IRID

Subsidy Project of Decommissioning and Contaminated Water Management in the FY 2018 Supplementary Budgets

Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Internal Structures*

Research Report for FY2019

August, 2020

International Research Institute of Technology (IRID)

*This project *was* named as *Development of Technology for Retravel of Fuel Debris and Internal Structure,* when the project started. According to the development plan of decommissioning research in FY 2020 disclosed at the 75th Secretariat Team Meeting for Countermeasures for Decommissioning and Contaminated Water Treatment, the project name was changed to *Development of Technology for Further Increasing the Scale of Retravel of Fuel Debris and Internal Structures*.

Contents

1. Purposes and goals of *Development of Technology for Further Increasing the scale of Fuel Debris and Internal Structures*

【Purposes of *Development of Technology for Further Increasing the scale of Retrieval of Fuel Debris and Internal Structures*】

In Tokyo Electric Power Company (TEPCO) Holdings Inc. Fukushima Daiichi Nuclear Power Stations (NPS), it is assumed that nuclear fuel has melted with reactor internals and existed as fuel debris at the reactor pressure vessel (RPV) and primary containment vessel (PCV).

Fuel debris in the RPV and PCV has been currently in a sub-critical state. However, as the reactor building (R/B), RPV and PCV were damaged by the accident, the plant has been in unstable conditions which are different from the original design. Therefore, fuel debris should be retrieved to maintain a sub-critical state so that radioactive materials will not spread, aiming to ensure the stable conditions.

Against the above background, this project started, aiming at accomplishing a large scale of fuel debris retrieval in cooperation with TEPCO Holdings for engineering and project management based on *the Mid-and-Long Term Roadmap toward the Decommissioning of TEPCO's Fukushima Daiichi NPS* (herein after Mid-and-Long Term Roadmap). The project results will be utilized for engineering conducted by TEPCO.

This project aims at smooth responses to decommissioning and contaminated water management for the Fukushima Daiichi NPS, as well as promotion of technology improvement in Japan, which contribute to technological development for the decommissioning of Fukushima Daiichi NPS and contaminated water management, based on the Mid-and-Long Term Roadmap and the development plan of decommissioning study in FY2019 (the 63rd Secretariat Team Meeting for Countermeasures for Decommissioning and Contaminated Water Treatment).

Specifically, the project development is planned for removal technology for interference objects to establish an access route in the R/B and PCV, fuel debris dust collecting technology and various element technologies to ensure the safety system during retrieving fuel debris and the reactor internals.

【 Project goal】

The project sets a goal to accomplish a large scale of fuel debris retrieval and conducts study according to the Mid-and-Long Term Roadmap.

【 Duration of project】April 2019 – March 2021 (two years)

2. Project achievements in the previous fiscal year (FY 2017-2018)

(1) Fundamental technology for retrieving fuel debris and internal structures

① Development of fuel debris collecting systems

Assuming that fuel debris is collected from the bottom of primary containment vessel (PCV), technological information for powdery fuel debris collecting system was organized. Additionally, the technological information on tools for processed fuel debris as well as pebble-like fuel debris was organized, which is effective for collecting fuel debris.

② Development of fuel debris cutting and collecting systems

A confirmation test for process capability of the Molten Core Concrete Interaction (MCCI) by chisel process and ultrasonic core boring was conducted to confirm processing characteristics and speed. In addition, components of the MCCI products and the test production method for simulated fuel debris are studied, and data on the distribution of particle diameters was also obtained by analysis of waste liquid that was processed in a test by using an actual prototyped test body.

③ Development of methods for preventing the spread of fuel debris

In order to prevent spreading fuel debris at the bottom of PCV into vent pipes and suppression chamber (S/C) during fuel debris retrieval work, element tests were conducted and confirmed the feasibility of remote installation, assuming that a weir is installed at PCV.

④ Development of element technology for work cells

By comparing confinement functions of the cell and technology for connecting PCV, these technologies were reviewed. In addition, element tests for inflatable seals that seals when connecting the cell and PCV were conducted to confirm the feasibility of work steps and to identify issues.

⑤ Development of removal technology for interference objects during fuel debris retrieval

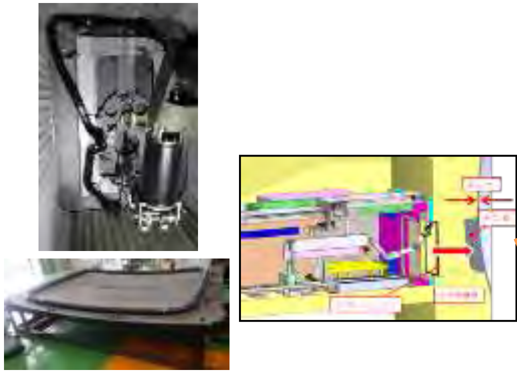
- ✓ Element tests for removing interference objects at the reactor bottom were conducted by the Partial Submersion Top Access Method, and confirmed basic cutting methods such as CRD housing and collection methods for cut pieces.
- ✓ Element tests for removing interference objects of the biological shield wall (BSW) and inside/outside the pedestal were conducted by the Partial Submersion Side Access Method, and offered the prospect of the feasibility for basic cutting and collecting work in narrow places.
- ✓ Issues were identified by conducting combination tests of a robot arm and an access rail. The feasibility of basic actions related to removal of fuel debris and interference objects was confirmed.

⑥ Development of remote maintenance technology for fuel debris retrieval device

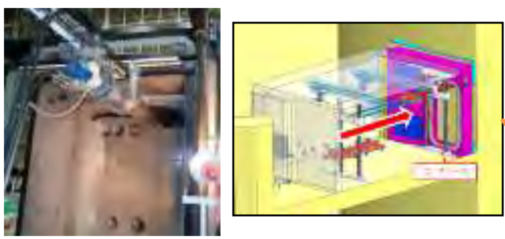
A basic concept of remote maintenance, for example: equipment in the cell in case of the Partial Submersion Side Access Method, was discussed to clarify maintenance classifications and maintenance equipment.

2. Project achievements in the previous fiscal year (FY 2017-2018)

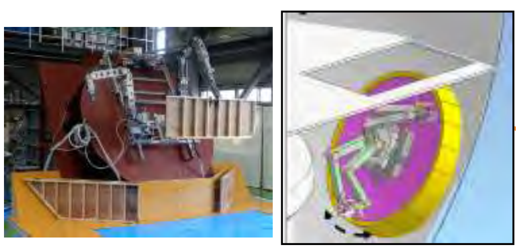
(1) Fundamental technology for retrieving fuel debris and reactor internals



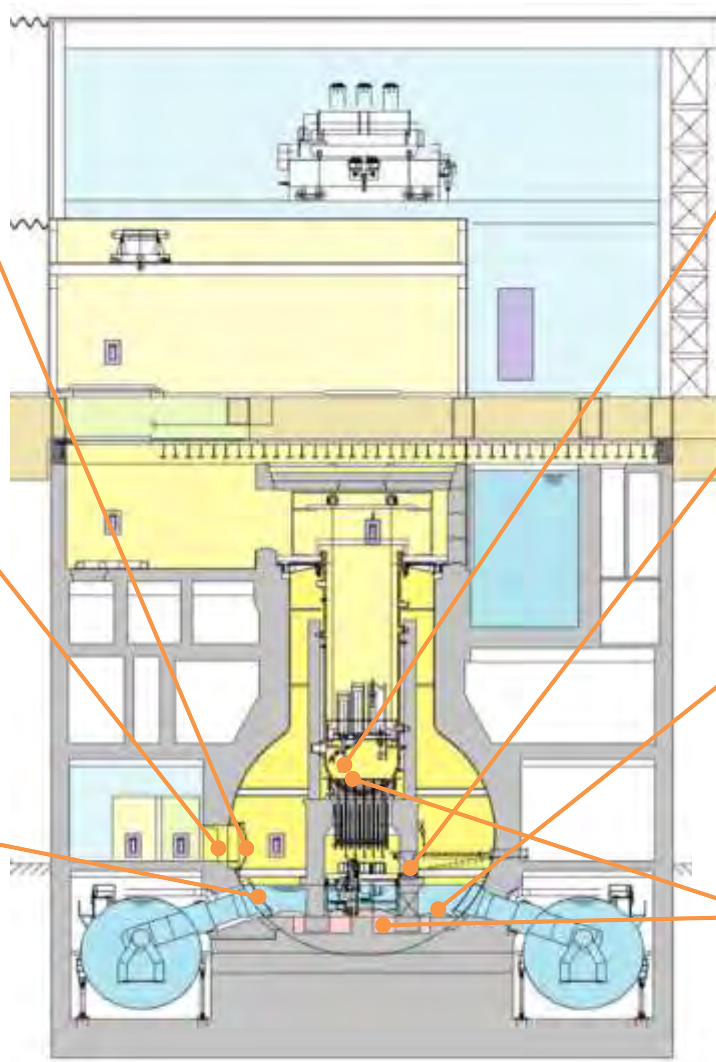
Work cell sealing method (inflatable seal)

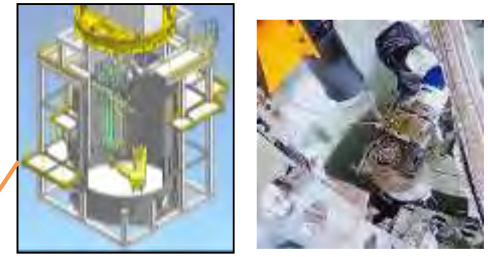


Opening holes of biological shielding wall



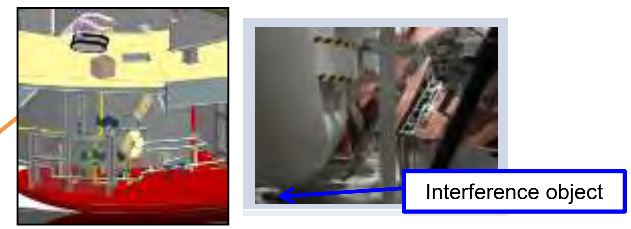
Equipment for preventing the spread of contamination into S/C





Technological development for removal of interference objects and the reactor bottom

Confirmation of operation performance for combination of robot arm and access rail



Interference object removal method by using fuel debris retrieval device as the side access method

Effective processing methods from the aspect of prevention of fuel debris spreading

2. Project achievements in the previous fiscal year (FY 2017-2018)

(2) Safety system technology during retrieving fuel debris and internal structures

(i) Technology development for confinement functions

It was confirmed that Airflow analysis through the GOTHIC code could identify the shape of the primary containment vessel (PCV), geometry information such as locations of damaged openings, air volume of nitrogen injection and PCV exhaust, air flow caused by air volume changes, distribution of hydrogen and oxygen concentrations, and qualitative characteristics of effects on dust behaviors. As a result, an airflow analysis evaluation method was established to contribute the system design for nitrogen injection and PCV exhaust system, aiming to secure confinement function during fuel debris retrieval work.

(ii) Technology development for collection and removal of dust generated from fuel debris (the air phase)

Existing technologies were surveyed to select technology that has advantages. The information on comparison study of equipment type is necessary . Missing data in the necessary information, which is to be applied to the decommissioning of Fukushima Daiichi Nuclear Power Station (NPS), was obtained from element testing.

(iii) Technology development for collection and removal of dust generated from fuel debris (the liquid phase: non-solubility)

Existing technologies were surveyed to select technology that has advantages. The information on comparison study of equipment type is necessary. Missing data in the necessary information, which is to be applied to the decommissioning of Fukushima Daiichi NPS, was obtained from element testing.

(iv) Technology development for collection and removal of dust generated from fuel debris (the liquid phase: solubility)

Existing technologies were surveyed to select technology that has advantages (adsorbent, etc.).Evaluation on removal capability in the water quality conditions during fuel debris retrieval is difficult, therefore, element test for Am was conducted as Pu and Am can be dominant in exposure evaluation. The data on removal capability which is used for the primary screening to apply applicable technology for NPS was obtained.

