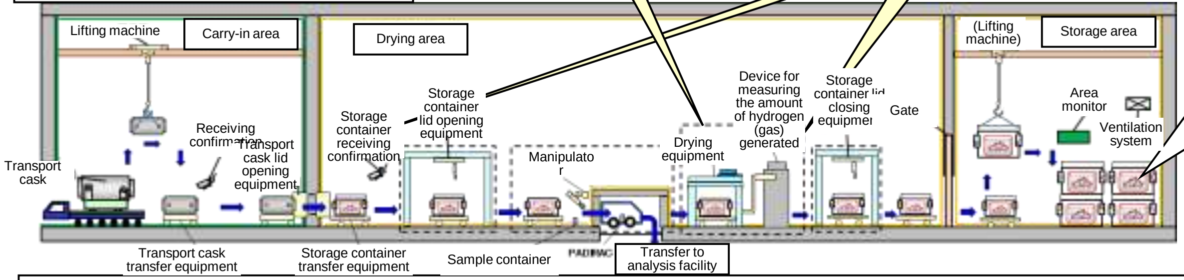
Study on drying treatment

Study on measurement items and measurement methods

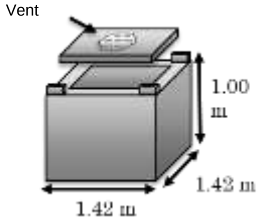
Legend

🟥 : Highly contaminated area
🟨 : Medium contaminated area
🟩 : Less contaminated area
- - : Processes, the necessity of which is under study

Receiving at the storage vault - treatment - storage



<Illustration of storage container>



・4 levels (0, 60, 140, 180 mm) of shielding are used based on the dosage of the waste.
・Maximum weight 7.1 ton
・Estimated number of containers
Approx. 2000 units (for 3 reactors)

<Concept>
●To use a storage container with a vent filter as a hydrogen measure during storage.
●For transportation inside the premises, a sealed transport cask is used to prevent the spread of α-contamination. Hydrogen concentration is controlled by means of time management during transfer.
● To prevent the spread of contamination and reduce work exposure, the areas are classified into three or more areas (red, yellow, green) based on the level of contamination.

In this subsidy project, the conceptual study of major equipment and facilities will be carried out, and the process flow will be updated to reflect the study results.

(a) Study and evaluation of storage and management methods

Table 1 (a) FY2019 and FY2020 (planned) results on the study and evaluation of storage and management methods

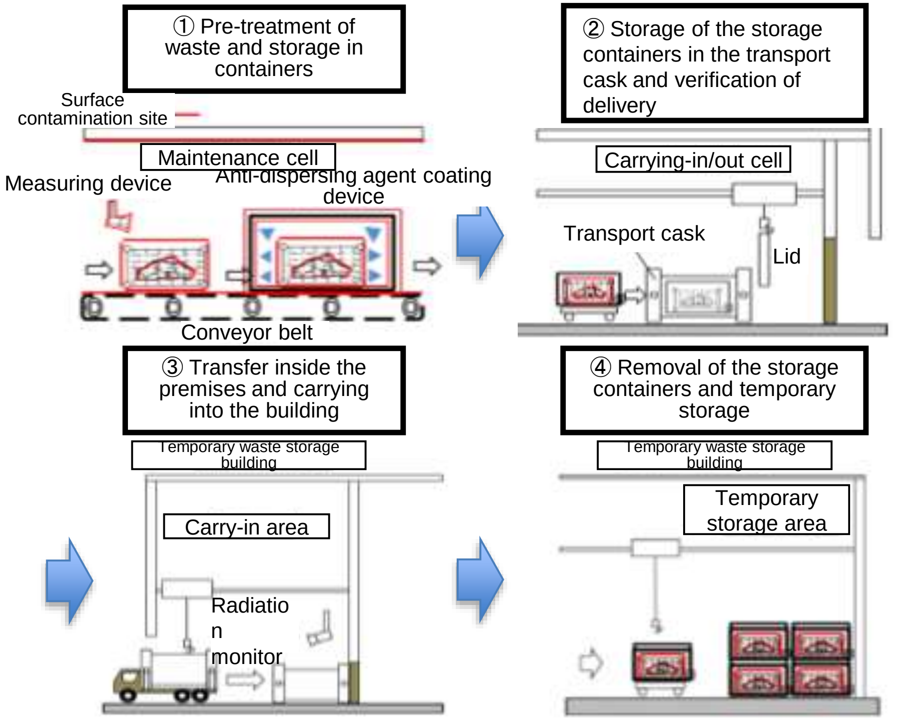
Items		FY2019 Results	FY2020 Results (planned)
① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste	Investigation and evaluation of waste information	The latest information such as the type and quantity of high-level radioactive waste was consolidated based on the status of study of fuel debris retrieval methods.	(Will be reviewed if necessary)
	Study on the scenarios	The possible scenarios (collection, transfer and storage flow) related to the handling process of high-level radioactive waste were presented.	The feasibility of multiple scenarios pertaining to the process of handling high-level radioactive waste will be presented.
② Study on container and storage facility requirements	Study on the shape and usage of inner container*	Practical inner container dimensions and operation methods were presented.	(Will be reviewed if necessary)
	Study on gas generation measures	Filter vent application results were investigated, and the concepts of filter vent, storage container, transport cask were presented.	The requirements for filter vent, storage container, transport cask will be presented.
	Study on drying treatment	The existing drying treatment technologies were investigated, and the primary draft on drying treatment equipment requirements was presented.	Equipment requirements for drying treatment, etc. will be presented.
	Study on measurement methods and measurement equipment	The measurement requirements were organized, and the measurement items were listed based on them.	Measurement method (measurement items, measurement location, measurement time, etc.) and the measurement equipment draft will be presented.

* Inner container: A container for collecting waste from the reactor. To be handled by the retrieval robot and stored in the storage container.

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste (Overview)

- Results up to FY2018
  - Methods for safely collecting, transferring, and storing high-level radioactive waste (core internals) generated during fuel debris retrieval were studied, and the collection, transfer and storage flow until storage was proposed.
  - Based on the proposed collection, transfer and storage flow, the functions required for the storage container were organized, and storage container candidates that satisfy the required functions were listed.
- Goals
  - To list down multiple possible scenarios for the handling process of high-level radioactive waste based on the latest waste information.
- Implementation details
  - In FY2019, the latest information such as the type and quantity of high-level radioactive waste was consolidated based on the status of study of fuel debris retrieval methods. Also, multiple possible scenarios for the handling process of representative high-level radioactive waste were studied.
  - In FY2020, the latest information such as the type and quantity of high-level radioactive waste will continue to be consolidated based on the status of study on fuel debris retrieval methods, and based on that information, the handling process up to the storage of high-level radioactive waste will be studied. Moreover, the effects on throughput, storage capacity, etc. with respect to the multiple scenarios studied will be evaluated and their feasibility will be confirmed.
- Indicators to determine goal achievement
  - (FY2019) Latest information such as the type and quantity of high-level radioactive waste should be listed. The multiple possible scenarios for the handling process of representative high-level radioactive waste should be listed.
  - (FY2020) The latest information such as the type and quantity of high-level radioactive waste should be listed, and based on that information, the handling process up to storage should be presented. The feasibility of the multiple scenarios presented should be listed.



① Pre-treatment of waste and storage in containers

② Storage of the storage containers in the transport cask and verification of delivery

③ Transfer inside the premises and carrying into the building

④ Removal of the storage containers and temporary storage

Fig. 1 Example of collection, transfer and storage flow for high-level radioactive waste (Overview)

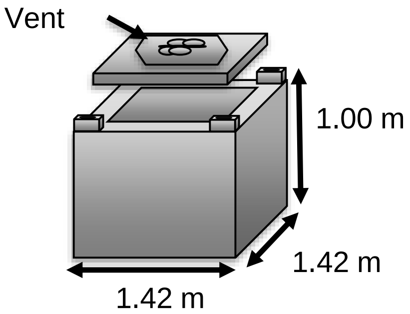


Fig. 2 Illustration of the external appearance of waste storage container (proposed for light weight container#)

The dimensions are temporarily set such that the current limit of the 1F waste container weight is not exceeded when shielding and waste weight are included.

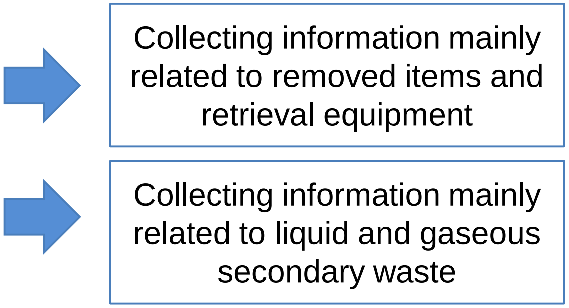
① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Investigation and evaluation of waste information (1/3)

< Investigation and evaluation of waste information>

● Reports from related Pjs investigated

- ･Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budgets Project for the Development of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures
- ･Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budgets Project for Advancement of Retrieval Method and System of Fuel Debris



Collecting information mainly related to removed items and retrieval equipment

Collecting information mainly related to liquid and gaseous secondary waste

● Investigation items

- ･Waste classification (removed items / consumables for retrieval equipment / liquid / gaseous)
- ･Name of equipment and waste
- ･Waste properties (material / shape)
- ･ Amount generated
- ･ Dose, etc.

● Main items updated based on the investigation

- ･Organizing the estimated amount of removed items for each method
- ･Shape of removed item after cutting
- ･Specification of waste names for retrieval equipment (identification of equipment that will become waste)
- ･Specification of waste names for liquid-/ gaseous secondary waste
- ･Amount of liquid secondary waste (partial) generated

● Evaluation items

- ･ Rate of generation of hydrogen from the removed items

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Investigation and evaluation of waste information (2/3)

Organizing the information on the waste generated during debris retrieval

Common preconditions for the studies mentioned from the next page onwards

Table 1 Overview of results of organizing information on waste generated during fuel debris retrieval[#1]

Important updates are shown in red.

Classification of generated waste		Main waste generated	Estimated dose	Method of generation	Shape of the waste[#2]	Estimated generation amount[#3] (Per reactor)
Removed items	**Items removed from floor**	Items removed from 1F L	–	Side-access retrieval	□260 mm to □500 mm / plate	1 ton (PLAN - C) 24 ton (PLAN - A, B)
	Items removed from containment vessel / pressure vessel	Shield plug DS slot plug	4 Sv/h	Top-access retrieval	□1800 mm × thickness 306 mm / plate	91 ton (Route A) 792 ton (Route B)
		PCV head / RPV heat insulating material RPV head / steam dryer Separator	4 to 400 Sv/ h	Top-access retrieval	・□108 mm to □500 mm / plate ・Φ150 mm / cylinder	
		Pedestal externals	–	Side-access retrieval	・□108 mm to □500 mm / plate ・Φ150 mm / cylinder	38 ton (PLAN - A) 157 ton (PLAN - B, C)
Retrieval equipment		Pit / cutter Wire / grip claw Cable / sealing material	–	Top-access retrieval, Side-access retrieval	–	–
Liquid secondary waste		Filter material of the filter / packing	–	Top-access retrieval, Side-access retrieval	–	–
Gaseous secondary waste		Filter material of the filter / packing	–	Top-access retrieval, Side-access retrieval	–	–

#1 Corresponds to "waste generated during fuel debris retrieval" in the waste stream classification.

#2 "□260mm to □500mm" refers to squares with lengths/widths from 260 × 260 mm to 500 ×500 mm. "Φ150 mm" refers to "a circle with a diameter of 150 mm".

#3 Route A, B method is debris top-access retrieval method, PLAN-A, B, C method is debris side-access retrieval method (Refer to the FY2018 Final report of the Project on Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures)

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Investigation and evaluation of waste information (3/3)

Evaluating hydrogen generation rate for representative waste

➡ (a) ② Used as input conditions for gas generation measures#

In FY2019, "(a) ② Gas generation measures" were studied based on the results of this evaluation.
Based on the study results, the evaluation model will be reviewed in FY2020 as necessary.

Table 1 Estimated hydrogen generation rate (Shows the maximum value of metal / concrete waste from top-access retrieval / side-access retrieval method)

Items		Top-access retrieval metal waste	Top-access retrieval concrete waste	Side-access retrieval metal waste	Side-access retrieval concrete waste
Dose (Bq/t)	Cs-137	1.90E+15	3.40E+12	3.40E+12	3.40E+12
Storage capacity per storage container (t)		0.6	2.08	1.3	2.08
Source (Bq)	Cs-137	1.1E+15	7.1E+12	4.4E+12	7.1E+12
Energy emitted (MeV/s)		1.3E+15	7.9E+12	4.9E+12	7.9E+12
Hydrogen generation rate (m^3/d)		1.8E-02	1.1E-04	7.1E-05	1.1E-04
<Reference> Anticipated waste		Dryer	Shield Plug	Removed items from outside the pedestal	Removed items from outside the pedestal

<Reference> Evaluation conditions (set with reference to the results of hydrogen generation measures in FY2017 -

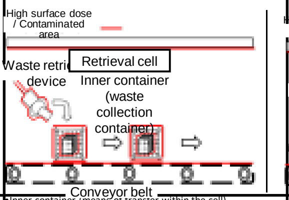
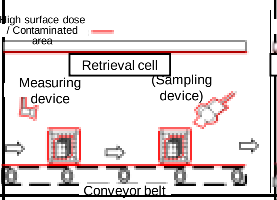
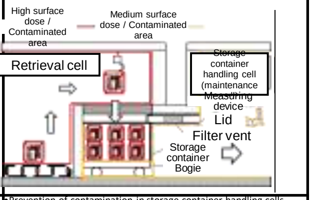
Calculation parameters	Set value
Evaluation formula	Hydrogen generation rate = $\sum_{i, j}$ (Decay heat of nuclide$_i$ x G value of ray type$_j$ x absorption efficiency of ray type$_j$) Decay heat of nuclide$_i$ = $\sum_j$ (Inventory of nuclide$_i$ × emission rate of ray type$_j$ × emission energy of ray type$_j$)
G value (β, γ rays)	0.45 (Set with reference to the results of FY2018 hydrogen generation measures)
Absorption efficiency	1.0 (Set to the most conservative value)
Energy released per disintegration of Cs-137	1.11 MeV (= 0.662 × 0.851 + 0.514 × 0.944 + 1.176 × 0.056) [Probability of occurrence per disintegration of γ and β rays × energy. Energy of β rays calculated at the maximum value (conservative)]

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Study on the scenarios (1/3)

‣ Based on the study results, the collection, transfer and storage flow was updated.
‣ It was confirmed that significant changes were not required in the updating of the collection, transfer and storage flow.

Work	1. Filling the waste inside the inner container and transferring it within the cell	2. Various measurements	3. Storing the inner container inside the storage container and closing its lid
Workflow			
Specifications	•Inner container (means of transfer within the cell) •No shielding (The inner container is usually handled through remote operations) • Study on a practical shape for the inner container, taking into consideration its contact with the retrieval equipment, storage efficiency in storage containers with multiple shielding thicknesses, etc. •Estimated number of containers (For 1 unit by means of the top-access retrieval Route B method) ① In the case of a □ inner container with dimensions 500 mm × 300 mm -> 10016 containers ② In the case of a □ inner container with dimensions 335 mm × 272 mm -> 27216 containers ③ In the case of a □ inner container with dimensions 450 mm × 272 mm -> 14612 containers ④ In the case of a □ inner container with dimensions 535 mm × 272 mm -> 10180 containers •Conveyor belt (example of means of transfer within the cell) •To improve throughput and simplify remote operations, a conveyor belt is used for transfer inside the retrieval cell. •The dimensions, appearance, surface condition, and materials are checked using a camera during retrieval. •Some large sized removed items may not be stored in an inner container and may be delivered from inside the PCV. •Some large sized removed items may be cut to match the size of the inner container and stored in the inner container.	•Various measurements (detailed study in progress) •Measured while stored in inner container •Candidates for measurement •Weight •Surface dose rate •Candidates for estimation •Amount of radioactivity (γ) •Amount of radioactivity (α and β) •Amount of nuclear material •Amount of heat generated •Hydrogen generation rate •Implementation of sampling (detailed study in progress) •The waste is sampled and transferred to the analytical facility, as needed. •Sub-process Example) If the measurement values exceed the standard values -> 2.a Change the number of inner containers stored inside each storage container -> 2.b Repack removed items	•Prevention of contamination in storage container handling cells •The double door system or other equivalent substitute between the retrieval cell and the storage container handling cell controls the contamination in the storage container handling cell. •Specification of storage container •Has shielding function (multiple shielding thicknesses depending on the contents: 0, 60, 140, 180) •Has filter vent function •Can be transferred to the transport cask through remote operations •Lid can be closed through remote operations •Considers corrosion during storage •Considering transportation by an unmanned forklift in the storage vault, the dimensions are set so that the weight of the container after storage does not exceed the current unmanned forklift weight limit. (Provisional outer diameter: 1.4 m x 1.4 m x 1.0 m) •Some large removed items may be cut to the size of the storage container and stored directly in the storage container. •The transfer of waste container inside the storage container handling cell is done using cranes, bogie or conveyor belt. •Various measurements of the storage container are taken if necessary. Example) Surface dose measurement, surface contamination •Sub-process Example) When a problem with lid closing arises -> (3.a Close the lid once again) Example) When surface contamination exceeds the receivable dose in the storage vault (3.b Decontaminate)

		Safety functions	Equipment and facilities		Safety functions	Equipment and facilities		Safety functions	Equipment and facilities	
			Inner container	Handling cell / Maintenance cell		Inner container	Maintenance cell		Storage container	Maintenance cell / Carrying-in / out cell
Major events	Spread of contamination / Internal exposure	Confinement	-	• Maintains the confinement function • Manages the exhausts using HEPA filter	Confinement	-	• Maintains the confinement function • Manages the exhausts using HEPA filter	Confinement	• Confinement of fine particles using filter vent	• Maintains the confinement function • Manages the exhausts using HEPA filter
	External exposure	Shielding	-	• Has a shielding function using thick shielding	Shielding	-	• Has a shielding function using thick shielding	Shielding	• Multiple thicknesses of shielding depending on the contents	-
	Fire	Hydrogen measures	• The top portion is always open.	• Ventilates	Hydrogen measures	-	• Ventilates	Hydrogen measures	• Has the filter vent function	• Ventilates
	Industrial accident	Operability	• Has operability to enable easy and safe handling	-	Operability	• Has operability to enable easy and safe handling	-	Operability	• Has operability to enable easy and safe handling	-

Issues	• Study on the practical shape of inner container	• Study on the various types of measurements of the inner container • Study on the sampling methods	•Storage in containers using remote operations •Closing of lid using remote operations •Prevention of spread of contamination in storage container handling cell using double door system •Development of filter vent •Study on various measurements

Fig. 1 Updated collection, transfer and storage flow (partial excerpt)

Table 1 Main locations of update and update details

Main update items	Update details
Waste information	‣ It was confirmed that there were no issues in the flow of the updated waste information.
Inner container	‣ Updated to store multiple inner containers inside the storage container ‣ The number of storage containers required was organized based on the shape of the inner container
Study on measurement methods	‣ A primary draft on the confirmation items and measurement items was added to each process.

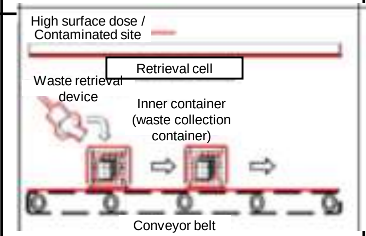
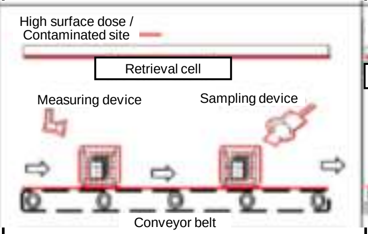
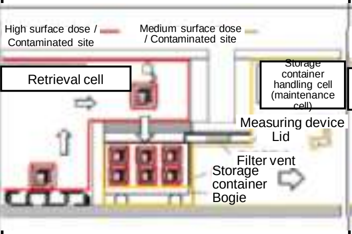
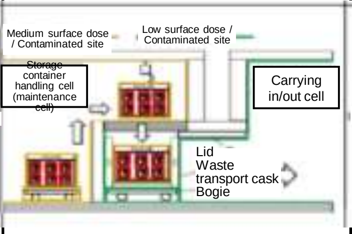
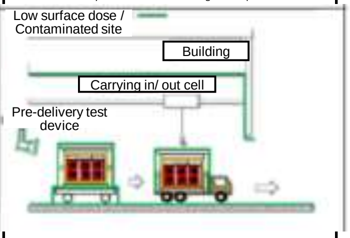
For the filter vent, storage container, transport cask, and drying equipment, the study results are planned to be reflected in FY2020.

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Study on the scenarios (2/3)

Updated collection, transfer and storage flow (1/2)

Work	1. Filling the waste inside the inner container and transferring it within the cell	2. Various measurements	3. Storing the inner container inside the storage container and closing its lid	4. Storing the storage container inside the transport cask and closing its lid	5. Delivery confirmation and loading of transport cask
Workflow					
Specifications	•Inner container (means of transfer within the cell) •No shielding (The inner container is usually handled through remote operations) • Study on a practical shape for the inner container, taking into consideration its contact with the retrieval equipment, storage efficiency in storage containers with multiple shielding thicknesses, etc. •Estimated number of containers (For 1 unit by means of the top-access retrieval Route B method) ① In the case of a □ inner container with dimensions 500 mm × 300 mm -> 10016 containers ② In the case of a □ inner container with dimensions 335 mm × 272 mm -> 27216 containers ③ In the case of a □ inner container with dimensions 450 mm × 272 mm -> 14612 containers ④ In the case of a □ inner container with dimensions 535 mm × 272 mm -> 10180 containers •Conveyor belt (example of means of transfer within the cell) •To improve throughput and simplify remote operations, a conveyor belt is used for transfer inside the retrieval cell. •The dimensions, appearance, surface condition, and materials are checked using a camera during retrieval. •Some large sized removed items may not be stored in an inner container and may be delivered from inside the PCV. •Some large sized removed items may be cut to match the size of the inner container and stored in the inner container.	•Various measurements (detailed study in progress) •Measured while stored in inner container •Candidates for measurement •Weight •Surface dose rate •Candidates for estimation •Amount of radioactivity (γ) •Amount of radioactivity (α and β) •Amount of nuclear material •Amount of heat generated •Hydrogen generation rate •Implementation of sampling (detailed study in progress) •The waste is sampled and transferred to the analytical facility, as needed. •Sub-process Example) If the measurement values exceed the standard values -> 2.a Change the number of inner containers stored inside each storage container -> 2.b Repack removed items	•Prevention of contamination in storage container handling cells •The double door system or other equivalent substitute between the retrieval cell and the storage container handling cell controls the contamination in the storage container handling cell. •Specification of storage container •Has shielding function (multiple shielding thicknesses depending on the contents: 0, 60, 140, 180) •Has filter vent function •Can be transferred to the transport cask through remote operations •Lid can be closed through remote operations •Considers corrosion during storage •Considering transportation by an unmanned forklift in the storage vault, the dimensions are set so that the weight of the container after storage does not exceed the current unmanned forklift weight limit. (Provisional outer diameter: 1.4 m x 1.4 m x 1.0 m) •Some large removed items may be cut to the size of the storage container and stored directly in the storage container. •The transfer of waste container inside the storage container handling cell is done using cranes, bogie or conveyor belt. •Various measurements of the storage container are taken if necessary. Example) Surface dose measurement, surface contamination •Sub-process Example) When a problem with lid closing arises -> (3.a Close the lid once again) Example) When surface contamination exceeds the receivable dose in the storage vault (3.b Decontaminate)	•Prevention of spread of contamination in storage container handling cell • A double door system or equivalent substitute between the retrieval cell and the storage container handling cell controls the contamination in the storage container handling cell. •Specification of transport cask • Has shielding function • Has confinement function • The storage container can be stored through remote operations. • The lid can be closed through remote operations. • Has a structural strength that prevents the contents from spilling out even if the container tumbles during transfer • Has a spatial volume that maintains the hydrogen concentration below the lower explosive limit • Make it a returnable container method where it can be used repeatedly. • The waste containers are transported within the carrying-in/out cell by means of cranes, bogie or conveyor belt. • Some of the large removed items may be stored directly in special containers.	• Delivery confirmation • Delivery confirmation (surface contamination confirmation, surface dose rate confirmation, seal check, external appearance confirmation (including ID confirmation)) of the storage container is required before transportation. • Surface dose measuring device (detailed study under progress) • Measuring the surface dose and determining the method for transfer within the premises • Transferring of waste within the 1F premises (at present) • Surface dose rate > 30 mSv/h: Remote (unmanned) transfer • Surface dose rate < 30 mSv/h: Manned truck transfer • Sub-process Example) When there is a problem with closing the lid -> (5.a Close the lid once again) Example) When surface contamination exceeds the standard transfer dose rate (5.b Decontaminate)

Major events – 1. Filling the waste inside the inner container and transferring it within the cell

Major events	Safety functions	Equipment and facilities	
		Inner container	Handling cell / Maintenance cell
Spread of contamination / Internal exposure	Confinement	-	• Maintains the confinement function • Manages the exhausts using HEPA filter
External exposure	Shielding	-	• Has a shielding function using thick shielding
Fire	Hydrogen measures	• The top portion is always open.	• Ventilates
Industrial accident	Operability	• Has operability to enable easy and safe handling	-

Major events	Safety functions	Equipment and facilities	
		Inner container	Maintenance cell
Spread of contamination / Internal exposure	Confinement	-	• Maintains the confinement function • Manages the exhausts using HEPA filter
External exposure	Shielding	-	• Has a shielding function using thick shielding
Fire	Hydrogen measures	-	• Ventilates
Industrial accident	Operability	• Has operability to enable easy and safe handling	-

Major events	Safety functions	Equipment and facilities	
		Storage container	Maintenance cell / Carrying-in / out cell
Spread of contamination / Internal exposure	Confinement	• Confinement of fine particles using filter vent	• Maintains the confinement function • Manages the exhausts using HEPA filter
External exposure	Shielding	• Multiple thicknesses of shielding depending on the contents	-
Fire	Hydrogen measures	• Has the filter vent function	• Ventilates
Industrial accident	Operability	• Has operability to enable easy and safe handling	-

Major events	Safety functions	Equipment and facilities		
		Storage container	Carrying-in/out cell	Transport cask
Spread of contamination / Internal exposure	Confinement	• Confinement of fine particles using filter vent	• Maintains the confinement function • Manages the exhausts using HEPA filter	• Has sealing function
External exposure	Shielding	• Multiple thicknesses of shielding depending on the contents	-	• Maintains shielding function using thick shielding
Fire	Hydrogen measures	• Has the filter vent function	• Ventilates	• Performs time management to prevent the hydrogen concentration from exceeding the explosion limit
Industrial accident	Operability	• Has operability to enable easy and safe handling	-	• Has operability to enable easy and safe handling

Major events	Safety functions	Equipment and facilities		
		Storage container	Carrying-in/out cell	Transport cask
Spread of contamination / Internal exposure	Confinement	• Confinement of fine particles using filter vent	-	• Has sealing function
External exposure	Shielding	• Multiple thicknesses of shielding depending on the contents	-	• Maintains shielding function using thick shielding
Fire	Hydrogen measures	• Has the filter vent function	• Ventilates	• Performs time management to prevent the hydrogen concentration from exceeding the explosion limit
Industrial accident	Operability	• Has operability to enable easy and safe handling	-	• Has operability to enable easy and safe handling

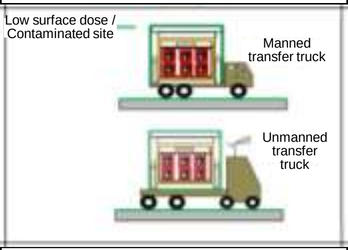
Issues	1.	2.	3.	4.	5.
Issues	• Study on the practical shape of inner container	• Study on the various types of measurements of the inner container • Study on the sampling methods	•Storage in containers using remote operations •Closing of lid using remote operations •Prevention of spread of contamination in storage container handling cell using double door system •Development of filter vent •Study on various measurements	• Storage of containers using remote operations • Closing of lid using remote operations • Prevention of spread of contamination in storage container handling cell by means of double door system	• Study on the delivery test items • Reduction of exposure while loading in transfer truck • Confirmation of sealing performance

(a) Study and evaluation of storage and management methods

① Investigation and evaluation of waste information and study on the storage methods of high-level radioactive waste

Study on the scenarios (3/3)

Updated collection, transfer and storage flow (2/2)

<table>
<tr><td colspan="2">Work</td><td colspan="4">6. Transfer within the premises</td><td colspan="4">7. Acceptance test of transport cask and carrying-in inside the storage building</td><td colspan="3">8. Removing the lid of transport cask and carrying-in of storage container</td><td colspan="3">9. Drying treatment</td><td colspan="3">10. Temporary storage</td></tr>
<tr><td colspan="2">Workflow</td>
<td colspan="4">
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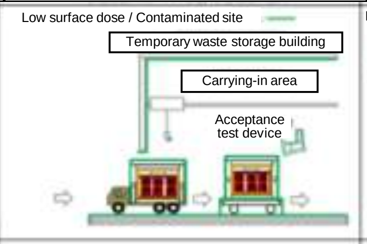
<td colspan="4">
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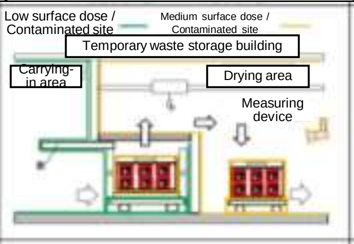
<td colspan="3">
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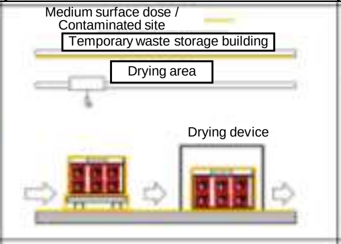
<td colspan="3">
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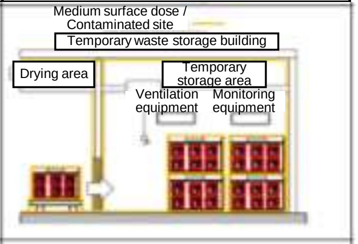
<td colspan="3">
</td></tr>
<tr><td colspan="2">Specifications</td>
<td colspan="4">• Transfer within the premises
• The transport cask has a fall prevention function and structural strength that prevents the contents of the waste container from being spilled if it falls.
• Transfer vehicle
• The storage container has a fall prevention function.
• It has a shielding function.</td>
<td colspan="4">• Acceptance test
• Carrying out measurements to check whether or not the transport cask meets the acceptance criteria of the storage building

• It is assumed that the acceptable dose limit of the storage vault is tentatively equivalent to that in basement 2nd floor of the solid waste storage building No.9.
• Acceptable dose limit of solid waste storage building No.9
• Surface dose < 30m Sv / h: basement 1st floor
• Surface dose < 10 mSv / h: basement 2nd floor</td>
<td colspan="3">• Prevention of contamination in carrying-in area
• Contamination in carrying-in area is controlled by means of the double door system between the carrying-in area and the drying area
• Carrying-in of storage container
• Removal of transport cask lid using remote operations
• Carrying-in of storage container using remote operations

• The transfer of storage container within the drying area is done using cranes, bogie, conveyor belt or unmanned forklift.

• Various measurements of the storage container are taken as necessary.</td>
<td colspan="3">• Drying treatment

• Moisture is removed to reduce corrosion during storage.</td>
<td colspan="3">• Hydrogen measures
• Prevents the increase in hydrogen concentration by means of ventilation in the temporary storage building or through the hydrogen treatment facility

• Monitoring
• Hydrogen concentration, radiation, etc., are monitored.

• Estimated total required storage floor area (per unit by means of the top-access retrieval Route B method)
① In the case of a □ inner container with dimensions 500 mm × 300 mm -> 2100 m^2
② In the case of a □ inner container with dimensions 335 mm × 272 mm -> 1200 m^2
③ In the case of a □ inner container with dimensions 450 mm × 272 mm -> 1300 m^2
④ In the case of a □ inner container with dimensions 535 mm × 272 mm -> 1400 m^2</td></tr>
<tr><td colspan="2" rowspan="2"></td><td rowspan="2">Safety functions</td><td colspan="3">Equipment and facilities</td><td rowspan="2">Safety functions</td><td colspan="3">Equipment and facilities</td><td rowspan="2">Safety functions</td><td colspan="2">Equipment and facilities</td><td rowspan="2">Safety functions</td><td colspan="2">Equipment and facilities</td><td rowspan="2">Safety functions</td><td colspan="2">Equipment and facilities</td></tr>
<tr><td>Storage container</td><td>Transport cask</td><td>Transfer vehicle</td><td>Storage container</td><td>Transport cask</td><td>Transfer vehicle</td><td>Storage container</td><td>Temporary storage building</td><td>Storage container</td><td>Temporary storage building</td><td>Storage container</td><td>Temporary storage building</td></tr>
<tr><td rowspan="5">Major events</td><td rowspan="2">Spread of contamination / Internal exposure</td><td>Structural strength</td><td>-</td><td>• Has a structural strength that prevents transport container from getting damaged if it falls.</td><td>-</td><td>Structural strength</td><td>-</td><td>• Has a structural strength that prevents transport container from getting damaged if it falls.</td><td>-</td><td rowspan="2">Confinement</td><td rowspan="2">• Confinement of fine particles using filter vent</td><td rowspan="2">• Maintains the confinement function
• Manages the exhausts using HEPA filter</td><td rowspan="2">Confinement</td><td rowspan="2">• Confinement of fine particles using filter vent</td><td rowspan="2">• Maintains the confinement function
• Manages the exhausts using HEPA filter</td><td>Corrosion measures</td><td>• Shield thickness is set considering the corrosion margin.</td><td>-</td></tr>
<tr><td>Confinement</td><td>• Confines fine particles using filter vent</td><td>• Has sealing function</td><td>-</td><td>Confinement</td><td>• Confines fine particles using filter vent</td><td>• Has sealing function</td><td>-</td><td>Confinement</td><td rowspan="2">• Confinement of fine particles using filter vent</td><td rowspan="2">• Maintains the confinement function
• Manages the exhausts using HEPA filter</td></tr>
<tr><td>External exposure</td><td>Shielding</td><td>• Multiple thicknesses of shielding depending on the contents</td><td>• Maintains shielding performance using the shielding thickness</td><td>• Has a shielding function (unmanned transportation for high-dose items)</td><td>Shielding</td><td>• Multiple thicknesses of shielding depending on the contents</td><td>• Maintains shielding performance using the shielding thickness</td><td>• Has a shielding function (unmanned transportation for high-dose items)</td><td>Hydrogen measures</td><td>• Multiple thicknesses of shielding depending on the contents</td><td>• Maintains the shielding function though shielding thickness</td><td>Hydrogen measures</td><td>• Multiple thicknesses of shielding depending on the contents</td><td>• Maintains the shielding function though shielding thickness</td><td>Shielding</td></tr>
<tr><td>Fire</td><td>Hydrogen measures</td><td>• Has a filter vent function</td><td>• Performs time management to prevent the hydrogen concentration from exceeding the explosion limit</td><td>-</td><td>Hydrogen measures</td><td>• Has a filter vent function</td><td>• Performs time management to prevent the hydrogen concentration from exceeding the explosion limit</td><td>-</td><td>Operability</td><td>• Has the filter vent function</td><td>• Installation of exhaust or hydrogen treatment facility</td><td>Operability</td><td>• Has the filter vent function</td><td>• Installation of exhaust or hydrogen treatment facility</td><td>Hydrogen measures</td><td>• Multiple thicknesses of shielding depending on the contents</td><td>• Maintains the shielding function though shielding thickness</td></tr>
<tr><td>Industrial accident</td><td>Operability</td><td>• Has operability that enables easy and safe handling</td><td>• Has operability that enables easy and safe handling</td><td>• Has a fall prevention function.</td><td>Operability</td><td>• Has operability that enables easy and safe handling</td><td>• Has operability that enables easy and safe handling</td><td>• Has a fall prevention function.</td><td>Confinement</td><td>• Has operability that enables easy and safe handling</td><td>-</td><td>Confinement</td><td>• Has operability that enables easy and safe handling</td><td>-</td><td>Operability</td><td>• Has the filter vent function</td><td>• Installation of exhaust or hydrogen treatment facility</td></tr>
<tr><td colspan="2">Issues</td><td colspan="4">• Increase in the throughput of unmanned operations</td><td colspan="4">• Study on acceptance test items
• Methods for measurement management</td><td colspan="3">• Opening of lid using remote operations
• Retrieval of storage container using remote operations
• Prevention of contamination in carrying-in area by means of double door system
• Study on various measurements</td><td colspan="3">• Study on drying treatment</td><td colspan="3">• Study on long-term storage measures
• Study on monitoring</td></tr>
</table>

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Overview

- ■ Results
  - ○ Overseas hydrogen gas countermeasures for high-level radioactive waste were surveyed, and the hydrogen generation countermeasures, methods and concepts in each country were consolidated.
- ■ Goals
  - ○ To list down the requirements for containers and storage facilities required for collection, transfer, and storage of high-level radioactive waste.
- ■ Implementation details
  - ○ (FY2019) A practical inner container# that can be stored in a storage container with multiple shielding thicknesses depending on the dose level was studied. The concept of transport cask and storage container with filter vent suitable for countermeasures against gases generated by the waste generated during fuel debris retrieval was organized. The concept of facilities such as drying equipment, etc. suitable for measures against corrosion during storage of waste generated during fuel debris retrieval, and for measures against gas generation assuming that the waste will be sealed at the time of disposal, was organized. The measurement methods and the concept of measuring equipment considering their priority and applicability to the site, for the measurement items required for the storage in the storage building, were organized.
  - ○ (FY2020) Requirements of transport cask and storage container with filter vent suitable for countermeasures against gases generated by the waste generated during fuel debris retrieval will be studied. The requirements of facilities such as drying equipment, etc. suitable for measures against corrosion during storage of waste generated during fuel debris retrieval, and for measures against gas generation assuming that the waste will be sealed at the time of disposal, will be studied. Measurement methods, requirements of measuring equipment, measuring locations and measurement duration considering their priority and applicability to the site, for the measurement items required for the storage in storage building, will be studied.
- ■ Indicators for determining goal achievement
  - ○ (FY2019) A practical inner container that can cope up with multiple shielding thicknesses should be identified. The concepts of transport cask and storage container with filter vent should be presented. The concepts of equipment for drying treatment, etc. should be presented. Measurement methods and the concepts of measurement equipment should be presented.
  - ○ (FY2020) The requirements of transport cask and storage container with filter vent should be presented. The requirements of equipment for drying treatment, etc. should be presented. The measurement methods, requirements of measuring equipment, measuring locations and measurement duration should be presented.

Inner container: A container for collecting waste from the reactor. To be handled by the retrieval robot and stored in the storage container.

Fig. 1 Example of transport cask used for high-level radioactive waste
(B type transport cask, USA: TRUPACT- II)

Fig. 2 Remote controlled type filter vent attachment device (DVS: Drum Venting System) External appearance
(Used at the Waste Isolation Pilot Plant (WIPP) in Carlsbad)

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on efficient shape and usage of inner container (1/3)

<Background and Purpose>

● Background

Inner container ･･･ Primary container for storing the waste cut from inside PCV

Example of functions ･･･ ① Cut waste is stored.
② Water can be drained due to the mesh structure.
③ Can be efficiently stored in storage container.

Studies so far ･･･ In the flow studied until FY2018, it was tentatively assumed that one inner container will be stored in one storage container. (Fig. 1)

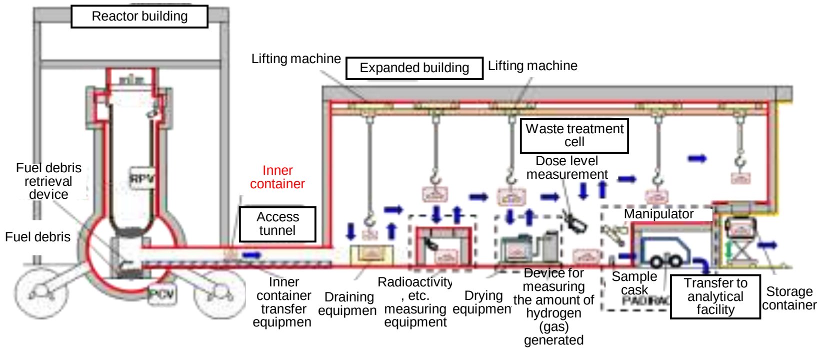


Fig. 1 Collection, transfer and storage flow
(Excerpts of only sections related to inner container)

● Issues

① As the storage container uses different inner lining shields depending on the amount of waste, it becomes necessary to use inner containers of different sizes.

② Also, the Retrieval project reported the dimensions of inner containers suitable for the equipment used in each retrieval method. (Table 1)
These values were smaller than last year's assumptions,
and it was assumed that multiple inner containers can be stored inside one storage container.

Table 1 Dimensions of inner containers used in each process of the Retrieval project

Method	Inner container dimensions (mm)
Side-access retrieval Plan A	—
Side-access retrieval Plan B	ϕ550×400 (ϕ390×400)
Side-access retrieval Plan C	ϕ400×810
Top-access retrieval Route A	ϕ400×400
Top-access retrieval Route B	□500×300

* "φ400" is a circle with diameter 400 mm, and "□500" is a square with length/width 500 mm.

● Purpose

To present a primary proposal for the shape and usage method of the inner container suitable for waste storage and management .

Evaluation from the viewpoint of storage and management

● Study procedure ･･･ As an evaluation index, the number of storage containers generated is compared.

① Estimate the number of storage containers generated based on the latest retrieval method.
② Study shapes of inner containers so as to efficiently reduce the number of storage containers generated.
③ Study usage methods so as to efficiently reduce the number of storage containers generated.
④ Based on the above studies, study efficient inner container shapes and usage methods.

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on efficient shape and usage of inner container (2/3)

【Confidential】

< Study Results ①: Study on the inner container dimensions>

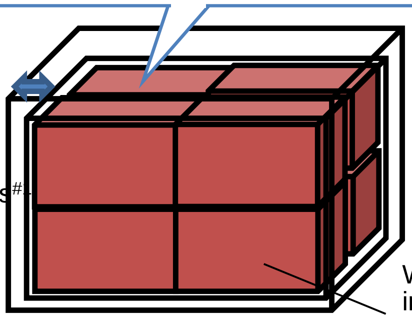
Case	Name of study case	Details of the study#	Required number of inner containers (containers / unit)	Required number of storage containers (containers / unit)
1	Provisional proposed method (An example of top-access retrieval Route B method)	When top-access retrieval Route B and the inner container for the latest retrieval method (☐500 x height 300 mm) are used.	10016	1425
2	<Study on the inner container dimensions>	Study on the cases wherein the length, width and height of the inner container are changed (Following are the examples of 3 patterns that minimize the required number of storage containers.) ① ☐335 x height 272 mm ② ☐450 x height 272 mm ③ ☐535 x height 272 mm	① 27216 ② 14612 ③ 10180	① 807 ② 867 ③ 956

With the assumed method, the storage efficiency is less and it requires a large number of storage containers.

Reduced by at most 43% by changing the dimensions.

The cask dimensions indicated refer to external dimensions. “☐500” indicates a square of 500 mm length and width.

Size of inner container
Provisional proposed method: ☐500 x height 300 mm
When the size of inner container is changed: ☐〇〇 mm x height XX mm



It can be filled up to 85% in the vertical direction considering a gap (25 mm).

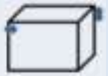
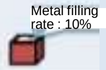
Container thickness (6.4 mm)
＋shielding thickness#1
＋ gap (25 mm)

Waste storage rate in the inner container
Metal waste: 10%
Concrete waste: 50%

#1: 4 types of 0, 60, 140,180 mm

Fig. 1 Illustration of the study on the provisional proposed method and the case when the size of inner container is changed

Table 1 (Reference) Method for calculating the number of storage containers and the number of inner containers

STEP	Calculation details	Calculation formula	Study image1	
①	Calculating the inner dimensions of the storage container	Inner length and width of storage container (m) = outer length and width of storage container – 2 x (thickness of shielding + thickness of storage container + gap) Inner height of storage container (m) = { outer height of storage container – 2 x (shielding thickness + storage container thickness) – gap } x 85%		The inner dimensions are calculated by subtracting the shielding thickness, container thickness, and gap from the outer dimension of the storage container (it is assumed that with the lid closed, the container can be used up to 85% in the direction of its height.)
②	Calculating the inner dimensions of the inner container	Case 1: Value obtained by subtracting the thickness of inner container from the inner dimensions of storage container Case 2, 4, 5: Value obtained by subtracting the thickness of inner container from the outer dimensions of the collection cask used in top-access retrieval method Route B Case 3: Decided based on the evaluation results where the dimensions of the inner container were used as parameters		Differs on a case-by-case basis, but basically the inner dimensions are obtained by subtracting the thickness of inner container (assumed to be 2 mm) from the outer dimensions of the inner container.
③	Calculating the number of inner containers stored inside each storage container	Along the length: inner length of storage container ÷ outer length of inner container = X (rounded-off) Along the width: inner width of storage container ÷ outer width of inner container = Y (same as above) Along the height: inner height of storage container ÷ outer height of inner container = Z (same as above) Number of inner containers stored inside one storage container = XYZ containers		The number of inner containers that can be stored along the length, width and height is calculated by dividing the inner dimensions of the storage container by the outer dimensions of the inner container.
④	Calculating the amount of waste that can be stored per inner container (m^3 / unit)	Amount of waste that can be stored per inner container (m^3 / unit) W = inner length of inner container (m) x inner width (m) x inner height (m) x waste filling rate (metal: 10%, concrete : 50%)		The amount of waste stored per inner container is calculated by multiplying the inner volume of the inner container by the filling rate for each material.
⑤	Calculating the amount of waste that can be stored per storage container (m^3 / unit)	Amount of waste that can be stored per storage container (m^3 / unit) = Amount stored inside the inner container W (m^3 / unit) x XYZ containers		The amount of waste stored per storage container is calculated from the number of inner containers that can be stored in a storage container and the amount of waste stored per inner container.
⑥	Amount of waste (m^3)	The value set for top-access retrieval method Route B is used.		-
⑦	Calculating the number of storage containers	⑥÷⑤		-
⑧	Calculating the number of inner containers	⑦ x ③		-

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on efficient shape and usage of inner container (3/3)

< Study results ②: Study on the usage method>

Case	Name of study case	Details of examination	Required number of inner containers (containers / unit)	Required number of storage containers (containers / unit)
1	<For comparison> Provisional proposed method (An example of top-access retrieval Route B method)	・When the inner containers for the top-access retrieval Route B and for the latest retrieval method (☐500 x height 300 mm) are used. ・No refilling	10016	1425
2	Case where refilling is done	･Waste is refilled into storage container. ･All of the inner containers are discarded. ･It is assumed that the waste inner containers are stored in a storage container with 0 mm shielding thickness and are discarded.	10016	1786
3	Case where waste is refilled and compressed	･It is assumed that the waste inner containers can be compressed up to 30% along the height under the same conditions as in Case 2.	10016	952
4	Case where refilling is done, and inner container is reused	・It is assumed that the waste container is returned to the PCV and reused 10 times under the same conditions as in Case 2.	1002	660

"☐500" indicates a square of 500 mm length and width.

The number of storage containers increases in the case where only refilling is done.

Compression or reuse depends on the method.

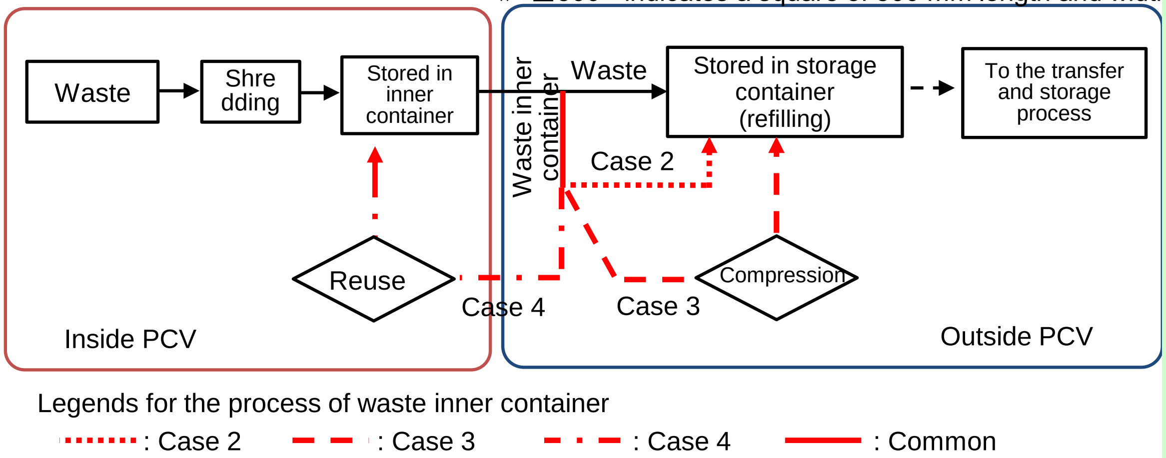


Fig. 1 Illustration of the study on the case where refilling is done (compression / reuse of inner container)

< Summary and considerations>

- As preconditions (such as the amount of waste per dose) are continually reviewed, quantitative comparisons of optimal dimensions and the number of storage containers generated are not considered to be very important.
- The following are the two important findings.

① The number of storage containers is likely to fluctuate greatly depending on the size of the inner containers, which has a large impact on storage. However, it is not practical to fix the inner container size at this point. Hence a design that can be changed flexibly to some extent is desirable.

② In cases where optimization of dimensions is difficult, it could be replaced from the usage perspective. However, the study on refilling equipment and reuse routes (return routes to PCV) becomes necessary and ensuring the traceability of waste also becomes necessary.

- Opinions were exchanged with the Retrieval project and the study results were recorded.

(a) Study and evaluation of storage and management methods
(b) ② Study on container and storage facility requirements
Study on measures against gas generation (1/3)

< Study results ③: Required number of filters and volume of void in transport cask>

When storing the storage container, the number of filters that need to be installed to keep the hydrogen concentration in the storage container below 4 vol% and the volume of void required at that time to keep the hydrogen concentration in the transport cask (sealed) below 4 vol% for 7 days, was evaluated.

Evaluation conditions

- The type of vent filter was tentatively selected from those that have a proven track record in the United States and that satisfy the hydrogen diffusion performance.
- It is known that the hydrogen diffusion performance of the vent filter depends on the temperature, and the lower the temperature, the lower the performance. Therefore, the temperature was corrected at 2℃, which is the minimum design temperature of the 1F solid waste storage vault.
- The maximum transfer period of waste inside the premises was 7 days (in accordance with the assumed conditions of the Canister project).

Table 1 Results of evaluating the required number of vent filters and the required volume of void in the transport cask

Assumed cases	**Metal waste top-access retrieval**	**Concrete waste top-access retrieval**	**Metal waste side-access retrieval**	**Concrete waste side-access retrieval**
Material	Metal	Concrete	Metal	Concrete
Hydrogen generation rate (m^3/d) (Restated)	1.8E-02	1.1E-04	7.1E-05	1.1E-04
① Minimum hydrogen release rate @ 4 vol% (mol/s/mol fraction)	2.3E-04	1.5E-06	9.2E-07	1.5E-06
Type of vent filter	NF016S	NF016L	NF016L	NF016L
② Hydrogen diffusion performance of vent filter (mol/s/mol fraction @ 2℃)	1.43E-04	3.22E-06	3.22E-06	3.22E-06
Minimum number of vent filters required	**2**	**1**	**1**	**1**
Volume of void in transport cask	**3.25m^3 or more**	**20L or more**	**10L or more**	**20L or more**

The hydrogen release rate required to maintain the hydrogen concentration in the storage container below 4 vol% is calculated using the following formula (based on concept used in the US) **(①)**

$$T_d = \frac{Q \times G}{N_A \times N \times X_{H2}}$$

T_d : Hydrogen release rate (mol/s/mol fraction)
Q : Decay heat (Joule/s)
G : G value (molecules/100 eV)
N_A : Avogadro constant (molecules/mol)
N : Conversion constant (Joule/eV)
X_{H2} : Hydrogen concentration inside the cask (4vol%)

The hydrogen diffusion performance (catalog value *) of the vent filter was temperature-corrected by the following formula (based on concept used in the US) **(②)**

$$T_{D,T} = T_{D,T_0} * \left(\frac{T}{T_0}\right)^{1.75}$$

$T_{D,T}$ = Hydrogen diffusion performance at temperature T
T_0 = Temperature at known hydrogen diffusion performance
* Test results at 21℃ (294K)

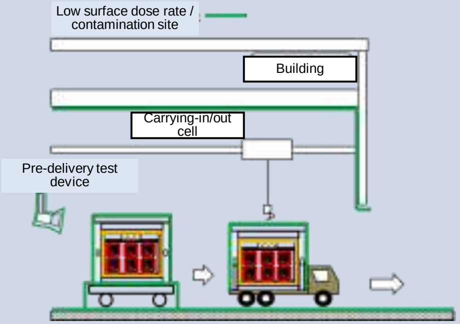
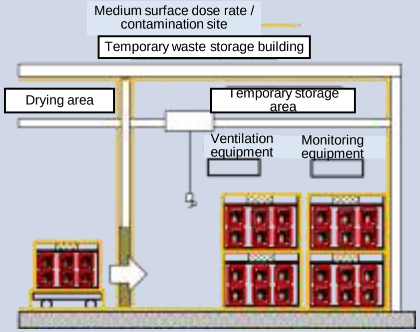
A number where ② > ①.

The volume of void required to keep the hydrogen concentration in the transport cask below 4 vol% for 7 days.

(a)Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on measures against gas generation (2/3)

< Filter events that need to be considered and their countermeasures (1/2) >

The filter events that need to be considered and their countermeasures were studied by referring to the process flow.

Work step	During transfer (including during transfer within the premises)	During temporary (long-term) storage
Illustration of the operation		
Filter events that need to be considered	(1) Clogging of the filter The contents rise during the transfer, clog the filter, which prevents the release of hydrogen. (2) Contamination due to scattering of contents Fine particles or gas components released from the filter contaminate the inside of the building and the inside of the transport cask.	(3) Corrosion and deterioration of the filter The filter corrodes or deteriorates due to long-term storage and does not satisfy the hydrogen diffusion performance anymore (the side where the opening narrows). Or the contents are more likely to scatter (the side where the opening widens). (4) Performance degradation due to filter condensation Moisture inside and outside the container condenses on the filter part, blocks the filter and the filter does not satisfy the hydrogen diffusion performance anymore.

(a)Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on measures against gas generation (3/3)

<Filter events that need to be considered and their countermeasures (2/2)>

Work step	During transfer	During temporary (long-term) storage
Proposed measures#	(1) Clogging of the filter •Install multiple filters (multiplexing) so that even if one clogs, hydrogen can be released through the others. •Make the mounting structure of the filter like a labyrinth so that the contents do not reach the filter directly. •As it is assumed that the filter gets clogged due to the contents flying during transportation, use a lid with a filter, which is exclusively used during transportation (during storage, replace it with a lid with a filter, which is exclusively used during storage). •Evaluate the effect on storage container in the event of an explosion at the expected hydrogen concentration (4 vol%). (2) Contamination due to scattering of contents •For fine particles, a particle collection efficiency equivalent to that of HEPA (99.97% particle collection rate for 0.3 μm particles) is required. •Gas components are taken care of with a ventilation system. •Set up areas classified (red, yellow, green) based on the assumed scattering from filters to control contamination. •Carry out surface contamination test (decontaminate if necessary) of the storage container before transferring inside the premises and before storage.	(3) Corrosion and deterioration of the filter •Select SUS316L or carbon composite materials that are corrosion-resistant in atmospheric environment for the filter media (sintered porous filter). •Check corrosion resistance with test pieces of the same material under the same conditions (or harsh conditions). (4) Performance degradation due to filter condensation •Control the temperature and humidity by means of the ventilation system of the storage facility to prevent condensation. •If the ventilation system of the storage facility stops functioning and condensation occurs, it is necessary to restore the ventilation system and eliminate condensation, before the hydrogen concentration in the storage container exceeds 4 vol%. Ensure that the hydrogen concentration inside the storage container does not exceed 4 vol% during the time that is required for restoring the ventilation system. If it exceeds (the time margin cannot be secured), ensure the functioning of the ventilation system at all times by multiplexing the ventilation system or by arranging for emergency power supply.

The applicability of the vent filter and the extent of countermeasures depends on the negotiations with the regulatory authorities.

(a)Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on drying treatment (1/3)

[FY2019 Implementation details]
(1) Investigation of the existing drying treatment technologies (including consolidation of conditions)
(2) Study on the requirements of drying treatment equipment

(1) Results of investigating the past drying treatment technologies

- **The preconditions for drying treatment** were studied. (Table 1)
- Based on the basic principle of drying, **8 methods were identified by combining heat transfer forms (4 methods) and waste transportation (2 methods).** (Table 2)
- The above methods were compared[#1], and it was confirmed that **the static (convection, conduction) method may be applicable to existing technologies, and multiple heat transfer forms (convection, conduction, radiation) can be used together.**

#1: Significant survey results were obtained showing that the methods can be applied to bulky metal and concrete waste (with due consideration of shape, moisture, radiation), interaction with other studies (container, storage building), items to be studied for container corrosion countermeasures and the impact (dust, hydrogen) during the drying process.

Table 1 Preconditions for the drying treatment

Major items	Minor items	Conditions
Properties of the waste targeted	Status of raw waste	・Items removed during debris retrieval (Wet due to the cooling water in the reactor, **draining assumed, bulky shape**)
	Treatment for temporary storage	・The raw waste generated during debris retrieval is cut inside the PCV into the size of the inner container or smaller, it gets drained by its own weight, and no treatment other than drying is performed before primary storage.
Application to retrieval flow		・For hydrogen measures, there are the options of **completely dry (sealed cask) or vent type (unsealed cask).** ・Drying in the storage building mainly contributes to **the confinement of the cask (corrosion countermeasures).** (Refilling is made possible within the container, until container corrosion measures during storage become feasible.)

Table 2 Results of investigating existing technologies related to drying treatment
(Results of comparative study of the eight identified methods)

Investigation items				Investigation results
Items compared	Applicability to bulky metal or concrete waste	Shape	Inner container	Static: Can be static or stationary inside the drying equipment Conduction - transfer: Cannot be stationary inside the drying equipment
			Bulky shape waste collected	Convection - static / transfer, conduction / radiation - static: Does not require additional processing and applicable to bulky shape. Conduction-transfer: In addition to retrieval from inner container, it requires additional processing. Radiation-transfer, microwave- static / transfer: If necessary, additional processing is required after removing it from the inner container. No water penetration / applicable to slightly bulky shape
		Moisture	Reduction index	Absence of moisture: Possible up to equilibrium moisture content Presence of moisture: For each method, there is a limit to the moisture content and a depth from the surface from which it can be irradiated.
			Amount brought-in	Static, convection radiation / microwave-transfer: No limitation Conduction-transfer: Has limitation
		Considerations related to radiation		Static: Requires shielding depending on the amount handled, and the number of sites to be maintained is less as there are only few drive parts and interior parts inside the equipment. Transfer: Requires shielding depending on the amount handled, there are a large number of sites to be maintained as there are many drive parts and interior parts inside the equipment.
	Compatibility with other studies	Container		Static: Dimensions and structure of inner container, transportation method of inner container Convection/radiation/microwave-transfer: Those said above +Transfer method inside the drying equipment Conduction-transfer: Method of retrieving wastes from the inner container, method of storing inside the inner container after drying
		Storage building		Common methods: Air supply / exhaust system, power (electric power) system
	Study items required for container corrosion measures			Common methods: Status of adhesion of free water on target waste (metal, concrete) Corrosion margin based on the amount of residual water after drying treatment
	Impact during the drying treatment	Dust (solid)		Common methods: Requires the confinement of air supply / exhaust systems (filter), including the generation of airflow in the drying equipment
		Hydrogen		Convection – static / transfer, conduction / radiation - static: scavenged to the outside of the system by exhaust (including vacuum) Conduction-transfer: Requires confirmation on the complexity of the structure of the drying equipment (difficult to scavenge) and the possibility to control temperature of the heat transfer part (hydrogen ignition prevention). Radiation-transfer, microwave-static/transfer: Though it is scavenged outside the system through the exhaust, requires confirmation on the possibility to control the temperature of the waste (hydrogen ignition prevention)

Blue notation: Details that meet the conditions   Red notation: Details the are difficult to or can’t meet the conditions.

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on drying treatment (2/3)

(2) Results of studying the dry treatment equipment requirements (1/2)

- ➢ The **Atomic Energy Society of Japan Standard** "Technical requirements and test method for manufacturing sub-surface industrial waste package: 2015”[#1] was referred to for the requirements for burial disposal of radioactive waste packages within Japan, and **the concept of drying treatment for the wastes in this study were compared and organized[#2].**
- ➢ As a result of the above study, it was confirmed that **among existing technologies**, **the convection (static) and conduction (static) methods are expected to be applicable** to the requirements for drying treatment, response to drying treatment procedure of each container, and to the concept of operation management indicators.

#2: It was confirmed that the following 7 points could be dealt with.
･Conditions of target waste to be considered ･Method for removing free water ･Method for drying free water ･Evaluation of appropriate removal or drying method
･Requirements that control the absence of a large amount of free water ･ Handling of the drying treatment procedure for each container ･ Operation management indicators or treatment conditions
(Free water described in the Atomic Energy Society of Japan Standard refers to the water that is brought into the container together with the radioactive waste when storing the radioactive waste in the container.)

Table 1 Comparison of the Atomic Energy Society of Japan Standard and the concept of drying treatment of the waste generated during fuel debris retrieval (excerpts)

Items	Concept related to drying treatment in the Atomic Energy Society of Japan Standard “Technical requirements and test method for manufacturing sub-surface industrial waste package: 2015”[*1]	Concept of drying treatment of waste generated during debris retrieval
1. Scope of application	Methods used by **operators to review conformance with requirements and technical standards during waste conditioning** for marginal depth disposal. (Does not include technical requirements from waste disposal facilities or pertaining to transportation)	**Treatment from the time of generation during retrieval up to temporary storage** (Not applicable to the treatment for waste conditioning)
4.1 Requirements (Attachment D (reference))	From the marginal depth disposal report[*3] and burial disposal project declaration[*4] (Table D.1), it is interpreted that the removal of free water contributes to the **"sufficient strength of waste packages" and “measures to prevent the spread of contamination (sealing of containers)”.**	The free water is removed before temporary storage to **prevent hydrogen gas generation and corrosion (container sealing)** when using a sealed container in temporary storge. (Does not include the complete drying for the strength of waste packages or for disposal)
4.2.1 Removal of free water when enclosing in a container	If free water remains in the waste package, the free water is removed before sealing the container (classified as “vacuum drying” or “other than vacuum drying”)	

*1: The Atomic Energy Society of Japan Standard "Technical requirements and test method for manufacturing sub-surface industrial waste package: 2015” (Standard for operators to perform burial disposal of radioactive waste generated from nuclear power plants and reprocessing facilities by means of waste conditioning.)
*3: Safety regulations related to marginal depth disposal of low-level radioactive waste (January 2008, Advisory Committee on Energy and Natural Resources, Nuclear and Industrial Safety Sub-committee, Waste Safety Sub-committee)
*4: The Regulation related to the Project for burial of type 2 waste resulting from nuclear fuel substances or from items contaminated by nuclear fuel substances. (Burial Project Regulations)

Table 2 Comparison of existing technologies and drying treatment requirements[#5]

Method	Form of heat transfer	Convection		Conduction		Radiation		Microwave	
	Transport of waste	Static	Transfer	Static	Transfer	Static	Transfer	Static	Transfer
Technological requirements for drying	Conditions of target waste	Among the conditions of the target waste existing inside the PCV, it is possible to create a plan for information such as type, shape, storage location (currently it is inside the PCV as it is yet to be retrieved). However, the state of free water is not certain.							
	Method of removing free water	●Free water can be removed based on the removal method ●The time required for removal depends on the amount of water brought-in			●Same as that on the left ●Presence of restrictions	Similar to conduction- static	●Free water can be removed based on the removal method ●The time required for removal depends on the amount of water brought-in		
	Method for drying the free water	●Existing technologies can be applied. ●Conditions and retention duration can be set.	●Larger number of maintenance sites within the equipment ●Same as that on the left	●Existing technologies can be applied. ●Same as that on the left	●Requires additional processing ●Transfer conditions get complicated		●Requires remote measurement of waste temperature ●Conditions and retention duration can be set.		
	Evaluation of appropriate removal methods and drying methods	●The concepts from the existing Atomic Energy Society of Japan Standard can be applied.			●The transfer model inside the drying facility gets complicated.		●The temperature concept from the Atomic Energy ●Society of Japan Standard is difficult to apply.		
	Requirements for ensuring that a large amount of free water is not present	●Operation conditions and required retention time can be set.			●Setting of transfer time within the drying facility gets complicated.		●The setting of operation conditions (temperature) gets complicated.		
Handling of drying treatment procedures of each container		●Can be handled.	●Same as that on the left (Increase in the size of equipment for the prevention of spread of contamination)	●Same as that on the left	●Requires retrieval of contents		●The impact of the container on irradiation needs to be confirmed.		
Operation management index	Operation conditions	●Can be set.			●The setting of transfer time gets complicated.		●The setting of operation conditions (temperature) gets complicated.		
	Amount of residual water	●Can be set.					●Impact of container on irradiation during operation time (retention time) needs to be confirmed.		

*5: Below is the distinction between the colored characters shown in the table.
Blue notation: Details that meet the conditions
Red notation: Details the are difficult to or can’t meet the conditions.

(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on drying treatment (3/3)

(2) Results of studying the dry treatment equipment requirements (2/2)

- **The requirements for the drying treatment facility** were created based on the results of investigating the existing technologies and by consolidating the requirements.

Table 1 Requirements for the drying treatment facility

Items		Requirements of drying treatment facility	Remarks
Applicability to the targeted waste	Shape, properties	It should be possible to handle waste generated during fuel debris retrieval (bulky metal or concrete, which got wet due to the reactor cooling water and was drained) **by means of storage containers (with inner containers stored in them)**.	Based on the properties set for the assumed waste
		It should be **possible to reduce the amount of free water** carried in along with the waste generated during fuel debris retrieval, **to a level where it can be temporarily stored**.	The applicable technology is selected by investigating the existing technologies.
	Considerations related to radiation	It should be **possible to have shielding** depending on the amount of waste handled, and there should either be **no drive parts or internal parts** inside the treatment facility OR **their maintenance should be possible.**	Same as above
Treatment for temporary storage		The raw waste generated during fuel debris retrieval should be **cut inside the PCV into the size of inner container or smaller**, **get drained by its own weight,** transported and received at the drying treatment facility. In the drying treatment facility, only the **drying before the temporary storage** should be performed.	Based on the collection, transfer and storage flow
Applicability to retrieval flow		**Hydrogen measures should be classified for sealed and non-sealed containers, and the drying treatment in the storage building should mainly be carried out for the confinement of the container (corrosion measures)**[#1] *1: It should be made possible to refill waste in the container, until container corrosion measures during storage become feasible.	Studied based on the targeted waste
	Compatibility with container and storage building	**The container (dimension, structure, transport method) and storage building (air supply / exhaust and power systems) should be compatible.**	The applicable technology is selected by investigating on the existing technologies.
Impact during drying treatment	Dust (solid), hydrogen	To prevent the spread of contamination, **the radioactive substances (dust) in the air supply / exhaust systems** of the drying treatment facility **should be removed (filtered).** The **hydrogen** generated during the drying treatment should be **scavenged outside the system** without allowing it to remain inside the facility.	Same as above
Technological requirements for drying	Conditions of targeted waste	It should be possible to set the **type, dimension, storage location and state of free water adhesion.** (Estimation of free water adhesion state is difficult at this point in time, and is set as metal: management category I, concrete: management category I or II (considering the moisture inside) based on the concepts in the Atomic Energy Society of Japan Standard)	The concepts in the existing Atomic Energy Society of Japan Standard can be applied.
	Measures for preventing the spread of contamination	**The confinement of radioactive substances in the container and at the drying treatment facility** before and after the drying treatment **should be possible.** Material: Carbon steel SS material Structure of the container: Attaching a filter vent capable of preventing the spread of contamination on a square shaped container that is being used in 1F premises is being studied.	
	Substances that may cause damage to the soundness	**The facility should dry free water that can impair confinement of sealed containers.** There should not be any material that significantly promotes corrosion (Waste acid: hydrogen ion index concentration of 2.0 or less, waste alkali: hydrogen ion index concentration of 12.5 or more) or that generates significant gas (pyrophoric substance, water reactive substances).	Based on the properties set for the assumed waste
	Method of removing free water, drying method and its evaluation	**It should be possible to remove free water using the methods in existing technologies, and it should be possible to evaluate the drying method.** (The time required for removal depends on the amount of water carried in along with the waste, and the conditions and retention duration can be set.)	The technology that can be applied to the requirements of drying treatment shall be identified through investigation of existing technologies. The concept described in the Atomic Energy Society of Japan Standard can be applied.
	Requirements for ensuring that a large amount of free water is not present	**It should be possible to set the operation and treatment conditions and required retention time.**	Same as above
Drying treatment for individual containers		**The drying treatment should be performed for individual containers after storing the radioactive substances (waste) inside the container.**	Same as above
Operation management indicators	Amount of residual water Operating conditions Operation time	It should be possible to set **the amount of residual water (representative value), operating conditions (pressure, temperature, amount of exhaust / ventilation) and operation time (retention time determined based on the tests) using the methods in existing technologies (vacuum drying, other than vacuum drying) depending on the condition of radioactive waste (management classification)** .	Same as above

(a)Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on measurement methods and measurement equipment (1/3)

<Background and Purpose>

● Background

Studies conducted so far ･･･ In the collection, transfer and storage flow studied up to FY2018, it was assumed that measurement would be performed, however, the measurement items, measurement methods, measurement equipment, etc. were not studied.

● Issues

① Inputs such as properties of waste, requirements for transfer within the premises, storage requirements, etc., were not determined.

② There are restrictions on measurement time, space for equipment installation, etc., for making the entire fuel debris retrieval process feasible (quantitative design requirements were not determined).

③ It is not practical to measure all the confirmation items. A logic for selection is required.

● Purpose

To draw up specifications of the measurement equipment (listing the requirements of the measurement equipment (measurement method, measurement location, measurement time, etc.)).

● Study procedure

1. From the process flow studied in FY2018, organize the confirmation items that are likely to be measured and investigated.

2. Study the priority for measuring the organized confirmation items.

3. Create a primary draft of the measurement flowchart based on the priority of each measurement item.

4. Investigate measurement methods and measurement equipment for high-priority measurement items.

5. Review the measurement flowchart and organize the requirements for each measurement.

1 to 3: Implemented in FY2019, 4 to 5: Planned to be implemented in FY2020

Fig. 1 Process for studying the measurement methods and measurement equipment

(a)Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on measurement methods and measurement equipment (2/3)

1. From the process flow studied in FY2018, organize the confirmation items that are likely to be measured and investigated.

2. Study the priority for measuring the organized confirmation items.

<Confirmation items>

- When stored in the inner container

Basic properties
Dimensions, capacity, weight, surface condition

Waste properties (composition)
Material, water, organic matter, corrosive substances

Radiochemical properties
Surface dose rate, the amount of radioactivity, amount of nuclear material

Heat generation characteristics
Hydrogen generation properties

- When storing in storage containers

External appearance
Weight
Filling rate
Surface dose rate
Surface contamination
Surface temperature
Hydrogen generation rate
Amount of nuclide emission

- When stored in transport cask

External appearance
Weight
Surface dose rate
Surface contamination
Surface temperature
Sealing

<Purpose and intent of the confirmation items>

Purpose and intent

Requirements for acceptance at the delivery facility
Requirements for transfer within the premises
Requirements for acceptance at the storage vault
Incorporation in the process up to storage
Incorporation in the process after storage

<Measurement plan for confirmation items>

Proposal for measurement technology

Details and targets for measurement

Implementation method
Implementation period
Place of implementation
Required value

Assumed issues

Priority based on the purpose
Are these items that require to be confirmed, such as requirements for acceptance at the facility, requirements for transfer within the premises?

Difficulty in measurement
Is it technically likely to be measurable during the process up to storage?

Can it be estimated from other measurements?
Is it relatively easy to estimate from alternative measurement items?

Possibility of avoiding measurement through operation, evaluation, preliminary investigation, etc.
Is it possible to substitute the measurement by operation, etc.?

<Policy for setting the measurement flowchart>
Based on each priority, the measurement items are set based on the following policy.
‣The confirmation of items up to the collection, transfer and storage such as requirements for acceptance at the facility, requirements for transfer within the premises, etc., shall be considered essential, while the items required for the processes after storage shall not be considered essential.
‣ Among the essential confirmation items, with respect to items for which measurement can be avoided through estimation from other measured values, or through operation, evaluation, preliminary investigation, etc., the policy shall be to avoid measurement, and the items for which measurement cannot be avoided shall be measured.

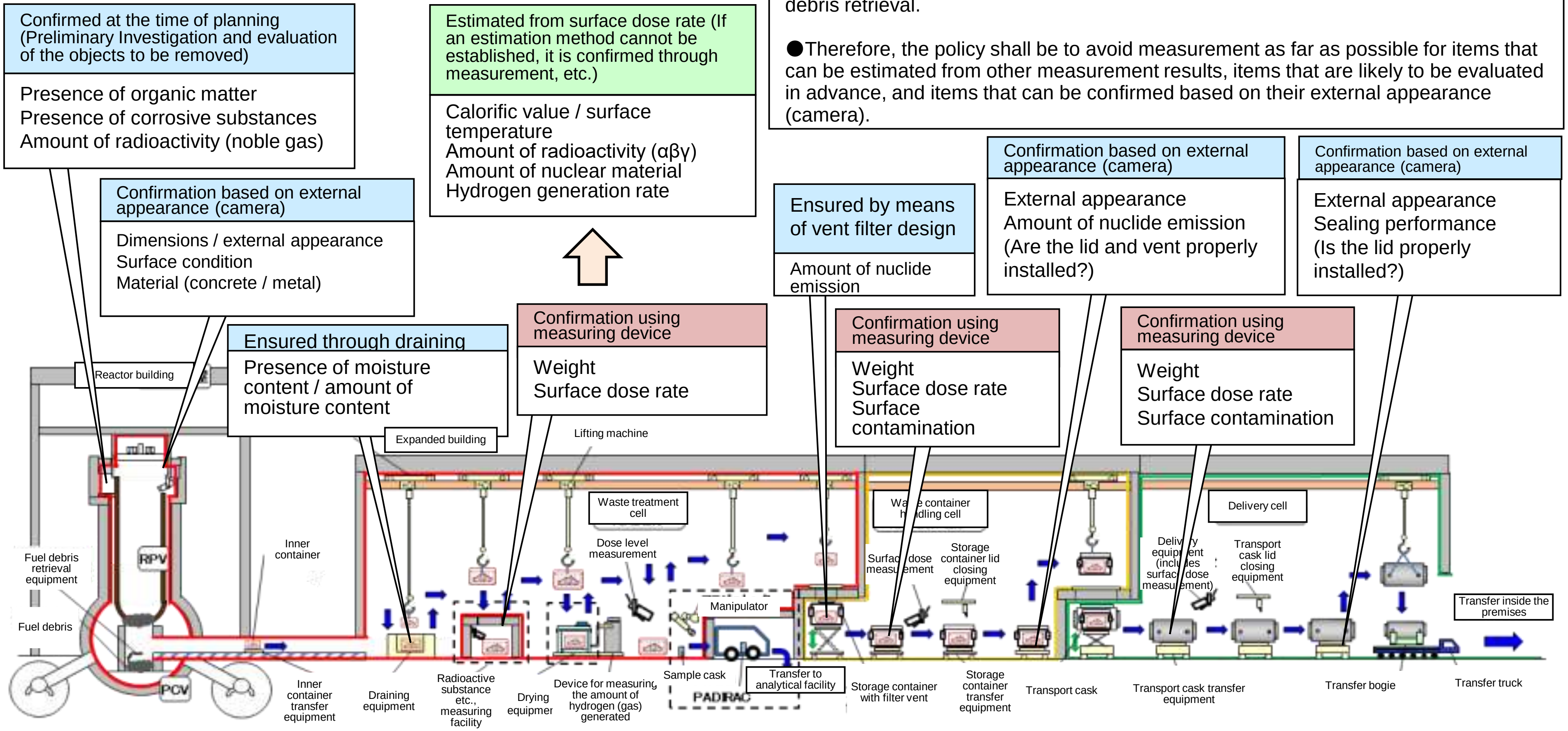
(a) Study and evaluation of storage and management methods
② Study on container and storage facility requirements
Study on measurement methods and measurement equipment (3/3)

3. Create a primary draft of the measurement flowchart based on the priority of each measurement item.

<Concept>

●If the number of measurement items increases, there is concern that the measurement time and equipment installation space will affect the overall plan for fuel debris retrieval.

●Therefore, the policy shall be to avoid measurement as far as possible for items that can be estimated from other measurement results, items that are likely to be evaluated in advance, and items that can be confirmed based on their external appearance (camera).



Confirmed at the time of planning (Preliminary Investigation and evaluation of the objects to be removed)
Presence of organic matter
Presence of corrosive substances
Amount of radioactivity (noble gas)

Confirmation based on external appearance (camera)
Dimensions / external appearance
Surface condition
Material (concrete / metal)

Ensured through draining
Presence of moisture content / amount of moisture content

Estimated from surface dose rate (If an estimation method cannot be established, it is confirmed through measurement, etc.)
Calorific value / surface temperature
Amount of radioactivity (αβγ)
Amount of nuclear material
Hydrogen generation rate

Confirmation using measuring device
Weight
Surface dose rate

Ensured by means of vent filter design
Amount of nuclide emission

Confirmation using measuring device
Weight
Surface dose rate
Surface contamination

Confirmation based on external appearance (camera)
External appearance
Amount of nuclide emission
(Are the lid and vent properly installed?)

Confirmation using measuring device
Weight
Surface dose rate
Surface contamination

Confirmation based on external appearance (camera)
External appearance
Sealing performance
(Is the lid properly installed?)

Fig. 1 Primary draft of measurement flowchart

<Summary and future plans>

- There is a possibility to estimate multiple confirmation items from the surface dose rate of the waste (stored in inner containers). The challenge is to develop an estimation method.
- In the future, the measurement methods and equipment for the confirmation items with high measurement priority identified in this year's study will be investigated. In addition, the measurement flowchart is planned to be updated based on the investigation results.

🟦	･･･Items for which it is believed that measurement can be avoided through operation, evaluation, and preliminary investigation
🟩	･･･Items that could be estimated from other measurements
🟥	･･･Items that are believed to require confirmation using measuring device

(b) Development of contamination evaluation technology for solid waste segregation

- Overview -

- **Results**
  - ○ In FY2018, a prototype (Fig 1) was developed as a measuring equipment that can measure alpha contamination remotely (Alpha camera) keeping in view the site environment and an element test was performed. Issues related to this method were identified based on the element test results and scope of application was specified.
- **Goals**
  - ○ To develop a scanning mechanism such as pan-tilt mechanism etc. as a measuring system for alpha contamination settled on the surface of the equipment and building concrete, and also develop a measuring system comprising image synthesis function that creates 3-dimensional contamination distribution. To design and develop systems for on-site application and conduct functional verification testing. In addition, to conduct mock-up test for alpha contaminated equipment on the site and carry out performance evaluation.
- **Implementation details**
  - ○ In FY2019, the prototype was improved based on the results of FY2018 element test and element tests continued to be performed. In addition, preliminary systemization test was conducted and the data required for designing the measuring system was collected. (Fig 2)
  - ○ In FY2020, a system based on the design will be developed and functional verification test for the system will be performed. Also, a mock-up test will be conducted for alpha contaminated equipment on the site and performance evaluation will be carried out.
- **Indicators to determine goal achievement**
  - ○ The data required for design completion should be acquired. (FY2019)
  - ○ Performance evaluation should be conducted by means of a mock-up test. (FY2020)

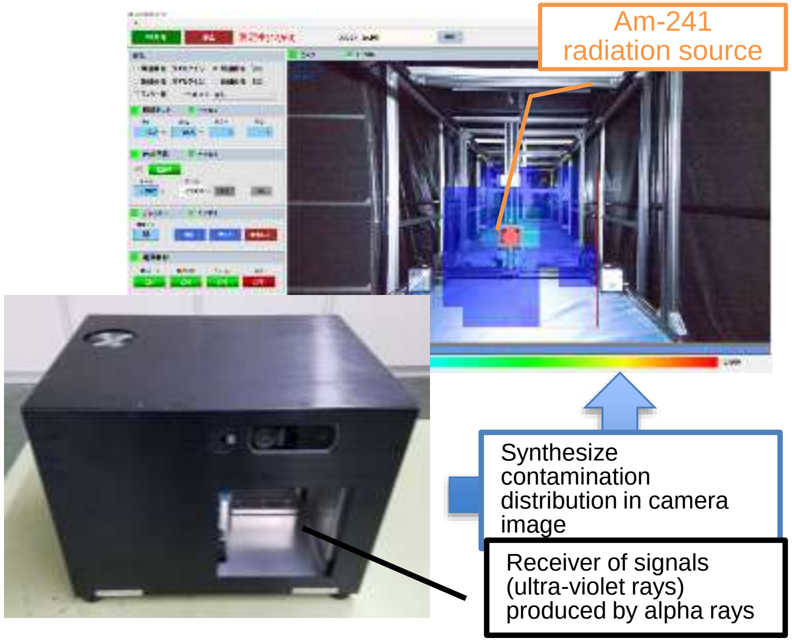


Fig. 1 Prototype developed in FY2019

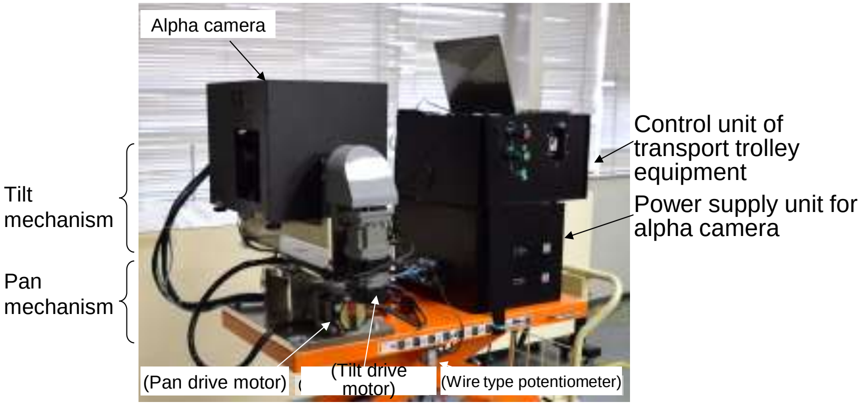


Fig. 2 Sample image of alpha ray contamination measuring system

(b) Development of contamination evaluation technology for solid waste segregation
- Principle of alpha camera -

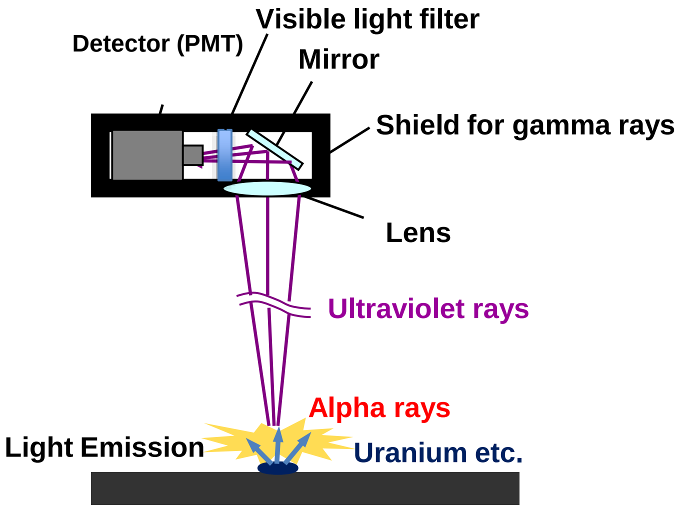


Fig. 1 Pattern diagram showing principle

Measurement principle

① Reaction takes place with nitrogen within alpha radiation range (several cm) to produce several 100 photonic ultraviolet rays.

② These ultraviolet rays are focused and imaged with a lens and the distribution of alpha rays is measured from the distribution of the number of photons reaching the light detector.

③ PMT (Photomultiplier Tube) is shielded as it is likely to be affected by Cherenkov radiation when gamma rays enter PMT.

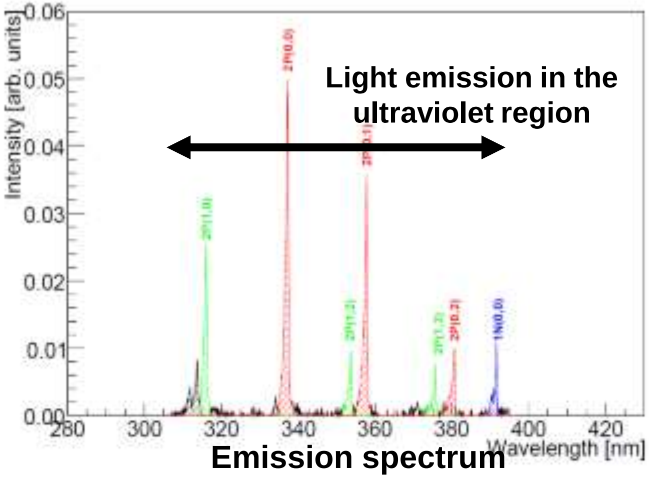


Fig. 2 Nitrogen emission spectrum

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

Example of presentations made in connection with alpha camera

1.IEEE2013 NSS, Remote Detector of Alpha-Ray Using Ultraviolet Ray Emitted by Nitrogen in Air

2. ICONE-23 REMOTE DETECTION OF ALPHA RADIATION USING UV PHOTONS EMITTED BY NITROGEN

3.Spring meeting of Atomic Energy Society of Japan in FY2013, Technology for remote measurement of alpha radiation

4. Autumn meeting of Atomic Energy Society of Japan in FY2014, Technology for remote measurement of alpha radiation–Application to lighting environment-

(b) Development of contamination evaluation technology for solid waste segregation
- Alpha camera development history -

■Development history

- Survey was undertaken on the assumed site environment and requirement specifications were formulated in connection with “R&D for Treatment and Disposal of Solid Wastes (R&D for Advanced Processing and Analytical Methods)” in FY2018.
- Basic performance of development method (Alpha camera) was verified on the basis of requirement specifications through element tests.

Table 1 Overview of requirement specifications and test results

Cited from FY2017 supplementary budget “Subsidy Project of Decommissioning and Contaminated Water Management (R&D for Treatment and Disposal of Solid Wastes (R&D for Advanced Processing and Analytical Methods))” FY2018 Research Report

	Items	Requirement Specifications	Test items	Result overview
Accessibility	Measurement distance	Max. 3 mm	Basic performance test: Lens evaluation	• Sensitivity is proportional to the square of the distance. • 100 mm lens, there are cases where 4 Bq/cm2 can be measured by increasing the measuring time.
	Profile of object to be measured	Spherical surface, uneven, plane surface	Element test: Complex radiation source evaluation	• There is less impact when measuring direction (spherical surface) is 0 to 90° . • When measuring the contamination in concave portion at a depth of 25 mm, sensitivity worsens to 71% and is 67% at a depth of 50 mm.
	Weight	Depends on the trolley	Element test: Environmental dose impact test	Confirmed gamma-ray sensitivity at 3.3 [s^{-1}/mSv/h] *Identified the location at angle of partial incidence where shielding effect is less. It needs to be improved.
Environment conditions	Environmental dose	About 50 mSv/h (Max.150 mSv/h approx.)		
	Environmental temperature	-5℃-35℃	Element test: Temperature test	No effect on noise by using heat control mechanism
	Environmental humidity	Max.100%	Element test: Humidity test	Sensitivity decreases by less than 3% even at 95% max. *Sensitivity tends to decrease when water is added to radiation source.
	Lighting	Lighting available depending on the case	Basic performance test: Optical filter evaluation	Sensitivity reduces by 78% due to optical filter.
	Powdery dust	Above outdoor dust levels	Element test: Powdery dust impact test	Change in sensitivity is max. 1% outdoors.
	Beta-gamma nuclide concentration	$\alpha/\beta\gamma=1\text{-}10^{6\text{-}8}$	Element test: Impact assessment test for beta-gamma nuclide concentration	Acquired sensitivity relative to alpha rays. Beta rays (Co-60): 0.36% Gamma rays (Cs-137): 0.009%

* Settings were specified based on the characteristics identified from FY2017 supplementary budget “Subsidy Project of Decommissioning and Contaminated Water Management (R&D for Treatment and Disposal of Solid Wastes (R&D for Advanced Processing and Analytical Methods))”

(b) Development of contamination evaluation technology for solid waste segregation
- Consolidation of FY2019 implementation details -

Issues identified from FY2018 implementation results

1. It was noticed that ghost-peak was formed with φ100 mm lens and detector combination.

⇒ Countermeasures for ghost-peak

2. It was noticed that the sensitivity is proportional to the square of the lens diameter and a φ 100 mm lens (it was φ 50 mm in the past) was used. It was confirmed that there were directions where the shield was ineffective, partly due to the increase in size.

⇒**Improvement of prototype**

Issues to be addressed from FY2019

3. Tasks up to the tests using stabilized and standard radioactive source in FY2018 are complete. However, material and shape simulation assuming on-site conditions has not been carried out.

⇒**Continuation of element test**

4. Tasks up to imaging at a fixed position in alpha camera unit test in FY2018 are complete.

It is necessary to design a system that can move the measurement location remotely and evaluate the data.

⇒**Addition of functions to software, design of measuring system**

(b) Development of contamination evaluation technology for solid waste segregation

- Current status of alpha contaminated waste management and issues thereof -

- **Current status of alpha contaminated waste management**

When smear measurement detects alpha nuclide contamination at surface contamination density 0.4 Bq/cm^2 or above, the waste is segregated and stored in a storage container. However, decommissioning work will commence on a full-scale in future and a large amount of waste will be produced. Hence, it is not realistic to carry out smear measurement and segregate all waste after dismantling, considering the time required for measurement and radiation exposure to workers.

- **Requirements pertaining to waste segregation technology**
  - Identify the surface contamination distribution of the target objects before dismantling.
  - Reduce the measuring time and reduce the exposure dose associated with measurement.

- **Purpose of this Project**

To examine its applicability to site and develop a technology that can measure the object (or area) to be dismantled in an exhaustive manner and also within a short period of time.

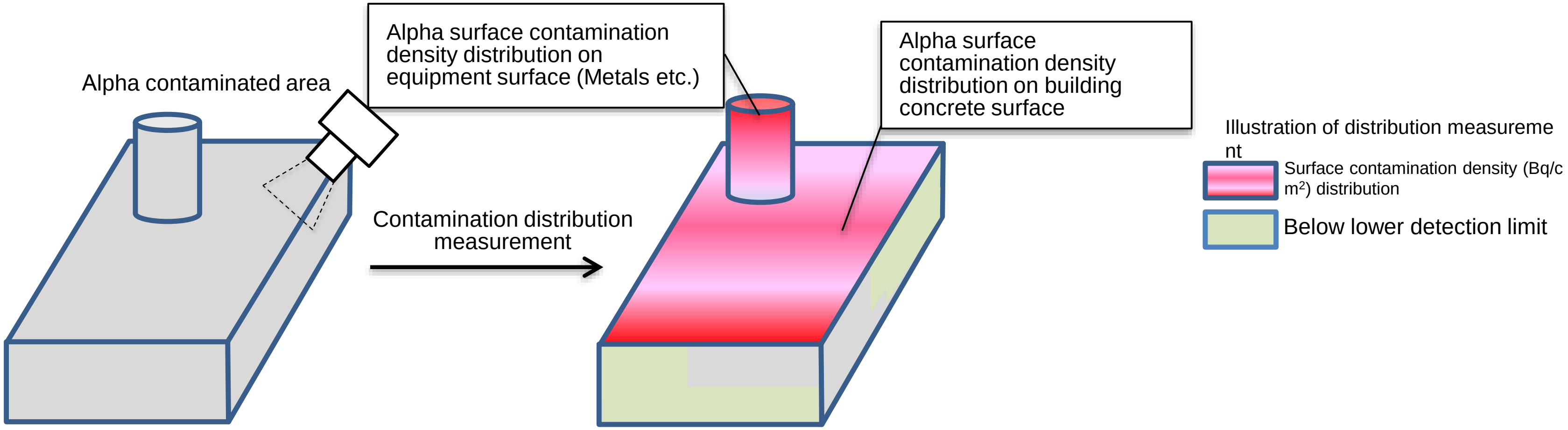
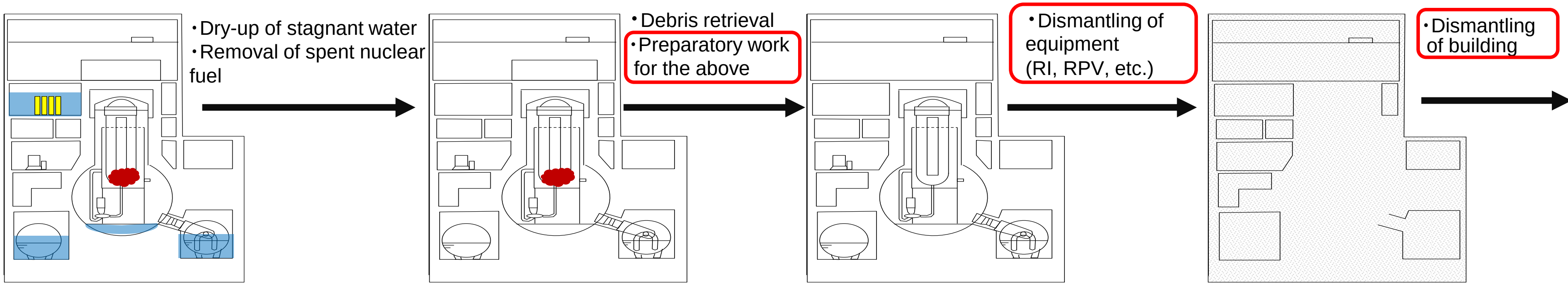


Fig. 1 Image showing distribution measurement using alpha camera

(b) Development of contamination evaluation technology for solid waste segregation
- Application targets -

Investigate the measurement needs and determine the timing of application and purpose of measurement.
“Understanding of contamination distribution” was established as an application target (uses) that can be used in the study of work planning such as preparatory works, equipment dismantling etc. pertaining to debris retrieval in future.

[Assumed decommissioning flow (Ex: R/B)]



- Dry-up of stagnant water
- Removal of spent nuclear fuel

- Debris retrieval
- Preparatory work for the above

- Dismantling of equipment (RI, RPV, etc.)