(v) Study on the α nuclide monitoring system associated with fuel debris retrieval

- The gas system can be monitored by using existing α monitoring technology.
- A continuous monitoring for the liquid system might be difficult by using existing α monitoring technology. A target level of concentration in the liquid is not defined from the aspect of workers and public exposure up to Level 3, therefore, manual analysis can be possible if measurement time requirement is long.

(vi) Optimization study on ensuring safety for fuel debris retrieval methods and systems

Exposure evaluation results were lower than the judgement criteria, and thus, the environment control system during fuel debris retrieval can be applicable.

2. Project achievements in the previous fiscal year (FY 2017-2018)

(3) Criticality Control Technology for Retrieval of Fuel Debris and Internal Structures

(i) Establishment of criticality control methods

① Study of control methods and procedures reflecting the study on retrieval methods

The consistency between daily retrieval target, schedule and criticality control requirements was confirmed.

② Establishment of methods for controlling criticality while increasing the scale of fuel debris retrieval in stages

A control method for full-scale retrieval was determined based on the internal investigation results.

(ii) Implementation of criticality control technology

Various tests were conducted to confirm how MCCI products can be processed using chisel and by means of ultrasonic core boring, and the processing characteristics and speed were verified. Moreover, the methods for creating prototypes of the components of MCCI products or simulated fuel debris were studied, and in addition, data pertaining to the particle size distribution, etc. was collected by processing actual prototypes during the processing test and analyzing the wastewater generated during the processing.

① Sub-criticality measurement and criticality approach monitoring technology

- Specifications for the monitoring systems and detector unit that can be operated with a robot arm, were formulated.
- The feasibility of sub-criticality measurement in a large system was verified by simulating the actual equipment.

② Re-criticality detection technology

- Detection performance of criticality was verified by using an operation method as part of the negative pressure control system.
- The calibration accuracy was quantified by establishing detector calibration technology.

③ Criticality prevention technology

- The concept of the method of spraying non-soluble neutron absorber was developed and the measurement concept for confirming the effect after spraying.
- It was confirmed that long-term irradiation of non-soluble absorber did not affect the integrity of canisters.
- The impact of using soluble neutron absorber (environmental impact at the time of leakage, compatibility with concrete) was evaluated.

3. Project overviews

3.1 Cooperation with other projects

This project is cooperated with other projects described below and holds joint meetings if necessary.

Development of technology for further increasing the scale of retrieval of fuel debris and reactor internals

- Development of fuel debris retrieval method
- Development of handling technology for fuel debris
  - Fuel debris collection and storage system
  - Treatment of fuel debris and deposits
  - Sorting of fuel debris and radioactive waste
- Technological development related to ensuring the safety during fuel debris retrieval
  - Confinement functions
  - Prevention of criticality and monitoring management method

Sharing of analysis needs/results

Characterization

Upgrading of the comprehensive understanding of conditions inside the reactor

Development of technology for fuel debris analysis/characterization

・Investigation needs /sharing of investigation results

Internal investigation

Development of Technology for Investigation inside RPV

Development of Technology for Detailed Investigation inside PCV

・Sharing of safety scenarios (during operation to stop water and retrieve fuel debris)

・Coordination of work steps for stopping water leakage

Construction of water circulation system

Development of technology for accessing and connecting inside PCV that has high applicability to the water circulation system.

Coordination of storage and transfer methods

Collection, transfer and storage technologies

Development of technology for collection, transfer and storage of fuel debris

・Sharing of safety scenarios

・Coordination of work steps

Increasing the scale of fuel debris retrieval in stages

Development of technology for increasing the scale of fuel debris retrieval in stages

・Needs of analysis

・Sharing of results

Dust collection

Development of technology for dust collection system of fuel debris

Coordination of collection and transfer methods

Solid waste

R&D for treatment and disposal of solid waste

3. Project overviews

3.2 Basic policy for developing technologies for fuel debris retrieval

The main response policies for implementing the plans under this project are described below.

[Basic policy]

Technology for establishing the access route, technology for collecting fuel debris and technology for maintaining the confinement function, which will be required for carrying out fuel debris retrieval work in an even large scale, shall be studied.

Moreover, from amongst the matters that had undergone design study as part of the Project for Development of Fundamental Technology, Project for Advancement of the System, or the Criticality Control Project during the previous fiscal year, studies on matters in which issues were found shall be materialized.

[Results based on the basic policy]

- **Method for establishing the access route for fuel debris retrieval, work procedures and feasibility of the device**
- **Collection method depending on the condition of fuel debris, method of storing fuel debris in the canister, and system feasibility**
- **Results of the study of adsorbent related data pertaining to the treatment of fuel debris and deposits, and that of the conceptual system of the wastewater treatment facility**
- **Results of technology investigation required for sorting the fuel debris and radioactive waste**
- **Technology related to the confinement function and the prevention and monitoring of criticality for ensuring safety during fuel debris retrieval work**

(Techniques for predicting the effect of removing aerosol from dust, method for connecting PCV and access tunnel, feasibility of sub-criticality measurement, etc.)

Specific development items and implementation policies are indicated in the following slides.

3. Project overviews

3.2 Basic policy for developing technologies for fuel debris retrieval

Based on the policies mentioned on the previous slides, implementation policies for each development item involving public participation projects are specified below.

Development items involving public participation projects	Implementation policy (proposed)	Reference
1) Development of fuel debris retrieval method	Technology shall be developed for establishing the access route based on site information, which will be needed to retrieve fuel debris existing in RPV and PCV. Moreover, a system for supporting the operation of the remote operation device, technology for preventing the spread of contamination outside the PCV and technology believed to be needed for establishing the access route, considering the construction of a shielding structure for exposure reduction in the reactor building (R/B), shall be developed.	**No.20 onwards**
2) Development of fuel debris handling technology (i) Technological development of the fuel debris collection and storage system	The collection method depending on the condition of fuel debris, and the method and system for storing fuel debris in the canister shall be developed for efficient fuel debris retrieval, and element tests shall be implemented as required to check feasibility.	**No.143 onwards**
(ii) Technological development pertaining to the treatment of fuel debris and deposits	Element tests shall be implemented related to adsorption technology for removing soluble nuclides that are believed to be dissolved in circulating cooling water from the fuel debris, and the most suitable adsorbent shall be selected. Moreover, treatment technology for separating solid materials from liquid and storing them, shall be developed considering the storage efficiency, remote operation, maintenance, etc. and the conceptual system design of the wastewater treatment facility shall be created.	**No.167 onwards**
(iii) Investigation of technologies related to sorting fuel debris and radioactive waste	Technologies required for sorting the matter retrieved from inside the PCV, into fuel debris and radioactive waste, shall be investigated.	**No.204 onwards**
3) Technological development related to ensuring safety during the fuel debris retrieval work (i) Development of element technology for confinement functions	Research and development shall be carried out concerning the combination of aerodynamic analysis of the inside of the PCV, which is needed for estimating the behavior of dust containing alpha nuclides inside the PCV, and the technology for analyzing aerosol behavior, and in addition, the effect of removing aerosol from the dust shall be estimated, appropriate monitoring technology shall be selected and the monitoring location shall be studied. Moreover, the structure of the connection parts, method, inspection, maintenance of the sealing material, etc. shall be studied, as technological development for ensuring the confinement function in the parts connected with existing structures such as the PCV, and the necessary element tests shall be implemented to check technical feasibility.	**No.229 onwards**
(ii) Development of element technology for preventing and monitoring criticality	The accuracy of sub-criticality measurement with a large and complex fuel distribution system shall be verified to check feasibility of sub-criticality measurement. Moreover, the site applicability of the neutron detector shall be confirmed. The usage methods of non-soluble neutron absorbers, such as the method of using the non-soluble neutron absorber differently depending on the condition of fuel debris during fuel debris retrieval, conceptual design of the absorber injection device, etc. shall be studied.	**No.271 onwards**

4. Project Implementation Schedule

[Legend]
- :Plan
- :Plan (After amendments)*
- :Consideration of an early start
- :Implementation as required

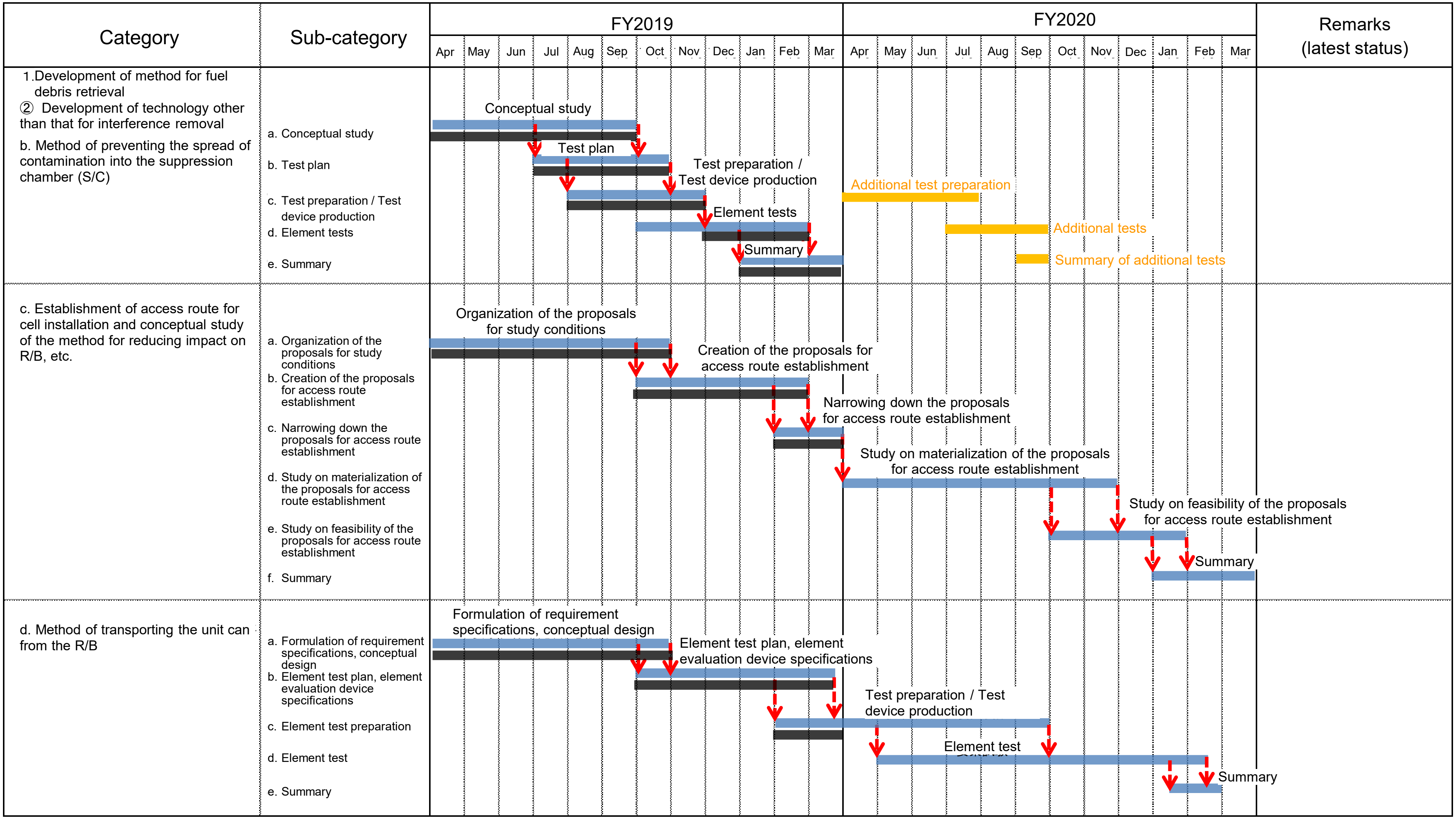
Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (1/7)

Category	Sub-category	FY2019 (Apr–Mar) / FY2020 (Apr–Mar)	Remarks (latest status)
1 Development of method for fuel debris retrieval ① Development of interference removal technology a. Method of retrieving and transporting large structures by accessing from the top.	a. Conceptual study b. Element test plan c. Preliminary tests needed for the conceptual study d. Element test preparation e. Element tests f. Summary	Conceptual study Element test plan Preliminary tests Element test preparation (Test device production) Element tests Summary	
b. Method of removing interferences from inside and outside the pedestal by accessing from the side.	a. Conceptual study / Issue identification b. Test plan c. Test preparation / Test device production d. Element tests e. Summary	Conceptual study / Issue identification Conceptual study / Issue identification Test plan Test plan (work outside the pedestal) Test plan (work inside the pedestal) Test preparation / Test device production Test preparation / Test device production (work outside the pedestal) Test preparation / Test device production (work inside the pedestal) Element tests Element test (work outside the pedestal) Element test (work inside the pedestal) Summary Summary (work outside the pedestal) Summary (work inside the pedestal)	
② Development of technology other than that for interference removal a. Development of remote operation support method in environments with low visibility and narrow spaces	a. Conceptual study b. Preparation and verification of the manipulator control software c. Mock-up preparation and verification d. Summary	Conceptual study Preparation and verification of the manipulator control software Mock-up preparation and verification Summary	

* The plan was revised to reflect the status of progress of the study and the results of element tests.