- Dismantling of building

Fig. 1 Image showing application targets for alpha camera

Applicable targets for surface alpha contamination measurement
- Timing: Before the preparatory work for debris retrieval and prior to equipment dismantling work
- Target: Surface of structures and equipment within the scope of the work
- Use: Understanding of contamination distribution

(b) Development of contamination evaluation technology for solid waste segregation
- Application timing for alpha camera -

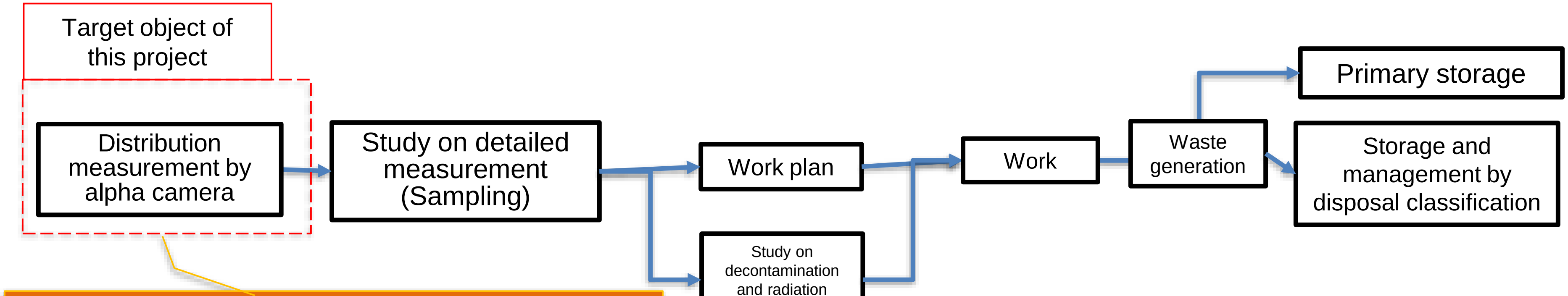
Investigate the latest needs (Purpose of contamination measurement) of TEPCO HD and determine the direction to aim for with respect to this technology.

Purpose of contamination measurement:

- **“Qualitative perspective on surface contamination density distribution” on the surface of the equipment and structures before dismantling**

Utilization of the measured contamination distribution (Proposed):

- Development of work plan without increase in contamination and wastes
- Study on radiation control methods in accordance with contamination concentration and work content
- Study of the plan and the need for detailed measurement such as sampling etc.



Evaluation points

- **Assessing the presence of contamination and distribution of qualitative contamination density**
- **Assessing the presence of localized contamination**

Fig. 1 Assumed work flow and application timing for alpha camera

(b) Development of contamination evaluation technology for solid waste segregation - Overview of FY2019 development results -

Table 1 Implementation details and achievements in FY2019

Items	Implementation details	Achievements
Verification test for countermeasures for ghost-peak	Countermeasures for ghost-peak (peaks other than radiation source location)	• Cause for ghost-peak was identified and devices were improved.
Improvement of prototype	Improvement of shielding structure ① Review of shielding structure ② Review of optical system in accordance with shielding structure	• Optical system and shielding structure were determined by ray tracing analysis and shielding calculation. • Optical system: Evaluation was completed for angle of view and resolution performance of this structure. • Shielding structure: Performance equaling or surpassing the analysis results was verified through irradiation test.
	Verification of the performance of improved alpha camera	• It was confirmed that there is no formation of ghost-peak. • Basic performance was re-evaluated and specifications of alpha camera were consolidated.
Continuation of element test	Evaluation of the performance of measurement using unsealed radioactive source etc. ① Simulation of adhesion to concrete, etc. ② Measurement of surface source, etc.	• Surface roughness of the object to be measured and its contamination profile were identified as the causes affecting the measuring performance of alpha camera and were reflected in test items. • Evaluation of characteristics based on surface roughness and contamination profile of the object to be measured was performed using unsealed Am-241 radiation source.
Addition of functions to software	Addition of measurement results mapping function	• Function was added for synthesizing the results acquired at multiple locations. • It was confirmed that image synthesis and 3D space mapping was possible by scanning the alpha camera.
Designing of measuring system	Study of on-site applicability	• Applicability was set.
	Study of specifications for measurement system	• Pan/tilt/raising and lowering functions were identified and reflected into the device as essential functions.
	Study on mechanism specifications and control methods	• Behavior of essential functions (pan, tilt, raising and lowering) was verified using the examined device. • Combination with mapping function was also confirmed.
	Basic verification of measurement system	• Basic verification was performed on contamination distribution measurement and issues concerning measurement system were identified.

(b) Development of contamination evaluation technology for solid waste segregation
- Countermeasures for ghost-peak (1/2) -

■ Purpose of implementation

To implement cause investigation for ghost-peaks identified in FY2018 and determine the structure that can solve the problem. To perform a test to ensure that there is no formation of ghost-peak.

■ Implementation details (Overview)

It was found that the lenses in optical system were not the only cause but the internal structure of photomultiplier tube PMT may also cause the formation of ghost-peak.

⇒Study the countermeasures against PMT structure.

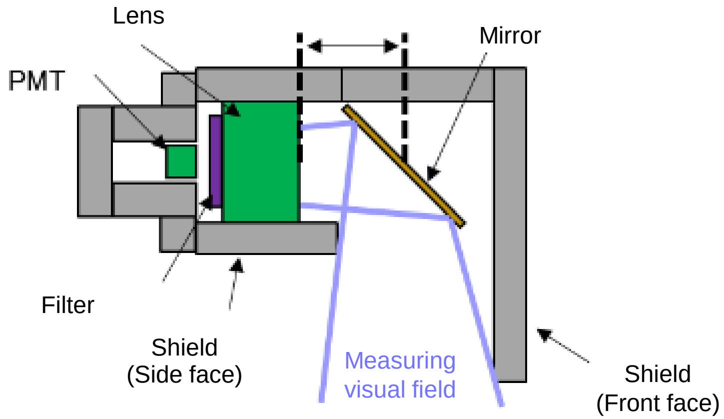


Fig. 1 Internal structure of the device

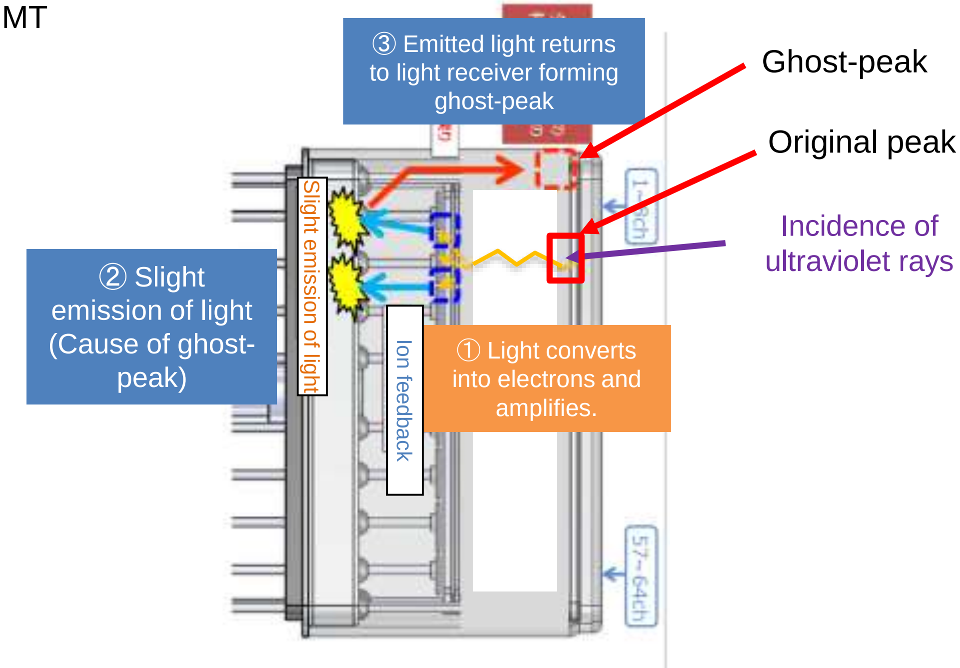


Fig. 2 Sectional diagram of PMT

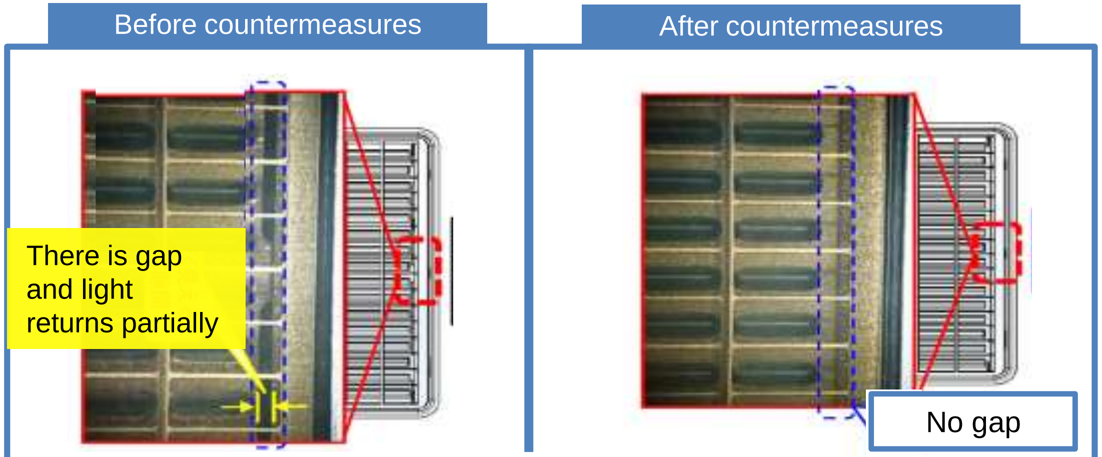
(b) Development of contamination evaluation technology for solid waste segregation

- Countermeasures for ghost-peak (2/2) -

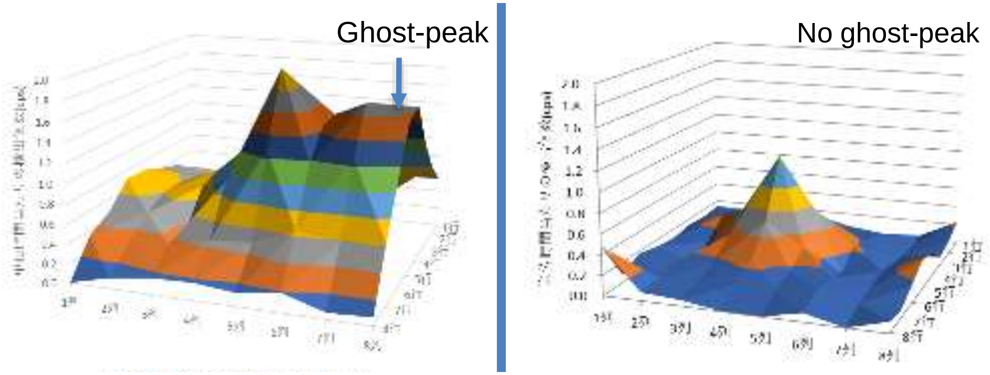
■Implementation Results

・Test was performed using PMT with gaps removed to prevent the return of light emission and it was compared with previous results.

・Decrease in ghost-peak was noticed at the end portion using a commercially available single lens (φ 50 mm).



Picture showing PMT imaging area (Pictu)



Distribution when measuring Am241 (φ 15 mm thin disc)

Fig. 1 Comparison before and after the countermeasures for ghost-peak

(b) Development of contamination evaluation technology for solid waste segregation

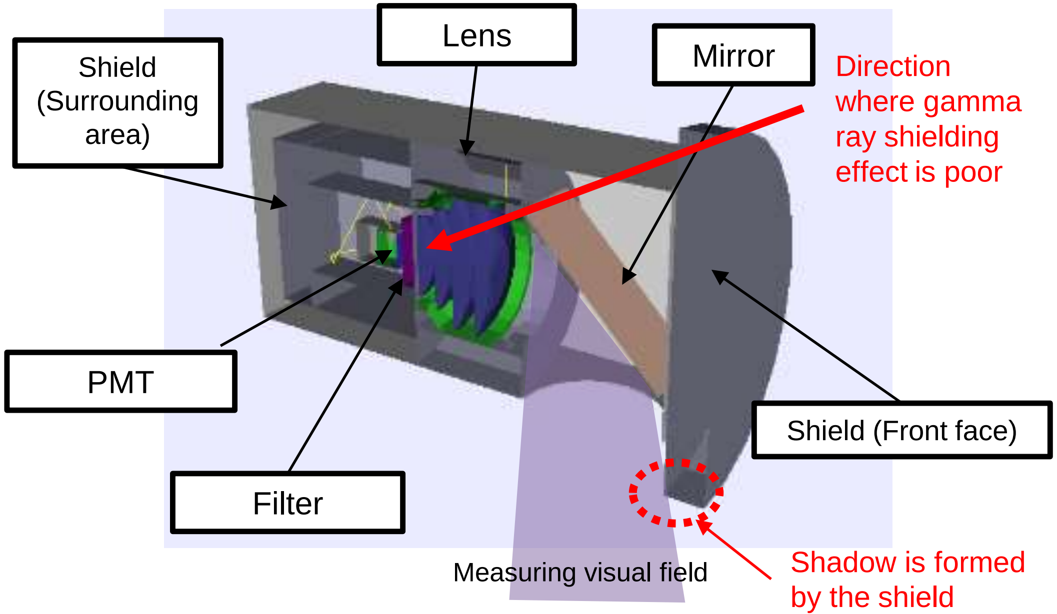
- Improvement of shielding structure (1/5) -

■ Purpose of implementation

To re-examine the design for shield and housing as it was noticed that shielding effect is weak in some directions in the prototype. Also, to perform the test again for the prototype after taking countermeasures and confirm the effects.

■ Implementation details (Overview)

Re-design and evaluation were carried out for the shieldable structure without obstructing the ultraviolet rays from alpha radiation.



Direction where gamma ray shielding effect is poor

Shadow is formed by the shield

Fig. 1 Shield structure in FY2018

Shield structure

•Improvement in shielding effect is possible by increasing the size of the shield (front face).

• However, sensitivity decreases since measuring visual field is partly missing due to the shield (shadow is formed).

(b) Development of contamination evaluation technology for solid waste segregation - Improvement of shielding structure (2/5) -

■ Implementation results

- Light tracing analysis was performed to evaluate the minimum size that light rays emitted from a light source within the angle of view, pass through. (Fig. 1 and Fig. 2)
- Study was conducted on a shielding structure that can be installed without obstructing the light rays. (Fig. 3)
- Analysis and evaluation were carried out to confirm the effects of the shielding structure. (Refer to improvement of shielding structure (3/5))
- Dependence on incidence angle was confirmed by irradiation test using Cs-137 radiation source. (Refer to improvement of shielding structure (4/5))

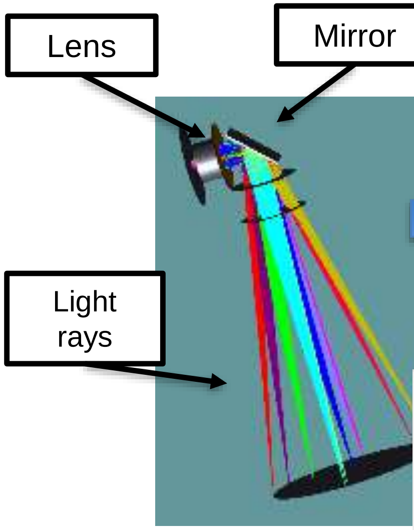


Fig. 1 Example of light ray analysis

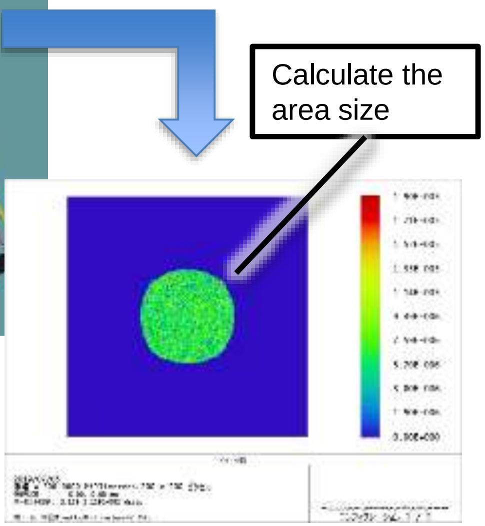
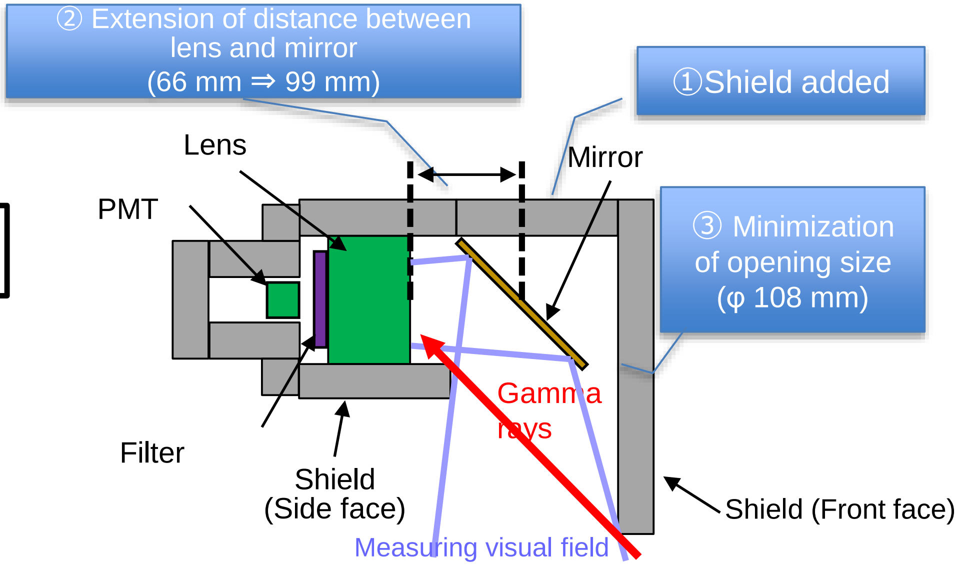


Fig. 2 Light rays passage area at the lower part of the mirror (Example)



Both shielding and visual field can be balanced by extending the distance between lens and mirror

Fig. 3 Image showing improvements and shield after improvement

(b) Development of contamination evaluation technology for solid waste segregation
- Improvement of shielding structure (3/5)-

<Results of analysis and evaluation>

- Gamma ray sensitivity was analyzed and evaluated assuming uniform contamination of Cs-137 in the surroundings of alpha camera.
- It was confirmed that gamma ray sensitivity can be reduced by 1/6.5 with a redesigned structure when compared to the structure used in FY2018.

Table 1 Analysis conditions

#	Distance between lens and mirror	Shield around mirror	Remarks
1	66.4 mm	No shield	FY2018 design model
2	66.4 mm	Opening size 120 x 120 mm	The opening size is evaluated with the distance between lens and mirror being 126.4 mm, so that ultraviolet rays cannot pass through.
3	96.4 mm	Opening size 120 x 120 mm	
4	126.4 mm	Opening size 120 x 120 mm	
5	96.4 mm	Opening size 108 x 108 mm	Improved model. Small opening with the distance between lens and mirror being 96.4 mm

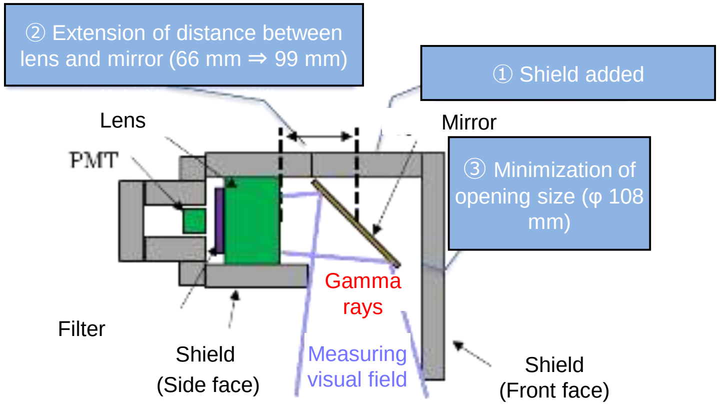


Fig. 1 Alpha camera structure and points for improvement

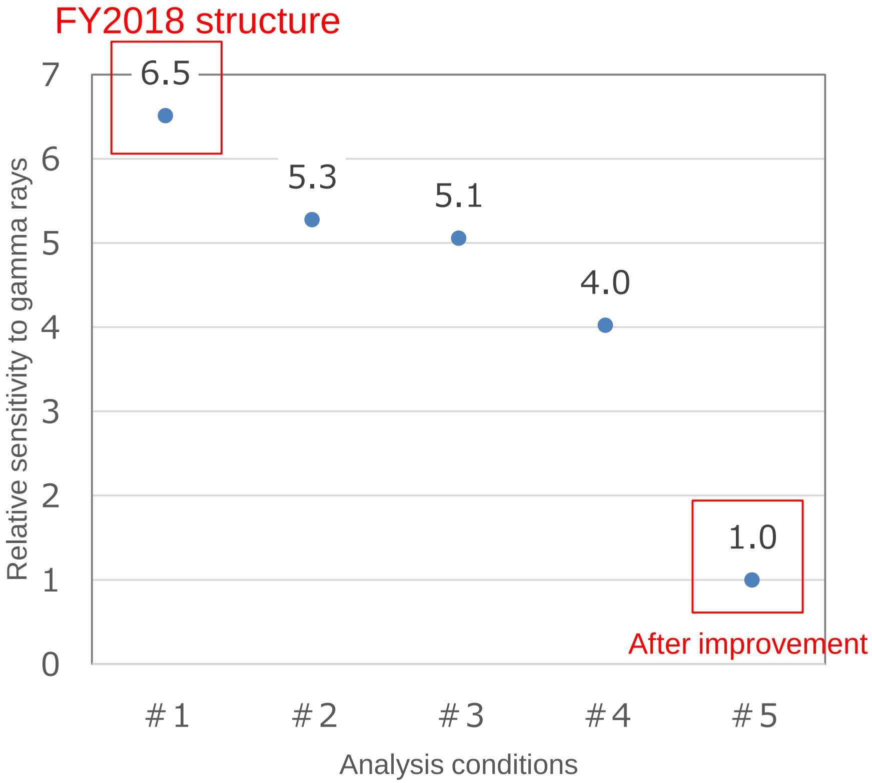
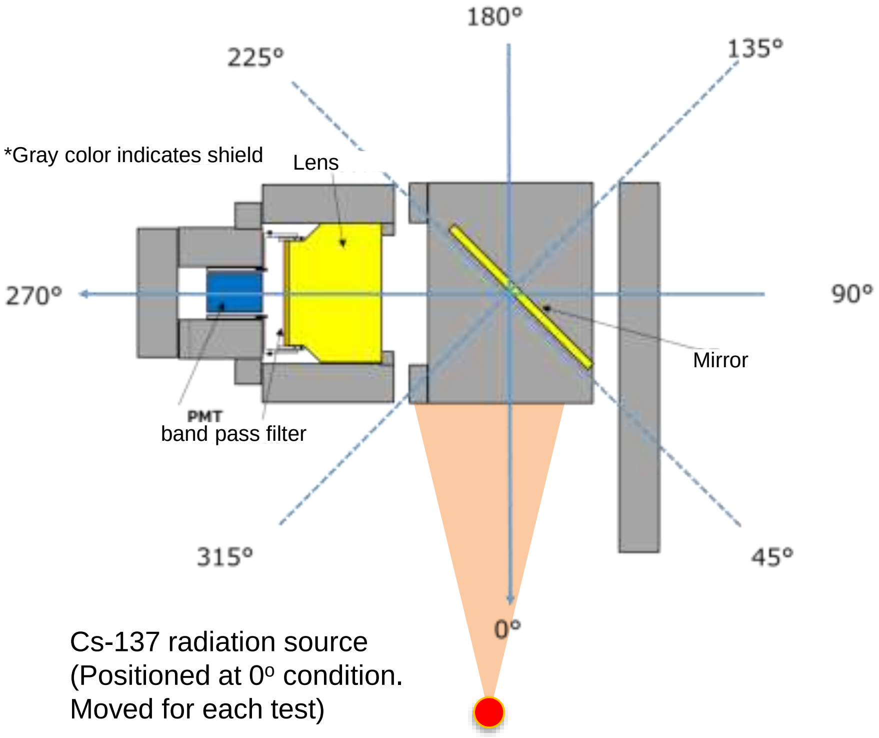


Fig. 2 Evaluation of gamma ray sensitivity using Cs-137 when the measuring environment is uniformly contaminated

(b) Development of contamination evaluation technology for solid waste segregation
- Improvement of shielding structure (4/5) -

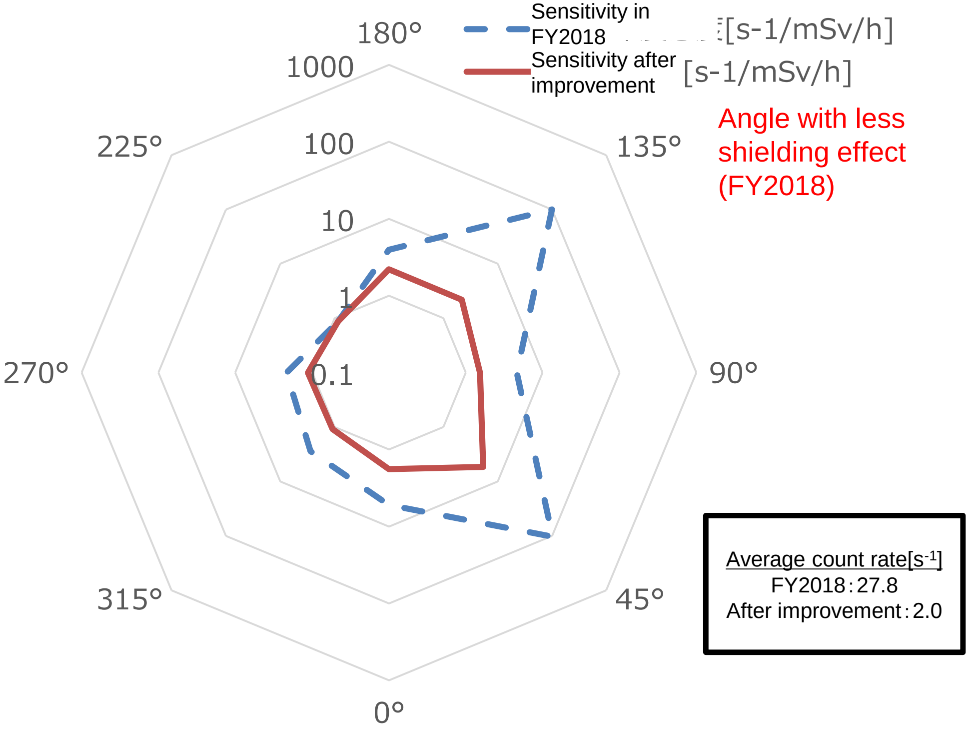
<Test Results>

- The dependence of gamma ray noise on the incidence angle was evaluated by controlling the incidence direction of gamma rays through rotation of alpha camera using an improved shield against Cs-137 radiation source (position fixing).
- Amount of noise reduced to max. 1/10 in FY2018 test under 45º and 135º conditions wherein the shielding effect was low.
- It was confirmed that the average value too can be reduced to 1/13.7, which is the same as the analytical value (Fig. 2). It was assumed that this was because the light produced by the lens was reduced by the filter placed between the lens and PMT.



Cs-137 radiation source
(Positioned at 0º condition.
Moved for each test)

Fig. 1 Test system



Angle with less shielding effect (FY2018)

Average count rate[s^{-1}]
FY2018：27.8
After improvement：2.0

Fig. 2 Dependence of gamma ray noise on the incidence angle

(b) Development of contamination evaluation technology for solid waste segregation

- Improvement of shielding structure (5/5)-

<Improvements in the prototype including the shield>

Table 1 Improvements in the prototype

	FY2018	FY2019 improvement details
PMT	Opening at the end portion of imaging area	Filled the opening at the end portion of imaging area
Shield	･Opening in the surroundings of mirror ･Distance between lens and mirror 66 mm	･Used a shield to cover the areas other than the entrance for ultraviolet rays from alpha radiation ･Distance between lens and mirror 96 mm
Cooling mechanism of PMT	PMT was given a cooling structure and a shield was installed outside it.	Reduced the size and improved cooling performance by changing it to a cooling structure (radiating fin) that cools the PMT and releases heat from the entire shield in the surroundings.
Remote control function	Did not function.	Added function that allows remote power ON/OFF operation.
Circuit for alpha camera	Mounted	Changed the profile in order to match it with the profile of the housing and shield (function is maintained).
Optical shutter	Installed at the bottom side of the mirror	Located in between lens and mirror
Filter	Fixed to the front face of PMT	Improved the jig to integrate the filter with the lens

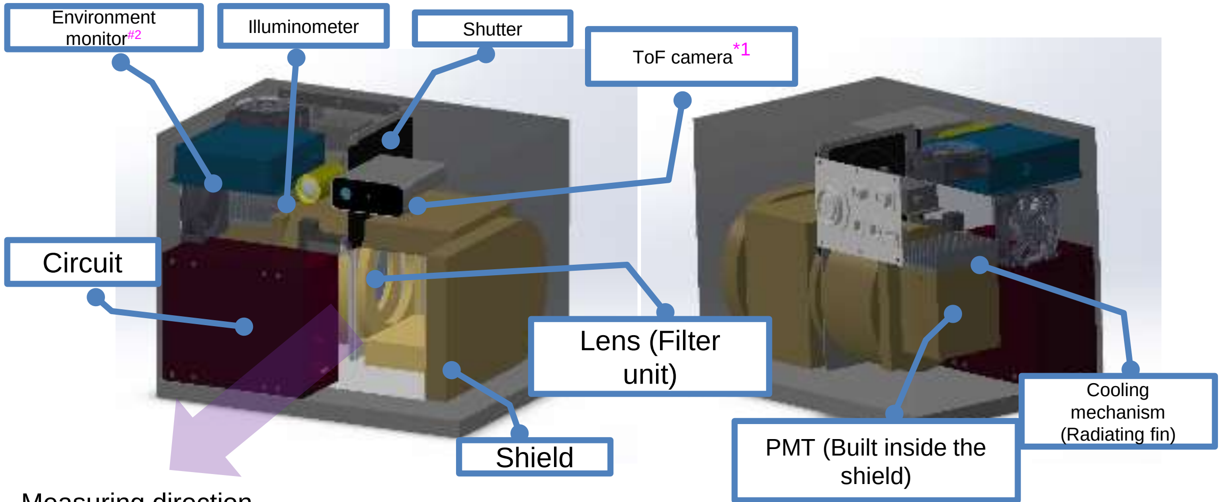


Fig. 1 Improved shield in FY2019

#1 ToF camera: Used in 3D mapping function. A camera with ToF (Time of Flight) function and which captures a normal camera image and distance data simultaneously.

#2 Environment monitor: Collects temperature of the cooling unit, values of illuminometer and the gamma ray intensity inside the shield

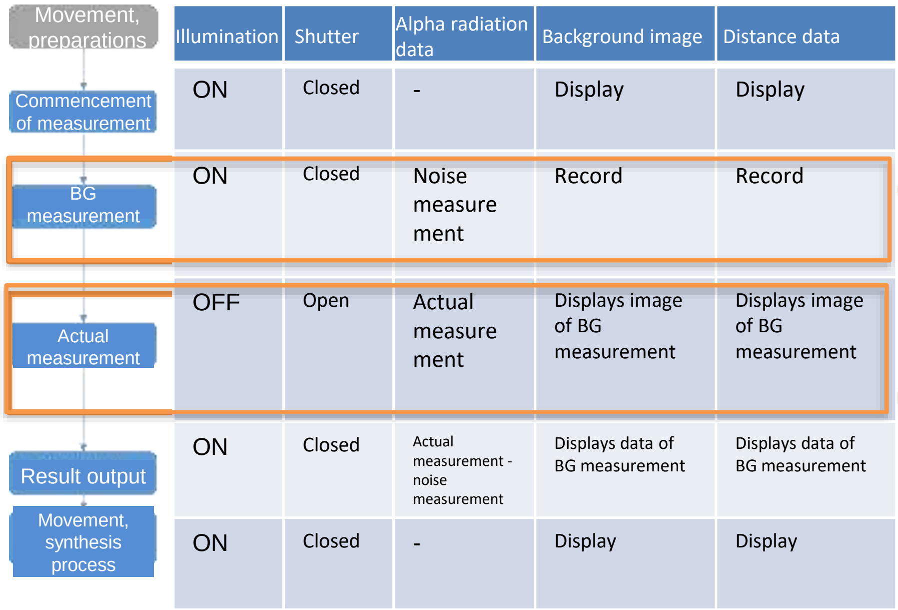
(b) Development of contamination evaluation technology for solid waste segregation - Verification of improved alpha camera performance (1/2) -

■Purpose of implementation

To re-evaluate the basic performance of an alpha camera with improved countermeasures for ghost-peak and shielding structure.

■Implementation details (Overview)

- Software developed in FY2018 was modified in accordance with the changes in optical system and power ON/OFF operation. (Fig. 1 – Fig. 3)
- Alpha radiation measurement sensitivity, angle of view, position resolution etc. were evaluated.



Movement, preparations	Illumination	Shutter	Alpha radiation data	Background image	Distance data
Commencement of measurement	ON	Closed	-	Display	Display
BG measurement	ON	Closed	Noise measurement	Record	Record
Actual measurement	OFF	Open	Actual measurement	Displays image of BG measurement	Displays image of BG measurement
Result output	ON	Closed	Actual measurement - noise measurement	Displays data of BG measurement	Displays data of BG measurement
Movement, synthesis process	ON	Closed	-	Display	Display

Fig. 1 Alpha camera measurement flow diagram

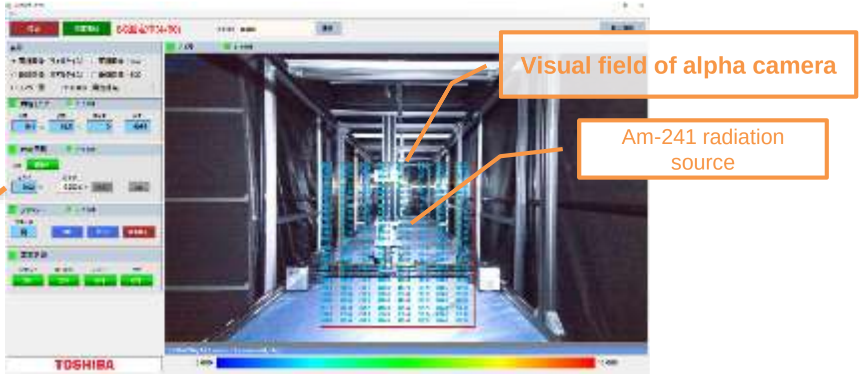


Fig. 2 Alpha camera software screen (During BG measurement)

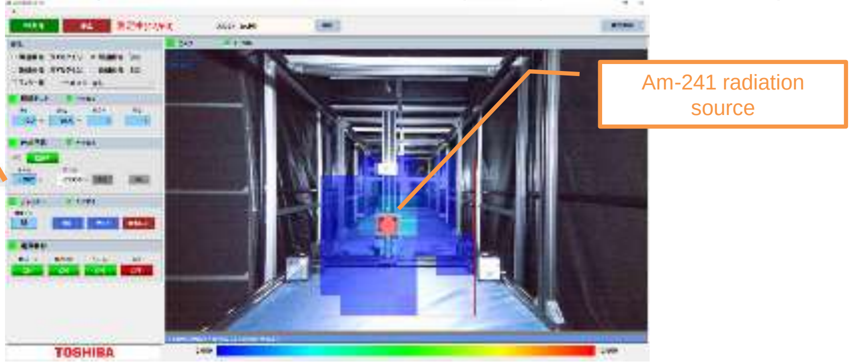


Fig. 3 Alpha camera software screen (During actual measurement)

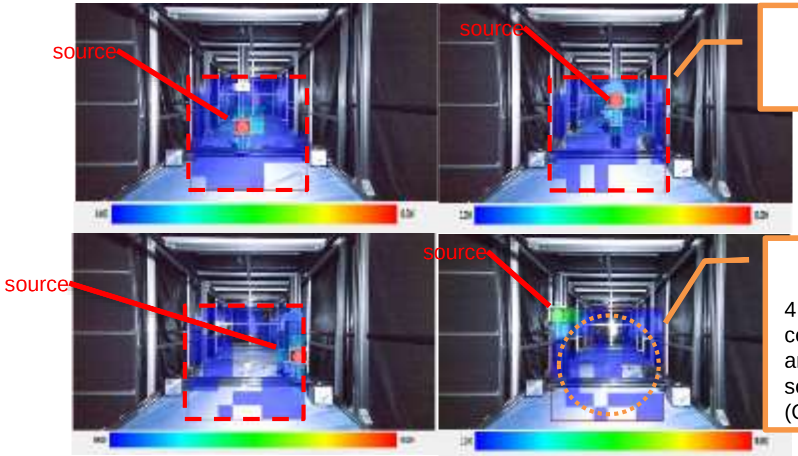
(b) Development of contamination evaluation technology for solid waste segregation
- Verification of improved alpha camera performance (2/ 2) -

■Implementation results

・Issues identified in FY2018 were resolved and evaluation of the basic performance of alpha camera was completed (Table 1)

Table 1 Overview of test methods and results

No.	Items	Test Methods	Results	Remarks
1	Sensitivity to alpha rays	Install 3 types of standard sources (10 cm square, thin plate) with different intensities at a distance of 1 m and carry out measurement.	0.23 s^{-1}/ (Bq/ cm^2)	Sensitivity is reduced by about 20% as compared to last fiscal year based on the review of optical filter.
2	Measurement angular field	Install Am-241 source of Φ36 mm 1 m ahead and evaluate the sensitivity at each position within the visual field.	Confirmed that ideal measurement angular field: 27.2° x 27.2° Effective measurement angular field: φ25.2°	Refer to Fig. 1. Area where sensitivity at 80% or above can be achieved is defined as an effective angular field.
3	Position resolution	Evaluate position resolution from measured distribution by simulating Am-241 point source at the aperture.	±21 mm	Major factor is the expansion of alpha ray-emitting region and dependence on measurement distance is less.
4	Distance property	Carry out measurement by changing the installed position of Am-241 source between 0.5 m – 3 m.	・Confirmed that it is inversely proportional to the square of distance. ・Confirmed that it can be corrected with distance data.	Refer to Table 2.
5	Sensitivity to beta rays	Measure Sr/ Y-90 source (9kBq) and evaluate sensitivity to beta rays.	0.05% of alpha ray sensitivity or less	Effect is reduced by an order of magnitude as compared to FY2018 results based on the review of optical system.
6	Sensitivity to gamma rays	Evaluate incidence angle dependence with irradiation facility.	2.0 s^{-1}/ (mSv/ h)	Improved as compared to 3.3 s^{-1}/ (mSv/ h) of the FY2018 results. Refer to improvements in shielding structure.



Ideal measurement angular field
(Red dashed line)

Effective measurement angular field
4 corners are far from the center of the measurement angular field, hence sensitivity is reduced.
(Orange dotted line)

Fig. 1 Measurement results for each source position

Table 2 Distance property and correction results

Distance [m]	Counting rate [S^{-1}]	Corrected counting rate [s^{-1}]
0.5	64.7	-
1	17.8	17.8
1.5	7.3	16.4
2	4.2	15.8
2.5	3.0	18.5
3	2.0	17.4

(b) Development of contamination evaluation technology for solid waste segregation
- Evaluation of measurement performance using unsealed source (1/ 5) -

■Purpose of implementation

Test was performed in FY2018 using the metallic sealed sources, thinned flat plate and thinned disc. However, it is assumed that irregular contamination occurs on non-metals such as concrete etc. on the site. Hence, the purpose is to conduct a test assuming contamination closer to the site and clarify the locations for application.

■Implementation details (Overview)

Multiple types of Am-241 [#1] unsealed sources were developed and combined with sealed sources to conduct the following tests. Further, in each test, the difference in measurement results was quantitatively evaluated by comparing with the existing detector (ZnS survey meter etc.).

#1：Nuclide specified with JIS4329:2004 radioactive surface contamination survey meter

Table 1 Test items

#	Test items	Test methods	Parameters
1	Performance evaluation for measurement of structures assuming the floor and walls at the site	Measurement of unsealed source by applying alpha radioactivity to concrete	Concrete surface painted or not
2	Evaluation of measurement performance in case of complex contamination profiles	Measurement by combining unsealed/ sealed sources and changing the surface contamination profile	Source profile

(b) Development of contamination evaluation technology for solid waste segregation

- Evaluation of measurement performance using unsealed source (2/ 5) -

■ **Implementation results**

- Factors behind the impact on lower detection limit with respect to surface contamination density were consolidated. (Fig. 1)
- Source profile and source surface profile were identified from these factors.
- Sources with different profiles and concentrations were created and measurement sensitivity was evaluated.

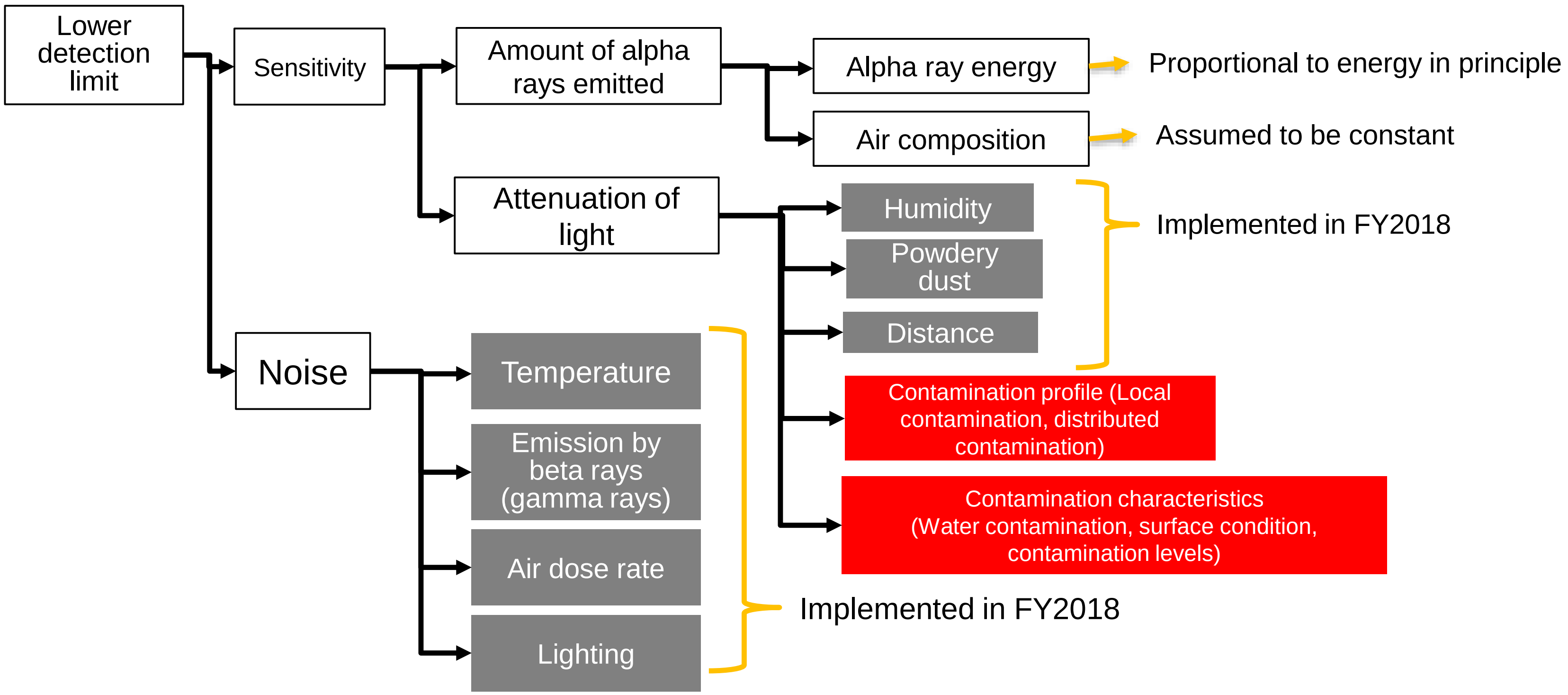


Fig. 1 Analysis tree for the factors influencing the lower detection limit

(b) Development of contamination evaluation technology for solid waste segregation - Evaluation of measurement performance using unsealed source (3/ 5) -

<Method for creating unsealed contaminants and test items>

Table 1 Test items and method of creating specimen

Evaluation items		Method of creating specimen	Test method
Contamination profile	Local contamination	Put drops of Am-241 on concrete. Use quantity of liquid dropped and concentration (Bq/ cc) as parameters.	Evaluation of sensitivity to alpha rays in different conditions
	Distributed contamination	Change the profile by tiling solid concrete with various contamination levels. (Fig. 1, Fig. 2)	
Contamination characteristic	Water contamination	Put drops of Am-241 on solid concrete and create aqueous Am-241 source. Change the moisture content with or without drying.	Comparison of sensitivity to alpha rays with surface roughness of each material
	Surface condition	Put drops of Am-241 on concrete (blasting process, solid, epoxy painting) and on the top of flat metal plate. (Fig. 3)	
	Contamination level	Use solid concrete with varying contamination levels.	Measurement of sensitivity to alpha rays

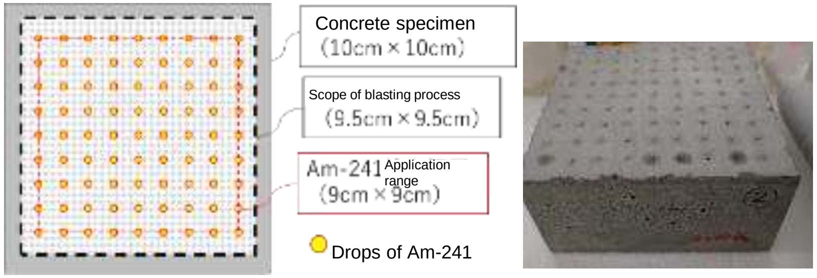


Fig. 1 Concrete source (solid) for tiling

Fig. 2 Condition of tiling for distribution measurement

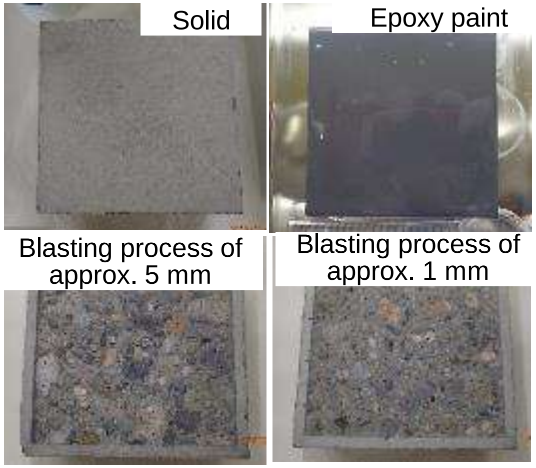


Fig. 3 Appearance of each concrete

(b) Development of contamination evaluation technology for solid waste segregation
- Evaluation of measurement performance using unsealed source (4/ 5) -

<Test Results Summary>

Evaluation was performed on the effects of moisture content and surface roughness of the measured object on the sensitivity.
In future, a study will be conducted on the evaluation of alpha contamination distribution while checking the surface condition of the measured object through the camera image.

Table 1 Test Results (Summary)

Test Name	Test Method	Results	Remarks
Contamination level	Apply radioactivity of 40 to 4000 Bq (0.4 to 40Bq/ cm^2) to solid concrete and carry out measurement from a location 1 m away.	Confirmed the counting rate in correspondence with concentration.	Refer to .Fig. 1
Local contamination	Control the amount of Am-241 source dropped onto the specimen, create source with a size ranging from φ 6 mm to φ 12 mm and carry out measurement from a location 1 m away.	Confirmed that sensitivity tends to increase when the size of the source is small.	It is assumed that emission spreads over multiple pixels if the size of the source is large.
Distributed contamination	Lay solid concrete tiling of 10 cm x 10 cm and carry out measurement from a location 1 m away. Compare tile laying and counting rate.	Confirmed that distribution can be measured approximately.	Refer to the next page.
Water contamination	Take 20 ul of solvent containing Am-241 at approx. 400Bq, put drops of this solvent onto solid concrete, and perform measurement before and after drying the solvent. Compare the sensitivity.	Confirmed that sensitivity will reduce to 44% when the cement contains moisture.	Refer to Fig. 2.
Surface condition	Apply Am-241 at 4 Bq/ cm^2 in the form of mesh on solid concrete, painted concrete and blasted concrete (2 types) with different surface roughness and carry out measurement from a location 1 m away.	・The higher the surface roughness, the more the sensitivity. ・Blasted concrete was found to be 6 times more sensitive than solid concrete.	・It is assumed this it is because of the increase in surface volume and increase in the rate of release into air. (Refer to Fig. 3)

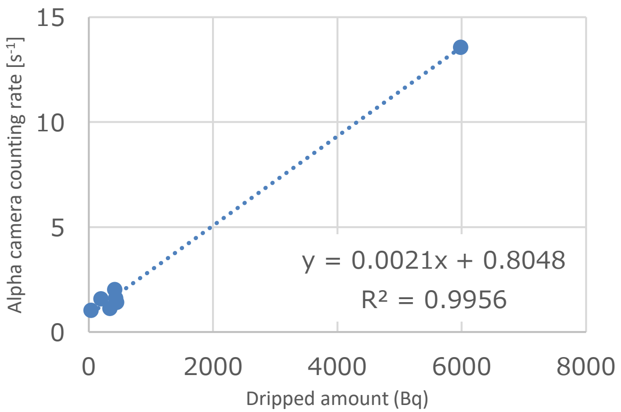


Fig. 1 Linearity at solid concrete source

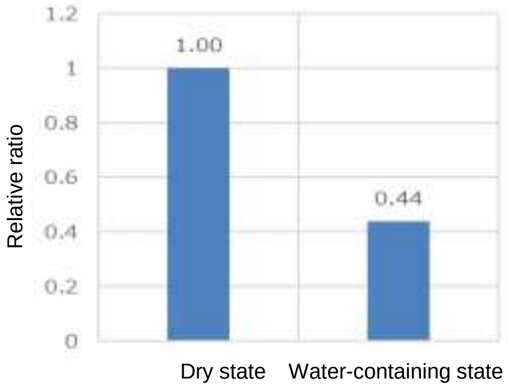


Fig. 2 Comparison of presence of water in contaminated area

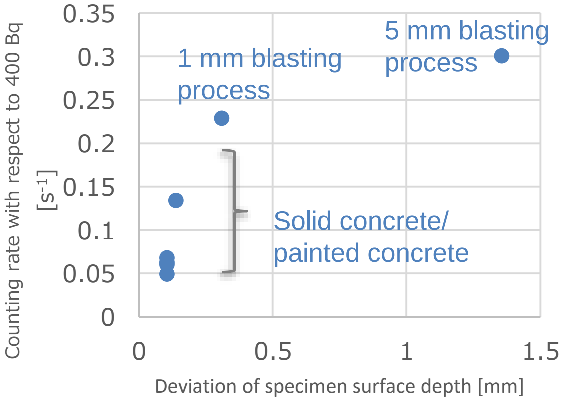


Fig. 3 Correlation of counting rate with surface roughness

(b) Development of contamination evaluation technology for solid waste segregation
- Evaluation of measurement performance using unsealed source (5/ 5) -

<Test Results (Effects of source distribution)>

- It was confirmed that distribution can be measured roughly in accordance with source radioactivity distribution.
- It was confirmed that the counting rate tends to increase depending on the expansion of light emitting area surrounding the pixels with high radioactivity.

Placement of source (Numbers specified in the squares represent radioactivity [Bq])

Equivalent to 1 pixel of alpha camera

Blurring due to expansion of emission

Fig. 1 Example of source placement and measured results (A section)

(b) Development of contamination evaluation technology for solid waste segregation - Addition of the function for mapping measurement results (1/ 2) -

■Purpose of implementation

Lower detection limit in alpha camera depends on measuring distance and environment. Hence, the purpose is to study the method for correcting the measurement results so as to enable evaluation with same standards using measuring distance and environmental conditions.

To develop a software by integrating the measurement results at multiple locations (creating a panorama) based on the software that synthesizes contour diagram with camera image created in FY2018.

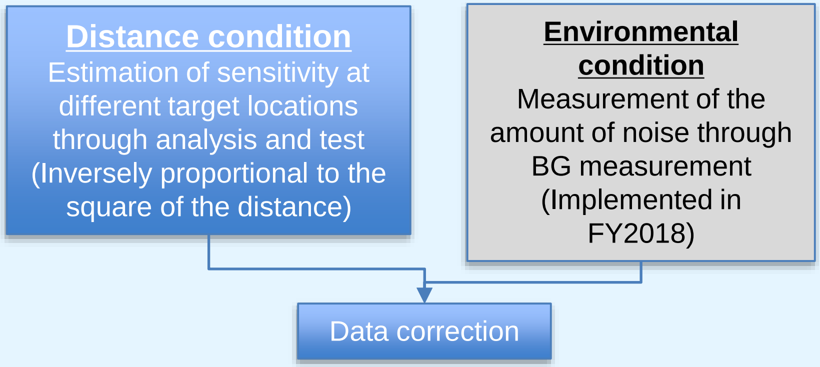
■Implementation Details (Overview)

1. Development of function for correction of measuring distance and environmental conditions
2. Development of software by integrating the results of measurement at multiple locations

1. Development of function for correction of measuring distance and environmental conditions

・It was confirmed in a FY2018 test that sensitivity [S^{-1}/ Bq/ cm^{2}] to alpha rays is inversely proportional to the square of the distance.

・Conduct a study on the addition of function for sensitivity estimation and study the methods for data correction while including the deviation in horizontal position within the angle of view.



Distance condition
Estimation of sensitivity at different target locations through analysis and test (Inversely proportional to the square of the distance)

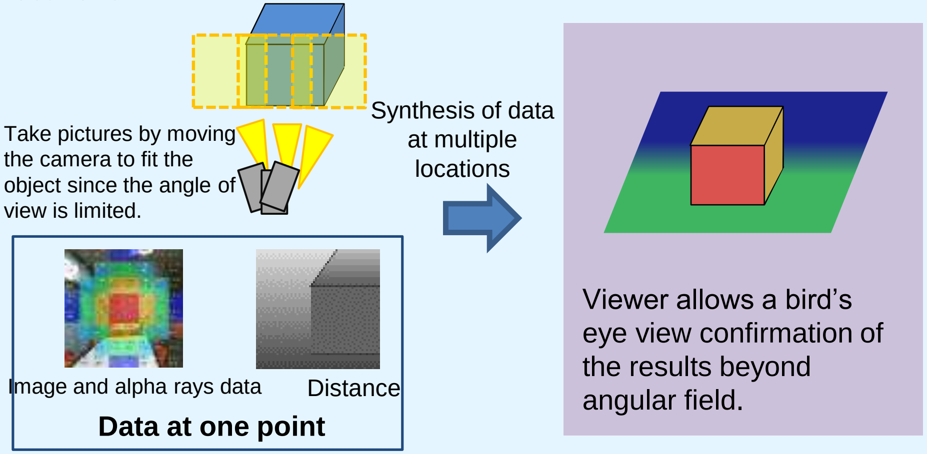
Environmental condition
Measurement of the amount of noise through BG measurement (Implemented in FY2018)

Data correction

Fig. 1 Data correction flow

2. Development of software by integrating the results of measurement at multiple locations

Develop viewer software that allows a bird's eye view of the synthesized data and the algorithm for synthesizing the sensor information (image, alpha dose, distance) acquired at multiple locations.



Take pictures by moving the camera to fit the object since the angle of view is limited.

Viewer allows a bird's eye view confirmation of the results beyond angular field.

Fig. 2 Illustration of software with overlay of images

(b) Development of contamination evaluation technology for solid waste segregation

- Addition of the function for mapping measurement results (2/ 2) -

■Implementation results

- Operation check was carried out by conducting study and test on the process flow pertaining to photographic data synthesis process at different locations resulting from pan, tilt and raising/ lowering of trolley. (Fig. 1)
- Anti-distortion measures assumed from the characteristics of 3D distance data (acquired by TOF camera), noise and color correction methods were implemented (Fig. 2) and test evaluation was performed.
- 3D data for the photographs of wall, floor and structures taken in different directions can be expressed with an image quality that is close to actual vision.

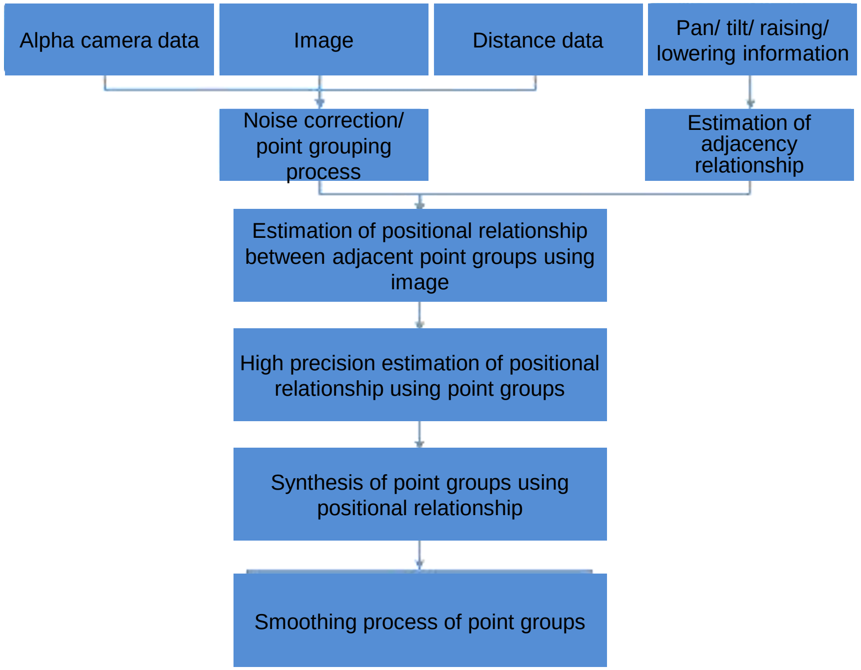
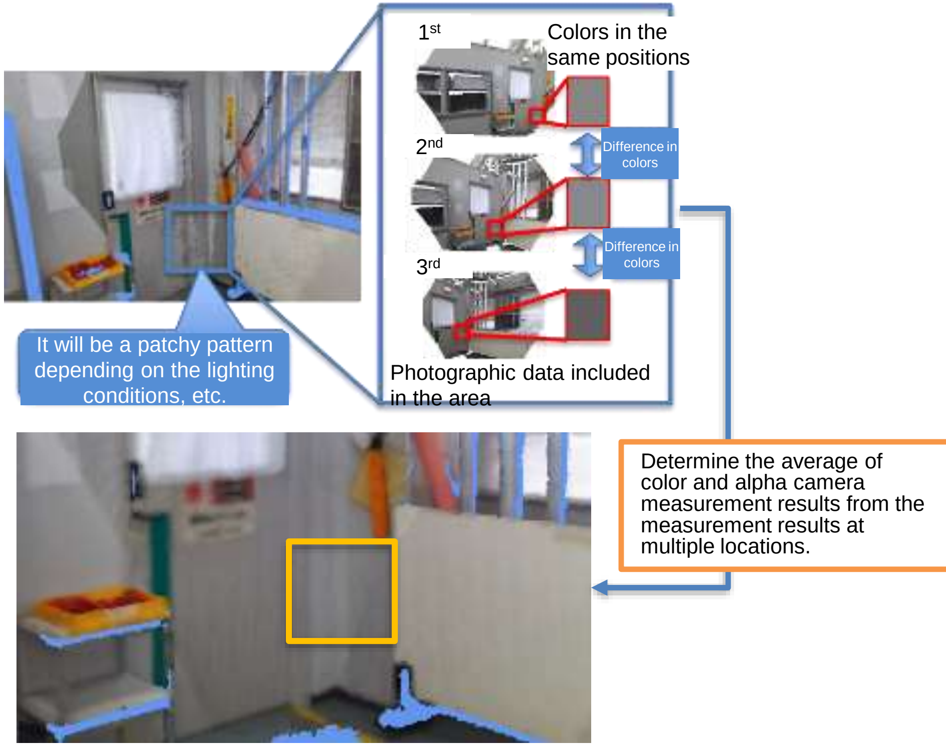


Fig. 1 Processing flow



3D data after processing

Fig. 2 Sample image of smoothing process

(b) Development of contamination evaluation technology for solid waste segregation

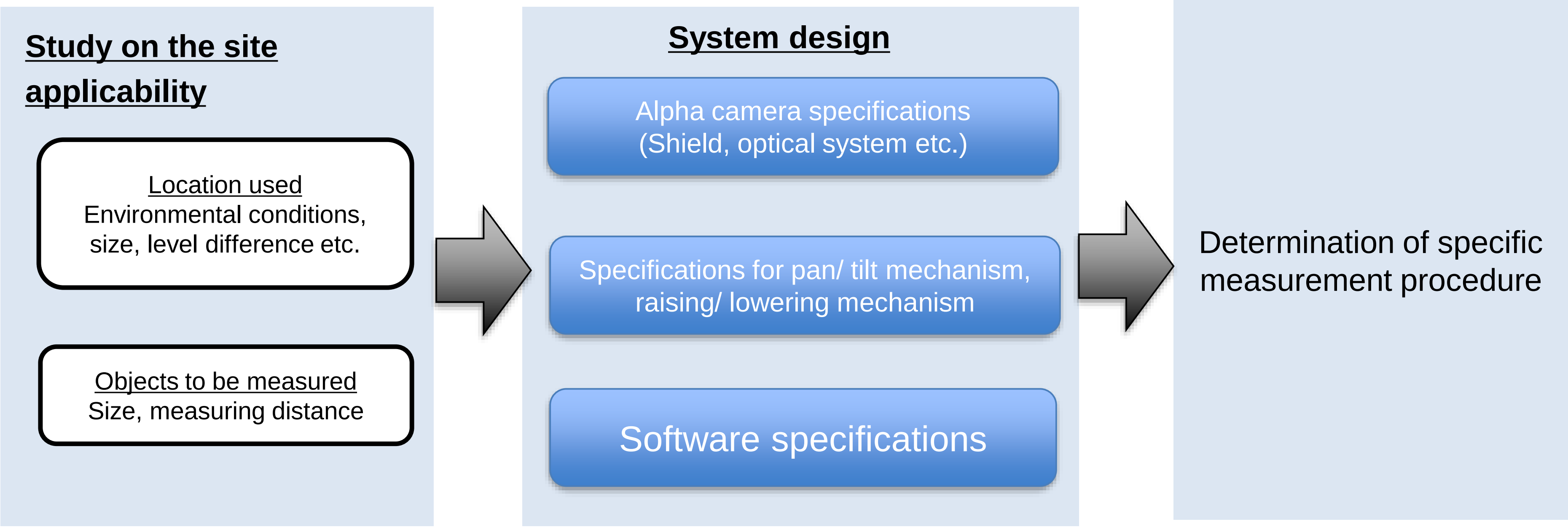
- Study on the site applicability (1/ 2) -

■ Purpose of implementation

- To conduct characterization with respect to environmental factors based on the element test results obtained until FY2018.
- To conduct study on alpha camera specifications (size, weight, measuring distance) and options for measurement objects. To clearly define the site applicability to design a system most suitable to these conditions.

■ Implementation details (Overview)

1. Study on the location used (operation floor or 1st and 3rd floor in R/ B)
2. Study on objects to be measured



Study on the site applicability

Location used
Environmental conditions, size, level difference etc.

Objects to be measured
Size, measuring distance

System design

Alpha camera specifications
(Shield, optical system etc.)

Specifications for pan/ tilt mechanism, raising/ lowering mechanism

Software specifications

Determination of specific measurement procedure

Fig. 1 System design flow

(b) Development of contamination evaluation technology for solid waste segregation

- Study on the site applicability (2/ 2) -

■ Implementation results

- Needs investigation was conducted in connection with the measurement of surface alpha contamination density. Need was identified by qualitatively assessing contamination distribution for establishing work plans such as dismantling etc. rather than segregation of wastes.
- The 3rd floor of Unit 1 R/ B, 1st floor of Units 2 and 3 R/ B and refueling floor of Unit 2 R/ B were assumed as the usage sites with high likelihood of work related to debris retrieval.
- Study was conducted on the configuration of the device to be used for distribution measurement and this information was incorporated into device specifications.

Table 1 Applicability of alpha camera

Items	Applicable conditions	Remarks
Lighting condition at measuring location	Dark room (No ultraviolet rays in particular)	・Not applicable in the presence of light that contains ultraviolet rays such as those of the sun, moon etc. ・Dark room at 0.1 lux if there are no ultraviolet rays
Dose rate in measuring environment	Max. 50 mSv/ h (Depends on low detection limit, evaluation results of last fiscal year)	Reflect the performance of the improved shield.
Surface βγ contamination density within measurement range	Max. 100 MBq/ cm^2 (Depends on low detection limit, evaluation results of last fiscal year)	Reflect the performance of the improved alpha camera.
Material of object to be measured	Concrete (solid, painted), metal. However, sensitivity reduces if object to be measured contains moisture.	Reflect the performance of the improved alpha camera.

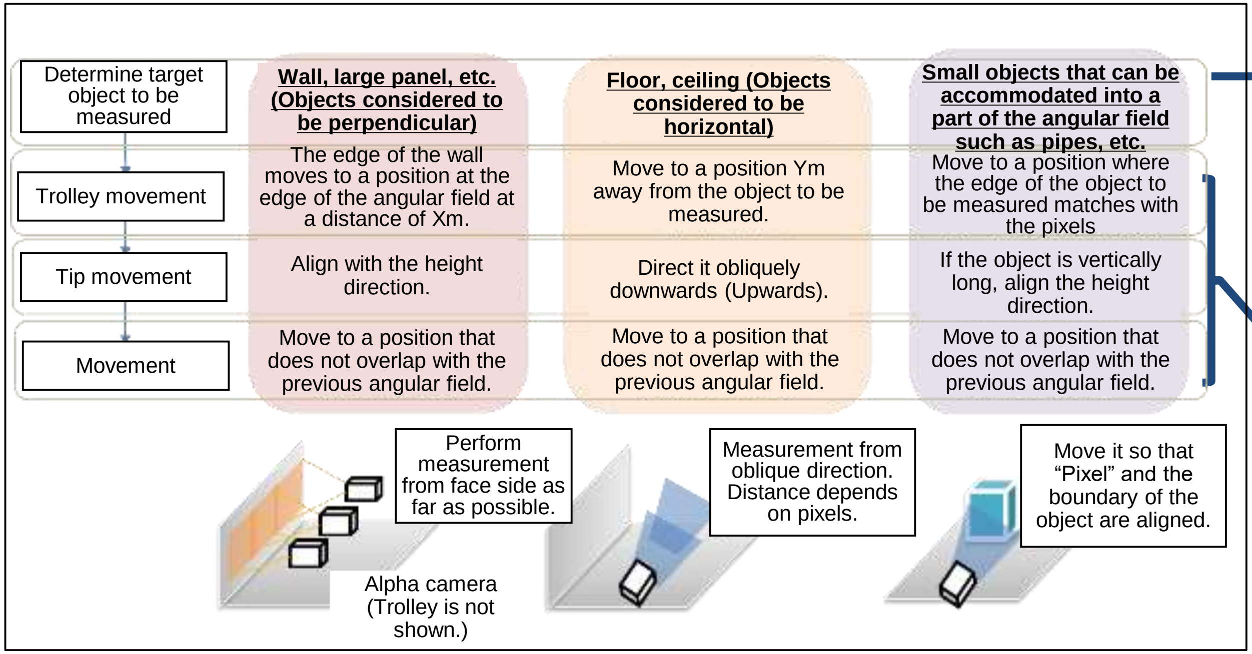
(b) Development of contamination evaluation technology for solid waste segregation
- Study on the specifications of measuring system (1/ 2) -

■ Purpose of implementation

To identify the functions required for the measuring system in conformance with site applicability. To determine the specific measurement procedure for the site based on the site applicability and decide the system specifications.

■ Implementation details (Overview)

・Study of the measurement methods in consideration of the information concerning angular field of alpha camera and changes in the characteristics depending on the measuring distance
・Evaluation of the necessary operating performance based on the studied measurement method



Determine target object to be measured	**Wall, large panel, etc. (Objects considered to be perpendicular)**	**Floor, ceiling (Objects considered to be horizontal)**	**Small objects that can be accommodated into a part of the angular field such as pipes, etc.**
Trolley movement	The edge of the wall moves to a position at the edge of the angular field at a distance of Xm.	Move to a position Ym away from the object to be measured.	Move to a position where the edge of the object to be measured matches with the pixels
Tip movement	Align with the height direction.	Direct it obliquely downwards (Upwards).	If the object is vertically long, align the height direction.
Movement	Move to a position that does not overlap with the previous angular field.	Move to a position that does not overlap with the previous angular field.	Move to a position that does not overlap with the previous angular field.

Perform measurement from face side as far as possible.

Alpha camera (Trolley is not shown.)

Measurement from oblique direction. Distance depends on pixels.

Move it so that "Pixel" and the boundary of the object are aligned.

Specification of the target objects
・Size
・Profile
・Material etc.

Specification of moving range
・Moving distance
・Types of movement (Horizontal, perpendicular, rotation)

Fig. 1 Measurement procedures studied in FY2018

Excerpts from FY2017 supplementary budget "Subsidy Project of Decommissioning and Contaminated Water Management (R&D for Treatment and Disposal of Solid Wastes (R&D for Advanced Processing and Analytical Methods))" IRID design review (G1#2) "Investigation and development of alpha contamination measurement methods"

(b) Development of contamination evaluation technology for solid waste segregation - Study on the specifications of measuring system (2/ 2) -

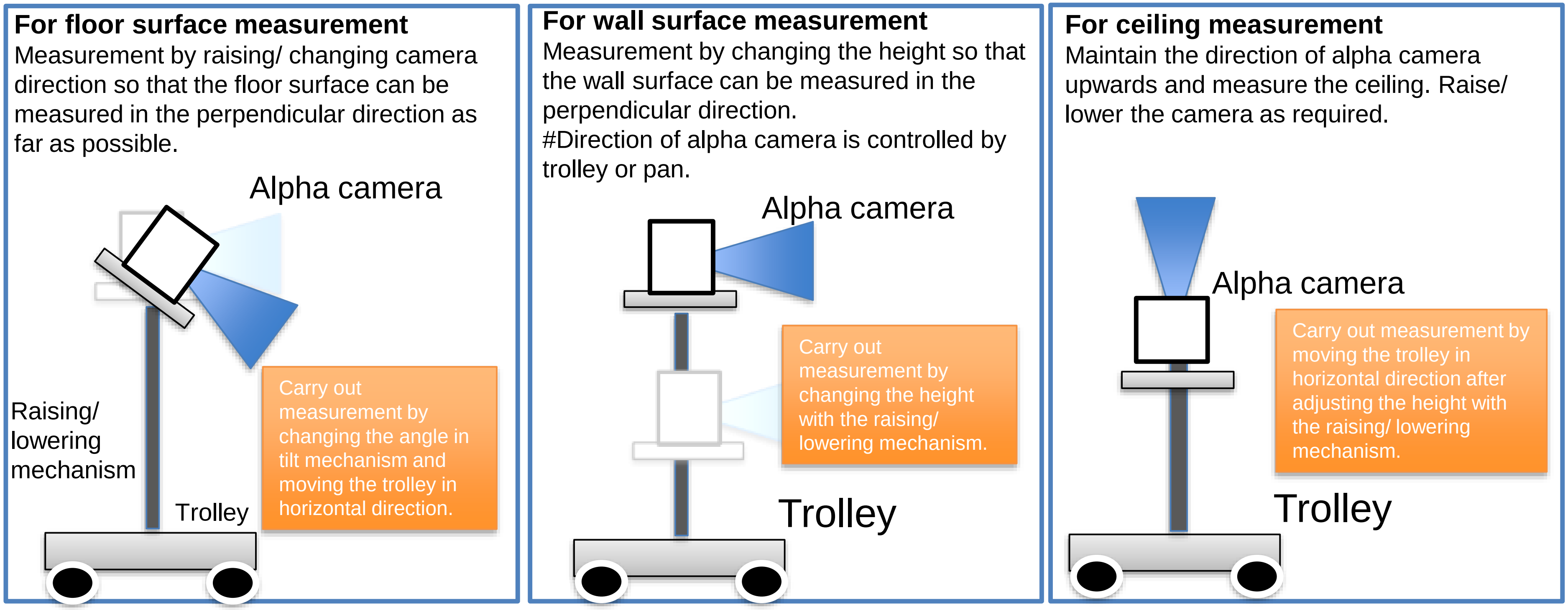
■Implementation results

・Study on the measurement method so that the distance with the target object to be measured becomes constant. (Fig. 1)

・The following functions were deemed mandatory or desirable in view of the measurement of floor surface, walls and ceiling in order to evaluate surface contamination distribution, which is the purpose of the measurement. It was decided to go for specifications incorporating both the functions.

1)Mandatory function: Tilt (Vertical oscillation) and raising/ lowering function

2)Desirable function: Pan (Oscillation in horizontal direction) function



For floor surface measurement

Measurement by raising/ changing camera direction so that the floor surface can be measured in the perpendicular direction as far as possible.

Carry out measurement by changing the angle in tilt mechanism and moving the trolley in horizontal direction.

For wall surface measurement

Measurement by changing the height so that the wall surface can be measured in the perpendicular direction.

#Direction of alpha camera is controlled by trolley or pan.

Carry out measurement by changing the height with the raising/ lowering mechanism.

For ceiling measurement

Maintain the direction of alpha camera upwards and measure the ceiling. Raise/ lower the camera as required.

Carry out measurement by moving the trolley in horizontal direction after adjusting the height with the raising/ lowering mechanism.

Fig. 1 Measurement image of alpha camera using raising/ lowering, pan/ tilt functions

(b) Development of contamination evaluation technology for solid waste segregation
- Study on mechanism specifications and control method (1/3) -

■ Purpose of implementation

It is necessary to control the measuring location and direction of alpha camera through remote operation since high radiation dose environment is expected at the site. Hence the purpose is to determine the specifications and control method for the mechanisms such as pan/ tilt, raising/ lowering mechanisms of alpha camera (approx. 150 kg or above) including the shield.

■ Implementation details (Overview)

・Study the driving mechanism of the alpha camera to enable remote operation of pan/ tilt and raising/ lowering mechanism.

・Study the system for sharing the data on measuring conditions (pan, tilt, height) required for mapping the measurement results.

・Study the fall prevention measures for alpha camera in view of emergencies such as earthquakes etc.

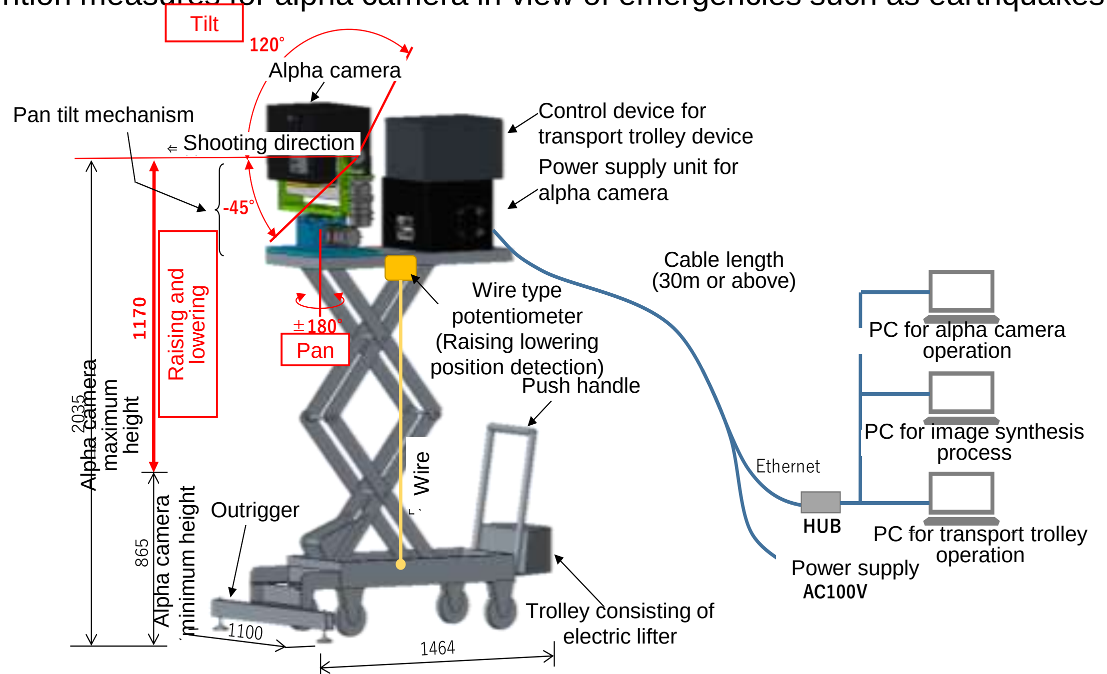


Fig. 1 Configuration of measurement system

(b) Development of contamination evaluation technology for solid waste segregation
- Study on mechanism specifications and control method (2/3) -

■Implementation results

<Trolley provided with pan/ tilt and raising/ lowering mechanisms>

- When measuring in the lower direction, the alpha camera was arranged in such a range, where the visual field of alpha camera is not obstructed by the trolley and also the alpha camera is arranged in such a position that it does not fall/ tilt while operating pan/ tilt and raising/ lowering mechanisms.
- A system that allows remote control of pan/ tilt and raising/ lowering operations was finalized. (Refer to Table 1.)

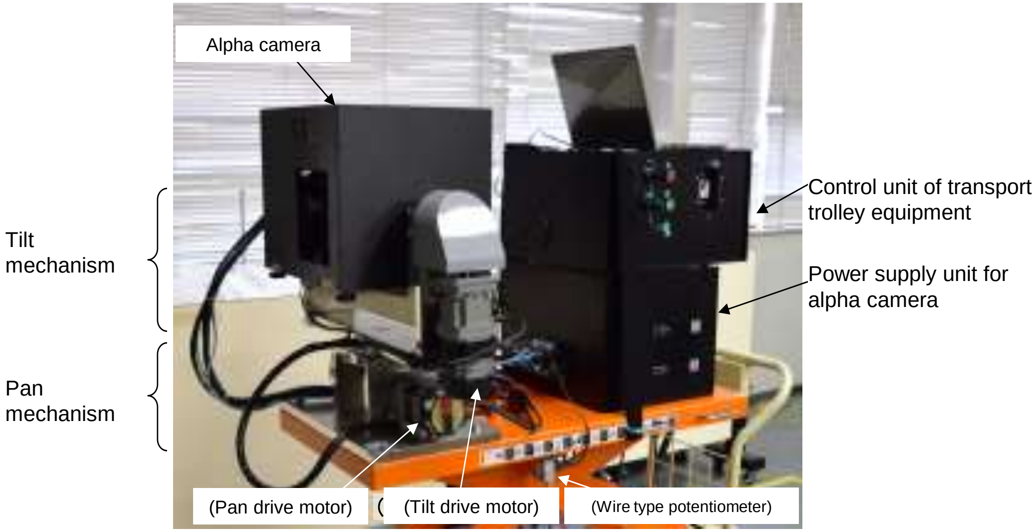


Fig. 1 Appearance of pan/ tilt mechanism

Table 1 Specifications of investigation system

Classification	Item	Requirement specifications	Remarks
Accessibility	Pan tilt range	Pan: ±180[°] Tilt: -45-230[°] (Operable upper tilt limit is till 90[°] when alpha camera is mounted. Refer to test results.)	Pan: Front face 0[°] Tilt: Horizontal 0[°]
	Raising/ lowering stroke	1170 [mm]	
	Alpha camera height	Raising/ lowering at the lower end: From floor surface 865 [mm] Raising/ lowering at the top end: From floor surface 2035 [mm]	Camera optical axis height
Axial direction measurement method	Pan tilt angle	Motor-mounted resolver	
	Raising/ lowering position	Wire type potentiometer	
Driving system	Pan tilt axis	Stepping motor with brakes	
	Raising and lowering axis	Motor pump driven hydraulic cylinder	Motor-operated lifter mounted
Control system	Pan tilt axis Raising and lowering axis	Target angle control: JOG operation (operation while pressing operation button) Target position control: JOG operation (operation while pressing operation button)	Acceleration/ deceleration control Constant speed operation by ON/ OFF control
Mobility	Movement method Fall prevention	Movement by hand pushing Installation of outrigger when alpha camera is raised to a higher position by raising/ lowering operation	Safety measures during earthquake etc.
	With/ without cable	With cable (AC100V cable and Ethernet)	Ethernet can be wireless in the current system too.
Remote operation	Operating area	Operation is allowed from a remote location of 30 [m] or above using the PC available for operation.	
	Communication system	Ethernet	
Weight/ contour	Weight	Pan tilt mechanism: 42 [kg] Control device: 16 [kg] Lifter trolley: 183 [kg]	(Weight of each single unit)
	Contour	Raising/ lowering at the lower end: [redacted] Raising/ lowering at the top end: [redacted] (Alpha camera, outrigger included)	Width (W) without outrigger is 759 [mm]

(b) Development of contamination evaluation technology for solid waste segregation
- Study on mechanism specifications and control method (3/3) -

<Image synthesis test>

・The pan/ tilt and raising/ lowering operations can be carried out with the alpha camera with shield mounted.

・It is confirmed that the measurement results (background image, distance data) for 45 conditions can be synthesized to 3 dimensional data.

Table 1 Synthesis data measuring conditions

	Raising/ lowering amount [mm]	Pan [°]	Tilt [°]	Acquired image count
Parameters	78 mm	0,20,40,60,80 (5 conditions)	-20,0,20 (3 conditions)	15
	493 mm	0,20,40,60,80 (5 conditions)	-20,0,20 (3 conditions)	15
	883 mm	0,20,40,60,80 (5 conditions)	-40,-20,0 (3 conditions)	15

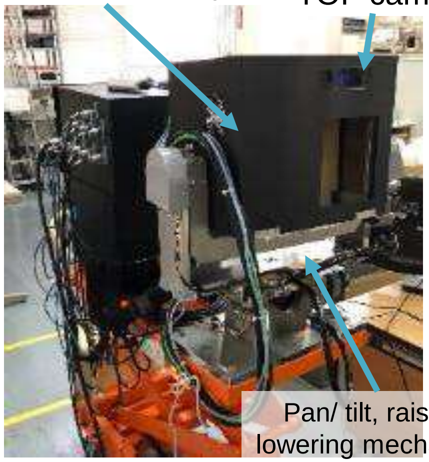
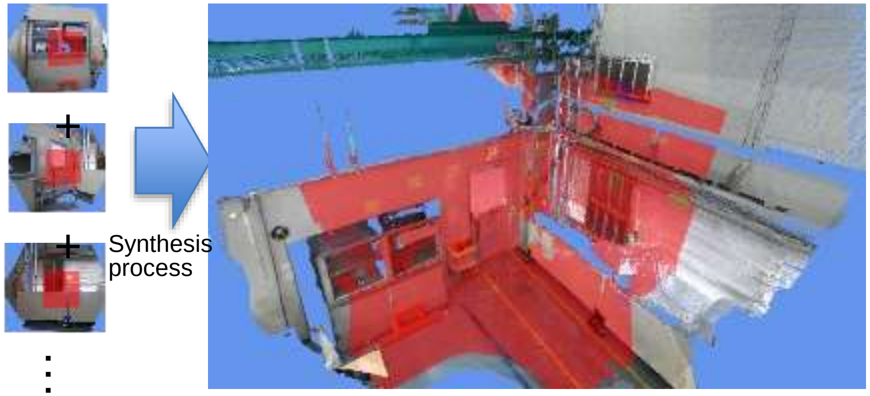


Fig. 1 Picture of the equipment



45 conditions (15 x 3) image

Blue portion: Range in which distance data cannot be acquired

Red portion: Alpha camera measurement area

Fig. 2 Example of 3D synthesis of the photographic data of multiple locations

(b) Development of contamination evaluation technology for solid waste segregation
- Fundamental verification of measurement system -

■ Purpose of implementation

・To measure alpha contamination distribution and identify the issues in measuring system as a part of fundamental verification of the examined measurement system.

■ Implementation details

・ Measurement was carried out by changing measuring direction (pan angle) with the standard alpha source arranged at multiple points in the dark room to evaluate alpha contamination distribution.

(Table 1, Fig. 1)

■ Implementation results

- It was confirmed that distribution can be viewed roughly.
- However, alpha contamination distribution is not displayed in case of source ① which lacked distance data. (Issue)
- Measurement could not be carried out for source ④220 Bq because of the distance and low surface density. (2 Bq/ cm^2).

Table 1 Am-241 source used

	Radioactivity	Profile
Source ①	2.96 kBq	100 x 100mm, flat plate
Source ②	9.4 kBq	Φ36mm, circular disc
Source ③	744 Bq	100 x 100mm, flat plate
Source ④	220 Bq	100 x 100mm, flat plate

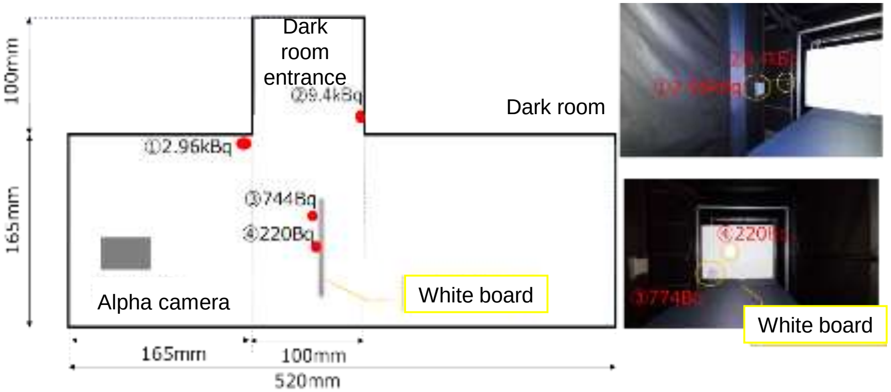
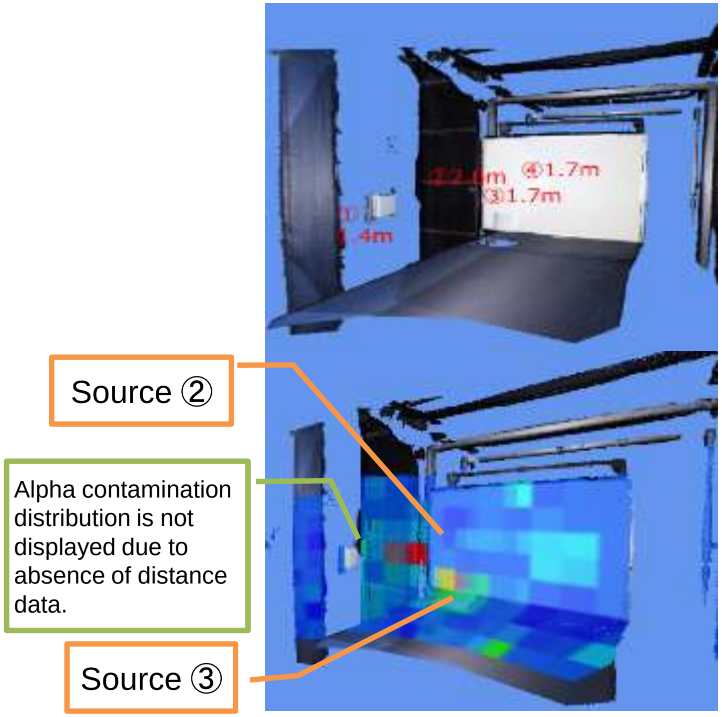


Fig. 1 Source arrangement inside dark room



Alpha contamination distribution is not displayed due to absence of distance data.

Fig. 2 Three-dimensional synthesis results

(b) Development of contamination evaluation technology for solid waste segregation

- Summary (1/2) -

<Ghost-peak countermeasures verification test>

- PMT was identified as the cause for ghost-peak formation and PMT was improved. As a result, it was confirmed that there is no ghost-peak formation.

<Improvement of prototype device>

- Shielding mechanism was designed by which shielding performance improved without blocking ultraviolet rays from alpha rays.
- It was confirmed from improved alpha camera test that alpha contamination distribution and necessary shielding performance can be achieved.

<Continuation of element test>

- The test was performed using unsealed source and the effects of source size, surface roughness of object to be measured and evaluation of moisture amount were confirmed.
- It was confirmed that sensitivity changes by 0.4 to 6 times when the surface is rough, or if there is water content.
- It is necessary to study the evaluation method for alpha contamination distribution with combined use of camera image (Issue)

<Functional addition to software>

- The function for mapping between 3D spaces by synthesizing the measurement results of multiple locations was developed.
- However, issues were identified in some objects to be measured, such as difficulty in acquisition of distance data in a few target objects to be measured, missing display and 3 dimensional data creation taking longer time (approx. 96 minutes are required for the synthesis of 15 images) etc. (Issue)

<Designing of measurement system>

- Designing of the system that can remotely control pan, tilt, raising/ lowering functions required for on-site measurements with alpha camera mounted, was completed.

(b) Development of contamination evaluation technology for solid waste segregation - Summary (2/ 2) -

<Proposal for FY2020 Implementation Plan>

① Study on the methods for determining specific measurement procedure and measurement results

・Study the methods for the evaluation of measurement methods and measurement results taking into account the effects of surface roughness of the material and issues involved in mapping to 3 dimensional model, which have been identified in this fiscal year.

② Development of investigation system for performance evaluation test and test preparations

・Carry out necessary preparations for development of required devices and required tests for performance evaluation.

③ Performance evaluation test

・Confirm measurement performance for alpha contamination distribution by applying development techniques in a beta and gamma nuclide contaminated environment.

④ Evaluation of development method for on-site applicability

・ Evaluate the applicability of development methods based on the performance evaluation test.

2. Project details

b. Establishment of the concept of treatment and disposal and development of safety assessment techniques

(a) Establishment of techniques for selecting the preceding processing method

- ① Low-temperature treatment technologies
- ② Study on the approach for evaluating the applicability of treatment technologies

(b) Presentation of disposal methods, and development of safety assessment techniques

- ① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques
- ② Development of techniques for assessing impact of affecting substances, etc. on disposal

(a) Establishment of techniques for selecting the preceding processing method

- Accomplishments till FY2018
  - ○ All the pros and cons of evaluation axes were weighed in order to assess both waste characteristics and treatment technology together and techniques (approaches) that allow diversified evaluation of technology were proposed.
  - ○ Out of the evaluation axes that were considered in connection with low-temperature treatment technology (Cement solidification, AAM solidification), with respect to the data on characteristics of solidifications, which was insufficient, data on solidifications that were not mixed with waste was acquired.

- Goals
  - ○ To acquire and evaluate data on high-temperature treatment technologies and low-temperature treatment technologies, required for identification of stabilization and solidification technology expected to be applicable to actual treatment, so as to contribute towards establishment of techniques for selecting the preceding processing method.

- Implementation items and overview

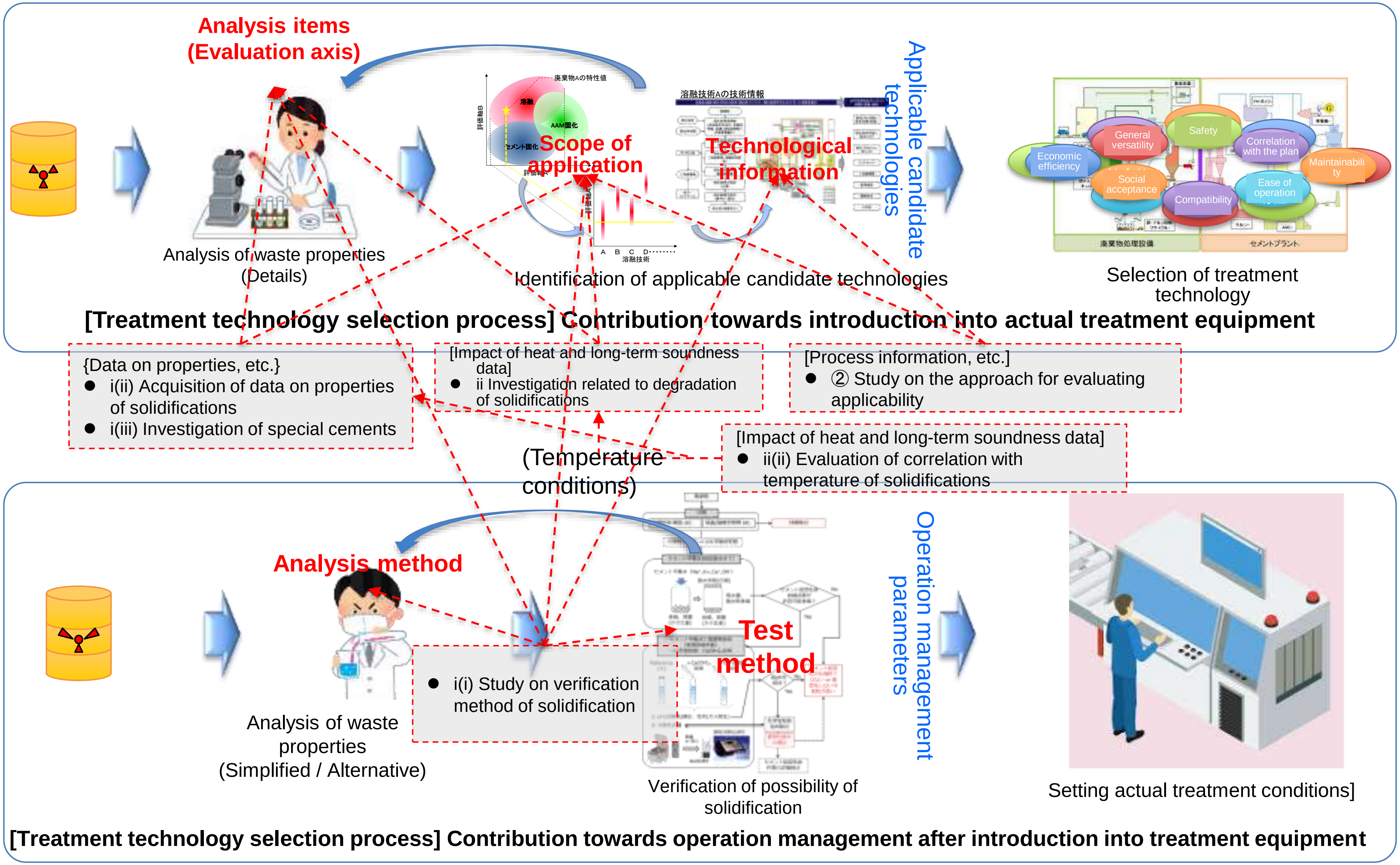
Implementation items			Overview
① **Low-temperature treatment** technologies	**i. Acquisition** and evaluation **of data** pertaining to low temperature treatment technologies, which would contribute towards identification of technology	(i) Study on **verification method** of low-temperature treatment solidification	Evaluation of applicability of test methodsto be used for determining the possibility of solidification and for setting the conditions
		(ii) Acquisition of **data on characteristics** of cement and AAM **solidifications** in the slurry	Preparation of simulated solidifications, measurement of each type of physical property and acquisition of data on characteristics
		(iii) Investigation of **special cements**	Investigation of useful special cements and acquisition and testing of data concerning Na_2CO_3 limit value, etc.
	ii. Investigation related to **degradation of solidifications**	(i) Investigation of **degradation of solidifications due to heating, etc.**	Acquisition of data based on the study and tests concerning degradation tendency due to heating, drying, etc.
		(ii) Evaluation of the correlation between inventories such as Cs, etc. and the **temperature of solidifications**	Clarification of the changes in heat conditions of solidifications depending on the difference in materials and different shapes of the containers
		(iii) Investigation and evaluation of factors having an impact on **long-term degradation**	Study and estimation of the application scope for calculation of thermodynamic equilibrium
② Study on the **approach** for evaluating the applicability of treatment technologies	**i.** Research and investigation concerning the **impact** of waste composition on the **performance of solidifications**		Study on the impact of solid waste composition on the performance of solidifications
	ii. Acquisition of data pertaining to **facility configuration, etc.** for each treatment technology		Acquisition of data on economic efficiency and addition/updating of the technological survey sheet
	iii. Investigation of **Cs volatilization volume and its control** during high-temperature treatment		Investigation of Cs volatilization and control mechanism

(a) Establishment of techniques for selecting the preceding processing method

Indicators to determine the implementation details and goal achievement

Implementation items			Implementation details	Indicators to determine goal achievement
① Low-temperature treatment	**i. Data acquisition**	**(i) Inspection technique**	Study on verification method of low-temperature treatment solidification	Presentation of proposed screening techniques to check the possibility of solidification
			Identification of the scope within which various types of low-temperature solidification are applicable	Verification of techniques and identification of scope of applicability
		(ii) Data on properties of solidifications	Acquisition of data on solidifications mixed in carbonate slurry	Management of data such as performance, etc. of solidifications when mixed with simulated carbonate slurry
			Acquisition of data on solidifications mixed in iron co-precipitation slurry	Management of data such as performance, etc. of solidifications when mixed with simulated iron co-precipitation slurry Presentation of scope of applicability concerning solidification properties
		(iii) Special cements	Investigation on available special cements	Identification of options wherein the scope is likely to broaden and understanding of the properties of base metal
			Study on the scope within which the various types of low-temperature solidification are applicable	Identification of the scope within which the various types of low-temperature solidification are applicable
	ii. Degradation of solidifications	**(i) Degradation of solidifications due to heating, etc.**	Investigation into changes in the properties due to heating/drying and study on the tendency of change in base metal properties	Presentation of the tendency of change in base metal performance
			Acquisition of data from near the inflection point at which change in properties occurs	Presentation of the scope of applicability based on the data from near the inflection point at which change in performance occurs
		(ii) Temperature of solidifications	Establishment of an analysis system and analysis concerning cement solidifications	Presentation of the correlation between cement solidifications inventory and heat
			Implementation of thermal analysis inclusive of AAM	Presentation of the correlation between cement solidifications inventory and heat, and estimated achieved temperature
		(iii) Long-term degradation	Trial run of the collection of thermodynamic data and calculation of thermodynamic equilibrium	Presentation of estimated results pertaining to changes in (Cement) mineral phase Presentation of the sufficiency of (AAM) thermodynamic data and applicability of equilibrium calculation
			Evaluation of the applicability of calculation for thermodynamic equilibrium	Presentation of the applicability of thermodynamic equilibrium calculations for phase change, and the results
② Approach	**i. Impact on the performance of solidifications**		Evaluation based on the collection of vitrification data and glass property models	Collection of data on glass properties and presentation of evaluation results pertaining to the filling density of secondary waste generated from contaminated water treatment based on Japan's National Glass Database
			Evaluation based on the US Glass Database and evaluation of the scope within which mixing is possible with respect to low-temperature treatment	Presentation of the scope within which the main secondary waste generated from contaminated water treatment can mix with glass Presentation of the scope of low-temperature treatment based on the data in ①i and ii
	ii. System configuration, etc.		Data acquisition pertaining to facility configuration, etc. for each treatment technology	Presentation of data such as facility configuration, treatment parameters, etc.
			Consolidation of investigation results for each treatment technology	Presentation of consolidated information on each technology
	iii. Cs volatilization and restraints		Consolidation of knowledge concerning Cs volatilization and control	Presentation of consolidated knowledge concerning Cs volatilization and control
			Measurement of the effect of controlling Cs volatilization during high-temperature treatment	Presentation of the effect of CS volatilization controlling techniques based on the tests

(a) Establishment of techniques for selecting the preceding processing method
- Implementation details and reflection destination-



Analysis of waste properties (Details)

Identification of applicable candidate technologies

Selection of treatment technology

[Treatment technology selection process] Contribution towards introduction into actual treatment equipment

{Data on properties, etc.}
- i(ii) Acquisition of data on properties of solidifications
- i(iii) Investigation of special cements

[Impact of heat and long-term soundness data]
- ii Investigation related to degradation of solidifications

[Process information, etc.]
- ② Study on the approach for evaluating applicability

(Temperature conditions)

[Impact of heat and long-term soundness data]
- ii(ii) Evaluation of correlation with temperature of solidifications

- i(i) Study on verification method of solidification

Analysis of waste properties (Simplified / Alternative)

Verification of possibility of solidification

Setting actual treatment conditions]

[Treatment technology selection process] Contribution towards operation management after introduction into treatment equipment

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
i. Acquisition and evaluation of data pertaining to low-temperature treatment technologies, which would contribute towards identification of technology
[Goals]

(i) Study on verification method of low-temperature treatment solidification

- To study techniques (Fig 1) for determining feasibility of solidification in advance, with respect to cement solidification and alkali activated materials (AAM) solidification, from among the low-temperature treatment solidification technologies, along with measuring the water absorbency, etc. of waste.

(ii) Acquisition of data on the properties of cement and AAM solidifications in the slurry

- To promote understanding of the solidification process phenomenon and also to acquire and present data by preparing samples (Fig 2) by mixing simulated slurries (carbonates, iron co-precipitation) individually and analyzing their strength, eluting property, etc.

(iii) Investigation of special cements

- To investigate cement based materials (Special cements) other than Ordinary Portland Cement (OPC) having characteristics designated to the required properties, in order to study their applicability to specific wastes containing components with adverse effects on Ordinary Portland Cement (OPC).

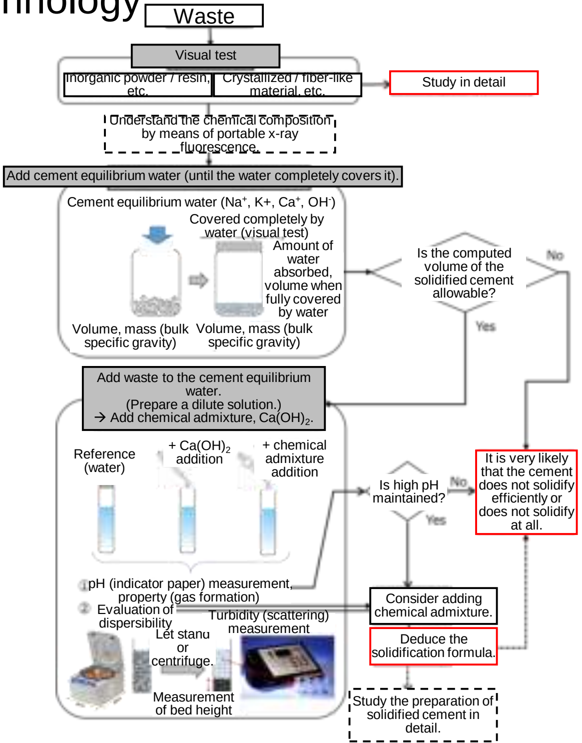


Figure 1 Example of cement solidification screening flow

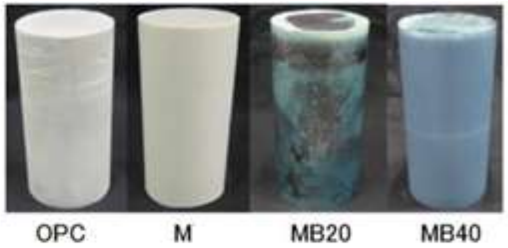


Figure 2 Example of samples
(M: Metakaolin, MB (xx): Blast furnace slag (xx) % substituted metakaolin)

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
i. Acquisition and evaluation of data pertaining to low-temperature treatment technologies, which would contribute towards identification of technology
(i) Study on verification method of low-temperature treatment solidification
[Implementation details]

Techniques for determining feasibility of solidification, with respect to cement solidification and AAM solidification, from among the low-temperature treatment solidification technologies, are studied in advance in combination with measuring the water absorbency, etc. of waste.

- Main performance required during the treatment is fluidity and factors influencing it include physical properties such as moisture content and form of waste, and chemical properties such as solubility, reactivity, etc.

- The verification method for the possibility of solidification are studied so as to simplify operation management.

- The formulated determination techniques will be reflected in the process flow, etc. created when the approaches were studied.

Year	Implementation details
2019	**Study on verification method of low-temperature treatment solidification** ・Study screening techniques to determine whether or not cement solidification is possible, while focusing on water absorption rate and solidification properties.
2020	**Identification of the scope within which the various types of low-temperature solidification are applicable** ・Verify the technique of evaluation through experiments pertaining to factors that impact the properties of solidifications and identify the applicable scope.

(a) Establishment of techniques for selecting the preceding processing method

① Low-temperature treatment technology

i. Acquisition and evaluation of data pertaining to low-temperature treatment technologies, which would contribute towards identification of the technology

(i) Study on verification method of low-temperature treatment solidification

[Study flow]

[Waste properties measurement method (left side of Figure 3)]

① Consolidate the properties that have an impact on low-temperature solidification and set the properties that need to be measured such as bulk density, absorption rate, chemical reactivity, etc.

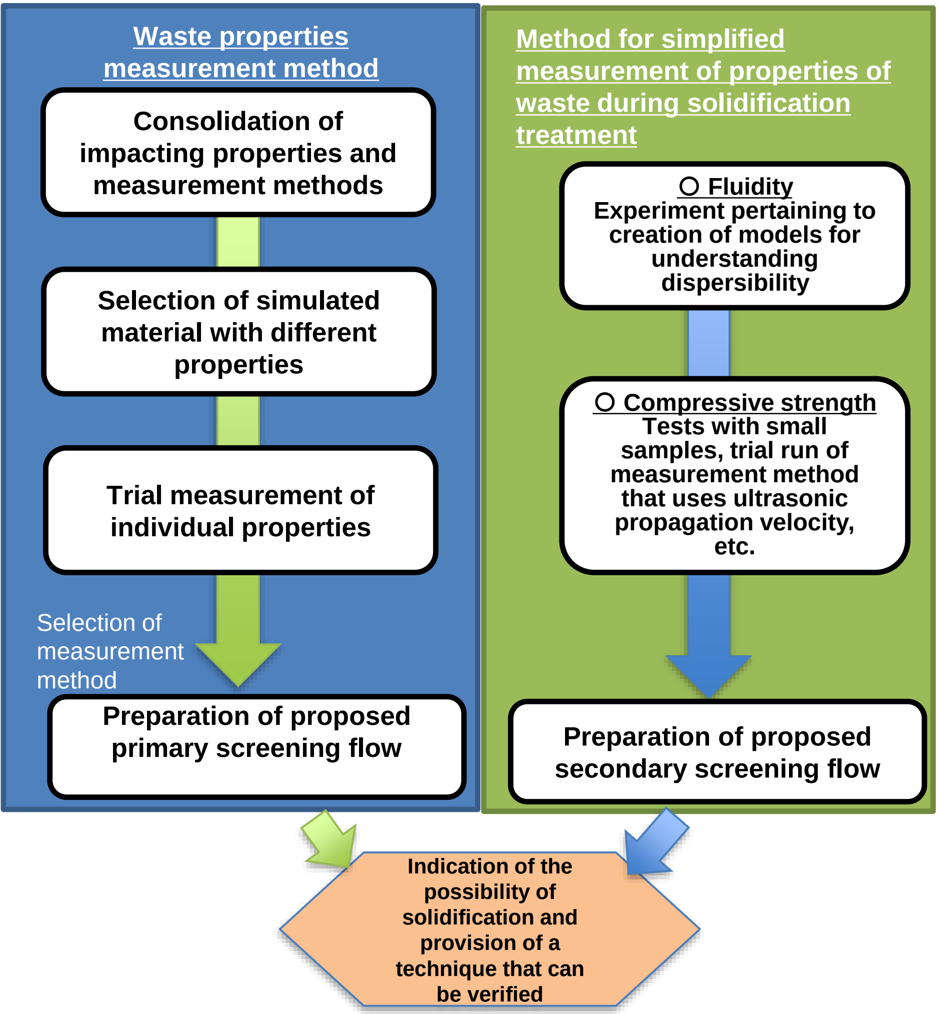
② Select material that waste is likely to contain and which is expected to lead to differences in the properties to be verified, as simulated material to be used in the trial run of the test methods.

③ Conduct a test trial, wherein individual properties set in ① are inspected in a small container, using information from other domains such as agriculture, soil, etc. as well.

④ Study the flow by combining test methods for the various properties mentioned above.

[Method of simplified measurement of properties of waste during solidification treatment (right side of Figure 3)]

⑤ In addition, study the methods for understanding fluidity and compressive strength in a much simpler manner through external measurements such as that of turbidity, ultrasonic propagation, etc.



Waste properties measurement method

Consolidation of impacting properties and measurement methods

Selection of simulated material with different properties

Trial measurement of individual properties

Selection of measurement method

Preparation of proposed primary screening flow

Method for simplified measurement of properties of waste during solidification treatment

○ Fluidity
Experiment pertaining to creation of models for understanding dispersibility

○ Compressive strength
Tests with small samples, trial run of measurement method that uses ultrasonic propagation velocity, etc.

Preparation of proposed secondary screening flow

Indication of the possibility of solidification and provision of a technique that can be verified

Fig. 3 Study items for test methods

[Study results]
- Selection of simulated material with different properties-

- ➢ A combination of properties affecting solidification and physical properties having an impact on solidification based on the investigation and findings till now, were studied. (Table 1)

Table 1 Correlation between properties of waste and properties of solidifications influencing the possibility of low-temperature solidification treatment

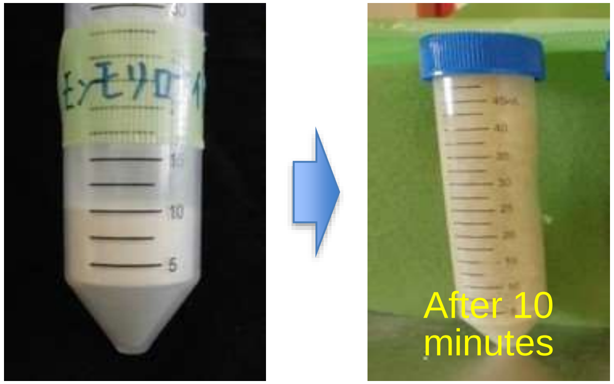
Properties of solidifications to be considered		Properties of waste													
Influencing processes	Properties	Form/size	Particle size distribution	Density	Bulk density	Moisture content	Chemical composition	Radiation dose	Properties at the time of liquid (Kneading water, etc.) addition						
									Water absorbency	Expansibility	Heat generation	Gas generation	Dispersibility	Solubility	pH
Treatment process	Working life		○				◎		◎	◎	◎		○		
	Fluidity	◎	◎	○	◎	○	◎	−	◎	◎	◎	◎	◎	◎	◎
	Homogeneity	◎	◎	○			○		△	○			◎	◎	
	Work safety						○	◎			◎	◎			
After solidification (Solids)	Strength of solidifications	◎	◎	○		◎	◎		◎	◎		◎	◎		◎
	Dimensional stability	○				○	◎		◎	◎	○	◎			
	Degradation after solidification					○	◎		◎	◎	○	○		○	○
	Nuclide fixation						◎		◎	◎					
Properties that have a major adverse impact on the feasibility of treatment process and performance of the solidifications							✓Indirect evaluation using other properties			✓	✓	✓			✓

•* (Legend) Extent of impact: (Major), (Medium), (Minor), (None), Blank (Impact unknown)

Select 12 types of simulated material (Silica sand, barium sulfate, etc.) wherein it is assumed that the properties affecting low-temperature solidification (Cement, AMM) are different, while keeping in mind the waste generated at Fukushima Daiichi Nuclear Power Station.

[Study results]
- Examples showing trial measurement of individual properties -

○ Water absorbency



Volume of montmorillonite (8g) is approx. 10cc

Status after 10 minutes since its addition to 40g pure water

Fig 4 Confirmatory results for absorbency (Expansibility) (Montmorillonite)

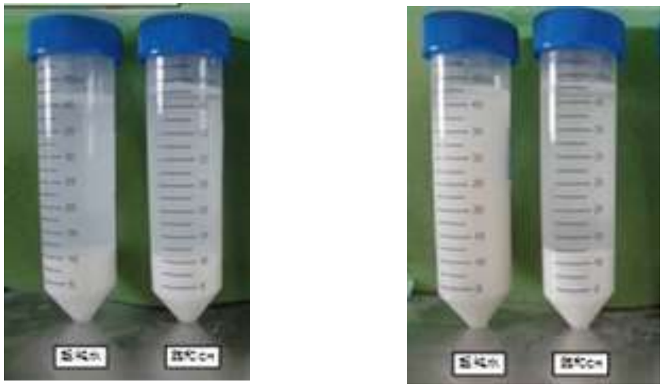
- ➢ 5 types of powders namely calcium carbonate (light, heavy), silica powder, silica sand and montmorillonite are mixed at a liquid to solid ratio 5 for 2 minutes.
- ➢ Only montmorillonite absorbs water and expands inside the entire centrifuge tube. (Fig 4)

⇒ As kneading water reduces, waste expands as well.

⇒ Even if cement solidification treatment is carried out, it is highly likely that filling rate is considerably low.

Cement solidification can be determined to be inappropriate.

○ Dispersibility



Calcium carbonate (heavy) after 180 minutes

Fine powder of silica after 180 minutes

Fig 5 Confirmatory results for solvent based dispersibility (Bulk density)

- ➢ Different solvents are added and stirred and the solution is let to stand for 180 minutes.

  Left side: Pure water; Right side: Saturated $Ca(OH)_2$ with simulated cement kneading water
- ➢ It is confirmed from the uniformly dispersed condition that the extent of dispersion varies depending on the differences in material and solvent.
- ➢ Calcium carbonate shows the same behavior in both, water and $Ca(OH)_2$ solution, whereas silica stone continues to disperse in pure water rather than $Ca(OH)_2$.

⇒ Such changes in behavior due to the combination of solid powder and solvent affect the success/failure and regulation of conditions during solidification of waste.

[Study results]
- Study of the proposed screening flow (1/2)-

- A test method (proposed) consisting of primary screening, which is the method of measuring waste properties by combining the measurements of individual properties (Step 1 to 5) (Table 2), and secondary screening involving the method of simplified measurement of properties during solidification treatment (Step 6 to 7)) (Table 3), was established.
- From amongst the investigated test methods, primary screening involved testing whether the waste does not have a detrimental adverse effect on the feasibility of low-temperature treatment solidification process or on the performance of the solidifications, using a small container (50mL small centrifuge tube).

Table 2 Primary screening (proposed)

Step	Goal (Property evaluated)	Operation	Tools used	Criteria to move on to the next Step
1	Form, bulk density	Put certain amount of sample in a centrifuge tube and after visually inspecting the form and size, tap 20 times and calculate bulk density.	Electronic balance Centrifuge tube	Reference value not known
2	Absorbency, expansibility, impact of addition of kneading water (heat generation, gas generation)	Add droplets of simulated kneading water in the centrifuge tube used in Step 1 and check for the amount of water absorbed, volume change and gas generation. Check for generation of heat using radiation thermometer.	Pipette Radiation thermometer	There shouldn't be significant expansion, excess gas generation and heat generation.
3	Dispersibility and particle size distribution in kneading water	Add simulated kneading water till the upper part of the centrifuge tube, in which Step 2 was performed, and shake it. Thereafter visually confirm the sedimentation status of the sample. (Method using turbidity meter may also be considered.)	Shaker (Turbidity meter)	Reference value not known
4 (Only cement)	Impact of adding cement suspension type simulated solution (heat generation, gas generation)	Add calcium hydroxide in the centrifuge tube in which Step 3 was performed and check for gas generation. Check for generation of heat using radiation thermometer.	Radiation thermometer	There shouldn't be excess gas generation and heat generation.
5	pH confirmation	Perform centrifugal separation for the cement using centrifuge tube after the operation in Step 4 and perform centrifugal separation for AAM using centrifuge tube after the operation in Step 3, and measure the pH of the supernatant. (It is simple to perform visual test by pouring BTB solution drop by drop.)	pH test paper, etc. BTB solution	Should exhibit alkalinity.
Confirm from the operation till Step 5 that the waste does not bring about any phenomena (significant expansion, gas formation, heat generation) detrimental to the feasibility (applicability) of treatment process.				

[Study results]
- Study of the proposed screening flow (2/2)-

- Fluidity and compression strength are evaluated in a simplified manner in secondary screening (Table 3) but study will be conducted to identify a method for screening on as small a scale (small quantities) as possible, since radioactive waste is used.

Compressive strength

・With respect to the strength of a small specimen of approx. 2cm square (1 inch cube), linearity is the same as Φ5×10 and it will be helpful in evaluating the strength easily.

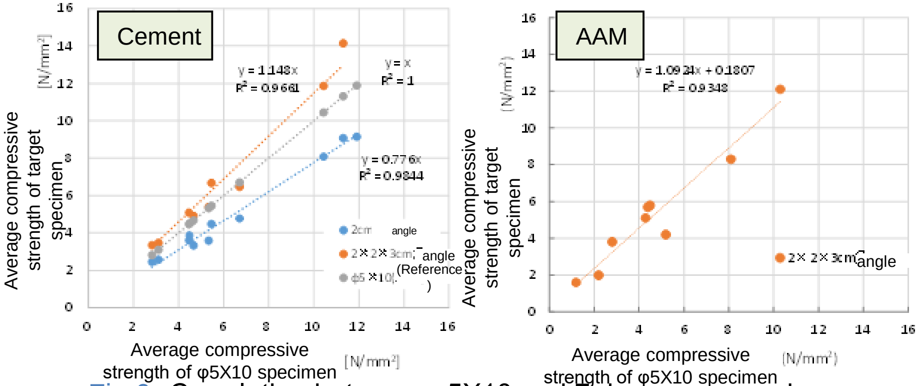


Fig 6 Correlation between φ5X10 and 7 days compressive strength of a small specimen

Required amount of sample
Φ5×10：200mL
2×2×3：12mL

Form-work made of silicon rubber with inner dimension of 2cm square

A proposal for secondary screening was made after confirming that both fluidity and compressive strength can be evaluated with about several dozen mL.

Table 3 Secondary screening (proposed)

Step	Objective (Property evaluated)	Operation	Tools used	Criteria to move on to the next Step
6	Fluidity at the time of solidification treatment	Knead the sample on a small scale (using a hand mixer, etc.) and evaluate the fluidity during solidification treatment by conducting a small scale flow test. (Perform the test by changing the composition.)	Hand mixer, etc. Small flow cone	Should satisfy the target flow.
7	Solid strength and improper condensation (working life) after solidification treatment	Knead the sample on a small scale (hand mixer, etc.), place it in a small form-work and cure it; thereafter evaluate the strength for short term i.e., 7 days, etc. Further, evaluate coagulation defects.	Small form-work Strength tester	Should satisfy the target strength.

[Study results]

- Study on the technique for predicting fluidity and compressive strength (2/2) -

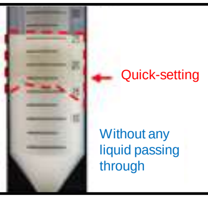
Trial screening was performed by means of the proposed test method using several materials.

Table 4 Example of primary screening verification using simulated carbonate slurry (Dried and ground

Step	1	2	3	4	5
Property evaluated	Form, size, bulk density	Expansibility, absorbency, heat generation, gas generation	Dispersibility, particle size distribution	Impact of cement uspension type simulated solution (heat generation, gas formation, etc.)	pH
Operation status					
Conditions, operation, etc.	Sample 8g	Sample 8g Amount of pure water added drop by drop 10.7cc	Amount of pure water added (Total) 40cc 60 minutes after completion of shaking	Prepare cement suspension and add simulated solution.	After shaking and centrifugal separation, add BTB to the supernatant drop by drop.
Determination	Form: Powder-like Bulk density 0.8g/cc	No expansion No heat generation No gas generation Amount of pure water added: 0.54cc/g		No heat generation No gas generation	Alkalinity (Reference) pH=10.8
Whether or not to move on to the next step	○	○	○	○	○

Study based on secondary screening

Table 5 Primary screening verification results for

Step	1	2	3～5	6
Property evaluated	Form, size and bulk density	Expansibility, absorbency, heat generation, gas formation		Fluidity Working life (condensation)
Operation status				
Operation conditions, etc.	Sample 8g	Sample 8g Amount of AAM kneading water added drop by drop 5.7cc		Composition: Filling rate 40wt%
Determination	Form: powder-like Bulk density: 0.8g/cc	Right after dripping, wet portion undergoes quick setting and expands. Severe heat generation (approx. 60℃). No gas generation.		Since the wet portion underwent quick setting right after dripping of kneading water, kneading was not possible. Severe heat generation (approx. 50℃). No gas generation.
Whether or not to move on to the next step	○	× (Quick setting and severe heat generation)		× (Quick setting and severe heat generation)

Determined as inappropriate

Certain decision can be taken regarding the applicability of cement solidification and AAM solidification.

In addition, study on estimating fluidity and compressive strength, which are the measurement items in secondary screening, was conducted along side as well, using the information obtained from primary screening.

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
i. Collection and evaluation of data on low-temperature treatment technology to contribute to the identification of technology
(i) Study on the verification method for low-temperature treatment solidification
[Summary/ Plan for the following year]

➢ Summary to date

- The physical properties that have impact on the feasibility of treatment were organized and simulated wastes with those properties were selected.
- Trial methods were performed using 50mL container for the evaluation of physical properties and proposal for screening methods was formulated by combining these methods.
- Trial screening was conducted using simulated wastes to confirm the possibility of a decision.

➢ Plan for the following year

- The validity and usability of screening flow (proposed) will be verified by using simulated dry iron coprecipitation slurry and new simulated waste materials.
- Based on the information obtained from the screening flow (planned), estimation methods for fluidity and strength will be studied. (Study on the information that would be an alternative to density information, review and study free water quantity calculation methods, etc.)
- Trials for quantification of data will be conducted.

(a) Establishment of techniques for selecting the preceding processing method

① Low-temperature treatment technology

i. Collection and evaluation of data on low-temperature treatment technology to contribute to the identification of technology

(ii) Collection of data on properties of cement and AAM solidifications for the slurry

[Goals]

Prepare specimens by mixing two types of simulated slurries (carbonate, iron coprecipitation) individually to analyze the strength, eluting property etc., and promote deep understanding of solidification phenomenon as well as acquire and present the data.

- The simulated slurry to be used will be prepared using two slurries, carbonate slurry and iron coprecipitation slurry, adjusted assuming dehydration treatment during storage.
- Conduct tests in FY2019, by mixing the carbonate slurry, and in FY2020, by mixing iron coprecipitation slurry and collect the data.

- Incorporate the collected data in the study on the applicability of OPC and AAM (approach study).
  ⇒ Evaluation axis: Solidification performance (leaching rate, hydrogen generation etc.), operability (water content in the waste, process) etc.

*Based on the results in FY2018, the plan is to conduct a study on the composition that reduces the fluidity of AAM and reduces the water content.

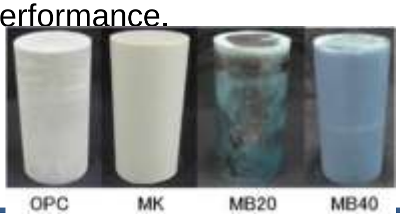
FY	Implementation details
2019	Collection of data on properties of cement and AAM solidifications for the slurry ・Collect data on each type of properties pertaining to simulated solidifications mixed with carbonate slurry.
2020	Collection of data on properties of cement and AAM solidifications for the slurry ・Collect data on each type of properties pertaining to simulated solidifications mixed with iron coprecipitation slurry and conduct a study on the applicability of OPC and AAM based on the data collected.

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
i. Collection and evaluation of data on low-temperature treatment technology to contribute to the identification of technology
(ii) Collection of data on properties of cement and AAM solidifications for the slurry
[Tests to be conducted]

Simulated slurry evaluation

Preparation conditions for solidifications and hardening properties

- Adjust the composition to prepare the specimens and conduct tests for fluidity and condensation performance.

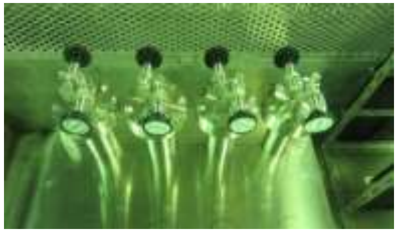


Elution properties

- Measure the components that are immersed and eluted in water. Plan for balanced elution using powder and non-balanced elution using solidifications.

Gamma radiation properties

- Evaluation of gamma radiation properties. Acquire information concerning the measurement of amount of hydrogen and evaluation of alteration of solidifications.



(a) Establishment of techniques for selecting the preceding processing method

① Low-temperature treatment technology

i. Collection and evaluation of data on low-temperature treatment technology to contribute to the identification of technology

(ii) Collection of data on properties of cement and AAM solidifications for the slurry

[Test items and parameters]

			Parameters	Selection of composition	Funnel or flow test	Viscosity test	Vicat needle test	Strength test	MIP	XRD	TG/DTA	EPMA	SEM/EDS	Liquid phase analysis	NMR	Hydrogen gas measurement	XRF	Particle size distribution
Simulated slurry evaluation			Carbonate slurry							●	●						●	●
			Iron coprecipitation slurry							●	●						●	●
Study of conditions for preparation of solidifications			M	●														
			MB20	●	z													
			MB40	●														
			OPC	●														
Hardening properties	Fluidity		M		●	●												
			MB20		●	●												
			MB40		●	●												
			OPC		●	●												
	Solidification time		M				●											
			MB20				●											
			MB40				●											
			OPC				●											
Properties of solidifications	Compressive strength		Curing period (Days)															
			3					●	●									
			7					●	●									
			28					●	●									
			91					●	●									
			Long material age 1					●	●									
			Long material age 2					●	●									
	Eluting property	Balanced solubility	Liquid-solid ratio: 5 levels															
			10							●	●			●				
			100							●	●			●	●			
			500							●	●			●				
			1000							●	●			●	●			
			2000							●	●			●				
		Non-balanced solubility	Immersion period (Weeks)															
			1						●	●		●	●	●				
			4						●	●		●	●	●				
			13						●	●		●	●	●				
	Gamma radiation property (Hydrogen generation etc.)		Ray intensity															
			Integrated dose 1					●		●	●					●		
			Integrated dose 2					●		●	●					●		
			Integrated dose 3					●		●	●					●		

•Each type of test for hardening and solidification properties is performed in accordance with representative mix determined through mix selection.

[Study Results]
- Production of simulated wastes (Carbonate slurry) -

- Compounding condition (Table 1) for the simulated dehydrated slurry (320 kg) used in the test was the same as filter press test.
- Slurry compressed by filter press, which was to be used at Fukushima Daiichi Nuclear Power Station was used (Fig. 1) while taking into consideration the storage conditions of actual waste.

Table 11 Compounding condition of carbonate slurry (Per 1m^3)

	Name	Additive amount (kg)	Remarks
A	Sodium chloride	28.5	Seawater component
B	Magnesium chloride hexahydrate	180	Seawater component
C	Calcium chloride dehydration product	79.5	Seawater component
D	Magnesium sulphate heptahydrate	6.82	Seawater component
E	Sodium carbonate	152	
F	48% Sodium hydroxide	130	Added so that slurry is maintained at pH12

Fig. 1 Slurry before compression (Left) and slurry after compression (Right)

Useful knowledge obtained through tests

Foaming occurred while washing when the filter cloth for the dehydration treatment was replaced.
It is likely to happen even when it is implemented on actual equipment.

Perform forecasting test using washing waste water in order to confirm that there is no obvious impact on solidification.

[Study results]
- Study on mixing methods for simulated wastes -

- Properties of dehydration products
  - It is like papier mâché which gets deformed when pressed firmly by hand, and has no fluidity. (Fig. 2)

  ⇒ When kneaded as is, it is not homogenized. (Fig. 3)
  - Water/ solid ratio in the dehydration product is approx. 0.47.

  ⇒ Extra water needs to be added in order to mix it in the dehydrated state and it is likely to produce excess water.

Fig. 2 Appearance of dehydration product

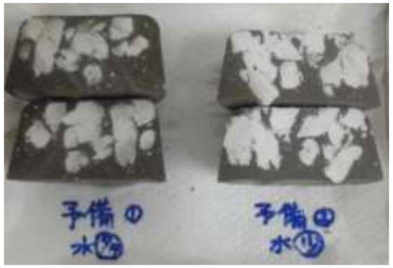


Fig. 3 Dehydration product when kneaded as is

- Mixing method for simulated wastes

Since the purpose of this research is to obtain fundamental data, such as properties during solidification and reaction between solidified materials and waste and so on, which could form an evaluation axis between treatment technologies, slurry particles and solidified particles were mixed uniformly for the test in order to be able to obtain data on properties.

Fig. 4 Drying in progress

Fig. 5 Pulverized and sieved product after drying

After drying (105℃, 24h) (Fig. 4)
Pulverized, and pulverized and sieved product (Fig. 5) is mixed with the powder of solidified material in advance.

As a result of the study, homogenous solidified sample was produced by mixing the dehydration product with dry powder in order to secure fluidity that will enable kneading without producing excess water.

[Study Results]
- Newly identified issues in actual implementation based on the study on mixing methods -

- It is necessary to establish a policy at the earliest in connection with the implementation of low-temperature treatment for dehydrated slurry since treatment process/ facilities, waste filling quantity, etc. are likely to vary considerably depending on the decision on whether to go for homogeneous solidifications or filled solidifications.
- If filled solidifications are used and if the solid needs a certain strength, it is necessary to separately confirm the strength by using the strength of the compressed material itself and filled quantity as parameters.
- In case of homogeneous solidifications, a study on appropriate pre-treatment methods such as re-fluidization of slurry after compression and so on must be conducted.
- Depending on the storage status of compressed substances, it is expected that drying and compaction of compressed substances will take place due to drying by contained radioactive decay heat and compression by laminated layers. Hence the above study that takes this into account, is necessary.

[Study Results]
- Solidified cement preparation conditions: Test method and criteria for the evaluation of composition adjustment -

- Criteria for determining the composition are set as follows.

	Fluidity	**Condensation**	**Compressive strength**
Test method	J14 Funnel flow time (JSCE-F-514 Test method for fluidity of filled mortar) 	Initial setting time (JIS R 5201 Physical testing methods for cement) 	Compressive strength (JIS R 5201 Physical testing methods for cement)  Φ 5 x 10 cm 20℃ Sealed curing
Criteria	**J14 funnel flow time =2 - 4 seconds**	Hardening took place without quick setting and without bleeding within 24 hours	**1.47 N/mm^2 or above (Material age 28 days)**

Definition of filling rate

$$\text{Filling rate (wt\%)} = \frac{\text{Wastes}}{\text{Base material powder + Base material liquid + Waste}} \times 100$$

Filling rate 30wt% Water/solid ratio 45wt% (Water-cement ratio wt80%)	**Water 31wt%**	**Cement 39wt%**	Dried and crushed carbonate **30wt%**
Filling rate 50wt% Water/solid ratio 45wt% (Water-cement ratio 164wt%)	**Water 31wt%**	**Cement 19wt%**	Dried and crushed carbonate **50wt%**

*When water/solid ratio is constant, the ratio of cement and AAM powder reduces as the filling rate increases.

[Study Results]

- Solidified cement preparation conditions (1/ 2) -

If simulated waste is filled into the solidified cement composition (water-cement ratio=45%) that was studied in the FY2018 project, there will be a considerable decrease in fluidity and a kneaded product without fluidity or without kneadability may be obtained. Hence, the properties data on fluidity, next day-hardenability (including the presence of bleeding) and compressive strength was obtained by using a composition with increased W/C and changing the filling rate of the simulated waste, to identify a composition that meets the established criteria.

Composition studied

W/C was set at 3 levels (100, 150, 200wt%) and each physical property was acquired by changing the filling rate of the simulated waste.

Table 2 Composition studied

W/C	Filling rate of simulated wastes （%）									Remarks
	0	15	20	25	30	35	40	45	50	
100	—	●	●	●	●	—	●	—	—	
150	—	—	●	—	●	●	●	—	●	
200	—	—	●	—	●	●	●	●	●	
45	●	—	—	—	—	—	—	—	—	FY2018 composition

「—」Not implemented、「●」•Physical properties acquired

Strength expression is extremely low and the composition may not solidify. Hence, not implemented.

Fluidity not achieved

Fluidity

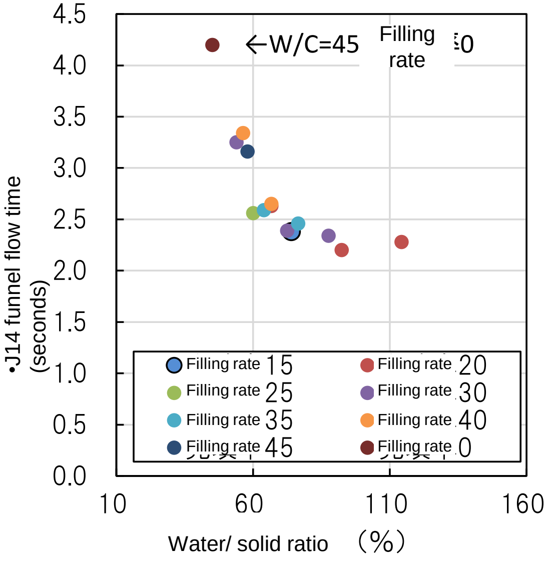


Fig. 6 Relation between water/solid ratio and flow time

*Water/solid ratio = Water weight / (Cement weight + Dry weight of the waste)

- If the relationship between water/solid ratio and flow time is organized in connection with the level at which fluidity that makes funnel test possible is obtained, the flow time increases as water/solid ratio decreases.
- All compositions that made funnel test possible were within the scope of criteria.

[Study Results]
- Solidified cement preparation conditions (2/ 2) -

Compressive strength

- Strength decreases significantly if simulated waste is filled.
- Strength decreases as water/solid ratio increases.
- Strength decreases as the filling rate increases.
- It is assumed that decrease in the amount of cement in unit volume is the cause for decrease in strength as the filling rate increases.

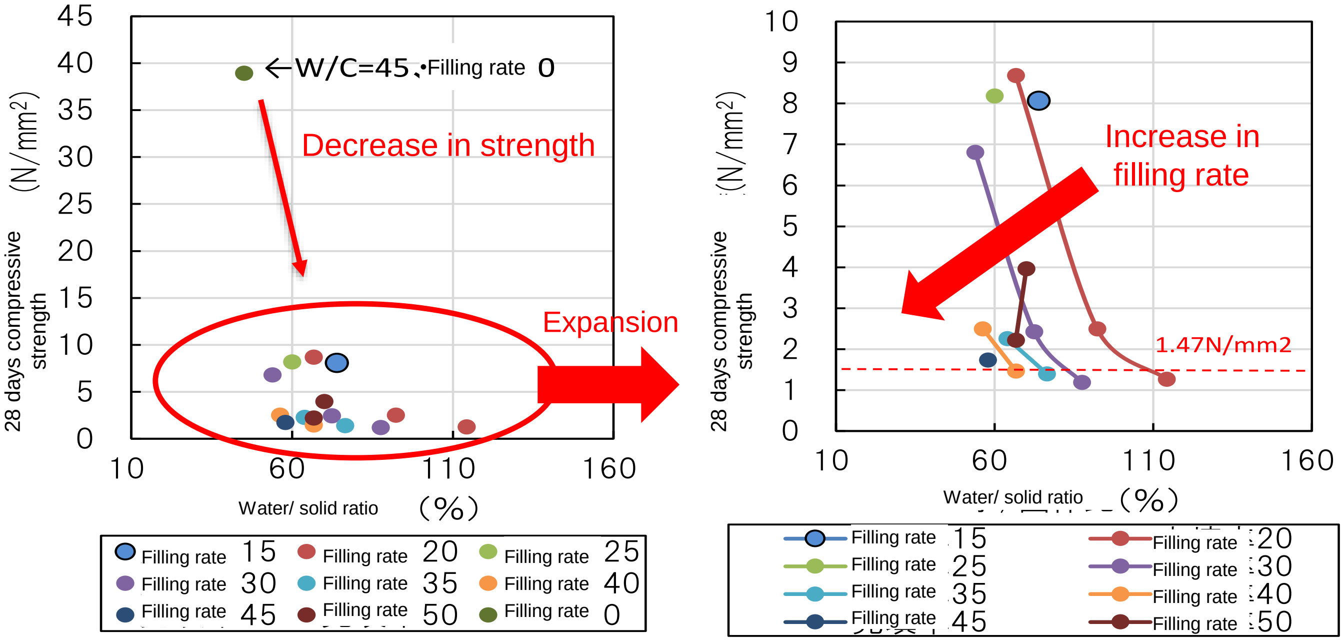


Fig. 7 Relation between water/solid ratio and compressive strength

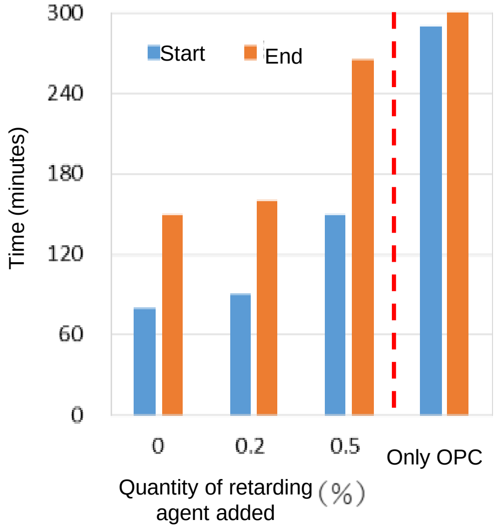
Condensation

- Bleeding occurred on the next day in the case of composition with W/C=150 and 200 and filling rate at 20wt%.
- In other compositions, bleeding did not occur on the next day and the surface hardened.

The composition "W/C=100, waste filling rate 30wt%" was selected from among the compositions that met the criteria taking into consideration the fluctuations in each physical property.

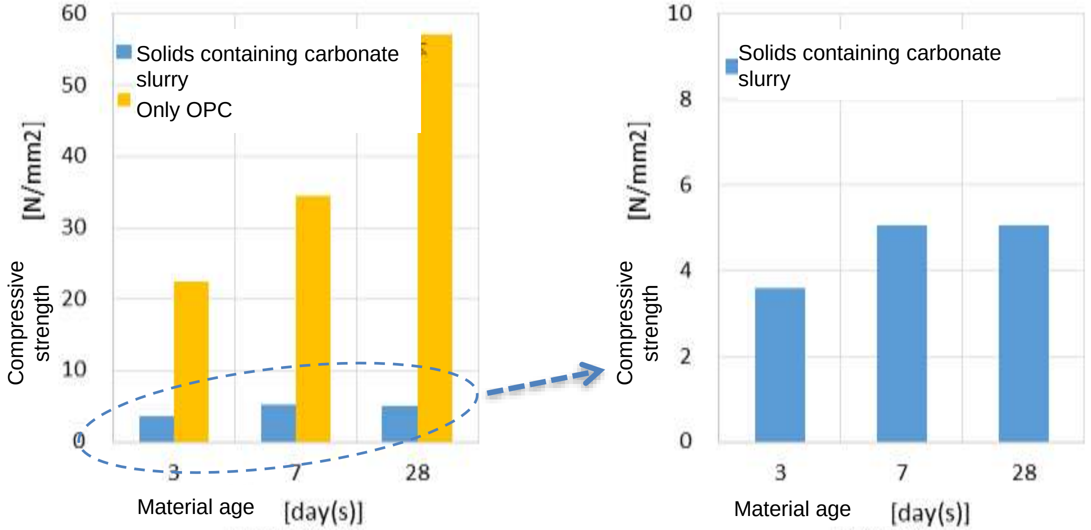
[Study Results]
- Hardening time, compressive strength -

Hardening time



The start and end of the solidified cement containing carbonate slurry (30 wt%) is faster than that of OPC alone, but the start and end times can be adjusted by the combined usage of a retarding agent.

Compressive strength

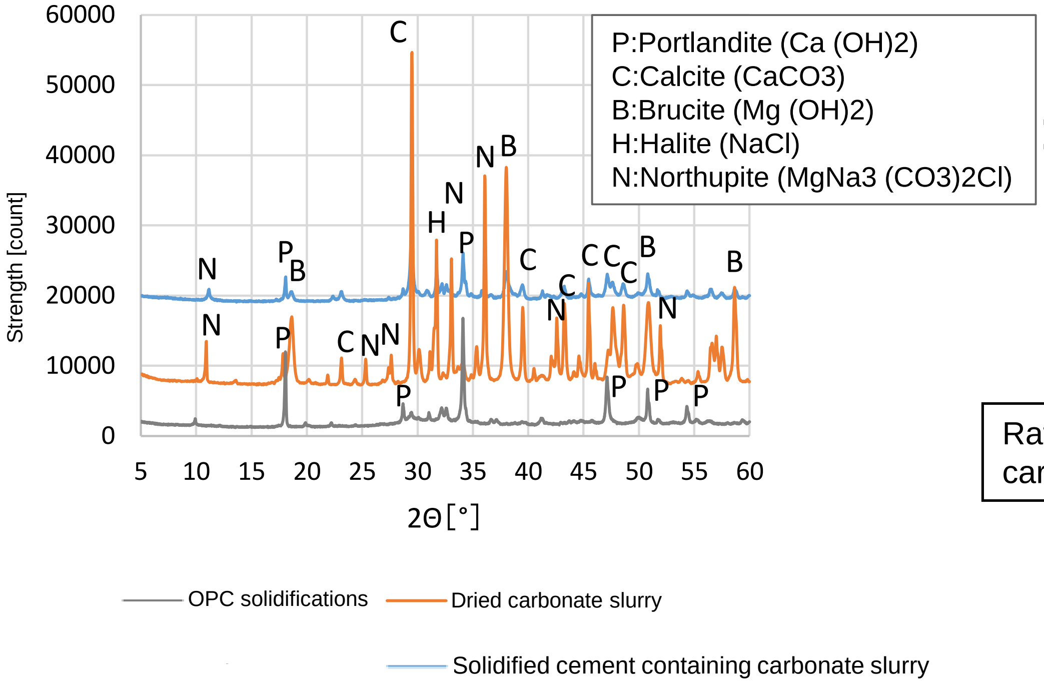


Strength of solidified cement containing carbonate slurry shows a significant decrease in strength when compared to OPC base material only.
Strength for material age of 7 days and 28 days is almost the same and there is no increase in strength.

Retarding agent: Frolic T (Super retarding agent for concrete)

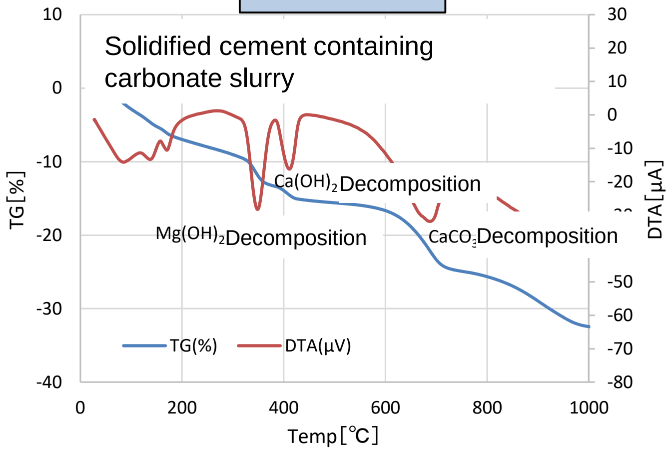
[Study Results]
- XRD, TG/ DTA -

Qualitative analysis of minerals

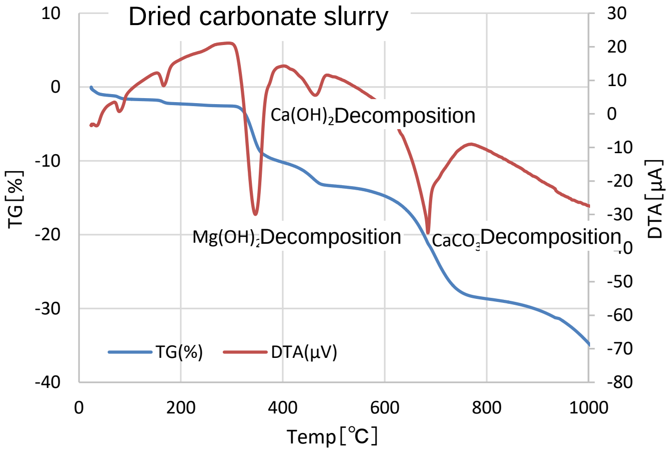


The OPC solidifications and minerals constituting the carbonate slurry were observed in the solidified cement containing carbonate slurry.

TG/ DTA



Rate of decrease in mass of solidified cement containing carbonate slurry at 50 -100℃ is approx. 32%.



[Study Results]

- Preparation conditions for AAM solidifications (Basic conditions of composition) -

- Study on the adjustment of AAM composition with a view to identifying a typical composition that meets the evaluation criteria of fluidity, condensation performance, and compressive strength, which are the basic properties of solidifications.
- Specifically, fluidity, condensation performance and compressive strength were evaluated by changing the “Design index (water/ total powder ratio, base material Na/ Si molar ratio) to design the composition of AAM base material solidifications” and the “Waste filling rate” which were identified in the FY2018 project.

Types	MK/ Base material powder [wt%]	BFS/ Base material powder [wt%]	Si/ Al molar ratio in base material [mol/ mol]	Waste filling rate [wt%]	Water/ solid ratio [wt%]	Na/ Si molar ratio in base material [mol/ mol]	
M	100	0	1.8	0	150	0.84	FY2018
MB20	80	20	1.8	0	110	0.50	
MB40	60	40	1.8	0	100	0.63	
M	100	0	1.8	30, 40, 50.	Verification of composition impact by making changes	Verification of composition impact by making changes	FY2019
MB20	80	20	1.8				
MB40	60	40	1.8				

M：
Metakaolin

BFS：
Blast furnace slag fine powder

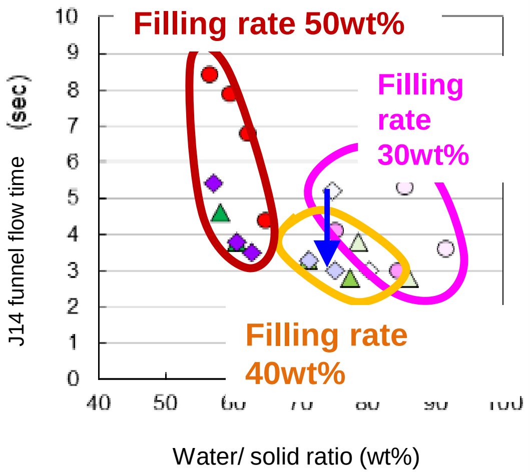
Solid = Base material powder + waste solid phase

M: Metakaolin only, MB20： 20wt% of metakaolin replaced with blast furnace slag, MB40：40wt% of metakaolin replaced with blast furnace slag

[Study Results]
- Preparation conditions for AAM solidifications: Changes due to the composition of properties of solidifications -

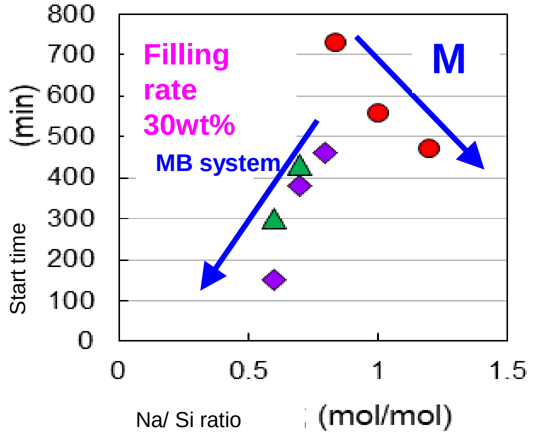
Legend: ● **M** ▲ **MB20** ◆ **MB40**

Fluidity



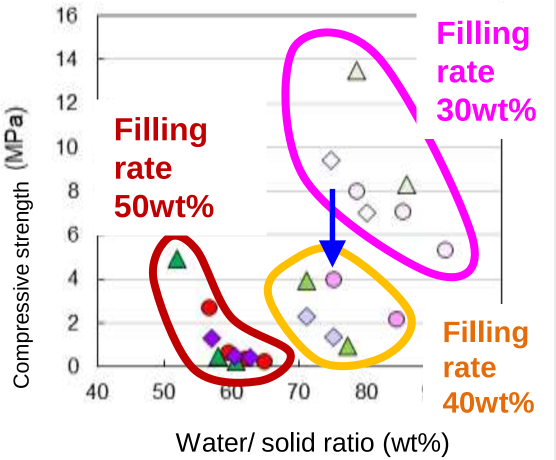
- Increase in filling rate (Water/ solid ratio constant) ⇒ Increase in fluidity
- Increase in water/solid ratio (Filling rate constant) ⇒ Increase in fluidity

Condensation



- Changes occurring due to base material Na/ Si molar ratio which may vary depending on powder type (trends same as base material; impact of filling rate is minor)
- Increase in water/solid ratio ⇒ Delayed setting

Compressive strength



- Increase in filling rate, water/solid ratio⇒ Decrease in strength
- Blast furnace slag replacement: Decrease in Na/ Si molar ratio ⇒ Decrease in strength

(AAM composition properties)

- ➢ If water/solid ratio is increased, fluidity is secured but strength deteriorates.
- ➢ If filling rate increases (when water/solid ratio is constant), fluidity increases, but strength deteriorates.
- ➢ Condensation performance is strongly influenced by Na/Si molar ratio. The effect is reversed depending on the inclusion of slag.

⇒ Since the changing trend based on the composition varies for each property, it is important to identify the composition that fulfills each property requirement.

[Study Results]

- Preparation conditions for AAM solidifications: Selection of composition that meets the evaluation criteria -

Compressive strength for the composition that meets the evaluation criteria of fluidity and condensation performance

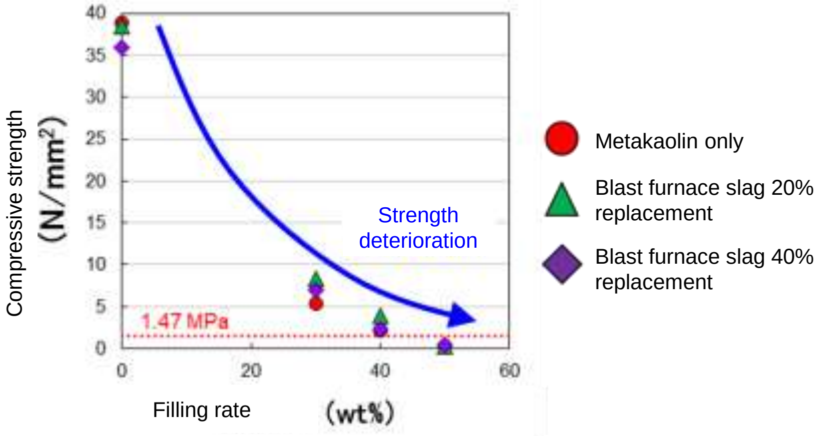


Fig. 8 Filling rate and compressive strength for dry carbonate slurry

Out of the compositions that meet the evaluation criteria, the following composition was selected taking into consideration the fluctuations in each physical property.

Type	Waste filling rate [wt%]	Water/ solid ratio [wt%]	Na/ Si molar ratio in the base material [mol/ mol]	J14 funnel flow time [sec]	Setting		28 days Compressive strength [N/ mm2]
					Start [min]	After 24h	
M	30	92	1.2	3.6	470	End	5.3
MB20	30	86	0.7	2.8	430	End	8.3
MB40	30	80	0.8	3.0	460	End	7.0

Like cement, composition “Waste filling rate 30wt%” was selected for AAM as well.

[Study Results]
- Data acquisition: Hardening properties -

○Hardening (Changes in viscosity)

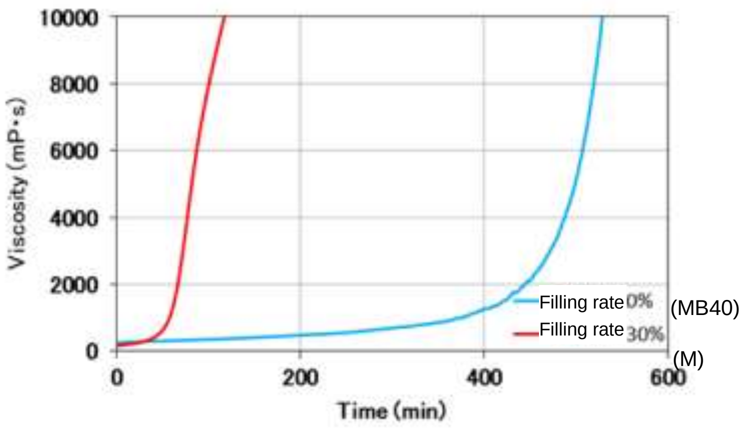


Fig. 9 Effects of viscosity during AAM solid hardening and waste filling rate

When 30wt% of slurry is included

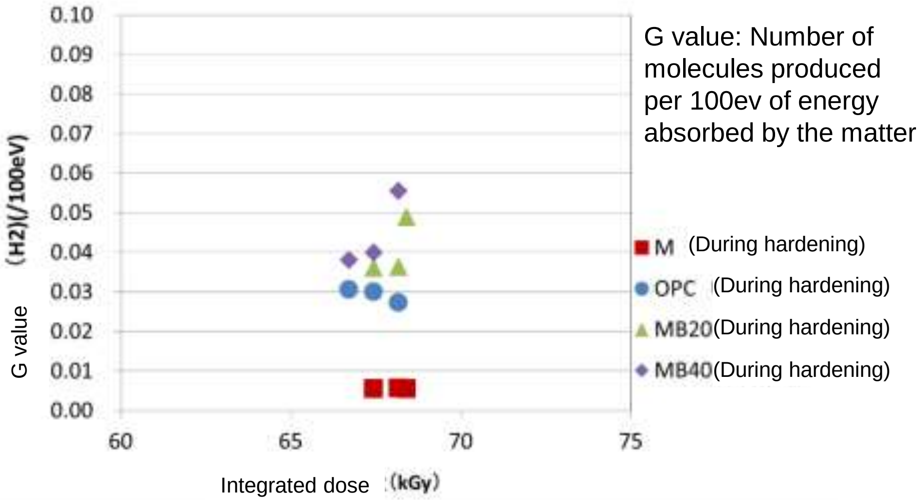
・Viscosity at initial stage is of same value.

・Viscosity tends to start increasing earlier.

・Change in the gradient for viscosity increase is slow (graphical form of time variation).

It also demonstrated the occurrence of complex changes in physical properties which affect the treatment.

○Irradiation test (During hardening)



G value: Number of molecules produced per 100ev of energy absorbed by the matter

Fig. 10 G value during hardening

- Gamma rays were irradiated on the paste immediately after kneading to investigate hydrogen generation behaviors while hardening was in progress.
- G value during hardening was bigger in the order of M<OPC<MB20<MB40.
- Efforts are being continued towards cutting of solidifications and analysis of internal bubble condition.

In addition, collection of data such as elution test, irradiation test (simulated solidifications) etc. also continues.

[Study Results]
- Data acquisition: Gamma radiation properties -

Table 3 Irradiation conditions

Test contents	Gamma radiation test for solid base material (FY2018 project)	Gamma radiation test for solidifications containing simulated slurry (This project)
Test site	Takasaki Advanced Radiation Research Institute, the National Institutes for Quantum and Radiological Science and Technology	
Specimen	OPC, M, MB20, MB40 (Base material only) Curing time: 28 days	OPC, M (Contains simulated carbonate slurry 30wt%) Curing time: 28 days
Irradiation conditions	Fixed irradiation (Fix the irradiation container towards radiation source)	
Radiation source	Co-60	
Dose rate	Approx. 1.8 -5 kGy/ h	
Integrated dose (Plan)	3 kGy, 10 kGy, 30 kGy	

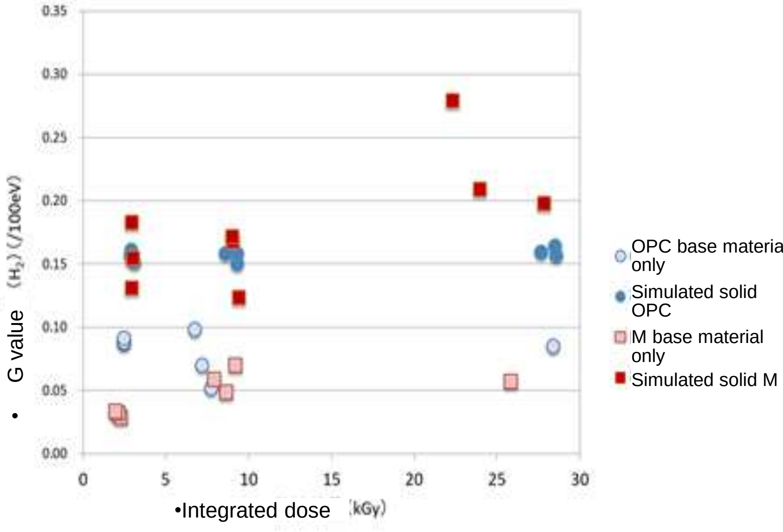
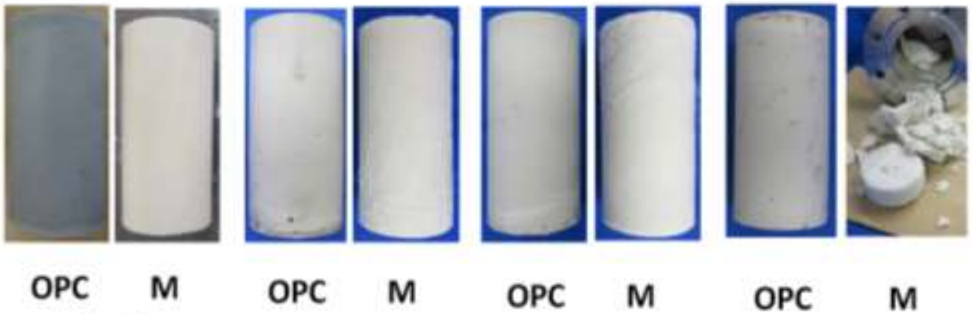


Fig. 12 G value of hydrogen gas with respect to integrated dose

When G value of hydrogen gas in solidifications containing carbonate slurry was compared with irradiation results for only the base material in the FY2018 project, the G value in case of solid containing slurry tended to be higher than that of the base material of both OPC and M.



Before irradiation

After 3 kGy irradiation

After 10 kGy irradiation

After 30 kGy irradiation

Fig. 11 Appearance before and after irradiation of solidifications containing simulated slurry

There was almost no change in the appearance of OPC before and after irradiation at any integrated dose. No change was noticed in M when irradiated with integrated doses of 3 kG and 10 kGy, but the solid after irradiation with 30 kGy was brittle and crumbled in the irradiation container and did not maintain its original shape.

・Irradiation test was performed in the same way for solid containing carbonate slurry (MB20, MB40). Cracks etc. did not occur after irradiation.
・Currently, analysis is being conducted on hydrogen gas etc.

【Confidential】

[Study Results]
-Data acquisition: Gamma radiation properties, dissolution test -

Compressive strength after irradiation test

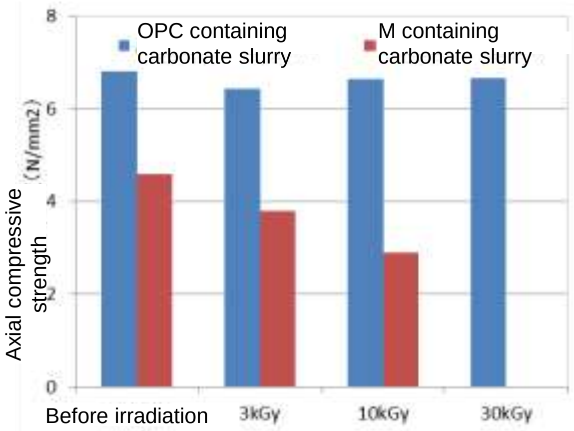


Fig. 13 Compressive strength before and after irradiation

Compressive strength of the solidifications containing carbonate slurry

- No change in strength was noticed in OPC before and after irradiation.
- In case of M, apart from brittleness and crumbling due to irradiation with 30 kGy, there was also slight deterioration in strength after irradiation. However, the strength was maintained above the strength standards (1.47 N/ mm^2).

Dissolution test Being performed currently

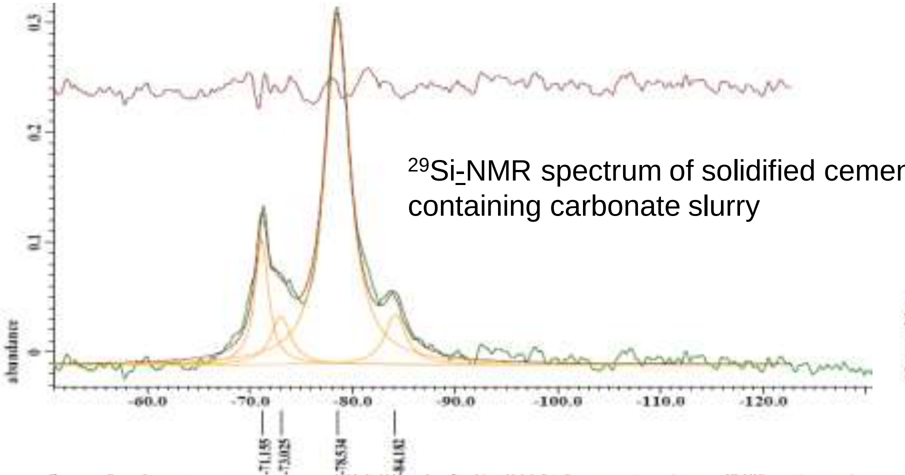
(Items for which data is being collected)

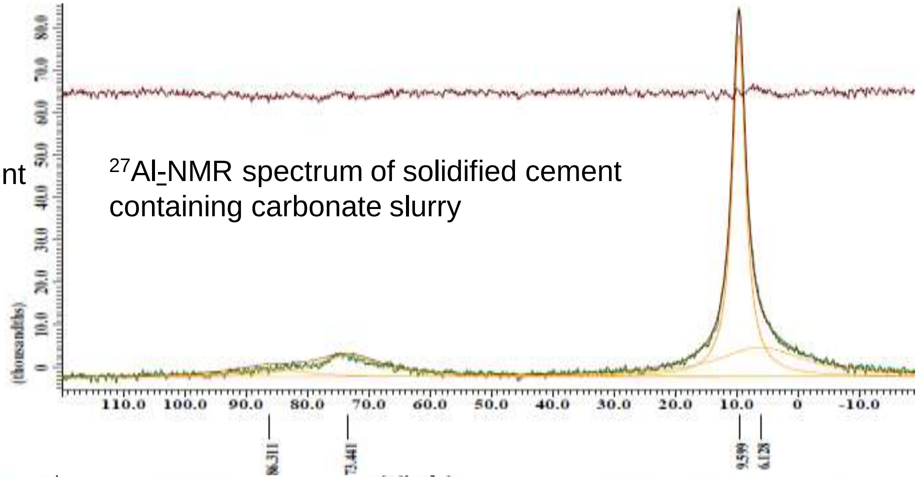
- ■ Continuation of dissolution test (Verification of each type of property such as solubility of solidifications, etc.)
- ■ Confirmation of water content (TG/ DTA), mineral phase (XRD) after gamma irradiation
- ■ Confirmation of leachability of simulated nuclides

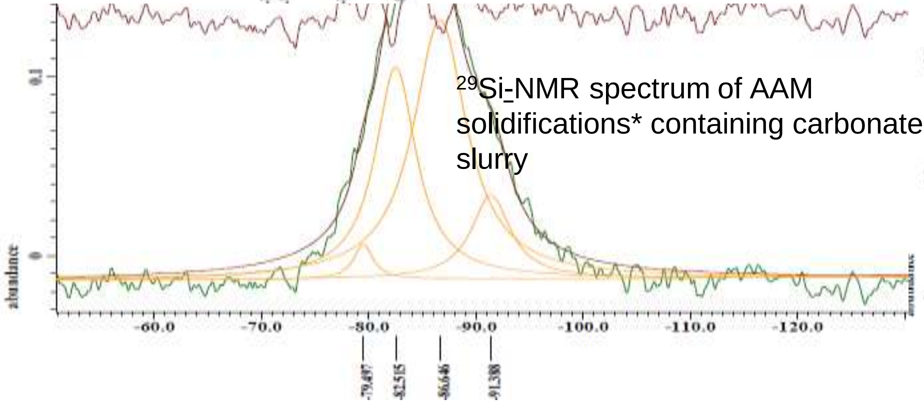
[Study Results]
- NMR of solid containing carbonate slurry -

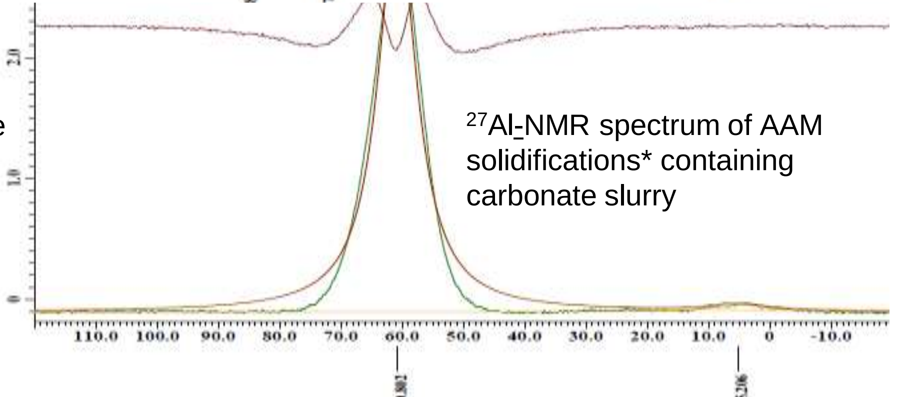
NMR

^{29}Si-NMR and ^{27}Al-NMR measurements were carried out for the initial samples of solidified cement and AAM solidifications (3 types)


^{29}Si-NMR spectrum of solidified cement containing carbonate slurry


^{27}Al-NMR spectrum of solidified cement containing carbonate slurry


^{29}Si-NMR spectrum of AAM solidifications* containing carbonate slurry


^{27}Al-NMR spectrum of AAM solidifications* containing carbonate slurry

*AAM solid in the graph is the solidified sample of metakaolin only without blast furnace slag

- In future, qualitative analysis of attributes will be carried out taking into account the results of qualitative XRD analysis of minerals.

(a) Establishment of techniques for selecting the preceding processing method 【Confidential】
① Low-temperature treatment technology
i. Acquisition and evaluation of data on low-temperature treatment technology that would contribute to the identification of technology
(ii) Acquisition of data on properties of cement and AAM solidifications in the slurry
[Summary/ Plan for the following year]

➢ Current Summary

- According to the studies conducted so far, the simulated carbonate slurry was prepared by simulating the process of dehydration by means of filter press, etc.
- The composition of cement and AAM was studied using the obtained carbonate slurry. The composition that fulfilled the evaluation criteria had a waste filling rate of up to 45 wt% (weight of dry powdered particles) for cement and up to 40 wt% for AAM.
- For a proper comparison, a composition having a waste filling rate of 30 wt% (weight of dry powdered particles) was selected as the representative composition considering variations in properties.
- After preparing solidified samples from the determined composition, data on viscosity measurement, irradiation testing, etc. was collected.

➢ Plan for the following year

- Simulated iron co-precipitation slurry will be made to collect data in a similar manner.
- The obtained results will be summarized, which will be utilized to clarify the scope of application for studying the approach.

(a) Establishment of techniques for selecting the preceding processing method

【Confidential】

① Low-temperature treatment technology

i. Acquisition and evaluation of data on low-temperature treatment technology that would contribute to the identification of technology

(iii) Investigation of special cements

[Implementation Details]

In order to study the applicability to secondary waste generated from contaminated water treatment, which have components with an adverse effect on Ordinary Portland Cement (OPC), conduct an investigation of cements other than OPC having the essential special properties.

(Overview of investigation)
After deciding the types of special cements to be investigated, investigate the properties of solidifications focusing on the essential properties, as well as the usage results and research examples pertaining to the uses for solidification of radioactive waste, and in addition, select the special cement solidifications to be tested and studied from the viewpoint of ease of availability of raw materials within Japan or feasibility of conducting tests.

FY	Implementation Details
2019	**Selection of special cements with high usage feasibility (Literature survey)** Viewpoint of investigation: Cements that reduce the impact of sodium carbonate as compared to OPC (cements with a wider scope of application as compared to OPC)
	Evaluation of base material Performance evaluation of base material that uses special cement
2020	Study that will contribute to the selection of the applicable range of various low-temperature solidifications (Addition of waste simulants, sodium carbonate and borate salt, etc.)

[Study Results]
- Selection of special cements -

- An investigation was conducted on the OPC solidification inhibitors until last year, and borate salt and sodium carbonate, etc. were identified as substances that were likely to have an impact even when these were present in small amounts in the secondary waste generated from contaminated water treatment.
- In conjunction with the AAM solidification applicability study, effective low-temperature treatment options for these substances were searched.
- Special cements having a high degree of technical maturity were selected comprehensively (Table 1), and their applicability was studied.

Table 1 Selected special cements

(1) JIS-standard types of cements	(2) Types of special cements (Other than JIS-standard)
Portland Cement	Types of cements with Portland cement as the base
・Ordinary Portland cement	・Expansive cement
・High-early-strength Portland cement	・Binary-system low-heat cement
・Ultra high-early-strength Portland cement	・Ternary-system low-heat cement
・Moderate-heat Portland cement	Types of cements in which the elements or particle size composition of the Portland cement has been changed
・Low-heat Portland cement	・White Portland cement
・Sulfate-resistant Portland cement	・Cement-based solidification material
Mixed cement	・Ultra fine particle cement
・Blast furnace slag cement (Types A, B, C)	・High belite cement
・Fly-ash cement (Types A, B, C)	Types of cements having elements different from Portland cement
・Silica cement (Types A, B, C)	・Ultra rapid-setting cement
Other cements	・Non-hydraulic cement
・Eco-cement (Ordinary, Rapid-setting)	・Alumina cement
	・Other cements (Calcium Sulphoaluminate (CSA) cements, Magnesia-phosphate cements (MFC))

[Study Results]
- Viewpoints of investigation and classification of the targeted special cements -

[Viewpoints of investigation]

① Usage results and research examples pertaining to the uses for solidification of radioactive waste

Investigation of presence of the usage results and research examples of said cements

② Impact of elements causing adverse effect on OPC

Inferences drawn from the information about the magnitude of influence of the components "Borate salt" and "Sodium carbonate (Na_2CO_3) " in the slurry, or the inferences drawn from the components of cement

③ Characteristics that specialize in the required properties

Attention to "High fluidity" from the viewpoint of feasibility of the solidification process or the suppression of the amount of hydrogen generated (decrease in the ratio of water and cement)

Attention to "High heat resistibility" from the viewpoint of waste nuclide inventory that can be handled or the possibility of leading to an increase in the waste filling rate

Classification of Cement	☐ **Types of cements with Portland cement as the base** • Expansive cement • Low-heat cement of multi-component systems (Investigation that includes admixture mixed cement which exceeds the substitution rate of JIS) ☐ **Types of cements in which the components or particle size composition of the Portland cement has been changed** • White Portland cement, • Cement-based solidification material, • Ultra fine particle cement, • High belite cement	☐ **Types of cements having components different from Portland cement** • Ultra rapid-setting cement • Non-hydraulic cement • Alumina cement (Includes cements with alumina cement as the base) • Calcium Sulfoaluminate cements (CSA) • Magnesia-phosphate cements (MFC)
Summarized features	● As OPC is the base, the reactions or the properties etc. are similar to those of OPC. ● Properties that are different from OPC, are strengthened as the quantity of admixture increases.	● As the components contained are significantly different from OPC, the reactions or properties are different. ● The properties tend to be extremely different since adjustments are made assuming a specific usage.

[Study Results]
- Applicability study based on the features of each special cement -

Example of investigation results of special cements

☐ Expansive cement	• No usage results and research examples pertaining to the uses for solidification were found. • There are results indicating control of cracking (near surface pit) when used in disposal facilities. • Based on the composition of the cement, it is inferred from the observations of this investigation that there is no major difference from ordinary cement. ⇒ It is inferred that the usage possibility is low
☐ Low-heat cement of multi-component systems (Investigation that includes admixture mixed cement that exceeds the substitution rate of JIS) Selection	• No usage results pertaining to the uses for solidification were found within Japan. • As regards research, usage possibility has been reported during the case of research of sodium carbonate solution solidification by means of blast furnace slag high substitution cement (1:9) • An applicability study of fly-ash and blast furnace slag high substitution cement ("Cast Stone") as the basic solidification material for low-level liquid waste (Nitric acid Na) was conducted overseas at Hanford. ⇒ Since the proportion of ordinary cement is extremely low in the "Finely powdered blast furnace slag high substitution cement (1:9) ", the level of impact of sodium carbonate and boric acid are different and hence it was determined to be usable.
☐ Alumina cement (Includes cements with alumina cement as the base) Selection	• No usage results pertaining to the uses for solidification were found. • There is a research example in which the material design for preventing the reduction in strength caused due to the defects of a stand-alone system of alumina cement such as the initial hydration heat or progression of aging of material, wherein fly-ash or blast furnace slag is mixed with alumina cement, was researched. Since the composition is quite different from ordinary cement, there is a possibility that the impact of sodium carbonate and borate salt will be different. • Heat resistance is high. As regards fluidity, it has been reported that high fluidity is obtained even with an ultra-low water cement ratio when an efficient water reducing agent is used. ⇒ It is determined to be usable from the viewpoint of impact of harmful components and heat resistance with respect to ordinary cement. ⇒ "Alumina cement + Fly-ash" is selected since it is considered important to control hydration heat and to control the reduction in strength that is caused by the progression of aging of material.
☐ Magnesia-phosphate cements (MFC)	• No usage results pertaining to the uses for solidification were found. • As for uses for solidification, there is an applicability study of "Ceramicrete" conducted at Hanford, which considers Magnesia-phosphate cements (MFC) for solidification of Nitric acid (Na) liquid waste. • Since the composition is quite different from ordinary cement, there is a possibility that the impact of sodium carbonate and borate salt will be different. ⇒ Inferred to be usable. ⇒ But testing is deemed difficult based on the manufacturing conditions (material and composition) and the presence of reference literature.

- Blast furnace slag high substitution cement

  ⇒ It is likely to have excellent applicability to the sodium carbonate mixed waste. (Carbonate slurry)
- Fly-ash mixed alumina cement

  ⇒ It is likely to have excellent heat resistance and fluidity. Also, the impact of components may be different from that of ordinary cement.

Study the representative composition, and acquire the basic physical properties like compressive strength etc. for the obtained representative composition.

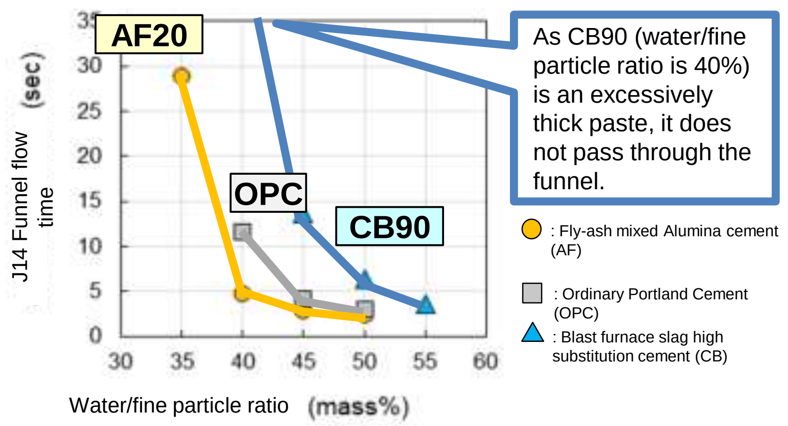
[Study Results]
- Relation between composition and fluidity/ condensation performance -

➢ Plan for the current fiscal year (Verification of basic required performance)

- Evaluation of setting properties and fluidity with respect to the solidifications manufactured by changing the composition (water/fine particle ratio)
- Selection of a representative composition and evaluation of compressive strength, pore size distribution, constituent phase (XRD) and moisture conditions (free water and absorbed water)

A representative composition was decided by measuring the fluidity and setting properties after changing the composition (water/fine particle ratio).

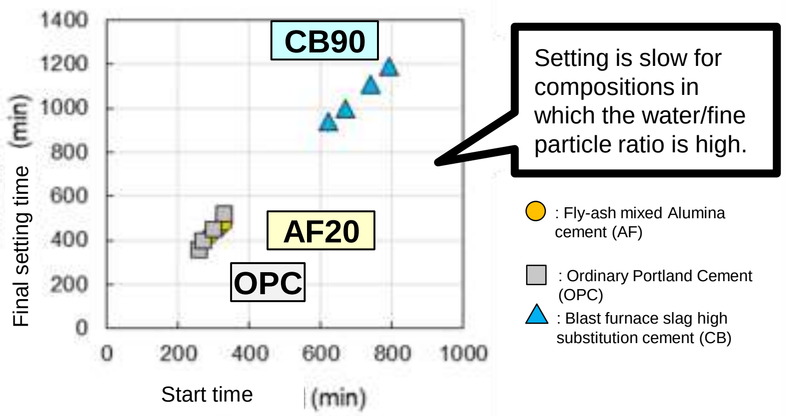
Fluidity (J14 Funnel flow test)



As CB90 (water/fine particle ratio is 40%) is an excessively thick paste, it does not pass through the funnel.

- Fluidity: Fly-ash mixed Alumina cement > Ordinary cement > Blast furnace slag high substitution cement
- Alumina cement has high fluidity as found in the literature survey.

Condensation (Vicat needle test)



Setting is slow for compositions in which the water/fine particle ratio is high.

- All the solidifications have a sufficient handling time (work life) and the final setting takes place within 24 hours, so it is expected that the manufacturing process can be established.

	Types	**Ratio of water/ fine particle** [wt%]	**J14 Funnel flow time** [sec]	Setting	
				Start [min]	After 24h
Representative composition	CB90	55	3. 6	790	1190
	AF20	40	4. 7	310	450
	OPC (For comparison)	45	4. 2	270	400

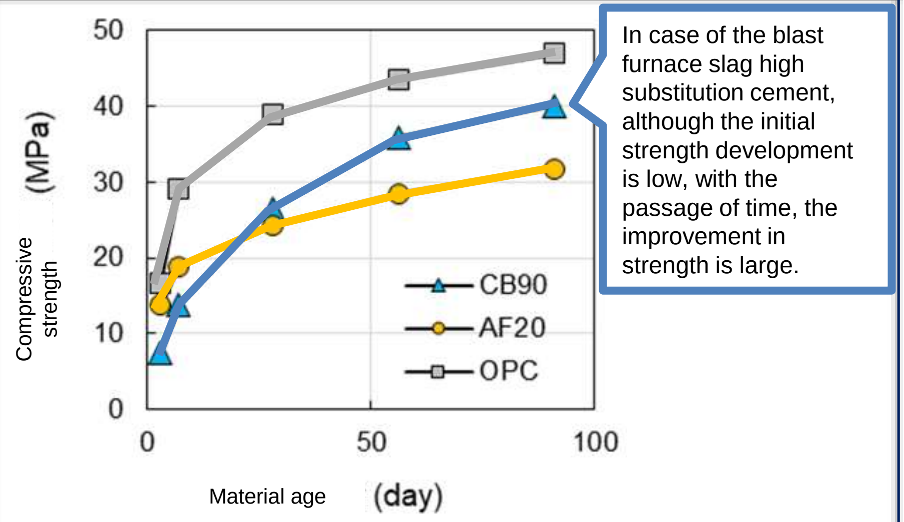
CB90: OPC/Blast furnace slag fine powder was mixed in the ratio of 10/90, AF20: Alumina cement/ Fly-ash was mixed in the ratio of 80/20.

[Study Results]

- Data on the properties of the representative composition and the representative composition solidifications -

- Solidified specimens were manufactured for the representative composition and properties such as compressive strength, amount of free water etc. were acquired.

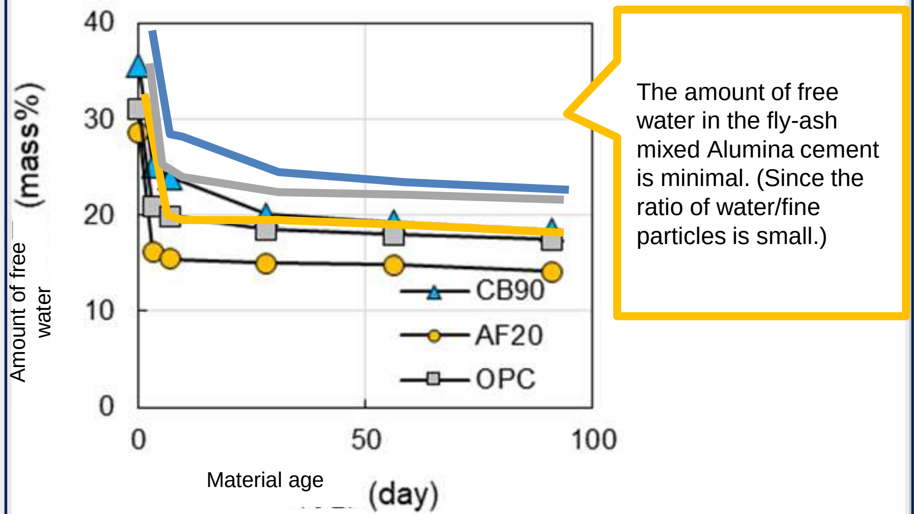
Compressive strength (Material aging changes)



In case of the blast furnace slag high substitution cement, although the initial strength development is low, with the passage of time, the improvement in strength is large.

- Strength at material age 28 days: Ordinary cement > Blast furnace slag high substitution cement ≒ Fly-ash mixed Alumina cement

Amount of free water (Material aging changes)



The amount of free water in the fly-ash mixed Alumina cement is minimal. (Since the ratio of water/fine particles is small.)

- Amount of free water at material age 28 days: Fly-ash mixed Alumina cement < Ordinary cement < Blast furnace slag high substitution cement

In the case of CB90, OPC : Blast furnace slag fine powder was mixed in the ratio of 10:90
In the case of AF20, Alumina cement : Fly-ash was mixed in the ratio of 80:20

- Additionally, data on the analysis items (pore size distribution, constituent phase (XRD)) is being collected.

(a) Establishment of techniques for selecting the preceding processing method ① Low-temperature treatment technology i. Collection and evaluation of data on low-temperature treatment technology to contribute to the identification of technology (iii) Investigation of special cements [Summary/ Plan for the following year]

➢ Current Summary

- A literature survey was carried out for the special cements, and blast furnace slag high substitution cement and the fly-ash mixed Alumina cement were chosen for testing as alternative materials for OPC.
- Basic data such as fluidity and compressive strength etc. were acquired by using the base material.
- Data on some data items (pore size distribution, constituent phase (XRD)) is being collected.

➢ Plan for the following year

- The impact on substances (sodium carbonate, borate salt etc.) that have an adverse effect on the OPC solidifications, simulated waste (various dried and powdered slurries) and of heating/ drying will be verified on the two types of special cements selected this year.
- When using a special cement, applicable range of waste properties for which cement solidification is available will be studied and examined. (Provided as feedback to ② Study on the approach for evaluating the applicability of treatment technologies)

Table 2 Study items of special cements

Applicability evaluation axis for specific waste properties, etc.	**Ordinary Portland Cement**	**Blast furnace slag high substitution cement**	**Fly-ash mixed Alumina cement**
Sodium carbonate	Cement wt% 2% or less	FY2020 Study	FY2020 Study
Boric acid	Cement wt% 0. 1% or less	FY2020 Study	FY2020 Study
Slurry simulated waste permissible filling rate	Carbonate: 30 to 40% (*Selected from i(ii) study)	FY2020 Study	FY2020 Study
Heating/ drying load impact	Selected from ii (i) study	FY2020 ii (i) Study	FY2020 ii (i) Study

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications
[Goals]

(i) Investigation of change in properties of solidifications due to heating, etc.

- To conduct a study on consolidation of factors that lead to change in properties of each solid material and the possibilities therein, based on the study of approach implemented in FY2018 and the investigation results of the methods of measuring the physical properties of the solidified materials. To clarify the change in properties of solidifications during the heating and drying states in low-temperature treatment, based on the results of TG acquired in FY2018.

(ii) Evaluation of the relation between the Cs inventory and the temperature of solidifications (Figure 1)

- To clarify the changes in the heating conditions of the solidifications inside containers of different shapes (several types of containers).
- To investigate the values of density and thermal conductivity for mixed waste, reflect them in the analysis, and clarify the magnitude of the effect.

(iii) Investigation of the influencing factors that contribute to long-term changes in properties and evaluation of the property change behaviors

- To calculate the stability phase assuming the shift to the crystallizing phase, rise in temperature (up to 60℃) and the leaching alteration. (Figure 2)

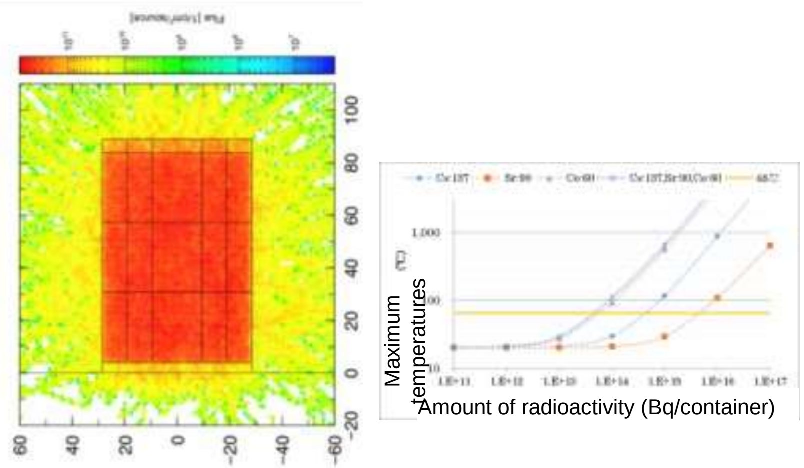


Fig. 1 Evaluation of the relation between the Cs inventory and the temperatures of solidifications (Example)

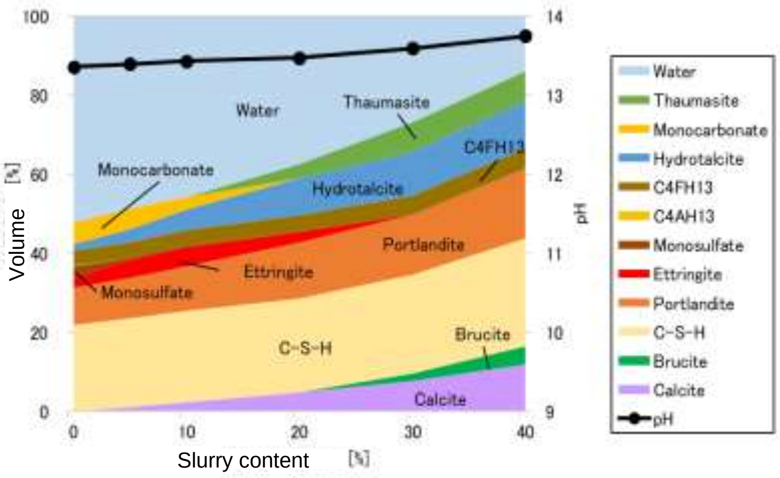


Fig. 2 Study of composition of the mineral phase when slurry is contained (Example)

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications
(i) Investigation of change in properties of solidifications due to heating
[Implementation Details]

The change in properties while in storage during the heating and drying states was investigated in order to study the effects of storage.

The findings regarding the possibility of change in properties were consolidated based on the survey of literature and investigation of test data obtained from other items, and tests were conducted to collect data on drying, etc., which was insufficient.

In FY2019, the findings regarding the possibility of change in properties were organized; and in FY2020, the insufficient data will be collected.

FY	Implementation Details
2019	**Investigation of changes in performance due to heating and drying** ・Organization of findings regarding the possibility of change in properties based on the literature survey
	Evaluation testing of the base material ・Evaluation of the "Effect of drying" and the "Compound effect of heating and drying" Evaluation of changes in the performance of the base material decided under "①-i-(ii) Collection of data on properties of cement and AAM solidifications for the slurry", caused due to heating and drying (The wide temperature zone and the wide drying strength zone were set up and verified.)
2020	**Evaluation testing of the base material** ・On receiving the FY2019 results, the range (temperature, drying strength) in which performance changes are significant will be narrowed down and verified.

[Study Results]

- Literature survey results for setting the test conditions -

- Findings regarding the possibility of change in properties have been organized on the basis of literature survey, etc.

Cement solidifications (OPC)

<Heating> Structural changes due to drying and heating

- 70 to 100°C: Dissipation of free water inside gaps and from partial hydrates (Ettringite) ⇒ Structural shrinkage, coarsening of gap size
- 100°C to 450°C: Dehydration of C-S-H ⇒ Further structural shrinkage and coarsening of gap size
- 450°C and more: Decomposition of Ca(OH) 2, CaCO3 (Conversion into CaO) ⇒ Loses the solidified appearance and there is a significant deterioration in strength (Figure 1)

<Dryness (Humidity) > Mainly structural shrinkage due to drying

H (relative humidity) due to 40°C drying and smaller shrinkage
stortion due to 11% drying (Figure 2)

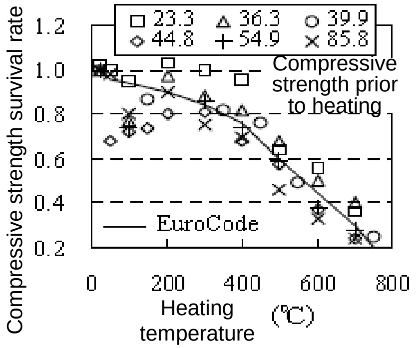


Fig. 1 Relation between temperature and strength in concrete (Up to 800°C) 1)

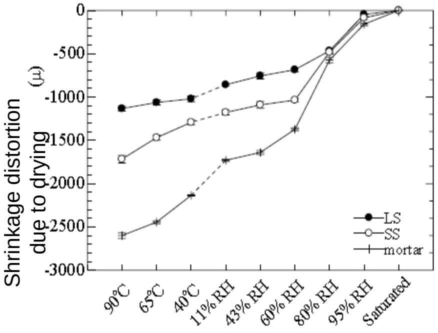


Fig. 2 Relation between concrete drying conditions and shrinkage distortion due to drying2)

AAM solidifications

<Heating> Structural changes due to drying and heating

- Up to 100°C: Dissipation of free water inside gaps ⇒ Structural shrinkage, coarsening of gap size (Inference)
- 100°C onwards: Continuous dehydration from gel formation ⇒ Structural shrinkage, coarsening of gap size

The strength deterioration at high temperatures is less as compared to cement solidifications. (Figure 3)

There are reports that high temperature (1000 °C onwards) heat resistance is low, when the Ca quantity is large.

<Dryness (Humidity) > Mainly structural shrinkage due to drying (Inference)

There are only a few research examples.

There is no unified opinion about the trends.

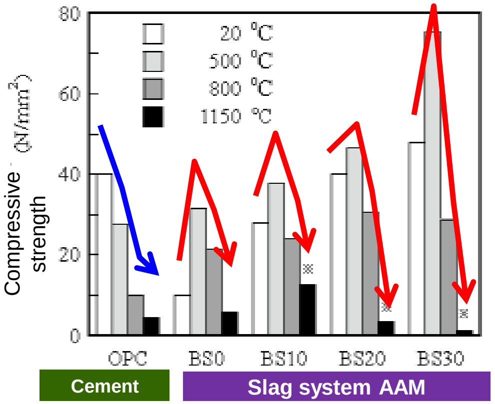


Fig. 3 Relation between temperature and strength in AAM (slag systems) 3)

It is necessary to collect data through testing for the heating/ drying effect of AAM (Compressive strength, shrinkage distortion)

Reference literature
1) Japan Society of Civil Engineers: Value Technology Research Subcommittee Report for Concrete Structures, Symposium thesis collection and Concrete technology series 63, pp. 32-38, FY2004
2) Itou et al: Study for tensile strengthening for cracking in concrete due to drying following temperature and humidity changes, Annual concrete engineering thesis collection, Vol. 36, pp. 382-387, FY2014
3) Ichinomiya et al: Composition of geo polymer with a fly-ash base and high temperature resistance, Annual concrete engineering thesis collection, Vol. 36, pp. 2230-2235, FY2014

[Study Results]

- Thermal load and drying load conditions set based on the investigation -

- Based on the investigation results, the thermal and drying load conditions are set as follows for the testing of solidifications.