4. Project Implementation Schedule

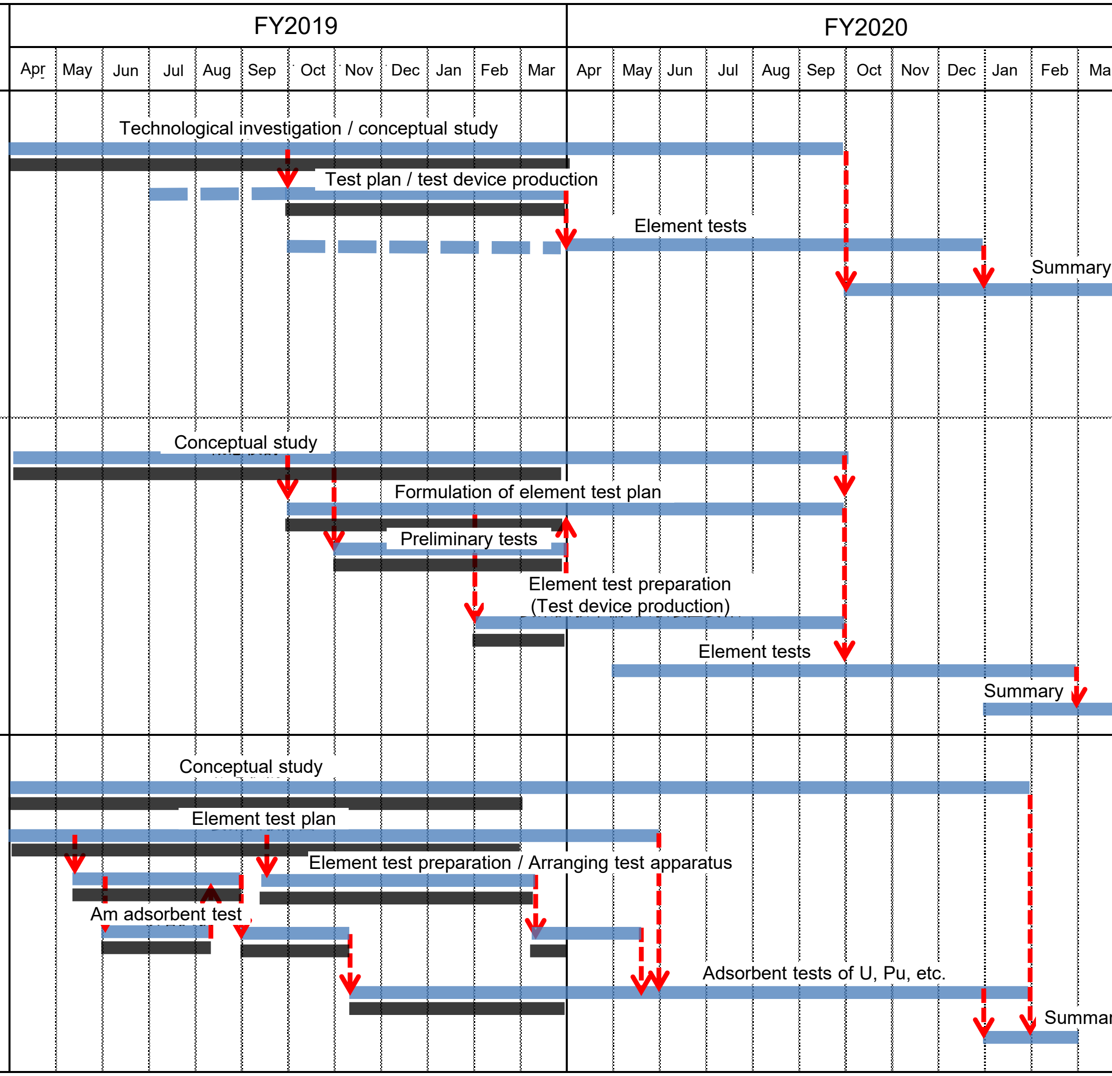
Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (2/7)



4. Project Implementation Schedule

Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (3/7)

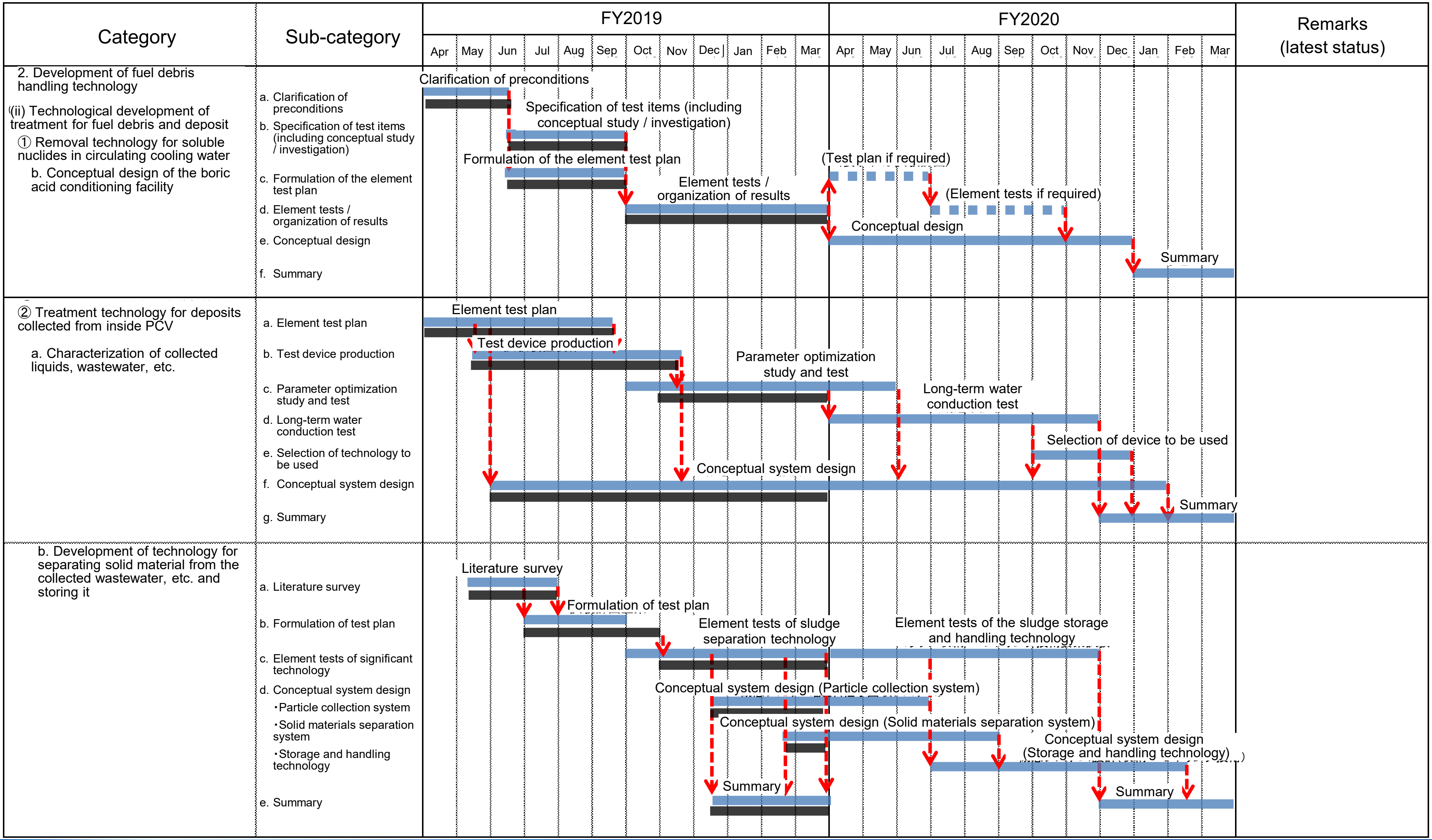
Category	Sub-category	Remarks (latest status)
2. Development of fuel debris handling technology (i) Technological development of the fuel debris collection and storage systems a. Development of suction collection system for particulate fuel debris	a. Technological investigation / conceptual study b. Test plan / test device production c. Element tests d. Summary	
b. Development of technology for transferring fuel debris and waste	a. Conceptual study b. Formulation of element test plan c. Preliminary tests needed for the conceptual study d. Element test preparation e. Element tests f. Summary	
(ii) Technological development of treatment for fuel debris and deposit ① Removal technology for soluble nuclides in circulating cooling water a. Conceptual system design of soluble nuclide removal facility	a. Conceptual study b. Element test plan c. Element test preparation d. Preliminary tests needed for the element test plan e. Element tests f. Summary	



4. Project Implementation Schedule

No.13

Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (4/7)



4. Project Implementation Schedule

Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (5/7)

Category	Sub-category	FY2019 (Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar)	FY2020 (Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar)	Remarks (latest status)
2. Development of fuel debris handling technology (iii) Survey on sorting technology for fuel debris and radioactive wastes	a. Organization of preconditions and scenario proposals	Organization of preconditions and scenario proposals		
	b. Survey of technologies required for sorting fuel debris	Technological survey		
	c. Evaluation of the feasibility of fuel debris sorting scenarios	Feasibility evaluation		
	d. Summary	Summary		
3. Development of technology for ensuring safety during fuel debris retrieval work (i) Development of element technology for confinement functions ① Technology for prediction of dust behaviors in PCV	a. Improvement in realistic dust behavior evaluation methods	Enhancement of realistic methods for dust behavior assessment		
	b. Aerodynamic analysis of the entire PCV and R/B	Aerodynamic analysis of the entire PCV and R/B		
	c. Evaluation the behavior of aerosol in R/B	Evaluation the behavior of aerosol in R/B		
	d. Evaluation of the effects of heat input on airflow	Evaluation of the effects of heat input on airflow		
	e. Summary	Summary		
② Technology for ensuring confinement functions in connection parts a. Method of connection with the PCV from the access tunnel	a. Conceptual study / Selection of connection method	Conceptual study / Selection of connection method		
	b. Test plan		Test plan	
	c. Test preparation / Test device production		Test preparation / Test device production	
	d. Element tests		Element tests	
	e. Summary		Summary	