(Thermal load conditions)

- 20°C (RH60%) (Standard)
- 80°C (Temperature often set during advance research for the thermal load test)
- 105°C (Dissipation of almost all the free water present inside the gaps (Conditions similar to the conditions for measuring quantity of free water))
- 200°C (Temperature zone wherein the dissipation had settled down during the TG analysis of the AAM solidifications) (Figure 1)

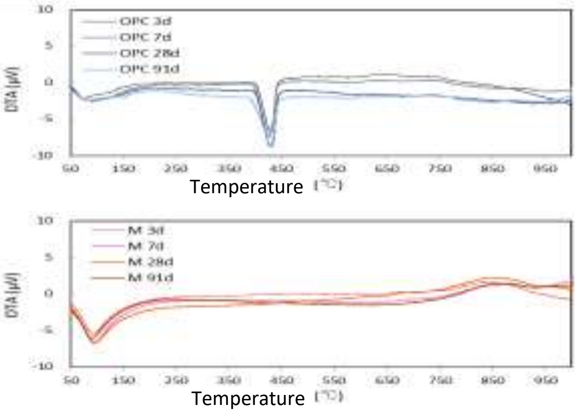


Fig. 1 DTA curve (FY2018 data)

(Drying load conditions (Figure 2)

- RH 100% (20°C) (When there is no drying)
- RH 80% (20°C)
- RH 60% (20°C) (Standard) # Same as the standard for thermal load
- RH 11% (20°C) (Cement solidifications: Dissipation of almost all the free water present

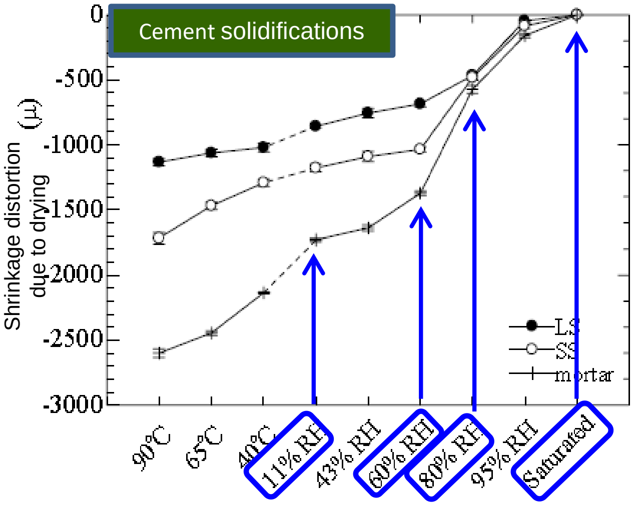


Fig. 2 Relation between drying conditions and shrinkage distortion due to drying

Presently, the thermal load test has been started by manufacturing solidifications of only the base material.

[Study Results]
- Evaluation testing of the base material: Test Overview -

Table 1 Composition conditions of the test specimen for the thermal and drying load tests

Types	M/ Base material fine particles [wt%]	BFS/ Base material fine particles [wt%]	Si/ Al molar ratio in base material [mol/mol]	Waste filling rate [wt%]	Water/solidifications ratio [wt%]	Na/Si molar ratio in base material [mol/mol]
OPC	-	-	-	0	45	-
M	100	0	1. 8	0	150	0. 84
MB20	80	20	1. 8	0	110	0. 50
MB40	60	40	1. 8	0	100	0. 63

Kneading and pouring

For strength test Φ5 x 10 cm

A 4x4x16 cm specimen has been made for measuring the shrinkage distortion

Curing

20℃
Sealed curing over a 28 day period

Drying and thermal load

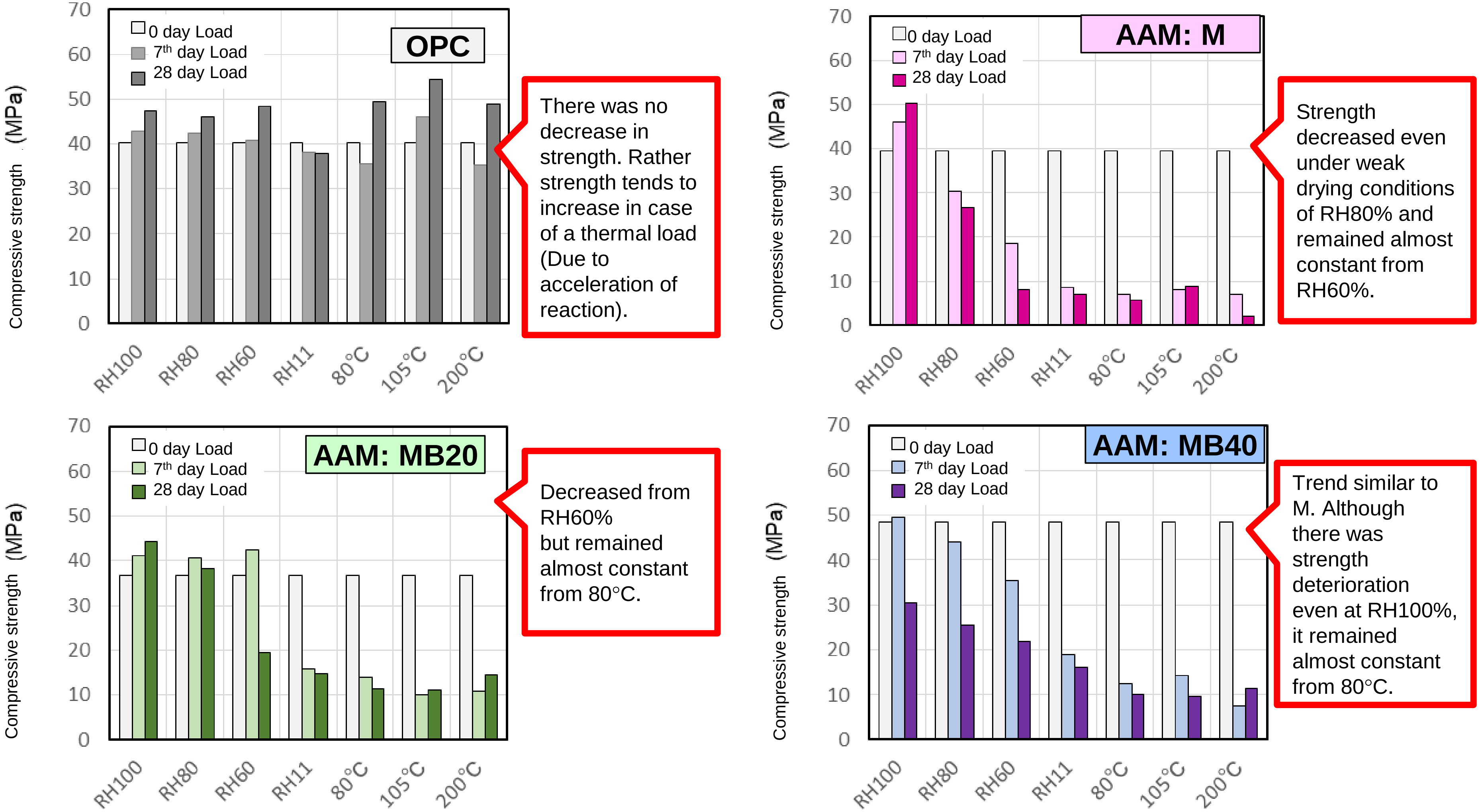
Drying
(Constant temperature and constant humidity desiccator)

Heating
(Electrical drying furnace)

- Changes in shrinkage distortion with the passage of time
- Changes in compressive strength with the passage of time
- Changes in the amount of free water, amount of bonding water and XRD analysis with the passage of time

[Study Results]

- Evaluation testing of the base material: Changes in compressive strength due to heating and drying -



There was no decrease in strength. Rather strength tends to increase in case of a thermal load (Due to acceleration of reaction).

Strength decreased even under weak drying conditions of RH80% and remained almost constant from RH60%.

Decreased from RH60% but remained almost constant from 80°C.

Trend similar to M. Although there was strength deterioration even at RH100%, it remained almost constant from 80°C.

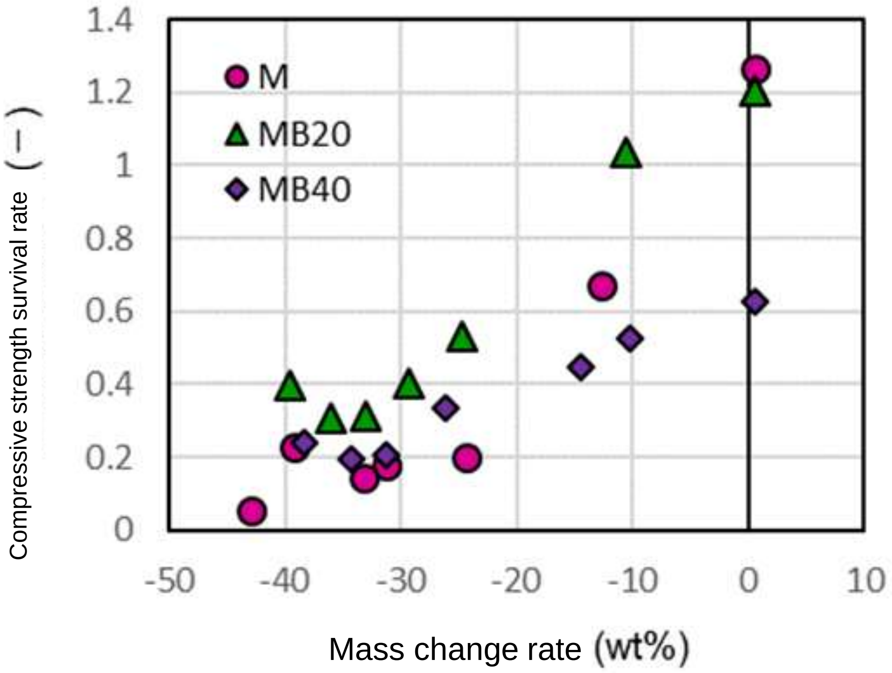
Fig. 1 Compressive strength changes in the various solidifications due to thermal and drying load

- OPC solidifications: There was no significant strength deterioration even when thermal and drying load was applied.
- AAM solidifications: There was strength deterioration even under weak drying conditions although the extent varied (the changes settled down after 7 days of load)

[Study Results]

- Evaluation testing of the base material: Changes in mass due to heating and drying -

Relation between rate of mass changes and compressive strength survival rate under various thermal and drying load conditions with 28 days of load



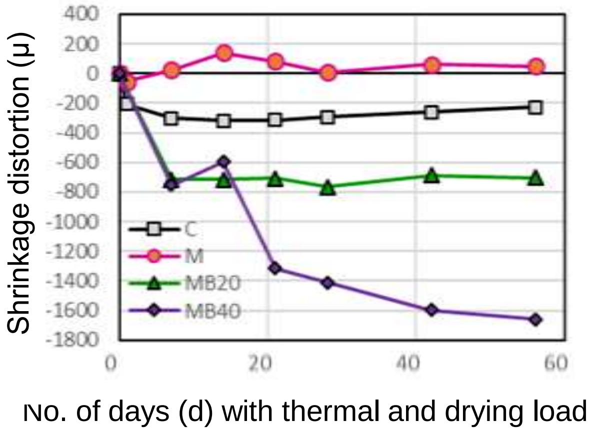
Temp ℃	Humidity %
20	100
20	80
20	60
20	11
80	(-No control)
105	(-No control)
200	(-No control)

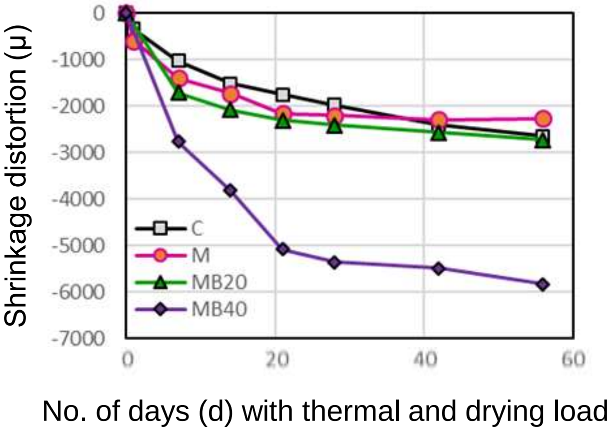
The mass decrease rate tended to be large.

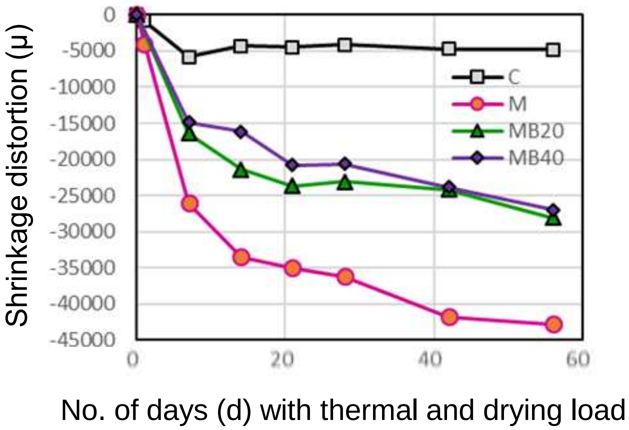
Fig. 1 Relation between mass change rate and compressive strength survival rate (28 days of thermal and drying load)

- The strength survival rate decreases as the mass change rate becomes larger. (However, in case of MB40 at RH100%, there was a deterioration in strength although there was no decrease in mass.)
  ⇒ Strength deterioration due to drying
  ⇒ Possibility of strength deterioration due to the generation of cracks following shrinkage distortions due to drying

[Study Results]
- Evaluation testing of the base material: Long-term changes due to heating and drying (shrinkage distortion) -







RH 100%

The shrinkage distortion of MB40 is large.

RH 60%

The shrinkage distortion of MB40 alone is significantly large.

80°C

Shrinkage distortion:
M>MB20≒MB40>>OPC

- On the whole, the shrinkage distortion is larger in case of the AAM solidifications as compared to the OPC solidifications.
- The main cause of the deterioration in strength of AAM solidifications is inferred to be shrinkage distortion, since there is a correlation between the changes in compressive strength and the magnitude of the shrinkage distortion of the AAM solidifications owing to heating and drying.
- Since the extent of moisture dissipation and shrinkage distortion due to drying will change due to various factors pertaining to the solidifications (amount of moisture, gap structure etc.), there is a possibility that the trend may be different in simulated waste solidifications.

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications
(i) Investigation of change in properties of solidifications due to heating
[Summary/ Plan for the following year]

➢ Current Summary

- The findings about the possibility of changes in cement and AAM due to heating and drying were consolidated based on the past literature surveys.
- Specimens were prepared and data related to compressive strength and amount of distortion under the heating and drying conditions was gathered, and it was verified that on the whole, shrinkage distortion was larger in case of AAM solidifications as compared to OPC solidifications.

➢ Plan for the following year

- The effect of heat and drying load on the special cement solidification will be verified.

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications (ii) Evaluation of the relation between the Cs inventory and the temperature of solidifications
[Implementation Details]

- Upper limits were decided for each type of material, since the performance of the solidifications is influenced by temperatures under the low-temperature solidification treatment technology (cement and AAM).
- It is expected that the limiting values for the waste filling amount will change according to the shape and size of containers, since heat transfer depends on the system.

The limiting values for the inventory that can be solidified, as studied from the decay heat, will be acquired as data by clarifying the changes due to shape and size, by conducting an analysis of the maximum temperatures.

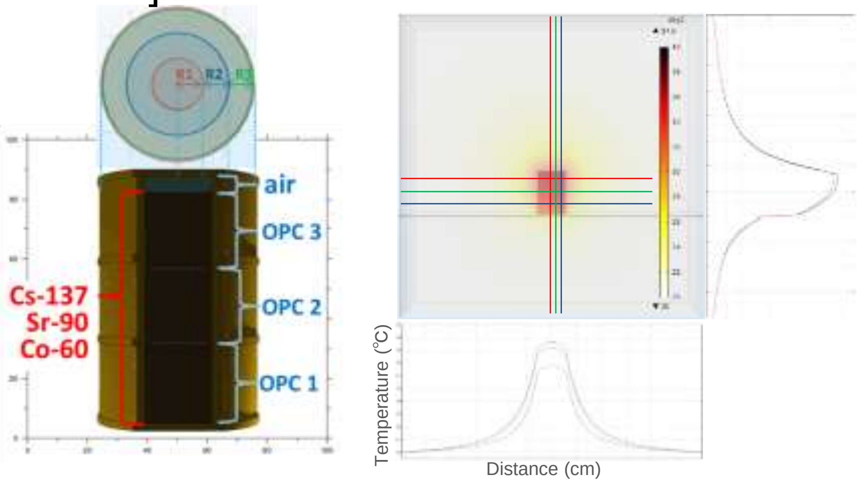


Fig. 1 Simulation result by PHITS and COMSOL (Example)

FY	Implementation Details
2019	**Investigation of the thermal effects due to the shape and inventory of the OPC solidifications** ・Selection of the system (cylindrical/rectangular etc.) ・System model creation and setting the analytical conditions ・Cs thermal effect analysis and thermal effect analysis of nuclides other than Cs
2020	**Investigation of thermal effects of newly solidified materials** ・Thermal effect analysis of AAM solidifications

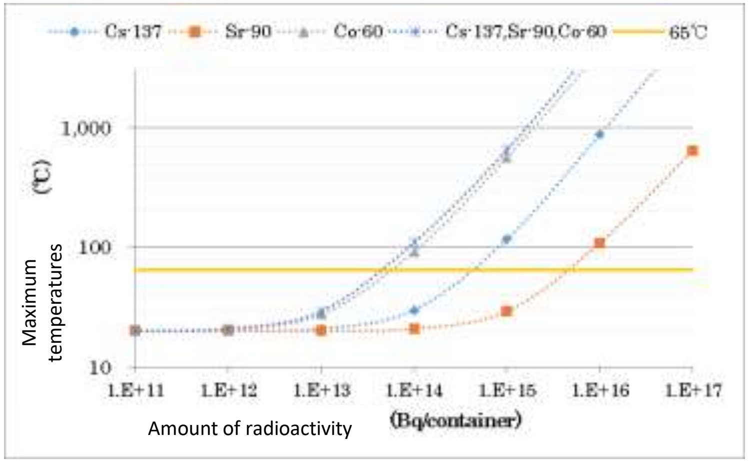


Fig. 2 Nuclide inventory and maximum temperature of solidifications (Example: 200L drum)

【Confidential】

[Study Results]
- Selection of containers for analysis -

- The containers to store the solidified waste have not been determined.
- The shapes and sizes of the typical waste containers that are in use at Fukushima Daiichi and other nuclear power facilities as well as the containers under study, etc. are being investigated.
- There are broadly 2 types of containers namely, cylindrical and rectangular, hence 3 containers from each type have been selected for analysis (Hatching of Table 1, 2).

Table 1 Main cylindrical containers

Cylindrical containers	Pail	Canister ·	Drum can	MJ PIC	HIC(type2)	Tank container
Container appearance						
Internal capacity (m³)	0.022	0.15	0.22	1.25	2.69	24.00
Filling capacity (m³)	0.018	0.12	0.17	1.00	2.15	19.20
Internal W/H	0.84	0.42	0.65	0.96	0.88	2.46
Other	JIS Z 1620	JAEA	JIS Z 1600	TAIHEIYO CEMENT, etc.	TEPCO	

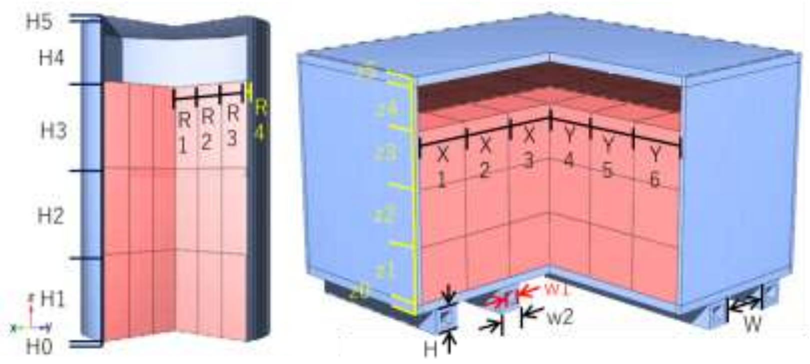
Table 2 Main rectangular containers

Rectangular containers	Uranium system containers -	1m^3	1m^3 (With inner lining)	LLW-2 type	6m^3	20FT
Container appearance				 From NFT HP		
Internal capacity (m³)	1.20	1.35	0.77	3.02	5.20	32.91
Filling capacity (m³)	0.96	1.08	0.62	2.42	4.16	26.33
Internal W/H	1.34	1.63	1.00	3.11	1.54	2.46
Other	JAEA	Assumed model	Assumed model (Shield thickness 70 mm)	NFT	Assumed model	JIS Z 1610

[Study Results]
- System model and analytical conditions -

➢ Creation of a system model

- A system model was created for use in the analysis of radiation during transportation and in the heat analysis of 6 containers.
  Cylindrical type: Pail, Drum, HIC
  Rectangular type: $1m^3$, $6m^3$, $1m^3$ with shield
- In each of the containers, solidifications containing radioactive nuclides were filled up to 80% of the volume.



Cylindrical container model

Rectangular container model

Fig. 3 System model used for the analysis of radiation during transportation (Example)

➢ Analytical conditions

- Solidification material
  Ordinary Portland Cement (OPC)
  Density 2.69 g/cm^3, thermal conductivity 0.5 W/(mk)
- Radioactive nuclides
  Typical nuclides contained in the secondary waste generated from contaminated water treatment were assumed.
  Sr-90, Co-60, Cs-137
- Radioactive concentration
  The values where any temperature change was expected were analyzed.
  1.0E+5 to 1. 0E+10 Bq/cm^3

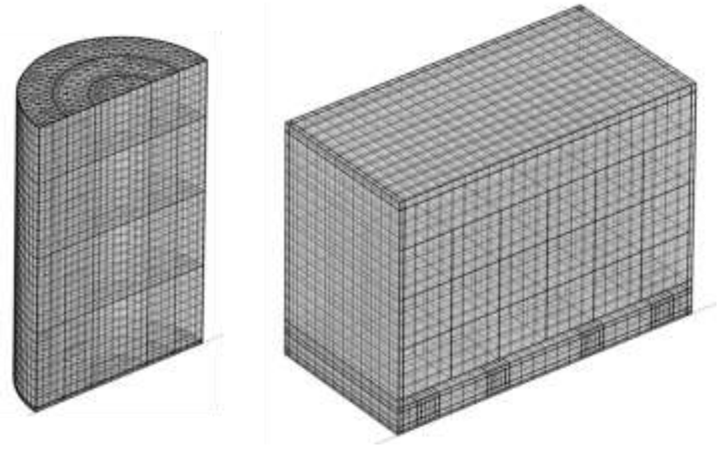


Fig. 4 System model used for heat analysis (Example)

[Study Results]

- Relation between the container system and maximum temperature -

➢ Changes in maximum temperature due to differences in containers

- Maximum temperatures were analyzed in 3 types of cylindrical containers and 3 types of rectangular containers.
- The trends in maximum temperatures were understood with respect to the volume of each shape (top image in Figure 6).
- It was suggested that the maximum temperature can be expressed with a single relational expression irrespective of shape by organizing it with the number obtained by dividing the volume of the solidifications by the distance between the center of the solidifications and the midpoint (edge) of the upper surface of the solidifications. (Bottom image in Figure 6)

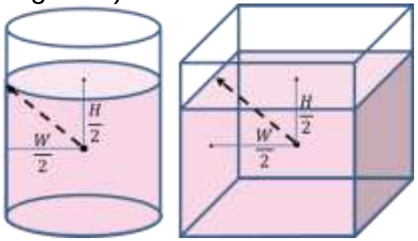


Fig. 5 Distance from the center of the solid till the edge

➢ Investigation concerning the influence of nuclides

- The temperature of the solidifications was investigated by changing the nuclides.
- It was estimated that there was no rise in temperature in case of Cs-137 and Co-60 based on a trial calculation carried out using the analytical values of radioactive concentrations of the secondary waste generated from contaminated water treatment.
- Meanwhile, a temperature rise of about 3°C was estimated in case of Sr-90

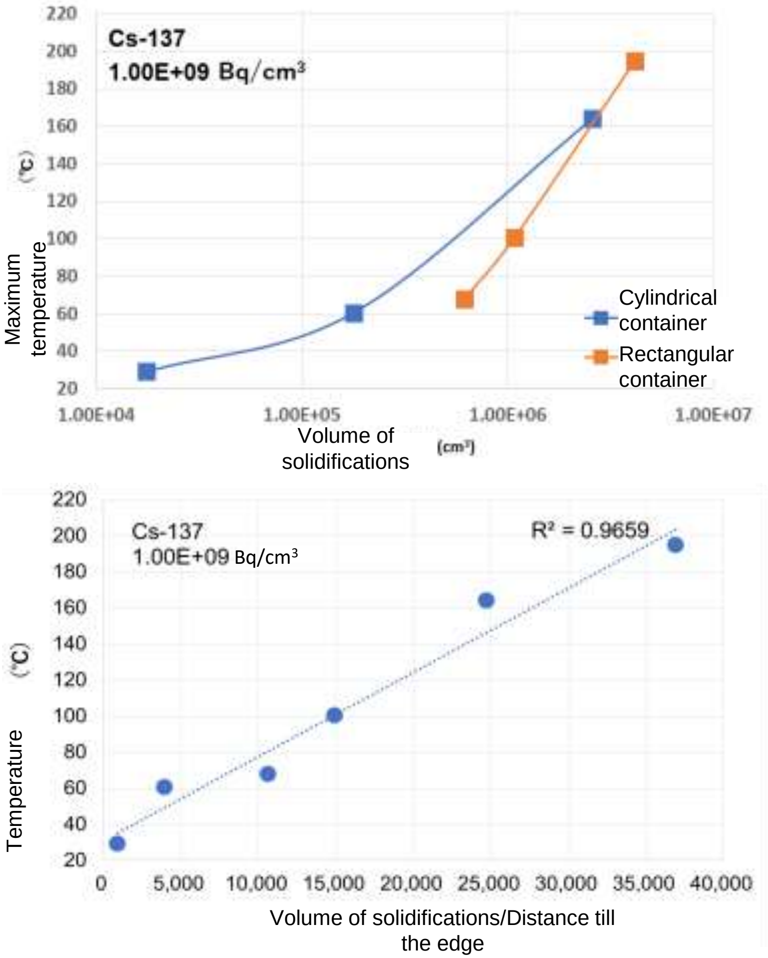


Fig. 6 Relation between temperature and the container systems

(a) Establishment of techniques for selecting the preceding processing method

【Confidential】

① Low-temperature treatment technology

ii. Investigation of change in properties of solidifications (ii) Evaluation of the relation between the Cs inventory and the temperature of solidifications

[Summary/ Plan for the following year]

- Current Summary
  - The shapes and sizes of the typical waste containers that are in use at Fukushima Daiichi and at other nuclear power facilities as well as the containers under study etc. were investigated.
  - There are two types of containers, cylindrical and rectangular, so 3 containers from each type were selected for analysis and their effect on the maximum temperature was analyzed. In a single container, there is a high possibility that the temperature will not reach such high levels so as to cause any change in properties, like the strength of the solidifications.
  - It was found that irrespective of the shape of the container, the maximum temperature can be derived by a relational expression of the distance between the center and the edge middle point.

- Plan for the following year
  - The thermal conductivity of the AAM solidifications prepared using the acquired data will be measured. After reflecting it in the calculations, AAM will be calculated and the difference with the cement solidifications will be surveyed.
  - A trial calculation of the coefficient that can estimate the temperature of the solidifications from the analytical values will be performed based on the calculations for the main nuclides. (Sr-90, Co-60, Cs137).

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications (iii) Investigation and evaluation of factors influencing long-term change in properties
[Implementation Details]

In order to investigate the long-term property change behaviors of solidifications, an investigation was conducted to study the effects of passage of time and external factors. An investigation of the thermodynamics data necessary for analyzing the cement solidifications and the AAM solidifications and the evaluation regarding the adequacy of the data was conducted with respect to the methods devised by means of the thermodynamics equilibrium calculations, which are based on the results of long-term property change behavior evaluation of cement.

From the information such as phase changes obtained as a result of evaluation, an attempt was made to select specific elements (waste) that affect the solidification process of OPC and AAM and which need to be excluded.

FY	Implementation Details
2019	Collection and organization of the thermodynamics data and the study of applicability of the thermodynamics equilibrium calculation Implementation of the stability phase calculation assuming the shift to the crystallizing phase, drying and rise in temperature (up to 60°C) ・Attempting of presumptions regarding the assessment of changes in the mineral phase that influences long-term behavior, by means of equilibrium calculation ・Study on the adequacy of the thermodynamics data used for forecasting long-term behavior and the applicability of the equilibrium calculation for AAM.
2020	Applicability of the thermodynamics equilibrium calculation technique for evaluating the property change behavior of solidifications Identification of the applicability range for various low-temperature solidifications. Simulation of property change behavior of solidifications due to contact with underground water. Study of adequacy and applicability of the thermodynamics data by comparing with the experiment results. ・Presentation of the findings regarding the effect of the carbonate slurry and the iron co-precipitate slurry on the long-term property changes in cement solidifications and demonstration of applicability of the thermodynamics equilibrium calculation technique for the evaluation of property change behavior of solidifications.

[Study Results]
- Study items and implementation status (1/6) -

➢ Collection and organization of the thermodynamics data (common for cement and AAM)

- The database used is 'Thermoddem' created by the French Geological Survey.
- The calculation code used is 'The Geochemist's Workbench'.
- The thermodynamics data of the N-A-S-H phase is investigated and added to the database to calculate the amorphous phase of AAM. It is confirmed that the minerals necessary for the calculations pertaining to cement have been included.

➢ Calculation of the AAM system material

- Study of the thermodynamics stability phase

Based on the findings (Figure 1) on the changes in the properties of naturally found Zeolite or natural minerals such as the ones found in the vicinity of salt water or alkali water lakes which resemble AAM in terms of constituents, the mineral phase emerging after the change in properties was estimated.

⇒ The mineral phase and the N-A-S-H phase presumed from the literature survey were used for the AAM calculations.

- Calculation of the mineral phase

Along with implementing the calculations of the AAM solid phase and the coexisting liquid phase, the calculations were compared with the leaching test results of the metakaolin system AAM acquired in FY2018. Figure 2 shows the comparison between the calculation result of the solid phase, the calculation result of the pH of the liquid phase and the experimental values.

⇒The solid phase was not consistent during the period of the equilibrium solubility test. In the calculation of the liquid phase, the result reproducing the tendency (The pH and Na concentrations were roughly reproduced. The Si concentration differed.) of being close to the experimental value was obtained.

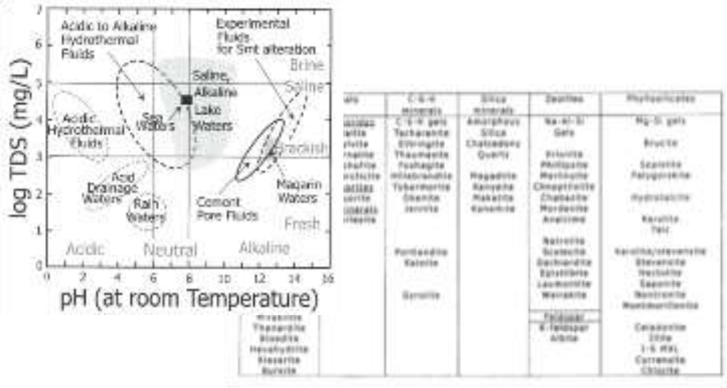


Fig. 1 pH of various natural water bodies and a list of secondary minerals found in salt water and alkali water lakes (Inoue 2004)

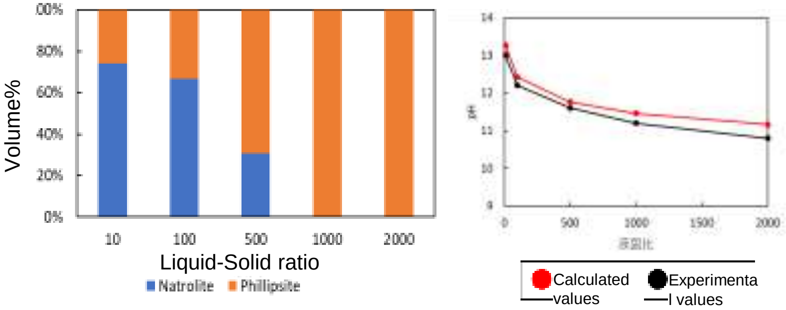


Fig. 2 Changes in volume and changes in pH of the mineral phase due to the changes in the Liquid-Solid ratio

[Study Results]
- Study items and implementation status (2/6) -

- Investigation of equivalent mineral phases

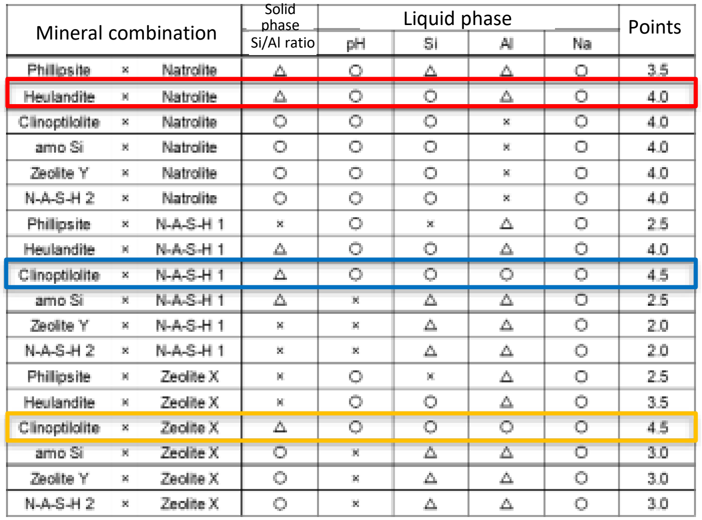
It was difficult to reproduce AAM with the N-A-S-H single phase, since AAM was amorphous in the thermodynamics equilibrium calculation, and had thereby become a combination of minerals. However, even in that state, the tendency of changes in the pH or the amount of components in the liquid phase could be reproduced partially.

If one can understand the tendency of changes in the liquid phase alone, then there is a possibility that it may contribute to the study of disposal, hence the combination of solid phase minerals (mineral phase equivalent to amorphous AAM) was studied as it can well reproduce the pH, Si/Al ratio, Si quantity, Al quantity, Na quantity, etc. of the liquid phase, which were obtained through the leaching test.
⇒A comparative evaluation of the calculation results and the experimental values was carried out. (Table 1)

There are a few combinations by which the liquid phase composition can be reproduced well, and also the solid phase Si/Al ratio can be reproduced to a certain extent.
⇒The pH (Al and Na concentrations) calculated under various conditions had values (Figure 4) closer to the experimental values in all of the mineral combinations. As for the Si/Al ratio of the solid phase, the calculated value was not close to the experimental value under the condition where the Liquid-Solid ratio was high.

Findings concerning the long-term behavior of the AAM material or the thermodynamics data are very few, but it is suggested that short-term leaching behavior can be reproduced by setting multiple metastable phases.

Table 1 Comparative evaluation of the calculation results and the experimental values using mineral combinations



Mineral combination			Solid phase	Liquid phase				Points
			Si/Al ratio	pH	Si	Al	Na	
Phillipsite	×	Natrolite	△	○	△	△	○	3.5
Heulandite	×	Natrolite	△	○	○	△	○	4.0
Clinoptilolite	×	Natrolite	○	○	○	×	○	4.0
amo Si	×	Natrolite	○	○	○	×	○	4.0
Zeolite Y	×	Natrolite	○	○	○	×	○	4.0
N-A-S-H 2	×	Natrolite	○	○	○	×	○	4.0
Phillipsite	×	N-A-S-H 1	×	○	×	△	○	2.5
Heulandite	×	N-A-S-H 1	△	○	○	△	○	4.0
Clinoptilolite	×	N-A-S-H 1	△	○	○	○	○	4.5
amo Si	×	N-A-S-H 1	△	×	△	△	○	2.5
Zeolite Y	×	N-A-S-H 1	×	×	△	△	○	2.0
N-A-S-H 2	×	N-A-S-H 1	×	×	△	△	○	2.0
Phillipsite	×	Zeolite X	×	○	×	△	○	2.5
Heulandite	×	Zeolite X	×	○	○	△	○	3.5
Clinoptilolite	×	Zeolite X	△	○	○	○	○	4.5
amo Si	×	Zeolite X	○	×	△	△	○	3.0
Zeolite Y	×	Zeolite X	○	×	△	△	○	3.0
N-A-S-H 2	×	Zeolite X	○	×	△	△	○	3.0

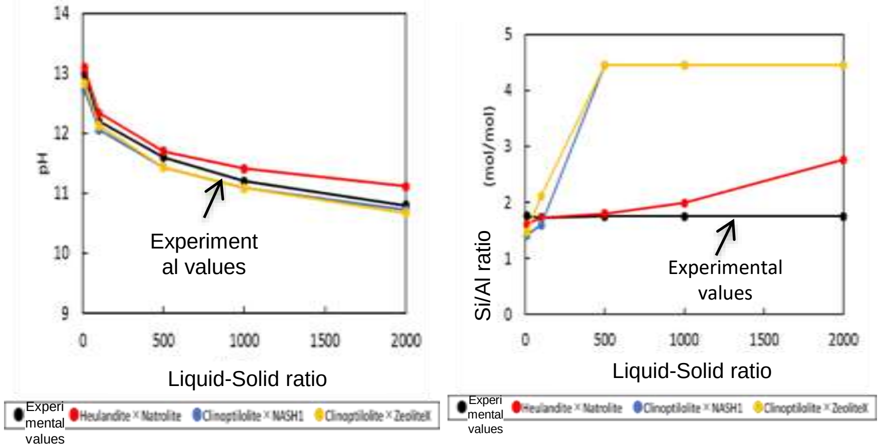


Fig. 4 Comparison with the equilibrium solubility test results
(pH and solid phase Si/Al ratio)

[Study Results]
- Study items and implementation status (3/6) -

➢ Calculation of cement material

- Study of the thermodynamics stability phase

There are results of evaluation of cement by means of the thermodynamics equilibrium calculation. However, based on experimental findings, manipulations were made to intentionally select the mineral phase.

➡ Not applicable for the analysis of solidifications containing waste without the experimental findings.

The analysis was performed by changing the method of excluding the mineral phase as follows.

[1]①	Calculation results considering all minerals in the DB
[1]②	Result recalculated after excluding the minerals assumed to be in the thermodynamics stability phase and the C-S-H minerals of the crystals from [1]①
[1]③	In addition to [1]②, calculation was carried out after further excluding the minerals not assumed to be generated due to the conditions such as temperature and pressure, etc.
[2]	The minerals assumed to be generated in the target system were selected from the DB, and the mineral phase composition was calculated under the conditions which would generate only the selected minerals.

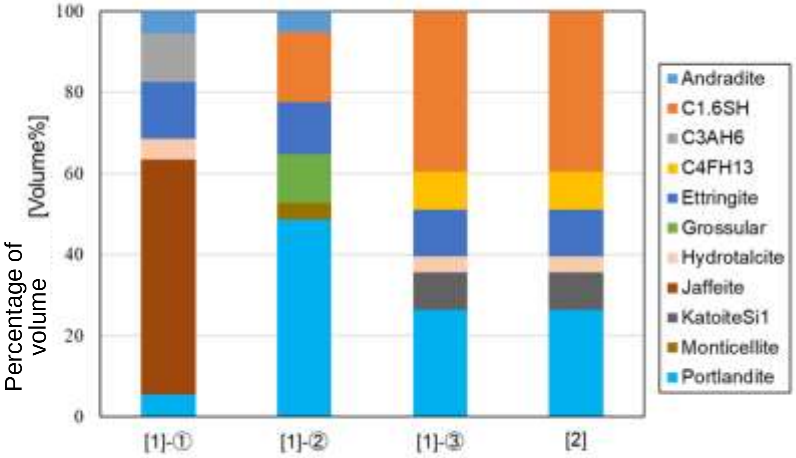


Fig. 4 Volume percentage of generated mineral phase at each level

Although the result (Figure 4) is significantly different due to the method of exclusion, it was found that the results obtained were similar to the case where the calculations were carried out by selecting minerals assumed to be generated based on findings, using the method of exclusion by following a certain rule based on the thermodynamics stability phase studied during this research, ([1]③ and [2])

[Study Results]
- Study items and implementation status (4/6) -

- The calculations for changing the content rate of the carbonate slurry, calculations for temperature changes and calculations for leaching due to contact with water, were carried out for the cement solidifications.

(# At the present stage, there are indications from the results obtained from the thermodynamics equilibrium calculation but a comparative verification with the experimental findings needs to be conducted separately.)

➢ Mineral phase composition when contained in the slurry (Figure 5)

Slurry: Carbonate slurry
Temperature: 20°C
Content is 0 to 55 [mass%] in increments of 5%
The calculation did not converge above 60 [mass%] or more.

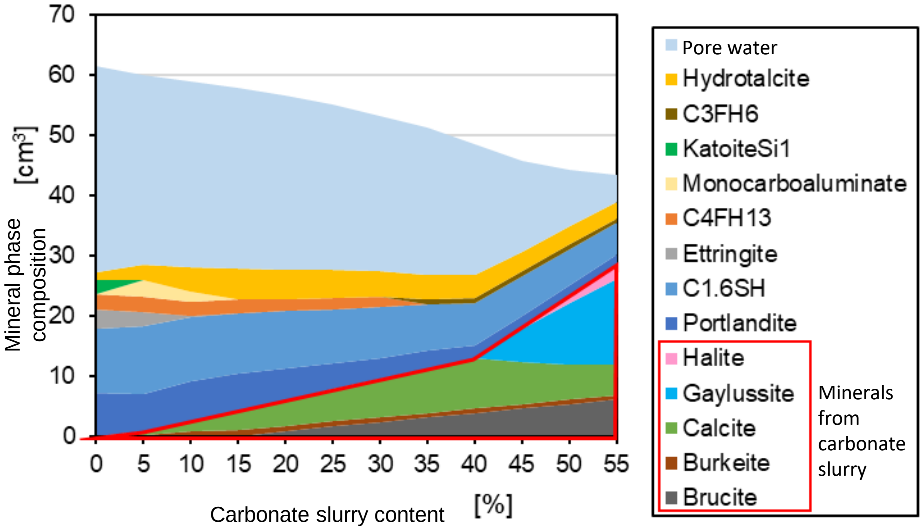


Fig. 5 Volume changes in the mineral phase of the cement solidifications following changes in the carbonate slurry content

[Indications from the calculation results]

○ Changes in the cement-based minerals due to the addition of carbonate slurry

・Decrease in portlandite, which is the main mineral in cement

・Changes in the Aluminate system minerals (KatoiteSi1, Ettringite → Monocarboaluminate, hydrotalcite)

・Changes in the ferrite-based minerals (C4FH13→C3FH6)

→ There are no major volume changes.

○ Carbonate slurry 45 mass% or more

Increase in the solid phase volume due to a newly generated phase originating from the carbonate slurry

[Study Results]
- Study items and implementation status (5/6) -

- Changes in the mineral phase composition during changes in temperature

・Waste content rate: Carbonate slurry is 30 [mass%]
・Temperature: 0 to 60 [℃], 100 [℃] (Crystallizing conditions)
The temperature at which calcium silicate hydrate (C-S-H) changes to the crystalline phase is unknown, hence the calculations were performed in the temperature range of 0 to 60 ℃ where there was no change, and at the temperature of 100 ℃, where the changes are presumed to have taken place.

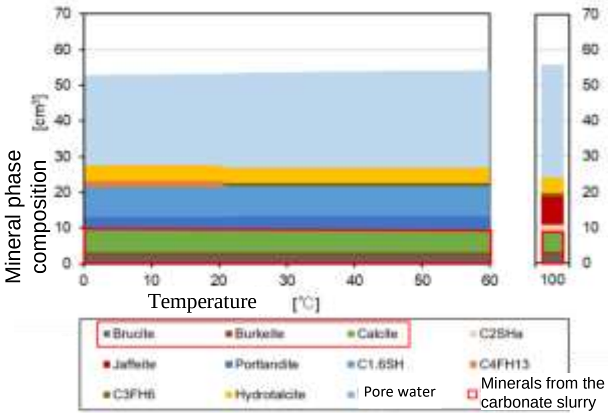


Fig. 6 Volume changes in the mineral phase of the carbonate slurry cement solidifications following temperature changes

[Matters indicated from the calculation results]
◯ A temperature rise of up to 60℃
・Changes in the Ferrite-based minerals (C4FH13→C3FH6)
・No changes in the minerals from the carbonate slurry.
→ No big changes were seen in the solidifications.
◯ Crystallizing conditions at 100℃
・C-S-H and Portlandite disappear and the crystal mineral is generated.
→ Changes in the mineral phase, decrease in volume in the solid phase.

- Mineral phase changes in case of leaching following contact with water

・Amount of waste filling: Carbonate slurry is 30 [mass%]
・Immersion conditions: Pure water
・Solid-Liquid ratio: 1:10, 1:100, 1:500, 1:1000, 1:2000
・During the calculations of the various Liquid-Solid ratios, the decreased portion of the mass and volume of the solid phase was assumed to be the leached out portion.

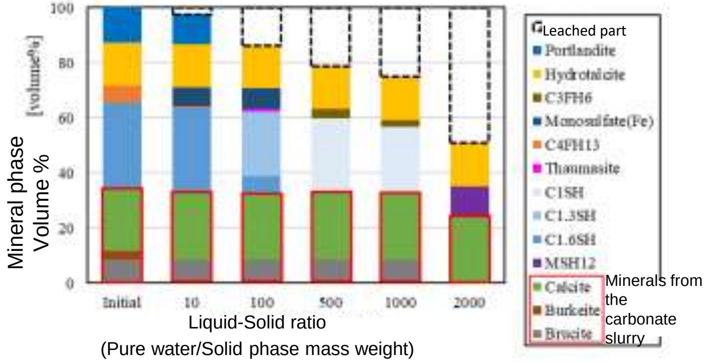


Fig. 7 Change in mass ratio in the mineral phase following changes in the Liquid-Solid ratio

[Matters indicated from the calculation results]
○ Solubility alteration in the cement-based minerals
・Portlandite disappears.
・The C/S ratio of C-S-H decreases.
・M-S-H is generated.
○ Changes in the minerals from the carbonate slurry
・At the Liquid-Solid ratio of 2000, Brucite disappears and Calcite decreases.
・M-S-H is generated.
→ Decrease in volume in the solid phase due to dissolution.

The calculation results for cement were obtained with respect to the essential filling rate, temperature changes and the leaching properties required for studying the waste solidifications.

(a) Establishment of techniques for selecting the preceding processing method
① Low-temperature treatment technology
ii. Investigation of change in properties of solidifications (iii) Investigation and evaluation of factors influencing long-term changes in properties
[Summary/ Plan for the following year]

➢ Current Summary

- The thermodynamics data was collected and maintained, and the thermodynamics stability phase and the metastable phase were selected from the literature survey.

(AAM)

- Calculations were implemented for the AAM solid phase and the coexisting liquid phase, were compared with the leaching test results of the metakaolin system AAM acquired in FY2018, and the possibility to reproduce was obtained by setting multiple metastable phases.

(Cement)

- As regards the solidifications containing carbonate slurry, analytical values were obtained for the mineral phase, mineral phase changes due to changes in temperature, and mineral phase changes in case of leaching following contact with water.

➢ Plan for the following year

(AAM)

- Additional calculations will be performed when waste elements are added to clarify the applicability of the thermodynamics equilibrium calculation at the present point and examine the issues.

(Cement)

- The iron coprecipitation slurry will be calculated. Additionally, analysis results of solidifications containing slurry and the calculated results for elution, heating and drying test which are being collected under other implementation items will be compared to clarify the applicability of the thermodynamics equilibrium calculation at the present and to examine the issues.

(a) Establishment of techniques for selecting the preceding processing method【Confidential】

② Study on the approach for evaluating the applicability of treatment technologies

[Goals]

i. Investigation and study regarding the influence of waste composition on the performance of solidifications

To study the effect of the composition and chemical form of solid waste and the impact of the composition of solidifications on the performance of the solidifications, in order to evaluate the range of solid wastes to which various treatment technologies may be applicable.

ii. Data acquisition for equipment configurations for various treatment technologies

To study the concept of solidification treatment equipment, collect data on economic efficiency such as equipment configuration and its treatment efficiency, maintenance details, types of consumables and replacement frequency and types and weight of secondary waste etc. and thereby make additions and updates in the Technology Investigation Table, in order to evaluate the waste specifications of various treatment technologies.

iii. Investigation regarding the volatility of Cs during high temperature treatment and its control

To study the volatility of Cs and its control mechanism and evaluate the volatile properties of Cs by means of treatment methods and operating conditions, since the volatility of Cs is a problem in the high temperature treatment technology.

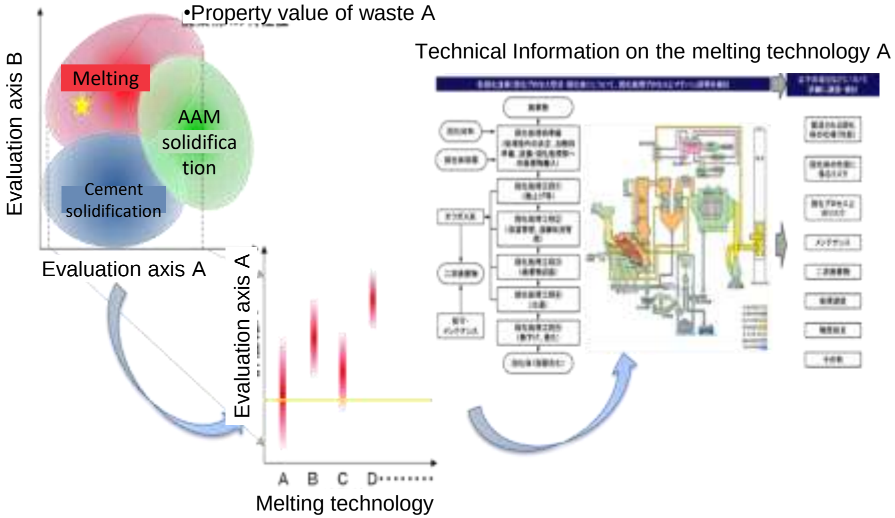


Fig. 1 Image showing the applicability evaluation method to be developed (Evaluation approach)

(a) Establishment of techniques for selecting the preceding processing method
② Study on the approach for evaluating the applicability of treatment technologies
i. Investigation and study of the effect of waste composition on the performance of solidifications
[Implementation Details]

In order to evaluate the range of solid wastes to which the various treatment technologies may be applicable, the effect of the composition and chemical form of the solid waste and the composition of solidifications on the performance of the solidifications was studied. The scope of the high-temperature treatments was studied using a database and the scope of the low-temperature treatments was investigated through the results of tests conducted under other items and through literature surveys.

In FY2019, the scope of applicability was studied using databases or literature, and in FY2020, the insufficient data will be collected experimentally and the scope of applicability will also be studied.

FY	Implementation Details
2019	Evaluation of the filling concentration (composition range) with respect to the various secondary waste generated from contaminated water treatment ・Collection of data on vitrification testing (including the supplementary activities) of the secondary waste generated from contaminated water treatment through literature survey, and organization of glass properties for various filling concentrations or compositions ・Incorporation of data in the glass properties model, and evaluation of the maximum filling concentration of the main secondary waste generated from contaminated water treatment in the range within which the glass properties such as the melting point, etc. are ensured
2020	Evaluation of filling concentration (composition range) when multiple wastes are mixed ・Reflection of the results obtained from the low-temperature system experiments and the results of the literature survey, and organization and evaluation of the limiting values for the range of waste properties and the filling concentration (possible mixing range) for the slurry ・Use of the glass properties model to evaluate maximum filling concentration of the main secondary waste generated from contaminated water treatment in the scope within which glass properties such as the melting point etc. are ensured. And verification of the properties by means of the glass melting test, if required (FY2019-2020)

[Study Results]
- Study methods-

- Collection of glass data from public literature together with the results of glass solidification tests of the simulated waste from the Fukushima Daiichi NPS, which was measured under the Government-led R&D Program on Decommissioning and Contaminated Water Management

- Setting up of restricting conditions (such as the melting point, viscosity and presence of precipitation phase etc.), and evaluation of the highest concentrations of the secondary waste generated from contaminated water treatment under these conditions by extrapolating the glass database
  - Analysis based on INTERGLAD ver. 8 of the New Glass Forum (NGF) and some proposers' data

- Evaluation of the secondary waste generated from contaminated water treatment as consisting mainly of Carbonate slurries (Ca, Mg, Na), the Zeolites (Si, Al, Na) and the Titanic acids (Si, Ti), which are present in large quantities

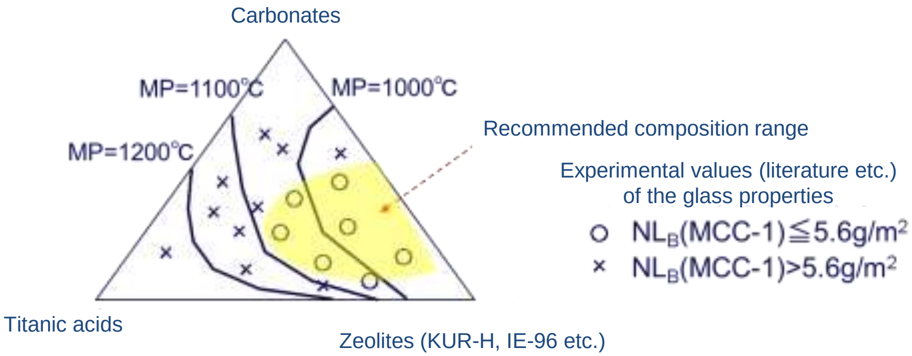


Fig. 2 Illustration of the Evaluation Results

[Study Results]
- Analysis with the Glass Properties Model -

- A total of 18,209 units of physical property data on glass containing more than 50% Zeolite could be extracted from INTERGLAD (Fig. 3), and it was possible to derive an estimation formula for liquid phase temperature, viscosity etc. by means of multiple regression analysis (Fig. 4). Meanwhile, since there was insufficient data about the glass containing carbonate slurry or titanic acid, it was difficult to derive an estimation formula for the same.

- On comparison with the PNNL estimation formula (which is in the public domain), the viscosities were almost the same below 10^3 dPa/s, but higher above that value (Fig. 5). The concentration range will be evaluated next year when the accuracy of the estimation formula will be improved by outsourcing PNNL.

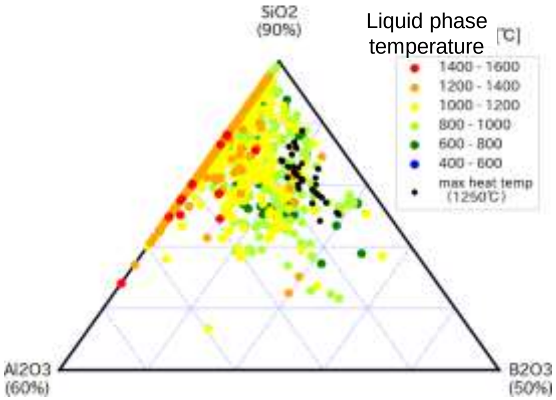
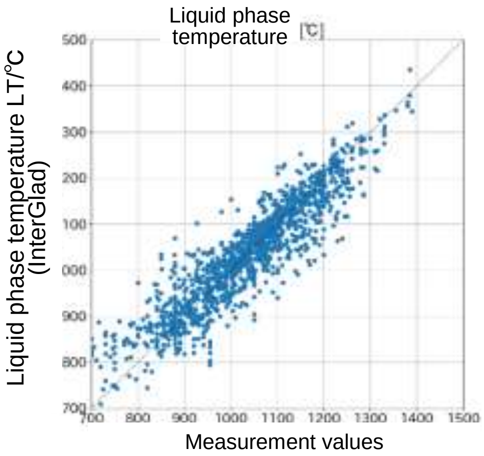


Fig. 3 Liquid phase temperature data
(The black spots confirm the melting point at 1250℃)



Estimation formula

$$\mathrm{LT[T/K]} = \sum a_i x_i$$

Fig. 4 Multiple regression results and estimation formula examples of the liquid phase temperature data ('x' shows the quantity of the contained element i while 'a' shows the coefficient for the element i.)

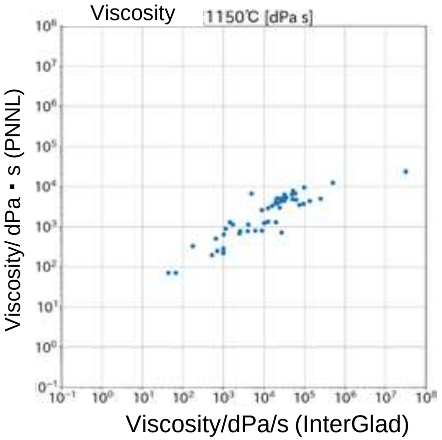


Fig. 5 Comparison of evaluation values with different viscosity estimation formulas (Estimation formula by INTERGLAD and publicly available formula of PNNL)

(a) Establishment of techniques for selecting the preceding processing method【Confidential】
② Study on the approach for evaluating the applicability of treatment technologies
i. Investigation and study of the effect of waste composition on the performance of solidifications
[Summary/ Plan for the following year]

➢ Current Summary

- Based on public data of INTERGLAD ver. 8 of the New Glass Forum (NGF) and the data proposed by related parties, analysis was carried out. The analysis showed that it was possible to derive an estimation formula through multiple regression analysis for the liquid phase temperature and viscosity of glass with Zeolite content.

➢ Plan for the following year

- Public data will be added to PNNL-specific database as well as the data obtained from companies involved in the project, which enables estimation of a glass physical properties. By using the estimation formula, the concentration range of the secondary waste generated from contaminated water treatment including Zeolites (chabazite), Silica and Titanic acids (CST) and Carbonate slurry, which can melt in glass, will be evaluated.

(a) Establishment of techniques for selecting the preceding processing method【Confidential】
② Study on the approach for evaluating the applicability of treatment technologies
ii. Collection of data on equipment configuration for the various treatment technologies
[Implementation Details] (1/2)

Economic data such as equipment configuration and its treatment efficiency, maintenance details, types of consumables and replacement frequency and types and weight of secondary waste etc. was investigated and organized in order to evaluate the waste specifications of various treatment technologies.

In case of some of the technologies, the lacking economic efficiency data was acquired by studying the concept of solidification treatment equipment, and this data was organized as technical information for various technologies.

The lacking economic efficiency data was collected in FY2019, and in FY2020, the investigation results including all the data obtained till date will be organized.

FY	Implementation Details
2019	Data acquisition on equipment configuration for each of the treatment technologies ・Investigation of equipment configuration and its treatment efficiency, maintenance details, types of consumables and replacement frequency, secondary wastes etc., as part of the applicability evaluation of various treatment technologies, and study of the target technologies. ・Further study in case of some of the technologies such as the study of the process flow or material handling etc., and organization of its results as technical information for the various technologies.
2020	Consolidation of the investigation results for each technology ・Consolidation of investigation results that will include all the data that has been collected till date.

(a) Establishment of techniques for selecting the preceding processing method

② Study on the approach for evaluating the applicability of treatment technologies

ii. Collection of data on equipment configuration for the various treatment technologies

- Technologies to be investigated -

Classification		Solidification treatment technology methods		Types of investigations (Major classification)	
				Technical Investigation (Investigation about the Process flow, Equipment configuration etc.)	Investigation based on economic efficiency data (Study of equipment scale etc. depending on the radiation dose)
High-temperature treatment	Vitrification	Flow type	Joule Heating (LFCM)	FY2019	△ (There are no examples for a low radiation dose and therefore, a study was conducted in FY2019 to see whether an investigation is possible.)
			Induction Heating (AVM, AVH)	- (It is determined that an alternative evaluation between Joule Heating and Induction Heating is possible)	- (It is determined that an alternative evaluation between Joule Heating and Induction Heating is possible)
			Induction Heating (CCIM)	[Partial project]	[Partial project]
		Incan type	Joule Heating (ICV)	FY2018	[Partial project]
			External Heating (Dem & Melt)	[Partial project]	[Partial project]
	Melting solidification	Flow type	Induction Heating	- (It is determined that an alternative evaluation between Incan and Induction Heating is possible)	- (It is determined that an alternative evaluation between Incan and Induction Heating is possible)
			Plasma Heating	FY2019	△ (There are no examples for a high radiation dose and therefore, a study in FY2019 to see whether or not an investigation is possible.)
		Incan type	Induction Heating	FY2018	△ (There are no examples for a high radiation dose and therefore, a study in FY2019 to see whether or not an investigation is possible.)
Low-temperature treatment	Cement solidification	Out drum type		FY2018	FY2019
		In drum type		FY2018	FY2019
	AAM solidification	Out drum type		- (Not studied from point of view of engineering. An alternative evaluation is deemed possible as there are compositions similar to cement.)	- (An alternative evaluation of the adaptability of the equipment to the differences in radiation dose is considered possible with cement solidification)
		In drum type		FY2018	

- ➢ Technical investigation of methods (Joule Heating method and Plasma Heating method) from amongst the solidification treatment technology methods that were not investigated
- ➢ Study of the cement solidification technology concerning equipment addition in line with the radiation dose (confinement or shielding) or the size of the equipment, as an investigation based on the data on economic efficiency

[Study Results]

- Investigation of applicability to the secondary waste generated from contaminated water treatment

- The properties of the secondary waste generated from contaminated water treatment were enumerated, and applicability of the high-temperature solidification treatment technology was investigated.

Waste	**Problematic waste properties**	**Limiting values**	
		LFCM	**Plasma Heating**
All types of waste	Melting point	Less than 1200°C	Less than 1650°C
	Viscosity	10Pa/s order or less at the treatment temperature #1 Must be less than equivalent viscosity even for hot water.	Approx. 1 Pa/s order or less at the treatment temperature #1 Must be less than equivalent viscosity even for hot water.
	Cs concentrations	There is migration to off gas regardless of the concentrations (Control measures with a cold cap can be executed).	There is a shift to off gas regardless of the concentrations.
	Moisture content	Can be supplied in liquid or slurry state	5 wt% or less is the standard
Ferrocyanide sludge	$BaSO_4$	Since the leaching tolerance of the solidifications decreases due to formation of the sulfate layer, it is necessary to curb the quantity of the waste mixture.	Due to the drop in melting point, the quantity of waste mixture is curbed. The quantity of waste input is about 50wt% for SiO2. There are no restrictions from the viewpoint of the formation of the sulfate layer, since it is expected to be volatile as SOx.
	Cyanide	CN decomposes or oxidizes and does not remain inside the solidifications.	CN decomposes or oxidizes and does not remain inside the solidifications.
Carbonate slurry	CaCO3	It is necessary to add the melting point lowering agent .	It is necessary to add the melting point lowering agent. (For instance, waste at weight ratio : SiO2 = 66:34)
	Mg(OH) 2	It is necessary to add the melting point lowering agent.	
	Na_2CO_3	Although there is no issue since Na lowers the melting point, depending on the chemical form of Na, there is a rise in the volatility of Na or Cs.	
	Boric acid	Although there is no issue since B lowers the melting point, depending on the chemical form, there is a rise in the volatility of B or Cs.	
Titanate	Titanate	When the melting point exceeds the treatment temperature, the melting point lowering agent is necessary.	

[#1] It is based on the investigation results. However, although it differs by an order of magnitude, it does not mean that a lower viscosity is required in principle in the case of plasma heating.

[Study Results]

- Collection of data on economic efficiency (Study results concerning layout) -

- Items such as confinement, shielding etc. or the scale of facility was investigated considering the radiation dose of the secondary waste generated from contaminated water treatment.

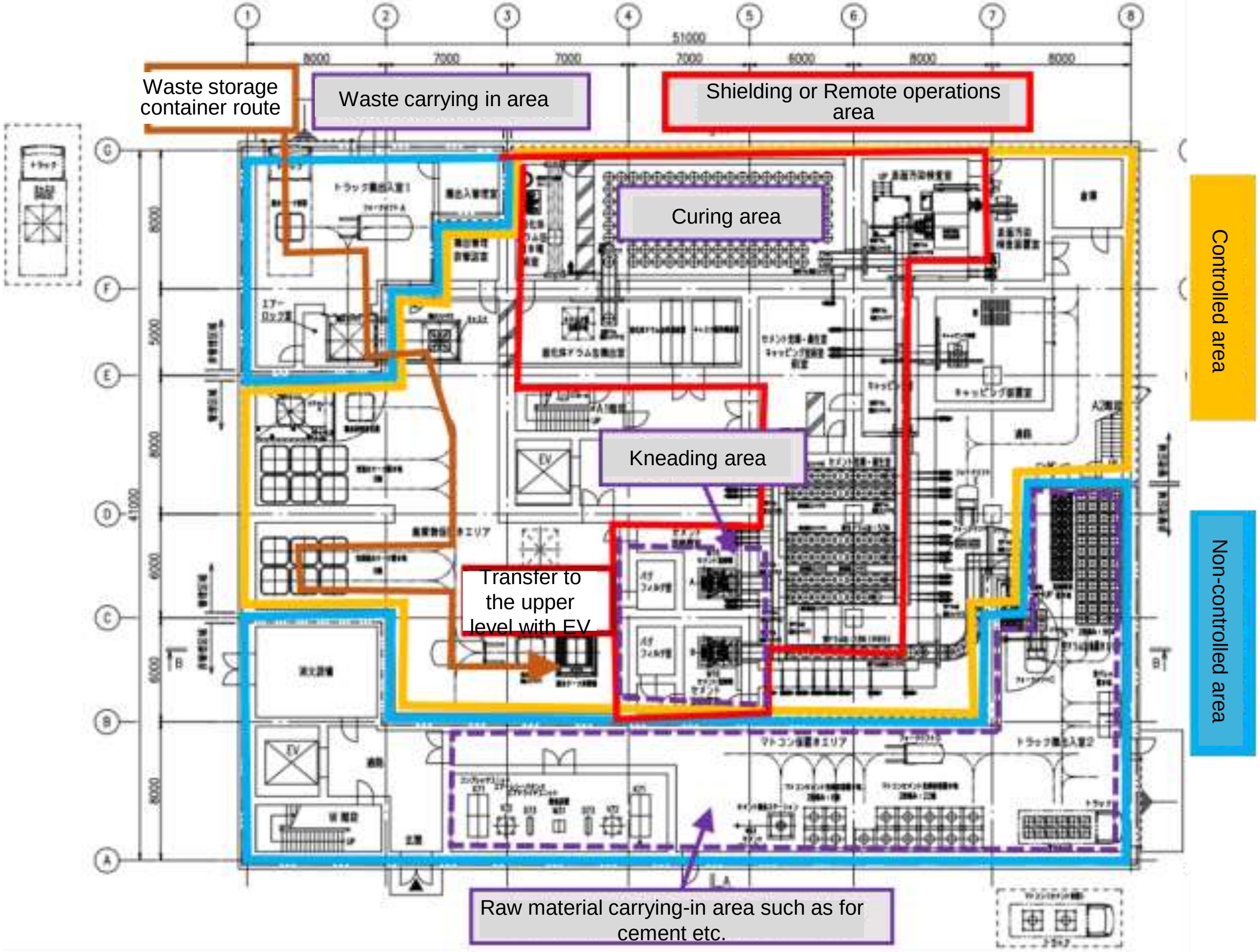


Fig. 1 Equipment layout plan for remote in-drum type cement solidification treatment

[Study Results]
- Collection of data on economic efficiency and comparison of practical engineering application -

- Comparison and study of practical engineering usage of the various technologies following from FY2018

Technology investigated this year			LFCM	Plasma heating	Cement solidification (In drum type) (High dose #1-Remote operations)
Target secondary waste generated from contaminated water treatment → Solid products			Zeolite＋Carbonate slurry → Glass solidifications	Carbonate slurry → Molten solidifications (slag)	Carbonate slurry → Cement solidifications
Main items of Evaluation	Technical achievements		Stage of practical application on an actual scale within Japan and overseas (HLW, LAW)	Stage of practical application on an actual scale within Japan and overseas (LLW)	Many waste (LLW) treatment results available within Japan and overseas
	Process	Treatment Temperature	1100 to 1200℃	Up to 1600℃	Room temperature
		Treatment Speed	Approx. Up to 0.3 t/h #2	Approx. 0.2 to 0.3 t/h #3	0.24 t/h (12 batches/ series) - 2 systems
		Cs Volatilization rate	Cs: Unknown #4	Cs: As an example it is 50%	None
	Operability	High influence parameters	Cold cap formation, Treatment temperature, Hot water output control	Composition adjustment, Treatment temperature, Hot water output control	Moisture content of waste, Amount of sodium carbonate
		Process Risk	Formation of non-homogeneous solidifications, blockage of hot water, container damage, uncontrollable cold cap	Leakage of cooling water, container damage, inadequate hot water supply	Back-up (water addition) difficult when fluidity is poor
	Economic	Main equipment configuration	Power supply equipment, off-gas system, shielding equipment	Drying equipment, power supply equipment, torches, off-gas systems, shielding equipment	Material supply equipment, agitator equipment, dustproof/ exhaust equipment, shielding equipment (remote control system), forklift with shielding
		Secondary waste generation	HEPA filter, Filter residue, Refractory re-covering, Electrodes	HEPA filter, Filter residue, Refractory re-covering, Electrodes	None
		Difficulties in remote operation	Refractory replacement in the furnace	Refractory replacement in the furnace	None
		Process in the shielded area	Waste supply/mixing, Vitrification/hot water	Unknown due to low dose performance only, estimated to be similar to LFCM	Waste crushing, Weighing, Kneading, Transfer of solidifications, Lid closure, Curing
		Shielding/Controlled Area/Total Building Area (m^2)	Unknown	0/Unknown/1450 (2F underground, 2F above ground, 4800 in total)	700/1400/2100
Estimated maturity for on-site application			Demonstration test at a full-scale level with simulated waste is required.	Demonstration test and active test at the full- scale level with simulated waste are required after optimizing the solidification treatment conditions.	Demonstration tests and active tests at a full-scale level with simulated waste are required.

#1 Approximately 1/100 of the maximum inventory measurement value of each nuclide in the currently obtained carbonate slurry was set as the threshold for high dose and low dose.
2 The glass production rate was 1 t / h, the waste filling rate in the solidifications was estimated to be 0.2 and the moisture content of the pretreatment waste was estimated to be 50 wt%.
3 As per the investigation results. Approximately 0.2 to 0.5 t / h when estimated with PACT-8 of Japan Atomic Power Company or with the Plasma melting furnace of JAEA. The composition ratio for treatment is Carbonate slurry : Glass material = 5: 5. Density of solidifications 2500 kg/m3, pretreatment waste moisture content 50wt% and the volatile matter in the solidifications in the carbonate slurry are considered.
4 The plan is to investigate the actual values in the United States next year.

(a) Establishment of techniques for selecting the preceding processing method
② Study on the approach for evaluating the applicability of treatment technologies
ii. Collection of data on equipment configuration for the various treatment technologies
[Summary/ Plan for the following year]

➢ Current Summary

- A technological investigation was carried out with respect to the high-temperature treatment techniques namely, the LFCM and Plasma melting.
- Items related to economic efficiency such as confinement, shielding etc. or the scale of facilities was investigated considering the dose of the secondary waste generated from contaminated water treatment with respect to the cement solidification (In-drum type), which is treated under low-temperature.

➢ Plan for the following year

- The data investigated so far will be organized and evaluation items that can be used as evaluation axis to compare technologies will be compiled. Additionally, the scope of application of each technology will be shown in figures.
- Any data required additionally during summarizing the data will be collected.

(a) Establishment of techniques for selecting the preceding processing method
② Study on the approach for evaluating the applicability of treatment technologies
iii. Investigation of Cs volatilization and control during high-temperature treatment
[Implementation Details]

The volatilizing of Cs is a problem in the high-temperature treatment technology and affects the model or the equipment configuration strongly.

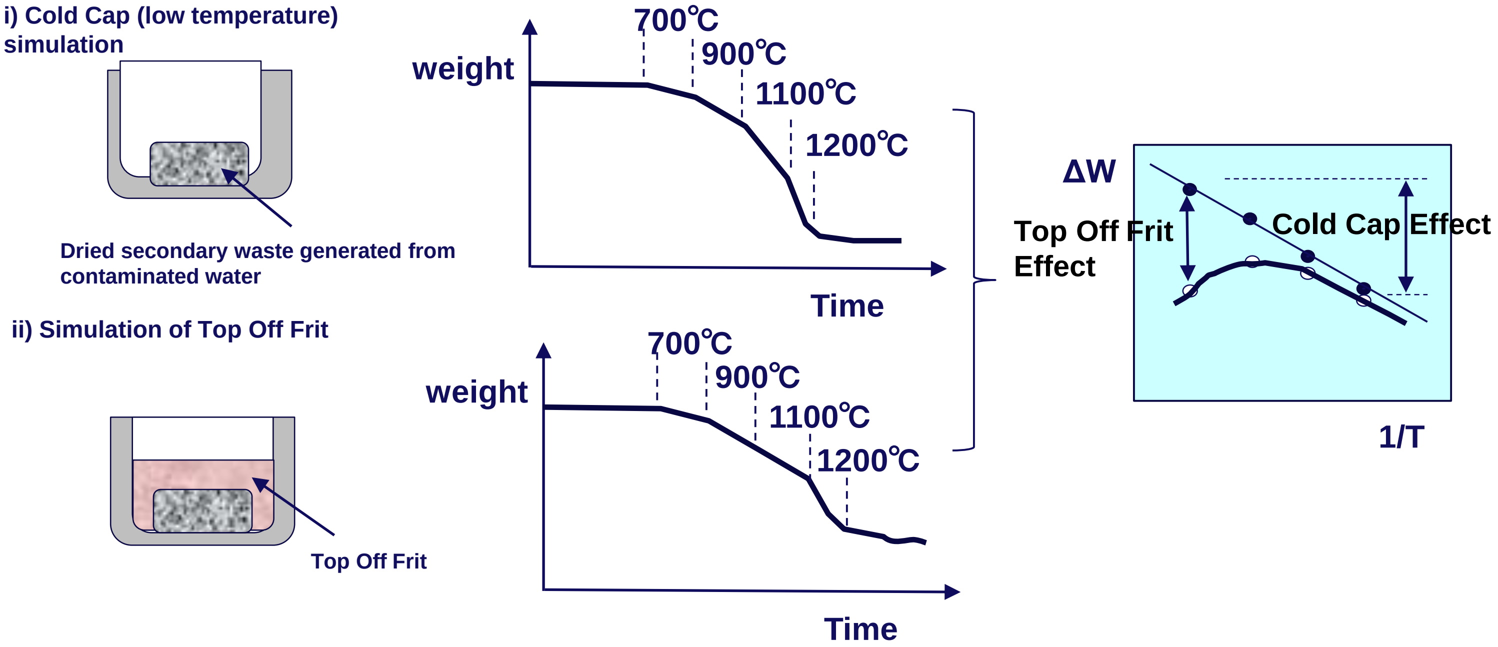
Therefore, the phenomenon of Cs volatilization and its control mechanism has to be evaluated on a laboratory scale, and the volatile properties of Cs have to be evaluated based on the treatment methods or the operating conditions. In FY2019, information regarding the Cs volatility was collected and a study was conducted regarding the control of Cs volatility, and in FY2020, data will be acquired by experimenting on small amount of samples.

The mechanism for implementing measures to control the volatilization rate of Cs by means of temperature control or additional loading of waste used in various facilities, was investigated and confirmed to evaluate the Cs volatilization rate and present effective control measures.

FY	Implementation Details
2019	Organization of findings related to volatility control of Cs during high temperature treatment of waste ・Organization of the concerned literature surveys and the engineering test results for each candidate technology.
2020	Measurement of the efficacy of Cs volatilization control during high temperature treatment of the secondary waste generated from contaminated water treatment ・ Evaluation of the Cs volatilization control effect with KURION-H, IE-96, silicate titanium acid etc. (FY2019-2020) ・Evaluation of the Cs volatilization control effect in a sample containing a glass component that simulates vitrification (FY2019-2020) ・Comparison of the engineering test results of each organized model with the volatilization control effect under the obtained ideal conditions. (FY2019-2020)

(a) Establishment of techniques for selecting the preceding processing method
② Study on the approach for evaluating the applicability of treatment technologies
iii. Investigation of Cs volatilization and control during high-temperature treatment
- Outline of the investigative tests (1/2) -

- Use TG-DTA, to measure the extent to which the control measures are able to bring down the volatility of CS from the secondary waste generated from contaminated water treatment.



Top Off Frit Effect: The effect of controlling volatilization by lowering the melting temperature by adding a low melting point vitrifying agent to the molten surface
Cold Cap Effect: The effect of decreasing the evaporation area to control volatilization by floating a solid cold cap at low temperature on the upper part of the molten substance

➢ Test flow

Assessing volatile behavior with a waste sample only

Assessing volatile behavior when a vitrifying agent has been added to the waste

Verifying the volatility control effect in the case of waste + vitrifying agent + Cold Cap

[Study Results]

- Consolidation of findings concerning Cs volatility control during high-temperature treatment of waste -

➢ Literature and actual results investigation

- It has been reported that the Cs volatility at the time of vitrification of Zeolite changed significantly depending on the melting temperature or the glass additives (B_2O_3 etc.). There are almost no reports on other adsorbents for Cs volatilization.
- The volatility rate of Cs differs depending on the model, but it is difficult to judge, since it depends not just on the device conditions such as air tightness or temperature control inside the reactor, stirring method (bubbling) etc. but also on the operating conditions such as the melting temperature or the cold cap formation, mixing ratios of waste, selection of vitrifying material etc., which continue to vary.

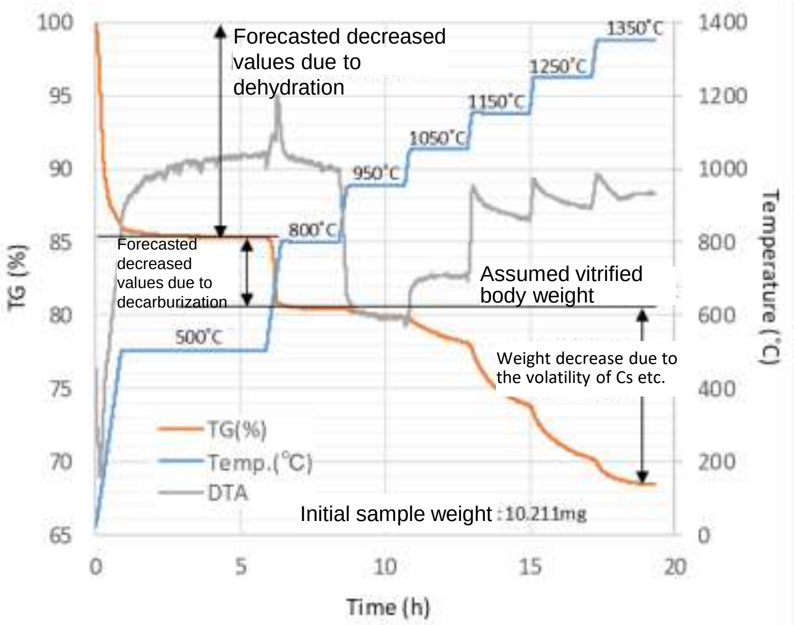
Model	Liquid Fed Ceramic Melter (LFCM)	Rotary kiln Induction heating (AVM, AVH)	Cold Crucible Induction Melting (CCIM)	Joule heating (GeoMelt)	External heating type (Dem&Melt)
Operating temperature/ heating method	1100 to 1200℃ /Direct energized joule heating	1150℃ /High frequency induction heating (metallic container)	1000 to 1200℃ /High frequency induction heating (glass)	1250℃ /Direct energized joule heating	900 to 1100℃ /External heater
Volatility data of Cs etc. during engineering scale testing/ Full-scale testing	・Real-time results with adsorbent infused high-reslurry at West Valley, SRS and Hanford. Real-time results with the high-level nitric acid liquid waste at WAK, JNFL. ・Results for Cs volatility are uncertain.	・Real-time operation with ORANO-UP3 ・There is a report that Cs volatility is a problem but no clarity about any specific amount of volatility.	・The off gas migration rate is **Cs = several % or more** during the engineering scale testing at IHI (There are no details for actual testing by other subsidy projects.)	・The off gas migration rate is **Cs = 1 to 9 %** during the engineering scale testing at KURION (There are no details for actual testing by other subsidy projects.)	・The off gas migration rate is **Cs = Less than 1%** during the engineering scale testing at ORANO (There are no details for actual testing by other subsidy projects.)
Method of controlling volatility	・Formation of Cold Cap	・A low temperature scorch layer is formed on the molten surface due to the supply of liquid waste.	・Formation of Cold Cap ・Decrease in the melting temperature because of optimization of the glass composition. ・Bubbling is minimized.	・Due to melting from the lower side and by maintaining low temperature on the upper side, volatility is controlled. ・Until the final stage where the waste has melted till the upper-most side, volatility is controlled by infusing a low-melting point glass material called Top Off Frit.	・Comparatively low temperature ・Temperature control easily controls the Cs volatility.

➡ Data on change in volatility properties depending on operating conditions is necessary in order to interpret the differences in the Cs volatility rate.

[Study Results]
- Verification of the effect of volatility control -

- ➢ Measurement of the amount of Cs volatility during high-temperature treatment

○Clarification of the amount of volatility in different temperature zones
・Zeolite that has adsorbed Cs is heated with the vitrifying agent and the weight decrease in each temperature zone is measured.



Forecasted decreased values due to dehydration

Forecasted decreased values due to decarburization

Assumed vitrified body weight

Weight decrease due to the volatility of Cs etc.

Initial sample weight : 10.211mg

Fig. 1 TG/DTA result of the sample added with reagent base

By measuring the amount of weight decrease due to volatility in the different temperature zones, an ideal volatility decreasing effect resulting from differences in the melting temperature could be clarified (Cold Cap).

○Changes in the amount of volatility due to the addition of a vitrifying agent
・The weight decrease is measured following heating after changing the vitrifying agent added to Zeolite that has adsorbed Cs.

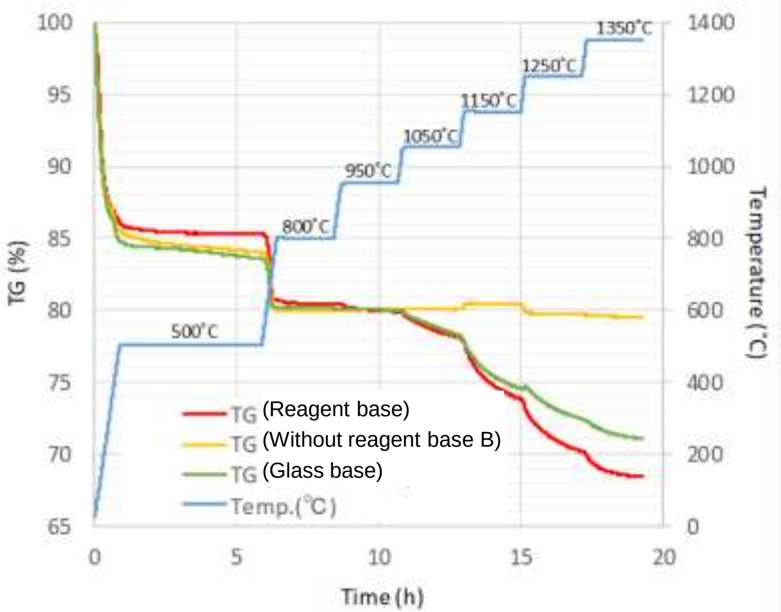


Fig. 2 TG analysis results for each method of addition

Due to differences in composition of the vitrifying agent (presence of B) and the form of addition (reagent powder, vitrified powder), there are changes in the amount of volatility, and data suggesting that the variations are significant at the temperature of 1000°C or more, is being collected.

⇒Continue collecting data in order to understand the tendency of changes in the rate of volatility due to variations in the operating conditions. Study whether the variations in the results of the engineering scale testing can be explained by the variations in the operating conditions, and reflect the results in the comparison of the rate of volatility of Cs based on the model.

(a) Establishment of techniques for selecting the preceding processing method
② Study on the approach for evaluating the applicability of treatment technologies
iii. Investigation of Cs volatilization and control during high-temperature treatment
[Summary/ Plan for the following year]

➢ Current Summary

- Findings concerning the control of volatility of Cs during high-temperature treatment of waste were organized.
- Measuring test of phenomenal Cs volatility on a laboratory scale was started.

➢ Plan for the following year

- Measuring test of phenomenal Cs volatility on a laboratory scale will continue to collect data.
- Differences in engineering test results will be studied whether the operating conditions affect the engineering test results. The study results will be reflected in the comparison of Cs volatility rate that can be an evaluation axis.

(a) Establishment of techniques for selecting the preceding processing method【Confidential】
- Summary of the Progress Status -

Implementation Items			Outline
① **Low-temperature treatment** technology	**i. Collection** and evaluation of **data** on low-temperature treatment technology to contribute to the identification of technology	**(i)** Study on the **verification method** for low-temperature treatment solidification	● Selection of simulated waste and study of evaluation methods has ended. ● The screening flow concept has been created.
		(ii) Collection of **data on properties** of cement and AAM **solidifications** for the slurry	● Simulated carbonate slurry has been manufactured. ● Composition conditions for the simulated solidifications have been selected. ● Simulated solidifications have been manufactured and the various analyses continue on an ongoing basis.
		(iii) Investigation of **special cements**	● Literature survey and selection of cement for testing has ended. ● Performance testing of the target special cements base material has ended
	ii. Investigation of **change in properties of solidifications**	**(i)** Investigation of **change in properties of solidifications due to heating**	● Literature survey regarding the change in properties of the solidifications due to heating etc., has ended. ● The heat addition test has been executed (part of it is still underway).
		(ii) Evaluation of the relation between the Cs inventory and the **temperature of solidifications**	● Modeling and simulation calculation (OPC) of the container has ended. ● Trial pertaining to the relation between inventory and temperature of solidifications
		(iii) Investigation and evaluation of factors influencing **long-term changes in properties**	● Comparison between the thermodynamics equilibrium calculation for the AAM solidifications with the experimental results ● Trial run of the thermodynamics equilibrium calculation pertaining to the property change behavior of the carbonate slurry cement solidifications is conducted.
② Study on the **approach** for evaluating applicability of treatment technologies	**i.** Investigation and study of the **effect** of waste composition on the **performance of solidifications**		● Collection and organization of the vitrification test data has ended. ● The calculation to evaluate the physical properties using the glass characteristic model (InterGlad) has ended.
	ii. Collection of data on **equipment configuration** for the various treatment technologies		● Investigation concerning plasma melting, LFCM and cement solidification has ended. ● Addition into and update of the Technology Investigation Table is carried out.
	iii. Investigation of **Cs volatilization and control** during high-temperature treatment		● Organization of literature survey and engineering test results concerning Cs volatility has ended. ● Testing to measure the amount of Cs volatility during high-temperature treatment continues to be carried out on an ongoing basis.

respect to slurry, it is mostly progressing as scheduled.

(b) Presentation of disposal methods, and development of safety assessment techniques
① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

- ■ Results
  - ○ Important case examples were identified by conducting an overseas disposal site survey. In addition, the applicability to the waste disposal at 1F was evaluated.
  - ○ A process for studying the disposal concepts was established in order to study waste management strategies.
- ■ Goals
  - ○ To create the image of waste packages and present disposal methods based on the classification of solid waste.
- ■ Implementation details
  - ○ In FY2019, several disposal methods were studied in accordance with the classification of solid wastes, based on the survey details on domestic and overseas disposal concepts and safety assessment techniques and based on the information on solid waste properties. The items that need to be studied for the establishment of safety assessment techniques for each disposal method were identified. The concepts of the studied disposal methods were organized to clarify the image of waste packages resulting from each of the treatment technologies applicable in accordance with the characteristics of solid waste.
  - ○ In FY2020, studies will be continued on multiple disposal methods in accordance with the classification of solid wastes, based on the survey details on domestic and overseas disposal concepts and safety assessment techniques and based on the information on solid waste properties. Necessary information regarding the identified items that need to be studied will be collected and consolidated. The image of waste packages resulting from each of the treatment technologies applicable in accordance with the characteristics of solid waste, for the studied disposal methods will be studied.
- ■ Indicators to determine goal achievement
  - ○ (FY2019) The items that need to be studied for the establishment of safety assessment techniques for each disposal method should be presented. The concept for clarifying the image of waste packages should be presented.
  - ○ (FY2020) Multiple disposal methods based on the classification of solid waste should be presented. Necessary information regarding the identified items that need to be studied should be presented. The image of waste packages should be presented.

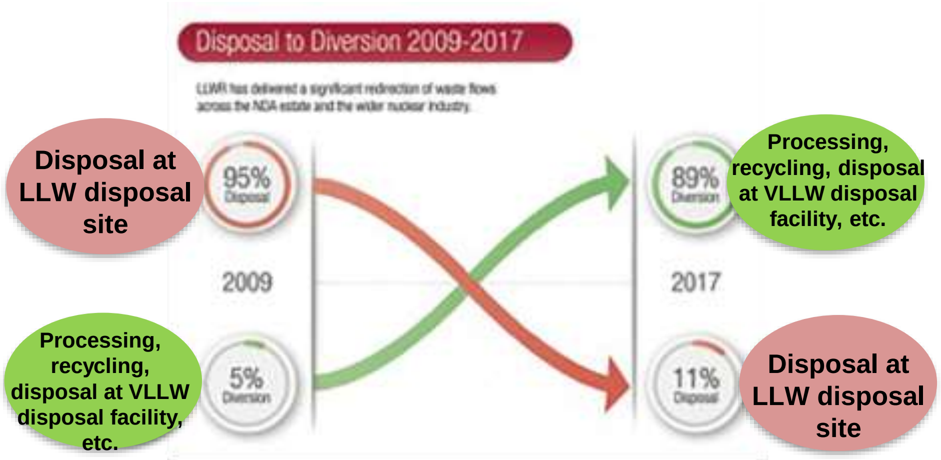


Fig. 1 Waste disposal strategy in the UK

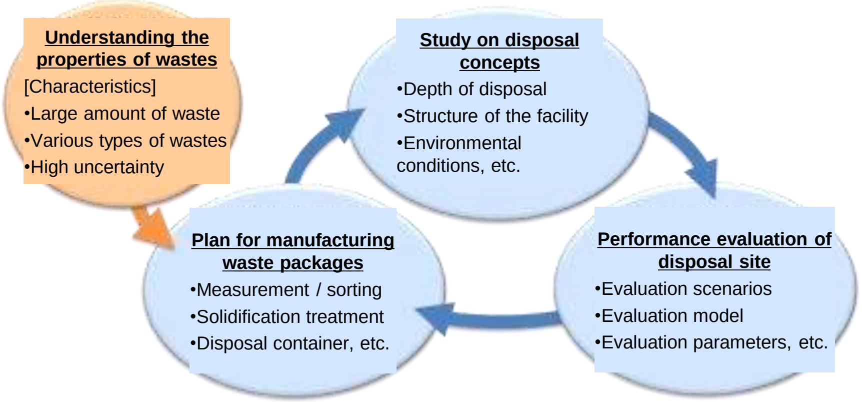
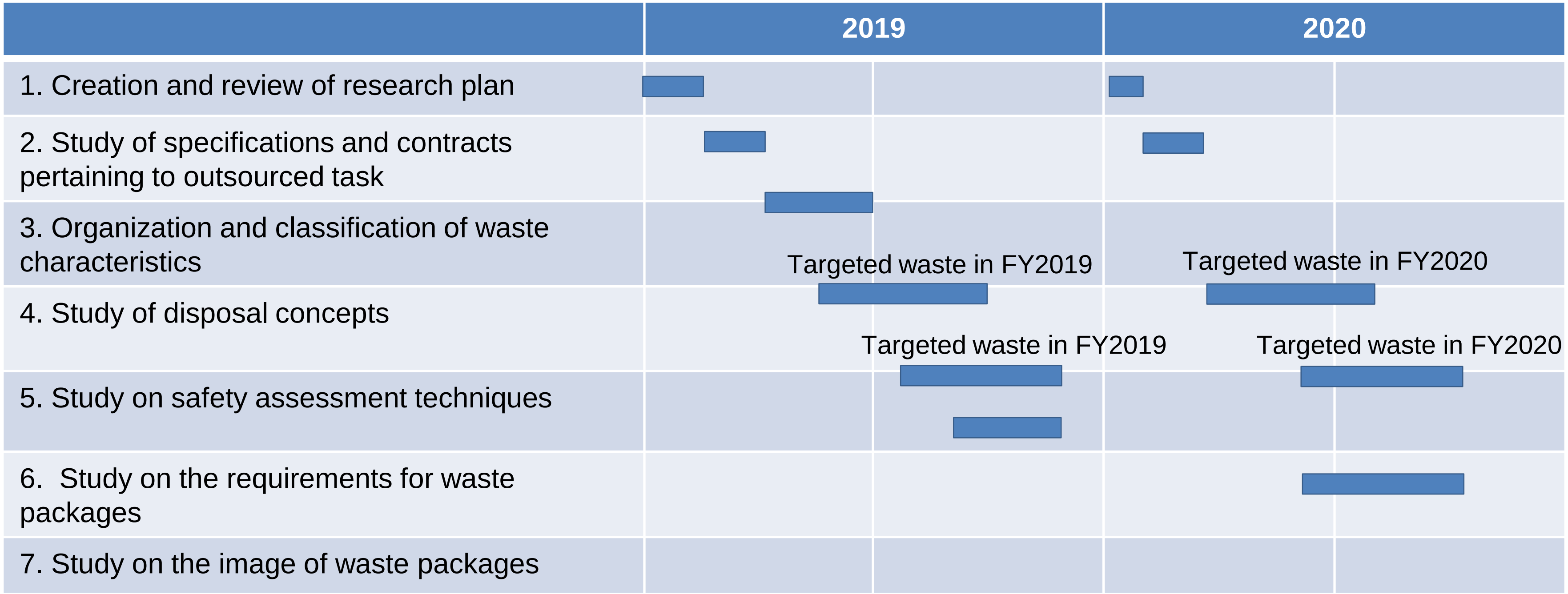


Fig. 2 Process for studying the disposal concepts

(b) Presentation of disposal methods, and development of safety assessment techniques

① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques



	2019	2020
1. Creation and review of research plan		
2. Study of specifications and contracts pertaining to outsourced task		
3. Organization and classification of waste characteristics		
4. Study of disposal concepts	Targeted waste in FY2019	Targeted waste in FY2020
5. Study on safety assessment techniques	Targeted waste in FY2019	Targeted waste in FY2020
6. Study on the requirements for waste packages		
7. Study on the image of waste packages		

- Implementation details (proposed)

1. The research plan will be created and reviewed.
2. Specifications and contracts of the outsourced task will be studied.
3. Waste characteristics will be organized and classified.
4. Disposal concepts suitable for the characteristics of solid wastes will be studied.
5. Performance of disposal site will be evaluated for the studied disposal concepts.
6. The requirements of waste packages from the perspective of disposal will be studied.
7. The image of waste packages based on the applicable treatment technology will be studied.

(b) Presentation of disposal methods, and development of safety assessment techniques

① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

Results and issues in FY2017 – FY2018, and study policy for FY2019 – FY2020

<Major results of FY2017 – FY2018>

1. Survey of case examples of overseas disposal sites

● Case examples from overseas disposal sites were identified and their applicability to 1F waste disposal was evaluated.

2. Establishment of a process for studying the disposal concepts

● The process for studying the disposal concepts, in which the plan for waste conditioning (measurement / sorting, solidification treatment, containers, etc.), the disposal concepts, and performance evaluation of disposal sites are studied serially, was established.

3. Case study on multiple disposal concepts

● A case study on improved confinement function of the disposal facility, disposal container, and solidifications respectively was conducted, and it was confirmed that the effect could be verified and feedback could be given.

<Issues and study policies for FY2019 – FY2020>

1. Study on disposal concepts considering the characteristics of each type of waste

‣ In the study to be conducted during FY2019 - FY2020, the characteristics of each type of waste will be studied and consolidated.

‣ The process for deriving the disposal concepts based on the characteristics of each type of waste will be studied.

2. Identification of issues in establishing safety assessment techniques and items that need to be studied

‣ Safety assessment of hypothetical waste packages and hypothetical disposal sites will be conducted in consideration of latest regulations, and the issues in safety assessment and necessary parameters will be studied.

3. Study on the concept of waste package requirements from the perspective of disposal safety

‣ The concept of waste conditioning and its requirements will be studied based on the characteristics of each type of waste.

Course of action for FY2019-FY2020 (1/2)

<Items discussed by the concerned parties while formulating the plan>

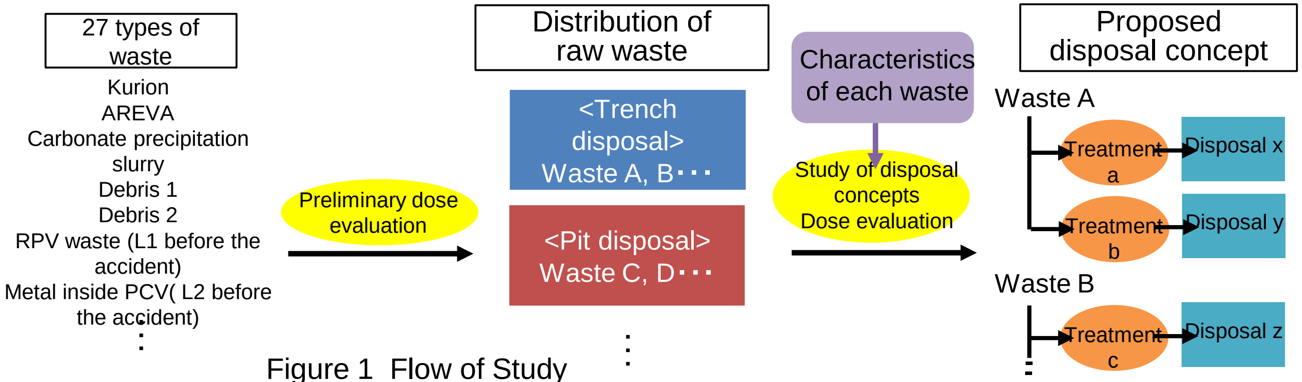
● 27 types of accident wastes from the assumed inventory studied by means of characterization, will be studied, based on the fact that these cover a wide range of wastes and that the results of studies conducted so far can be used.

● At present, since the inventory is uncertain and there is uncertainty in dose evaluation parameters as the disposal sites are yet to be determined, it is estimated that the result of dose evaluation will include significant uncertainty.

Therefore, in this study, the focus will be on establishing a process for determining the disposal methods and on identifying related issues, using the results of dose evaluation as reference values.

● First, as a starting point, preliminary dose evaluation will be performed. The dose, when 27 types of accident waste is considered as raw waste and hypothetically disposed of in trenches, pits or at medium depths, will be evaluated, and compared with the standard value including the one under study by the Nuclear Regulation Authority. As a base for the disposal concepts, a preliminary study will be carried out on which disposal classification is expected for each type of waste.

Based on this disposal classification, the aim is to study the treatment and disposal measures based on the characteristics of each type of waste and to present a disposal concept based on the waste classification.


27 types of waste
Kurion
AREVA
Carbonate precipitation slurry
Debris 1
Debris 2
RPV waste (L1 before the accident)
Metal inside PCV(L2 before the accident)
⋮

Preliminary dose evaluation

Distribution of raw waste
<Trench disposal>
Waste A, B・・・
<Pit disposal>
Waste C, D・・・
⋮

Characteristics of each waste
Study of disposal concepts
Dose evaluation

Proposed disposal concept
Waste A
Treatment a → Disposal x
Treatment b → Disposal y
Waste B
Treatment c → Disposal z
⋮

Figure 1 Flow of Study

Table 1 Examples of 27 types of accident waste

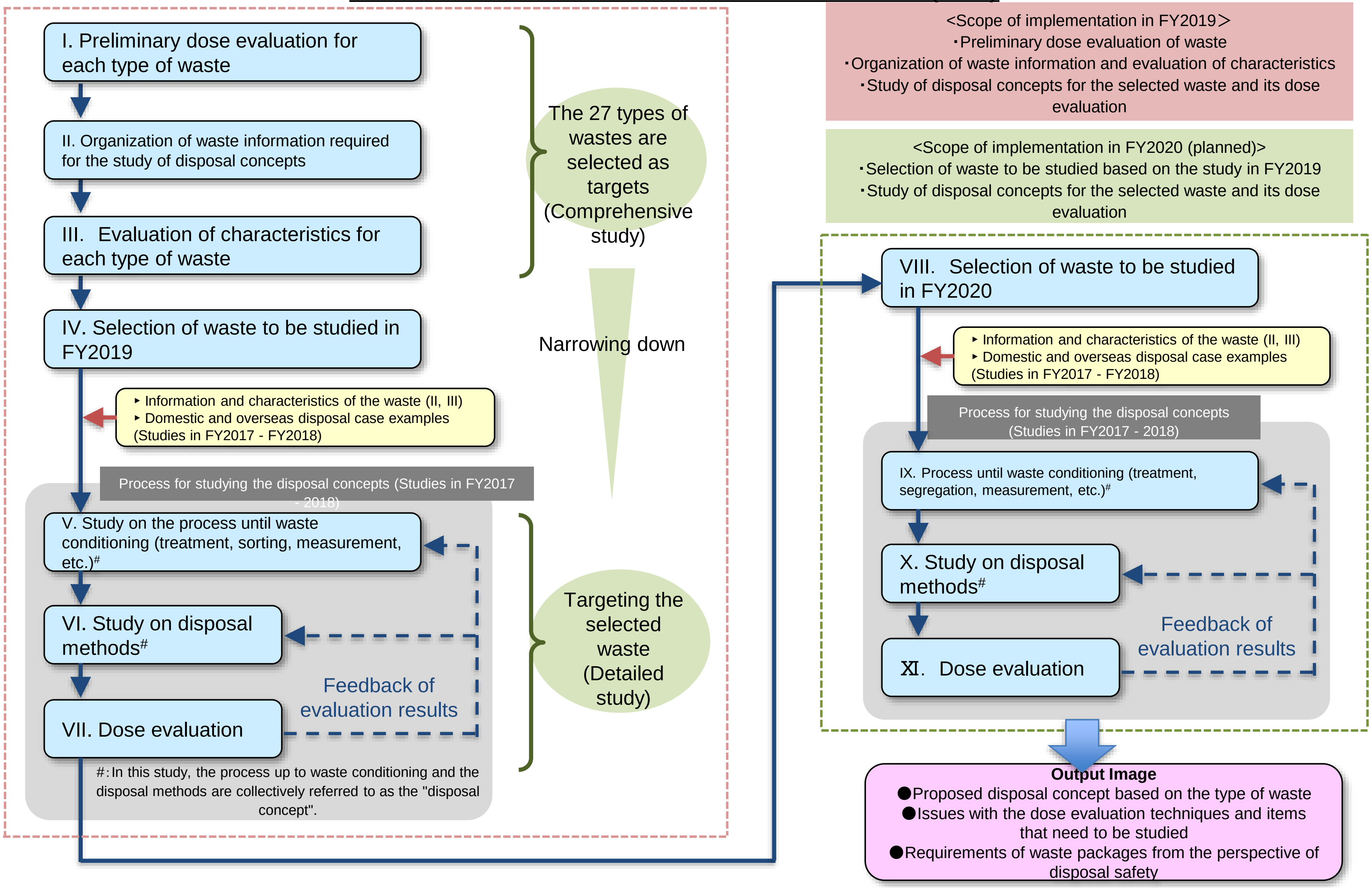
Types of waste	
Waste generated from water treatment	Kurion
	AREVA sludge
	SARRY
	Carbonate precipitation slurry
	Used adsorbent from ALPS (Titanate)
Debris	<0.005 mSv/h
	0.005-0.1 mSv/h
	0.1-1 mSv/h
	1-30 mSv/h
	>30 mSv/h
Dismantling waste	RPV waste (L1 before the accident)
	Metal inside PCV (L2 before the accident)
	Metal inside the building (L3 before the accident)
	Concrete inside the building (Not released before the accident)

⋮

(b) Presentation of disposal methods, and development of safety assessment techniques

① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

Course of action for FY2019-FY2020 (2/2)



I. Preliminary dose evaluation for each type of waste

II. Organization of waste information required for the study of disposal concepts

III. Evaluation of characteristics for each type of waste

IV. Selection of waste to be studied in FY2019

The 27 types of wastes are selected as targets (Comprehensive study)

Narrowing down

- Information and characteristics of the waste (II, III)
- Domestic and overseas disposal case examples

(Studies in FY2017 - FY2018)

Process for studying the disposal concepts (Studies in FY2017 - 2018)

V. Study on the process until waste conditioning (treatment, sorting, measurement, etc.)#

VI. Study on disposal methods#

VII. Dose evaluation

Feedback of evaluation results

Targeting the selected waste (Detailed study)

#: In this study, the process up to waste conditioning and the disposal methods are collectively referred to as the "disposal concept".

<Scope of implementation in FY2019>

- Preliminary dose evaluation of waste
- Organization of waste information and evaluation of characteristics
- Study of disposal concepts for the selected waste and its dose evaluation

<Scope of implementation in FY2020 (planned)>

- Selection of waste to be studied based on the study in FY2019
- Study of disposal concepts for the selected waste and its dose evaluation

VIII. Selection of waste to be studied in FY2020

- Information and characteristics of the waste (II, III)
- Domestic and overseas disposal case examples

(Studies in FY2017 - FY2018)

Process for studying the disposal concepts (Studies in FY2017 - 2018)

IX. Process until waste conditioning (treatment, segregation, measurement, etc.)#

X. Study on disposal methods#

XI. Dose evaluation

Feedback of evaluation results

Output Image

- ●Proposed disposal concept based on the type of waste
- ●Issues with the dose evaluation techniques and items that need to be studied
- ●Requirements of waste packages from the perspective of disposal safety

I. Preliminary dose evaluation for each type of waste

Purpose

The 27 types of accident waste (secondary waste generated from contaminated water treatment, debris, felled trees, dismantling waste) will be allotted for trench disposal, pit disposal, medium depth disposal, and geological disposal.

- In I, raw waste is assumed. However, the sensitivity to exposure dose during the elution period in the Groundwater Scenario is evaluated by a parameter study.

- In I, overseas case examples (artificial barriers, etc.) surveyed during FY2017 - FY2018 are not considered.

Overview of evaluation methods

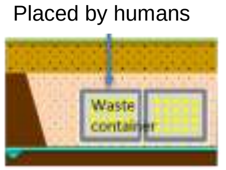
Groundwater Scenario and Nearing Scenario are used.

Inventory (27 types of waste)

The assumed inventory for the 27 types of accident waste (secondary waste generated from contaminated water treatment, debris, felled trees, dismantling waste), which is the result of the FY2017 - FY2018 IRID study, was used.

Dose evaluation in Nearing Scenarios

The following parameter surveys were conducted.
- Inventory (50 %ile, 95 %ile)
- Generation time (trench: 50 to 600 years, pit: 300 to 600 years)

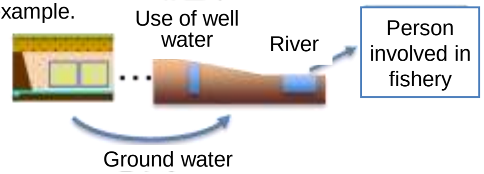


Exposure route
- Person staying at site
- Excavation worker
- Geotechnical engineer
- Lab analyst

*In the preliminary dose evaluation, a person staying at the site is evaluated as a representative example.

Dose evaluation in Groundwater Scenarios

The following parameter surveys were conducted.
- Inventory (50 %ile, 95 %ile)
- Impact on disposal depending on the presence of affecting substances
- Elution period (1y to 100,000y), amount of penetrated water (reference value x 1 to x 0.001)



In the preliminary dose evaluation, the river route is evaluated as a representative example.

Allotment with respect to preliminary disposal classification

The 27 types of accident waste (secondary waste generated from contaminated water treatment, debris, felled trees, dismantling waste) were allotted for trench disposal, pit disposal, medium depth disposal, and geological disposal.

I. Preliminary dose evaluation for each type of waste

Summary of preliminary dose evaluation results

The 27 types of waste were allotted disposal classes assuming that these consist mainly of raw waste.

➡ In the Nearing Scenario, the dose when the scenario occurs largely depends on the disposal method (stationary density).
Following could be the countermeasures for this scenario.
・Reducing the maintainability of the inventory
・ Extension of management period

➡ In the Groundwater Scenario, most of the waste needs to be disposed in deep depths if no measures are taken.
Following could be the countermeasures for this scenario.
・Reducing the maintainability of the inventory
・The elimination of impacts of substances with impact on disposal does not reduce the distribution and sorption performance of the natural barriers and of areas where distribution equilibrium is achieved.
・ Nuclide migration measures (Solidification treatment, installation of artificial barriers)

➡ Sensitivity evaluation of the effects (changes in dose and disposal classification) upon implementing the above measures was performed and the results were organized based on the type of the waste.

II. <Organization of waste information>

The waste information necessary for studying the disposal concepts was organized, based on the results of the preliminary dose evaluation and the IRID studies conducted so far.

Targeted waste

27 types of waste linked to the inventory

Secondary waste generated from contaminated water treatment
- KURION
- AREVA
- SARRY
- Slurry 1 Iron co-precipitation
- Slurry-2 Carbonate precipitation
- ALPS-4 Ag impregnated activated carbon
- ALPS-2 Titanate

etc.

Debris, felled tress
- Debris 1 to 5
- Felled trees

Dismantling waste
- RPV waste (L1, L2 before the accident)
- PCV waste (metal) (L2, L3 before the accident)
- PCV waste (concrete) (L2, L3 before the accident)
- Waste inside the building (metal) (L3 before the accident, not released)
- Waste inside the building (concrete) (L3 before the accident, not released)

Organized items (excerpts)

<Source of information>

Basic Information
- Quantity

Radioactivity properties
- The amount of radioactivity per nuclide
- Uncertainty in the amount of radioactivity

Inventory estimated during the FY2018 study

- Form of disposal
  Nearing Scenario, Groundwater Scenario

I. Preliminary dose evaluation

Physical properties
- Physical properties
  Shape, size, shape stability, dispersibility, Solubility, confinement property
- Chemical properties
  Material/substance, moisture content, inclusions (toxic substances, impacting substances, organic substances)

Storage and treatment
- Storage status
  Status of occurrence (existing occurrence, future occurrence), storage form
- Treatment options

Study results of Waste project, public information, etc.

III. Evaluation of waste characteristics

The characteristics of 27 types of waste were evaluated focusing on quantity, diversity, and uncertainty.

Example of waste in large "quantity"

- Type of debris - Debris 1 (0 to 0.005 mSv/h), etc.
  The entire quantity of debris is to the order of a few hundred thousand m^3, which is about the same as the maximum planned amount at Rokkasho.
- Concrete inside the building (not released before the accident)
  The quantity is to the order of a few hundred thousand m^3 as the material has become radioactive waste due to contamination at the time of the accident. The quantity changes depending on the state of contamination.
- KURION, carbonate slurry
  The quantity of secondary waste generated from contaminated water treatment is relatively small, however, as an adsorbent KURION is greatest in number and as slurry sludge the quantity of carbonate slurry is largest.

Examples of waste with great "diversity"

- General secondary waste generated from contaminated water treatment
  Waste specific to 1F. The amount of radioactive substances and chemical substances mixed in the same type of waste differs depending on the operation history of the facility.
- Types of debris
  Although the main waste comprises metals and concrete, there are variations in contamination (amount, form of contamination) and contaminants (type, amount).
- Dismantling waste
  Similar to the dismantling waste generated during general reactor decommissioning, the waste itself is radioactivated, and the extent of contamination by radioactive gas, fine particles, and contaminated water is large.
  Contamination is likely to occur due to other types of waste and chemicals during fuel debris retrieval and dismantling.
- Concrete inside the building (not released before the accident)
  It is not classified as radioactive waste in general decommissioning and is a contamination unique to 1F.

Examples of waste with high "uncertainty"

- General secondary waste generated from contaminated water treatment
  The amount generated may fluctuate depending on the operating conditions of the equipment in the future. There is also great uncertainty in the radioactivity properties due to variations in the amount of nuclides adsorbed.
- Dismantling waste
  Uncertainty is high as the radioactivity properties vary depending on the contamination status.
- Concrete inside the building (not released before the accident)
  Uncertainty is high as the amount of waste generated and the radioactivity properties vary depending on the contamination status.

IV. Selection of waste to be studied each year

8 types of waste were selected for detailed study (V to VII) based on the results of the studies conducted so far.

Table 1 Selected waste

No.	Waste	Category	Overview of waste
1	KURION	Secondary waste generated from contaminated water treatment	Adsorbents such as zeolite that adsorbed radionuclides such as C-137, and metal containers containing them
2	AREVA	Secondary waste generated from contaminated water treatment	Precipitates containing radionuclides such as Sr-90 (including ferrocyanide, barium sulfate, etc.)
3	Slurry-2 Carbonate precipitation	Secondary waste generated from contaminated water treatment	Sr-90 is a typical nuclide of carbonate slurry (Main components are $CaCO_3$, $Mg(OH)_2$) generated in water treatment facilities.
4	Debris 1 (0 – 0.005 mSv/h)	Various debris	The main materials are metal and concrete contaminated by the crushing and dismantling of structures such as buildings inside the premises.
5	Debris 2 (0.005 – 0.1 mSv/h)	Various debris	Similar to Debris 1 except that it has a higher amount of radioactivity
6	Waste from pressure vessel (L1 before the accident)	Dismantling waste	Fuel debris, cesium, etc. from the accident that are adhered to the activated metal in the pressure vessel
7	Waste inside PCV (metal) (L2 before the accident)	Dismantling waste	Fuel debris, cesium, etc. from the accident that are adhered to the radioactivated metal (PCV body, equipment) in the containment vessel.
8	Waste inside the building (concrete) (not released before the accident)	Dismantling waste	Highly concentrated contaminated water and / or contaminated air that are adhered to the building and the non-radioactive concrete in the building

<Representativeness of selected waste>

Radioactivity concentration	Covers waste from extremely high-level radioactive waste (KURION, waste from pressure vessel) to low-level radioactive waste (Debris 1).
Expected disposal concepts	Covers waste from L3 to L1 and waste that is expected to be geologically disposed.
Physical form Types of substances	Includes slurries, building materials (building concrete), and metal-based reactor components.
Affecting substances	Includes disposal of various debris that may contain organic matter, and substances affecting the environment (AREVA).
Quantity of raw waste	Covers waste from the two most abundant raw wastes (Debris 1 and concrete inside the building (not released before the accident)) to the least abundant raw waste.
Category	Multiple wastes are selected from the categories of secondary waste generated from contaminated water treatment, various debris, and dismantling waste.
Important nuclides	Includes short half-life nuclides and long half-life nuclides caused by radioactivation and contamination.
Uneven radioactivity distribution	Includes relatively uniformly contaminated secondary waste generated from contaminated water treatment and solid waste with uneven surface contamination.
Water content and mobility	Includes wet waste that may require solidification to reduce the risk of hazards.
Time of occurrence	Includes existing waste currently stored at the site (debris, etc.) and dismantling waste that will be generated decades later.

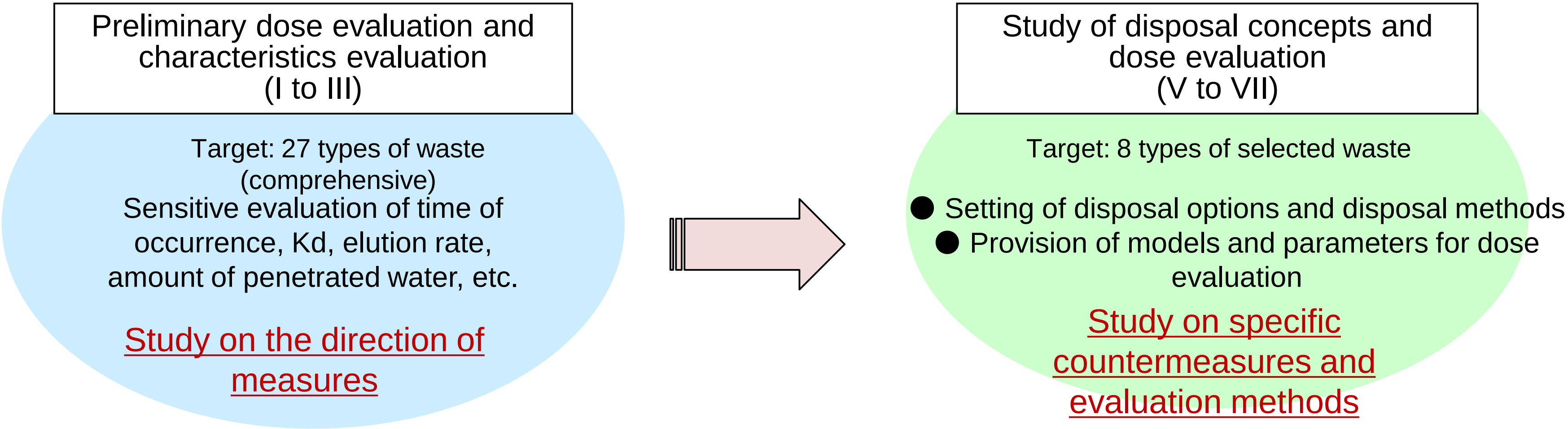
IV. Selection of waste to be studied each year

Study policy for “V. Study on the process until waste conditioning”, “VI. Study on disposal methods” and “VII. Dose evaluation”

① In “V. Study on the process until waste conditioning”, multiple treatment options shall be studied based on the characteristics of each waste.

② In “VI. Study on disposal methods”, the concept of disposal site with artificial barriers to reduce the amount of penetrated water shall be studied for the three categories, namely, surface disposal concept (L3), near-surface disposal concept (L2), and medium depth disposal concept (L1).

③ In “VII. Dose evaluation”, the treatment options studied in V and VI and the model parameters for incorporating the artificial barrier into dose evaluation, shall be studied. Here, with long-term institutional control as the pre-requisite, parameters such as nuclide migration and biosphere shall be reviewed with reference to cases from other countries.



Preliminary dose evaluation and characteristics evaluation
(I to III)

Target: 27 types of waste (comprehensive)
Sensitive evaluation of time of occurrence, Kd, elution rate, amount of penetrated water, etc.

Study on the direction of measures

Study of disposal concepts and dose evaluation
(V to VII)

Target: 8 types of selected waste

- Setting of disposal options and disposal methods
- Provision of models and parameters for dose evaluation

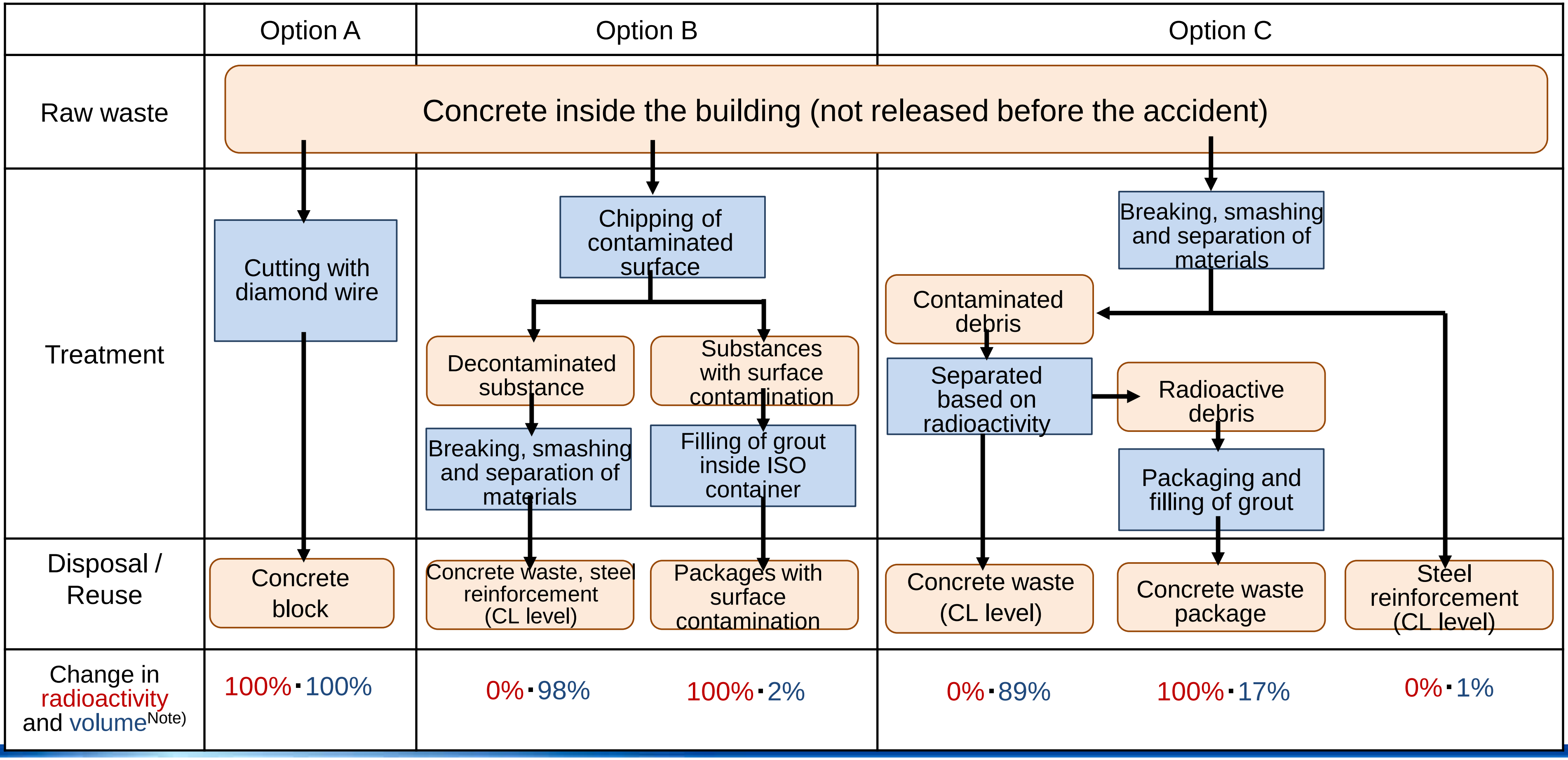
Study on specific countermeasures and evaluation methods

V. Study on the process until waste conditioning

Multiple processes up to waste conditioning from the concrete inside the building (not released before the accident) are studied and the amount of radioactivity and quantity for each waste package that gets generated is set.

Fig.1 Sample image of building concrete

Table 1 Flow of each treatment option
(Illustration of waste inside the building (concrete) (not released before the accident))



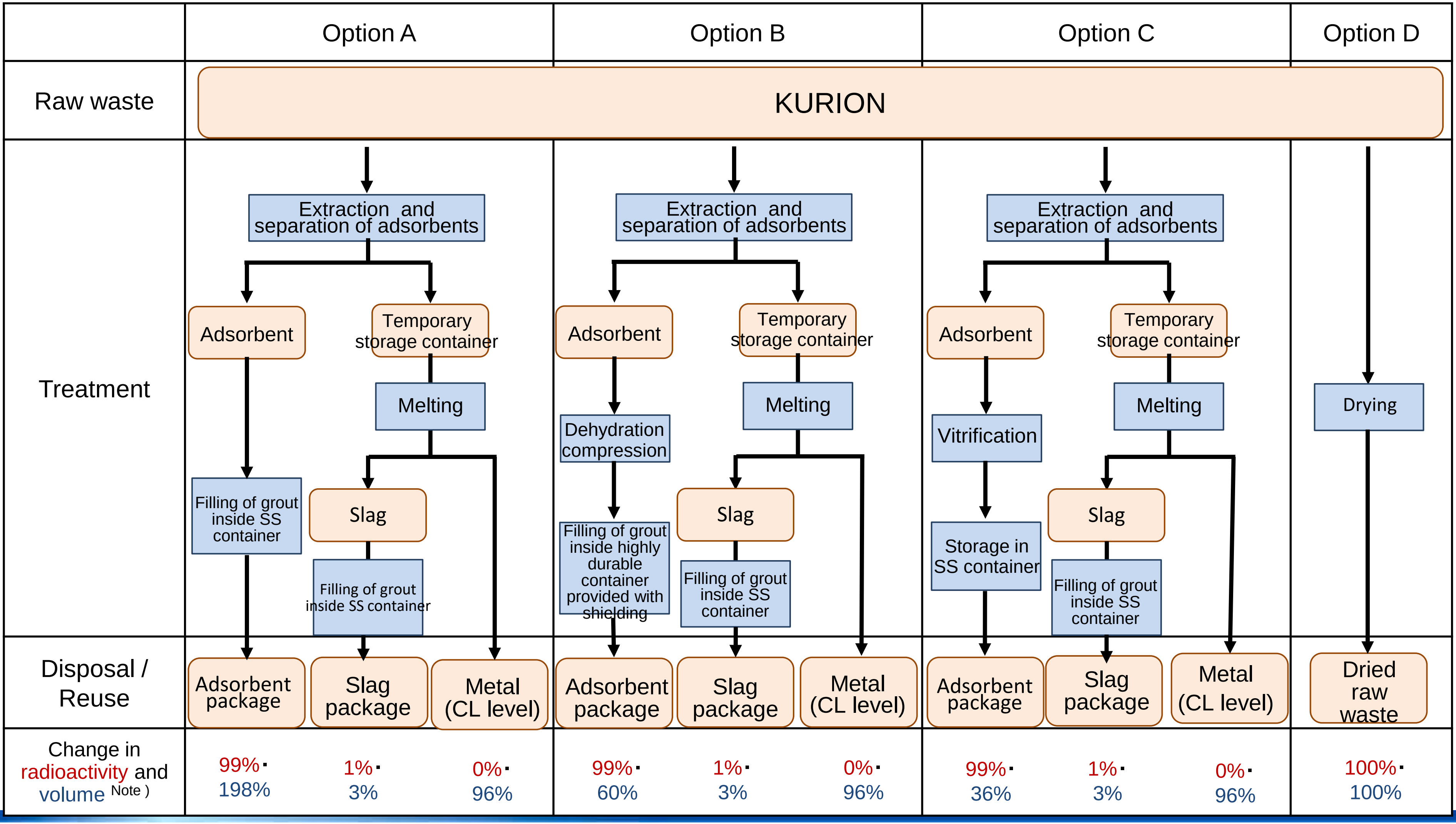
	Option A	Option B		Option C		
Raw waste	Concrete inside the building (not released before the accident)					
Treatment	Cutting with diamond wire	Chipping of contaminated surface Decontaminated substance Breaking, smashing and separation of materials	Chipping of contaminated surface Substances with surface contamination Filling of grout inside ISO container	Breaking, smashing and separation of materials Contaminated debris Separated based on radioactivity	Separated based on radioactivity Radioactive debris Packaging and filling of grout	Breaking, smashing and separation of materials
Disposal / Reuse	Concrete block	Concrete waste, steel reinforcement (CL level)	Packages with surface contamination	Concrete waste (CL level)	Concrete waste package	Steel reinforcement (CL level)
Change in radioactivity and volume$^{Note)}$	100%・100%	0%・98%	100%・2%	0%・89%	100%・17%	0%・1%

Note) Set with reference to NEA / RWM / R (2011) and NDA / RWM / 120 (2015). % is the percentage against raw waste.

V. Study on the process until waste conditioning

Multiple processes up to KURION waste conditioning are studied and the amount of radioactivity and quantity for each waste package that gets generated is set.

Table 1 Flow of each treatment option (Illustrating KURION)



	Option A	Option B	Option C	Option D
Raw waste	KURION			
Treatment	Extraction and separation of adsorbents Adsorbent → Filling of grout inside SS container Temporary storage container → Melting → Slag → Filling of grout inside SS container Melting → Metal	Extraction and separation of adsorbents Adsorbent → Dehydration compression → Filling of grout inside highly durable container provided with shielding Temporary storage container → Melting → Slag → Filling of grout inside SS container Melting → Metal	Extraction and separation of adsorbents Adsorbent → Vitrification → Storage in SS container Temporary storage container → Melting → Slag → Filling of grout inside SS container Melting → Metal	Drying
Disposal / Reuse	Adsorbent package Slag package Metal (CL level)	Adsorbent package Slag package Metal (CL level)	Adsorbent package Slag package Metal (CL level)	Dried raw waste
Change in radioactivity and volume Note)	99%・198% 1%・3% 0%・96%	99%・60% 1%・3% 0%・96%	99%・36% 1%・3% 0%・96%	100%・100%

Note) Set with reference to IAEA. TRS No 401 (2001), NDA / RWM / 120 (2015), IHI Engineering Review / Pp 25 Vol 5, Issue 1 (2018). % is the percentage against raw waste.

(b) Presentation of disposal methods, and development of safety assessment techniques

① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

V. Study on the process until waste conditioning

Table 1 Treatment options for secondary waste generated from contaminated water treatment

Waste	Treatment option	Explanation	Waste package	Change in radioactivity and volume Note)
AREVA	A	Grout filling of sludge in stainless steel (SS) container	Sludge package (grout filling in SS container)	100%･330%
	B	Compression of sludge by dehydration and storage in a highly durable container provided with shielding	Sludge package (high durability container)	100%･100%
	C	Vitrification of sludge and storage in SS container	Vitrified solid package (SS container)	100%･60%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%･100%
Kurion	A	Segregation of temporary storage containers and adsorbents Grout filling of primary waste (adsorbents) in SS container Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Adsorbent package (grout filling inside SS container)	99%･198%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･96%
	B	Segregation of temporary storage containers and adsorbents Compression by dehydration of primary waste (adsorbents) and grout filling in a highly durable container provided with shielding Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Adsorbent package (grout filling in highly durable container)	99%･60%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･38%
	C	Segregation of temporary storage containers and adsorbents Vitrification of primary waste (adsorbents) and storage in SS container Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Vitrified solid package (SS container)	99%･36%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･38%
	D	Dried inside the temporary storage container and disposed directly	Dried raw waste	100%･100%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%･100%
Slurry-2 Carbonate precipitation	A	Segregation of temporary storage container and slurry. Grout filling of primary waste (slurry) in SS container Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Slurry package (grout filling inside SS container)	99%･195%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･45%
	B	Separation of slurry and high-performance containers. Compression by dehydration of primary waste (slurry) and storage in a highly durable container provided with shielding Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Slurry package (high durability container)	99%･53%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･45%
	C	Segregation of slurry and high-performance containers. Vitrification of primary wastes (slurry) and conditioning in SS container Melting of secondary wastes (temporary storage container) and grout filling of slag inside SS container	Vitrified solid package (SS container)	99%･32%
			Slag package (grout filling inside SS container)	1%･3%
			Metal (CL level)	0%･45%
	D	Dried inside the temporary storage container and disposed directly	Dried raw waste	100%･100%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%･100%

Note) Set with reference to IAEA. TRS No 401 (2001), NDA / RWM / 120 (2015), IHI Engineering Review / Pp 25 Vol 5, Issue 1 (2018). % is the percentage against raw waste.

(b) Presentation of disposal methods, and development of safety assessment techniques

① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

V. Study on the process until waste conditioning

Table 1 Treatment options for various types of debris and dismantling waste

Waste	Treatment Option	Explanation	Waste package	Change in radioactivity and volume Note 1)
Concrete inside the building (Not released before the accident)	A / Raw waste	Cut with diamond wire, made into concrete block and disposed directly	Concrete block	100%・100%
	B	Chipping of parts of the contaminated surface Grout filling of contaminated surface inside ISO container	Concrete waste (CL level)	0%・98%
			Steel reinforcement (CL level)	0%・1%
			Package with surface contamination (grout filling inside ISO container)	100%・2%
	C	Broken and sorted into radioactive concrete waste, non-radioactive concrete and steel reinforcement Grout filling of radioactive concrete waste into ISO container	Concrete waste (CL level)	0%・89%
			Steel reinforcement (CL level)	0%・1%
			Concrete waste package (grout filling in ISO container)	100%・17%
Metal inside PCV (L2 before the accident)	A	Disassembled, shredded and grout filled in stainless steel (SS) container	Package of dismantled solidifications (grout filling inside SS container)	100%・255%
	B	Dismantling and chipping of contaminated surfaces Grout filling of primary waste (surface contamination) in SS container Grout filling of secondary waste (radioactivated metal) in SS container	Package with surface contamination (grout filling inside SS container)	Set for each nuclide Note 2) , 17%
			Radioactivated metal package (grout filling inside SS container)	Set for each nuclide Note 2) , 153%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%・100%
RPV waste (L1 before the accident)	A	Disassembled, shredded and grout filled in (SS) container	Package of dismantled solidifications (grout filling inside SS container)	100%・255%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%・100%
Debris 1 (0 – 0.005 mSv/h)	A	Volume reduced by crushing and grout filling inside ISO container	Debris package (grout filling inside ISO container)	100%・170%
	B	Sorted into radioactive debris and non-radioactive debris through measurement Grout filling of radioactive debris inside ISO container	Debris (CL level)	0%・65%
			Debris package (grout filling inside ISO container)	100%・60%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%・100%
Debris 2 (0.005 – 0.1 mSv/h)	A	Volume reduced by crushing and grout filling inside ISO container	Debris package (grout filling inside ISO container)	100%・170%
	B	Segregated into radioactive debris and non-radioactive debris through measurement Grout filling of radioactive debris inside ISO container	Debris (CL level)	0%・65%
			Debris package (grout filling inside ISO container)	100%・60%
	Raw waste	Disposal of raw waste (treatment / conditioning is not studied)	Raw waste	100%・100%

Note 1) Set with reference to NEA / RWM / R (2011), NDA / RWM / 120 (2015), NWP-REP-120-Issue 1 (2016), ED26.RP / 340737 / PROJ / 00033 Version 2 (2015). % is the percentage against raw waste.

Note 2) Set for each nuclide as it is accompanied by activation products (Be-10, C-14, Cl-36, Ca-41, Ni-59, Ni-63, Co-60, Mo-93, Nb-94).

VI. Study on disposal methods

An image of the surface disposal concept (L3)

It is assumed that the floor and side walls have low permeability, and the upper part has a low permeability layer that reduces the amount of penetrated water and is covered with soil. The disposal facility is backfilled with soil.

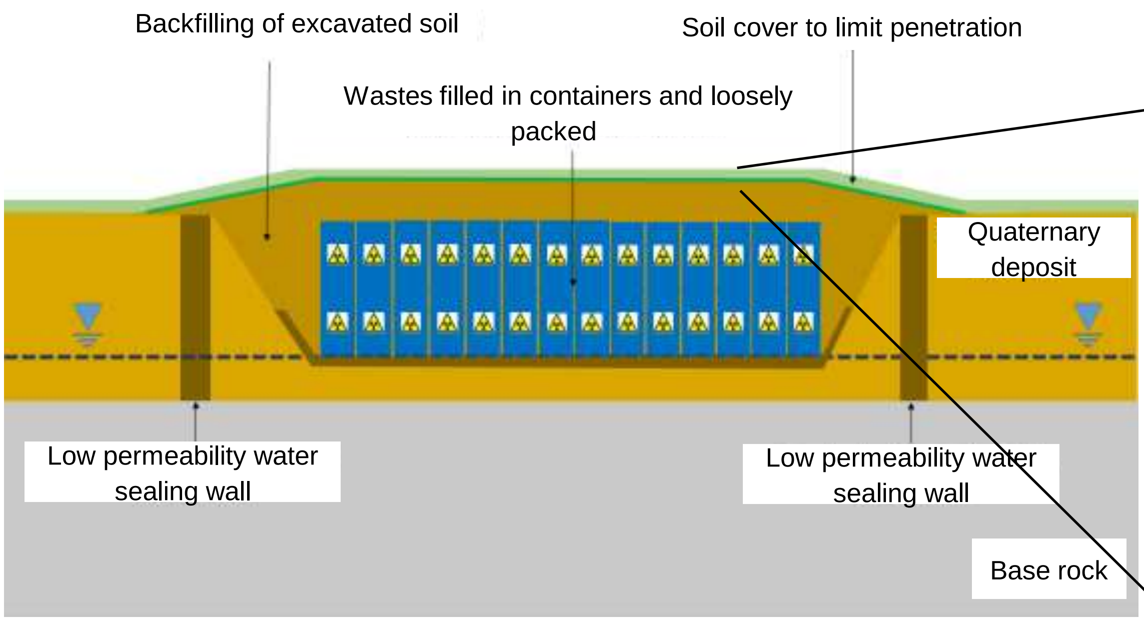
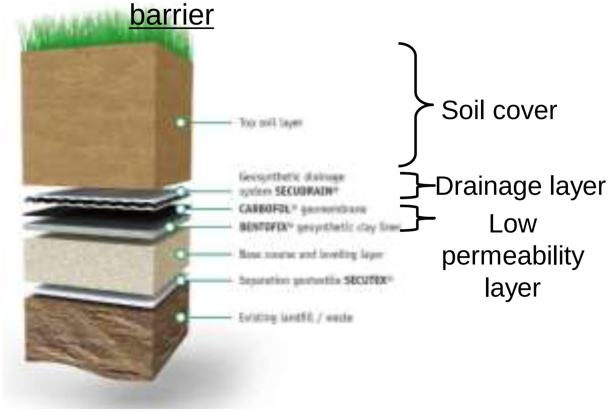


Illustration of artificial barrier



Example of artificial barrier at VLLW disposal site (Kings Cliffe) in the UK
(Based on the 2017-2018 overseas disposal facility survey results)

<Assumptions pertaining to near-field during dose evaluation>

- ✓ The soil clay liner after the soil cover continuously maintains a permeability coefficient of 1E-09 m/s.
- ✓ The container is sound until the initial damage period, after which the container gets damaged at a unit rate.
- ✓ The nuclide release begins immediately after the container is damaged. In addition, the contaminants are instantly transported from the waste package to the backfill.
- ✓ The saturation periods of grout waste and debris shall be conservatively ignored. Complete saturation occurs immediately after the damage of container.
- ✓ The backfill is modeled as a mixed compartment with no cracks. Advection is assumed as the dominant transport process to the outside through backfilling.
- ✓ The effect of the organic complex is considered in terms of the solubility increasing coefficient and the sorption decreasing coefficient.
- ✓ It is assumed that the soil cover always has a smaller effective permeability coefficient than the bottom and side walls of the facility. Therefore, the flow of seepage water through the near field is dominated by the permeability of the soil cover.
- ✓ The transport through the unsaturated layer is ignored. That is, the nuclide transport from backfilling to the outside goes directly to the saturated layer.

An image of the concept of near-surface disposal (L2)

Similar to surface disposal facilities. The possible differences are:

- Large amount of cement is used as grout / backfilling material
- Highly durable barrier that suppresses water flow
- Low permeability transportation route

It consists of a reinforced concrete vault in which low-permeability clay is laid on the floor and the upper part is covered with multiple soils. The disposal facility is backfilled with cement grout#. The bentonite wall surface controls seepage water.

#: When burying vitrified solidifications, bentonite is used for backfilling.

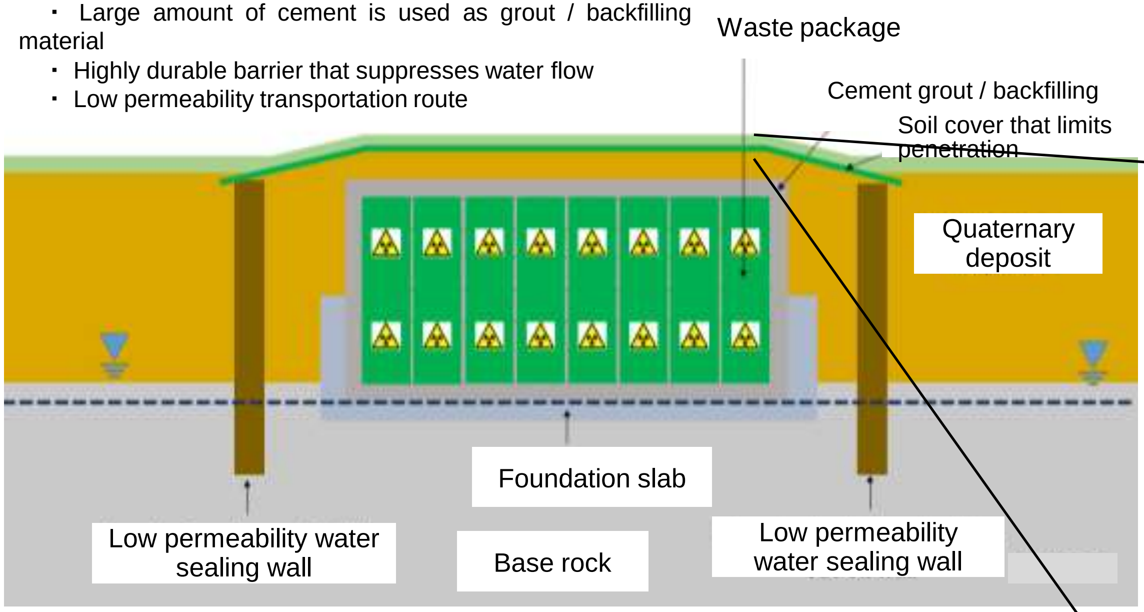
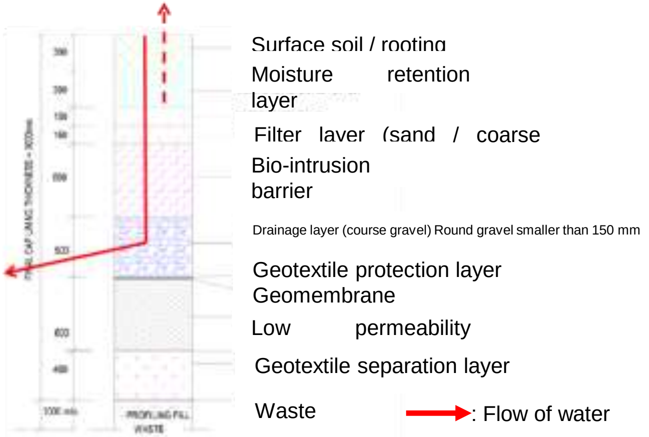


Diagram of artificial barrier



Example of artificial barrier at LLW disposal site (Drigg) in the UK
(Based on the 2017-2018 overseas disposal facility survey results)

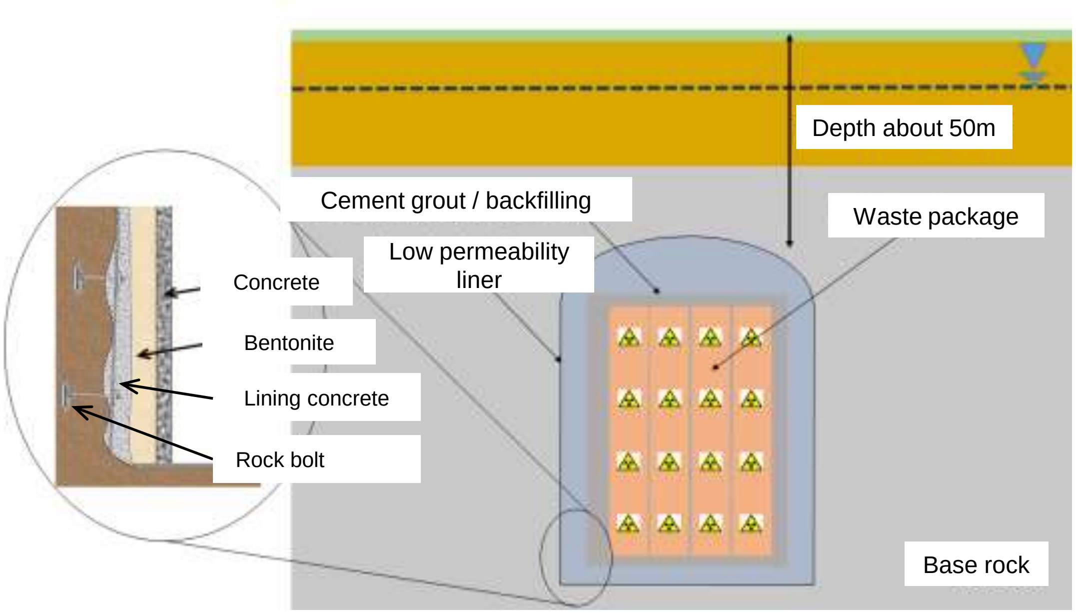
<Assumptions pertaining to near-field during dose evaluation>

Same as surface disposal except for the following items.

✓ The initial pH of backfilling is maintained for a long period of time, ignoring the evolution of backfilling pH over time.

VI. Study on disposal methods

An image of medium depth disposal facility (L1)



It is installed at about 50m below the ground. It consists of a tunnel with concrete walls. It is plugged in and closed. The voids are backfilled with cement grout.

<Assumptions pertaining to near-field during dose evaluation>

Same as surface disposal except for the following items.

✓ The permeability coefficient of the barrier of the medium depth burial facility shall be similar to the structural concrete typically used in nuclear facilities. As a result, the initial permeability coefficient is set to 1E-10 m/s, and after 5000 years, the function of the permeability coefficient of the medium depth burial facility will be completely lost, and the permeability coefficient will become the same as that of the base rock.

VII. Dose evaluation – Overview of evaluation

Setting of evaluation conditions for dose evaluation

- The scenarios and reference dose used here are the same as those used for I. Preliminary dose evaluation (some scenarios that were not considered earlier, are also evaluated).
- For nuclide migration / biosphere parameters, the parameters that have a proven track record overseas are used.
- Study on the evaluation methods for the amount of penetrated water, nuclide release, and time of container damage (an example is shown on the next page).

Table 1 Overview of the dose evaluation conditions and comparison with the preliminary dose evaluation

Major items	Items	VII Dose evaluation	<Comparison> I. Preliminary dose evaluation
Scenario	Nearing scenario	Land users (L3, L2), excavators (L3, L2), Concentration limit (L1)	Land users (L3, L2), concentration limit (L1)
	Nearing scenario reference dose	300 μSv/y (L3), 1 mSv/y (L2), 20 mSv/y (L1)	
	Groundwater scenario	River users, sea users, well users	River users, sea users
	Groundwater scenario reference dose	10 μSv/y per type of waste	
Parameters	Institutional control period (y)	About 400y (until 2400)	50 to 600y (L3), 300 to 600y (L2)
	Nearing scenario inventory	Takes groundwater migration into consideration	Does not take groundwater migration into consideration
	Release of nuclides	Set for each waste package	Instant release (Raw waste)
	Container damage time	Set for each container	Not used (Raw waste)
	Amount of penetrated water	Controlling the amount of penetrated water by means of artificial barrier	Typical setting in Japan (L3:1, L2:0.1, L3:0.16 m/y)
	Migration distance to the well	50 m (L3, L2), 150m (L1)	
	Migration distance to the river	100 m (L3, L2), 300m (L1)	
	River flow	10^7 m^3/y	
	Nuclide migration parameters in cement-based materials and soil	Data from LLWR in the UK (LLWR 2011 ESC)	Typical setting in Japan
	Biosphere transition coefficient	Data from LLWR in the UK (LLWR 2011 ESC)	Typical setting in Japan
	Changes in distribution - sorption coefficient due to substances having an impact on disposal	Set based on the data from LLWR in the UK (LLWR 2011 ESC)	Two sets of distribution - sorption coefficient are set and are evaluated individually.

<Assumptions pertaining to the geosphere and biosphere in dose evaluation>

- ✓ The geosphere shall be a porous medium.
- ✓ The biosphere model of LLWR2011ESC is applied. These are time-dependent models. The effective dose of PEG is evaluated by multiplying the nuclide flux in ocean and geosphere by the biosphere coefficient.
- ✓ The impact of organic matter in the geosphere is considered by evaluating the concentration of organic matter in the geosphere and the sorption inhibition coefficient. This method is the same as the method for considering the impact on backfilling.

VII. Dose evaluation - Example of model and parameter settings

<Setting the amount of water penetrated from artificial barriers in L3 and L2 facilities>

The L3 facility is assumed to have a clay liner, and the L2 facility is assumed to have an artificial barrier composed of a clay liner and geomembrane.

Burial disposal facility	Artificial barrier	Amount of penetrated water (initial)	Degradation behavior
L3	Clay liner	3.16e-2 m/y	—
L2	Clay liner	3.16e-2 m/y	—
	Geomembrane (Asphalt sheet)	3.16e-5 m/y	Damage starts from 150y Loss of function at 1000y

<Reference> SERCO/E.003796/010 issue Feb 2011

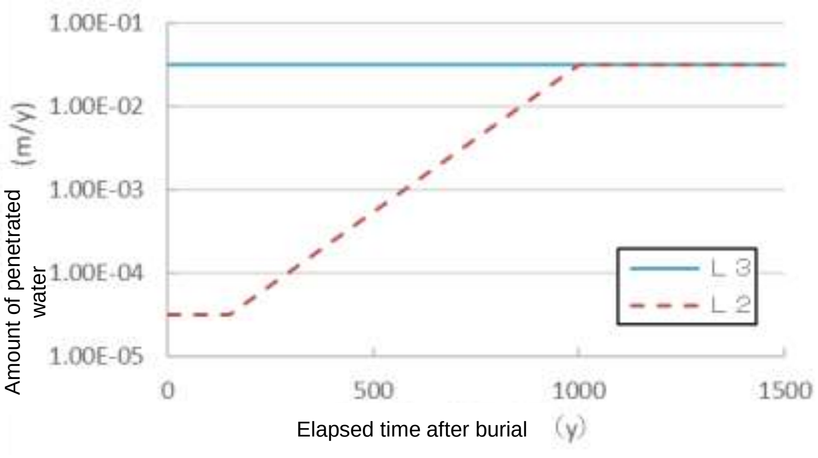


Fig. 1Changes in the amount of penetrated water over time at the L3 and L2 facilities

<Setting of container confinement function>

The container shall have the function of trapping radionuclides from the waste package for a certain period of time. In addition, empirically, the settings were configured such that once the damage starts the damage of the container is distributed over the same period as the damage time, and the nuclides are released in stages over a period of the same length as the damage period.

Type of container	Damage time (year after closing)	Damage period (year)
ISO Container	10	10
Stainless steel container	300	300
Highly durable container with shielding	1000	1000

<Reference> SA/ENC-0658 issue Feb, 2007

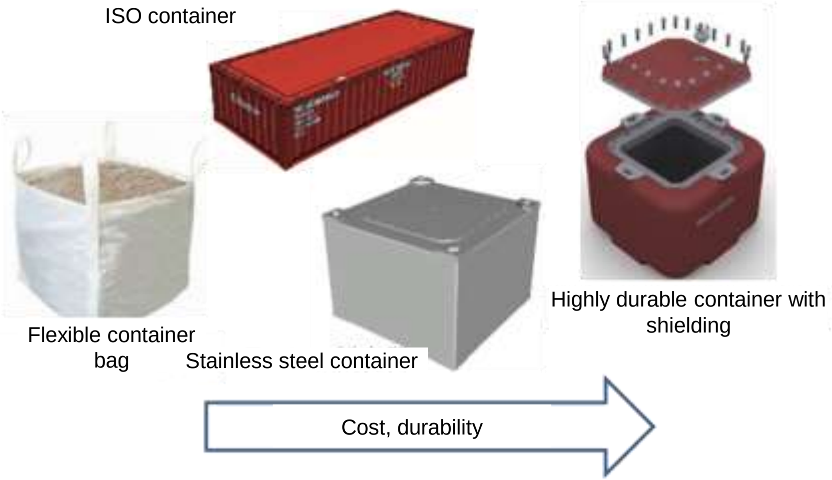


Fig. 2 Illustration of disposal containers

(b) Presentation of disposal methods, and development of safety assessment techniques
① Study on disposal methods in accordance with classification of solid wastes and collection & consolidation of information for establishing safety assessment techniques

Summary and Challenges

Summary

- ✓ The accident waste was comprehensively classified into 27 types and preliminary dose evaluation was performed to determine their anticipated disposal class, indicating their disposal in trench, pit, medium depth, or geological disposal. A parameter survey was conducted on the percentile of the inventory, the sorption distribution coefficient, the time of occurrence of the Nearing Scenario, the elution rate of the waste package, and the amount of penetrated water, and the sensitivity was evaluated with respect to the changes in the disposal classification, when respective measures were implemented. (I)
- ✓ The information necessary for studying the disposal concepts pertaining to the 27 types of waste was consolidated and the characteristics were evaluated. From these results, 8 types of waste were selected, for which disposal concepts were studied in detail. (II to IV)
- ✓ For each of the selected wastes, multiple possible treatment options were presented. In addition, the disposal images of L3, L2, and L1 with the artificial barrier installed were presented. (V, VI)
- ✓ The models and parameters for the dose evaluation of disposal concepts were provided, dose evaluation for multiple treatment options was performed, and the expected disposal class was presented. (VII)

Challenges

The evaluation of this study presumes that there is a large amount of uncertainty, and the challenge for the future is to alleviate the uncertainty of the techniques developed here. Following are the challenges for each type of uncertainty. Challenges pertaining to individual waste are described in VII.

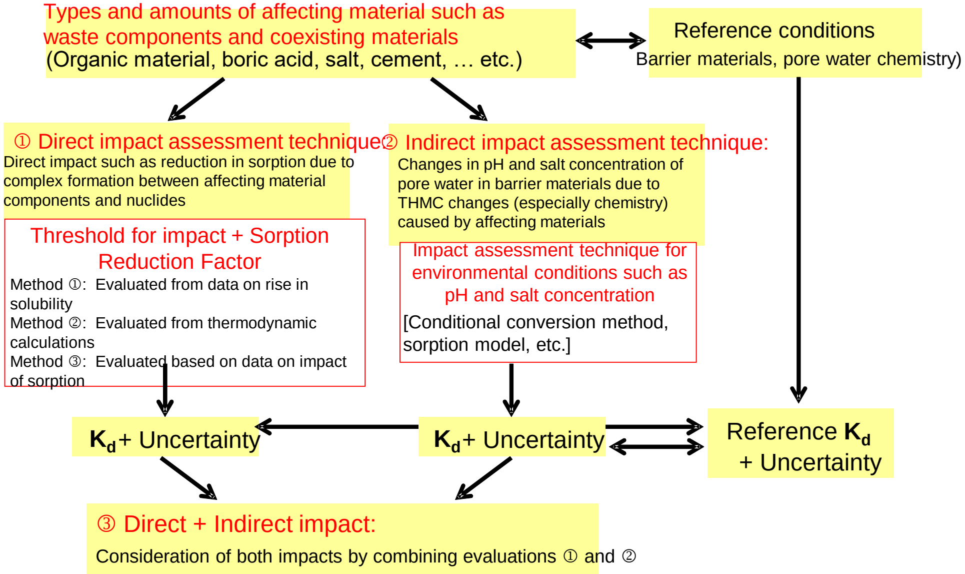
- ✓ Uncertainty of inventory: First of all, it is important to provide feedback on characterization. Then, it is necessary to consider the methodology for alleviating the uncertainty of inventory. For example, C-14 and I-129 are the dominant nuclides in many wastes. The uncertainty can be expected to be reduced by increasing the accuracy of these inventories on a priority basis.
- ✓ Uncertainty in parameters: Overseas literature is referred to for some of the safety evaluation parameters. It is necessary to consider the regulations in Japan and the characteristics of waste at 1F. For example, with respect to the performance of solidifications, more realistic parameters need to be provided, such as by incorporating the study results of latest treatment methods.
- ✓ Uncertainty of disposal site: The challenge is that there is significant uncertainty depending on the disposal site. Although this uncertainty cannot be eliminated until the disposal site is determined, countermeasures must be studied in consideration of the possibility that the disposal site may not be determined early. One approach is to set parameter sets for multiple hypothetical disposal sites and study the site uncertainty through mutual comparison.

(b) Presentation of disposal methods, and development of safety assessment techniques

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Goals and implementation details -

- Results
  - ○ Nuclide migration parameters and barrier materials that have a high priority in assessing the impact on nuclide migration during disposal were selected based on the investigation of substances having an impact, which are likely to be contained in solid waste, and the assumed concept of disposal.
  - ○ The approach towards the method for assessing the understanding of the affecting processes based on the substances having an impact, and the impact on nuclide sorption parameters based on the data volume, was established. (Fig.1)
- Goals
  - ○ To develop methods to quantitatively evaluate the impact of various affecting materials on nuclide migration during disposal along with the data required for the evaluation, and to incorporate them in the studies on the feasibility of disposal and as the basic information for safety evaluation.
- Implementation details (Fig.2)
  - ○ In FY2019, the findings that had been insufficient to evaluate the impact of the main substances affecting nuclide migration were investigated and the data was expanded together with improving the methods for quantitatively evaluating the impact (Sorption Reduction Factor: SRF) on nuclide sorption during disposal.
  - ○ In FY2020, the investigation of insufficient findings and expansion of data will continue, impact assessment methods for nuclide sorption will be established, and trial settings will be specified for the nuclide sorption parameters (distribution coefficient: Kd) and their uncertainty range with respect to the current safety evaluation assumption conditions and issues pertaining to the settings, will be identified.
- Indicators to determine goal achievement
  - ○ Data required for assessing the impact of the combination of important affecting substances and nuclides should be expanded and the impact assessment techniques should improve. (FY2019)
  - ○ Trial settings should be specified for the nuclide sorption parameters and their uncertainty range with respect to the safety assessment assumption conditions and issues pertaining to the same should be identified. (FY2020)



Types and amounts of affecting material such as waste components and coexisting materials
(Organic material, boric acid, salt, cement, … etc.)

Reference conditions
Barrier materials, pore water chemistry)

① Direct impact assessment technique
Direct impact such as reduction in sorption due to complex formation between affecting material components and nuclides

Threshold for impact + Sorption Reduction Factor
Method ①: Evaluated from data on rise in solubility
Method ②: Evaluated from thermodynamic calculations
Method ③: Evaluated based on data on impact of sorption

② Indirect impact assessment technique:
Changes in pH and salt concentration of pore water in barrier materials due to THMC changes (especially chemistry) caused by affecting materials

Impact assessment technique for environmental conditions such as pH and salt concentration
[Conditional conversion method, sorption model, etc.]

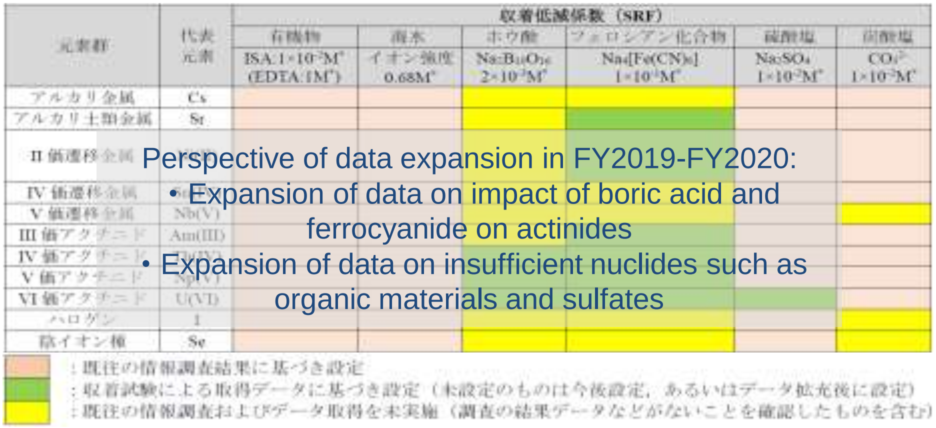
K_d + Uncertainty

K_d + Uncertainty

Reference K_d + Uncertainty

③ Direct + Indirect impact:
Consideration of both impacts by combining evaluations ① and ②

Fig.1 Overview of the method of assessing the impact of affecting materials on nuclide sorption



元素群	代表元素	収着低減係数（SRF）					
		有機物	海水	ホウ酸	フェロシアン化合物	硫酸塩	炭酸塩
		ISA:1×10⁻²M* (EDTA:1M*)	イオン強度 0.68M*	Na₂B₁₀O₁₆ 2×10⁻²M*	Na₄[Fe(CN)₆] 1×10⁻¹M*	Na₂SO₄ 1×10⁻²M*	CO₃²⁻ 1×10⁻²M*
アルカリ金属	Cs	🟧	🟧	🟨	🟨	🟧	🟧
アルカリ土類金属	Sr	🟧	🟧	🟨	🟩	🟧	🟧
II 価遷移金属	[illegible]	🟧	🟧	🟨	🟩	🟧	🟧
IV 価遷移金属	Sn(IV)	🟧	🟧	🟨	🟨	🟧	🟧
V 価遷移金属	Nb(V)	🟧	🟧	🟨	🟨	🟧	🟨
III 価アクチニド	Am(III)	🟧	🟧	🟨	🟩	🟧	🟧
IV 価アクチニド	Th(IV)	🟧	🟧	🟩	🟩	🟧	🟧
V 価アクチニド	Np(V)	🟧	🟧	🟩	🟩	🟧	🟧
VI 価アクチニド	U(VI)	🟧	🟧	🟩	🟩	🟩	🟧
ハロゲン	I	🟧	🟧	🟨	🟨	🟧	🟨
陰イオン種	Se	🟧	🟧	🟨	🟨	🟧	🟨

🟧 ：既往の情報調査結果に基づき設定
🟩 ：収着試験による取得データに基づき設定（未設定のものは今後設定，あるいはデータ拡充後に設定）
🟨 ：既往の情報調査およびデータ取得を未実施（調査の結果データなどがないことを確認したものを含む）

Perspective of data expansion in FY2019-FY2020:
- Expansion of data on impact of boric acid and ferrocyanide on actinides
- Expansion of data on insufficient nuclides such as organic materials and sulfates

Fig.2 Sample chart of organization of the Sorption Reduction Factors for the barrier materials with respect to the affecting factors

(b) Presentation of disposal methods, and development of safety assessment techniques 【Confidential】

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Overall flow of the study -

Table List of affecting substances (Example of consolidation of the relation of impact)

共存物質/廃棄体化処理追加成分	影響
ホウ酸水	・ホウ酸イオンは核種と錯体を形成し、溶解度及び分配係数に影響を及ぼす可能性がある。 ・ホウ酸塩として存在する場合、そのカウンターイオン放出により間隙水イオン強度が増加する可能性がある。
海水成分	・海水成分の陽イオンは、核種の収着において競合する可能性があるほか、イオン強度増加により溶解度等に影響を及ぼす可能性がある。 ・海水成分の溶出によって間隙水のイオン強度が上昇し、溶解度等に影響を及ぼす可能性がある。 ・海水成分によって、セメント中での二次鉱物生成や、ベントナイトのイライト化が生じる可能性がある。
油分	・核種によっては、油分の有機相に核種が取り込まれ、油分とともに移行する可能性がある。 ・油分の[illegible]が生じる可能性がある。
シリカ系（無機系飛散防止剤）	・無機系の飛散防止剤（ケイ酸塩）が溶出してシリカを放出した場合、ベントナイトのセメンテーションやセメント中C−S−H相形成が生じる可能性がある。
有機物（草木、有機系飛散防止剤）	・有機物により、その分解生成物と核種での錯形成が生じる可能性がある。
金属	・溶出した鉄イオンによって、ベントナイトの変質や鉄系コロイドの形成が生じる可能性がある。 ・腐食時に周辺間隙水のEh変化や腐食生成物によるコロイド形成が生じる可能性がある。
セメント系材料	・高pH間隙水を形成し、ベントナイトの変質や、核種溶解度の変化が生じる可能性がある。 ・セメント水和物起源のコロイドに核種が収着する可能性がある。

Identification of materials for study

- Target substances: 6 substances identified
  (Organic substances, seawater component, boric acid, ferrocyanides, sulfates, carbonates)

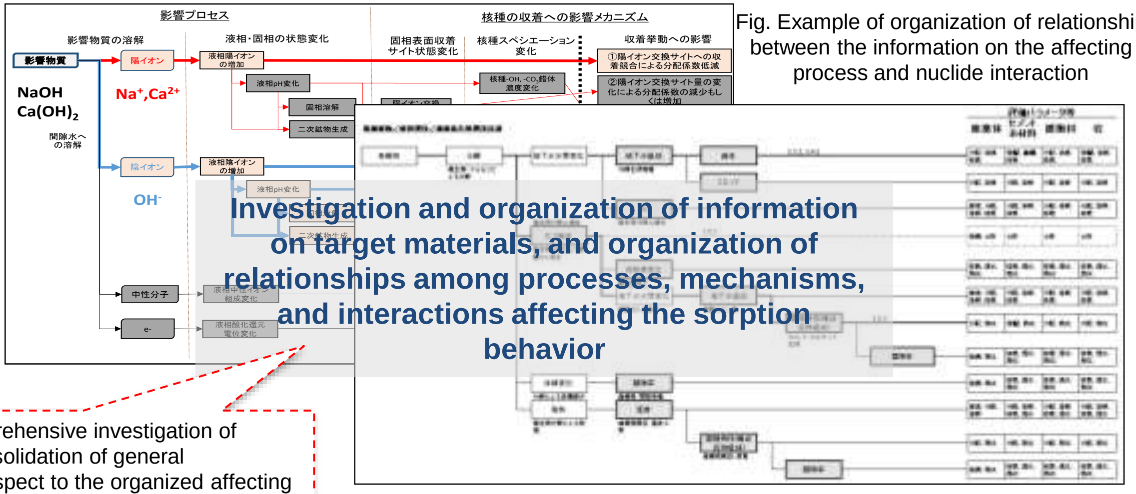


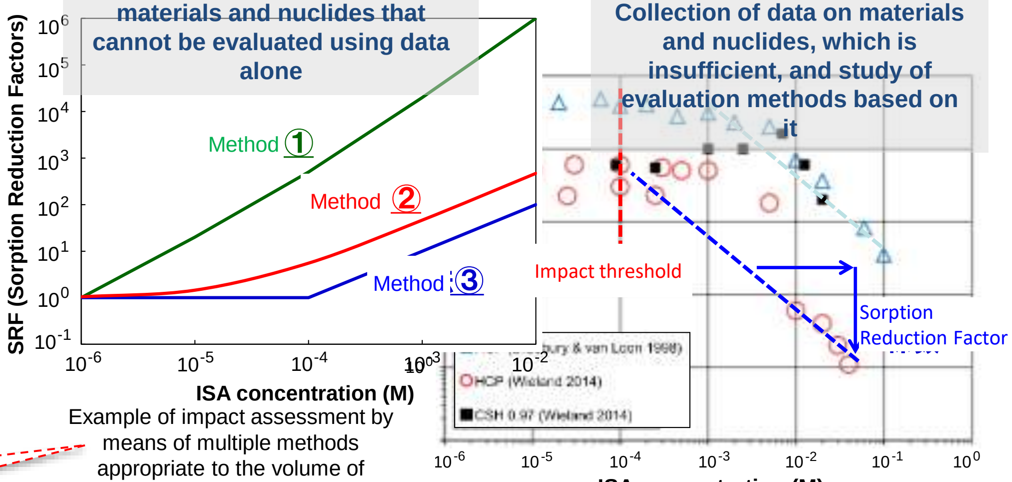
Fig. Example of organization of relationship between the information on the affecting process and nuclide interaction

Investigation and organization of information on target materials, and organization of relationships among processes, mechanisms, and interactions affecting the sorption behavior

- Completion of comprehensive investigation of information and consolidation of general relationships with respect to the organized affecting substances

Study of evaluation methods for materials and nuclides that cannot be evaluated using data alone

Collection of data on materials and nuclides, which is insufficient, and study of evaluation methods based on it



Example of impact assessment by means of multiple methods appropriate to the volume of information

Sorption Reduction Factor of Am to cement in an organic material (ISA) coexisting system

Cases of evaluation based on existing data

Organic material effect of Am on Kd

Element group	Representative element	Sorption Reduction Factors (SRF)					
		Material A	Material B	Material C	Material D	Material E	Material F
Alkali metal	Cs	1	2	2	1	2	46
Alkali earth metal	Sr	1	7	3	10	8	31
Divalent transition metal	Ni (II)	1	10	36	1	12	1
Tetravalent transition metal	Zr (IV)	1	10	10	10^3	12	109
Pentavalent transition metal	Nb (V)	1	10	10	1	12	10
Trivalent actinide	Am (III)	1	10	10	10^2	12	1
Tetravalent actinide	Th (IV)	1	10	10	10^6	12	1
Pentavalent actinide	Np (V)	1	100	10	10^2	12	1
Hexavalent actinide	U (VI)	1	100	10	10^2	12	1
Halogen	I	–	–	–	1	–	–
Anionic species	Se	–	–	–	–	–	–

Presentation of impact assessment data for substances having an impact on disposal, which contributes to safety evaluation

Sample chart of organization of Sorption Reduction Factors for barrier materials with respect to affecting factors

- Sorption affecting data that is unavailable/insufficient is being collected, mainly for ferrocyanides, sulfates, and carbonates.
- Evaluation methods appropriate to the volume of data are being studied and assessed.

(b) Presentation of disposal methods, and development of safety assessment techniques
② Development of techniques for assessing impact of affecting substances, etc. on disposal
- Study results up to FY2018 “Selection of affecting materials and barrier materials for evaluation”-

■ Affecting substances to be evaluated

- ○ Organic substances, seawater component, and boric acid solution were selected as coexisting substances commonly contained in most of the accident waste.
- ○ Ferrocyanides, sulfates, and carbonates were selected as raw waste components that may have an impact among secondary waste generated from contaminated water treatment that are not very common but have a relatively high priority.

⇒ Selection was done with respect to these 6 types of affecting substances (Table 1)

■ Barrier materials, parameters, and nuclides to be evaluated

- ○ Barrier materials and nuclide sorption parameters that are common to all disposal concepts and are expected to be significantly impacted by affecting substances in areas close to waste, were selected (Fig.1).
- ○ Target nuclides were selected from the nuclides to be evaluated for the existing disposal concepts and from the approach of grouping based on chemical similarity.

■ Combination of affecting substances and barrier materials to be evaluated

- ○ The existing findings and methods can be applied to indirect impact due to chemical changes in pore water. Hence the focus of this study is on the direct impact of affecting substances for which the existing findings are insufficient.
- ○ For the direct impact, evaluation targets were selected in consideration of the level of sufficiency of existing knowledge (limiting targets for buffer material).

Table 1 Major accident waste and affecting substances contained therein

Raw waste		Secondary waste generated from contaminated water treatment												Debris/ felled trees							Dismantling waste		
		Cesium adsorption tower	No. 2 cesium adsorption tower	Decontamination system sludge	Iron coprecipitation slurry	Carbonate slurry	Ag-loaded activated carbon	Titanate	Titanium oxide	Ferrocyanides	Chelating resin	Resin-based adsorbents (column)	Filters	Debris (concrete)	Debris (metal)	Debris (other)	Felled trees	Soil	Used protective clothing	Fuel debris	Dismantling waste (concrete)	Dismantling waste (metal)	Dismantling waste (other)
Affecting substances Raw waste components	Zeolite	○	○																				
	Silica-based materials	○		○																			
	Iron hydroxide			○	○																		
	Carbonate					○																	
	Magnesium hydroxide					○																	
	Sulfate			○																			
	Activated carbon						○																
	Organic material			○	○	○	○	○	○	○	○	○	○			○	○	○	○				○
	Titanium-based material		○					○	○														
	Ferrocyanides			○						○													
	Metals	○	○		○	○	○	○	○	○	○	○		○	○					○	○	○	
	Concrete													○							○		
	Debris																			○			
	MCCI debris																			○			
	Borides/ carbides																			○			
Coexisting substances	Seawater component	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○
	Boric acid solution	○	○	○	○	○	○	○	○	○	○	○	○							○	○	○	○
	Oil content	○	○	○	○	○	○	○	○	○	○	○	○							○	○	○	○
	Organic substances	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			○	○	○
	Silica-based substances													○	○	○							
	Fuel deposits																				○	○	○

O: Affecting substances contained in raw waste

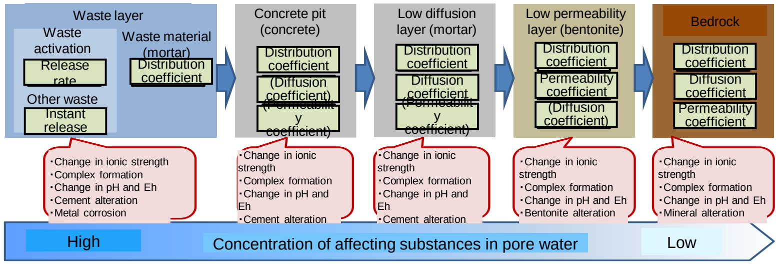


Fig.1 Impact on nuclide sorption in each barrier layer

(b) Presentation of disposal methods, and development of safety assessment techniques
② Development of techniques for assessing impact of affecting substances, etc. on disposal
- Status of data collection and parameter settings -

Cement based

Element group	Representative element	Hazardous substances					
		Organic substances*1	Seawater*1	Boric acid	Ferrocyanides	Sulfates	Carbonates
Alkali metal	Cs	○	○	●	●	○	○
Alkali earth metal	Sr	○	○	●	○	○	○
Divalent transition metal	Ni(Ⅱ)	○	○	●	○	●	○
Tetravalent transition metal	Sn(Ⅳ)	○	○	■	■	■	○
Pentavalent transition metal	Nb(Ⅴ)	○	○	■	■	■	■
Trivalent actinide	Am(Ⅲ)	○	○	●	●	●	○
Tetravalent actinide	Th(Ⅳ)	○	○	×	×	×	○
Pentavalent actinide	Np(Ⅴ)	○	○	●	○	●	○
Hexavalent actinide	U(Ⅵ)	○	○	●	○	○	○
Halogen	I	○※3	○※3	○※3	○※3	○※3	○※3
Anionic species	Se	○※3	○※3	○※3	○※3	○※3	○※3

Bentonite based

Element group	Representative element	Hazardous substances	
		Boric acid	Ferrocyanides
Alkali metal	Cs	●	●
Alkali earth metal	Sr	●	○
Divalent transition metal	Ni(Ⅱ)	●	○
Tetravalent transition metal	Sn(Ⅳ)	■	■
Pentavalent transition metal	Nb(Ⅴ)	■	■
Trivalent actinide	Am(Ⅲ)	●	●
Tetravalent actinide	Th(Ⅳ)	×	×
Pentavalent actinide	Np(Ⅴ)	●	○
Hexavalent actinide	U(Ⅵ)	●	○
Halogen	I	○※3	○※3
Anionic species	Se	○※3	○※3

*1 Isosaccharinic acid (ISA)
*2 Ionic strength 0.68 M
*3 Set at Kd = 0
O: Data has been set up
●: New data to be collected or set up in this fiscal (to be continued next fiscal if data is insufficient)
■: New data to be collected or set up in the next fiscal
x: Data acquisition is difficult
: Additional investigation and settings planned in this fiscal

(b) Presentation of disposal methods, and development of safety assessment techniques
② Development of techniques for assessing impact of affecting substances, etc. on disposal
- Study of sorption impact assessment techniques for each affecting material: Trial parameter setting -

Example of study on assessment of impact of organic substances ①

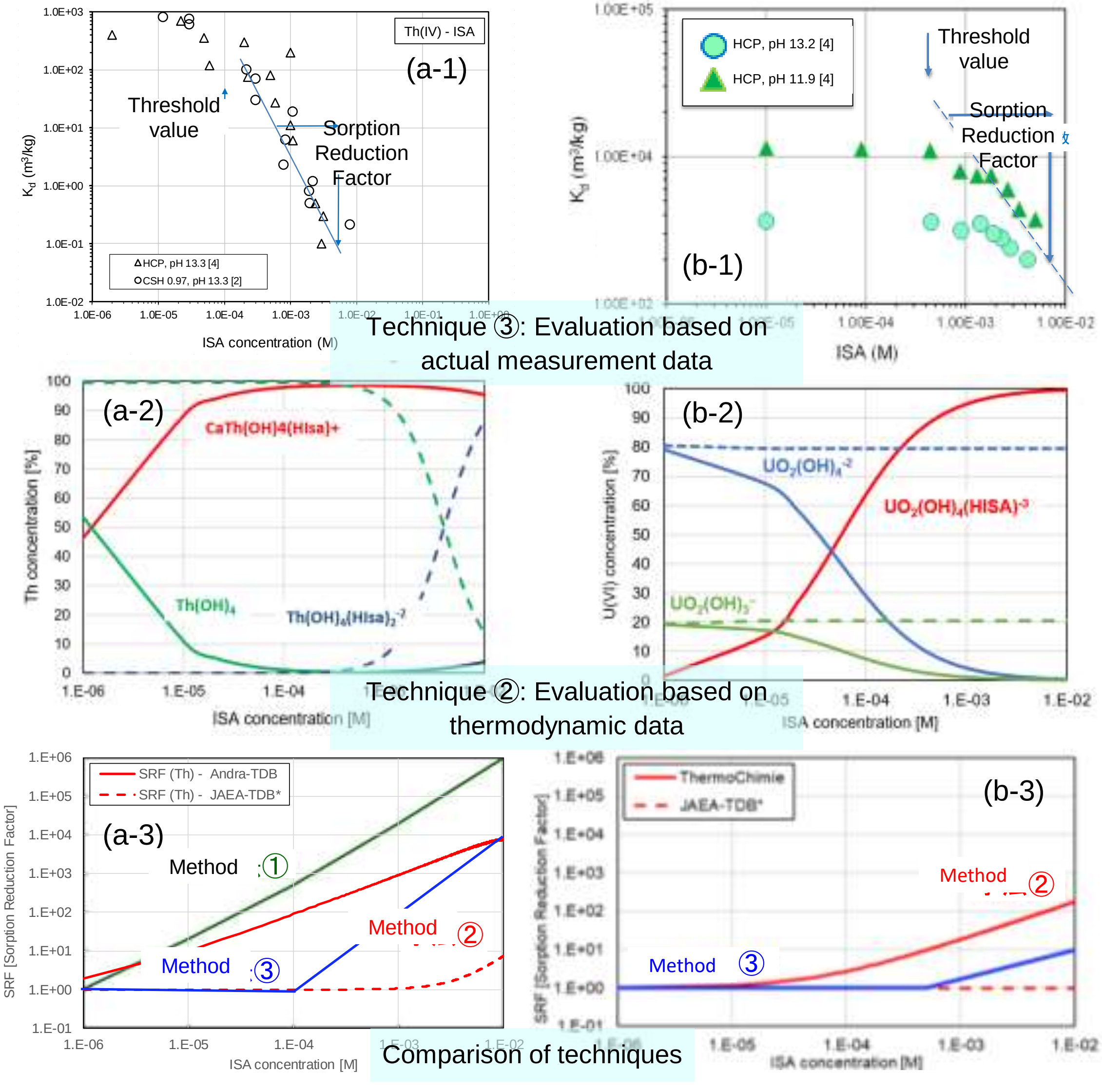
- In FY2019, the comparison of the three techniques# proposed as the techniques for evaluating the Sorption Reduction Factor and the evaluation cases of their effectiveness were improved.
  - In addition to the past evaluation cases of trivalent actinide Am targeting the sorption effect of isosaccharinic acid (ISA), which is said to have the greatest impact, application and evaluation targeting tetravalent actinide Th (IV) and hexavalent actinide U (VI) were studied.
  - It was confirmed that evaluation technique ② based on thermodynamic data for all nuclides leads to more conservative evaluation results than technique ③ based on ideal actual measurement sorption data.
  - Meanwhile, it was also confirmed that technique ② largely depends on thermodynamic data, and that selection of thermodynamic data and verification of its reliability are important.

#Three evaluation techniques for the Sorption Reduction Factor

Technique ①: Evaluated from data on rise in solubility

Technique ②: Evaluated from thermodynamic calculations

Technique ③: Evaluated based on data on impact of sorption



Technique ③: Evaluation based on actual measurement data

Technique ②: Evaluation based on thermodynamic data

Comparison of techniques

Fig.1 Evaluation results based on each technique and example study of comparison (Left: Th (IV), right: U (VI))

(b) Presentation of disposal methods, and development of safety assessment techniques

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Study of sorption impact assessment techniques for each affecting material: Trial parameter setting -

Example of study on assessment of impact of organic substances ②

- The typical domestic and overseas evaluation cases pertaining to the impact of sorption on various organic substances were investigated and organized.
  - ➢ The target organic substances and their evaluation techniques are organized for each evaluation case considered in the evaluations in Sweden SKB, Swiss Nagra, and Japan's Second TRU report.
  - ➢ Each evaluation case mainly studies the evaluation of isosaccharinic acid (ISA). For other organic substances, if there is an impact, the ISA value is assigned conservatively or the actual measurement data is used to evaluate whether the impact will become apparent.

⇒ In light of the above, the Sorption Reduction Factor is set for ISA based on the actually measured sorption data.

Literature	Target organic substances	Technique for assessment of impact concentration (threshold value)	Technique for assessment of impact of organic substances (Sorption Reduction Factor)
SKB TR14-10	ISA	• Set from experimental results, chemical analogs, etc. • Consideration to Ca concentration	The Sorption Reduction Factor is set from the experimental results and chemical analogs. Divide the reference settings of distribution coefficient by that value to set the distribution coefficient considering the impact of organic substances.
	Organic substances other than ISA, such as EDTA and NTA	Roughly set from the ISA chemical analog	
	Concrete admixture and its deteriorated material	Assuming no potential effect as it does not strongly affect metal ions	
Nagra NTB 14-08	Nitrate/ nitrite	Low content, hence not evaluated.	
	EDTA	None	Sorption Reduction Factor of Ni, Co, Pb is set
	Cyanide	None	Sorption Reduction Factor of Ni, Co is set
	Ammonia, amine	None	Cement deterioration stage and high NH_3 concentration affects Ni, Co
	ISA	Set from experimental results, chemical analogs, etc.	• The Sorption Reduction Factor is set from the experimental results and chemical analogs. Divide the reference settings of distribution coefficient by that value to set the distribution coefficient considering the impact of organic substances. • A constant Sorption Reduction Factor is set in the range from a concentration that has no impact to the maximum concentration expected at the disposal site.
	GLU	Same as above	Same as above
	Concrete admixture	The concentration in pore water is low and has no impact.	
	Organic polymer	The impact is negligible.	
	Bitumen, degradation products of acidic ion-exchange resin	The concentration in pore water is low and does not affect nuclides other than Ni.	
Second TRU compilation	Organic substances such as waste cloth	• Cases evaluated based on experimental results were referenced. • The concentration in the filler pore water was evaluated assuming that all organic substances contained in Group 2 are decomposed into ISA by cellulose.	• The Sorption Reduction Factor is set at the ASA concentration from the setting example of the solubility increase coefficient. • The Sorption Reduction Factor is assumed to be equal to the solubility increase coefficient.
	Solvent waste	• Thermodynamic data confirmed that DBP does not affect Ni solubility. • Experimental results confirmed that TBP and DBP do not affect U solubility.	
	Asphalt solidification	The results of Pu solubility experiments using asphalt leachate indicated absence of impact.	
	Cement admixture	The distribution coefficient data for Pu in the presence of a water-reducing agent indicated a low impact.	

(b) Presentation of disposal methods, and development of safety assessment techniques

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Study of sorption impact assessment techniques for each affecting material: Trial parameter setting -

Example of study on assessment of seawater impact

- The information on the assessment of the impact of seawater in setting the nuclide sorption parameters for cement-based materials in other countries was investigated.
  - ➢ In the latest case in Switzerland, detailed studies and parameter settings were carried out, including the mechanism of the sorption effect of seawater components on each nuclide and the effects of seawater components on cement alteration and secondary mineral formation.
  - ➢ A comparison of the trends of increase and decrease in sorption due to the impact of seawater in the table confirmed that the trends of increase and decrease of many nuclides are different in each report, reflecting the complexity of the sorption mechanism of nuclides on cement.

⇒ **<u>Here, the Sorption Reduction Factor is set based on the Nagra case (Wieland, 2014), which studied the impact of seawater, including its mechanism, most systematically.</u>**

	JAEA-Review 2006-011 (Mihara, 2006)	Nagra NTB 14-08 (Wieland, 2014)	Ochs et al, 2016
Cs (I)	No impact on measured values	Sorption Reduction Factor 2 was set.	Decrease in distribution coefficient Conflicting sorption with Na, K, Ca
Sr (II)	Increase in distribution coefficient under seawater system conditions	Sorption Reduction Factor 6 was set. Conflicting sorption associated with cement alteration	-
Ni (II)		No impact	No impact
Zr (IV)	No impact on measured values	A value that is smaller by an order of magnitude is set for a salt water environment See trivalent actinides	-
Nb (V)	Increase in distribution coefficient or no impact under seawater system conditions		
Am (III)	Increase in distribution coefficient under seawater system conditions	A value that is smaller by an order of magnitude is specified in Kd settings (Assuming that the sorption phase in the cement paste is only C-S-H, the decrease in sorption due to cement alteration is taken into consideration)	
Th (IV)		A value that is smaller by an order of magnitude is set for a salt water environment See trivalent actinides	Very little impact
Np (V)	-		Np is sensitive to salt concentration Increase in distribution coefficient in salt water
U (VI)			-
I	Decrease in distribution coefficient under seawater system conditions Conflicting sorption with anions	The distribution coefficient 0 is set. Conflicting sorption with Cl, no sorption into C-S-H	Decrease in distribution coefficient Conflicting sorption with stable Cl
Se	Decrease in distribution coefficient under seawater system conditions	The distribution coefficient 10^{-4}m^3/kg is set considering that a lot of ettringite in the sorption phase remains even after alteration.	-

#The findings that reduce the distribution coefficient are hatched red, and those that increase the coefficient are hatched blue.

(b) Presentation of disposal methods, and development of safety assessment techniques【Confidential】

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Setting of data collection targets and conditions for specifying the Sorption Reduction Factor -

- In FY2019, data was collected for the affecting substances, barrier materials, and nuclides to be evaluated that have been specified so far, and for which no data had been collected or for which data needed to be collected again.
- In order to collect the data of sorption in the presence of boric acid, ferrocyanides, and sulfates, a sorption test was conducted with the concentrations of these affecting substances and liquid conditions (pH, etc.) as parameters.
- Considering the actual environment, the nuclides that form the carbonic acid complex were tested under conditions wherein some carbonic acid was added. (Table 1)

Table 1 Data acquisition conditions

Affecting materials	Boric acid				Sulfate	
Solid phase	Bentonite		Cement		Cement	
Test solution	NaCl	NaCl + Carbonic acid	NaCl	NaCl + Carbonic acid	NaCl	NaCl + Carbonic acid
pH	7, 9.3		Cement equilibrium moisture (Approx. pH12.5)		Cement equilibrium moisture (Approx. pH12.5)	
Test parameters	Boric acid concentration	Boric acid concentration Carbonic acid concentration	Boric acid concentration NaCl concentration	Boric acid concentration Carbonic acid concentration	Sulfate concentration	Sulfate concentration Carbonic acid concentration
Target nuclides	Np (V)	Am, Th	Cs, Sr, Ni,	Eu, Np (V), U (VI)	Ni	Eu, Np (V)

Affecting materials	Ferrocyanides		
Solid phase	Bentonite		Cement
Test solution	NaCl	NaCl + Carbonic acid	NaCl
pH	4-12	8.8	Cement equilibrium moisture (Approx. pH12.5)
Test parameters	Ferrocyanide concentration	Ferrocyanide concentration Carbonic acid concentration	Ferrocyanide concentration
Target nuclides	Cs	Th	Cs, Eu

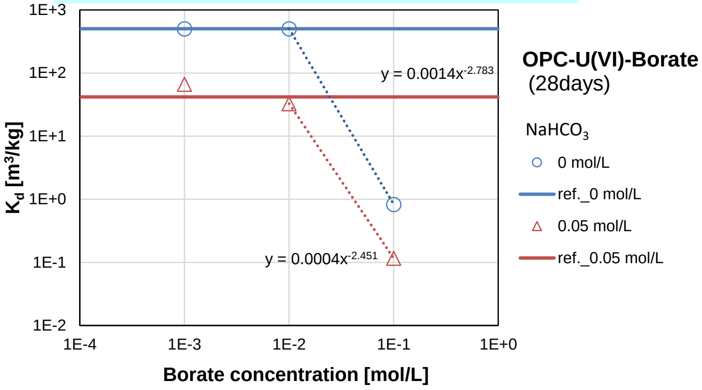
Kunipia F manufactured by Kunimine Industries is used for bentonite, and OPC Cement paste is used for the cement sample..

(b) Presentation of disposal methods, and development of safety assessment techniques
② Development of techniques for assessing impact of affecting substances, etc. on disposal
- Results of data collection for setting the Sorption Reduction Factor (boric acid) -

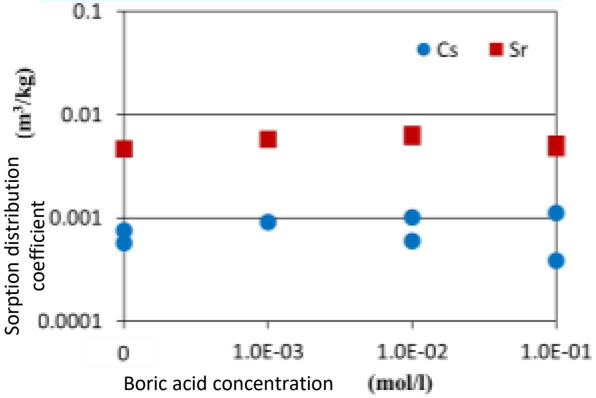
Study on assessment of boric acid impact

- Since the sorption data from the boric acid coexisting system has hardly been reported in the previous studies, the Sorption Reduction Factor is set based on the sorption data collected in this project so far.
- The effect of reduction in the impact of boric acid in the presence of carbonic acid and the impact assessment considering the concentration of carbonic acid contained in cement pore water and bentonite pore water was studied.
- For the nuclides collected up to this year, based on their data of sorption in the presence of boric acid and carbonic acid, it was evaluated that the boric acid effect was not significant for nuclides other than U (VI) (Cs, Sr, Eu (III), Np (V)).