4. Project Implementation Schedule

Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (6/7)

Category	Sub-category	FY2019 (Apr–Mar) / FY2020 (Apr–Mar)	Remarks (latest status)
3. Development of technology for ensuring safety during fuel debris retrieval work (ii) Development of element technology for preventing and monitoring criticality ① Technological development of criticality monitoring control method a. Verification of the feasibility of sub-criticality measurement	Sub-criticality measurement method with simulated debris	Plan; Preparation; Sub-criticality measurement method verification test (KUCA); Evaluation	
b. Verification of applicability of the neutron detector to the field	Evaluation of alternative neutron detectors (RosRAO CORONA)	Service licensing procedures; Prototype specifications; Device production; Transportation; Installation of test device; Detector evaluation test （KUCA）; Evaluation	
	Evaluation of alternative neutron detectors (IPL semi-conductors)	Preparation; Device design; Device design and production; Study of testing system for detector evaluation; Detector evaluation test （KUCA）; Evaluation	
	Device installed on the debris	Planning and design; Device production; Environment resistance test	
c. Study of criticality approach monitoring procedures	Criticality approach monitoring control procedures	Summary; Establishment of measurement method; Selection of options for the detector	

4. Project Implementation Schedule

Implementation schedule for the development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (7/7)

Category	Sub-category	FY2019 Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	FY2020 Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Remarks (latest status)
3. Development of technology for ensuring safety during fuel debris retrieval work (ii) Development of element technology for preventing and monitoring criticality ② Development of technology for preventing criticality a. Study of the device and operating method for injecting non-soluble neutron absorber	Study of the method of using the non-soluble neutron absorber differently depending on the case	Scenario clarification			Clarification of conditions			Criticality analysis			Summary															
	Design, production and element tests of the injection device	Planning			Preparation				Underwater injection test		Evaluation															
	Verification of effects of debris processing	Planning			Preparation			Absorber processing test			Evaluation															
b. Study of corrosion effect considering the use of an antirust agent under radiation	Study of corrosion effect under radiation considering the use of an antirust agent	Planning			Preparation			Absorber irradiation test			Evaluation															
Major milestones								▲ Interim report (10/15)						▲ Interim report (4/22)						▲ Interim report					▲ Final report	

5. Project organization

Tokyo Electric Power Company Holdings, Inc.

- Various coordination for site application (coordination to reflect the conditions of approval and authorization, and decommissioning site)

International Research Institute for Nuclear Decommissioning (IRID)

- Coordination of overall planning and technology management
- Coordination of technology administration including technology development progress management

Hitachi-GE Nuclear Energy, Ltd.

【Elemental test, technical development】

(1) Development of fuel debris retrieval method

① Development of technology for interference object removal

・Large-scale structure removal and transfer methods by accessing from the top

・Interference object removal method for inside/outside pedestal by accessing from side

② Other technological development

・ Prevention method for spreading contamination into S/C

(2) Development of fuel debris handling technology

(ii) Technological development for treatment of fuel debris and deposits

① Removal technology for soluble nuclides in circulated water

② Treatment technology for deposits collected from PCV

(iii) Investigation of sorting technology for fuel debris and radioactive waste

(3) Technological development for ensuring safety during fuel debris retrieval

(i) Development of element technology for confinement functions

① Prediction technology for dust behaviors in PCV

② Technology for ensuring confinement functions of connecting parts

(ii) Development of element technology for criticality control and monitoring

① Technological development of criticality monitoring method

② Development of criticality control technology

Toshiba Energy Systems & Solutions Corporation

【Elemental test, technical development】

(1) Development of fuel debris retrieval method

① Development of technology for interference object removal

・Large-scale structure removal and transfer methods by accessing from the top

② Other technological development

・Transfer method for unit cans in R/B

(2) Development of fuel debris handling technology

(i) Technological development for fuel debris collection and storage systems

・Development of technology for processing fuel debris and waste transport

(ii) Development of treatment technology for fuel debris and deposits

① Removal technology for soluble nuclides in circulated water

② Treatment technology for deposits collected from PCV

(iii) Investigation of sorting technology for fuel debris and radioactive waste

(3) Technological development for ensuring safety during fuel debris retrieval

(i) Development of element technology for confinement functions

① Prediction technology for dust behaviors in PCV

(ii) Development of element technology for criticality control and monitoring

① Technological development of criticality monitoring method

② Development of criticality control technology

Mitsubishi Heavy Industries, Ltd.

【Elemental test, technical development】

(1) Development of fuel debris retrieval method

② Other technological development

・Development of remote operated support method in poor visual and narrow environments

・Establishment of access route for cell installation Conceptual study of impact reduction method for R/B

(2) Development of fuel debris handling technology

(i) Technological development for fuel debris collection and storage systems

・Development of particulate fuel debris suction and collecting system

(ii) Development of treatment technology for fuel debris and deposits

① Removal technology for soluble nuclides in circulated water

② Treatment technology for deposits collected from PCV

(iii) Investigation of sorting technology for fuel debris and radioactive waste

(3) Technological development for ensuring safety during fuel debris retrieval

(ii) Development of element technology for criticality control and monitoring

① Technological development of criticality monitoring method

Project teams to cooperate for technological development

- Fuel Debris Characterization
- Development of Technology for Collection, Transfer and Storage of Fuel Debris
- R&D on Solid Waste Treatment and Disposal
- Development of Technology for Investigation Inside the PCV
- Development of Technology for Investigation Inside RPV
- Development of technology for construction of water circulation system
- Development of technology for dust collection system of fuel debris

5. Project Organization

Tokyo Electric Power Company Holdings, Inc.

- Various coordination for site application (Coordination to reflect the conditions of approval and authorization, and the conditions of the decommissioning site, etc.)

International Research Institute for Nuclear Decommissioning (IRID)

- Coordination of overall planning and technology management
- Coordination of technology administration including technology development progress management

Hitachi-GE Nuclear Energy, Ltd.

- TOKO Corporation (Chugai Technos Corporation)
  ・Development of technology for removing interferences from within and outside the pedestal
  ・Development of technology for preventing the spread of contamination to the S/C
- Shimizu Corporation
  ・Development of technology for preventing the spread of contamination to the S/C
- Misuzu Seiko Co., Ltd.
  ・Characterization of collected wastewater
- Hitachi Power Solutions Co., Ltd.
  ・Development of technologies for separating solid material from collected liquids and wastewater, and storing it
  ・Study of corrosion effect under radiation considering the use of an anti-rust agent
- Mitsubishi Hitachi Power Systems
  ・Method of connecting to the PCV from the access tunnel
- Kyoto University
  ・Sub-criticality measurement test

Toshiba Energy Systems & Solutions Corporation

- IHI
  ・Large-scale structure removal and transfer methods by accessing from the top
  ・Development of technology for transferring fuel debris and waste
- CLEO, CEGELEC, Irie Koken Co., Ltd.
  ・Method of transporting the unit can from the R/B
- PaR Systems, Tokyo Denshi Kogyo
  ・Development of technology for transferring fuel debris and waste
- NFD
  ・Conceptual system design of soluble nuclide removal facility
- Watari Co., Ltd.
  ・Method of transporting the unit can from the R/B
- Kurita Water Industries
  ・Characterization of collected liquids and wastewater
- RosRAO
  ・Evaluation of alternative neutron detector
- Shibuya Diving Industry
  ・Designing, production and element tests of the injection device
- Daiichi Cutter Kogyo K.K.
  ・Checking the impact of fuel debris processing
- CETD
  ・Device to be installed on top of fuel debris
- Kyoto University
  ・Sub-criticality measurement test

Mitsubishi Heavy Industries, Ltd.

- MHI-NS Engineering
  ・Development of remote operation support method in environments with low visibility and narrow spaces.
  ・Development of suction collection system for particulate fuel debris
- ORANO
  ・Conceptual study on the establishment of access route for cell installation and the method of reducing the impact on R/B, etc.
- MHI Solution Technologies Co., Ltd., NDC, Sasakura Engineering Co., Ltd.
  ・Conceptual design of boric acid conditioning facility
- Kobelco Research Institute Inc.
  ・Characterization of collected liquids and wastewater
  ・Development of technologies for separating solid material from collected liquids and wastewater, and storing it
- Chugai Technos Corporation
  ・Development of technologies for separating solid material from collected liquids and wastewater, and storing it
- IPL
  ・Evaluation of alternative neutron detector
- Kyoto University
  ・Sub-criticality measurement test

6. Details of Subsidy Project

[Purpose]

To implement design study and element tests in coordination with engineering or project management carried out by the Tokyo Electric Power Company Holdings, Inc., and make preparations so that development of devices for the actual operation and systems for ensuring safety can be initiated for further increasing the scale of fuel debris retrieval.

[Main scope of the project】

1) Development of fuel debris retrieval method
Technology will be developed for establishing the access route based on site information, which will be needed to retrieve fuel debris existing in RPV and PCV. In particular, the technology for removing interferences, which can shorten the process of fuel debris retrieval, will be studied assuming actual conditions to confirm feasibility. Moreover, a system for supporting the operation of the remote-operated device, the method for carrying out maintenance of the equipment inside PCV, technology for preventing the spread of contamination outside PCV and technology believed to be needed for establishing the access route, considering the construction of a shielding structure for exposure reduction in the reactor building (R/B), will be developed besides the technology for removing interferences.

2) Development of fuel debris handling technology
The collection & storage method and system will be developed depending on the condition of fuel debris, the adsorbent most suitable for removing soluble nuclides will be selected, and technology for treating wastewater generated as a result of filter backwash, etc. will be developed. Moreover, technology required for sorting fuel debris and radioactive waste, will be surveyed.

3) Technological development related to ensuring safety during the fuel debris retrieval work
Element technologies for confinement of radioactive substances, prevention of criticality, etc., which are essential to ensure the safety of the public and workers during fuel debris retrieval work, will be developed.

7. Implementation Items of this Project

1) Development of fuel debris retrieval method

① Development of interference removal technology

Technology will be developed for establishing the access route based on site information, which will be needed to retrieve fuel debris existing in RPV and PCV. Based on the results of investigating the R/B equipment or the equipment inside PCV, in particular for the interference removal technology that can shorten the process of fuel debris retrieval, conditions such as misalignments, deformation, damage, etc., or specific conditions such as heat induced deformation at locations that have not been investigated such as the RPV, etc. will be assumed, the technology, basic specifications of equipment and procedures for removal will be studied and feasibility will be confirmed by implementing element tests as required. Further, equipment, etc. assumed to become an interference for each of the access methods are mentioned below.

・Top access to RPV: Well shield cover, PCV head, RPV head, reactor internals, etc.

・Side access to PCV: Devices, equipment and piping, etc. inside R/B (specifically around the penetration), outside the pedestal, and inside the pedestal

The following will be included as the main development and study items. Element tests will be conducted as required to identify problems and organize them. Further, maintenance will be considered as well during the study.

a. <u>Large-scale structure removal and transfer methods by accessing from the top</u>

・Conceptual study pertaining to the access route and the method of transporting the structures will be conducted.

b.<u>Method of removing interferences from within and outside the pedestal by accessing from the side</u>

・Element tests related to common utilities will be implemented to check the feasibility of the method.

[1) ① Development of interference removal technology]

a. Large-scale structure removal and transfer methods by accessing from the top

- Purpose of development
  - To study the work procedures or the device used for establishing the access route to the reactor core, which is necessary for fuel debris retrieval, in an effort to improve throughput.

- Issues that must be resolved
  - Specification of work procedures and device used for establishing the access route
  - Confirmation of feasibility of the planned work procedures and equipment
  - Shortening of throughput

- Approaches to development
  - Procedures for removing interferences (cutting off, storing in canisters, transporting) up to the reactor core will be specified. (desk study)
  - Procedures and equipment (hoisting attachments, shielding, fall protection gear) for removing interferences even if the damage is severe, will be studied assuming the damage inside the reactor in Units 1 - 3.
  - Issues will be identified during the desk study, test plans will be formulated for the reactor internals for which element tests need to be conducted and for the stages of removal (cutting, holding, lifting, etc.), and element tests will be conducted.
  - The feasibility and throughput of the planned methods will be evaluated and a comparative evaluation with past methods will be conducted.

- Expected outcome
  - Feasibility of work procedures and device used for establishing the access route
  - Shortening of throughput

7. Implementation items of this project

【1) ① Development of interference removal technology】

a. Top-access method for removal and transport methods of large-scale structures

■ Study flow

: Explained at a briefing meeting

Achievements and issues in previous subsidy projects

Plan in FY2018: **Cutting of structures at the site and transport them in canister after storage**

- Long-term retrieval time schedule: 31.3 years (route A*) and 41.1 years (route B*) (original target schedule : 10 years)
- Many times of cutting: 2000 times, 2100 times for canister (ex. Steam-water separator)
- Increasing size of the cell. No enough space due to severe loading conditions of container (4500t)

Approach policy of issues in FY2019

- **Removal and transport of the whole structure and fuel debris as much as possible**

Preconditions for study

- Prediction of work area air dose rates in each stage of removing interference objects
- Spread of contamination and confinement requirements in work area
- Deformation of the structures during the accident

Study of specific plan 1: Removal and transport of the whole structure

Study of specific plan 2: Combination of separating structures and decontamination

Study of issues to implement plan 1 (including tests)

Study of issues to implement plan 2 (including test)

Partly common issues (sharing of technology), Ex. Suspending technology for structure

Executed in a subsidy project

Investigation results of the site condition (damaged conditions of the reactor internals)

Applicable plan selection for practical use

*: Overviews of the route A and B are described in No. 286.

7. Implementation items of this project

【 1)① Development of interference removal technology 】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Development schedule

Study items	FY 2019												FY 2020											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Major milestones							Interim report ▼					Interim report ▼							Interim report ▼					Final report ▼
1.Conceptual study																								
2.Planning of element test																								
3.Preliminary test required for conceptual study													(Testing will be conducted if necessary)											
4.Preparation of element test (test device production)																								
5.Element test																								
6.Summary																								
Remark																								

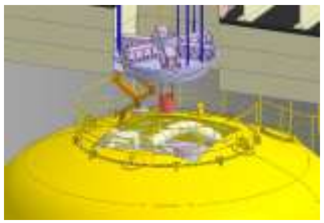
7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

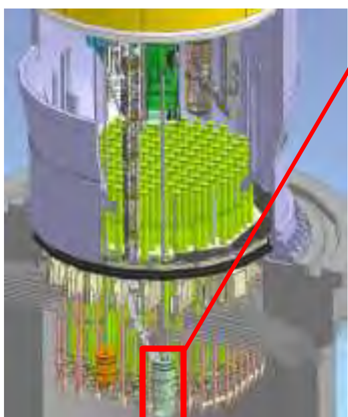
■ Major results of study in previous years

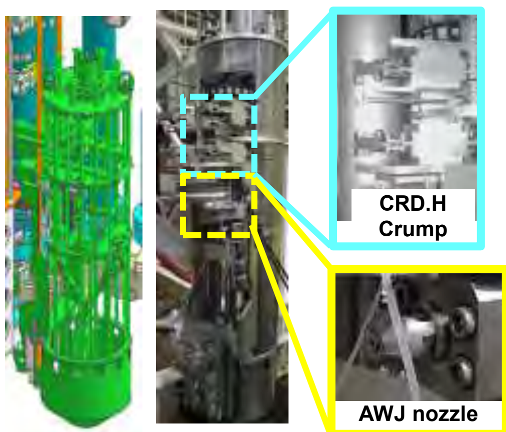
- The image of the access route (to remove interference objects) that are from the top floor (operation floor) to the reactor core and from the reactor core to the pedestal was established and the procedures was considered.
- The duration of retrieval (throughput) was estimated, assuming unit cuts, the shape and thickness of the cut, and procedures of a cutting method,.
- Additionally, element tests for the reactor bottom that is assumed to be the most complicated and deformed were conducted by using simulated structures to verify the feasibility of the removal procedures.

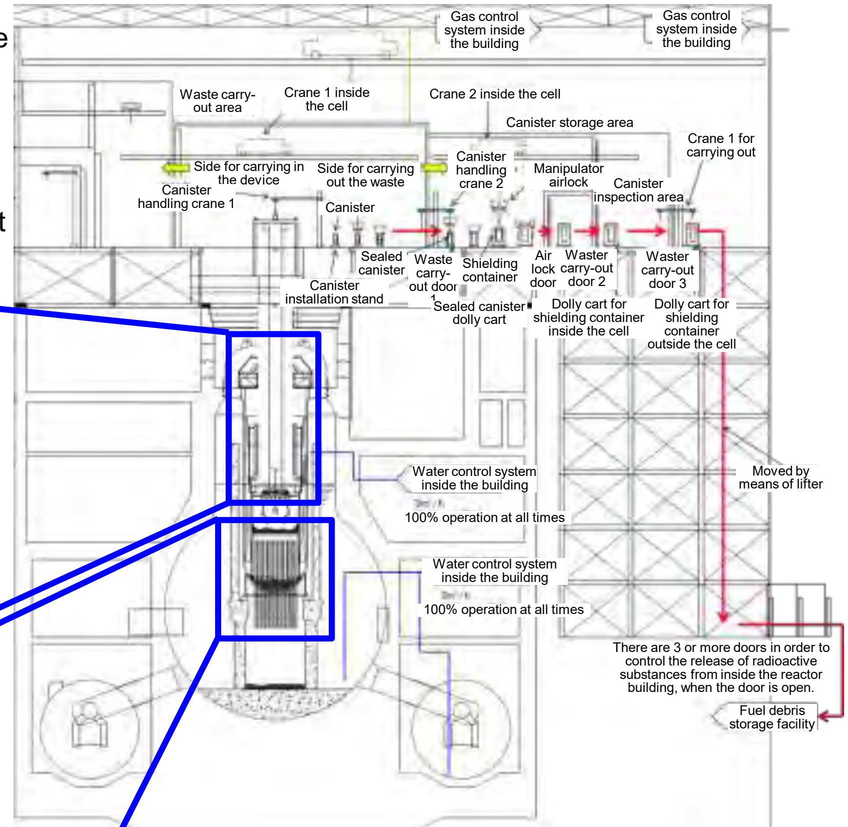

Opening of PCV head


Access to steam-water separator


Cutting for opening shroud head


Removal of large-scale structure at the reactor bottom





A transport method to transfer the structure after stored in the unit canister (UC) would be challenging in the aspect of workability and work hours.

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Challenges and issues based on the previous year's results

- The duration of retrieval was estimated 31.3 years (route A) and 41.1 years (route B) despite the target duration of 10 years. A shortening of time schedule is required.
  【Ex.】A number of cutting steam-water separator is 2000 times and 2100 times for the canister. Most structures need to be cut many times.
  Throughput
- A cell size is increased. The strict loading conditions of the building and container (approx. 4500t)
  Loading of the building
- There is no enough space to allocate a cell on the operation floor and no buffer when trouble occur in specific equipment. Risk of suspending the whole work (a potential risk of delay in schedule).
  Maintenance performance and throughput
- Remote maintenance is required because contaminated devices are allocated closely, therefore a bad accessibility affects workers.
  Maintenance performance

■ A policy and goal of this subsidy project

✓ **Improvement of throughput**

A duration of work was evaluated in previous years: Approx. 4 years for establishment of the access route and 27.2 – 37.2 years for fuel debris (estimation is different depending on plans). A target goal was set to complete within 10 years: 1.5 years for establishment of the access route and 8.5 years for fuel debris retrieval.

✓ **Improvement of loading in the building**

A work implementation plan in the work cell was reviewed and improvement of loading in the building was promoted by optimizing requirement functions for the cell.

Confirmation of the feasibility **of a cutting method that a larger-sized structure is removed and cut into pieces in another building (*1)**

Preparation (set of device)		5
Work hours of cutting (h)		55.65
	Positioning (h)	0.5
	Cutting (h)	0.03
	Total (h)	0.53
	Number of cutting	105
Work hours of 11-devided height (10 cuttings, h)		1060
	Positioning (h)	0.5
	Cutting (water jet, h)	0.03
	Total (h)	0.53
	Number of cutting	2000
Other work hours (h)		5355
	Fall protection device of cut pieces (h)	1
	Sampling transport (h)	0.05
	Storage of cut pieces in collection canister (h)	0.5
	Removal of collection canister (h)	0.5
	transport of empty canister and preparation of acceptance (h)	0.5
	Total (h)	2.55
	Number of work	2100
Total work hours		6470.65
Days		269.6104
Clean-up		5
	Total work days	**279.6104**

Separator removal procedures and duration of removal (route A)【results of FY2018】

No.	Method	Work hours to remove interferences	Work hours to retrieve fuel debris	Total	Remark
1	Route A	Shield plug 0.8yrs. Including shroud head 3.3yrs. Total: 1 yr.	Reactor ore and reactor bottom 14.6yrs. Inside pedestal 12.6yrs. Total: 27.2yrs.	31.3yrs.	Except for shroud and jet pump
2	Route B	Shield plug 1.5yrs. Including shroud head 2.4yrs. Total: 3.9yrs.	Reactor ore and reactor bottom 24.1yrs. Inside pedestal 13.1yrs. Total: 37.2yrs.	41.1yrs.	Plugs are transport by using waste canister. 16.8 yrs. For UC 400φ

Summary of the throughput (top-access method)【results of FY 2018】

*1: After confirming the feasibility, the study of maintenance performance will start .

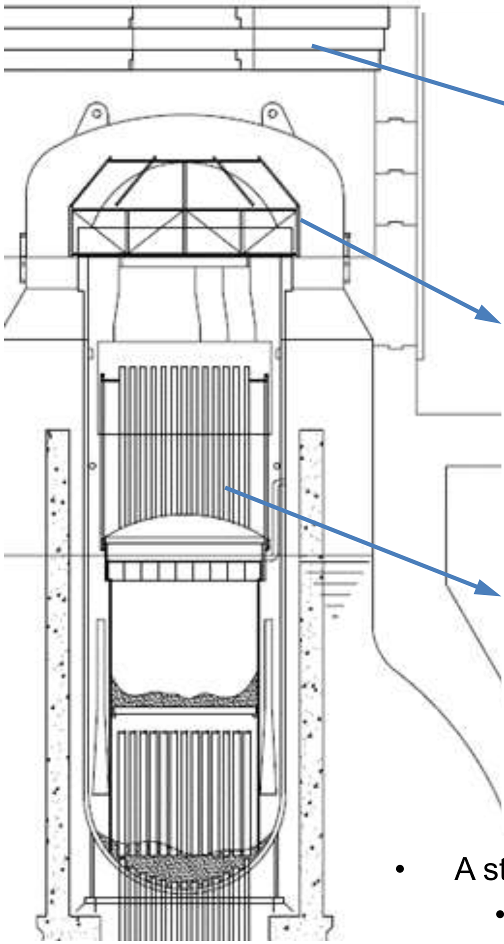
7. Implementation items of this project

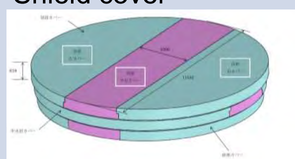
【1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

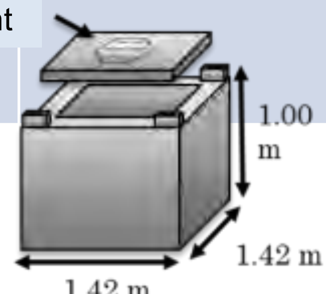
■ <u>Preconditions for study(surface dose of the structure that will be removed)</u>

- Interference objects to be removed, contamination prediction, the surface dose and conditions of storage canister
  - On a basis of MAAP analysis results and actual dose data, contamination levels and dose conditions were calculated which will be preconditions for removal of the structure.