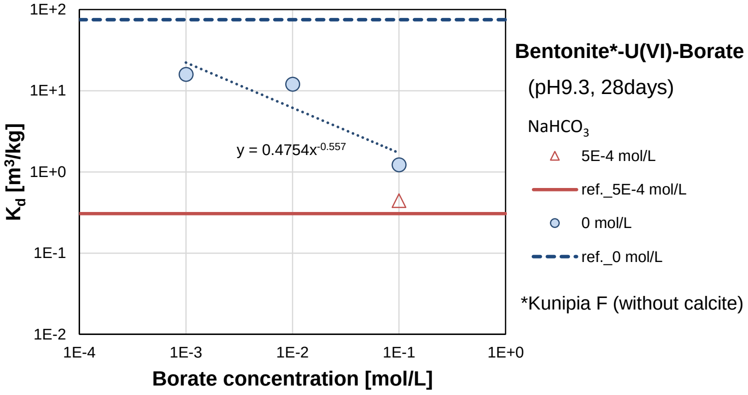
Test results for sorption of **U (VI)** into Cement **(OPC)** in the presence of boric acid



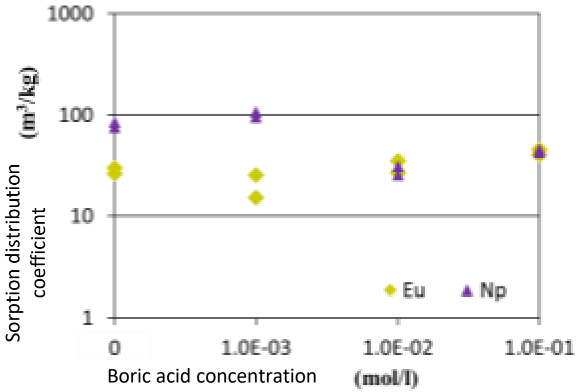
Test results for sorption of **Cs, Sr** into Cement **(OPC)** in the presence of boric acid



Test results for sorption of **U (VI)** into Bentonite in the presence of boric acid



Test results for sorption of **Eu (III), Np (V)** into Cement **(OPC)** in the presence of boric acid



(b) Presentation of disposal methods, and development of safety assessment techniques【Confidential】

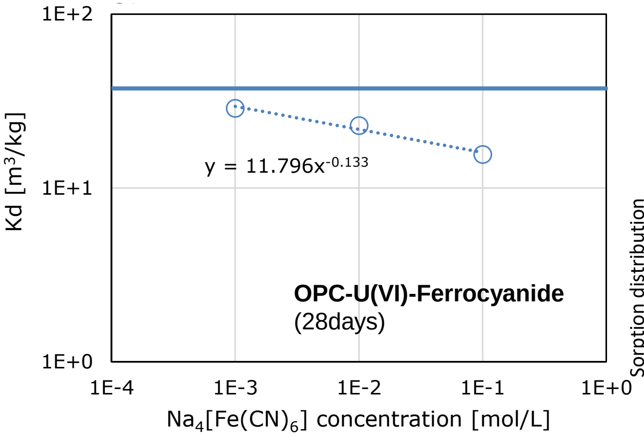
② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Results of data collection for setting the Sorption Reduction Factor (sulfate)-

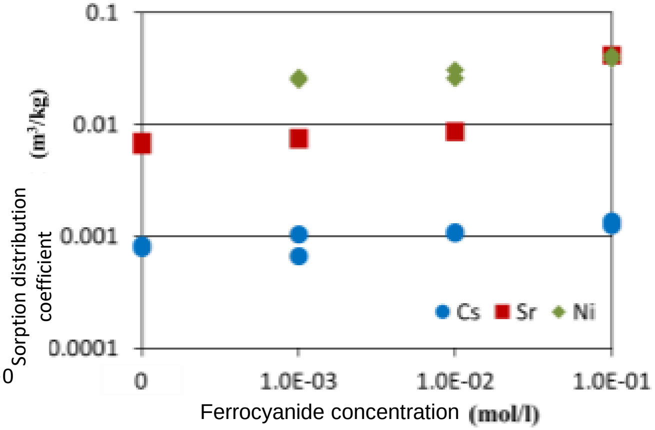
Study on assessment of ferrocyanide impact

- Since the sorption data from the ferrocyanide coexisting system has hardly been reported in the previous studies, the Sorption Reduction Factor is set based on the sorption data collected in this project so far.
- The sorption data was collected focusing on the direct impact of ferrocyanide complex formation and the pH dependence of the impact (wide range of impact including Bentonite pore water pH).
- Based on the data of sorption in the presence of ferrocyanides collected until this year, SRF was set up in U (VI) and it was evaluated that the impact of ferrocyanide was not significant for Cs, Sr, Ni.

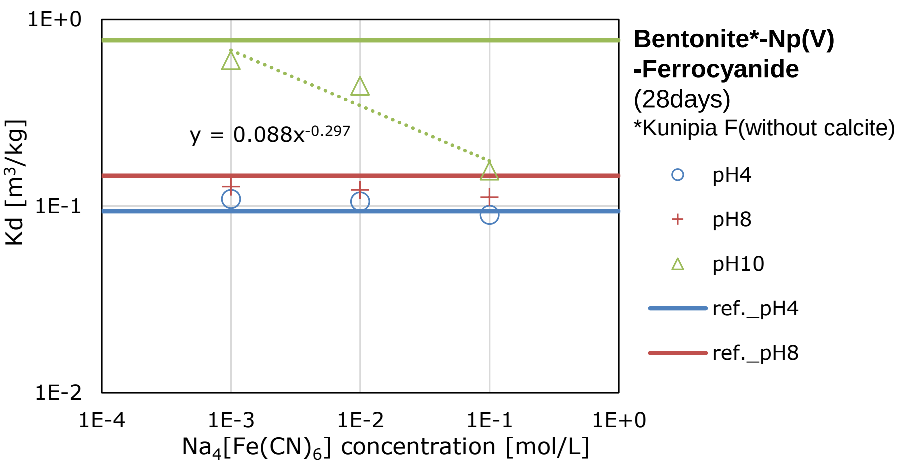
Test results for sorption of **U (VI)** into Cement **(OPC)** in the presence of ferrocyanides



Test results for sorption of **Cs, Sr, Ni** into Cement **(OPC)** in the presence of ferrocyanides



Test results for sorption of **Np (V)** into Bentonite in the presence of ferrocyanides



(b) Presentation of disposal methods, and development of safety assessment techniques【Confidential】

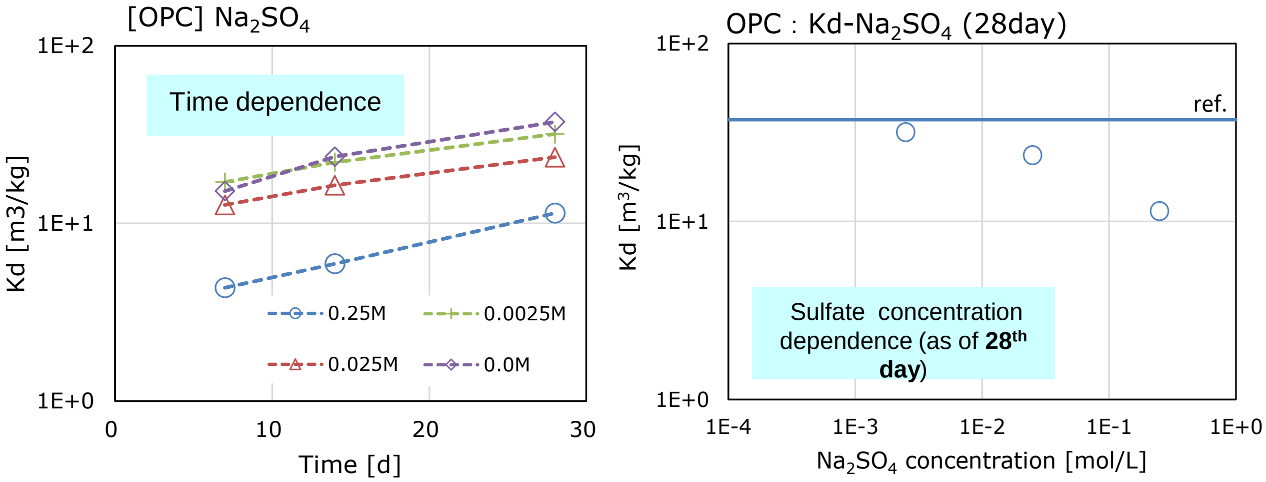
② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Results of data collection for setting the Sorption Reduction Factor (sulfate)-

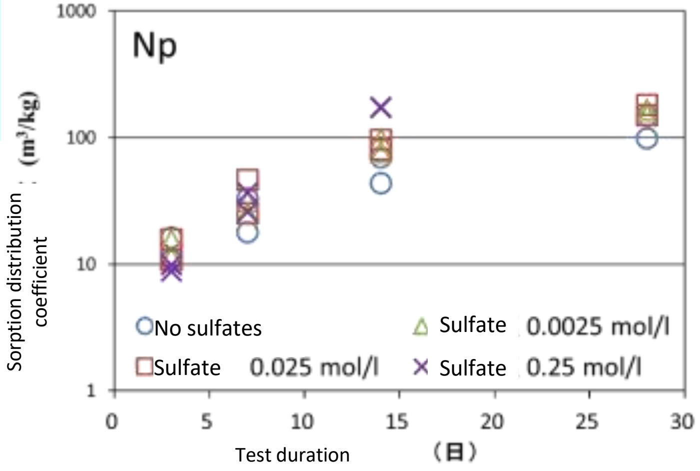
Study on assessment of sulfate impact

- Previous investigations have suggested that the direct impact of complex formation with sulfates may not be apparent in many nuclides in the impact assessment based on thermodynamic data, but since almost no data of sorption in the presence of sulfates has been reported, data has been collected in this project.
- The data of sorption in the presence of sulfate ions shows a clear time dependence, and a 28-day test confirmed that sufficient sorption equilibrium may not have been reached.
- From the data at the stage where sufficient equilibrium was not reached, it was confirmed that U (VI) was affected, while the impact was not clear in Np (V).

Test results for sorption of **U (VI)** into Cement **(OPC)** in the presence of sulfates



Test results for sorption of **Np (V)** into Bentonite in the presence of sulfates: Time dependence of sorption



(b) Presentation of disposal methods, and development of safety assessment techniques
② Development of techniques for assessing impact of affecting substances, etc. on disposal
- Summary of results of trial parameter setting (Impact threshold and Sorption Reduction Factor) -

Cement based

Element group	Representative element	Impact concentration (threshold value) and Sorption Reduction Factor (SRF)						
		Organic substances (ISA)		Seawater	Boric acid		Ferrocyanides	
		Threshold value	SRF	SRF[*3]	Threshold value	SRF	Threshold value	SRF
Alkali metal	Cs	–	1	2	–	1	–	1
Alkali earth metal	Sr	1×10^{-2} M[*1]	10	8	–	1	–	1
Divalent transition metal	Ni	–	1	1	Issues present	Issues present	–	1
Tetravalent transition metal	Sn	1×10^{-4} M	100	10	🟨	🟨	🟨	🟨
Pentavalent transition metal	Nb	1×10^{-4} M	100	10	🟨	🟨	🟨	🟨
Trivalent actinide	Am	1×10^{-4} M	10	10	–	1	–	1
Tetravalent actinide	Th	1×10^{-4} M	100	10	Issues present	Issues present	Issues present	Issues present
Pentavalent actinide	Np	1×10^{-4} M	10	10	–	1	1×10^{-3} M	3
Hexavalent actinide	U	5×10^{-4} M	10	10	1×10^{-2} M	500	1×10^{-3} M	3
Halogen	I	—[*2]	1	—[*2]	🟨	🟨	🟨	🟨
Anionic species	Se	—[*2]	1	—[*2]	🟨	🟨	🟨	🟨

Bentonite based

Element group	Representative element	Impact concentration (threshold value) and Sorption Reduction Factor (SRF)			
		Boric acid		Ferrocyanides	
		Threshold value	SRF	Threshold value	SRF
Alkali metal	Cs	–	1	–	1
Alkali earth metal	Sr	–	1	–	1
Divalent transition metal	Ni	🟨	🟨	🟨	🟨
Tetravalent transition metal	Sn	🟨	🟨	🟨	🟨
Pentavalent transition metal	Nb	🟨	🟨	🟨	🟨
Trivalent actinide	Am	🟨	🟨	–	1
Tetravalent actinide	Th	Issues present	Issues present	Issues present	Issues present
Pentavalent actinide	Np	–	1	1×10^{-3} M	4
Hexavalent actinide	U	–	1	1×10^{-3} M	2
Halogen	I	🟨	🟨	🟨	🟨
Anionic species	Se	🟨	🟨	🟨	🟨

[*1] •Set M: mol/L, *2 Kd = 0 (m^3 kg^{-1})

[*3] •SRF between precipitation conditions => seawater conditions

🟧 : Set based on the past information investigation results

🟩 : Set based on data collected through sorption tests (values that are not specified, will be set hereafter, or will be set after improving the data.)

🟨 : Investigation of past information and data collection not implemented (includes items for which absence of investigation results data has been confirmed)

(b) Presentation of disposal methods, and development of safety assessment techniques 【Confidential】

② Development of techniques for assessing impact of affecting substances, etc. on disposal

- Summary and future plans -

- The data investigation and collection scheduled for this year was completed, the threshold value and SRF were set according to the existing data, and it was confirmed that the values based on the thermodynamic data are evaluated more conservatively than the experimental method.
- In the next fiscal year, the plan will be studied again based on the evaluation results of this fiscal year and the disposal exposure dose evaluation results, and the data that is considered to be highly important will be collected, and attempts will be made to set the SRF.

Table Current evaluations and future challenges with regard to affecting substances

Affecting substances	Current evaluation of impact of sorption during disposal	Future challenges
Organic substances	・Regarding the impact of organic substances, the existing knowledge is relatively rich, and the sorption impact data of isosaccharinic acid (ISA), which has the greatest impact, is extensive, so at present, it is appropriate to study the evaluation of settings based on actually measured data of sorption in the presence of ISA. ・Although data on the impact of other organic substances is inadequate, evaluations based on thermodynamic data may be applicable.	・It is essential to study the applicability and validity of evaluation techniques, including techniques based on thermodynamic data, for various combinations of organic substances and nuclides, assuming organic substances and their degradation products that may be included in accident waste.
Seawater component	・As for the effect of seawater components on nuclide sorption, the existing knowledge is relatively extensive, and it is possible to evaluate sorption reduction to some extent quantitatively based on the understanding of sorption mechanism such as sorption conflicting with seawater component.	・Further review of the settings based on the latest knowledge on the sorption mechanism of each nuclide and the impact assessment of the seawater component is required.
Boric acid solution	・Regarding the impact of boric acid, sorption impact data was collected, and based on the results, it can be evaluated that the impact of boric acid is small for alkali metals and alkali earth metals, while boric acid has some impact on actinides. However, considering the coexistence of carbonic acid, the impact is not significant. ・When the boric acid content of waste has a high concentration, it is necessary to properly consider the impact of boric acid concentration evaluation and nuclide migration around the waste, in addition to the fact that boron is an environmental standard material.	・ The challenge is to obtain test data with sufficient accuracy for high sorption nuclides such as actinide nuclides, and it is necessary to continue to study the evaluation of the Sorption Reduction Factor with due consideration given to the relationship between the impact of boric acid complex formation and sorption reduction, the evaluation of conflict with other ligands such as carbonic acid complexes, and the consistency of the impact between nuclides.
Ferrocyanides	・For ferrocyanides, data of sorption in the presence of ferrocyanides was collected, and it was confirmed that its impact on alkali metals and alkali earth metals is small, and that there is a possibility that its impact on sorption will become apparent in some actinides. ・In addition to the fact that all cyanides are environmental standard materials, it is necessary to evaluate the behavior of ferrocyanide itself in the waste and in the disposal environment, and to conduct studies including measures during pretreatment.	・It is presumed that their impact is complicated depending on conditions such as nuclides and pH, and it is necessary to expand the data on the relationship between the impact on complex formation due to ferrocyanides and the reduction of sorption, to confirm the consistency of the impact between nuclides, and to study the evaluation of the Sorption Reduction Factor.
Sulfates	・From the evaluation based on thermodynamic data, it was estimated that the sulfate complex had almost no impact on nuclide sorption. On the other hand, in the sorption test of U (VI) to cement-based materials in a sulfate coexisting system, the dependence of the distribution coefficient on the sulfate concentration was confirmed at a relatively high sulfate concentration, and clear time dependence of sorption was confirmed.	・A clear time dependence has been confirmed in the sorption test in the presence of sulfates, and further data collection and evaluation are required, including the data on the possibility of the impact of solid phase transition.
Carbonates	・Regarding the impact of carbonates, it is a component originally contained in the natural rock and groundwater environment, and its impact assessment technique, which has been examined in conventional studies, can be utilized. ・Even in the absence of carbonates from accident waste, the impact of carbonic acid ion concentration in the pore water is taken into consideration, and it is believed that it is not necessary to further consider the impact of carbonates contained in accident waste.	・It is necessary to confirm the validity of the evaluation described in the left column.

2. Project details

c. Characterization efficiency improvement

(a) Characterization efficiency improvement

① Establishment of a characterization method that combines evaluation data based on analytical data and migration models

- i. Understanding the contamination mechanism
- ii. Evaluating the representativeness of analytical data
- iii. Investigation and consolidation of the characteristics of analytical data
- iv. Statistical inventory estimation method
- v. Acquisition of analytical data
- vi. Evaluation and management of analytical data

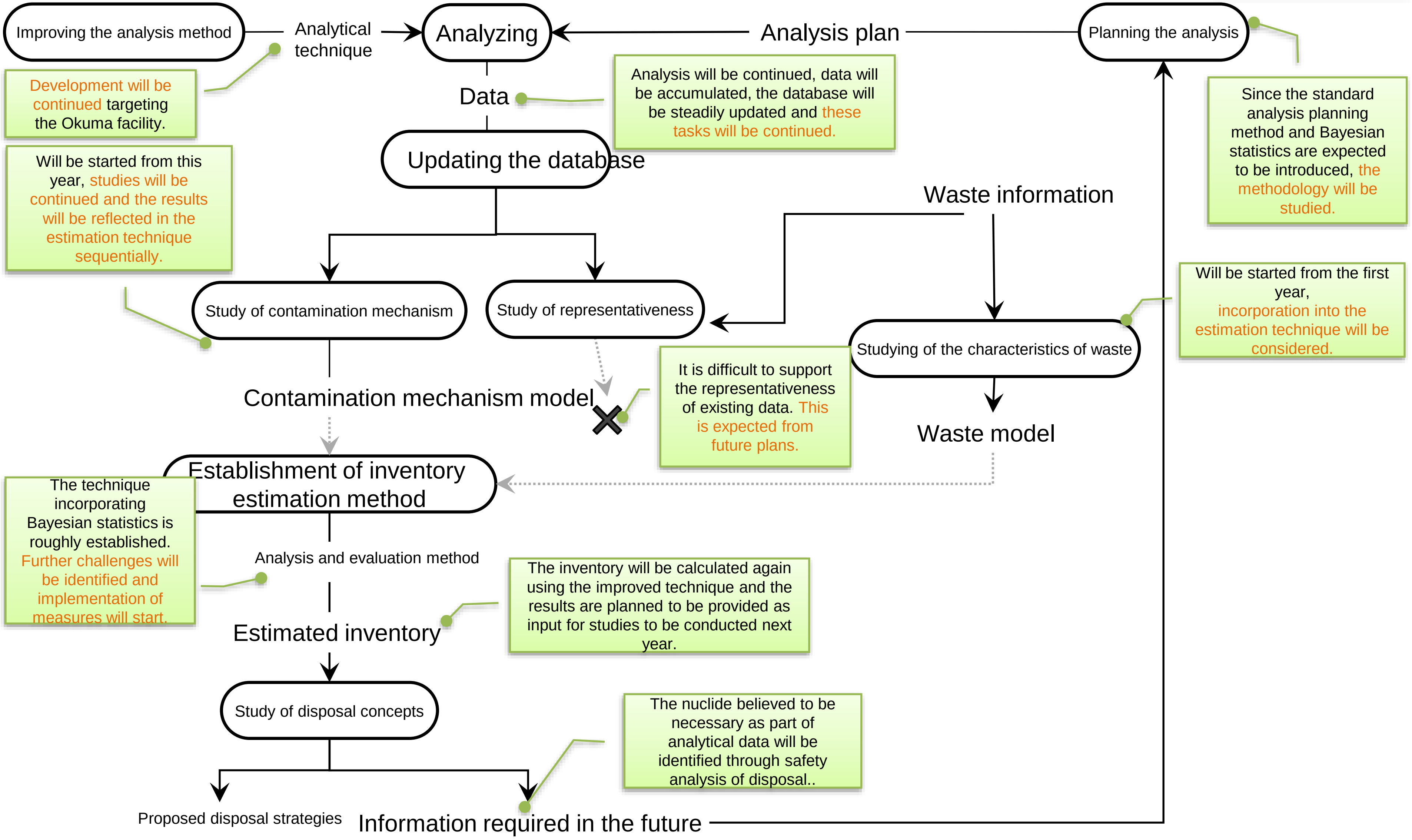
② Simplification and speeding-up of analytical methods

- i. Development of sampling technology
- ii. Study on streamlining the separation process
- iii. Development of automation technology
- iv. Establishment of standard analytical techniques

(b) Development of sampling technology

(a) Characterization efficiency improvement
Overview of analysis, and R&D using that data

Legend: Status of initiatives
This year's course of action



Improving the analysis method

Analytical technique

Analyzing

Analysis plan

Planning the analysis

Development will be continued targeting the Okuma facility.

Data

Analysis will be continued, data will be accumulated, the database will be steadily updated and these tasks will be continued.

Since the standard analysis planning method and Bayesian statistics are expected to be introduced, the methodology will be studied.

Updating the database

Will be started from this year, studies will be continued and the results will be reflected in the estimation technique sequentially.

Waste information

Study of contamination mechanism

Study of representativeness

Will be started from the first year, incorporation into the estimation technique will be considered.

Studying of the characteristics of waste

It is difficult to support the representativeness of existing data. This is expected from future plans.

Contamination mechanism model

Waste model

Establishment of inventory estimation method

The technique incorporating Bayesian statistics is roughly established. Further challenges will be identified and implementation of measures will start.

Analysis and evaluation method

The inventory will be calculated again using the improved technique and the results are planned to be provided as input for studies to be conducted next year.

Estimated inventory

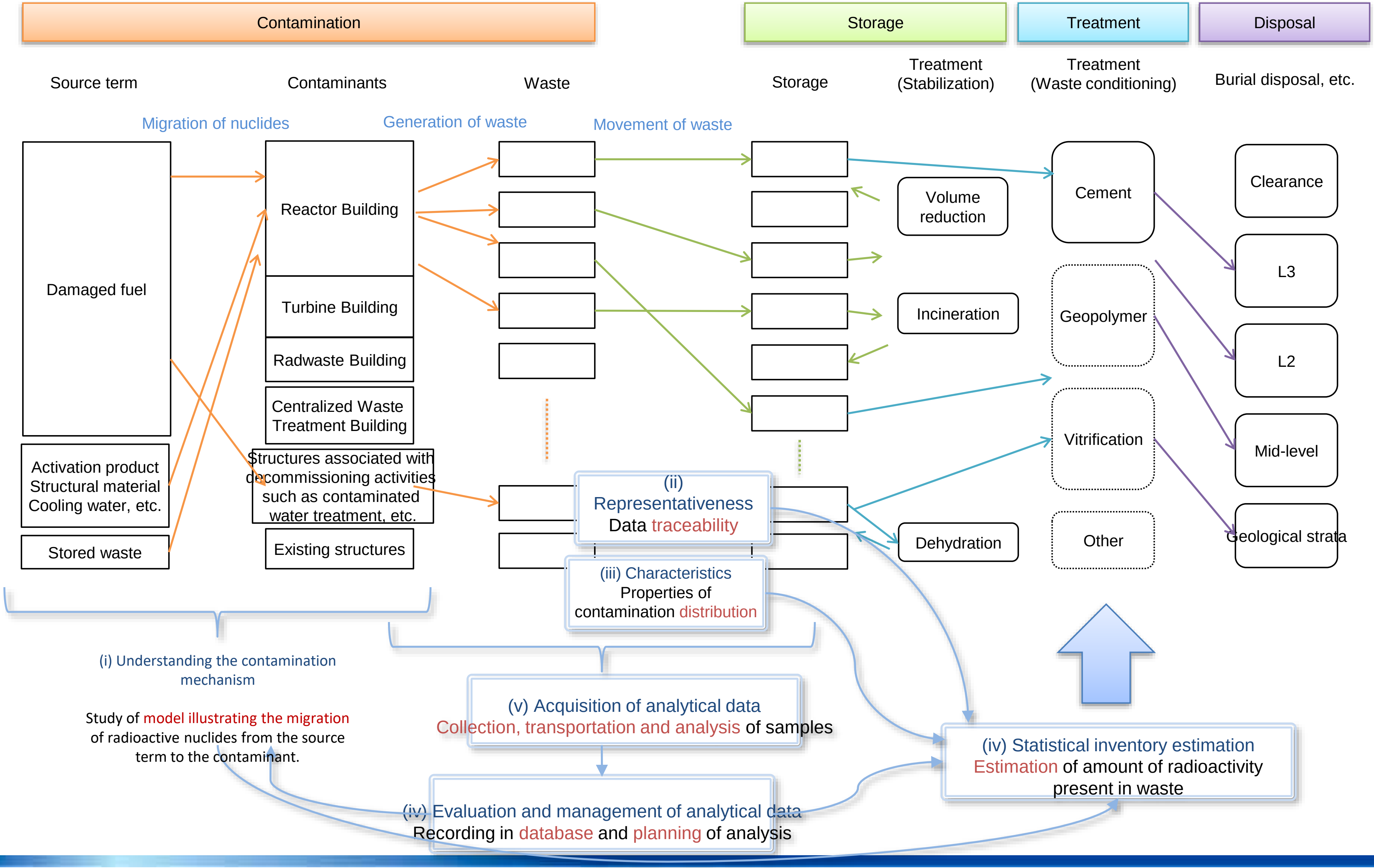
Study of disposal concepts

The nuclide believed to be necessary as part of analytical data will be identified through safety analysis of disposal..

Proposed disposal strategies

Information required in the future

(a) Characterization efficiency improvement
① Establishment of method for characterization
- Flow from generation of radioactive waste to its disposal, and implementation details -



Contamination | Storage | Treatment | Disposal

Source term | Contaminants | Waste | Storage | Treatment (Stabilization) | Treatment (Waste conditioning) | Burial disposal, etc.

Migration of nuclides | Generation of waste | Movement of waste

Damaged fuel

Activation product Structural material Cooling water, etc.

Stored waste

Reactor Building

Turbine Building

Radwaste Building

Centralized Waste Treatment Building

Structures associated with decommissioning activities such as contaminated water treatment, etc.

Existing structures

Volume reduction

Incineration

Dehydration

Cement

Geopolymer

Vitrification

Other

Clearance

L3

L2

Mid-level

Geological strata

(ii) Representativeness
Data traceability

(iii) Characteristics
Properties of contamination distribution

(i) Understanding the contamination mechanism

Study of model illustrating the migration of radioactive nuclides from the source term to the contaminant.

(v) Acquisition of analytical data
Collection, transportation and analysis of samples

(iv) Statistical inventory estimation
Estimation of amount of radioactivity present in waste

(iv) Evaluation and management of analytical data
Recording in database and planning of analysis

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism

■ Results
- ○ The analytical data of a variety of samples was collected and the contamination behavior of the nuclides was organized. For example, U in the contaminated water has a different ratio to Cs depending on whether it is present in PCV or in the downstream side of PCV (Fig. 1). Also, Np shows a different behavior than U and Pu (Fig. 2).
- ○ Similarly, the concentrations of radionuclides in solidifications and contaminated water were compared relative to each other with Cs as reference, and the group of elements with similar behavior were studied.

■ Goal
- ○ To understand the contamination mechanism in order to create a model that expresses migration behavior of radionuclides.

■ Implementation details
- ○ Study models containing multiple source terms and multiple mediums with respect to migration of nuclides. Radionuclides have things that are considered important in waste management. Hence if data cannot be obtained through analysis, estimate the behavior.
- ○ (FY2019) The elemental processes of contamination was examined, considering the fact that the phenomenon of contamination is generally approximated by means of log-normal distribution.
- ○ (FY2020) The study results will be reviewed based on the newly obtained data.

■ Indicators to determine goal achievement
- ○ A model that represents the contamination phenomenon should be created. (FY2019)
- ○ The model should be reviewed. (FY2020)

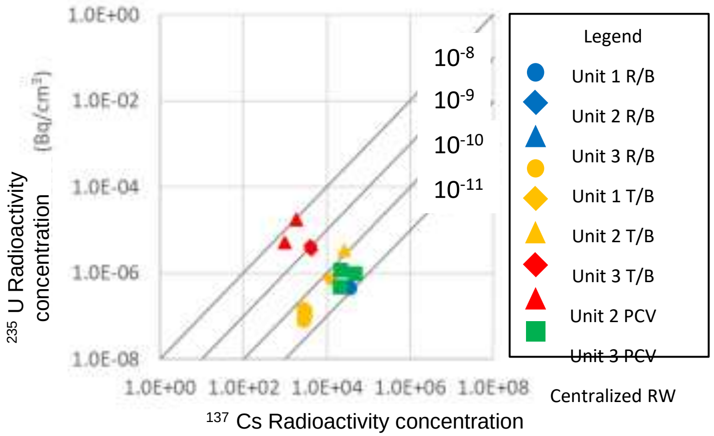


Fig. 1 Ratio of radioactivity concentration of ^{235}U and ^{137}Cs in a variety of contaminated water samples[#1]

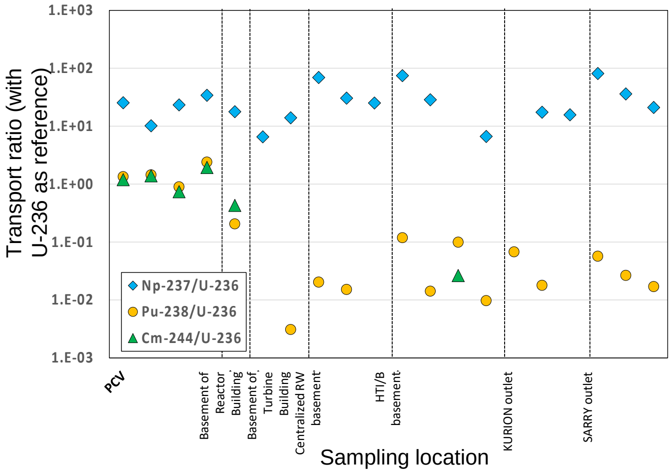
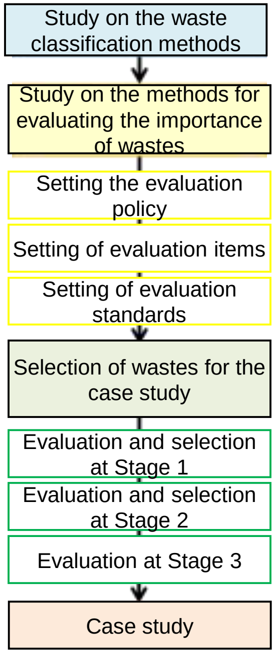


Fig. 2 Ratio of radioactivity concentration of ^{237}Np and ^{236}U in a variety of contaminated water samples
(Normalized transport ratio in fuel composition)

#1 * The 56th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting, Jul 26, 2018.

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism

- As the contamination status of waste varies widely depending on the material and the place of generation, a “case study” with limited targets was conducted (Fig. 1).
- In the case study, the classification of target waste was studied and 21 types of waste were set up (Table 1). The method for evaluating the "importance" of waste was studied, selection was conducted in 3 stages using this index and the target wastes for this case study were selected.
  - ○ In the first stage, it was narrowed down to 7 types including debris (3 types), secondary waste generated from contaminated water treatment (2 types), and dismantling waste (2 types).
  - ○ Finally, the Reactor Building dismantling waste was selected. Of the Reactor Buildings, Unit 2 with a large amount of analytical data was targeted. The two possible mechanisms for contamination of the reactor building were considered to be via air and contaminated water, which were suitable for the study. (Fig. 2)



Study on the waste classification methods

Study on the methods for evaluating the importance of wastes

Setting the evaluation policy

Setting of evaluation items

Setting of evaluation standards

Selection of wastes for the case study

Evaluation and selection at Stage 1

Evaluation and selection at Stage 2

Evaluation at Stage 3

Case study

Fig. 1 Case study flow

Table 1 Waste classification for the case study

Category 1	Category 2	Material	Stage 1	Stage 2
Debris	< 0.005 [mSv/h]	Concrete, Metal	☑	
	0.005 - 0.1 [mSv/h]	Concrete, Metal	☑	☑
	0.1 – 1 [mSv/h]	Concrete, Metal		
	1 - 30 [mSv/h]	Concrete, Metal		
	> 30 [mSv/h]	Concrete, Metal	☑	
Protective clothing, etc.		Burned ash		
Felled trees		Burned ash		
Contaminated soil		Contaminated soil		
Secondary waste generated from contaminated water treatment	KURION	(For each adsorbent)	☑	
	SARRY	(For each adsorbent)		
	Decontaminating device (AREVA)	Sludge		
	ALPS slurry	Iron co-precipitation, Carbona precipitation		
	ALPS adsorbent	(For each adsorbent)		
	Mobile type treatment device	(For each adsorbent)		
	Concentrated liquid waste	Slurry		
Dismantling waste	Inside the pressure vessel	Concrete, Metal		
	Inside the containment vessel	Concrete, Metal		
	Inside the Reactor Building	Concrete, Metal	☑	☑
	Other buildings	Concrete, Metal	☑	☑
	Waste from decommissioning work (including debris retrieval)	Various devices (Metal, etc.) Debris is likely to have adhered.		
	Deposits	Deposits		

After narrowing down in stages, finally the contamination inside the Reactor Building was selected.

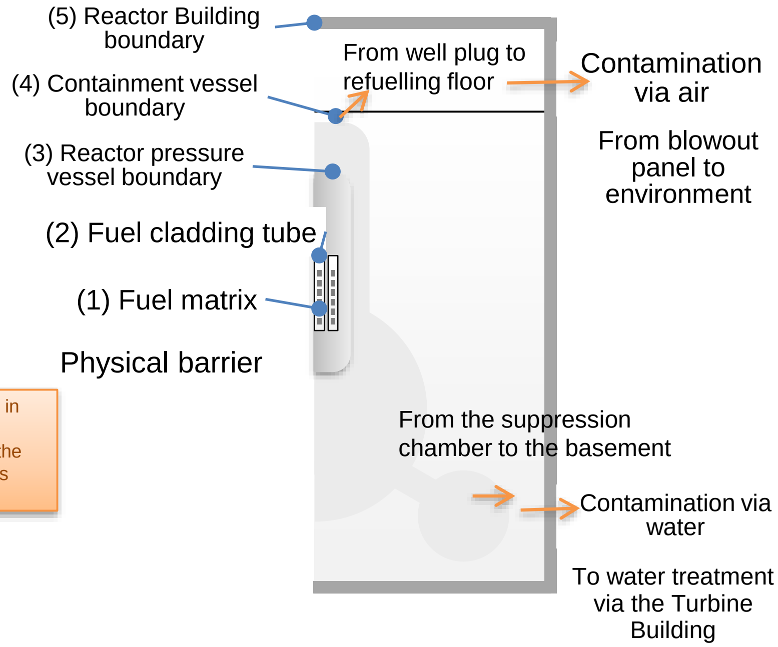


Fig. 2 Case study on contamination model
(Dismantling waste from inside the Unit 2 Reactor Building)

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism (Continued …)

- For contamination via air inside the Reactor Building of Unit 2, the data on analytical samples with precise collection location was studied (Table 1).
- For the transport ratio of major nuclides (relative value to 137Cs, normalized in fuel composition) , similar values are shown for elements with similar chemical properties (Fig. 1). The change in nuclide composition seemed to be small in the process of migrating through the medium (air). The analysis-based inventory estimation was carried out by reflecting these findings.
  - ○ Meanwhile, it is suggested that nuclides (3H, 14C, 60Co, etc.) with a different tendency to correlate with Cs may have a different source term and migration mechanism than other nuclides.
- Regarding local nuclide migration in contaminated areas, measurement data was collected using an imaging plate (Fig. 2). It was found that the contamination remained on the surface layer.
- Radiochemical analytical data provides information on the location of contamination, but does not include direct information on the source terms or nuclide migration processes. It is necessary to study an inductive approach based on analytical data.

Table 1 Analysis sample from Unit 2 Reactor Building (Radiochemical analysis)

Sampling location		Properties of the sample	Number of samples
5th floor	Ceiling	Deck plate coating	5
	Floor - shield plug east side	Boring core surface coating	1
	Floor - well plug upper part (center)	Boring core - lower layer coating, Concrete - upper and lower layers	3
	Floor - northeast side	Same as above	3
3rd floor	Floor - north side (Near RCW pump)	Boring core strippable paint	1
2nd floor	Floor - north side passage (Near RCW Hx)	Boring core strippable paint	1
1st floor	Floor- northwest corner (Personal airlock room entrance)	Boring core	1
PCV	TIP piping	Pipe blocking material	1

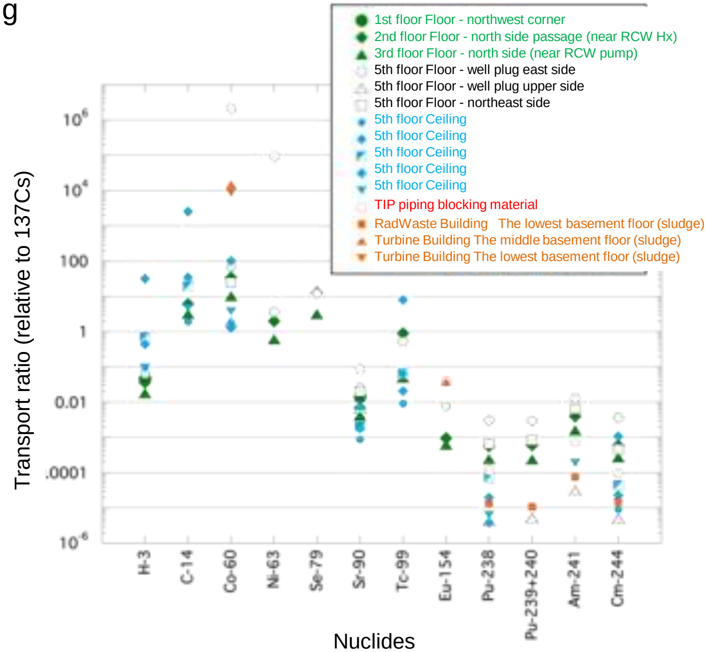
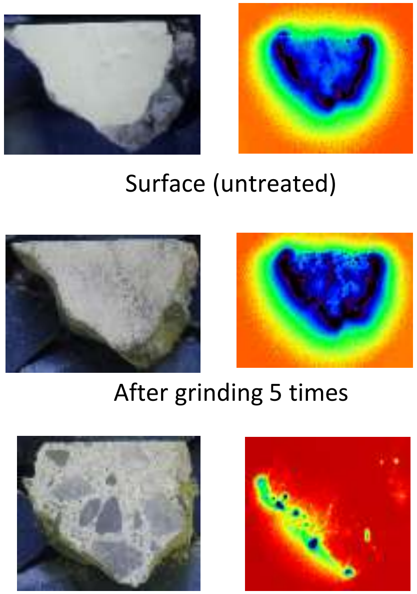


Fig. 1 Transport ratio of important nuclides to each floor of Unit 2 Reactor Building (concentration ratio relative to normalized ^{137}Cs)


Surface (untreated)

After grinding 5 times

After grinding 15 times

Fig. 2 Example of contamination distribution data by means of an imaging plate [#1] (Sample number 3RB-OP-C1)

[#1] The 56th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting, Jul 26, 2018.

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism (continued...)

- Regarding the contamination of the Reactor Building via contaminated water, the analytical data is limited to contaminated water. Studies are under progress with the analytical data of the stagnant water and the solid contents (sludge) contained in it as a clue.
- The behavior of actinide nuclides in contaminated water appears to be different for U, Np, and Pu-Am-Cm respectively (Fig. 1).
  - ○ Compared to U, migration of Np to contaminated water is likely to be at a higher rate. There are cases where U may be contributed by natural Uranium suggesting elution from structural materials. In the process of migrating from PCV to the Reactor Building and Turbine Building, Pu, Am and Cm were lost from water suggesting that these got changed to another form.
- U, Pu and Am were detected in the analytical data on sludge contained in stagnant water, and their movement to the sludge was proved from the mass balance with water (Fig. 2).
- Contaminated water is circulated, because of which a certain percentage of radionuclides are continuously flowing in. It is important to study the process of migration from source terms to water. Moreover, it is necessary to estimate the sedimentation of insoluble actinide.
  - ○ Unlike in the case of air, as it is not possible to take an inductive approach, it is necessary to expand and enrich the analytical data (including the acquisition of various types of samples) and refer to findings from other projects as well.

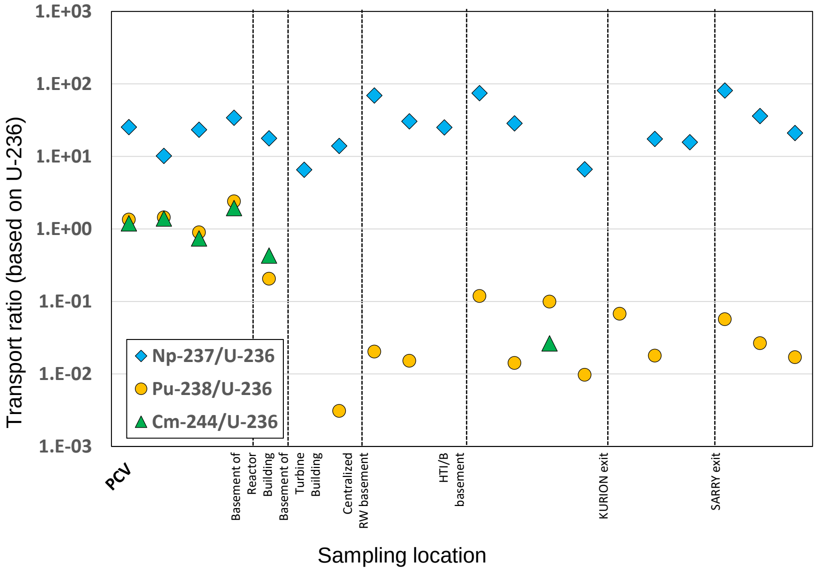


Fig. 1 Transport ratio of important nuclides to contaminated water (Concentration ratio relative to normalized ^{236}U) #1

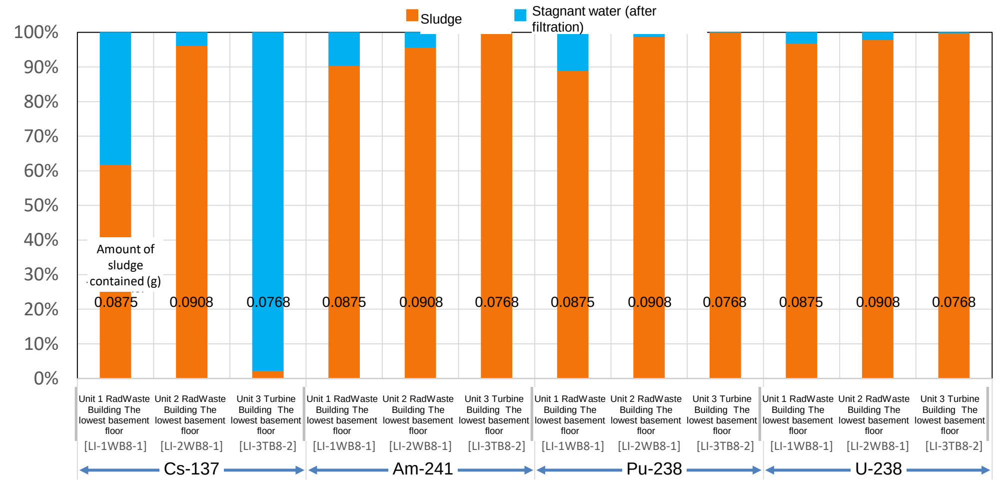


Fig. 2 Distribution of Cs and actinide nuclides in stagnant water containing solidifications (sludge) #1

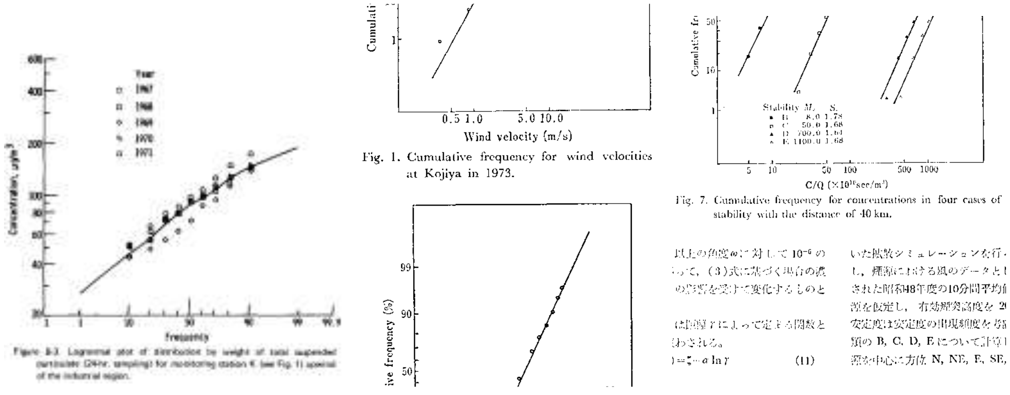
#1 The 67th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting, Jun 27, 2019.

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism (continued...)

- It is desirable to determine the concentration of radionuclides contained in the waste by the simplest method possible. The scaling factor method is used for difficult-to-measure nuclides contained in waste generated in association with the operation of nuclear reactors. Here, the concentration ratio is approximated by means of log-normal distribution.
- We have assumed that the transport ratio, which is the normalized concentration ratio, can be approximated by means of log-normal distribution, and have used it for inventory estimation. Cases of log-normal distribution were examined and its applicability to the waste at Fukushima Daiichi Nuclear Power Station was studied.
- The log-normal distribution is used for the distribution with respect to events in a variety of fields. In the field of atmospheric science, the particle size of the aerosol and the concentration of the contaminating substances are expressed by means of log-normal distribution with respect to the contaminating substances. (Table 1). Moreover, considering the elemental processes of contamination, log-normal distribution is applicable to the formation of particles (solid fine particles and water droplets), the flow of air which is the medium (wind velocity), and the concentration distribution which is the result of contamination. (Fig. 1).
- Normal distribution is reproducible, and due to its nature, log-normal distribution also has similar reproducibility. It is considered reasonable that particle size, wind velocity and contamination distribution, all have log-normal distributions. We will continue to study and assume log-normal distribution for inventory estimation.

Table 1 Various events to which log-normal distribution is applicable [#1]

Field	Examples where log-normal distribution applies	Competing distributions
Event time	Incubation period of infectious disease, illness recovery time, survival period, years of service, resale time, talk time, problem solving time, etc.	3 parameter log-normal, Inverse Gaussian, Weibull, Gamma, Beta Prime distribution, etc.
Economics	Stock price, stock earning rate, insurance claim amount	3 parameter log-normal, Pearson type, inverse Gaussian, etc.
Industrial	Survival time distribution related to the applications of thermal ion electron tube system, particle size suppression, metal fatigue, etc.	
Biology	Concentration of blood components, lowest lethal dose	General gamma, Dirichlet, multivariate gamma
Ecology	Population	Negative binomial distribution, logarithmic series distribution
Atmospheric science	Aerosol particle size, concentration of contaminating substances, flood frequency	Extreme value, Johnson, Weibull, Beta
Geology	Particle size	Multivariate normal distribution (for spatial correlation)



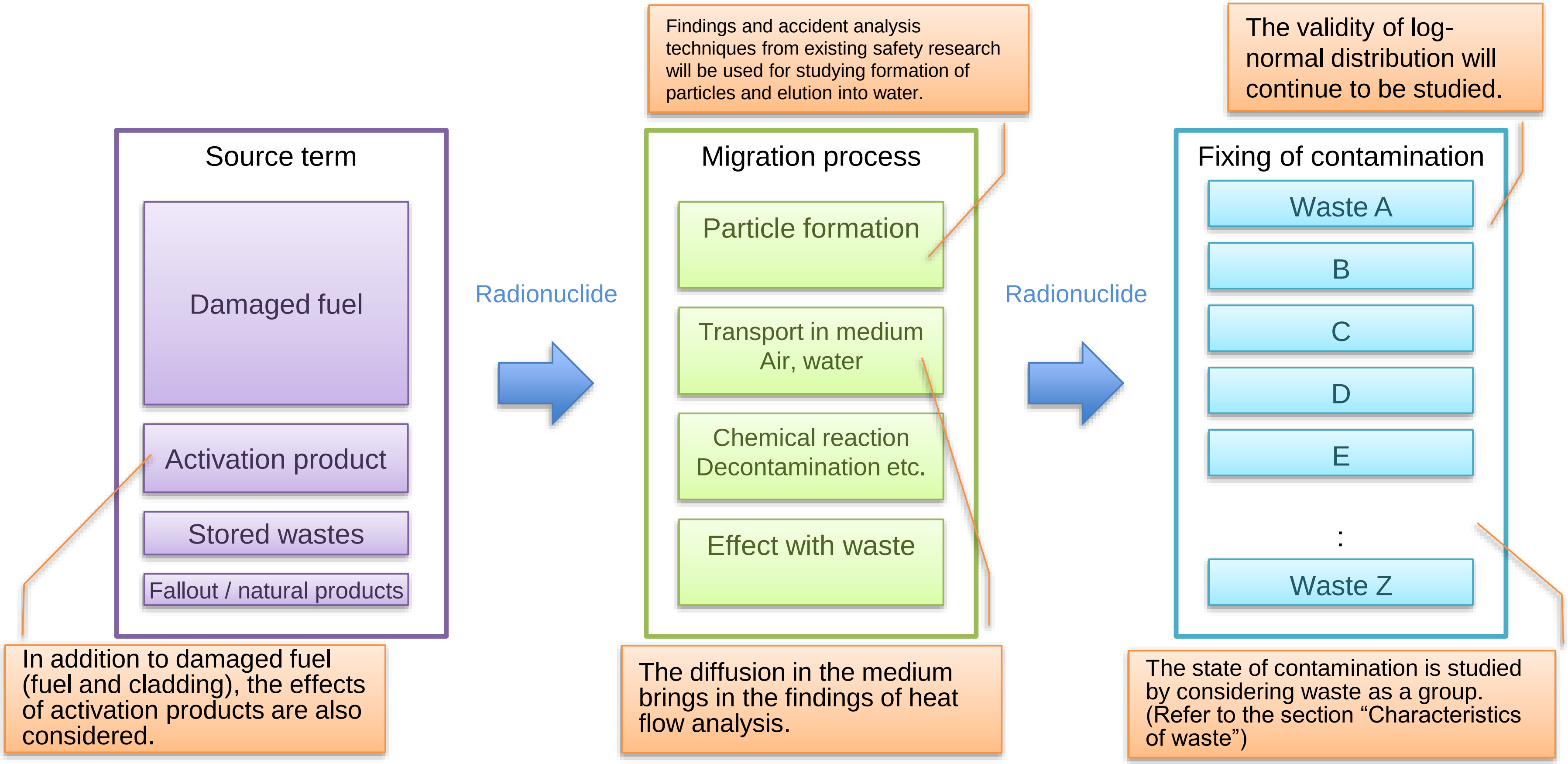
Particle mass　　Wind velocity　　Contamination concentration

Fig. 1　Log-normal distribution associated with radionuclide contamination [#2,3]

#1 Kunio Shimizu, Applied Statistics, 17 (1), 55–59 (1988). #2 H. Neustadter et al., EPA-650/4-74-038 (1974) . #3 Jun Hiroo et al., Journal of the Air Pollution Control Association, 14 (8), 311 (1979).

(a) Characterization efficiency improvement
① Establishment of method for characterization
i. Understanding the contamination mechanism (continued...)

- The study of contamination mechanism focuses mainly on inductive approach based on radiochemical analytical data. Based on the gradual accumulation of analytical data, the study will be continued by referring to the findings from analytical and experimental approaches and by combining them. (Fig. 1)
  - ○ Along with the targets of contamination, limited nuclides (as a standard 137Cs, which is easy to handle and 14C and 129I which are important actinides in disposal safety assessment) will be studied .



Findings and accident analysis techniques from existing safety research will be used for studying formation of particles and elution into water.

The validity of log-normal distribution will continue to be studied.

In addition to damaged fuel (fuel and cladding), the effects of activation products are also considered.

The diffusion in the medium brings in the findings of heat flow analysis.

The state of contamination is studied by considering waste as a group. (Refer to the section “Characteristics of waste”)

Fig. 1 Direction of the study on contamination mechanism

(a) Characterization efficiency improvement
① Establishment of method for characterization
ii. Evaluating the representativeness of analytical data

- Results
  - We have started digitization (creation of database) of information on radioactive waste that is being stored and managed, and have already accumulated about 60,000 units of data. (Fig. 1)
  - Meanwhile, analytical data on various samples has been accumulated, and it was found that the concentration can be expressed by means of log-normal distribution. (Fig. 2)
- Goal
  - To find a way to evaluate the representativeness of the data obtained through analysis.
- Implementation details
  - Group the forms of waste generation into several categories and study the methods for estimating the inventory for each of them.
  - (FY2019) Regarding contamination distribution of waste, the processes from generation to accumulation and storage were assumed and the changes in contamination distribution were studied based on the analytical data. The usefulness of Bayes estimation to statistically study the subjects for which the parent population has not been determined was investigated.
  - (FY2020) The study results will be reviewed based on the newly obtained data. A statistical method for inventory estimation will be studied based on the results of the previous year. In addition, the applicability of the method will be evaluated using analytical data.
- Indicators to determine goal achievement
  - The waste information should be organized, and the waste characteristics should be evaluated. (FY2019)
  - A method to indicate the position of analytical data with respect to waste information should be presented. (FY2020)

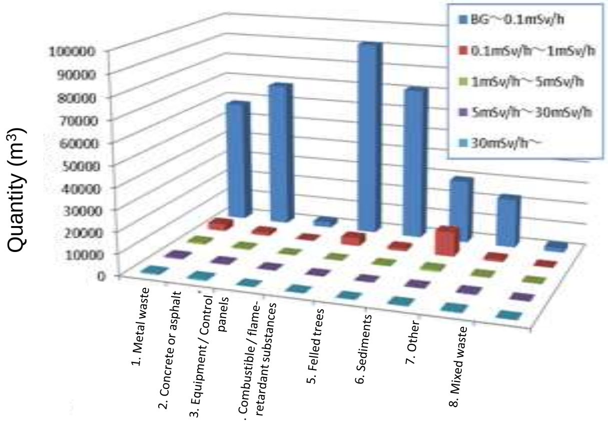


Fig. 1 An example of identification of information on stored waste

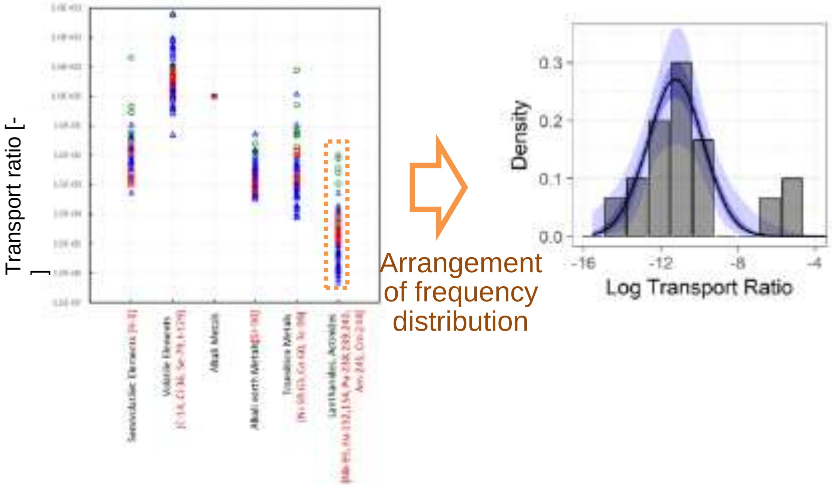
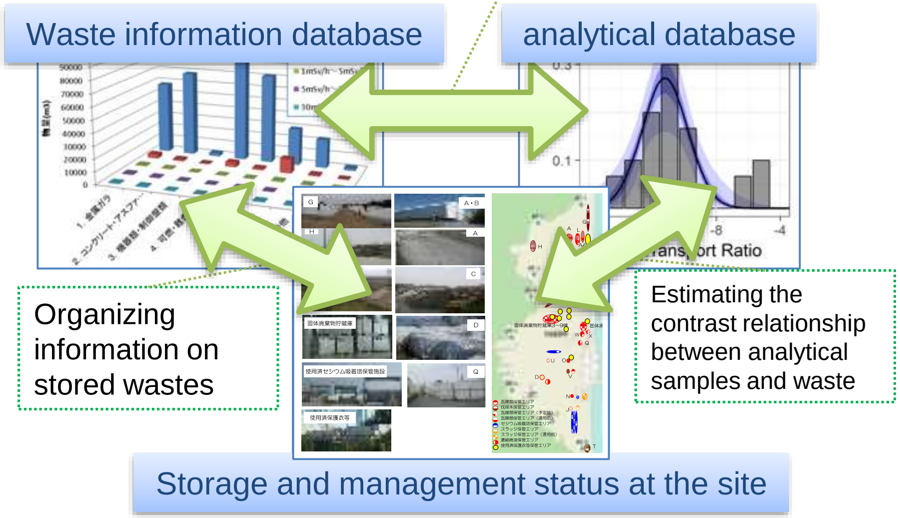


Fig. 2 Study on statistical handling methods of analytical data (Example of rate of release into the air inside the building)

(a) Characterization efficiency improvement
① Establishment of method for characterization
ii. Evaluating the representativeness of analytical data

- To estimate the relationship between the analytical samples and waste, the storage and management status at the site is collated with the analytical database. (Fig. 1)
- It was found that the storage areas with traceability are limited to "Area Q" and "solid waste storage vault”. (Table. 1)
  - ○ The debris that was present in "Area Q" has already been transferred to the solid wastes storage vault, and as a result, the only traceable storage area at present is the "solid wastes storage vault”.
- The representativeness of the analytical data must be studied in accordance with the traceability of the waste.

Estimating the distribution position of analysis samples in the parent population.



Waste information database

analytical database

Organizing information on stored wastes

Estimating the contrast relationship between analytical samples and waste

Storage and management status at the site

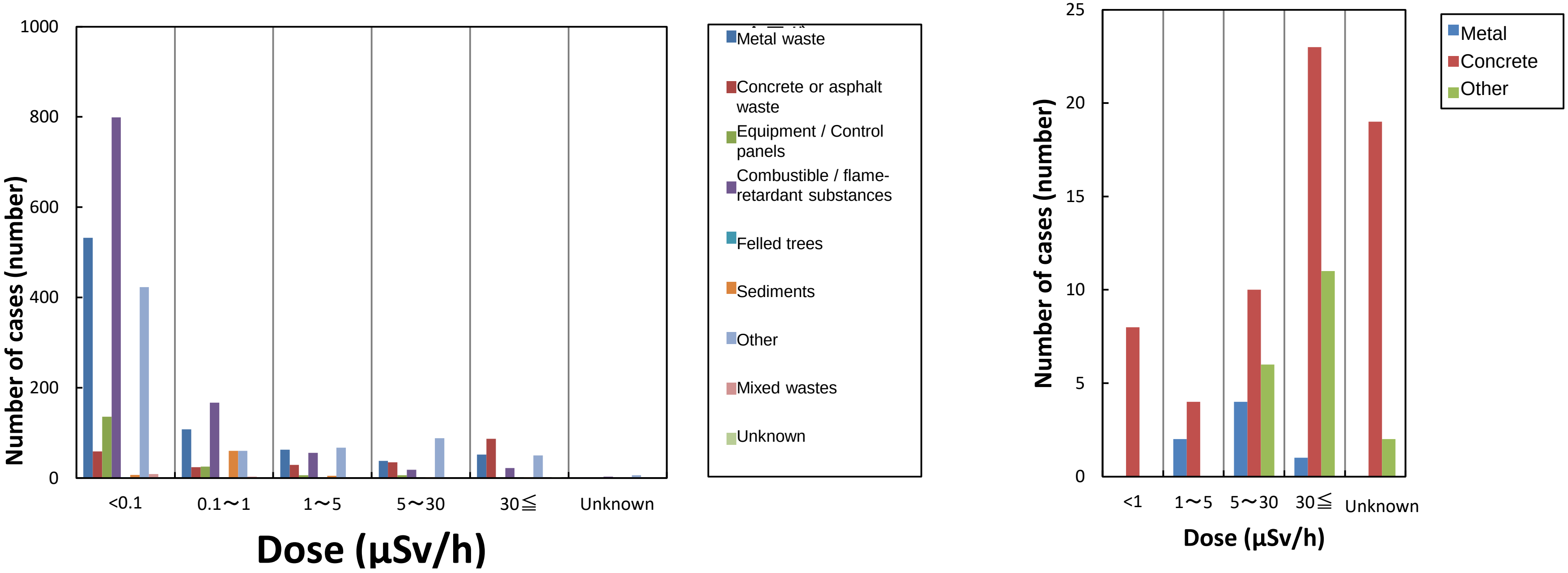
Fig. 1 References of waste data regarding the representativeness of analytical data

Table 1 Storage area information and waste traceability (as of August 30, 2019)

Area	Storage methods	Stored item	Surface dose rate classification (mSv/h)	Area occupancy rate	Traceability
B	Open storage	Various debris	0.1 or less	95%	No
C	Open storage	Various debris	0.1 or less	99%	No
F2	Open storage	Various debris	0.1 or less	85%	No
J	Open storage	Various debris	0.1 or less	78%	No
N	Open storage	Various debris	0.1 or less	96%	No
O	Open storage	Various debris	0.1 or less	83%	No
P1	Open storage	Various debris	0.1 or less	80%	No
U	Open storage	Various debris	0.1 or less	100%	No
V	Open storage	Various debris	0.1 or less	80%	No
AA	Open storage	Various debris	0.1 or less	26%	No
D	Covering with sheet	Various debris	0.1 - 1	58%	No
E1	Covering with sheet	Various debris	0.1 - 1	88%	No
P2	Covering with sheet	Various debris	0.1 - 1	62%	No
W	Covering with sheet	Various debris	0.1 - 1	27%	No
X	Covering with sheet	Various debris	0.1 - 1	65%	No
L	Soil cover type temporary storage facility	Various debris	1 - 30	100%	No
A	Temporary storage facility	Various debris	1 - 30	14%	No
E2	Storage in containers	Various debris	1 - 30	26%	No
1F	Storage in containers	Various debris	1 - 30	99%	No
Q	Storage in containers	Various debris	1 - 30	0%	Yes, depending on the item
solid wastes storage vault	Storage in containers	Various debris	—	36%	Yes
G	Open storage	felled trees, trunk, roots, branches and leaves	—	63%	No
H	Open storage	felled trees, trunk, roots, branches and leaves	—	74%	No
M	Open storage	felled trees, trunk, roots, branches and leaves	—	88%	No
V	Open storage	felled trees, trunk, roots, branches and leaves	—	2%	No
G	Temporary storage tank	felled trees, branches and leaves	—	88%	No
T	Temporary storage tank	felled trees, branches and leaves	—	94%	No
Small character areas	Open storage	Used protective clothing	—	81%	No

(a) Characterization efficiency improvement
① Establishment of method for characterization
ii. Evaluating the representativeness of analytical data

- Frequency of dose rates in the waste storage data and analytical data was compared focusing on the areas in Units 1 to 4 and the indoor environment. (Fig. 1)
  - Waste storage data contained a lot of combustible / flame-retardant materials, metal waste, and felled trees with a low dose, and concrete with ≥30 mSv/h. The analytical data contained a lot of concrete with its dose exceeding 5 μSV/h.
- The analytical samples thus illustrate characteristic contamination rather than being just a simple representation of distribution.
- Based on these facts, the study on the representativeness and the method for evaluating it will be continued.



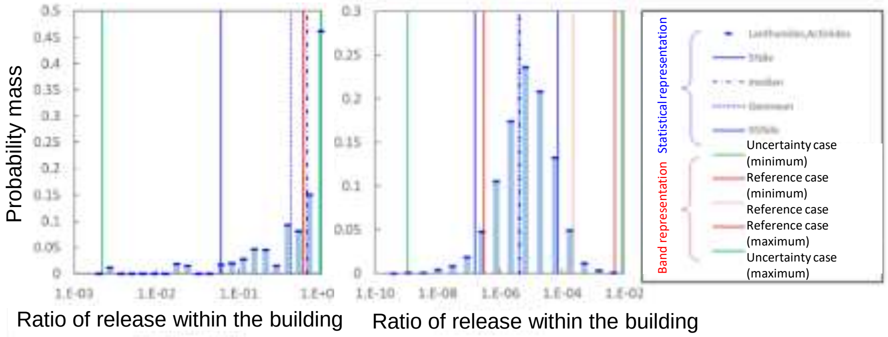
Waste storage data

Analytical data

Fig. 1 Indoor dose of debris in areas of Units 1 to 4

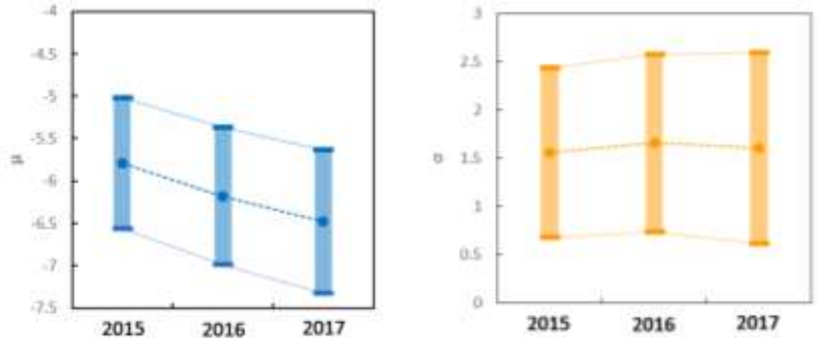
(a) Characterization efficiency improvement
① Establishment of method for characterization
iii. Investigation and consolidation of the characteristics of analytical data, iv. Statistical inventory estimation method

- Results
  - ○ It was found that the migration rate of nuclides can be estimated from the analytical data by expressing it as probability distribution based on Bayesian statistics. (Fig. 1)
  - ○ Although the distribution parameters (mean and variance) change with the accumulation of analytical data, it was found that improvements may not be seen depending on the type of nuclide and waste, and hence it is necessary to improve the model and treatment methods. (Fig. 2).
- Goal
  - ○ To establish a method for statistically estimating the amount of radioactivity (inventory) contained in waste.
- Implementation details
  - ○ Group the forms of waste generation into several categories and study the methods for estimating the inventory for each of them.
  - ○ (FY2019) The usefulness of Bayes estimation to statistically study the subjects for which the parent population has not been determined, was investigated. The processes from generation to accumulation and storage were assumed and the changes in contamination distribution were studied based on the analytical data.
  - ○ (FY2020) The study results will be reviewed based on the newly obtained data. A statistical method for inventory estimation will be studied based on the results of the previous year. In addition, the applicability of the method will be evaluated using analytical data.
- Indicators to determine goal achievement
  - ○ The characteristics of the analytical data should be organized and shown. The statistical methods suitable for application should be identified (FY2019)
  - ○ Study results should be reviewed. A statistical method for inventory estimation should be proposed. The applicability should be evaluated and shown. (FY2020)



Alkali metal nuclides   Lanthanide and actinide nuclide

Fig. 1 Nuclide migration ratio obtained with the help of Monte Carlo calculations based on Bayesian statistics (expressed in terms of probability density distribution)



Average (μ)   Variance (σ)

Fig. 2 Changes in log-normal distribution parameters with increase in data (Transport ratio of alkaline earth metal elements to the Reactor Building)

(a) Characterization efficiency improvement
① Establishment of method for characterization
iii. Investigation and consolidation of the characteristics of analytical data

- Characteristics such as dose rate are being investigated based on waste information in order to clearly specify the characteristics of waste that is currently stored.
- As there are relatively high number of records of stored waste generated in and around Units 1 to 4, it is expected that by understanding the contamination of the Reactor Building, the characteristics of the waste that is currently stored can be roughly understood.
- It appears that waste unevenly exists in the container, and this was investigated from the dose rate data of the container. (Fig. 1) Variations in data measured from multiple directions suggested that there had to be specific distribution.
- The relationship between the dose and quantity of waste stored in the facility was investigated (Fig. 2). Although there were variations in the blocks in which waste was stored, as a whole it was found that there was specific distribution.
- Therefore, when the variation in the amount of waste and the dose rate is considered as a group, it was found that the distribution of each could be discussed.
- Therefore, the state of waste accumulation will be modeled in three stages (individual waste, stored in a container, and stored in the facility), and an attempt will be made to study and quantify the characteristics of contamination distribution for each of them. (Fig. 3)

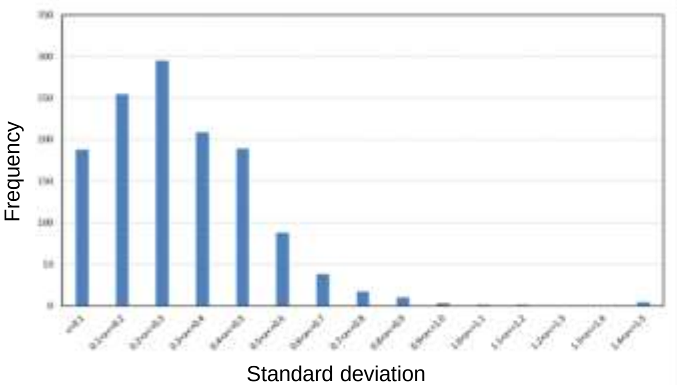


Fig. 1 Uneven distribution of dose rates in high-dose debris containers (variation in measurement values from multiple directions)

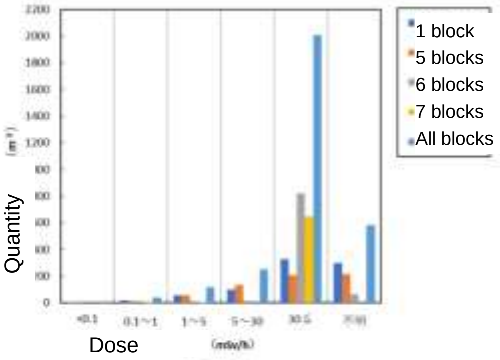


Fig. 2 Amount of debris stored in solid wastes storage vault No.8 (B2F)

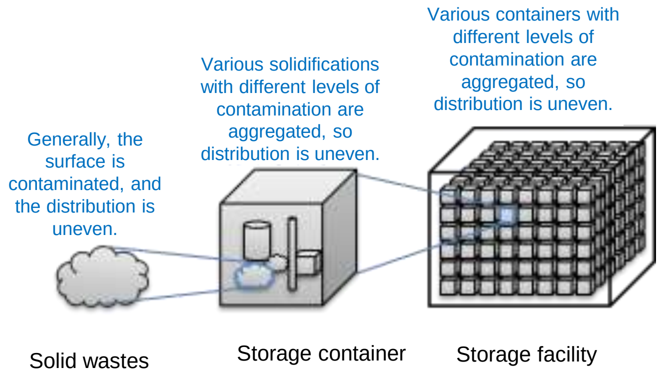
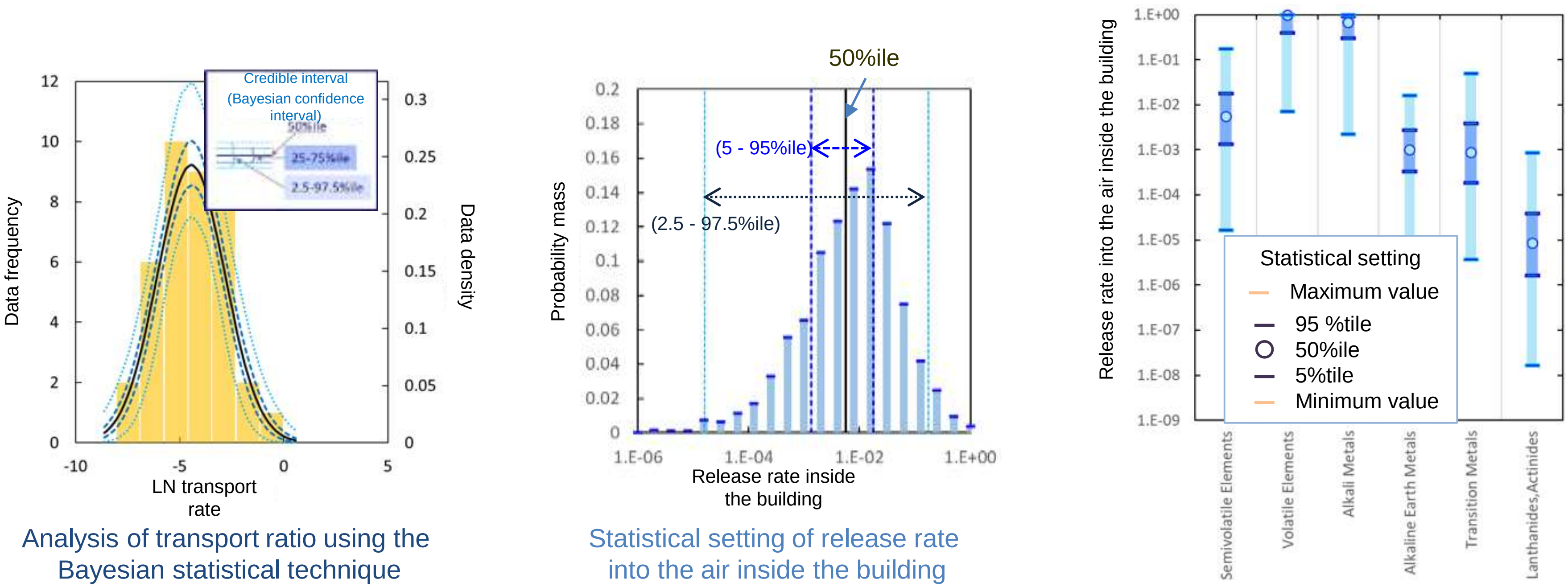


Fig. 3 Hierarchical structure related to waste accumulation and variations in contamination distribution

(a) Characterization efficiency improvement
① Establishment of method for characterization
iv. Statistical inventory estimation method

- A method to set the parameters of the analytical nuclide migration model based on the continuously accumulated analytical data was established. (Fig. 1)
- In this method, the distribution of relative and normalized concentrations (transport ratios) is analyzed based on Bayesian statistics, and the uncertainty of the parameters (mean and standard deviation) is quantitatively represented. Thus, the migration rate can be represented as a probability density distribution. Moreover, as a result, the certainty of the estimated inventory can be shown together with radioactivity.
- Along with the accumulation of analytical data, the changes in the certainty of parameters can be investigated and used in the analysis plan.



Analysis of transport ratio using the Bayesian statistical technique

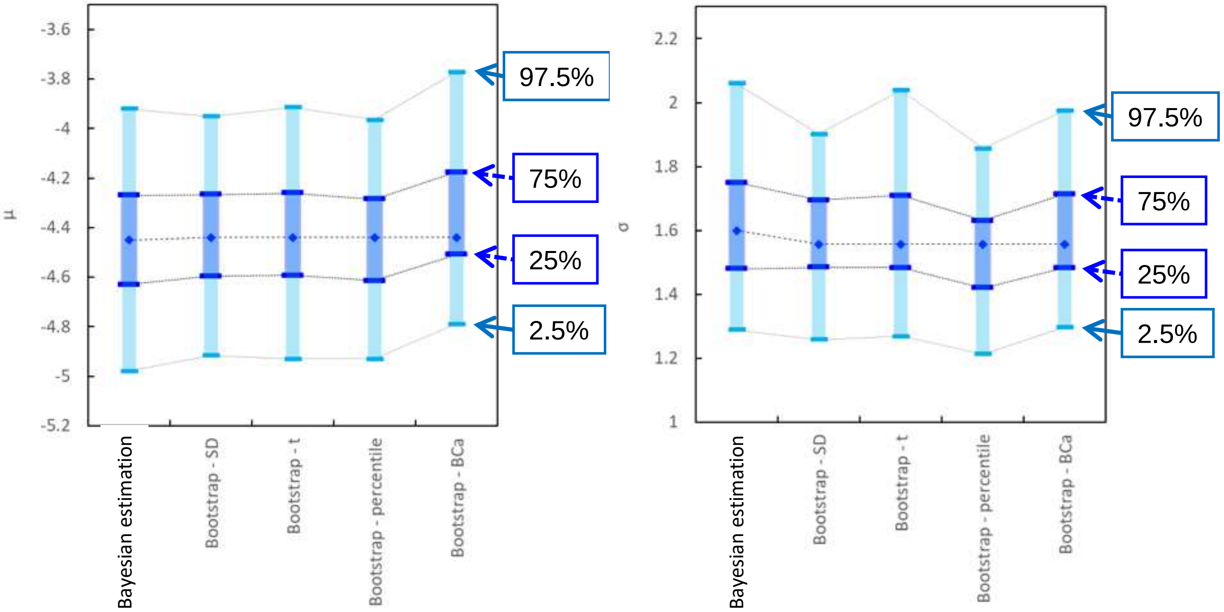
Statistical setting of release rate into the air inside the building

Release rate into the air inside the building for each element group

Fig. 1 Flow of setting migration parameters based on Bayesian statistics

(a) Characterization efficiency improvement
① Establishment of method for characterization
iv. Statistical inventory estimation method

- The bootstrap method and the jackknife method, which are methods for frequency-wise parameter interval estimation, were studied in order to study the validity of introducing the Bayesian statistical methods, and as the bootstrap method was found to be more suitable when the amount of data is less, its probability distribution parameters were compared with the Bayesian statistical method. (Fig. 1)
- While applying these to the inventory estimation of the accident waste at Fukushima Daiichi, currently, there is a restriction, in that the amount of data that can be referenced is limited to about 10 to several dozen units. When the number of data is less, the methods based on frequency-based statistics have disadvantages such as the possibility of giving smaller confidence intervals than needed, requiring verification by simulation, etc.
- If the form of distribution of the target is known, the Bayesian statistical method can estimate the parameters even when there is little data. There is both theoretical and practical experience, that this method enables parameter estimation even in situations where there is little actual data such as failure rates in probabilistic risk assessment of nuclear power plants. In addition, it is possible to visualize the process of updating confidence intervals and improving the extent of confidence by sequentially adding data.
- From these, its applicability to the inventory estimation of accident waste in Fukushima Daiichi is considered high.



Logarithmic average of transport ratio

Logarithmic standard deviation of transport ratio

Fig. 1 Comparison of statistical estimation results of probability distribution parameters (rate of semi-volatile nuclides released into the air inside the building)

(a) Characterization efficiency improvement
① Establishment of method for characterization
iv. Statistical inventory estimation method

- Using the results of the study, the inventory of various wastes was recalculated (Fig. 1). These results can be used for the study of disposal concepts in the next fiscal year.

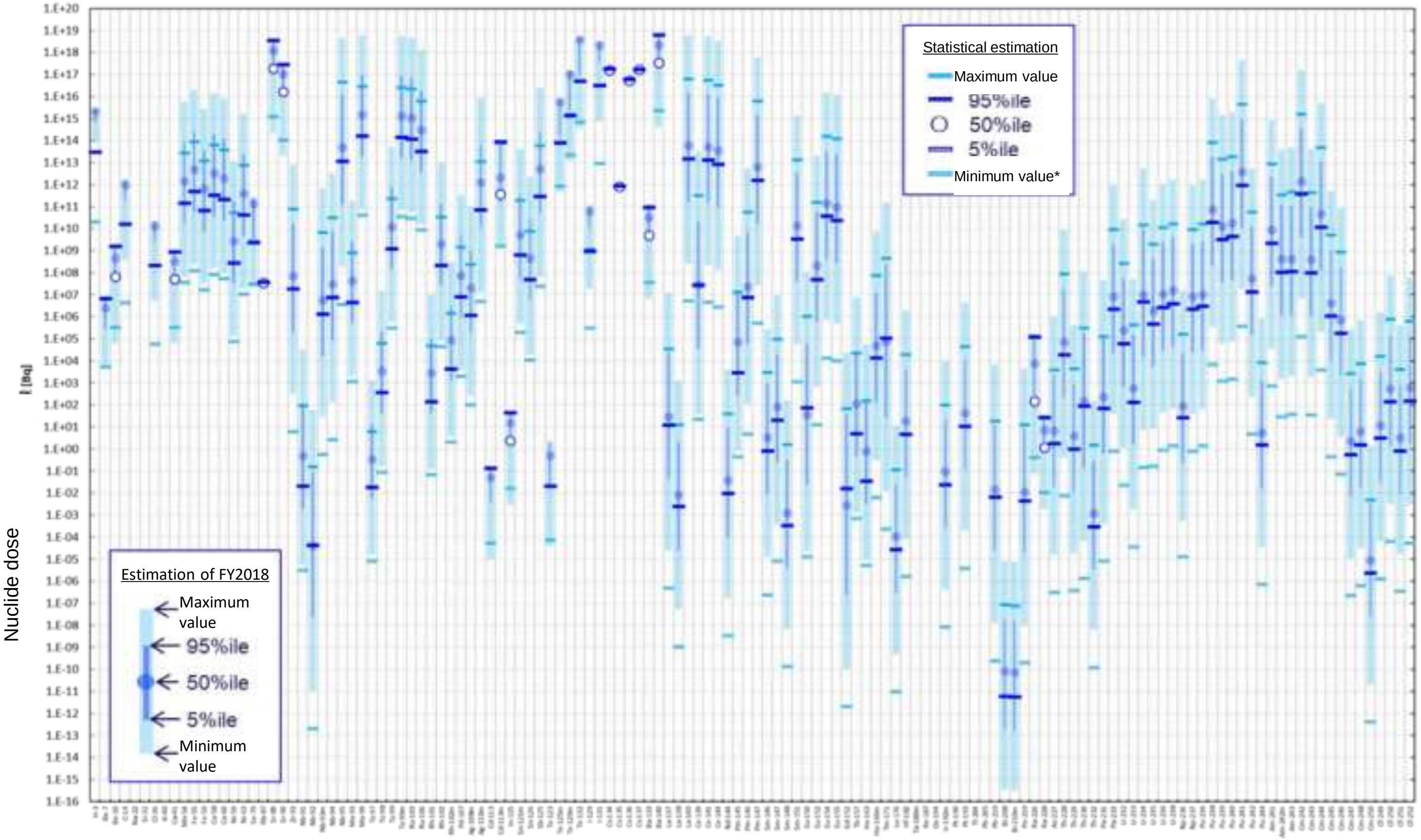


Fig. 1 Example of statistical inventory estimation results (Total radioactivity of KURION adsorption tower used for secondary waste generated from contaminated water treatment)

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- Results
  - ○ Analytical samples were either collected or obtained from TEPCO, which were then transported and analyzed (Fig. 1). The obtained analytical data was published subsequently (Fig. 2) and a database was created and made available for test.
- Goal
  - ○ To accumulate analytical data to establish a method for characterization.
- Implementation details
  - ○ The samples for analysis were either collected or obtained from TEPCO. The obtained analytical samples were stored and managed in cooperation with TEPCO and were transported to the analytical facility. Samples were analyzed at a licensed facility. (FY2019, FY2020)
  - ○ The obtained analytical data was published subsequently and made available for test via the Internet. In addition, the data that must be further expanded and enriched was studied in consideration of the accumulated data and the prediction on waste generation. (FY2019, FY2020)
- Indicators to determine goal achievement
  - ○ Analytical samples should be collected, stored and managed, transported, and analyzed. Analytical data should published on an ongoing basis. Missing analytical data and samples should be indicated. (FY2019, FY2020)

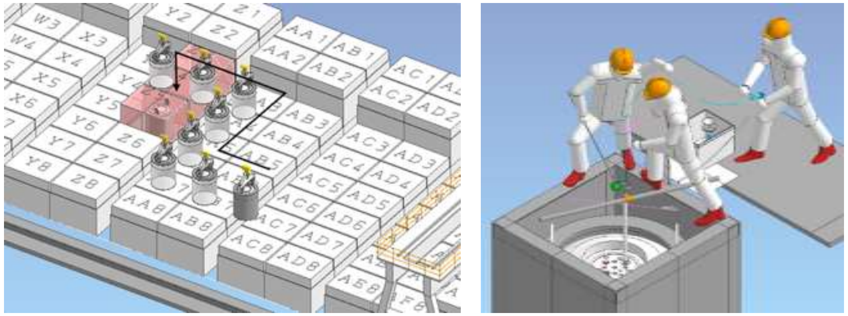
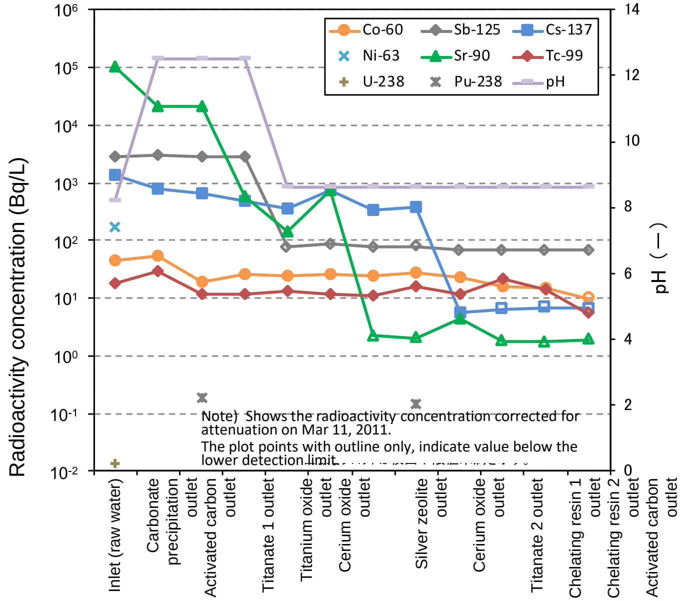


Fig. 1 Collection of samples of secondary waste generated from contaminated water treatment from the storage cask (HIC)



Note) Shows the radioactivity concentration corrected for attenuation on Mar 11, 2011.
The plot points with outline only, indicate value below the lower detection limit.

Fig. 2 Radioactivity concentration at the outlet of the main equipment in the multi-nuclide removal facility (expanded B System) #1

#1 The 60th Session of Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting, Nov 29, 2018.

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- The analytical samples of contaminated secondary waste generated from contaminated water treatment were collected from the facilities and from stored containers, respectively.
- Processed water from the cesium adsorption facility (SARRY II) and ALPS adsorbent were collected.
  - ○ The used adsorption towers were collected during the transfer and discharge to high-integrity containers (HIC). As the amount of contaminated water decreased, there was a decrease in the delivery frequency of adsorbents and hence samples were collected from only 3 towers. (Table. 1)
- The samples that were collected from HICs that were generated before April 2016 were studied in FY2018, and 29 HICs were selected as sampling targets. In FY2018, 12 out of 29 units were sampled, and the remaining 17 units were sampled in FY2019. (Table. 2)

Table. 1 Collection results of treated water and secondary wastes generated from contaminated water treatment in ALPS

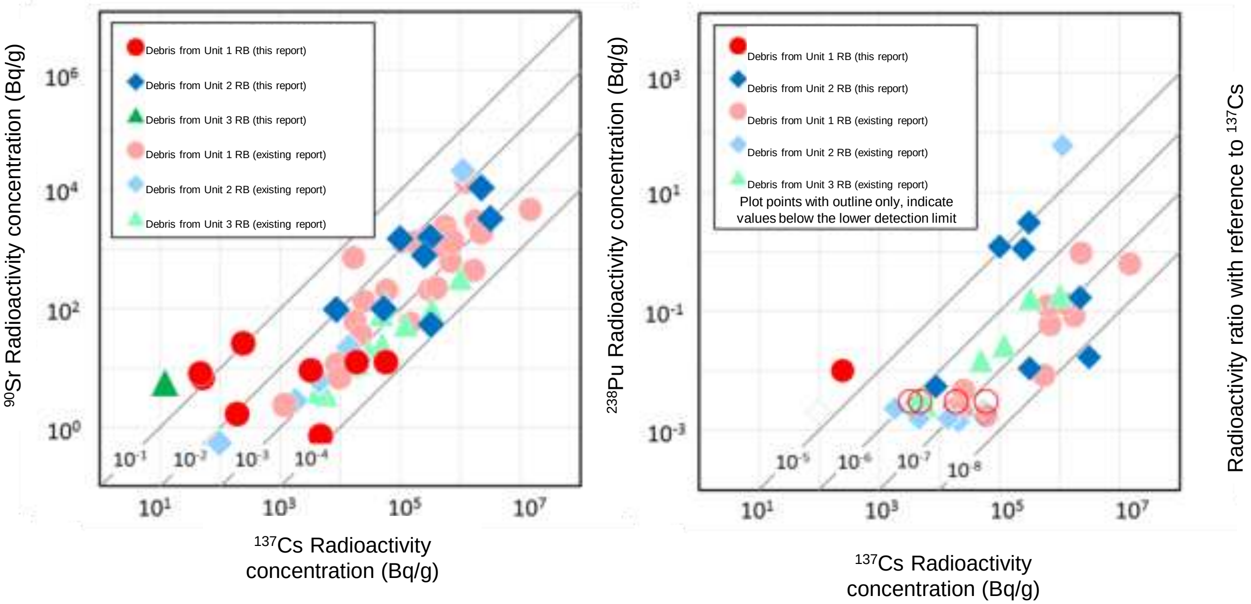
Classification	Sampling date	Sample name
Treated water	Dec 3, 2019	SARRY II
	Jan 30, 2020	"
	Mar 17, 2020	"
Adsorbent	Aug 26, 2019	ALPS III chelating resin 1
	Sep 12, 2019	ALPS III chelating resin 2
	Nov 29, 2019	ALPS I Titanate1

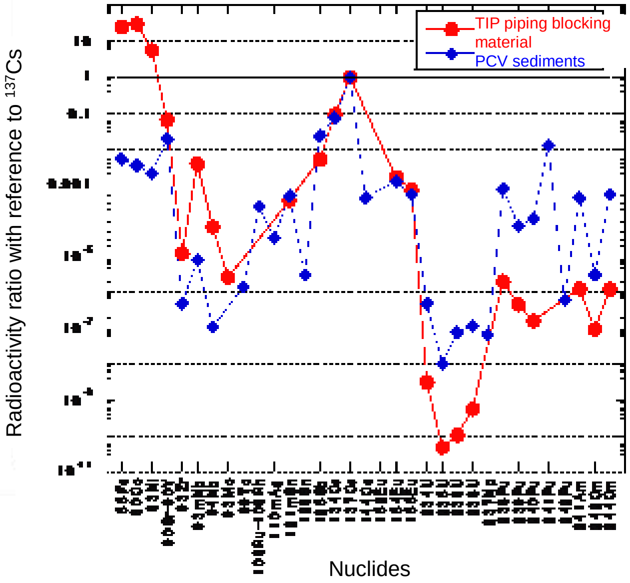
Table. 2 Collection results of samples that are being stored inside HIC

Facility	Name of sample	Sampling date	Number of samples	Maximum dose rate [mSv/h]				
				Side surface of HIC	HIC sampling hole		Surface of sample container (about 10 ml)	
				γ	γ	γ + β	γ	γ + β
ALPS I	Iron coprecipitation slurry	Dec 18, 2019	1	0.535	0.7	60	0.0035	1.7
		Dec 19, 2019	1	3.114	3.5	210	0.025	8.0
		Dec 20, 2019	1	3.430	3.0	300	0.020	4.5
		Dec 23, 2019	1	4.000	1.2	120	0.035	13
		Dec 24, 2019	1	4.550	2.8	200	0.024	10
		Dec 25, 2019	1	1.859	2.5	160	0.055	15
		Jan 9, 2020	1	1.237	3.5	150	0.013	5.5
		Jan 10, 2020	1	1.462	0.6	40	0.035	13
		Jan 14, 2020	1	2.658	2.5	260	0.025	14
		Jan 17, 2020	1	4.240	2.5	100	0.060	15
		Jan 20, 2020	1	3.430	7.0	400	0.045	23
		Jan 24, 2020	1	4.550	4.0	300	0.080	22
	Carbonate slurry	Jan 23, 2020	1	6.583	3.0	180	0.75	220
ALPS III	Carbonate slurry	Jan 15, 2020	1	7.873	15	800	1.1	350
		Jan 21, 2020	1	9.547	15	1000	0.80	350
		Jan 22, 2020	1	5.305	2.5	170	0.40	130
	Chelating resin 2	Jan 27, 2020	3	0.018	0.002	0.1	0.0005	0.08

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- During the 65th Session of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (April 25, 2019), the results of analyzing debris samples (floor boring core and strippable paint accompanying decontamination) collected from inside the Reactor Buildings in Units 1, 2 and 3 (Fig. 1), containment vessel sediment deposit samples from Unit 1 and TIP pipe blocking material samples from Unit 2 (Fig. 2), were reported.





- Regarding the ^{90}Sr/^{137}Cs ratio, the ratio tends to be high in the samples collected from the 1st floor of Unit 1 (near the through hole X6) and the 1st floor of Unit 3.
- Regarding the ^{238}Pu/^{137}Cs ratio, the ratio tends to be high in the samples collected from the 1st floor of Unit 1 (near the through hole X6) and the upper floor of the well plug on the 5th floor of Unit 2.
- For ^{90}Sr and ^{238}Pu, it was suggested that there were places where there was a difference in contamination against Cs.

- The ratio of radioactivity based on ^{137}Cs is remarkably high for ^{55}Fe, ^{60}Co and ^{63}Ni in the TIP pipe blocking materials. Meanwhile, it is extremely low for actinide nuclides such as U and Pu.
- Even inside the containment vessel, the tendency of contamination varies greatly from place to place.

Fig. 1 Nuclide concentrations detected in debris samples (floor boring core and strippable paint accompanying decontamination) collected from inside the Reactor Building (RB) (plot against ^{137}Cs)

Fig. 2 Concentration of nuclides detected in the sediments of Unit 1 containment vessel (PCV) and Unit 2 TIP pipe blocking material (ratio against ^{137}Cs)

IRID

Waste sample analysis results, Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (63rd session), Feb 28, 2019

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

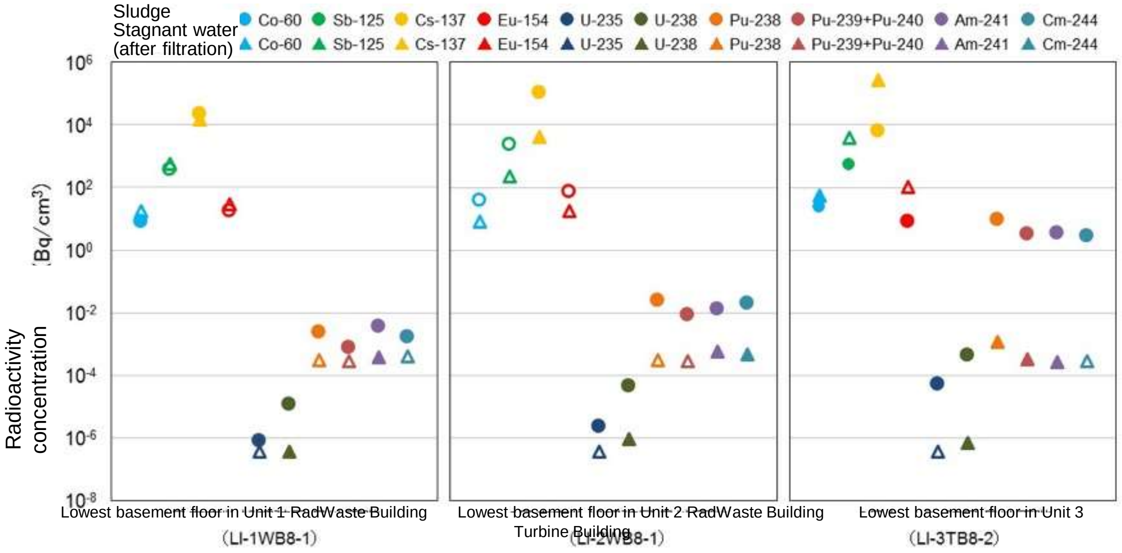
- During the 67th Session of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (Jun 27, 2019), the results of analyzing stagnant water collected from Unit 4 R/B basement, Units 2 to 4 T/B basement and Units 1 to 4 Rw/B basement, and the sludge contained in it, were reported. (Fig. 1)

○ A tendency for the sludge to be enriched with U and Pu nuclides was seen.

- In addition, the analysis results of ^{237}Np and ^{129}I were reported for the stagnant water and treated water, for which the analysis results had already been reported.

○ Regarding ^{237}Np, 18 samples including stagnant water in Unit 1 Reactor Building, water near the water surface of Unit 3 PCV, and water from the outlet of SARRY, etc., were analyzed, and the detected concentration of ^{237}Np was less than 9×10^{-3} Bq/cm^3, which was the regulatory concentration limit#. The concentration in the water near the water surface of Unit 3 PCV was 2.5×10^{-3} Bq/cm^3, which was the highest. Other detected concentrations were to the order of 10^{-4} to 10^{-5} Bq/cm^3.

○ From amongst the 47 analytical samples including stagnant water in Unit 1 Reactor Building, water from the outlet of KURION, etc., ^{129}I was detected in 1 sample of the water from the KURION outlet and 2 samples of the water from the AREVA outlet. Radioactivity concentration was 1.6×10^{-1} Bq/cm^3 for the water from the KURION outlet and 2.7×10^{-1} Bq/cm^3, 8.5×10^{-2} Bq/cm^3 for the water from the AREVA outlet.



Note) Radioactivity concentration was calculated by dividing by the volume of stagnant water before filtration. The plot points with only outline represent values that are below the detection limit. Radioactivity concentration was corrected for attenuation on March 11, 2011.

> - ➢ Many α-nuclides were detected in the sludge from the stagnant water (after filtration). The α-nuclide concentration in the sludge of Unit 3 Turbine Building, in which ^{154}Eu was detected, tends to be higher than that in the Unit 1 and Unit 2 RadWaste Buildings.
> - ➢ ^{94}Nb, ^{152}Eu were not detected in any of the samples.

Fig. 1 Concentration of nuclides detected in the stagnant water (after filtration) and sludge collected from the basement floor of each building

Concentration limit in the water outside the surrounding monitored area as stipulated in the “Notice defining the dose limit based on the provisions of the Ministerial Ordinance for Commercial Nuclear Power Reactors concerning the Installation, Operation, etc.”

IRID # Waste sample analysis results, Team for Countermeasures for Decommissioning and Contaminated Water Treatment / Secretariat Meeting (67th session), Jun 27, 2019

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- The boring core on the outer wall of the Unit 2 Reactor Building was analyzed. These samples will help in finding the distribution of contamination present inside and outside the wall.
  - ○ Boring core samples were collected from two places in the upper part (around 5,300 mm in height) and two places in the middle part (around 3,000 mm in height) of the western side outer wall opening (width 5,230 mm x height 6,650 mm).
  - ○ With these analytical samples, the waterproofing material from the exterior of the boring core, and the outer side wall and the inner side wall of the concrete part were analyzed, respectively. (Fig. 1, 2)
- The ratio of $^{90}Sr/^{137}Cs$ was similar to the values reported so far. The ratio of $^{238}Pu/^{137}Cs$ was about an order of magnitude larger than the values reported so far. (Fig. 3)
- This is the data on the local contamination distribution of Unit 2, and the distribution will be studied together with other data (rooftop, ceiling back, floor, etc.).

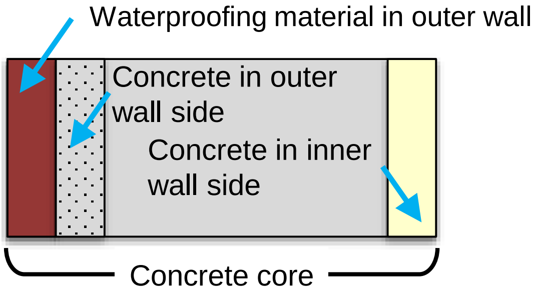
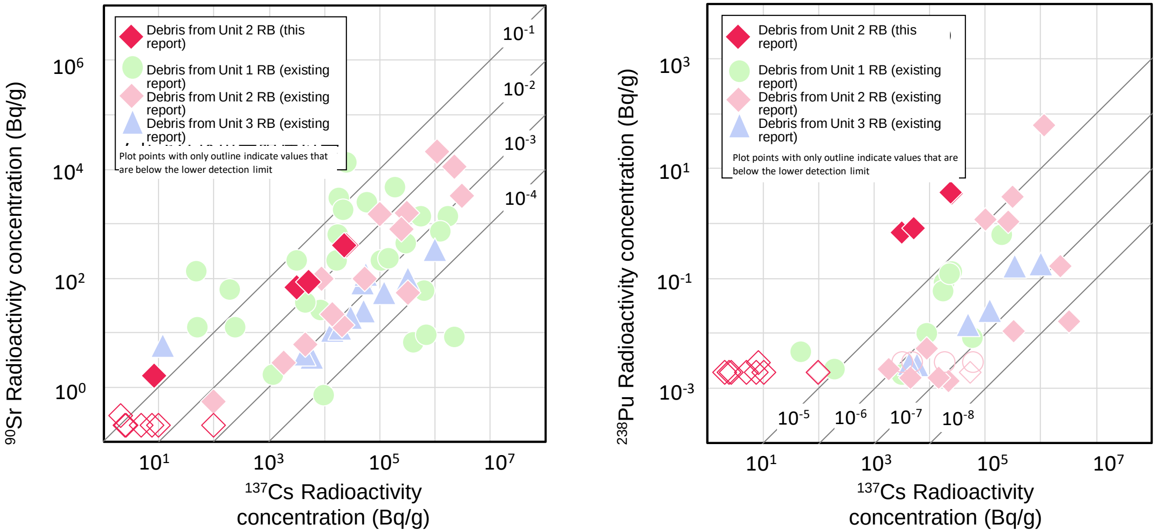


Fig. 1 Overview of analytical sample

Fig. 2 External appearance of analytical sample (outer wall waterproofing material)



Sr-90 Pu-238

Fig. 3 Concentration of nuclides detected in the sample from the western outer wall of the Unit 2 Reactor Building (Plotted with reference to ^{137}Cs)

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- The used adsorbents, which are the secondary waste generated after contaminated water treatment from the multi-nuclide removal facility (ALPS), contain different nuclides depending on their types. Hence radioactivity analysis is important in order to study their treatment and disposal methods. The absorbents were analyzed for the first time.
- For activated carbon adsorbents, the analysis method was studied in advance. Due to the low concentration of radioactive Cs nuclides, γ -ray analysis was performed directly without removing the Cs nuclides. For α-ray and β-ray analysis, a method of treatment in which a solid sample is dissolved in acid, etc. to bring it in the liquid state (making a solution), was studied and applied. (Fig. 1)
- As a result of the analysis, ^{60}Co, ^{106}Ru, ^{125}Sb and ^{137}Cs were detected and quantified (Table. 1). ^{54}Mn, ^{90}Sr, ^{94}Nb, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{238}Pu, $^{239Pu+240}$Pu, ^{241}Am and ^{244}Cm were not detected. From these facts, the nuclides that can be captured in the final stage of the process became clear.

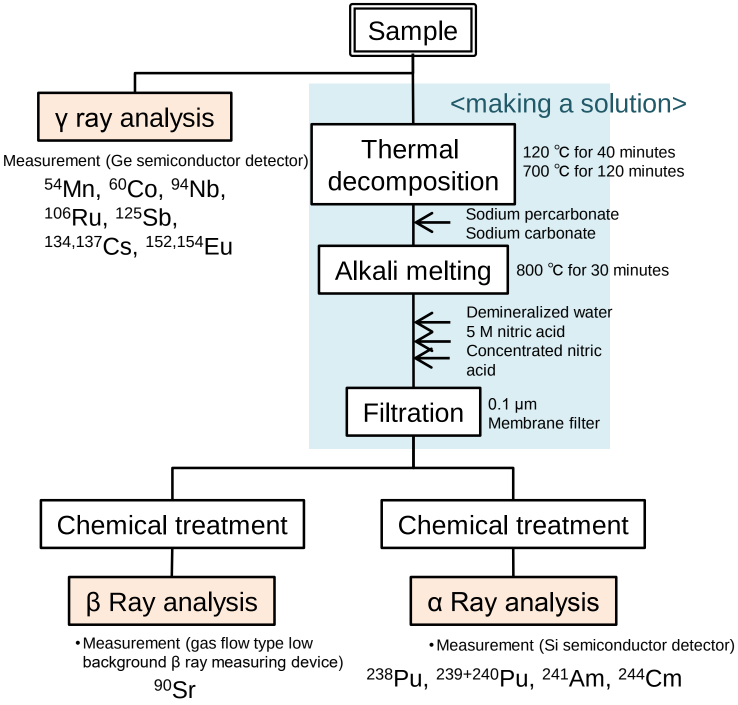


Fig. 1 Analysis flow of activated carbon adsorbents

Table. 1 Concentration of radionuclide detected in activated carbon adsorbent

Name of sample	Radioactivity concentration〔Bq/g〕			
	^{60}Co (About 5.3 years)	^{106}Ru (About 374 days)	^{125}Sb (About 2.8 years)	^{137}Cs (About 30 years)
ADC-AAL8-2	$(2.8 \pm 0.1) \times 10^{1}$	$(2.8 \pm 0.3) \times 10^{2}$	$(1.3 \pm 0.1) \times 10^{1}$	$< 6 \times 10^{-2}$
ADC-AAL8-3	$(1.6 \pm 0.1) \times 10^{1}$	$(2.1 \pm 0.2) \times 10^{2}$	$(6.9 \pm 0.3) \times 10^{0}$	$< 5 \times 10^{-2}$
ADC-EAL9-1	$(3.1 \pm 0.1) \times 10^{1}$	$(3.8 \pm 0.3) \times 10^{2}$	$(1.6 \pm 0.1) \times 10^{1}$	$(7.8 \pm 1.9) \times 10^{-2}$

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- Current analytical samples

Items	Analysis facility	Samples
Debris/contaminated water, etc.	JAEA (Nuclear Science Research Institute)	Debris from concrete core on the west wall of Unit 2 Reactor Building refueling floor
Secondary waste generated from contaminated water treatment	JAEA (Nuclear Fuel Cycle Engineering Laboratories)	Stagnant water that contains building sludge, adsorbents used in multi-nuclide removal system (Cerium oxide, activated carbon, silver zeolite etc.)
Contamination distribution, etc.	JAEA (Oarai Research and Development Institute)	Debris from cover soil temporary storage facility
Sludge, debris etc. from buildings	NDC	Debris from buildings, debris from cover soil temporary storage facility, stagnant water containing building sludge
Contaminants from PCV	NFD	Unit 1 PCV deposits, Unit 2 TIP piping blockage

- Results of transportation of analytical samples from Fukushima Daiichi NPS to various analysis facilities

Transportation frequency	Date of transport	Destination	Analytical samples
Transport 1	9/26/2019	①JAEA (Nuclear Science Research Institute), ② NDC	① Stagnant water, treated water ②Debris
Transport 2	12/19/2019	①JAEA (Nuclear Fuel Cycle Engineering Laboratories), ②NFD	① Slurry from multi-nuclide removal system ② Sludge from buildings
Transport 3	2/19/2020	①JAEA (Nuclear Science Research Institute), ② JAEA (Oarai)	① Debris ② Debris

(a) Characterization efficiency improvement
① Establishment of method for characterization
v. Acquisition of analytical data

- Continuous implementation of operations on the database FRAnDLi (Fukushima Daiichi Radwaste Analytical Data Library) (Fig. 1).
  - Relevant data released by TEPCO is also compiled in addition to the data acquired in this project (Table 1).
- The statistical data on accesses showed that there is constant usage throughout the year (Fig. 2).
- In addition to continuous expansion of data, improvements will be examined in the next fiscal year in consideration of long term accumulation of analytical data.

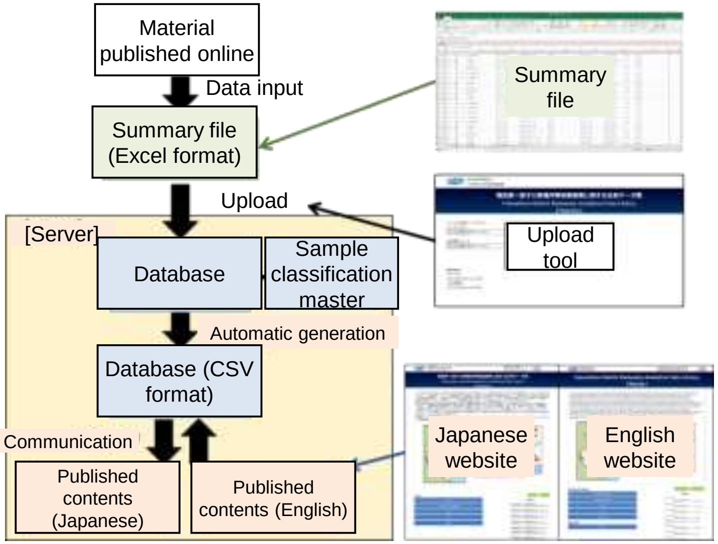


Fig. 1 Overview of database (FRAnDLi) for analysis results

Table 1 Compilation of data from the last fiscal year

(As of Feb 14, 2020)

Data (Sample)	Data reporting organization	Total stored items
Contaminated water	IRID/ JAEA	11
Debris	IRID/ JAEA	17
Building sludge	IRID/ JAEA	12
Contaminated water	Tokyo Electric Power Company	68
Storage amount	Tokyo Electric Power Company	1012
Total for FY2019	-	1120
Total data items	-	11180

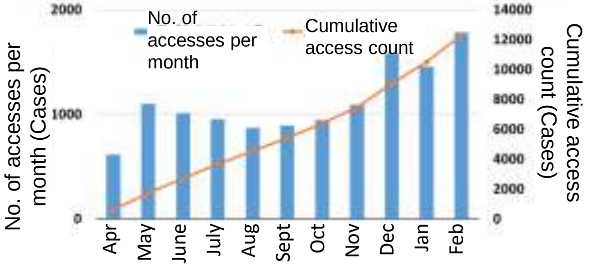


Fig. 2 Transition in number of times the database is accessed (Including repeated access)

(a) Characterization efficiency improvement
① Establishment of method for characterization
vi. Evaluation and management of analytical data

- Study on the contamination of stored waste
  - The current analytical data contains little data on alpha nuclides and on I-129, which is important for the evaluation of safety of disposal. Study was conducted on the utilization of waste storage data in order to expand the analytical data for these nuclides.
  - Waste storage data was organized according to contamination classification in order to study the wastes to be analyzed. (Fig. 1)
  - The occurrence locations where alpha-contaminated waste has been recorded are limited to the area of Units 1 to 4. However, alpha-contaminated wastes recorded are in very small amounts in the wastes generated from Units 1 to 4 areas. (Fig. 2)
- Study of sampling methods as considered necessary for future analysis based on the organized data of waste storage.
  - The following 3 approaches were studied in connection with the sampling methods using waste storage data:
    - Collection from the containers in the solid radioactive waste storage facility
    - Collection from the existing storage area (Other than solid radioactive waste storage facility)
    - Collection during work planned in the future

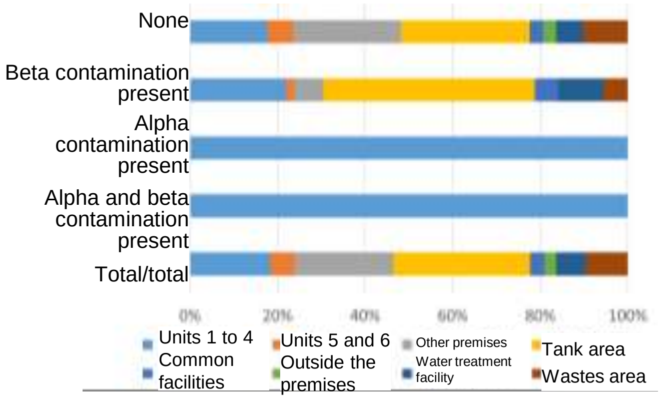


Fig. 1 Percentage of occurrence locations according to contamination classification of waste storage data

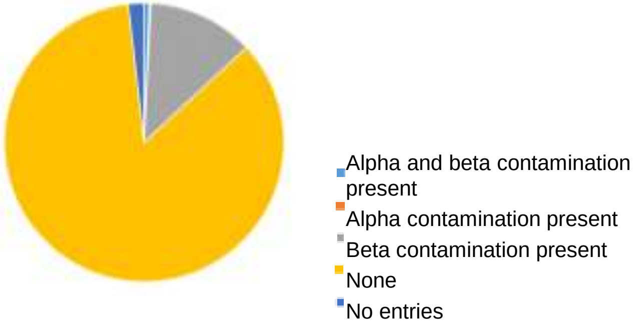
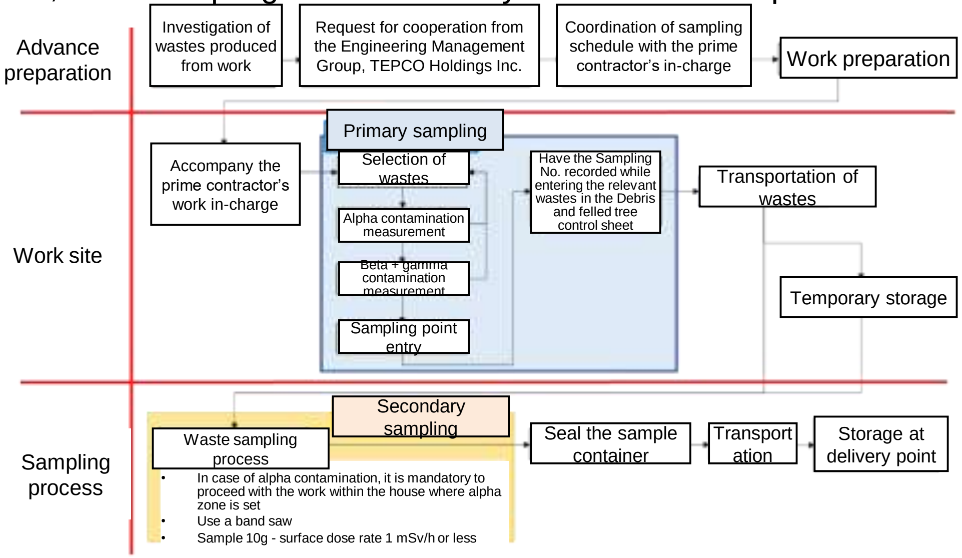


Fig. 2 Contamination classification ratio for the wastes generated from Units 1 to 4

(a) Characterization efficiency improvement
① Establishment of method for characterization
vi. Evaluation and management of analytical data

- Study was conducted on types of debris using the debris types database compiled in FY2018 for the sampling methods to be implemented in future.
  - ○ A conceptual study was conducted on the method of collecting samples from the containers inside the solid radioactive waste storage facility, and the method of collecting samples from the wastes that will be generated in future (Fig. 1), and issues related to the facilities, operations and exposure during work were identified.
  - ○ It may be reasonable to conduct a study on collecting samples from the wastes that will be generated in future on a priority basis, since sampling from the already stored wastes requires considerable manpower and time.



Advance preparation

Investigation of wastes produced from work

Request for cooperation from the Engineering Management Group, TEPCO Holdings Inc.

Coordination of sampling schedule with the prime contractor's in-charge

Work preparation

Work site

Accompany the prime contractor's work in-charge

Primary sampling

Selection of wastes

Alpha contamination measurement

Beta + gamma contamination measurement

Sampling point entry

Have the Sampling No. recorded while entering the relevant wastes in the Debris and felled tree control sheet

Transportation of wastes

Temporary storage

Sampling process

Secondary sampling

Waste sampling process

- In case of alpha contamination, it is mandatory to proceed with the work within the house where alpha zone is set
- Use a band saw
- Sample 10g - surface dose rate 1 mSv/h or less

Seal the sample container

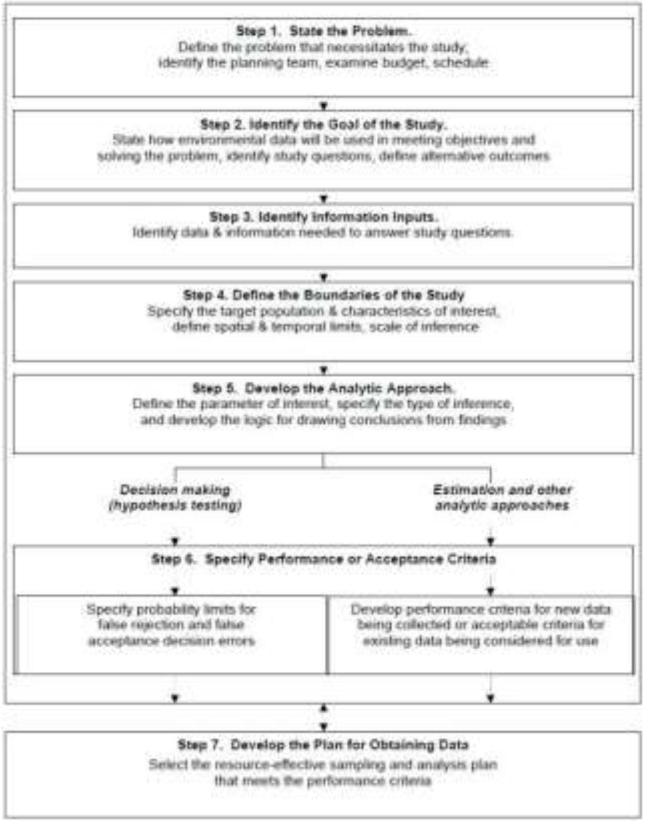
Transportation

Storage at delivery point

Fig. 1 Example of work flow for the method of collecting samples from the wastes that will be produced in future

(a) Characterization efficiency improvement
① Establishment of method for characterization
vi. Evaluation and management of analytical data

- It is indispensable to establish an approach to the analysis plan in conformity with the characteristics of Fukushima Daiichi wastes in order to continue the analysis. Hence, investigation was carried out in a joint effort with NNL in U.K.
- DQO process (Data Quality Objectives Process) is an approach to the analysis plan developed by U.S. Environmental Protection Agency (EPA) for environmental restoration (Clearance)#. This approach is recognized as the standard method in the field of radioactive wastes. (Fig. 1)
- This approach is applied in the analysis of wastes in U.K. In addition, it is also combined with Bayesian statistics for subjects with uncertain parent population. (Fig. 2)



Step 1. State the Problem.
Define the problem that necessitates the study;
identify the planning team, examine budget, schedule

Step 2. Identify the Goal of the Study.
State how environmental data will be used in meeting objectives and
solving the problem, identify study questions, define alternative outcomes

Step 3. Identify Information Inputs.
Identify data & information needed to answer study questions.

Step 4. Define the Boundaries of the Study
Specify the target population & characteristics of interest,
define spatial & temporal limits, scale of inference

Step 5. Develop the Analytic Approach.
Define the parameter of interest, specify the type of inference,
and develop the logic for drawing conclusions from findings

Decision making
(hypothesis testing)

Estimation and other
analytic approaches

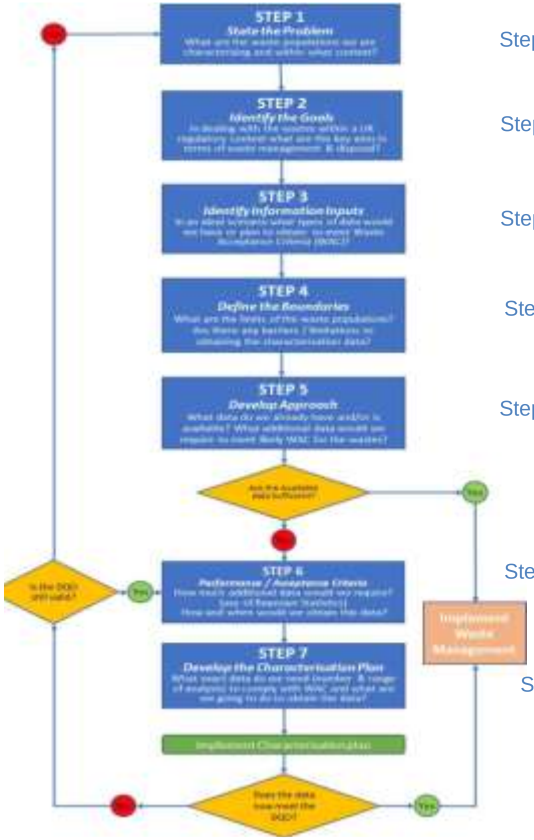
Step 6. Specify Performance or Acceptance Criteria

Specify probability limits for
false rejection and false
acceptance decision errors

Develop performance criteria for new data
being collected or acceptable criteria for
existing data being considered for use

Step 7. Develop the Plan for Obtaining Data
Select the resource-effective sampling and analysis plan
that meets the performance criteria

Fig. 1 DQO process of U.S. EPA



Step 1	State the problem
Step 2	Identify the goals
Step 3	Identify the information inputs
Step 4	Define the boundaries
Step 5	Identify the necessary data
Step 6	Study the effects of additional analysis
Step 7	Develop the analysis plan

Fig. 2 DQO Process applied in waste analysis in U.K.

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* US EPA, "Guidance on Systematic Planning Using the Data Quality Objectives Process. EPA QA/G-4 (2006).

(a) Characterization efficiency improvement
① Establishment of method for characterization
vi. Evaluation and management of analytical data

- ■ Case study was conducted by selecting debris, felled trees, waste generated from contaminated water treatment (slurry) as waste characteristic to the Fukushima Daiichi NPS. Assuming the conditions in the U.K., evaluation was conducted on the required analysis score by estimating the concentration distribution using Bayesian statistics.
  - ○ It is important that debris has a dose rate classification closer to concentration levels in disposal classification and it is necessary to conduct analysis in stages.
  - ○ In case of felled trees, the required analysis points were estimated in comparison with the concentration levels in disposal classification assuming the concentration after incineration. (Fig. 1)
  - ○ In case of slurry, radioactive concentration was high when compared to disposal classification and hence the necessity of analysis was low. Since it is discharged from technologically-designed facilities, it is easier to characterize compared to debris, etc.
- ■ Using this example as reference, it was decided to proceed with the study in the next fiscal year presuming the situation within Japan.

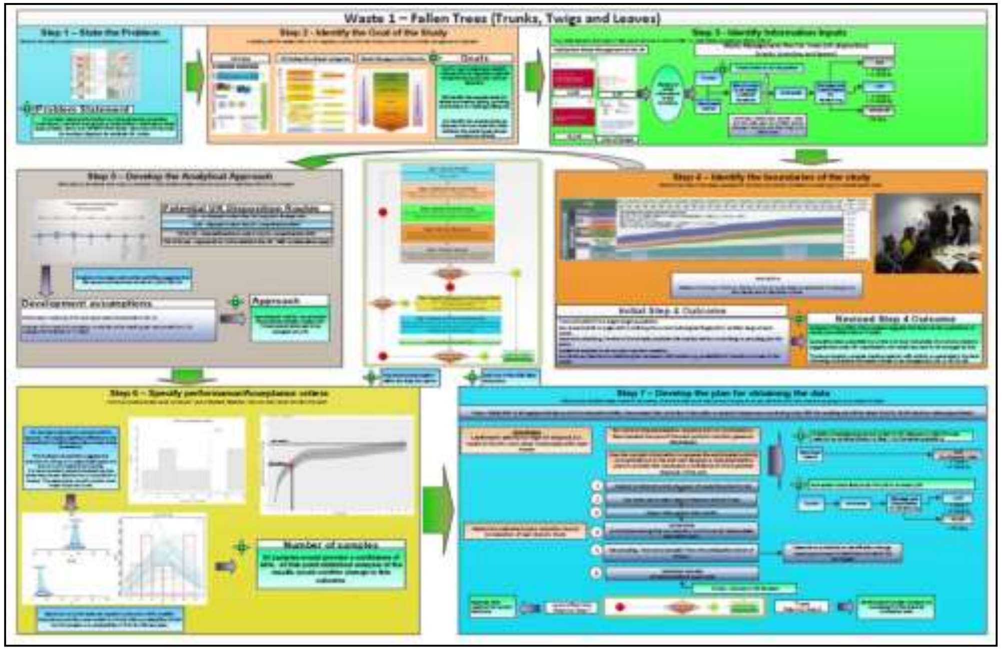


Fig. 1 Example of study conducted on the analysis score for felled trees using a method incorporating DQO and Bayesian statistics

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods

- A study was conducted for the simplification and speeding-up of the current methods of analysis with an aim to establishing analysis methods that will be used regularly for the analysis of accident waste. (Figure.1)

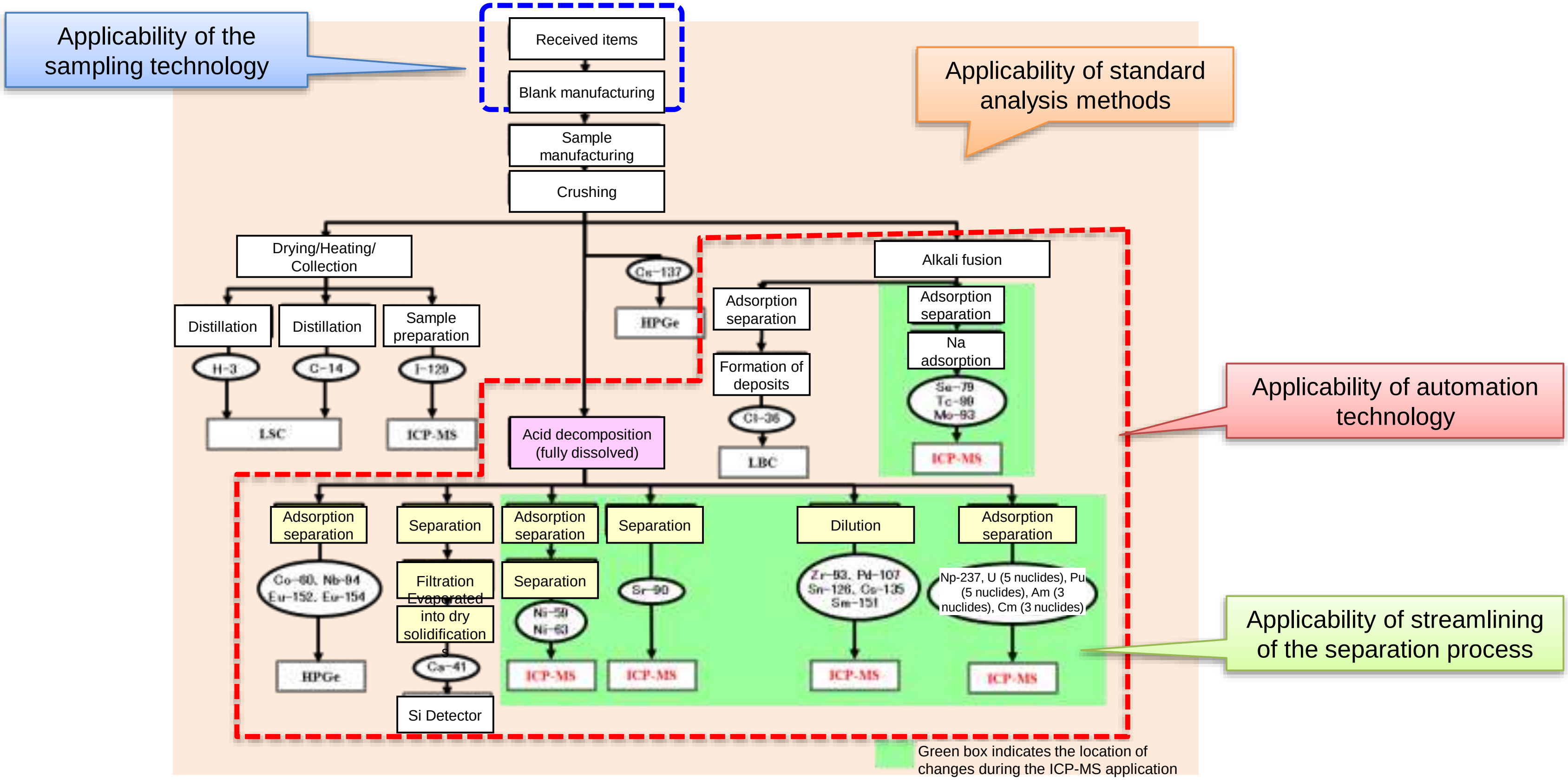


Fig.1 Targets for analysis method improvement and strategies for the same

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
i. Development of sampling technology

■ Results

○ By ensuring the representativeness of the sample through evaluation of the distribution of radioactive concentrations on the surface of radioactive waste by a non-destructive analysis, a methodology that would work with as minimal sampling as possible, was developed (Fig. 1).

○ A device that would measure the distribution of the gamma ray releasing nuclides on the sample surface and a device that would collect the sample in the form of powder from any location, were prototyped (Figures 2 and 3).

■ Goal

○ To highlight specific strategies along with manufacturing a mock-up device for sampling and thereby, to identify the issues in the verification of functionality and in real-time application in order to establish a practical sampling method.

■ Implementation details

○ The methods to decide the collection location and the methods to verify the sampling accuracy and the validity of the sampling size were studied in FY2019 with respect to the sampling size from the statistically evaluated sample surface. Moreover, based on the findings obtained from the prototype manufactured in FY2018, a mock-up device was designed by carrying out tests to verify the selection of conditions etc. to optimize the design. During the verification testing related to the mapping device, optimization of background correction methods and the optimization of the positional relation between the samples and the detector was studied, so that highly sensitive and quantitative measurements were possible. During the verification testing related to the sampling device, collection methods that suit the material and the optimization of the design in order to accurately collect the cut sample from any location, were studied.

○ In FY2020, the mock-up device will be manufactured, and any points of improvements or issues to be resolved will be selected from the point of view of site application.

■ Indicators determining achievement of goals

○ Specific strategies should be presented for a practical sampling method for the analysis samples. (FY2019)

○ A blueprint of the mockup device to be used for the sampling device should be prepared. (FY2019)

○ Any points of improvements or issues concerning the manufacturing of the actual equipment should be presented. (FY2020)

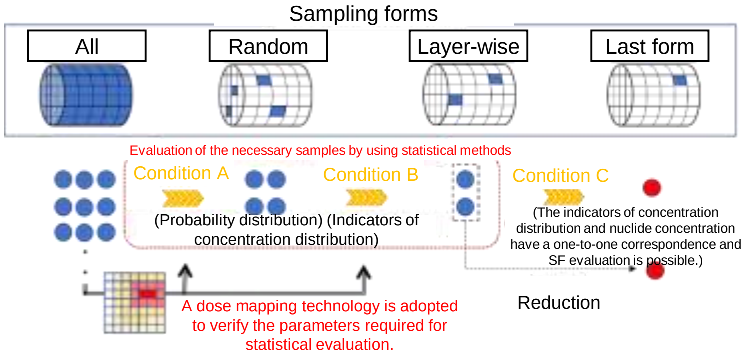


Fig.1 Illustration of sampling technology that can work with a minimal amount of sample

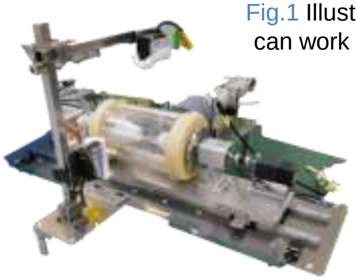


Fig.2 Prototype sample mapping device

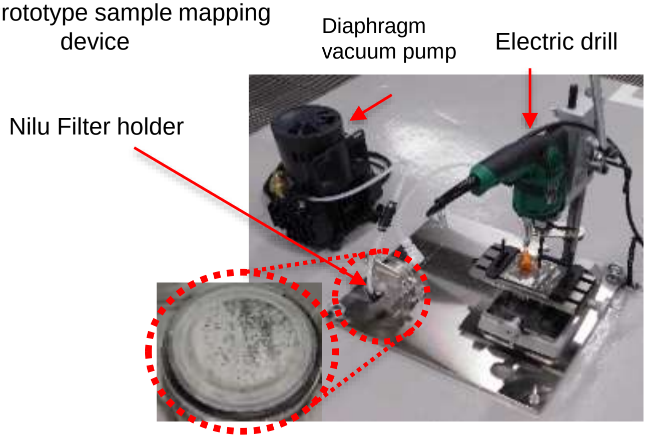


Fig.3 Sampling device prototype

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
i. Development of sampling technology

- A mock-up device for the device that would measure the distribution of the gamma ray-releasing nuclides on the sample surface (mapping device) was designed based on the findings obtained from the prototype manufactured in FY2018.
  - The device consists of a sample feeding part, a sample fixing part, a shape measuring part and a radiation measuring part (Fig. 1).
  - A system was designed to record the geometrical shape and the radiation data of the target sample obtained by means of measurements.
- A mock test was conducted to examine which radioactivity other than that of the part to be measured would influence the measurement value. The influence from the surroundings of the part to be measured was about 6% higher, and it could be confirmed that there was sufficient resolution to evaluate the distribution. (A-B in Fig. 2). Even when the difference in the concentrations was large, the influence was about 50% and the shades of the radioactive concentrations could be confirmed with high resolution (A’-C in Fig. 2).
- A study regarding a statistical methodology was conducted to enable evaluation with a minimal amount of sample, while ensuring the representativeness of the sample concentration on the basis of the data on the distribution of the gamma ray-releasing nuclide concentration on the sample surface.
  - With regard to the distribution of radioactive concentrations on the sample surface, evaluation formulas for the number of samples were studied assuming two cases based on normal assumptions.

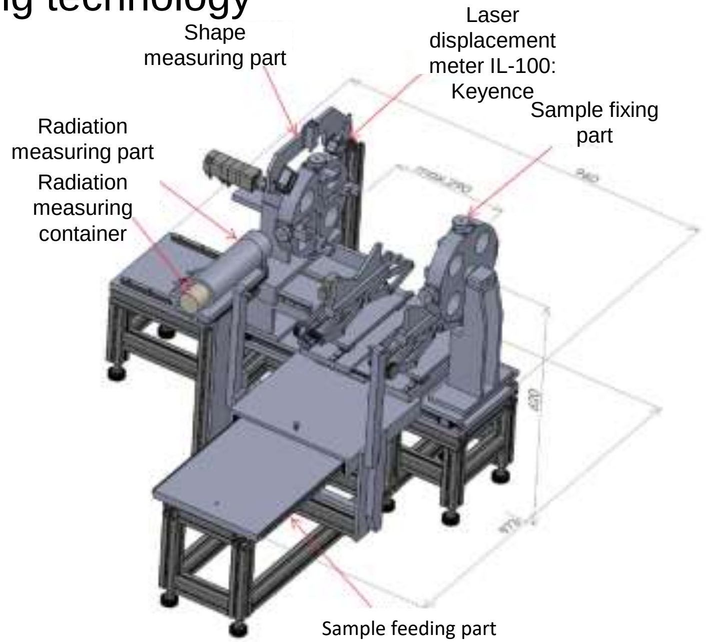
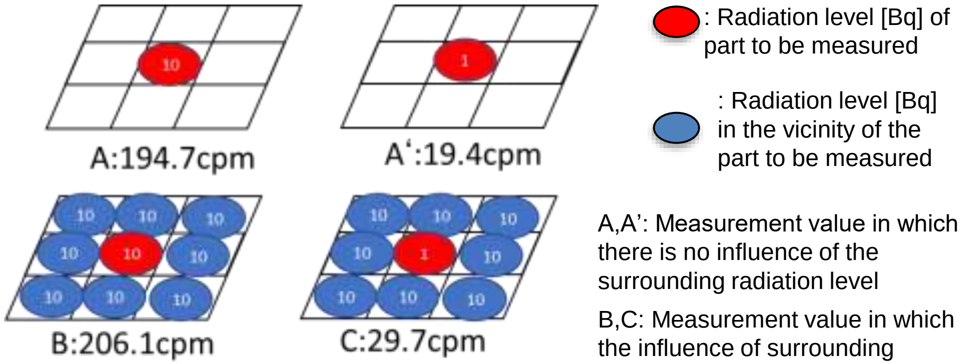


Fig.1 Entire outline of the mock-up device of the device to measure the distribution of the gamma ray-releasing nuclides on the sample surface (mapping device)



🔴: Radiation level [Bq] of part to be measured

🔵: Radiation level [Bq] in the vicinity of the part to be measured

A,A’: Measurement value in which there is no influence of the surrounding radiation level

B,C: Measurement value in which the influence of surrounding radiation level is considered

Fig.2 Test concerning resolution for measurement (3 cm square)

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
i. Development of sampling technology

- A mock-up device for the device that would perform the sampling of the analysis sample from the sampling surface was designed, based on the findings obtained from the prototype manufactured in FY2018.
  - ○ A drill material suitable for the target material was studied, and a drill blade was designed and prototyped with a shape that enabled the powder generated during cutting to accumulate around the cutting hole instead of being dispersed in the surroundings, and which could facilitate the easy collection of this cutting powder (Fig. 1).
- A concrete cutting test was conducted to evaluate the validity of the study results. The collection rate of the powder was obtained (Table 1 shows the results for a depth of 25 mm) by cutting at various depths (25, 50, 75, 100 mm).
  - ○ A high collection rate of 96% or more was obtained in case of all the cutting depths.
  - ○ It was understood that the relative standard deviation (RSD) was 7% or less for all the cutting depths, and the cutting powder could be collected with a high level of repeatability.

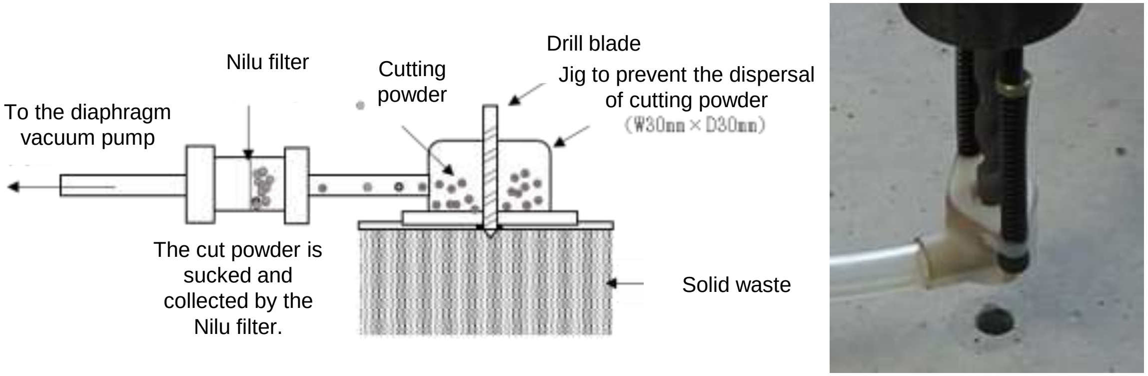


Fig.1 Proposed study of the sampling mechanism

Table 1 Cutting powder collection test results (cutting depth 25 mm)

No.	Weight of the Nilu filter [g]			Weight of the concrete block [g]			Cutting powder collection rate [%]
	Packing	With cutting powder	Difference	Prior to test	After the test	Difference	
1	143.81	147.67	3.86	1857.52	1853.57	3.95	97.7
2	143.81	147.50	3.69	1853.57	1849.79	3.78	97.6
3	143.81	147.36	3.55	1849.79	1846.14	3.65	97.3
4	143.81	147.29	3.48	1846.14	1842.51	3.63	95.9
5	143.81	146.94	3.13	1842.51	1839.27	3.24	96.6
6	143.81	147.13	3.32	1839.27	1835.82	3.45	96.2
		Average value	3.51			Average value	96.9
		Standard deviation	0.24				
		RSD【%】	6.8				

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
ii. Study on streamlining the separation process

■ Results

○ The triple quadrupole ICP-MS (ICP-MS/MS) is believed to be useful from the viewpoint of streamlining of the separation process because the influence of nuclides of the same atomic mass number (isobars) can be reduced by reaction with gas, and the device on its own has a high separation performance. Therefore, the latest findings (information about lower limit of detection, effective solid phase extraction agent and effective reaction gas etc.) related to analysis using the ICP-MS method, were organized (excluding actinides). As a result, it was possible to propose a separation process, which was changed from beta-ray measurement using a liquid scintillation counter (LSC) requiring complicated pretreatment, to the ICP-MS method, which can simplify the pretreatment process for eight nuclides. (Fig. 1)

■ Goals

○ To evaluate the optimal separation and measurement conditions for the proposed separation process by testing with simulated radioactive waste samples.

○ To propose a similar streamlined separation process for actinides.

■ Implementation details

○ In FY2019, the optimal separation and measurement conditions for the separation process proposed in FY2018 were studied by testing with simulated samples. Optimum liquidity and fluid volume of reagents during the extraction or the separation process were studied for the separation conditions. With reference to the measurement conditions (ICP-MS/MS), device conditions such as the optimal types of gas and flow rate were evaluated for the separation from hindering nuclides. Moreover, like FY2018, even in case of actinides, a rational separation process presuming alpha ray spectrometry and ICP-MS, which is believed to be able to separate and measure multiple nuclides in batches, were proposed, and calibration methods for that device were also proposed.

○ In FY2020, in continuation with FY2019, tests using the simulated samples will be conducted.

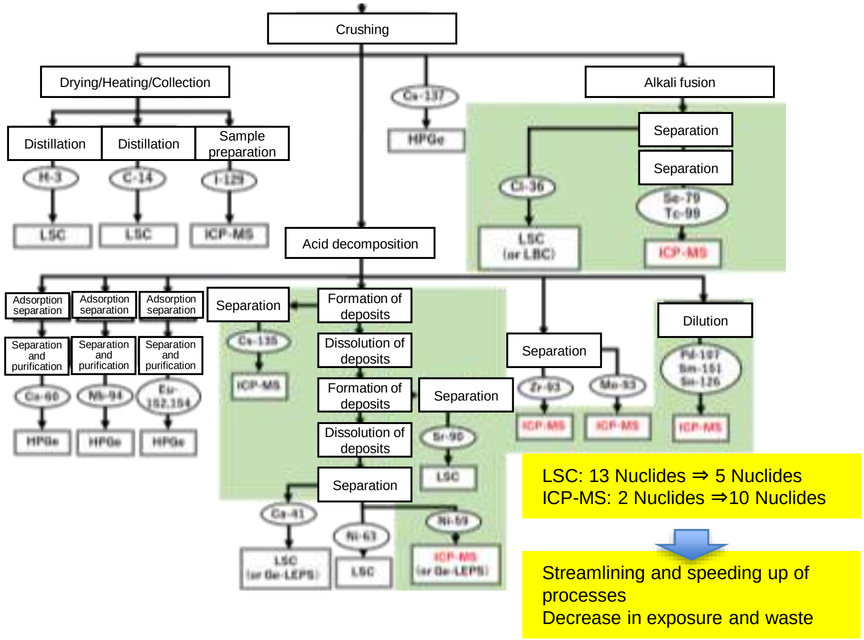
■ Indicators for determining goal achievement

○ Optimal separation and measurement conditions for a streamlined separation process should be presented. (FY2019, FY2020).

○ A list of the current analysis methods for actinides should be presented. (FY2019)

○ A proposed practical method concerning actinides should be presented. (FY2019)

○ Proposed calibration techniques for devices used for actinide measurement should be presented. (FY2019)



LSC: 13 Nuclides ⇒ 5 Nuclides
ICP-MS: 2 Nuclides ⇒10 Nuclides

Streamlining and speeding up of processes
Decrease in exposure and waste

Fig.1 Outline of the separation process introducing the new ICP-MS method

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
ii. Study on streamlining the separation process

- Items to be evaluated during the tests to evaluate validity or feasibility were decided (Table 1).
- Validity evaluation testing of the separation process was conducted with the separation process applying the ICP-MS method and with the radioactivity measurement method#.

The beta ray measurement nuclides (^{36}Cl, ^{41}Ca, ^{63}Ni, ^{90}Sr) for which the application of the ICP-MS method is deemed unsuitable from the viewpoint of detection sensitivity

- For the chemical separation of ^{93}Zr and ^{93}Mo, a method with a high selectivity for Zr and Mo while separating out the hindering Nb, was proposed (Fig.1).
- The conditions to separate Nb were found during the analysis of ICP-MS/MS, when ammonia was used as a reactive gas (Fig. 2, 3).

Table 1 Evaluation items for the validity or feasibility tests

ICP-MS method	Radioactivity measurement method
• Collection rate evaluation • Evaluation of the effects of spectral interference concerning isotopes • Evaluation of the effects of spectral interference concerning isobars • Evaluation of the effects of spectral interference concerning a sample matrix	• Collection rate evaluation • Evaluation of nuclides that could hinder measurements due to similarities in chemical behavior, etc. • Evaluation of the decontamination coefficient of hindering nuclides

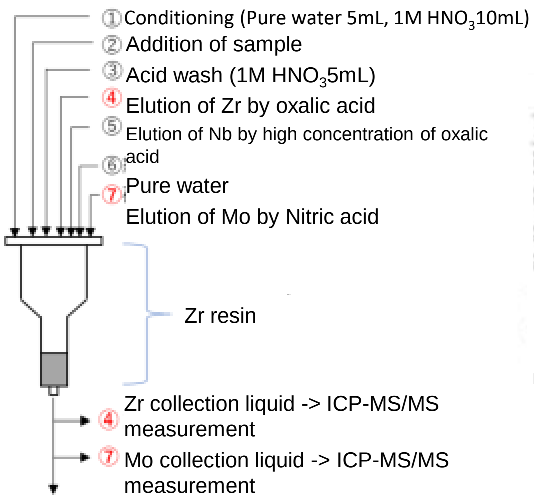


Fig.1 Separation process of ^{93}Zr and ^{93}Mo

Zr is effectively separated from the isobars (^{93}Nb,^{93}Mo) by using the NH_3 gas

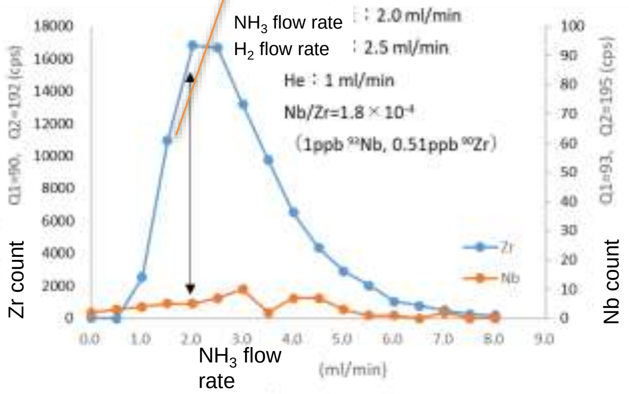


Fig.2 Separation of Nb and Zr by means of a reactive gas

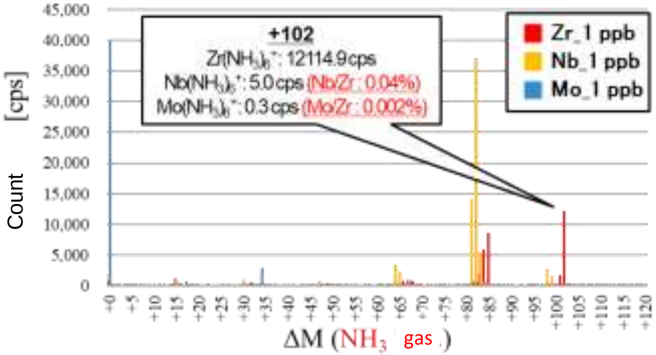


Fig.3 Separation of ^{93}Zr from ^{93}Nb, ^{93}Mo by means of ICP-MS/MS

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
iii. Development of automation technology

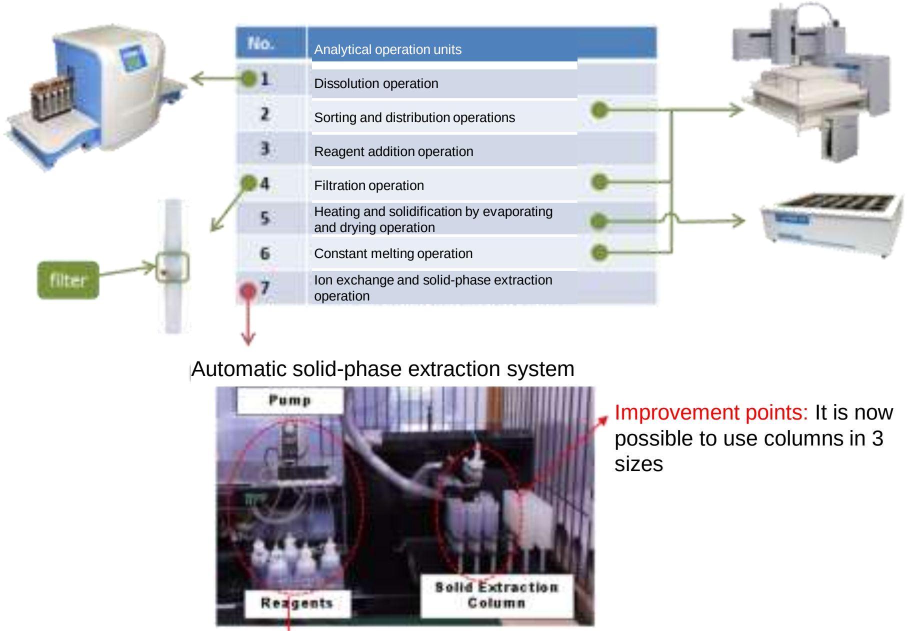
- Results
  - The performance of the manufactured automated systems was compared with operations carried out by skilled personnel (Fig. 1). A series of analytical operations were carried out for Ni assuming the most complex Ni-63 separation operations and the utility of the automated systems was proven as similar collection rates and accuracy were achieved when the collection rates were compared (Table 1).
- Goal
  - To evaluate the feasibility of the separation process of nuclides to be measured using the manufactured automated systems.
- Implementation details

Separation and purification tests using the automated systems were conducted and their feasibility was evaluated with respect to the separation process which was studied under "(ii) Streamlining of the separation process" throughout FY2019 and FY2020. Since the aim of these tests is to evaluate the feasibility under the actual analytical conditions, the tests will be conducted by using simulated radioactive waste samples.

Among the separation processes, the types or quantities of the solid-phase extraction agents and the types and concentration of reagents that will be used for each of the elements subject to separation during the solid-phase extraction operation, will be different. For this reason, it is necessary to evaluate the feasibility of the operation conditions of the automatic solid-phase extraction system by selecting the column size and optimizing the reagent flow rate during the separation operation according to each target element. In particular, if there is a large difference between the rate of reagent addition to the resin and the liquid passing rate in the resin, the reagent may accumulate at the top of the column, overflowing the reagent, or mixing with the reagent in the next step, which may have a large impact on the separation accuracy. Therefore, it is important to evaluate the optimum operation content under each analysis condition.

In addition, if a problem that cannot be sufficiently addressed within the operating condition range of the current automation device is found in the test from the viewpoint of accuracy and speed, improvement of the device will be considered to solve the problem.

- Indicators for determining goal achievement
  - The feasibility evaluation results for the separation operation using the automated system for the streamlined separation process should be presented. (FY2019 and FY2020)



No.	Analytical operation units
1	Dissolution operation
2	Sorting and distribution operations
3	Reagent addition operation
4	Filtration operation
5	Heating and solidification by evaporating and drying operation
6	Constant melting operation
7	Ion exchange and solid-phase extraction operation

Automatic solid-phase extraction system

Improvement points: It is now possible to use columns in 3 sizes

Improvement points: System improvements such that it is possible to insert air between the reagent addition operations so that there is no mixing between the various chemicals

Fig.1 Configuration of the automation technology and the improved automatic solid-phase extraction equipment

Table 1 Performance evaluation of the automated system (Comparison of collection rates during the Ni-63 analysis)

Operations	Ni Collection rates	Standard deviation
Automated systems	**89.8%**	**2.9%**
Skilled analysts	**87.0%**	**2.2%**

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
iii. Development of automation technology

- The validity and feasibility of the examined automated equipment was evaluated with respect to the size of columns filled with resin and the reagent liquid passing speed.
- The automatic solid-phase extraction equipment consists of a column unit, a pump unit and a control computer. It is possible to process 4 samples at the same time (Fig. 1).
- The applicability of the automatic solid-phase extraction equipment was studied by targeting the analysis methods which combined the extraction chromatography with the ICP-MS/MS (Table 1). As for the repetition accuracy of the Zr collection rate, an excellent result was obtained when compared with the relative standard deviation of 2.6%. when done manually.
- A phenomenon wherein the eluant might not spread throughout the resin was observed (Fig. 2). In FY2020, a further speeding-up will be studied by optimizing the liquid passing speed along with making further improvements in the repetition accuracy and the collection rate through improvements in this phenomenon.

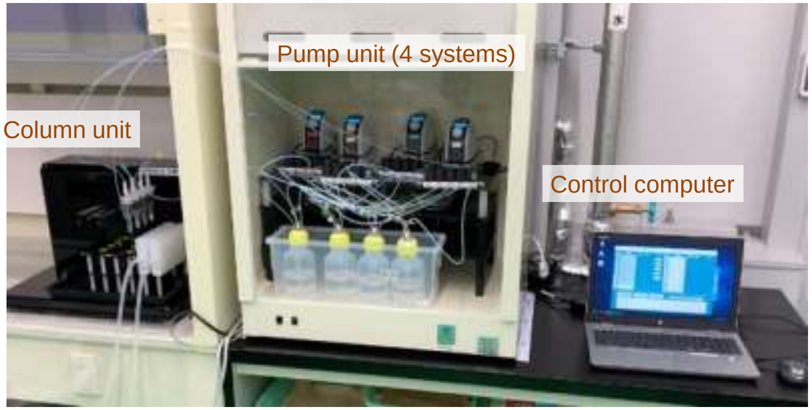


Fig.1 Automated system with the automatic solid-phase extraction equipment at the core
(Part of the ion-exchange and solid-phase extraction)

Table 1 Reproducibility of extraction and separation of Zr and Mo with the automatic solid-phase extraction equipment

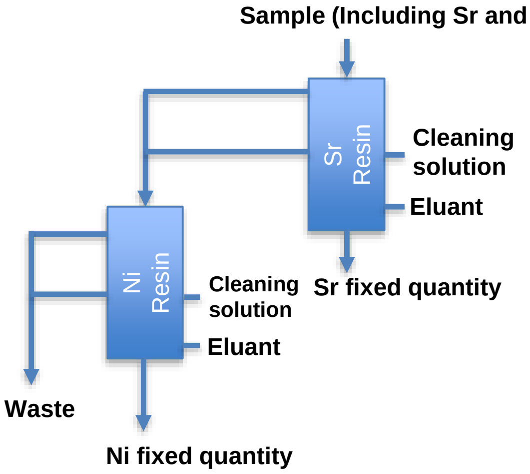
		Zr collection rate [%]	Mo collection rate [%]
Day 1	Pump A	73.8	94.5
	Pump B	82.9	95.0
	Pump C	84.5	80.1
	Average	80.4	89.8
	Relative Standard Deviation	7.1	9.4
Day 2	Pump A	70.3	92.5
	Pump B	82.6	94.6
	Pump C	75.0	93.6
	Average	76.0	93.5
	Relative Standard Deviation	8.1	1.1
Day 3	Pump A	74.3	91.2
	Pump B	76.0	88.9
	Pump C	82.3	89.9
	Average	77.5	90.0
	Relative Standard Deviation	5.5	1.3
全体	Average	78.0	91.1
	Relative Standard Deviation	5.1	4.7

The flow of the eluant was not uniform.

Fig.2 State of the column after the Mo elution operation

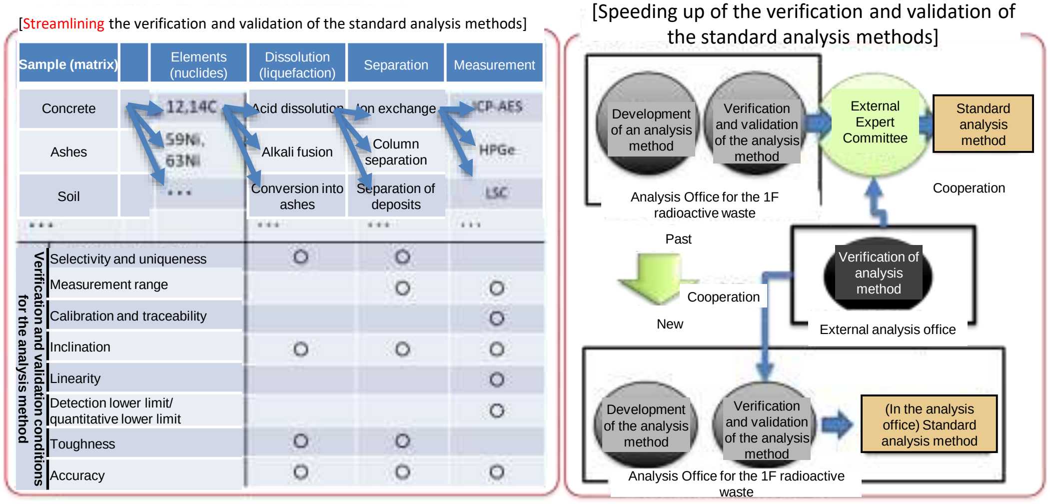
(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
iv. Establishment of standard analytical techniques

- Results
  - ○ In order to evaluate the feasibility of the proposed separation process for the beta ray measurement nuclides, separation and purification tests were carried out for the target nuclide elements. Excellent results were obtained for both the collection rates as well as the standard deviations, and it was therefore expected that it could be applied to radioactive waste analysis (Fig. 1). Moreover, since beta nuclides generally require complex chemical separation operations prior to measurements, techniques to train engineers who will start new analysis on this topic were studied.
  - ○ A Quality Assurance guideline draft was created, which could be reflected in a system conforming to the ISO9001 Standard, and which takes into account the swift verification and validation of standard analysis methods (Fig. 2) for a wide variety of analysis samples that are characteristic of radioactive waste.
- Goal
  - ○ To evaluate the feasibility of the methods of analysis using the streamlined separation process, in consideration of quality assurance in the form of radioactive waste analysis method.
- Implementation details
  - ○ Throughout FY2019 and FY2020, each parameter corresponding to the test conditions shown in Fig. 2, was evaluated for the analysis method that uses the separation process examined in "(ii) Streamlining of the separation process", and its feasibility as a radioactive waste analysis method was assessed. If it is determined that the verification and validation conditions are not satisfied, such as the lower limit of detection cannot be obtained due to the influence of hindering nuclides, the influence removal method or alternative analysis method will be considered.
- Indicators for determining goal achievement
  - ○ Feasibility evaluation results for the radioactive waste analysis methods with respect to the analysis methods using the streamlined separation process should be presented. (FY2019 and FY2020)



	Collection rate	Standard deviation
Sr	88.1%	2.8%
Ni	95.8%	3.7%

Fig.1 Example of separation and purification test (System separation of the Sr and Ni nuclides)


[Streamlining the verification and validation of the standard analysis methods]

Sample (matrix)		Elements (nuclides)	Dissolution (liquefaction)	Separation	Measurement
Concrete		12,14C	Acid dissolution	Ion exchange	ICP-AES
Ashes		59Ni, 63Ni	Alkali fusion	Column separation	HPGe
Soil		・・・	Conversion into ashes	Separation of deposits	LSC
・・・			・・・	・・・	・・・

Verification and validation conditions for the analysis method	Dissolution (liquefaction)	Separation	Measurement
Selectivity and uniqueness	○	○	
Measurement range		○	○
Calibration and traceability			○
Inclination	○	○	○
Linearity			○
Detection lower limit/ quantitative lower limit			○
Toughness	○	○	
Accuracy	○	○	○

[Speeding up of the verification and validation of the standard analysis methods]

Fig.2 Specific methods of streamlining and speeding up verification and validation

(a) Characterization Efficiency Improvement
② Simplification and speeding-up of analytical methods
iv. Establishment of standard analytical techniques

◆ Presentation of proposed specific evaluation items regarding the verification and validation conditions for the standard analysis methods **(Table 1).**

Table 1 Verification and validation methods for standard analysis methods

Sample (matrix)		Elements (nuclides)	Dissolution (liquefaction)	Separation	Measurement
Concrete		C 14C 12C・・・	Acid dissolution	Ion exchange	ICP-AES
Ashes		Ni 59Ni 63Ni・・・	Alkali fusion	Column separation	HPGe
Soil		・・・	Conversion into ashes	Separation of deposits	LSC
・・・			・・・	・・・	・・・
Verification and validation conditions for the analysis method	Selectivity and uniqueness		○ ①	○ ③⑥⑦⑧	
	Measurement range			○ ④	○ ⑫⑬
	Calibration and traceability				○ ⑩
	Inclination		○ ①	○ ③⑥⑦⑧	○ ⑨⑩
	Linearity				○ ⑫
	Detection lower limit/ quantitative lower limit				○ ⑪
	Toughness		○ ②	○ ⑤	
	Accuracy		○ ①	○ ③	○ ⑩

Study of specific evaluation items (Proposed)

[Dissolution]

①: Dissolution/ leaching rate and their repetition accuracy

②: Influence on solubility or on the repetition accuracy due to differences in the sample properties or sample elements

[Separation]

③#: Collection rate and repetition accuracy

④ : Necessity of enrichment operation to obtain the necessary sensitivity

⑤#: Influence on the collection rate or on the repetition accuracy due to differences in the sample properties

⑥#: Do the nuclides believed to hinder measurements satisfy the decontamination coefficient required for the Fukushima Daiichi radioactive waste analysis methods? **(Beta ray measurement nuclides)**

⑦ : Evaluation using methods confirming that the hindering nuclides can be removed from the measurement sample (Gamma ray nuclide measurement from the measurement samples) **(Beta ray measurement nuclides)**

⑧#: Evaluation of spectral interference by comparison of the B.G counts of operation BLANK test and the simulated sample **(ICP-MS measurement nuclides)**

 # : Executed with validity evaluation from the "Study on streamlining of the separation process"

[Measurements]

⑨ : Impact of the difference in the matrices of the calibrated sample and the measurement sample on the measurement values

⑩ : Device calibration and its measurement accuracy that ensures traceability

⑪ : Evaluation of the method detection lower limit/ quantitative method lower limit

⑫ : Linearity of calibration curve including the quantitative lower limit **(ICP-MS measurement nuclides)**

⑬ : Range of energy for the beta ray measurements **(Beta ray measurement nuclides)**

(b) Development of sampling technology

- Past results (FY2018)
  - A conceptual design was created for the sampling devices inside the adsorption towers of the cesium adsorption apparatus (KURION) and the secondary cesium adsorption apparatus (SARRY). (Fig. 1)
  - A testing apparatus was manufactured for the collected elements and tests were conducted to gather the zeolite samples from inside the adsorption tower to verify the collection performance of the sampling tool. (Fig. 2)
  - On the basis of the test results, the structure of the sampling tool was studied and a basic design was developed. (Fig. 3)

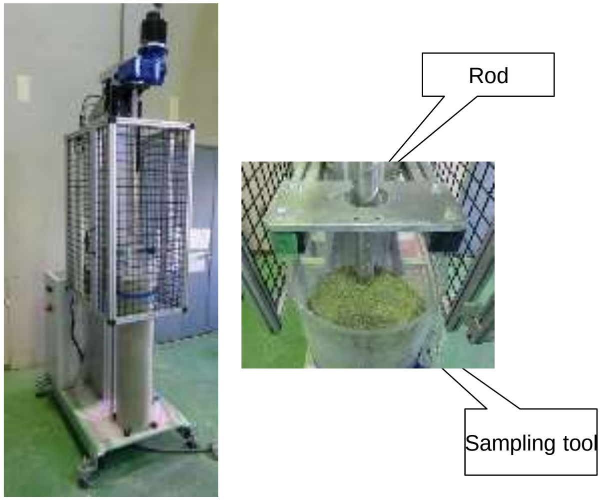


Fig. 2 Testing apparatus for the collected elements

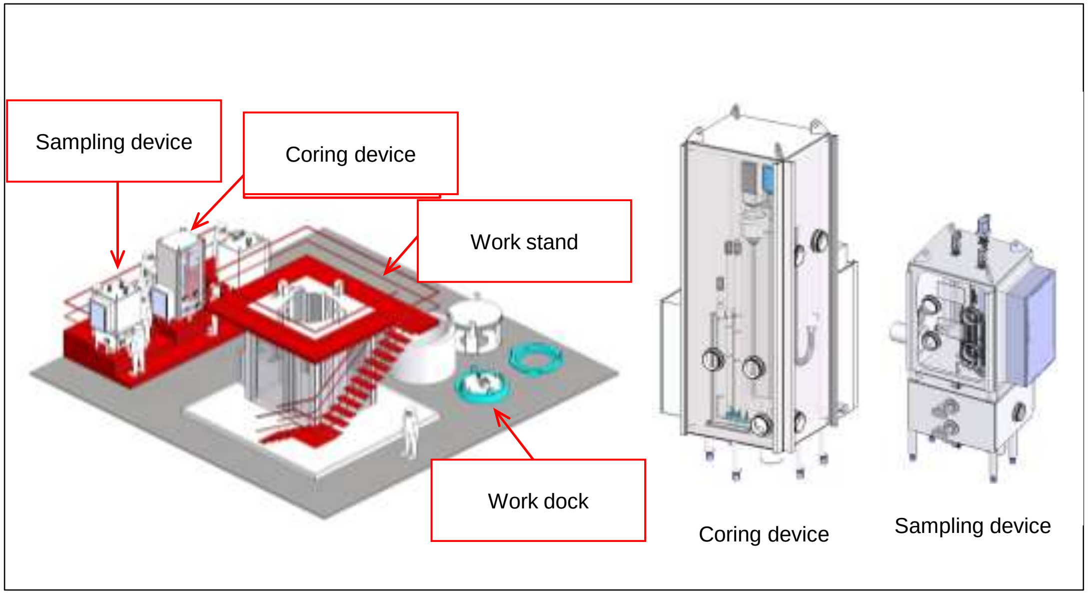


Fig.1 Conceptual design of the sampling device

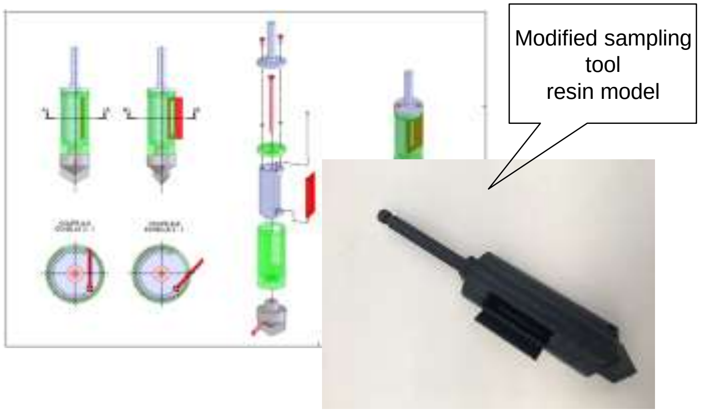


Fig.3 Sampling tool design

(b) Development of sampling technology

■ Goal

To study the sampling devices compatible with the cesium adsorption apparatus (KURION) as well as the secondary cesium adsorption apparatus (SARRY) for the collection of cesium adsorbent, and to test and evaluate the element technology necessary for designing the mock-up devices.

■ Implementation details

- FY2019

During the study of sampling devices, information such as the contents inside the adsorption towers, stage of generation, water flow time, surface dose rate etc. was organized and depending on the analysis requirements, the adsorption towers to be collected, were selected. Together with this, the collection conditions were reviewed. Based on the study results of the sampling devices compatible with both, the cesium adsorption apparatus (KURION) as well as the secondary cesium adsorption apparatus (SARRY) adsorption towers for which the conceptual design was created, items for the element tests including an opening method of the adsorption tower, collection of samples, closing of the opening. required for the mock-up device were selected, the required element test devices and the simulated adsorption towers for testing were designed and manufactured, and test preparations were carried out.

- FY2020

Once the element test device is ready, element tests will be conducted and evaluation will be carried out for making openings of the adsorption towers, collection of samples, and closure of the opening. Based on the evaluation results, a perspective will be obtained on the collection methods and devices applicable at the site.

■ Indicators for determining goal achievement

FY2019	Selection of element test items necessary for designing the mock-up sampling device and preparation for testing. (Target TRL at completion: Level 3→4)
FY2020	Completion of element tests necessary for designing the mock-up device and evaluation of the same. (Target TRL at completion: Level 3→4)

[Excerpts from the Subsidy Project Manuals]

(b) Development of sampling technology

- Conditions for selecting and collecting the adsorption towers (1/4) -

Selection policies for the samples to be collected from the adsorption towers were studied in order to select the adsorption tower to be used for collection of samples.

- Analysis and evaluation requirements

  - Alpha nuclides have been detected during the analysis of stagnant water. Since the alpha nuclides have a very high sorption distribution coefficient, there is a possibility that they exist in the vicinity of the adsorbent surface.

  - The results of the interim report on safety evaluations during disposal indicate the importance of confirming the existence of predominant nuclides (C-14, I-129 etc.) during disposal.

  - The properties of the adsorption tower will change significantly depending on the types of adsorbent, composition of the stagnant water, operating conditions etc. The assessment and evaluation of individual differences is important.

  - The adsorption towers, which were used during the initial stage of the earthquake, should be collected on priority because the concentration of nuclides in the stagnant water is high in such adsorption towers.

- Approach to representativeness

  - Regarding the representativeness of the collected samples, two approaches can be considered: one focused on the adsorption towers (individual differences between the adsorption towers) such as the structure of the adsorption tower, period when it was used, adsorbent used, and the content of radionuclides, and the other focused on the adsorbent location (spatial non-uniformity) such as the radionuclide distribution inside the adsorption tower.

(b) Development of sampling technology

- Conditions for selecting and collecting the adsorption towers (2/4) -

Individual differences between the adsorption towers

- There are 10 or more types of adsorbents used for the adsorption towers.
- The composition of stagnant water changes with the passage of time and the composition of the contaminated water passing through the adsorption tower also changes as per the "Structure” and "Arrangement" of the adsorption tower which acts as the treatment system.
- Therefore, the nuclide composition and the radioactivity concentration for each adsorbent solid varies. It has actually been indicated that the variation in the surface dose of the adsorption towers is large, and that the individual differences are large.
- Especially, the nuclide composition captured by the adsorbent has a large impact on treatment method selection and the treatment equipment design, and it is necessary to understand the trends.

KURION adsorption towers
No. of towers: Approx. 800 units

SARRY adsorption towers
No. of towers: Approx. 200 units

Fig.1 State of storage of the used adsorption towers

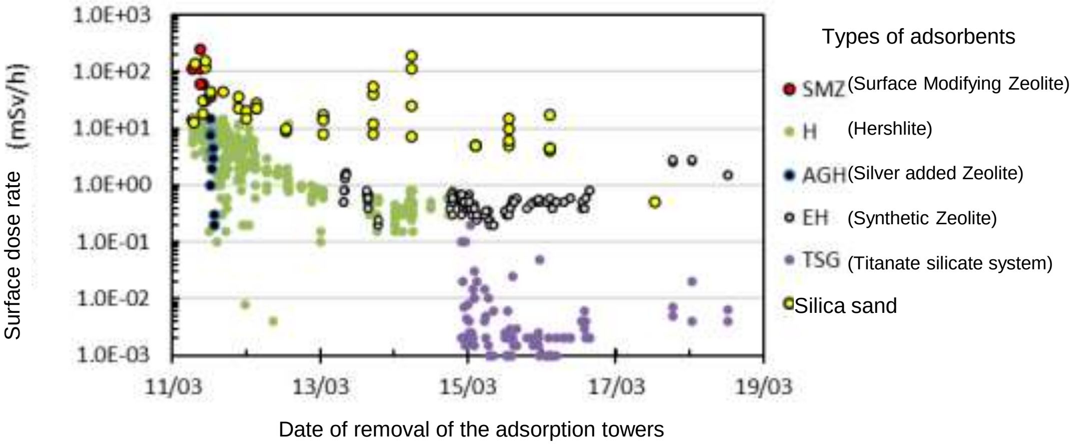


Fig.2 Example of data organization of the KURION adsorption towers (Contents, dose rate and date of generation)

(b) Development of sampling technology

- Conditions for selecting and collecting the adsorption towers (3/4) -

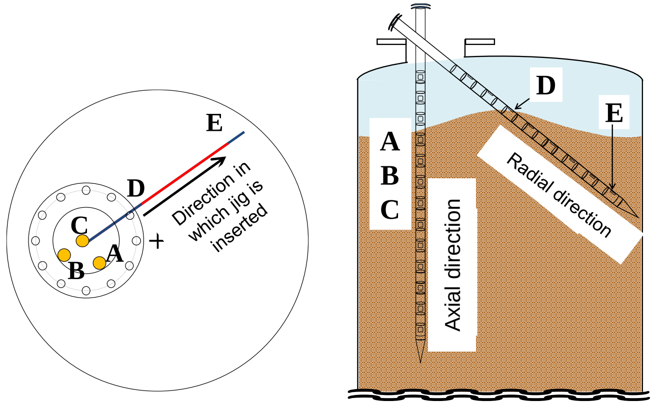
- Spatial non-uniformity

➢ In FY2015, Cs adsorption distribution measurements (JAEA/ IRID#) (Fig. 2) were carried out by filling IE-96 adsorbent in a full-scale SARRY adsorption tower internal mock-up facility (Fig. 1).

- It was found that the Cs concentration distribution in the direction of depth accurately matched with the analytical value.

- It was confirmed that there was almost no concentration distribution in the circumferential direction.

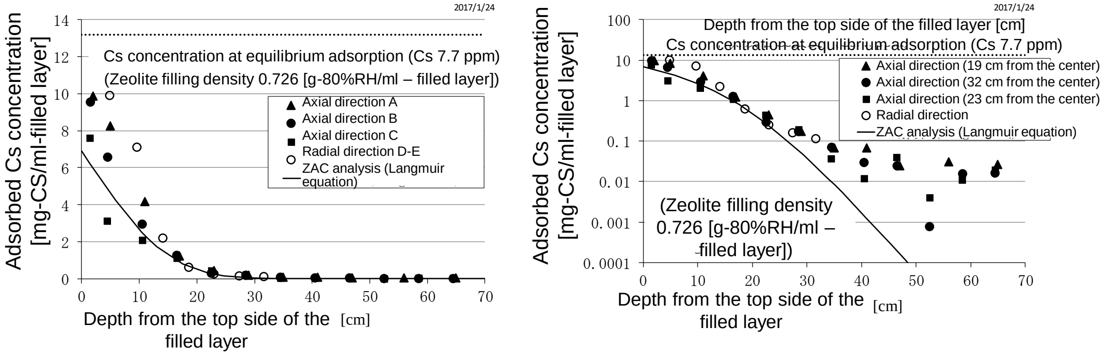
⇨ **The concentration distribution of the entire adsorption tower can be presumed if the adsorption concentration of one place is actually measured.**



Top view

Side view

Fig.1 SARRY adsorption tower internal mock-up facility



Cs adsorption distribution measurement value (linear display)

Cs adsorption distribution measurement value (Semi-logarithmic display)

Fig.2 Cs adsorption distribution measurement value #

#IRID (2017): "Subsidy Project of Decommissioning and Contaminated Water Management in the FY2014 Supplementary Budgets, R&D for Treatment and Disposal of Solid Radioactive Waste (Final report)" pp. 3-20 – 3-22, pp. 4-381 – 4-386

(b) Development of sampling technology

- Conditions for selecting and collecting the adsorption towers (4/4) -

Selection of adsorption towers

- The adsorption towers used during the first stage of the operations when the concentration of nuclides in the stagnant water was high, have a higher priority.
- The SARRY adsorption towers used in the first stage of operations correspond to the flange type.
- Samples are collected giving priority to the adsorption towers installed on the upstream side.

Number of adsorption tower sampling points

- Collect samples from one point on each adsorption tower.

Collection location

- The surface range is set from the surface of the adsorbent (top end) to 100 mm.

Table1 Conditions for selecting and collecting the adsorption towers

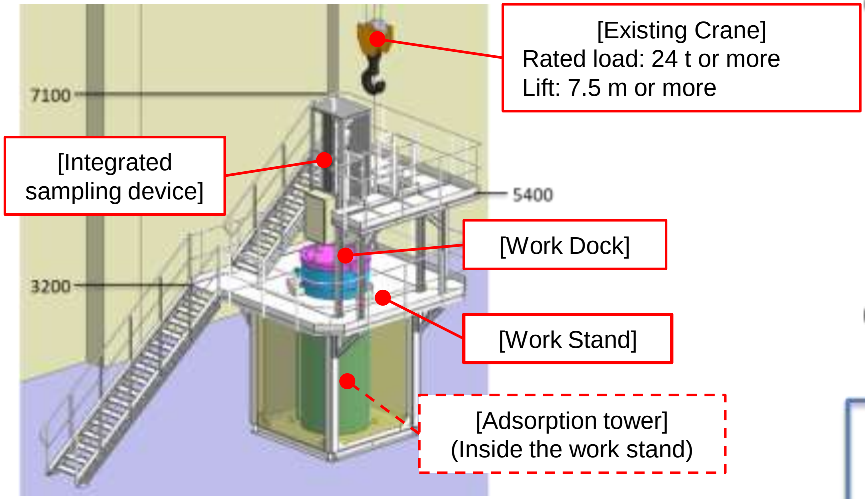
Items		Selection and collection conditions for the adsorption towers
Collection targets	Types	The adsorption towers used during the first stage of the operations are given priority. Especially, those on the upstream side of the system are given priority.
	Structures	KURION : All adsorption towers have a common structure. SARRY : The flange type adsorption tower is applicable.
Amount of collection		10 to 20 mL/sample
No. of sampling points per tower		One point in the circumferential direction x One point in the depth direction (One point per adsorption tower in total)
Collection depth from the surface		Surface to about 100 mm
Position		KURION: Top plate side of the adsorption tower SARRY: Adsorption material filling port flange
Diameter of opening in adsorption tower		Approx.φ 50 mm
Method of closing the opening		A pressure resistance of 1.37 MPa is ensured in the closed part. The closing plug is a detachable structure.

(b) Development of sampling technology

- Selection of element test items (1/3) -

Assumptions during actual work

Risks were evaluated assuming actual work at the site and the necessary element test items and the element test device were studied.



[Existing Crane]
Rated load: 24 t or more
Lift: 7.5 m or more

[Integrated sampling device]

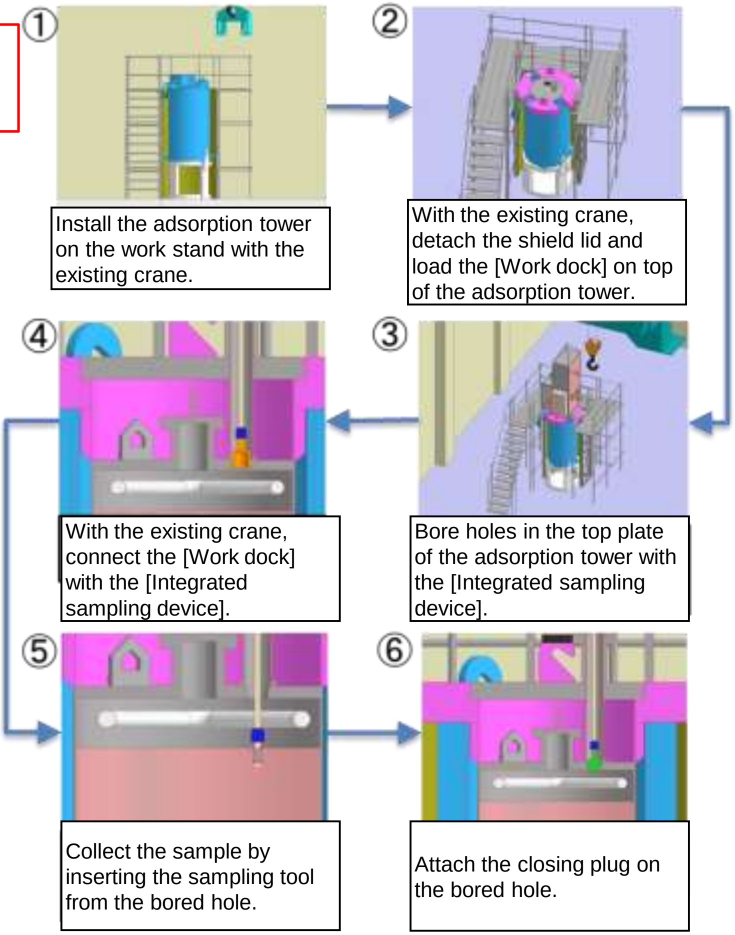
[Work Dock]

[Work Stand]

[Adsorption tower]
(Inside the work stand)

Structures	Functions
Existing Crane	To install the adsorption tower, the integrated sampling device and the work dock.
Integrated sampling device	A device that remotely executes a series of work processes such as making openings, sample collection, and closing of the opening by switching the vertical slide unit and tip tool.
Work dock	Its function is to shield the upper part of the adsorption tower, connect the adsorption tower with the sampling device, secure the boundaries and control the shaking of the rod core during making openings.
Work stand	Installation of the adsorption tower and for shielding the sides. A scaffold for the workers to work on.

Fig.1 Equipment layout



① Install the adsorption tower on the work stand with the existing crane.

② With the existing crane, detach the shield lid and load the [Work dock] on top of the adsorption tower.

③ Bore holes in the top plate of the adsorption tower with the [Integrated sampling device].

④ With the existing crane, connect the [Work dock] with the [Integrated sampling device].

⑤ Collect the sample by inserting the sampling tool from the bored hole.

⑥ Attach the closing plug on the bored hole.

Fig..2 Work steps (KURION Adsorption tower)

(b) Development of sampling technology

- Selection of element test items (2/3) -

■ Risk evaluation

Table 1 Evaluation of the risks involved in a series of work processes

Risk items	Risk details	Risk reduction measures
Contamination	Spread of contamination in the surroundings due to the sampling heads after collection	Evaluating the surface adhesions (contamination) on the sampling apparatus after collection and appropriate curing and enclosure
	Diffusion of contaminants from inside the adsorption tower during the collection work	Securing the boundaries during the collection work
	Leakage of contaminants from the closed part	Ensuring appropriate sealing
Exposure	Excessive exposure of workers due to the operation and maintenance of the sampling device	Shielding (shielding by the work dock) the upper part of the adsorption tower Shortening of human working hours
Hydrogen ignition	Ignition of hydrogen generated in the adsorption tower	Ventilation and measurement of hydrogen concentration inside the adsorption tower
Change in properties of the adsorption tower	Change in properties of the flange gasket of the adsorption tower due to frictional heat or the shearing force during making openings	Reducing the frictional heat by appropriate conditions of making openings and lubrication
	Difference in the plate thickness, or in case of the flange type tower, difference in the assumed number of flange plates	Remote verification by camera leaving a margin for the cutting ability and stroke
Foreign material intrusion	Mixing of cutting splinters in the adsorption tower	Collecting by suction and assessing the cutting conditions so that the mixing is minimal
Falling or flying objects	Fall during the installation operation of the work dock and the ISM	Use of special hoisting attachments and surveillance with camera
Equipment damage	Damage during transportation of the adsorption tower	Use of special hoisting attachments
	Interference with the internal piping during collection	Checking the insides with a camera after making openings
	Interference due to shaking of the shaft during making openings and collecting samples	Assessing the amount of shaking of the shaft beforehand
	Equipment parts caught during making openings and closing the opening	Understanding the conditions under which making openings or closure can be carried out in a stable manner
Failure in integrity of the adsorption tower	Pressure resistance lacking in the closing plug	Process control based on a prior pressure test
	Failure in withdrawal of the rods due to failure in return of the sampling head vane (damage)	Study of the vane structure Study on a head shape that does not require vanes

🟨 : Indicates items that must be evaluated through actual tests and are considered as test items in this research.

(b) Development of sampling technology

- Selection of element test items (3/3) -

- Element test items

Table 1 Element test items

Test items	Test goals	Measurement items
Test for making openings	・Verification of operating conditions ・Determining the need for shaft holding mechanism ・Reflection in the study on the working hours	・Load factor of motor (rotation direction and vertical direction) ・Durability of cutting blade ・Rotation speed and feed speed ・Time required for making openings ・Cutting splinter status and cutting oil supply conditions ・Status of shaking and vibration of the shaft
	・Verification of effect on the subsequent work processes (collection and closure) ・Verification of validity of the blade for making openings	・Shape of the hole (circular, coaxial etc.) ・Amount of cutting splinters and cutting oil mixed in the adsorption tower
	・Evaluation of workability of joints ・Validity of equipment layout ・Determining the necessity of contamination prevention measures	・Replaceability and time of replacement of the tool for making openings ・Scope of work from the glove port ・Dispersion status of the cutting splinters and cutting oil ・Identification of any other issues
Collection test	・Verification of operating conditions ・Verification of required performance (10 to 20 ml) ・Determining the necessity of contamination prevention measures	・Rotation speed and feed speed ・Amount of collection ・State of sample dispersion
	・Evaluation of workability of joints ・Understanding the information input to exposure evaluation (distance and time)	・Handling properties and handling time of collection tools ・Scope of work from the glove port ・Identification of any other issues
Closure test	・Verification of operating conditions	・Closing torque value ・Feed speed
	・Verification of the structure of the closing plug ・Setting the operating conditions	・Pressure resistance (test pressure: Approx. 2 MPa) ・Loosening torque value for detachment
	・Evaluation of workability of joints ・Validity of equipment layout	・Installability and installation time of the closing plug ・Scope of work from the glove port ・Identification of any other issues
Installability confirmation test	・Structural verification of the parts aligned with the work dock ・Measurement of the work dock installation time	・Installability of work dock in the simulated adsorption tower (alignment) ・Identification of issues from the viewpoint of actual work
	・Structural verification of the parts that match the position of the element test device	・Installability of the device on the work dock ・Identification of issues from the viewpoint of actual work

(b) Development of sampling technology

- Format of the element tests -

- Step 1: Preparation for element tests ... Execution of "Design and manufacturing of the element test device" and "Preliminary testing (making openings, sample collection and closing of the opening)"
- Step 2：Element tests... Verification of the feasibility of a series of work processes with the element test device

Preparation for element tests

(Step 1) Ongoing. Scheduled for execution by the first half of FY2020.

Organization of the conditions presumed for the designing of the element test device

Designing and manufacturing of the element test device

Design and manufacture the device (Fig. 1) that is required to carry out the element tests.

Integrated sampling device for the test

Work dock for the test

Simulated adsorption tower

Fig.1 Configuration of the element test device

Preliminary testing

Verify the basic performance necessary for making openings, sample collection and closing of the opening through preliminary testing (Fig. 2).

Making openings

Collection

Closure

Fig.2 Preliminary testing

Reflection of the result of the preliminary test in the design

Element tests

(Step 2) To be executed in the second half of FY2020.

Verify the feasibility of a series of work processes related to sampling by using the element test device (Fig. 3).

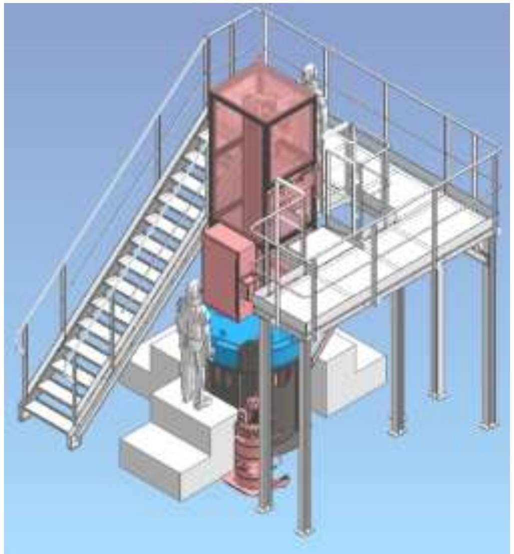


Fig.3 Illustration of the element test device

(b) Development of sampling technology

- Preparation for element tests - Designing and manufacturing of the element test device (1/7) -

Presuming the site environment and based on the study of the collection conditions and the sampling procedures and the results of the preliminary tests, a detailed design was created for each component required to perform the element tests, such as making openings of the adsorption tower, collection of samples, closure of the opening etc., and manufacturing of the equipment was started.

- Configuration of the element test device

Table 1 Configuration and functions of the element test device

Configuration	Functions
Integrated sampling equipment for the test	To make openings, collect and close by switching the tool attached to the tip of the rotating rod that operates in the vertical direction.
Work dock for the test	To fix the integrated sampling device for the test and align it with the upper surface of the adsorption tower.
Simulated adsorption tower	To reproduce the superstructures of the SARRY and the KURION adsorption towers.
Work stand for the test	To support the device during testing and prevent any falls. It is the scaffold used during work, such as switching the tools etc., around the integrated sampling device for the test.

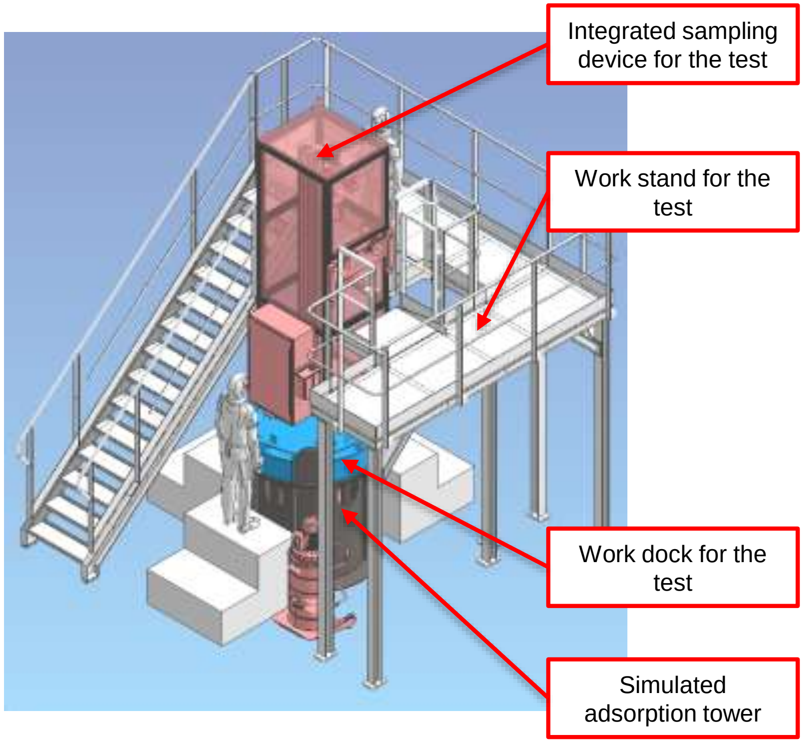


Fig.1 Configuration of the element test device

- ➢ Since the aim is to perform the element tests in a cold environment, the boundary securing functions and the shielding functions will be omitted for every equipment, but the profile such as the shield thickness, which affects the workability, will be reproduced.

(b) Development of sampling technology

- Preparation for element tests - Designing and manufacturing of the element test device (2/7) -

■ Integrated sampling device for the test

- ➢ Making openings, collecting and closing by switching the tool.
- ➢ The tool is switched manually through the glove port.

Table 1 Specifications of the integrated sampling device for the test

Items		Specifications	Basis of the specifications
External appearance		1100 x 950 x 3200 mm	The external appearance is decided based on the assumed crane lifting height, the necessary stroke, the workability through the glove port, etc.
Vertical drive	Drive method	Vertical drive with ball screw	High positioning accuracy due to high rigidity.
	Motor specifications	Output: 0.75 kW Torque: 20 Nm Rotation speed: Up to 250 rpm	Depends on the machine tool manufacturer's findings. To suit the feed speed of the blade for making openings.
	Stroke	2000 mm	It should be possible to insert the sampling tool till a depth of 100 mm from the adsorbent surface.
Rotational drive	Motor specifications	Output: 5 kW Torque: 300 Nm Rotation speed: Up to 150 rpm	Depends on the machine tool manufacturer's findings. To suit the cutting speed of the blade for making openings.
Making openings		･Tool for opening (φ 60, 50, 40 mm) ･Cutting splinter sucking function ･Cutting oil spraying function	･Bore holes of multiple diameters forming stepped holes. ･Installation of a suction mechanism so that the cutting splinters do not get mixed inside the adsorption tower. ･Installation of an oil spraying mechanism for cooling and lubrication.
Collection		Sampling tool (Collection capacity max. 20 mL)	The collection capacity is set at 20 mL, since the target value for collection is 10 to 20 mL.
Closure		Insertion of the closing plug with the closure tool	The closing plug is remotely installed in the stepped hole that is formed.