Structures	Contamination	Dimensions/mass	Surface dose calculated from contamination
Shield cover 	1.0E+08Bq/cm2 The inner well is assumed to be evenly contaminated.	11828×3200×t618 mm, 55ton (center, upper stage)	3.8E+03mSv/h (surface) 3.4E+01mSv/h（10m） 7.6E+02μSv/y（800m） Firstly, it will be removed.
RPV head 	Calculated from MAAP analysis Outer surface: 3.08E+13Bq Inner surface: 2.86E+15Bq	Φ6200×h2800mm Approx. 90ton	3E+04mSv/h (inner face) 1E+04mSv/h (outer face) Dose rates increase after removal.
Steam-water separator 	Calculated from MAAP analysis 2.24E+16Bq (separator) 4.77E+15Bq (shroud head)	Φ4800×h5080mm Approx. 51 ton	6E+04mSv/h (upper face) 7E+04mSv/h (side face) Highest radiation dose

- A storage canister for waste (under consideration by the waste project team)
  - Maximum surface contamination levels when storing waste: 10Sv/h
  - When transferring in the premises, wastes are stored in the transport canister: contamination of the surface 30mSv/h



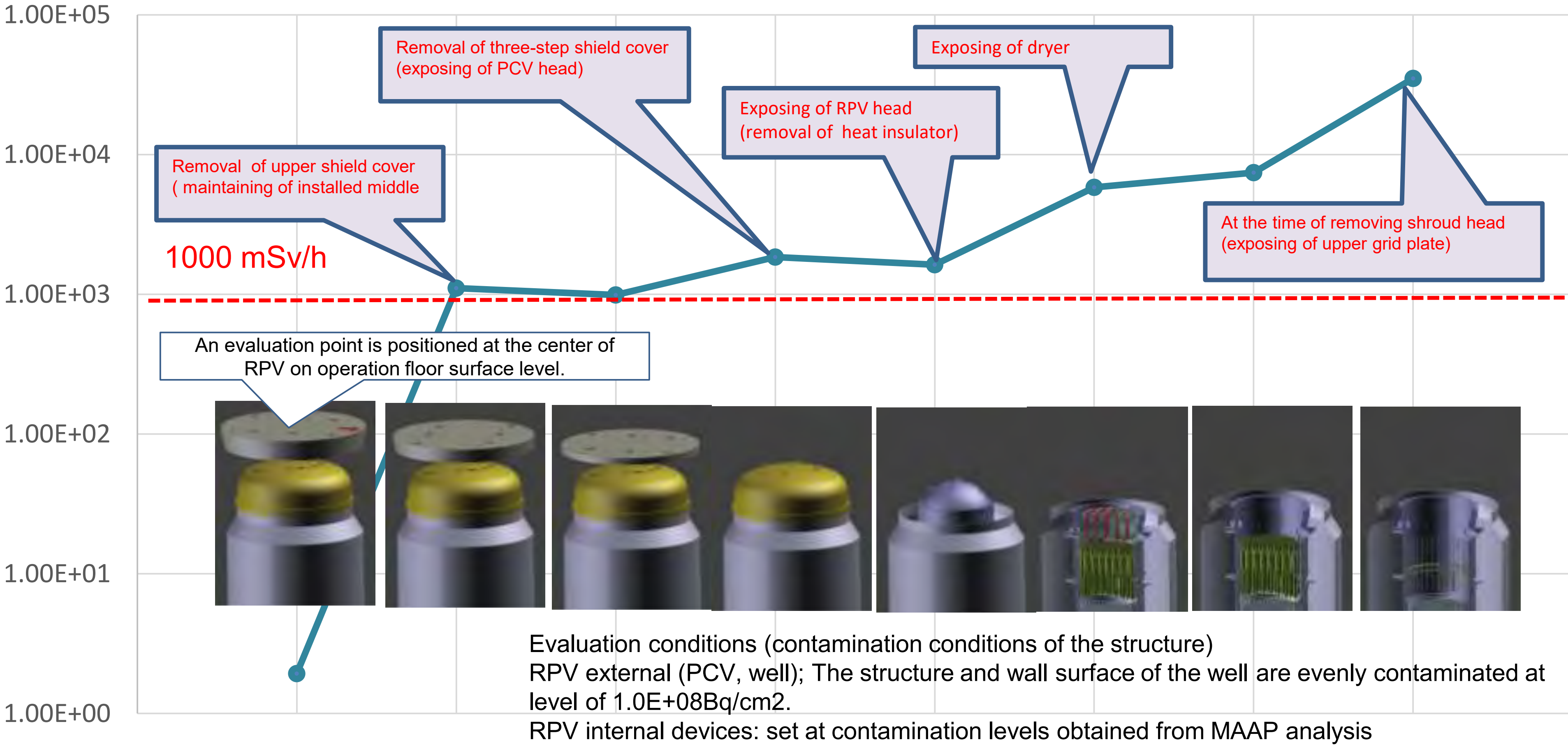
7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Preconditions for study (air dose rates in work area)

- Dose calculation of work area in each step of interference object removal.
  - Air dose rates of work area (mainly operation floor and RPV) in each construction step were calculated based on contamination of the structure.
  - A radiation dose was over 1 Sv/h at the time of removing upper part of the shield cover (the site boundary dose rate is approx. 800μSv/h(@1000m), approx.90μSv/h(@1000m)), therefore it is necessary to install the shield before removing the upper shied.



7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

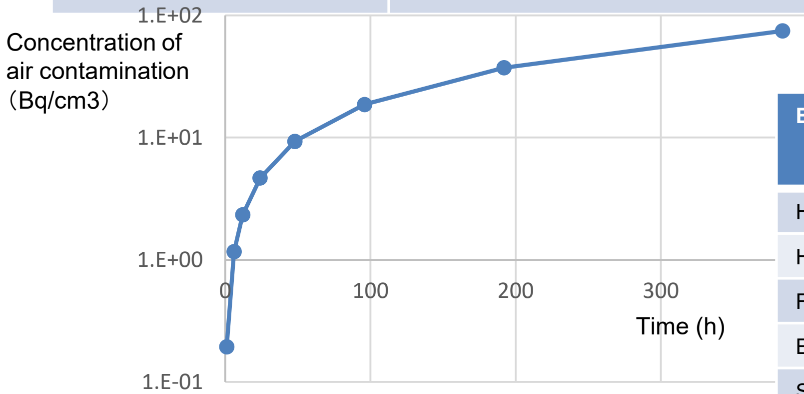
■ Preconditions for study (contamination levels in work area)

● Spread of contamination and confinement requirements of work area (when removing a shield cover)

- The well reactor was exposed after removing the lower shield cover. When it was exposed, concentration of air contamination in work area was evaluated and requirements of confinement were studied.
- By setting contamination levels in the well internal (1.0E+8Bq/cm2), concentration of air contamination was predicted by dust scattering rates and volumes of inside the well.
- In case that contamination remains in the well, contamination levels are estimated to be several Bq/cm3. This estimate suggests that it is significantly a higher level of contamination than work standards in Fukushima Daiichi. In fact, contamination would decrease affected by re-adhesion, however, confinement functions to prevent gases in the well from being released to outside are required, which was reflected into work area plan.

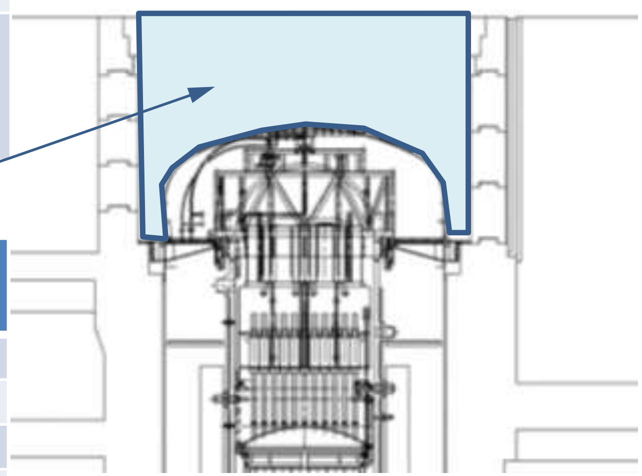
Items	Setting values	Remark
Adhered contamination of the well internal	4.14E+14Bq (well internal) 7.48E+13Bq (outer surface of PCV head)	Assuming that same amount of Cs-137 and Ba-137m exist.
Spread rate of adhered contamination	1.0E-10/s	*Cited by reference
Volume in the well	9.04E+08cm3	=Radioactivity amount of wall surface in the well * dust scattering rates per 1 sec. * 24 hrs. / spatial volume in the well

* (Reference): G.A.Sehmel et.al, PARTICLE RESUSPENSION RATES, BNWL-SA-5124, 1974



Standards of equipment for work in Fukushima Daiichi

Equipment	Acceptable levels of contamination concentration
Half face mask	～2E-03Bq/cm3
Hood mask	～2E-03
Full face mask	～2E-02
Electric fan with mask	～2E-01
Supplied-air respirator	2E-03～



7. Implementation items of this project

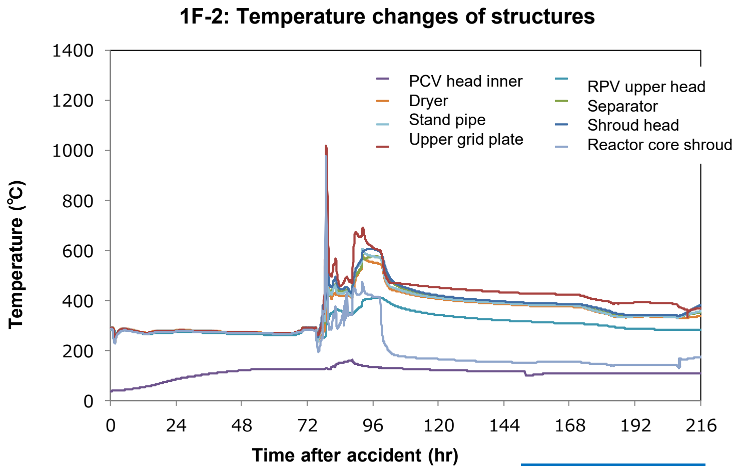
【1) ① Development of interference removal technology】

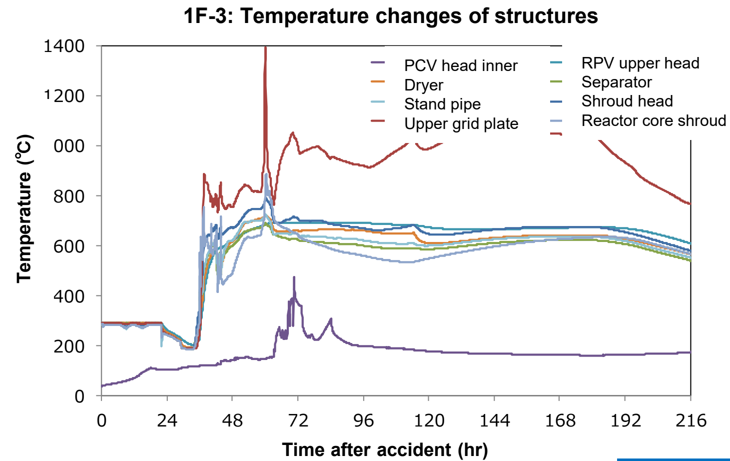
a. Removal and transport methods for large-scale structures by accessing from the top