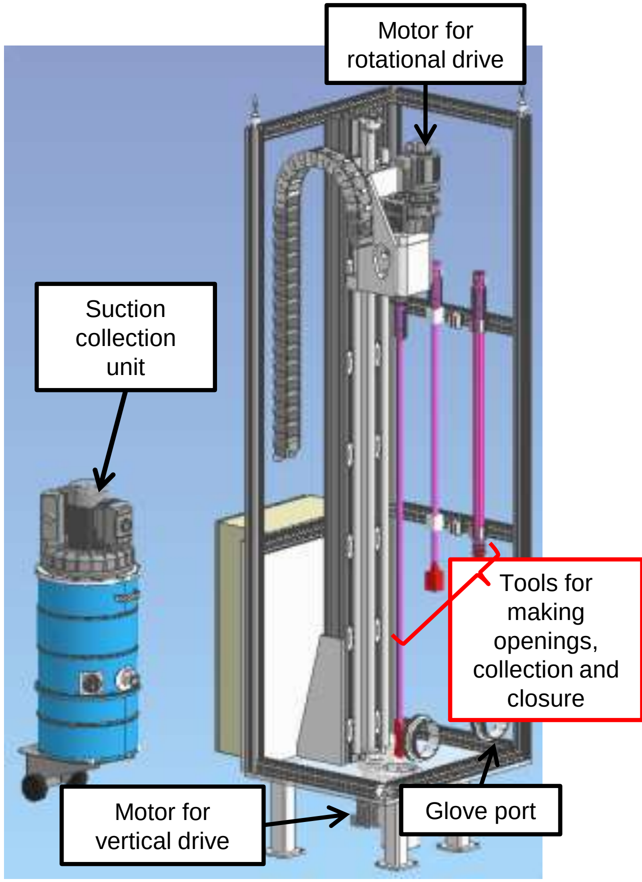


Fig.1 Internal image of the integrated sampling device for the test

(b) Development of sampling technology

- Preparation for element tests - Designing and manufacturing of the element test device (3/7) -

- Detailed design of the integrated sampling device for the test (illustration)

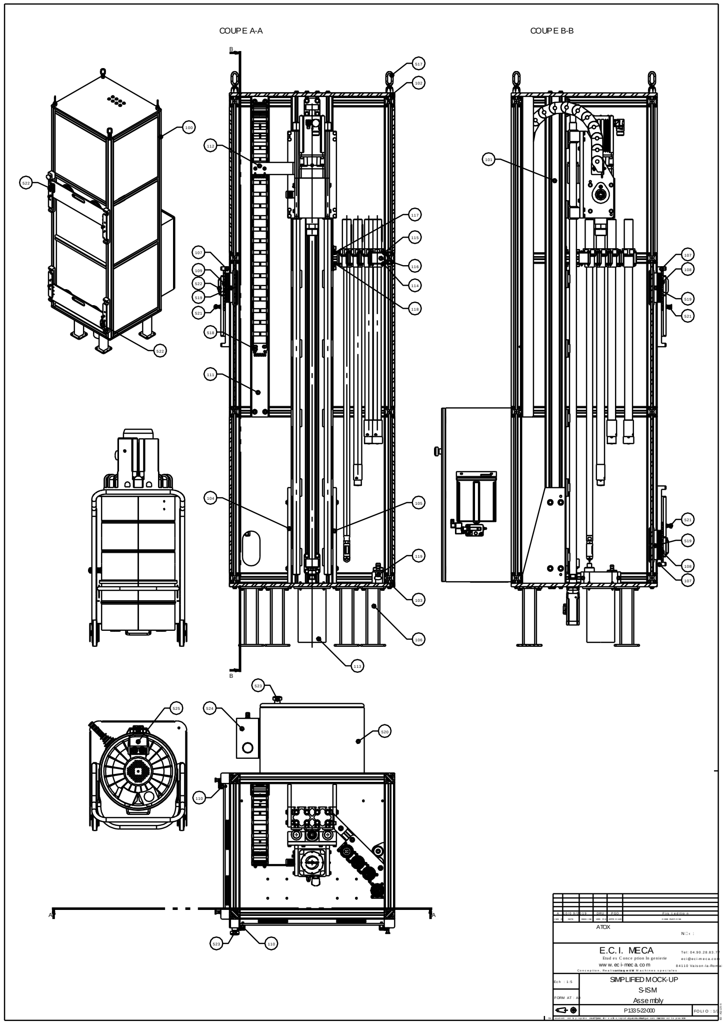


Fig.1 Overall layout of the integrated sampling device for the test

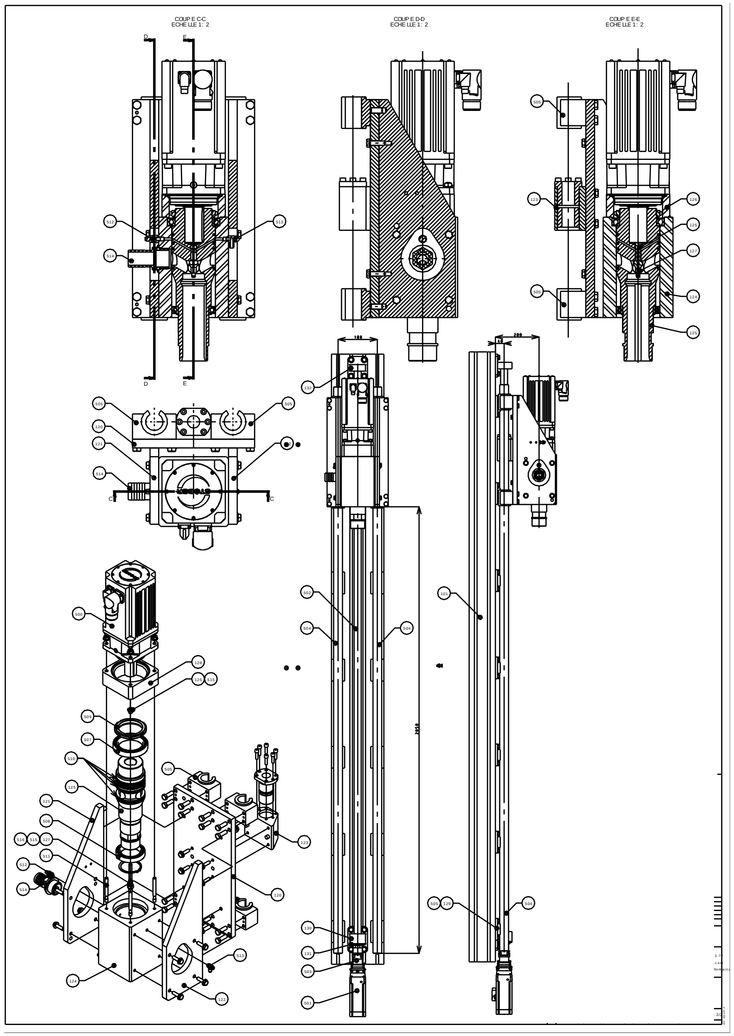


Fig.2 Diagram of the partial assembly of the rod drive mechanism

(b) Development of sampling technology

【Confidential】

- Preparation for element tests - Designing and manufacturing of the element test device (4/7) -

■ Making openings

Table 1 Functions of the tool

Requisite functions	Device functions
To be able to remotely bore holes on the KURION and the SARRY adsorption towers at positions where the sampling tool will be inserted. (Fig. 1)	･Remotely operate the tool to perform cutting (tool switching is a manual operation). ･Friction control and cooling by spraying the cutting oil (Fig. 2). ･Collection of the cutting splinters and the cutting oil by suction (Fig. 2). ･Holding mechanism for controlling the shaking of the rod core.

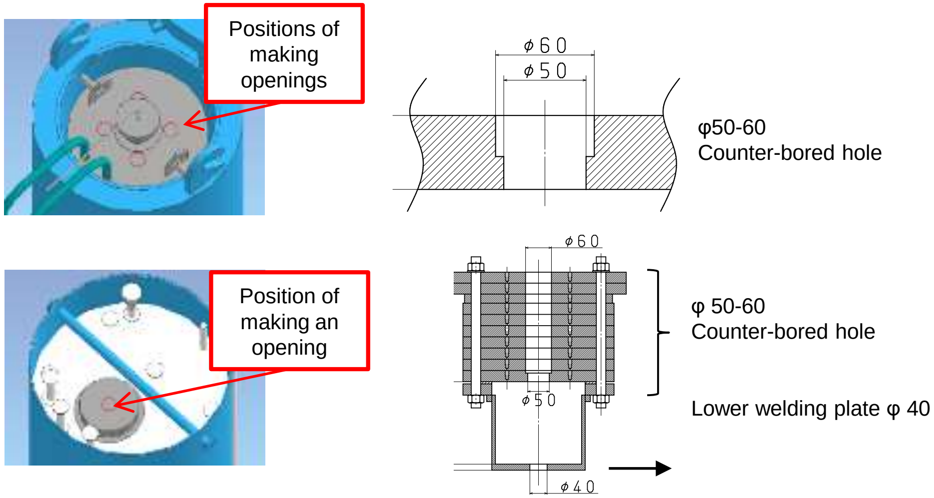


Fig.1 Positions of making openings and oepnings sectional view
(Above: KURION adsorption tower, Below: SARRY adsorption tower

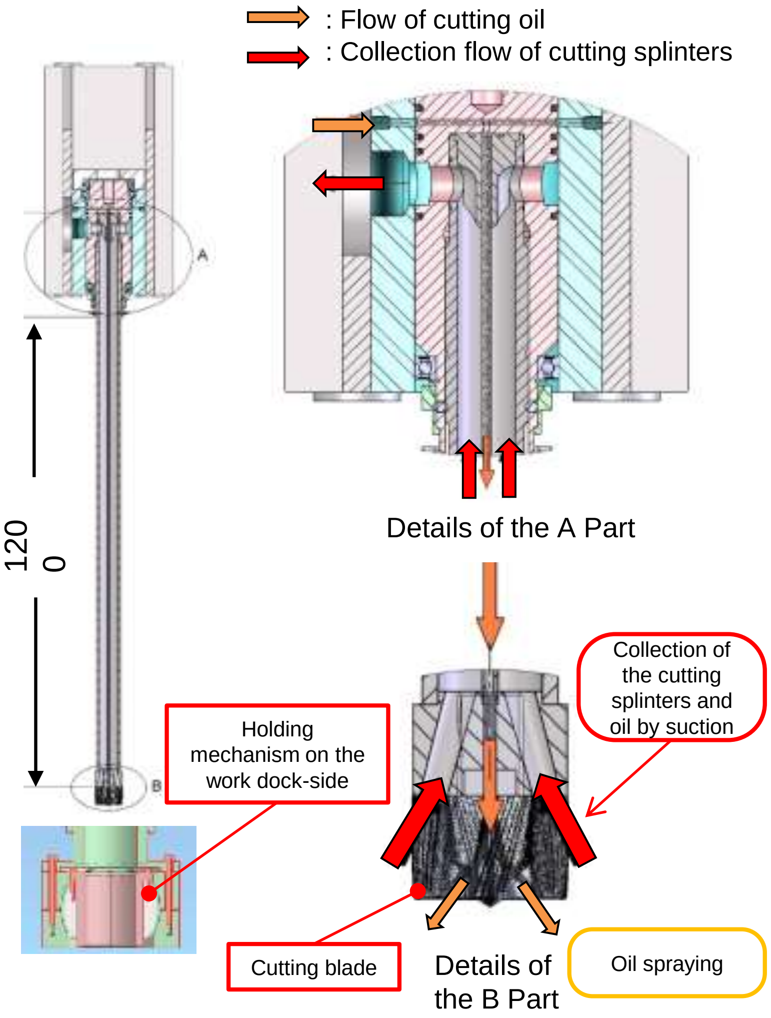


Fig.2 Illustration of opening tool

(b) Development of sampling technology

【Confidential】

- Preparation for element tests - Designing and manufacturing of the element test device (5/7) -

■ Tool for making openings

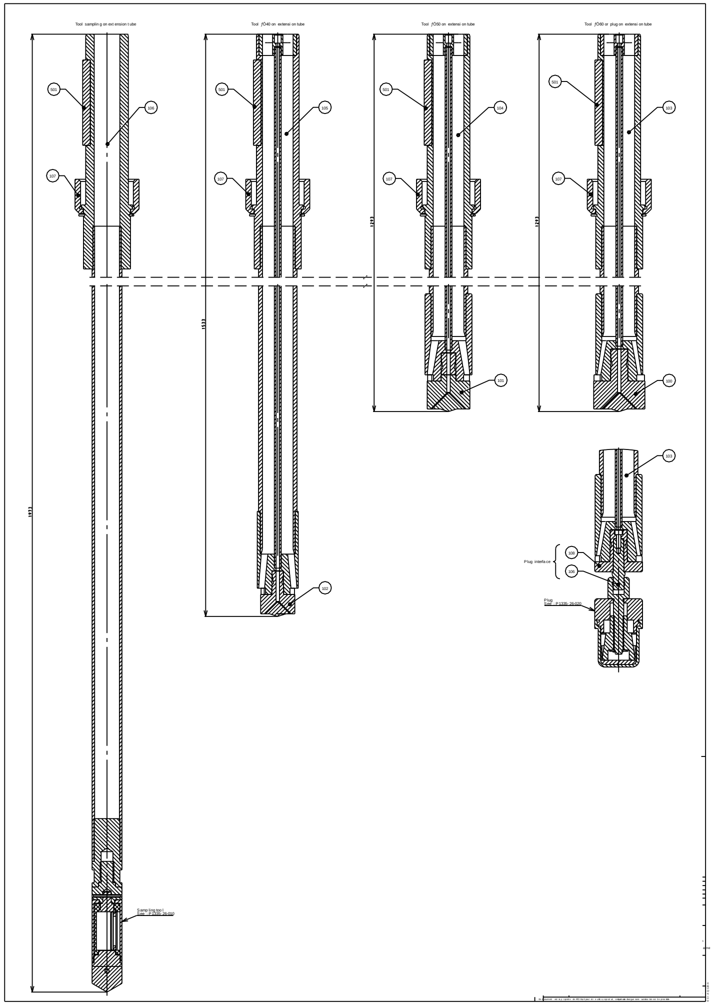
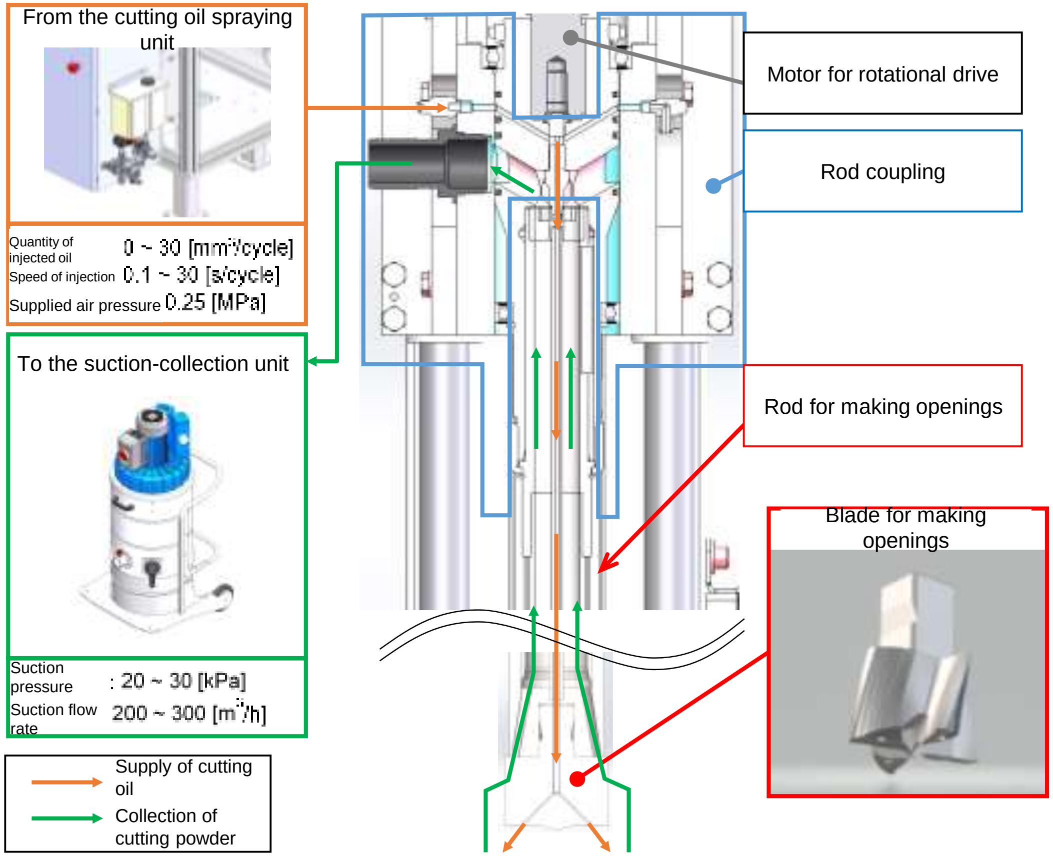


Fig.1 Tool design for making openings



From the cutting oil spraying unit

Quantity of injected oil 0 ~ 30 [mm^3/cycle]

Speed of injection 0.1 ~ 30 [s/cycle]

Supplied air pressure 0.25 [MPa]

To the suction-collection unit

Suction pressure : 20 ~ 30 [kPa]

Suction flow rate 200 ~ 300 [m^3/h]

The cutting oil supplied by the "Cutting oil supply unit" is supplied to the tip of the blade via the center of the rod, and this cutting oil along with the cutting powder gets sucked into the suction-collection unit from the outer side of the rod.

Fig.2 Configuration of the mechanism for making openings

(b) Development of sampling technology

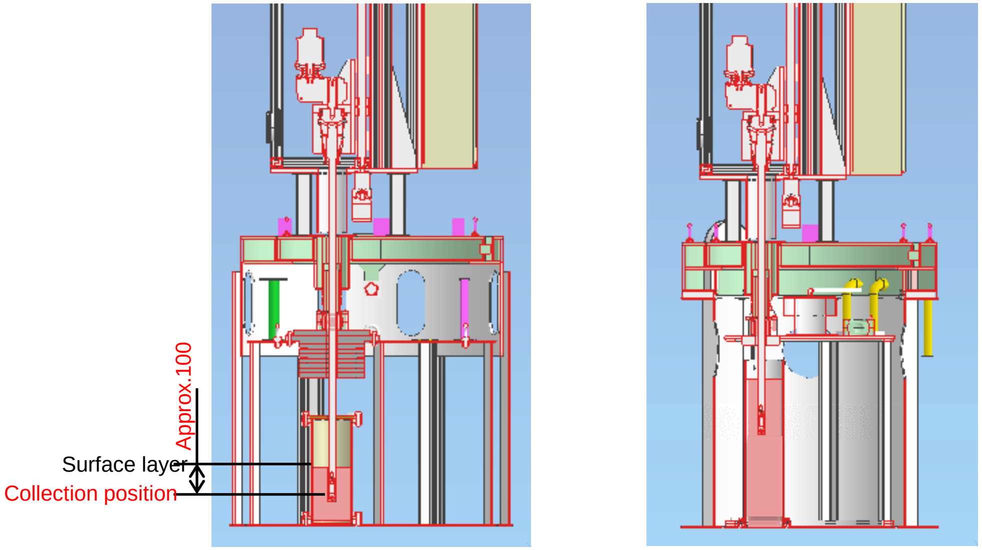
- Preparation for element tests - Designing and manufacturing of the element test device (6/7) -

Collection (Sampling)

- Samples from inside the adsorption tower will be collected by inserting a sampling tool through the bored holes (φ 50)

Table 1 Collection (sampling) tool functions

Requisite functions	Device functions	
It should be able to remotely collect 10 to 20 mL sample from the vicinity of the surface	Collection position (Fig. 1)	The stroke is set such that samples can be collected from the surface (in the vicinity of 100 mm) of the adsorption tower.
	Sampling tool (Fig. 2)	Stroke the sampling tool by rotating it clockwise (closing the sampling port), and when it reaches the sampling position, rotate it counterclockwise to open the sampling port and at the same time slide out the vane and scrape off the adsorbent for sampling. (Collection port volume: Approx. 20 mL).



(a) SARRY (b) KURION

Fig.1 Sample collection position

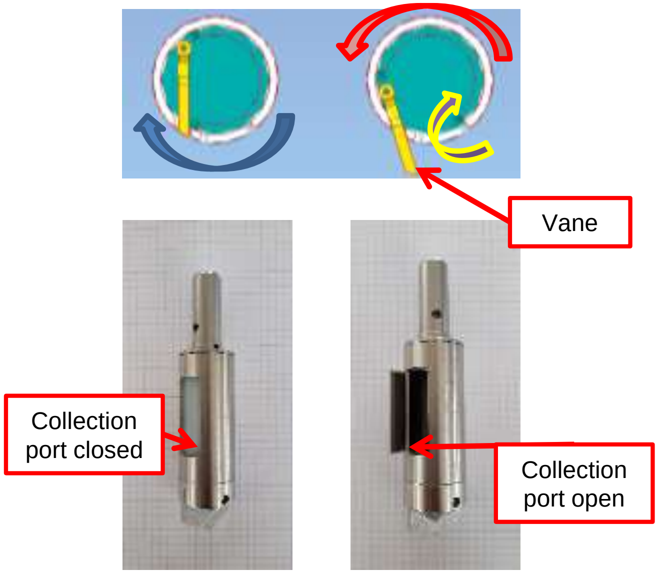


Fig.2 Vane opening-closing type sampling tool

(b) Development of sampling technology

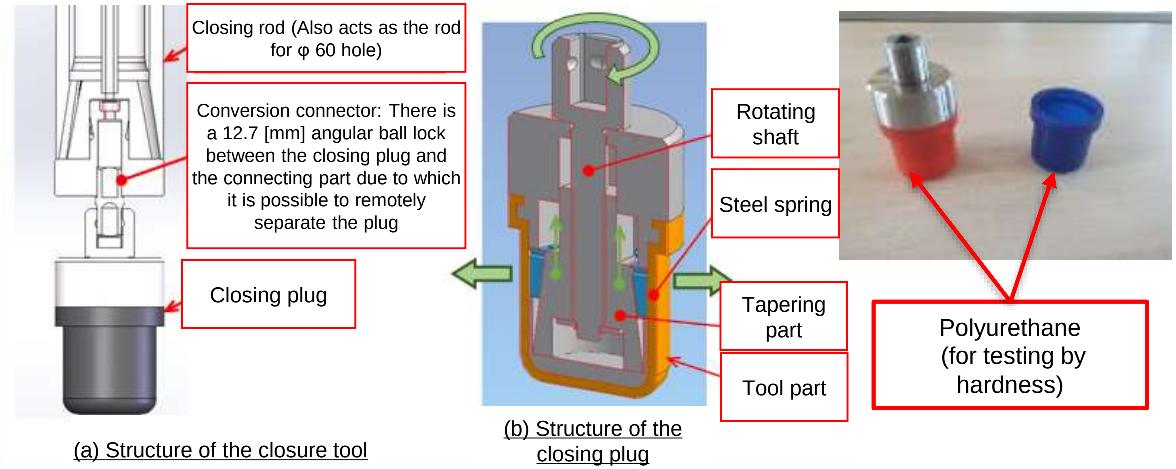
- Preparation for element tests - Designing and manufacturing of the element test device (7/7) -

Closure

- To perform the closure operation by inserting the closing plug in the bored holes after the collection is over (Fig. 1, 2).
- During routine storage, no pressure is applied, but it is assumed that pressure is applied on the adsorption tower due to the method of the pulling out operation. Therefore, studies were conducted for a closing plug with the same pressure resistance performance as the adsorption tower.

Table 1 Functions of the closing tool

Requisite functions	Device functions	
It should be possible to close the bored holes remotely	Installation method	By rotating the shaft while pressing the closing plug into the stepped hole, the steel spring is extruded, the polyurethane part is expanded, and the bored hole is closed. The steel spring can also be removed by rotating the shaft in the reverse direction.
	Specifications	・Max. pressure: Approx. 1.37 MPa (Maximum Working Pressure of the adsorption tower) ・ Closing port diameter: φ 50 mm ・Compatible with both KURION and the SARRY adsorption towers



Closing rod (Also acts as the rod for φ 60 hole)

Conversion connector: There is a 12.7 [mm] angular ball lock between the closing plug and the connecting part due to which it is possible to remotely separate the plug

Closing plug

(a) Structure of the closure tool

Rotating shaft

Steel spring

Tapering part

Tool part

(b) Structure of the closing plug

Polyurethane (for testing by hardness)

Fig.1 Closing plug (left: image, middle: disassembly image, right: prototype)

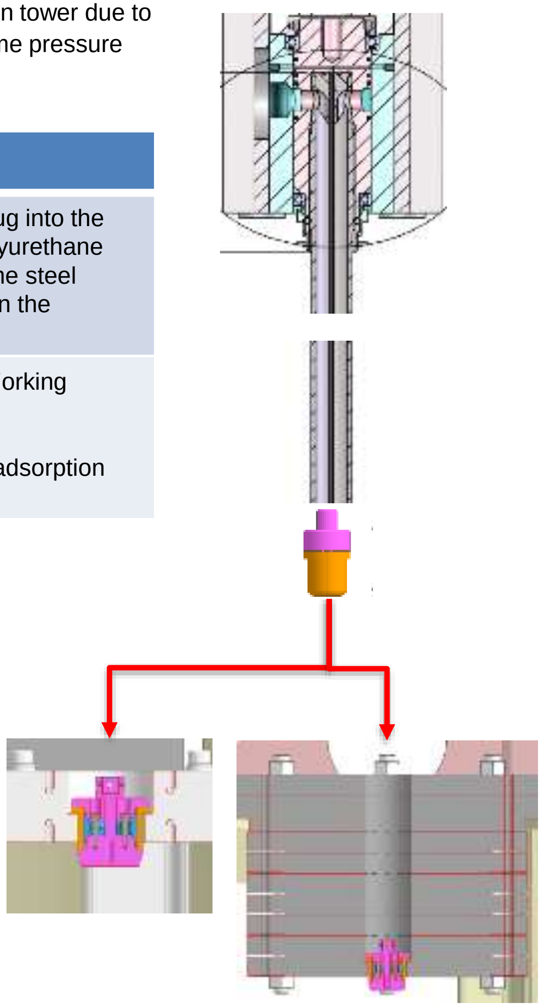


Fig.2 Installation of the closing plug (Left: KURION, Right: SARRY)

(b) Development of sampling technology

- Preparation for element tests - Preliminary test for making openings -

■ Preliminary test for making openings

- Preliminary test for making openings of a steel plate was carried out by installing a rod for opening and a prototype blade for the preliminary test on the machining center (Fig. 1).
- It was found that it was possible to reduce the size of the cutting splinters (approx. 5 mm or less) by shaping the blade for making openings.
- It was confirmed that it was possible to improve the accuracy of the bored holes by installing the holding mechanism.
- An insight was obtained on the bored holes from the preliminary test results, and this will be reflected in the element test device.

Preliminary test equipment for making openings

Appearance of preliminary test for making openings

Installation of holding mechanism

Condition of the bored holes

Fig.1 Preliminary test for opening

(b) Development of sampling technology

- Preparation for element tests - Preliminary test for collection (1/2) -

Preliminary test for collection

- The preliminary test for collection was carried out with the element test device for collection which had been manufactured in the previous years (Fig. 1).
- The vane opening-closing sampling tool was newly manufactured in order to deal with the issue of insufficient amount of collection encountered during the previous years' preliminary test for collection.
- During the previous years' test, only one kind of property was set for the collection target (zeolite). Presuming an actual test, the preliminary test for collection was executed for multiple test targets (Fig. 2).

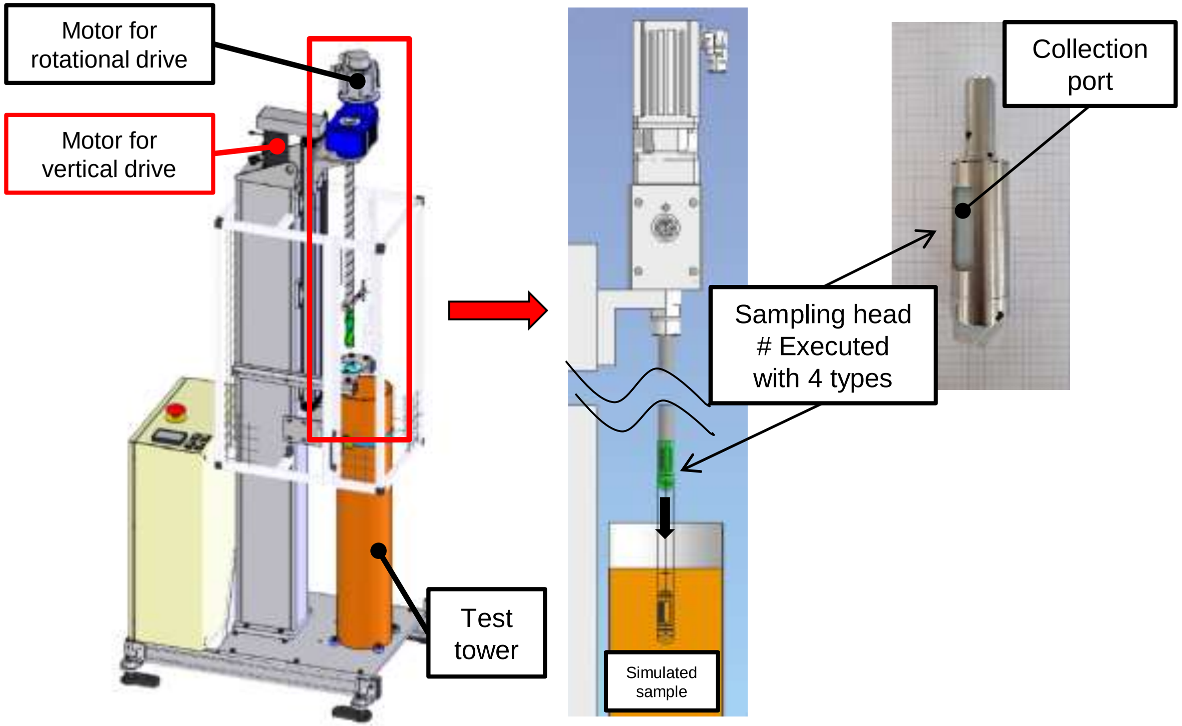
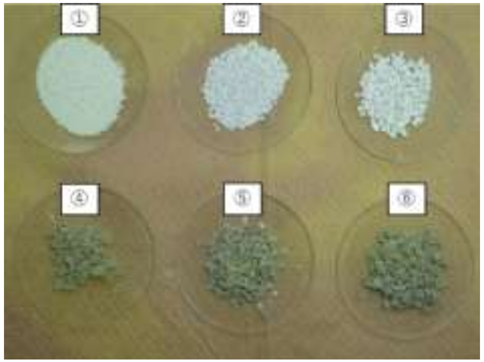


Fig.1 Element test device for collection



Test targets	
①	Itaya zeolite Z-05 Particle size 0.5 to 1 mm Dry
②	Itaya zeolite Z-12 Particle size 0.5 to 2 mm Dry
③	Itaya zeolite Z-13 Particle size 1 to 3 mm Dry
④	Itaya zeolite Z-05 Particle size 0.5 to 1 mm Moist
⑤	Itaya zeolite Z-12 Particle size 0.5 to 2 mm Moist #
⑥	Itaya zeolite Z-13 Particle size 1 to 3 mm Moist

#: Samples collected during the previous years' tests

Fig.2 Test targets

(b) Development of sampling technology

- Preparation for element tests - Preliminary test for collection (2/2) -

■ Results of the preliminary test for collection

The results of the preliminary test for collection are shown below (Fig. 2) using various sampling tools (Fig. 1).
The optimal values from the previous years' tests were used for the operating conditions during collection.

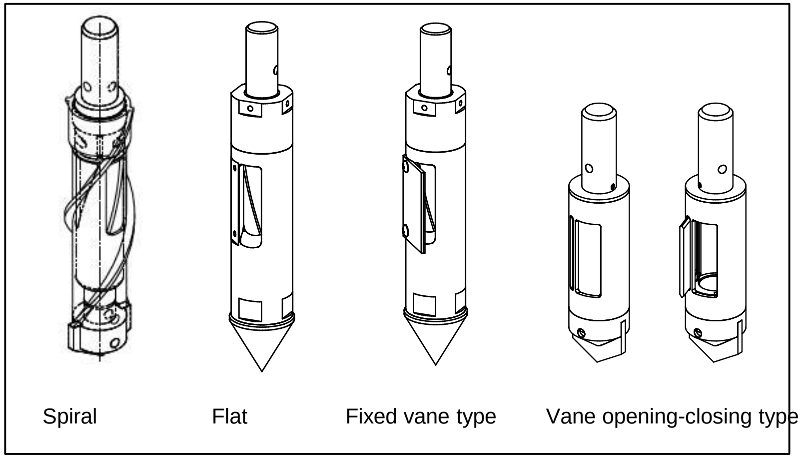
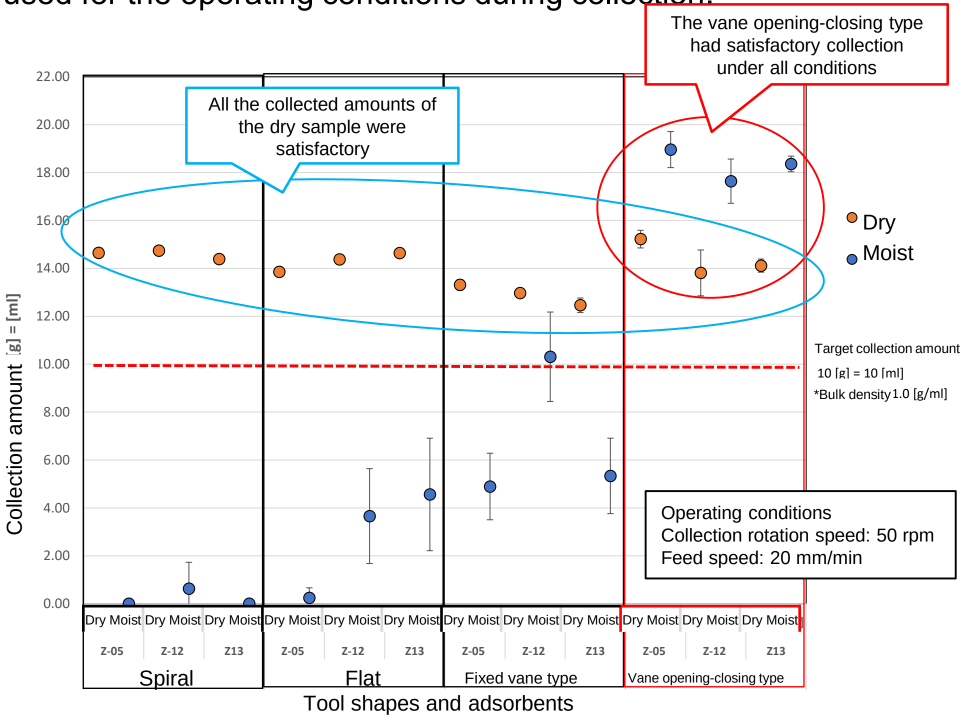


Fig.1 Various sampling tools



The vane opening-closing type had satisfactory collection under all conditions

All the collected amounts of the dry sample were satisfactory

Target collection amount
10 [g] = 10 [ml]
*Bulk density 1.0 [g/ml]

Operating conditions
Collection rotation speed: 50 rpm
Feed speed: 20 mm/min

Fig.2 Results of the preliminary test for collection

- ➢ It was possible to collect sufficient amounts of sample with all the tool forms since the dry sample had a high fluidity.
- ➢ Since the moist samples had a high adhesiveness, the samples could not be collected in a stable manner, except in case of the vane opening-closing type of tool.
- ➢ The vane opening-closing type had satisfactory collection under all the sample conditions.
  However, zeolite was found to be caught in the opening and closing mechanism of the vane opening-closing type. Moreover, since there is a risk of interference from or damage to the vane at the time of withdrawing the tool from the bored holes, the shape will be further reviewed and study on the risk reduction measures will continue.

(b) Development of sampling technology

- Preparation for element tests - Preliminary test for closure -

Preliminary test for closure

- The preliminary test for closure was carried out by mounting the prototyped closing plug on the pressure resistance tester (Fig. 1).
- The closing plug was mounted with a manual tool, pressure was applied with a hydraulic pump and the pressure values were noted for the leakage from the closing plug.
- It was confirmed that with respect to the maximum working pressure of 1.37 Mpa for the adsorption tower, there was no leakage from the prototyped closing plug even at 1.4 MPa.
- A study will be conducted for the optimization of the material and structure with an aim to developing a closing plug which will not leak in a pressure resistance test for approx. 2 Mpa, which is 1.5 times of 1.37 MPa.

Prototyped closing plug

Preliminary test for closure

Mounting status of the closing plug

Closing plug when it has risen up due to internal pressure

Fig.1 Preliminary test for closure

(b) Development of sampling technology

- Summary (1/2) -

■ Overview of the results and issues in the current year

➢ Collection conditions and adsorption tower selection policy

The collection conditions and the selection policies for adsorption towers (KURION, SARRY) were studied (Table 1). Note that these will be reviewed based on the future results of analysis.

➢ Selection of the element test items

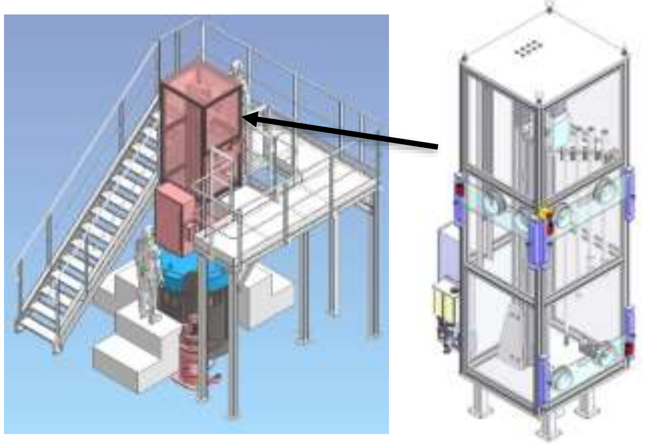
The element test items for the series of operations namely, making openings, collection and closure, were selected.

➢ Design of the element test device

The contents of the element tests for a series of work processes (making openings, collection and closure of the adsorption tower) were studied assuming the actual work conditions. Moreover, in order to conduct the test, the designing of the element test device was completed and its manufacturing was started (Fig. 1 and 2).

Table 1 Outline of the collection conditions

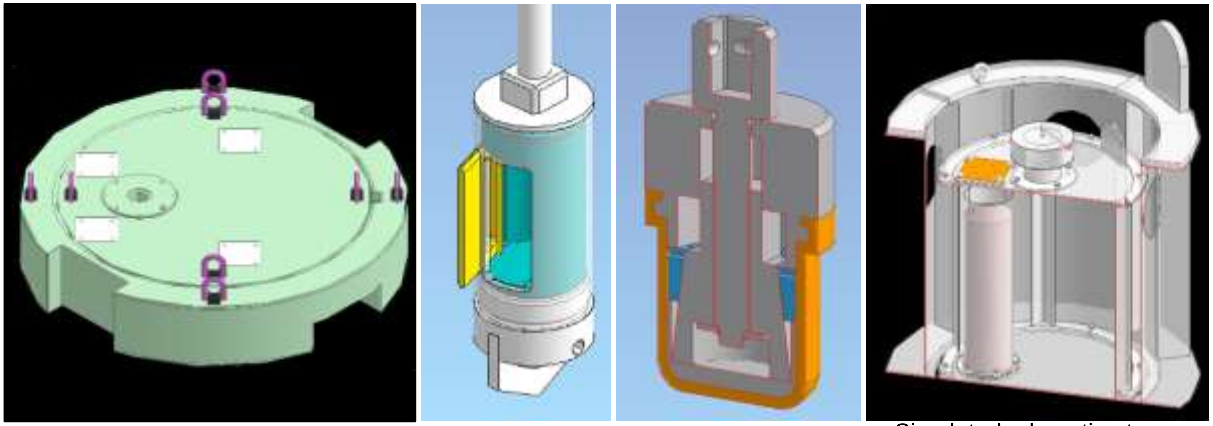
	Items	Specifications
Collection targets	Types	Priority to the adsorption tower used during the first stage of operations Especially, priority for the upstream-side adsorption tower
	Structure	KURION: Compatible with all adsorption towers SARRY：Flange type
Collection conditions	No. of sampling points	One point each
	Depth	Depth of 100 mm from the surface of the adsorbent
	Amount	10 to 20 mL
	Opening diameter	φ 50 mm
	Closing plug	Pressure resistance at 1.37 MPa (short term), Detachable



Overall layout

Integrated sampling device for the test

Fig.1 Element test device



Work dock for the test

Sampling tool

Closing plug

Simulated adsorption tower (KURION)

Fig.2 Components of the element test device

(b) Development of sampling technology

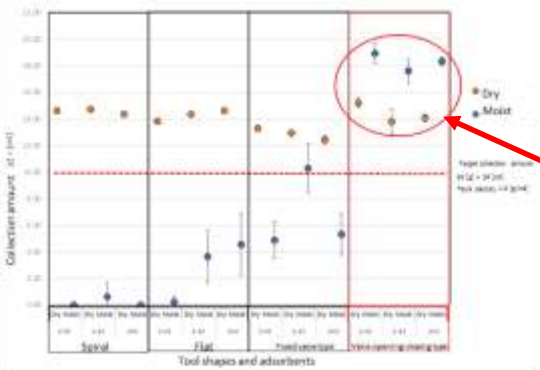
- Summary (2/2) -

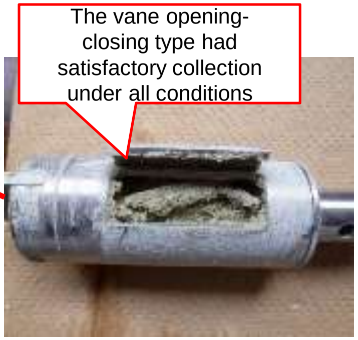
■ Overview of the results and issues in the current year

➢ Execution of preliminary tests

- Preliminary tests were conducted for making openings, sample collection and closing of the opening (Fig. 1 to Fig. 3).
- A perspective of an opening method was obtained from the preliminary test.
- There will be an ongoing study regarding the methods of collection and closure.

Fig.1 Preliminary test for making openings





The vane opening-closing type had satisfactory collection under all conditions

Fig.3 Status of the preliminary test for closure

➢ Risk evaluation

- The risks involved in a series of work processes were identified. The risks were evaluated through the element tests.
- The exposure during the series of work processes was evaluated. The validity of the assumed working hours was evaluated through the element tests.

■ Overview of the plan for the following year

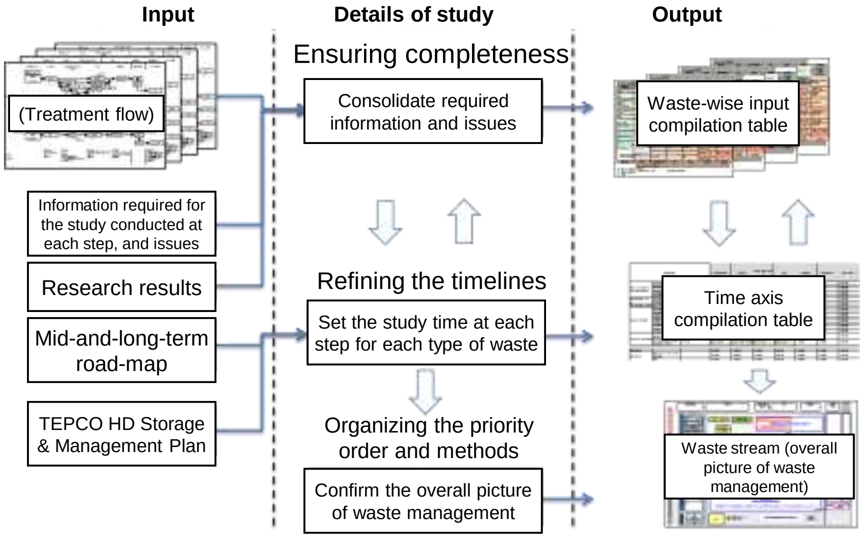
- ➢ The sampling tool will be improved based on the results of the preliminary test for sample collection.
- ➢ The preparations for the element tests will be completed after manufacturing the element test equipment and simulated adsorption towers etc., which are required for the element tests.
- ➢ The series of element tests for making openings in the adsorption tower, collecting samples and closing an opening of the adsorption tower will be conducted.
- ➢ The possibility of applicability for collection methods and equipment that are applied at the site will be provided based on the test results.

2. Project Details

d. Integration of R&D Results

d. Integration of R&D
- Study on waste stream -

- Results
  - ○ By FY2018, methods were developed for integrative evaluation of consistency in results, progress status and pending issues by reflecting the latest results obtained through previous research (Fig. 1). Further, consistency in results, progress status and pending issues were presented in these developed methods.
- Goals
  - ○ To incorporate the results obtained in other researches into waste stream and perform integrative evaluation of consistency in results, progress status and pending issues.
- Implementation details (Details are shown on the next page)
  - ○ In FY2019, options were developed for treatment methods from the perspective of both treatment and disposal, by reflecting into the waste stream the requirements on the basis of the R&D results of disposal (waste conditioning, waste preliminary storage) as also R&D results of treatment (pre-treatment, treatment, re-processing). Further, the entries in the Input compilation table were revised for each target waste (Fig.2).
  - ○ Waste stream will continue to be updated in FY2020 by incorporating the issues and R&D results obtained in FY2019 and the results of evaluating progress status, consistency in results and pending issues will be presented.
- Indicators for determining goal achievement
  - ○ Waste stream should be updated. (FY2020)
  - ○ The input compilation table should be updated. (FY2020)



Input

(Treatment flow)

Information required for the study conducted at each step, and issues

Research results

Mid-and-long-term road-map

TEPCO HD Storage & Management Plan

Details of study

Ensuring completeness

Consolidate required information and issues

Refining the timelines

Set the study time at each step for each type of waste

Organizing the priority order and methods

Confirm the overall picture of waste management

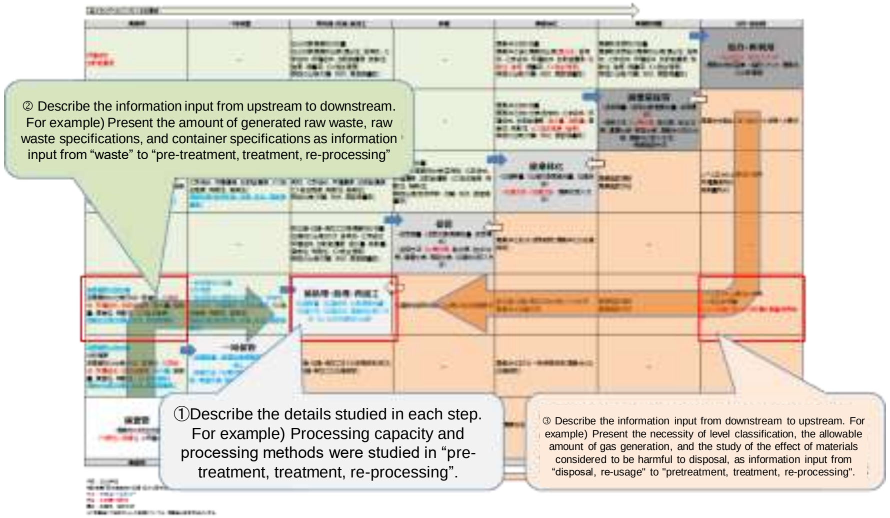
Output

Waste-wise input compilation table

Time axis compilation table

Waste stream (overall picture of waste management)

Fig. 1 Overview of the study on the waste stream



② Describe the information input from upstream to downstream. For example) Present the amount of generated raw waste, raw waste specifications, and container specifications as information input from “waste” to “pre-treatment, treatment, re-processing”

①Describe the details studied in each step. For example) Processing capacity and processing methods were studied in “pre-treatment, treatment, re-processing”.

③ Describe the information input from downstream to upstream. For example) Present the necessity of level classification, the allowable amount of gas generation, and the study of the effect of materials considered to be harmful to disposal, as information input from “disposal, re-usage” to “pretreatment, treatment, re-processing”.

Fig. 2 Example of input compilation table

d. Integration of R&D

- Background and goals -

Background

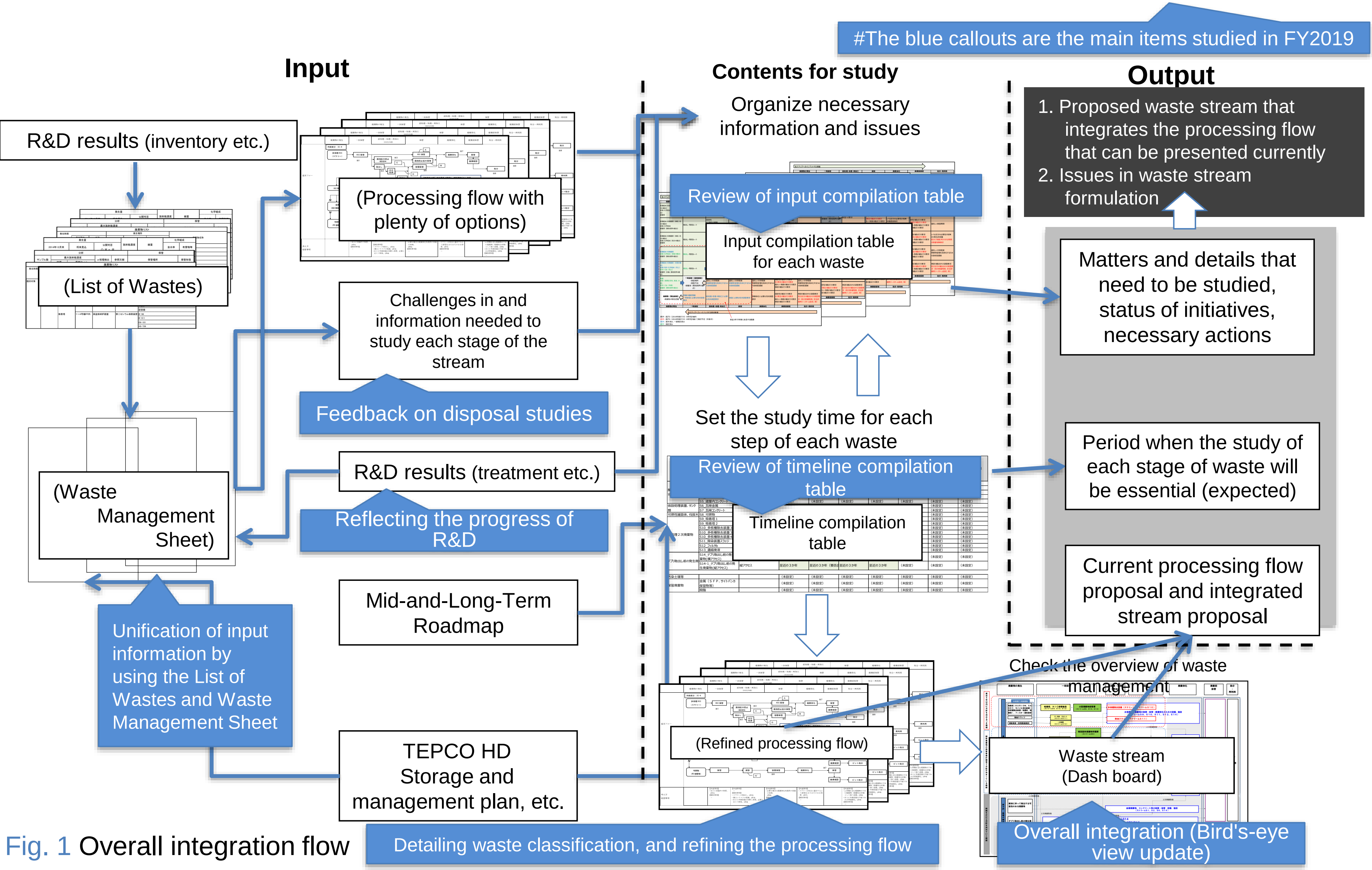
1. Various kinds of waste generated in Fukushima Daiichi and each has its own requirements from a safety perspective effected on the site. In addition, properties of some waste are uncertain.
   - ✓ As of end of FY2018, IRID has prepared a list of 890 types of solid wastes inclusive of already existing wastes and wastes expected to be generated in the future. There may be a further increase in types of wastes.
2. These wastes should be processed and stored safely and it is necessary to provide a path for the disposal of these wastes.
   - ✓ It has been decided to have a “Technical perspective concerning the policy on treatment, disposal and its safety” in the Mid-and-Long-Term Roadmap by around 2021.
     - ① In this connection, it is necessary to develop the flow (waste stream) from the generation of solid waste, to its storage and treatment (segregation, volume reduction, stabilization etc.) and eventually to long term storage or disposal.
     - ② In this subsidy project, we are working towards narrowing down the waste streams having multiple options depending on the characteristics of wastes and various efforts are being made to identify issues.
3. Meanwhile, it requires a lot of time to complete research pertaining to characterization of wastes and safe methods for waste treatment and disposal.
   - ✓ It is necessary to conduct R&D in a reasonable and efficient manner.
     - ① In this subsidy project, we are striving to promote streamlining and efficiency of overall R&D while providing information feedback mutually for each and every aspect of R&D. (Role of “Integration of R&D results”)

Target setting for integration of R&D results in this subsidy project

- **The following targets will be presented toward the Mid-and-Long-Term Roadmap Third Phase (From FY2021 onwards).**
  - ✓ **Updated input compilation table and proposal for waste streams as of then**
  - ✓ **Evaluation results of the issues to be addressed when developing a waste stream**

d. Integration of R&D

- Overall integration flow (formulation of waste stream) in this subsidy project -



#The blue callouts are the main items studied in FY2019

Input

R&D results (inventory etc.)

(List of Wastes)

(Processing flow with plenty of options)

Challenges in and information needed to study each stage of the stream

Feedback on disposal studies

(Waste Management Sheet)

R&D results (treatment etc.)

Reflecting the progress of R&D

Unification of input information by using the List of Wastes and Waste Management Sheet

Mid-and-Long-Term Roadmap

TEPCO HD Storage and management plan, etc.

Contents for study

Organize necessary information and issues

Review of input compilation table

Input compilation table for each waste

Set the study time for each step of each waste

Review of timeline compilation table

Timeline compilation table

(Refined processing flow)

Detailing waste classification, and refining the processing flow

Output

1. Proposed waste stream that integrates the processing flow that can be presented currently
2. Issues in waste stream formulation

Matters and details that need to be studied, status of initiatives, necessary actions

Period when the study of each stage of waste will be essential (expected)

Current processing flow proposal and integrated stream proposal

Check the overview of waste management

Waste stream (Dash board)

Overall integration (Bird's-eye view update)

Fig. 1 Overall integration flow

d. Integration of R&D

- Overview of 1F waste treatment summarized at present in this subsidy project –
(Waste stream dashboard)

We are trying to integrate the whole picture and accumulate the R&D results, but it is necessary to further refine the processing flow despite lack of information, in order to have an insight into the feasibility of treatment and disposal.

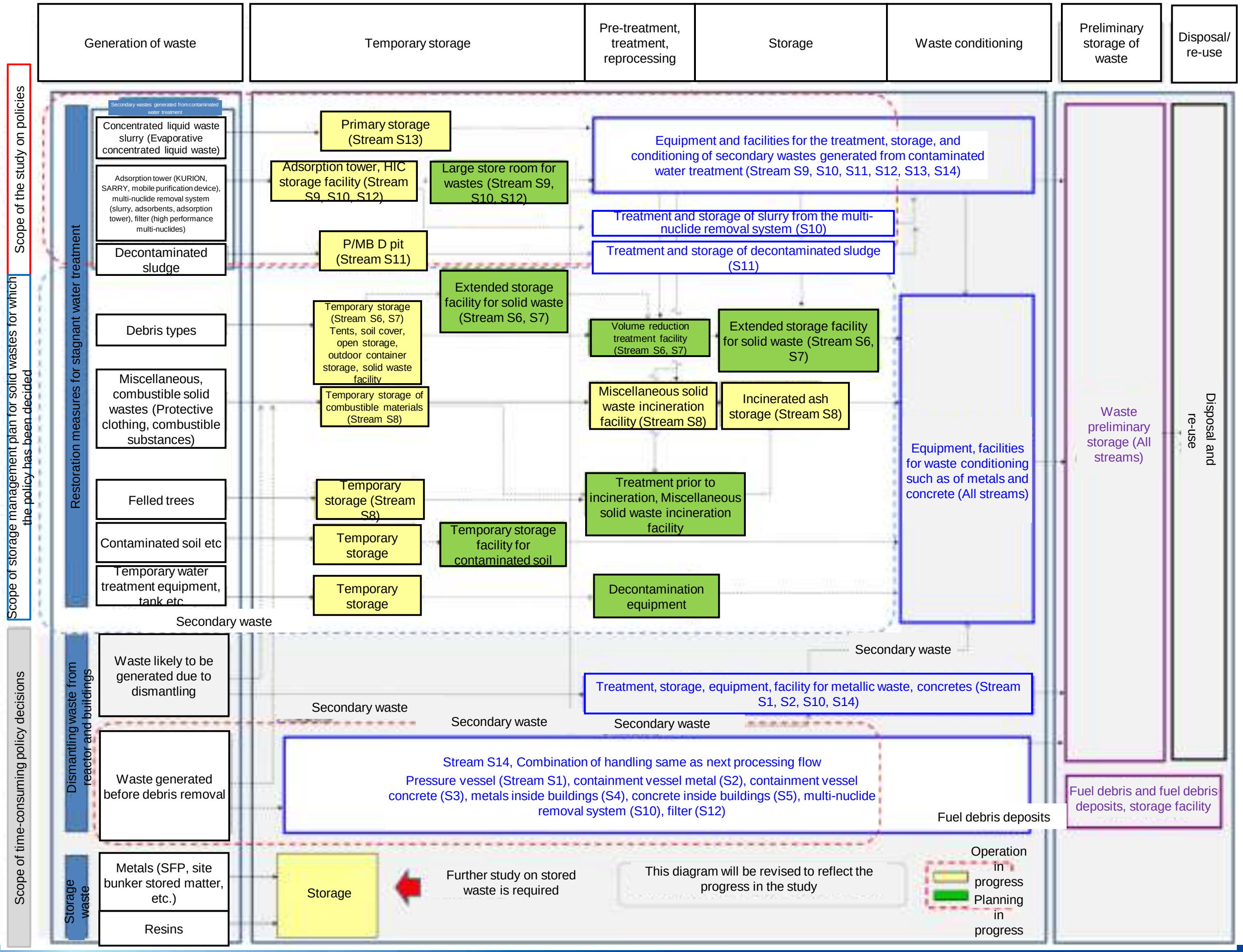


Fig. 1 Waste stream dashboard (Created in FY2018)

The blue frame represents the area where deeper study is required

d. Integration of R&D

- Example of study on refining the treatment flow and current issues (Example of HIC slurry) -

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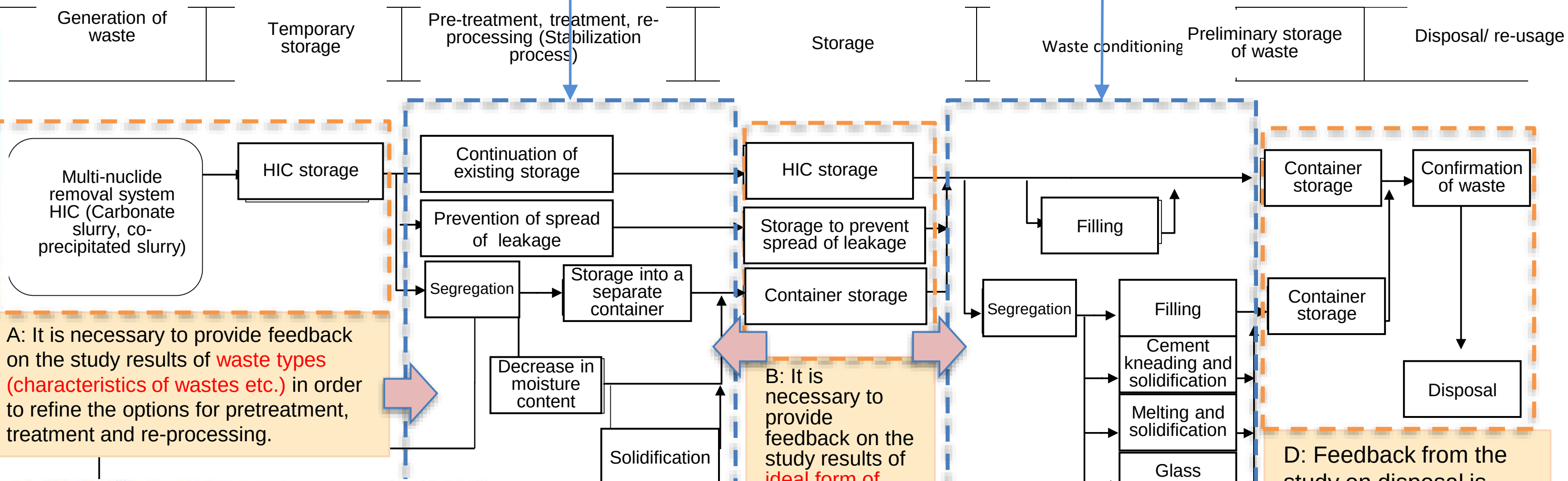
① Multiple options for pre-treatment, treatment and re-processing

② Multiple options for the methods related to waste conditioning

HIC Image (Before SUS reinforcement)

Basic flow



Generation of waste

Temporary storage

Pre-treatment, treatment, re-processing (Stabilization process)

Storage

Waste conditioning

Preliminary storage of waste

Disposal/ re-usage

Multi-nuclide removal system HIC (Carbonate slurry, co-precipitated slurry)

HIC storage

Continuation of existing storage

Prevention of spread of leakage

Segregation

Storage into a separate container

Decrease in moisture content

Solidification

HIC storage

Storage to prevent spread of leakage

Container storage

Filling

Segregation

Filling

Cement kneading and solidification

Melting and solidification

Glass hardening

Sand filling

Container storage

Confirmation of waste

Container storage

Disposal

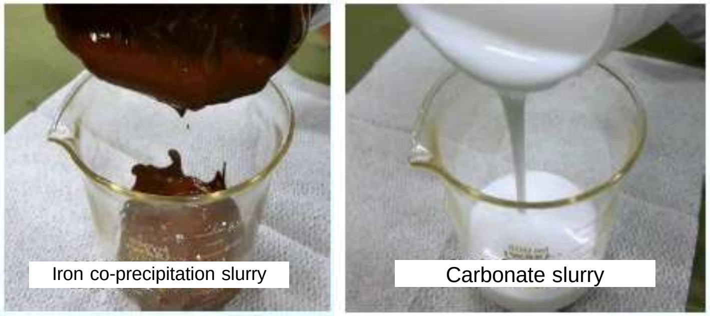
Dismantling/ segregation

A: It is necessary to provide feedback on the study results of waste types (characteristics of wastes etc.) in order to refine the options for pretreatment, treatment and re-processing.

B: It is necessary to provide feedback on the study results of ideal form of storage (anticipated requirements) in order to refine the options for pretreatment, treatment, re-processing.

C: It is necessary to provide feedback on the study results of ideal form of storage (anticipated requirements) in order to refine the options for waste conditioning

D: Feedback from the study on disposal is required in order to refine the options for waste conditioning. (Minimum requirements for waste, such as mechanical strength and multi-nuclide confinement performance)



Iron co-precipitation slurry

Carbonate slurry

Sample image of slurry from the multi-nuclide removal system (Pictures represent simulants)

Combustible material (PE container etc.)

Stream S8

Fig. 1 Example of refining the treatment flow and current issues (Example of HIC slurry)

d. Integration of R&D

- Study policies for current issues -

1. It is necessary to have consistency in waste classification, which will be used during the study of each stage from characterization to disposal.

<Study Policy>

a. To re-organize the classification in order to link it to the radioactivity evaluations in the distant future.

b. To study integrated management by consolidating the inventory information etc. into a waste list.

c. To revise the already created treatment flows into flows considering the nuclides or the physical amounts etc.

2. It is necessary to determine the specific details of the ideal form of storage.

<Study policy>

a. To study the ideal form of storage and examine the pre-treatment, treatment and re-processing required for it.

3. It is necessary to indicate the minimum requirements of a waste form.

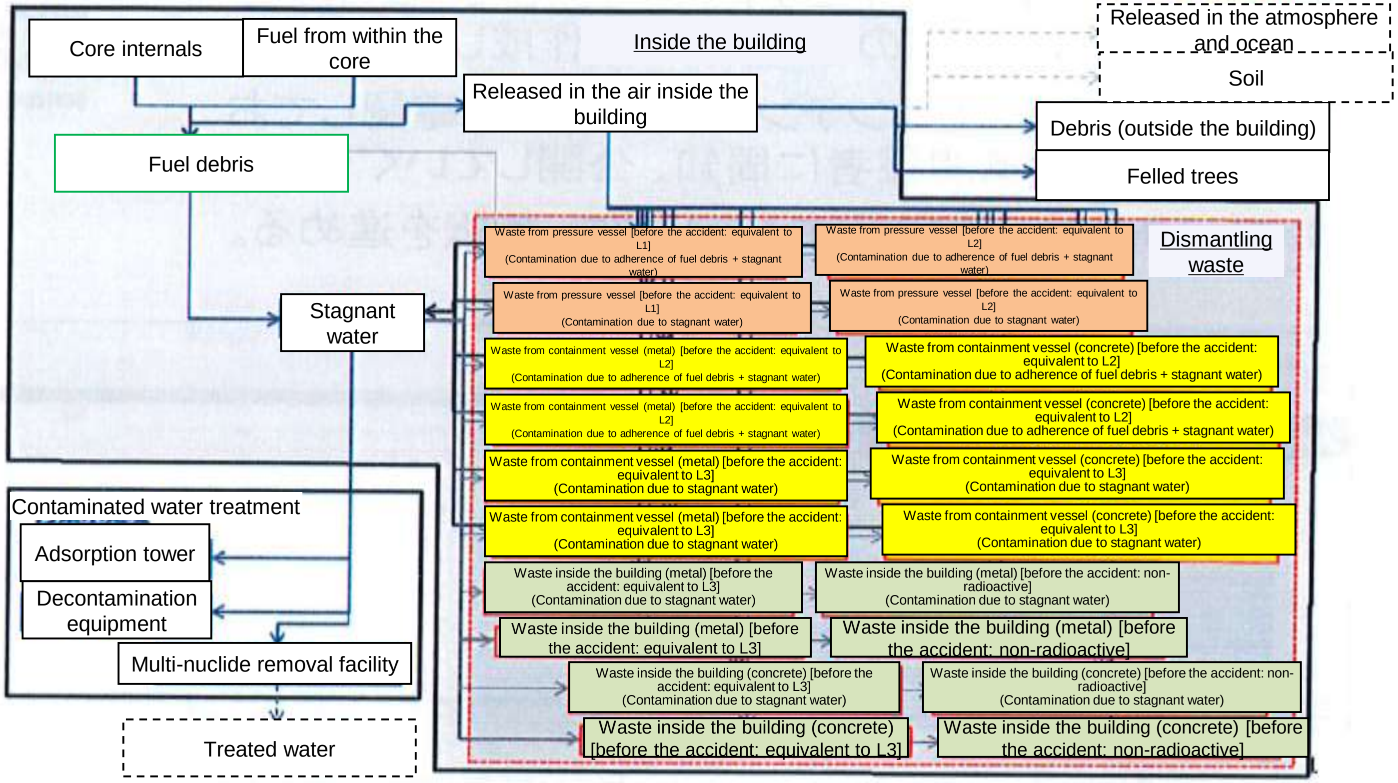
<Study policy>

a. First of all, disposal concepts are considered to confirm the feasibility, in case that a waste form are not required the best confinement performance.

d. Integration of R&D
- Study policies for current issues –
1. Waste classification

In order to link the solid waste at 1F to the radioactivity evaluations in the distant future, it was considered appropriate to broadly classify waste under the following four types. The definitions (proposed) and characteristics of each type of waste were studied. These classifications were also defined in detail.

(1) Dismantling waste, (2) Types of debris, (3) Secondary wastes generated from contaminated



R&D concerning the treatment and disposal of solid waste, Interim report (April 5, 2018), cited from Classification of waste based on contamination.

The study will continue in FY2020

d. Integration of R&D

- Study policies for current issues -

1. Waste classification

(1) Dismantling waste

Definitions (proposed)	The waste which is managed by storage in container units depending on various waste properties and when the waste is generated, in accordance with the decommissioning plan.
Characteristics	The waste present at 1F even before the accident and some of which is radioactively contaminated, etc.

(2) Debris types

Definitions (proposed)	Waste that consists mainly of metal and concrete, but organic matter (gum tape and curing generated during work) is also mixed in it, and the contents are not managed.
Characteristics	The waste present at 1F even before the accident, and variation in the properties of the inventory and materials is large.

(3) Secondary wastes generated from water treatment

Definitions (proposed)	Waste such as used adsorbents generated from contaminated water treatment facility. Note that it does not include the dismantling waste of the contaminated water treatment facility itself.
Characteristics	Properties such as inventory and water content differ depending on when the waste is generated and the water treatment facility at the source of waste generation, but the waste is segregated and managed at the time of generation for each type of adsorbent.

(4) Others

Definitions (proposed)	The waste that is not included in the above-mentioned dismantling waste, types of debris or the secondary wastes generated from contaminated water treatment.
Characteristics	Waste that differs significantly in terms of material or inventory, physical amounts, properties etc. and which is difficult to define uniformly.

d. Integration of R&D
- Study policies for current issues -
1. Waste classification

The detailing of waste classification was carried out jointly with the operators.

For conformity with the input compilation table, a waste management sheet was created for each type of waste and the mechanism to improve the searchability of information was studied.

In FY2019, an example was created for the consolidation of information into the waste management sheet for the main secondary wastes generated from contaminated water treatment.

Fig. 1 Input compilation table

The Waste Management Sheet for each type of waste is maintained so that the details or progress of the R&D results for each item in the input compilation table can be referenced.

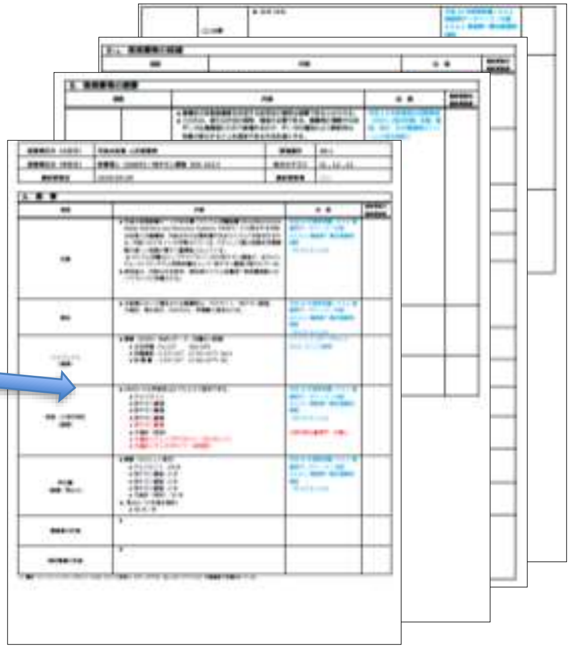


Fig. 2 Waste Management Sheet

d. Integration of R&D
- Study policies for current issues -
2. Ideal form of storage

From “Basic approach to nuclear safety" (Atomic Energy Society of Japan (AESJ))

Purpose of Nuclear Safety

The purpose is to protect humans and the environment from the harmful impact of radiation resulting from nuclear power facilities and their activities.

Basic Principles of Nuclear Safety

Nuclear Safety	Category		Principles	
Protection of humans and the environment from the risk of radiation	1	Responsibility and Management	1	Obligation to safety
			2	Role of Government
			3	Role of regulatory organizations
			4	Leadership and management for safety
			5	Development of safety culture
	2	Protection of humans and the environment	6	Explanation on the validity of the nuclear power facilities and their activities
			7	Risk control for humans and environment and continuous efforts for the same
	3	Confinement of radiation risk source	8	Prevention of accidents and impact mitigation
			9	Preparation and response during emergencies
			10	Protection measures for reducing the existing radiation risk or the uncontrolled radiation risk

Principles related to organizations and systems (which will be studied in the future)

It is necessary to decrease the amount of the site boundary radiation dose and prevent any leakage or diffusion during storage based on these viewpoints

Principles related to disaster prevention measures such as evacuation etc. (which will be studied in future)

Principles related to natural radiation sources (which will be studied in future)

d. Integration of R&D

- Study policies for current issues -

2. Ideal form of storage

Ideal form of storage considering nuclear safety (Proposed)

- ■ Ensure the shielding of radiation.
- ■ Ensure the confinement of radioactive materials. (Maintain in a state where there is no leakage or diffusion, and leakage or diffusion does not take place easily)
- ■ When the gases are released in a controlled manner, ensure that the radioactive materials have been sufficiently diluted by the ventilation and air-conditioning system of the storage facility.

(When hydrogen is discharged through the container vent etc.)

Using the above principles, the form of storage for each type of waste will be studied in consideration of the future waste conditioning treatment and ensuring safety during storage, etc.

For instance, following are the assumptions for the secondary wastes generated from contaminated water treatment such as slurry etc. illustrated by a specific example in FY2019.

The ideal form of storing the other types of waste will also be studied in FY2020.

- The study assumes that the radiation is shielded at the storage facility.
- The study assumes that the radioactive materials are confined inside containers and the storage facilities.

  The amount of free water is reduced as much as possible so as to lower the uncertainty (risk) of any further leakage or diffusion. The study assumes that solidification treatment is not performed considering the effect on future waste conditioning treatment.
- It is assumed that the gas generated from waste is released in a controlled manner. The study assumes that it is ensured that the radioactive materials have been sufficiently diluted by the ventilation and air-conditioning system of the storage facility.

The study will also be continued from the viewpoint of functional requirements with respect to the ideal form of storage.

d. Integration of R&D
- Study policies for current issues -
3. Minimum requirements for waste packages

Identification of factors that have a large impact on refining the waste conditioning treatment for the waste stream

(1) "Necessity of Solidification" has a particularly large impact on the study of waste streams.
(2) "Necessity of Mineralization and Detoxification" has a large impact on refining of the waste stream

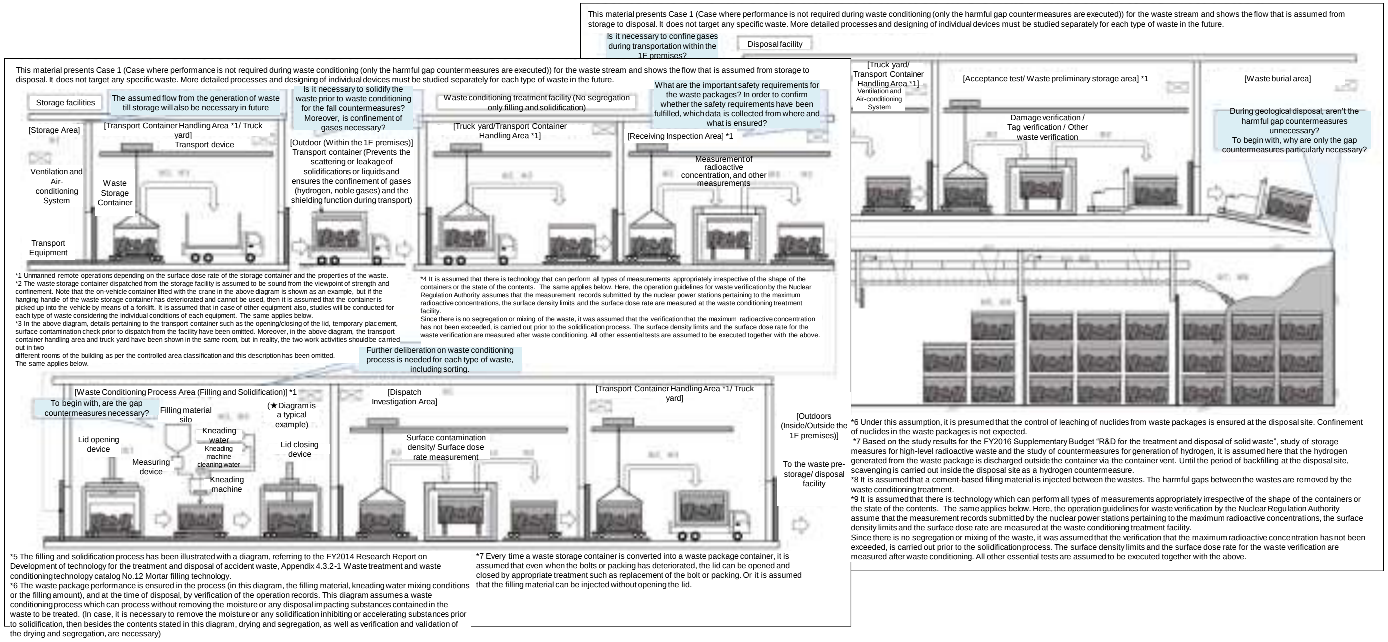
Study of the waste stream when the best waste package performance is not required.

① In order to obtain a technical outlook, a case of waste conditioning treatment wherein the introduction of equipment is as limited as possible, and which is feasible up to disposal, will be assumed as Case 1 (Base case) in the waste stream.
② First of all, in order to minimize the waste conditioning process (equipment introduction), a waste stream will be developed wherein waste package performance such as confinement of waste during waste disposal is not required, and the feasibility of this waste stream will be studied.
③ In Case 1, volume reduction is not considered while identifying issues. (Equipment that has been introduced or is planned to be introduced is excluded)
④ Other cases will also be studied based on Case 1.

d. Integration of R&D
- Study policies for current issues -
3. Minimum requirements for waste packages

Based on the set pre-conditions and through the study of treatment and disposal processes and discussions with the concerned parties, it was decided that the waste packages must have harmful gap countermeasures at the very least.

- It was assumed that the other waste package functions (confinement, strength etc.) will be ensured by means of the containers or at the disposal sites.



This material presents Case 1 (Case where performance is not required during waste conditioning (only the harmful gap countermeasures are executed)) for the waste stream and shows the flow that is assumed from storage to disposal. It does not target any specific waste. More detailed processes and designing of individual devices must be studied separately for each type of waste in the future.

*1 Unmanned remote operations depending on the surface dose rate of the storage container and the properties of the waste.
*2 The waste storage container dispatched from the storage facility is assumed to be sound from the viewpoint of strength and confinement. Note that the on-vehicle container lifted with the crane in the above diagram is shown as an example, but if the hanging handle of the waste storage container has deteriorated and cannot be used, then it is assumed that the container is picked up into the vehicle by means of a forklift. It is assumed that in case of other equipment also, studies will be conducted for each type of waste considering the individual conditions of each equipment. The same applies below.
*3 In the above diagram, details pertaining to the transport container such as the opening/closing of the lid, temporary placement, surface contamination check prior to dispatch from the facility have been omitted. Moreover, in the above diagram, the transport container handling area and truck yard have been shown in the same room, but in reality, the two work activities should be carried out in two
different rooms of the building as per the controlled area classification and this description has been omitted.
The same applies below.

*4 It is assumed that there is technology that can perform all types of measurements appropriately irrespective of the shape of the containers or the state of the contents. The same applies below. Here, the operation guidelines for waste verification by the Nuclear Regulation Authority assumes that the measurement records submitted by the nuclear power stations pertaining to the maximum radioactive concentrations, the surface density limits and the surface dose rate are measured at the waste conditioning treatment facility.
Since there is no segregation or mixing of the waste, it was assumed that the verification that the maximum radioactive concentration has not been exceeded, is carried out prior to the solidification process. The surface density limits and the surface dose rate for the waste verification are measured after waste conditioning. All other essential tests are assumed to be executed together with the above.

*5 The filling and solidification process has been illustrated with a diagram, referring to the FY2014 Research Report on Development of technology for the treatment and disposal of accident waste, Appendix 4.3.2-1 Waste treatment and waste conditioning technology catalog No.12 Mortar filling technology.
*6 The waste package performance is ensured in the process (in this diagram, the filling material, kneading water mixing conditions or the filling amount), and at the time of disposal, by verification of the operation records. This diagram assumes a waste conditioning process which can process without removing the moisture or any disposal impacting substances contained in the waste to be treated. (In case, it is necessary to remove the moisture or any solidification inhibiting or accelerating substances prior to solidification, then besides the contents stated in this diagram, drying and segregation, as well as verification and validation of the drying and segregation, are necessary)

*7 Every time a waste storage container is converted into a waste package container, it is assumed that even when the bolts or packing has deteriorated, the lid can be opened and closed by appropriate treatment such as replacement of the bolt or packing. Or it is assumed that the filling material can be injected without opening the lid.

This material presents Case 1 (Case where performance is not required during waste conditioning (only the harmful gap countermeasures are executed)) for the waste stream and shows the flow that is assumed from storage to disposal. It does not target any specific waste. More detailed processes and designing of individual devices must be studied separately for each type of waste in the future.

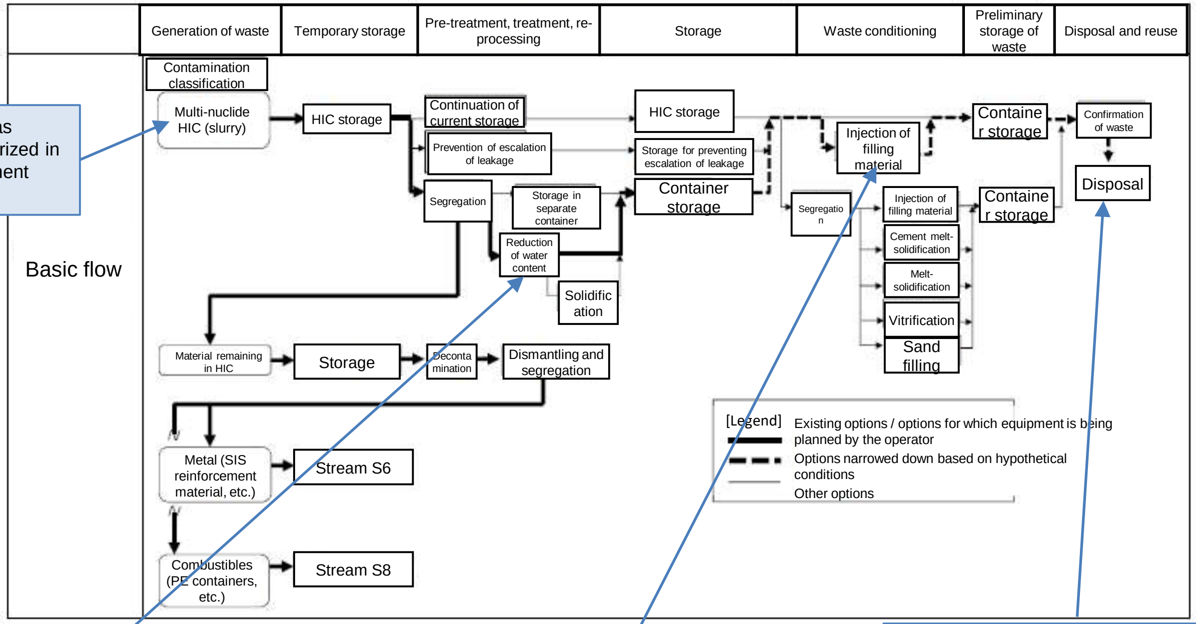
*6 Under this assumption, it is presumed that the control of leaching of nuclides from waste packages is ensured at the disposal site. Confinement of nuclides in the waste packages is not expected.
*7 Based on the study results for the FY2016 Supplementary Budget "R&D for the treatment and disposal of solid waste", study of storage measures for high-level radioactive waste and the study of countermeasures for generation of hydrogen, it is assumed here that the hydrogen generated from the waste package is discharged outside the container via the container vent. Until the period of backfilling at the disposal site, scavenging is carried out inside the disposal site as a hydrogen countermeasure.
*8 It is assumed that a cement-based filling material is injected between the wastes. The harmful gaps between the wastes are removed by the waste conditioning treatment.
*9 It is assumed that there is technology which can perform all types of measurements appropriately irrespective of the shape of the containers or the state of the contents. The same applies below. Here, the operation guidelines for waste verification by the Nuclear Regulation Authority assume that the measurement records submitted by the nuclear power stations pertaining to the maximum radioactive concentrations, the surface density limits and the surface dose rate are measured at the waste conditioning treatment facility.
Since there is no segregation or mixing of the waste, it was assumed that the verification that the maximum radioactive concentration has not been exceeded, is carried out prior to the solidification process. The surface density limits and the surface dose rate for the waste verification are measured after waste conditioning. All other essential tests are assumed to be executed together with the above.

Conversion of storage containers to waste package containers, and process verification and validation for waste package performance were set as the preconditions. The verification of these preconditions will be needed in future in order to verify feasibility.

d. Integration of R&D
- Proposal for refining the treatment flow -

The refining of the treatment flow was carried out for the main secondary wastes generated from contaminated water treatment based on the study results for ideal form of storage and for the minimum functions required for waste packages.

The classification was detailed and summarized in the Waste Management Sheet.



Generation of waste
Temporary storage
Pre-treatment, treatment, re-processing
Storage
Waste conditioning
Preliminary storage of waste
Disposal and reuse

Basic flow

Contamination classification
Multi-nuclide HIC (slurry)
HIC storage
Continuation of current storage
Prevention of escalation of leakage
Segregation
Storage in separate container
Reduction of water content
Solidification
HIC storage
Storage for preventing escalation of leakage
Container storage
Injection of filling material
Container storage
Confirmation of waste
Disposal
Segregation
Injection of filling material
Cement melt-solidification
Melt-solidification
Vitrification
Sand filling
Container storage
Material remaining in HIC
Storage
Decontamination
Dismantling and segregation
Metal (SIS reinforcement material, etc.)
Stream S6
Combustibles (PE containers, etc.)
Stream S8

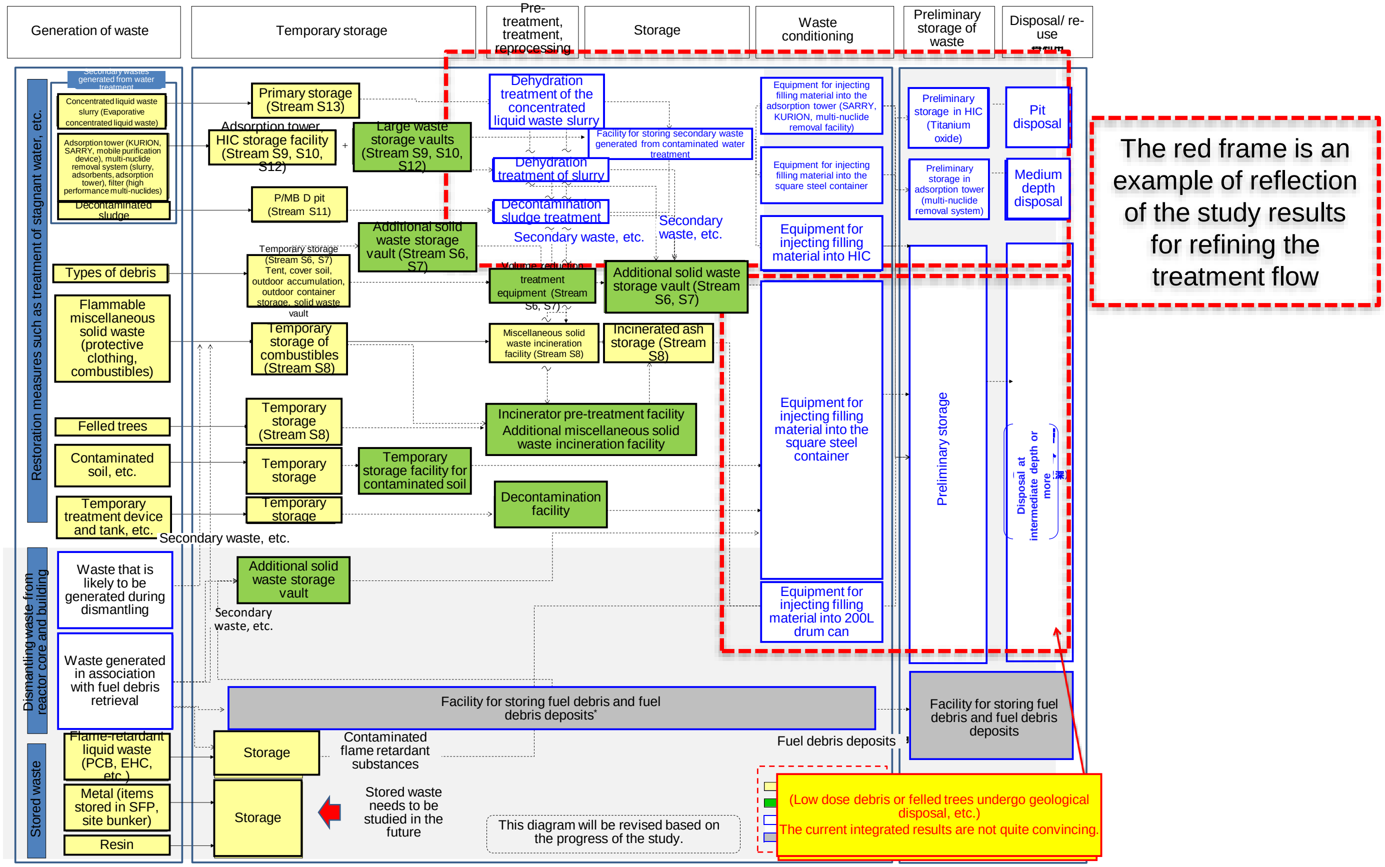
[Legend]
Existing options / options for which equipment is being planned by the operator
Options narrowed down based on hypothetical conditions
Other options

From the TEPCO HD plan and the study of the ideal form of storage, it was assumed that the moisture in the secondary wastes generated from contaminated water treatment will be reduced.
It was assumed that the waste will not be solidified.

From the study of the minimum requirements for the waste packages, it was assumed that filling material will be injected as the minimum response. In this case, it was assumed that a storage container will be converted into a waste package container.

Geological disposal (marginal depth or deeper) was assumed from the results of the study on the disposal concept. Moreover, the waste conditioning treatment facility is assumed to carry out the process of verifying and validating waste packages.

d. Integration of R&D
- Example of reflection into the waste stream (Dashboard) -



This diagram will be revised based on the progress of the study.

The red frame is an example of reflection of the study results for refining the treatment flow

(Low dose debris or felled trees undergo geological disposal, etc.)
The current integrated results are not quite convincing.

※燃料デブリ取り出しに関する研究開発の検討結果を反映していくものとする
2019/9/23東芝ｴﾈﾙｷﾞｰｼｽﾃﾑｽﾞ作成

Fig.1 Example of reflection in the waste stream (Dashboard)

d. Integration of R&D
- Summary -

Summary of FY2019 Results

1. The waste classification was reviewed and defined in detail, and summarized in the Waste Management Sheet.
2. The ideal form of storage (proposed) was studied and the required treatments were examined.
3. The cases in which the best waste package performance is not expected were studied, various R&D results were incorporated and a waste stream proposal that indicated the current status and required the least amount of treatment (the load on the disposal side is large) was developed.

Main issues in the third stage highlighted through the R&D in FY2019

- ✓ The integrated results of the R&D outcomes for Case 1 suggested based on the current evaluation that countermeasures such as solidification or man-made barriers would become necessary for near surface or deeper disposal even for the comparatively low radiation wastes such as the low radiation debris (surface dose rate of 0 to 5 μSv/h) or the felled trees. A further study is necessary from a rational viewpoint.

  Especially, regarding the settings for important nuclides (C-14 and I-129) which are below the detection lower limits, it is important to improve the degree of certainty of the inventory presumptions that are done on the basis of the contamination mechanism.
- ✓ During the study of Case 1, it was assumed that the harmful gap countermeasures were necessary during the waste conditioning treatment, and the use of the current storage containers as waste package containers and the verification and validation of the waste package performance processes were assumed to be the preconditions. In order to ensure feasibility, it is necessary to verify the technical support for these preconditions with respect to each type of waste.

FY2020 Plan (Proposed)

A waste stream will be developed as Case 2, in case that existing concepts concerning the light water reactor can be applied to waste management in Fukushima Daiichi NPS. (Excluding disposal)

3. R&D Management

- Human resource development, knowledge gathering, clarification of conditions and specifications, setting indicators -

■ Mid-and-long-term human resource development

- ○ The IRID Symposium 2019 was held in Iwaki city, Fukushima Prefecture on August 1, 2019. At the symposium, an exhibition panel was provided to introduce research results and future plans of the project for promoting understanding of research and supporting educational activities.
- ○ At the Fall Session of the Atomic Energy Society of Japan (Sept 13 - Sept 15, 2019), presentation on 12 research results were delivered to promote understanding of research and support educational activities.

■ Gathering of knowledge from Japan and overseas

- ○ Cooperation with research institutions (CRIEPI) has been continued since FY2014. Furthermore, information on the same cases was obtained from research institutions overseas and investigation on the information was conducted. Useful information was acquired from experts and experienced persons.
- ○ The IRID design review meeting was conduced to confirm the validity of the output that is an objective of the project. (on June 4, July 19, December 10, 2019 and February 25, 2020)

■ Clarification of test conditions and development specifications

- ○ The IRID design review meeting was conducted to exchange opinions with experts from and outside IRID concerning preconditions, hypothetical conditions and details of the project output, etc. on June 4, 2019. The test conditions and specifications were clarified.

■ Setting an index for determining goal achievement

- ○ To start an index setting, an index for determining the achievement of project goals were considered, and the targeted Technology Readiness Level (TRL) was determined.

- Coordination with other R&D, and research and operation management -

- Coordination with the reactor decommissioning task and other R&D
  - ○ Information related to the progress made by each project and the challenges faced were shared by conducting regular meetings between concerned persons from related projects. Moreover, the mechanism (archive) for sharing project plans, management of information on results, which has been developed until now, will continue to be developed and utilized.
  - ○ In order to carry out thorough research and development related to treatment and disposal of waste generated during fuel debris retrieval, without leaving anything out, the R&D team participated in the working of the Canister Project and the Retrieval Project so as to be able to share information from the respective projects.

    (April 22, May 20, June 17, 2019 and February 18, 2020)

- Research management
  - ○ Persons concerned with this project met (Waste treatment and disposal project coordination meeting) every month on a regular basis. During the meeting the R&D schedule and progress status were shared, and in addition, policies for resolution of issues encountered were decided and accordingly measures were implemented.

    (April 5, May 10, June 6, July 4, August 2, September 5, October 3, November 5, December 6, 2019 and January 9, February 2, March 2, 2020#
    #Meeting conducted in writing)

- Reflection of site information of Fukushima Daiichi, etc. and operation management considering on-site applicability
  - ○ A "Memorandum of understanding related to initiatives for decommissioning Fukushima Daiichi" was exchanged between IRID and TEPCO, the required management system was developed in cooperation with TEPCO and appropriate safety measures were implemented.

- Project report, communication of information, alternative plans -

- Project report
  - ○ The first debrief meeting was held on October 29, 2019 and in addition, a progress report was submitted to the MRI Secretariat every month-end.
- Enhancing communication of information
  - ○ The results of this report were posted on the IRID website in an attempt to communicate information to the general public in an easy-to-understand manner. Moreover, the results of this project were communicated by holding presentations at various conferences held within Japan and overseas by AESJ or overseas institutions, etc.
- Advance preparation of alternative plans
  - ○ Alternative plans were studied in advance as required, in preparation for circumstances during the project period, wherein the project does not progress as planned. However, such circumstances did not arise during this project.