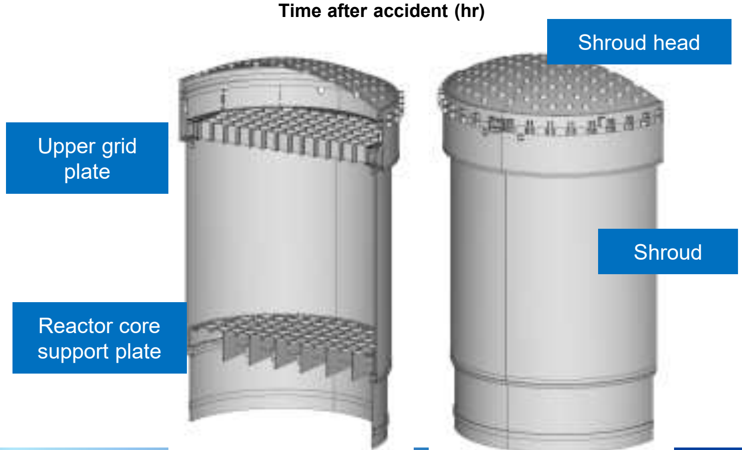
■ <u>Preconditions for study (estimation of the structure conditions)</u>

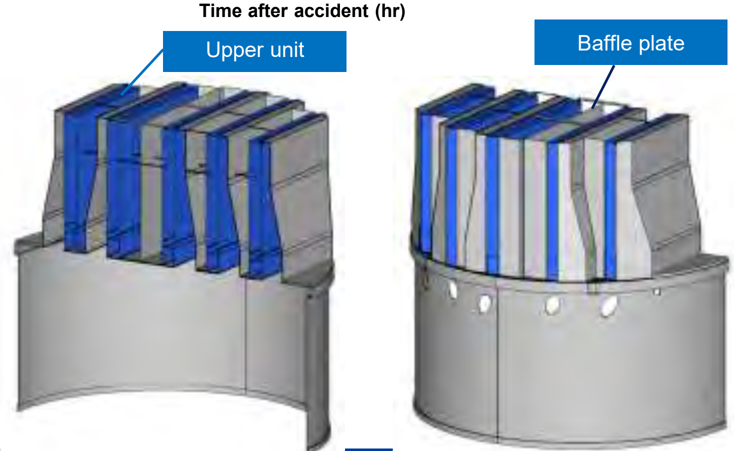
● Prediction of the structure deformation behaviors under high-temperature conditions after the structural accident

- Analysis items (1) Estimation of static stress (estimation of short-time strength)
  (2) Prediction of creep deformation (estimation of long-time (max.3 weeks) deformation)
- Analysis for: shroud head, shroud and dryer
- Analysis temperature: a wide set of temperatures on 650℃, 700℃, 800℃, 900℃ (max.) at a basis of the MAAP analysis.









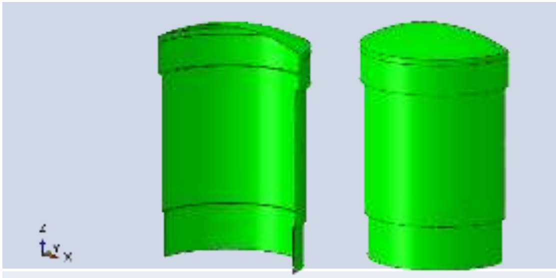
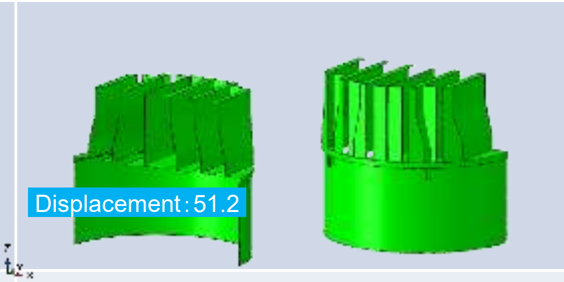
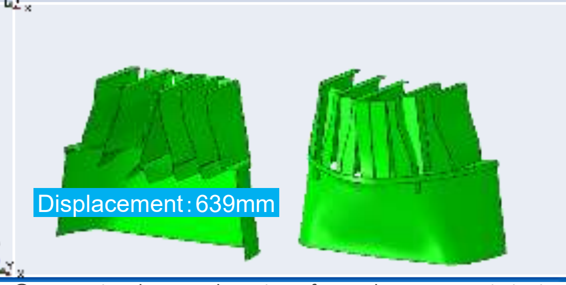
7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ <u>Preconditions for study (estimation of the structure conditions)</u>

- Prediction of the structure deformation behaviors under high-temperature conditions after the structural accident, results and summary
  - The structure deformation was estimated based on temperature changes of the reactor internals that were obtained from the MAAP analysis.
  - To widely estimate the structural deformation, temperature setting was increased by up to approximately 200℃, including reduction of components that would restrict the deformation.
  - A short-time static stress estimation revealed that part of a steam dryer reached a yield stress at 900℃, but the whole part did not cause the plastic deformation.
  - An estimation of three-week creep deformations revealed that the upper end of the shroud head was slightly deformed, but the displacement was less then 1mm and there was not a significant change of the shape such as inclining and decaying. On the other hand, a deformation evaluation revealed that the center of dryer dented and the skirt part was deformed, and eventually the dent displacement increased at 600mm. Effects of contacting peripheral equipment will be discussed in future.
  - Additionally, these deformation might be caused by a simplified model and therefore, not-simplified model can be considered.
  - The most significant change is the position of the upper end of each structure. So, measuring of the position changes for the upper end of the structure could be effective to estimate the changes of the whole structure. Furthermore, the structure information will be reflected for the study of removing internal structures (study on removal of the deformed state).

	Figure of deformation after 3 weeks (magnification x 1)	Figure of deformation after 3 weeks (magnification x 1)
700℃		
900℃		

7. Implementation items of this project

【 1) ① Development of interference removal technology】

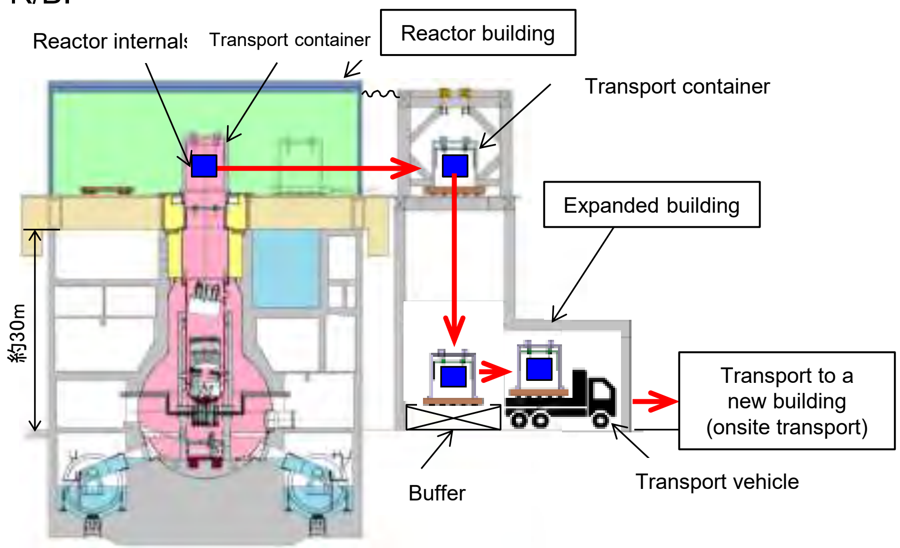
a. Removal and transport methods for large-scale structures by accessing from the top

■ Concepts of a new top-access method

Policy direction in FY 2019: Confirmation of the feasibility of **the method that the large-scale structure is transported and cut into pieces in the other building.**

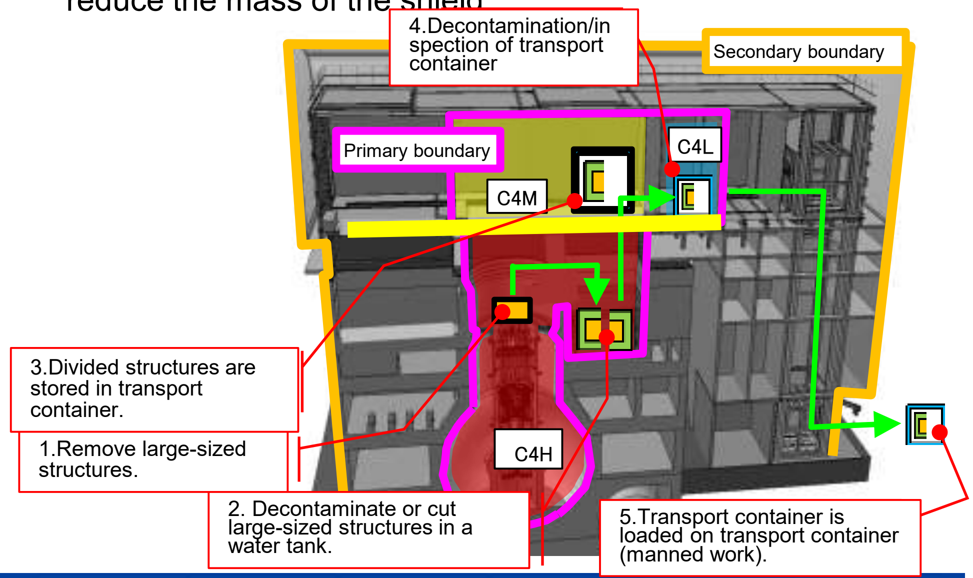
【Plan ①】Removal and transport of the whole unit

- ✓ The whole structure in integrated state is removed and transported.
- ✓ The reactor core is divided into several units. The reactor bottom is cut and removed the RPV end head from RPV.
- ✓ Materials that will be transported are shielded and air-tighted depending on a container and an access route, or their combination.
- ✓ Removed structures are cut into pieces and stored in a container, which will be performed in the building far from the R/B.



【Plan ②】Combination with divided large structure and contamination

- ✓ The structure that will be transported should be as large as possible. The combination with decontamination and shielding is performed depending on the transport condition.
- ✓ Decontamination and dividing work are performed at the SFP and DSP.
- ✓ The reactor well is utilized to ensure shielding and airtightness.
- ✓ The confinement area is formed by lines connecting the reactor well and decontamination/dividing area (SFP or DSP). The position of the confinement should be as low as possible to reduce the mass of the shield.



7. Implementation items of this project

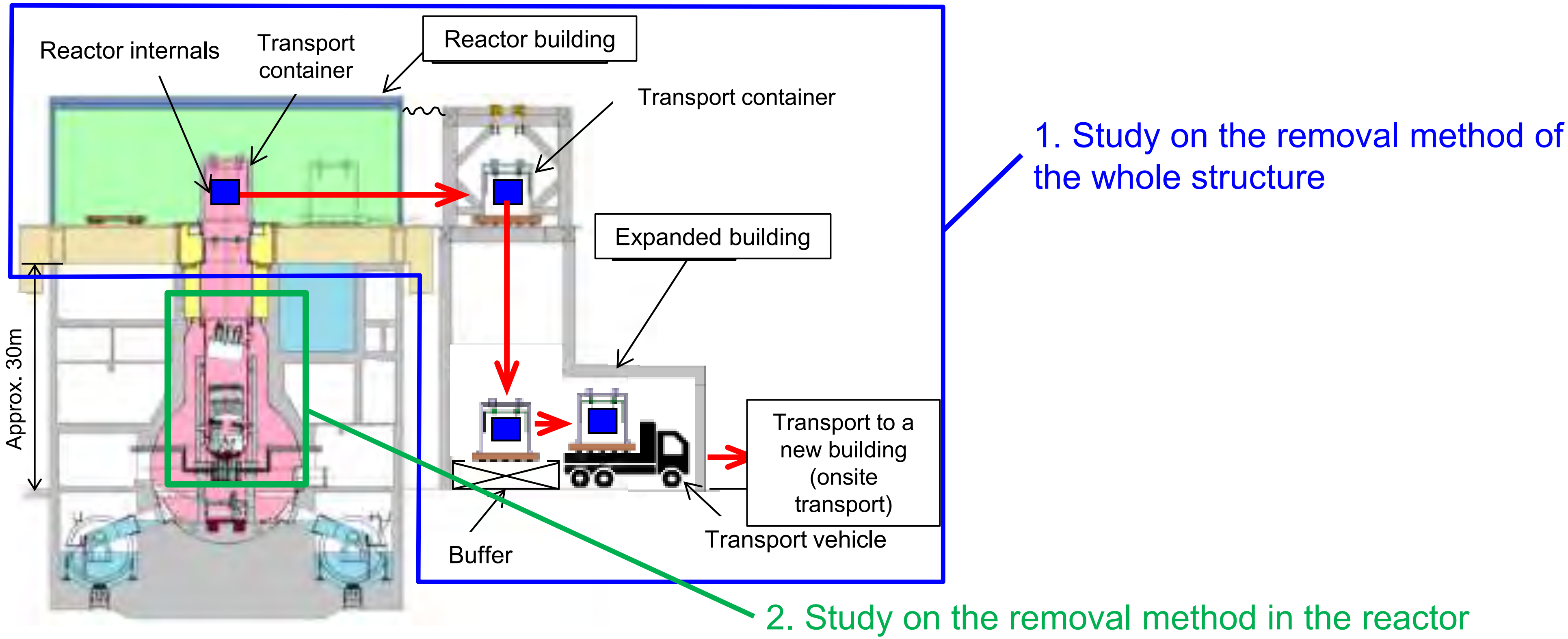
【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ <u>Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Approach to study</u>

To study the method for removing the structure as a unit, there are significant differences of issues to be discussed. 1. The structure is removed from the reactor and then transported. 2. The structure is separated from the reactor.

⇒ Two different methods are discussed (discussions on these methods are promoted while providing feedbacks each other).



<u>Conceptual diagram of the removal method of the whole structure</u>

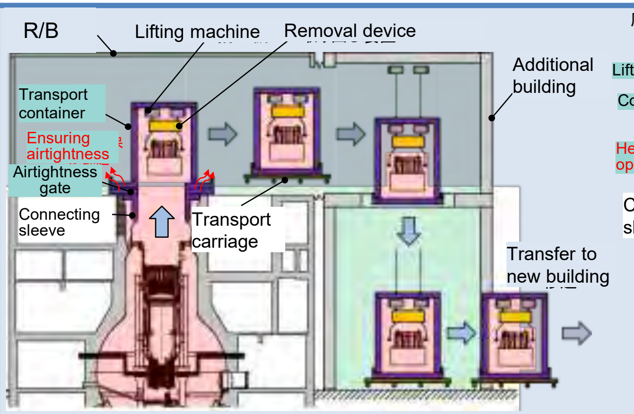
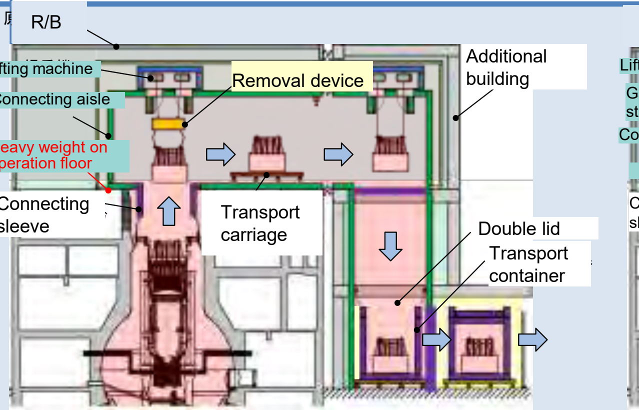
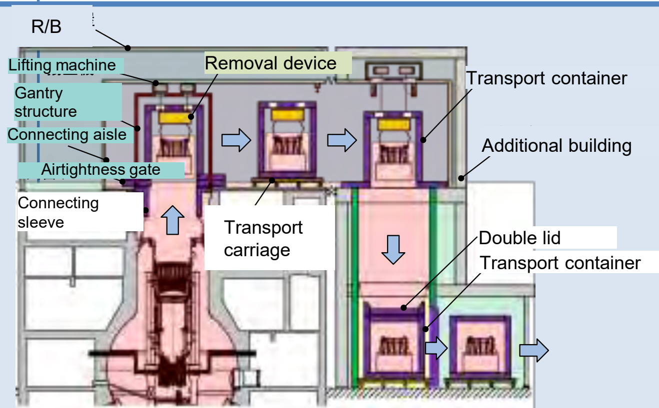
7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Top-access method for retrieving large-scale structures and transport method

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Study on transport method and removal of the whole structure in integrated state

Comparative evaluation on three clarified plans was performed.

<table>
<tr><th></th><th>(Plan A)
Transport canister method</th><th>(Plan B)
Connecting aisle method</th><th>(Plan C)
Transport canister +Connecting aisle method</th></tr>
<tr><td>Conceptual diagram</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Issues</td><td>• Feasibility of airtightness gate in canisters and on the well.
• Feasibility of storing the lifting machine on or in canisters.
• Maintenance is difficult, specifically, the lifting machine for canister installation.
• Emergency recovery of removal device is difficult.</td><td>• Mass reduction of the connecting aisle
• Maintenance of the lifting machine on the connecting aisle/replacement method</td><td>• The height of the gate type structure increases because the canister and rack are required, so the height of the connecting aisle also increases.
• Maintenance of the lifting machine is difficult.</td></tr>
</table>

Significant issues of each method* were studied: 1. Feasibility of ensuring airtightness, 2. Acceptability of the mass reduction of the connecting aisle.

* Maintenance performance is also significant issue, however above two issues are more important to evaluate the feasibility of each plan. Therefore, these issues started to be studied as priority issues.

7. Implementation items of this project

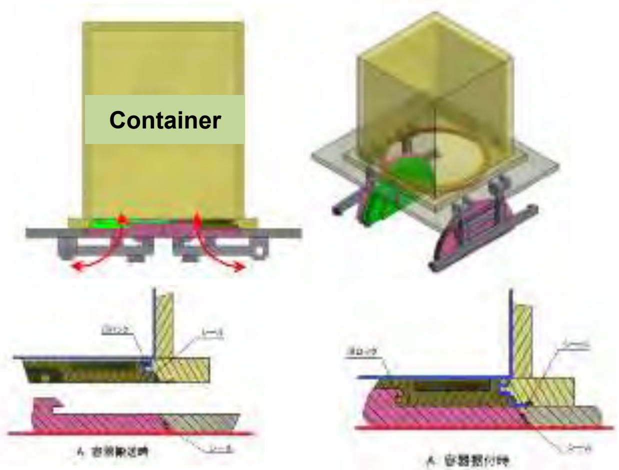
【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Feasibility of ensuring airtightness

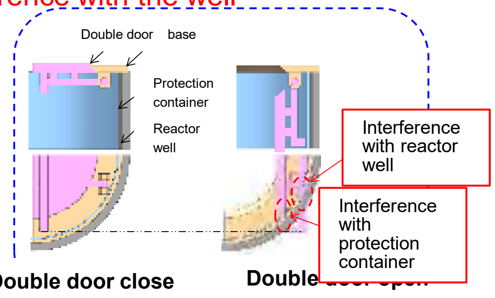
(A) Double door method

- The shielding lid is installed for both side of the container and the reactor well (for connection of the container).
- After contacting both lids of the container and the well sides, they can adhere well by rotating actions. Then, they performed open-close movements.
- When withdrawing from the container, the shielding functions did not lose and radiation shielding can be secured in the reactor.



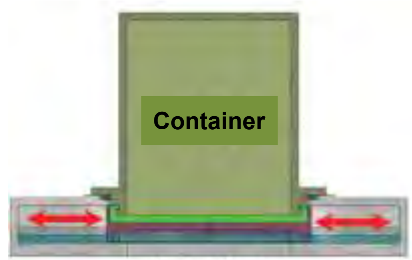
【Issues】

- ✓ Possibly of radiation contamination in connecting surface of the gate
- ✓ Gate driving method
- ✓ Interference with the well



(B) Double gate method

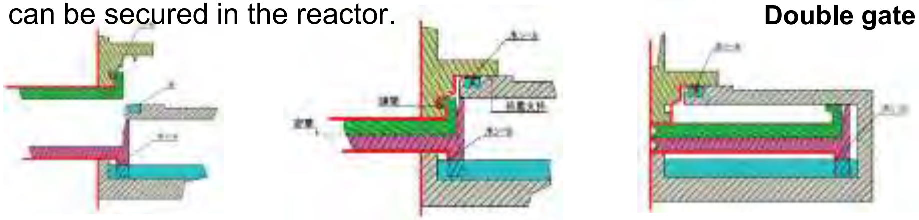
- The shielding gate is installed for both sides of the container and the reactor well.
- Both lids of the container and the well side are connected and adhered, and performed open-close movements.
- Therefore, shielding functions are not lose when withdrawing from the container and radiation shielding can be secured in the reactor.

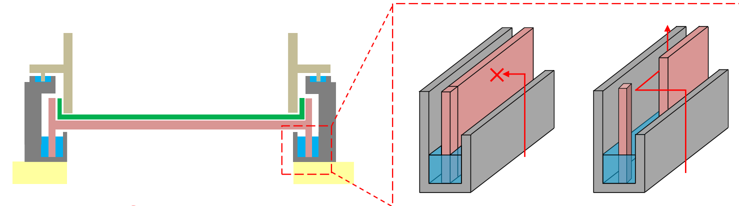


Double gate

【Issues】

- ✓ Spreading contamination in the lower gate of sliding part (water contamination)
- ✓ Possibly of radiation contamination in connecting surface of the gate.
- ✓ Gate driving method
- ✓ Leakage of contaminated materials when opening the gate.





Both methods were unsuccessful. The result revealed that there is a significant issue in ensuring airtightness.

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Feasibility of shield thickness in connecting aisle

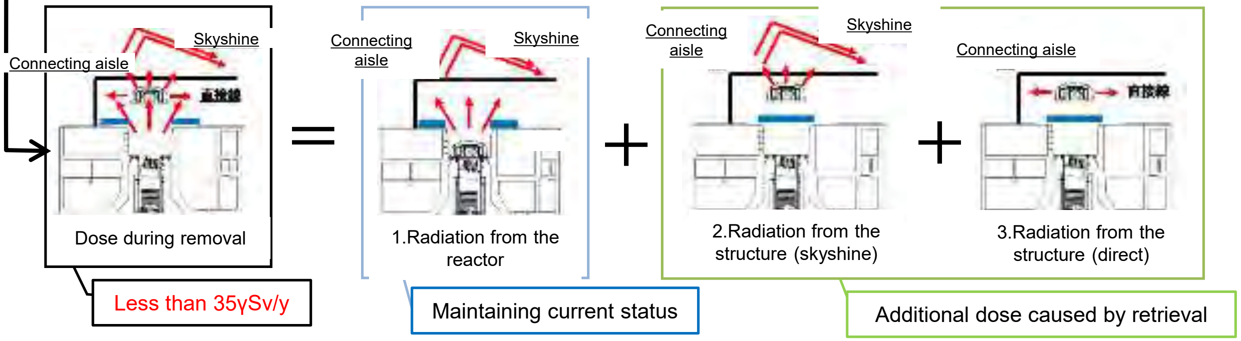
To assess the feasibility of shield thickness of the connecting aisle, the mass reduction of the connecting aisle was discussed.

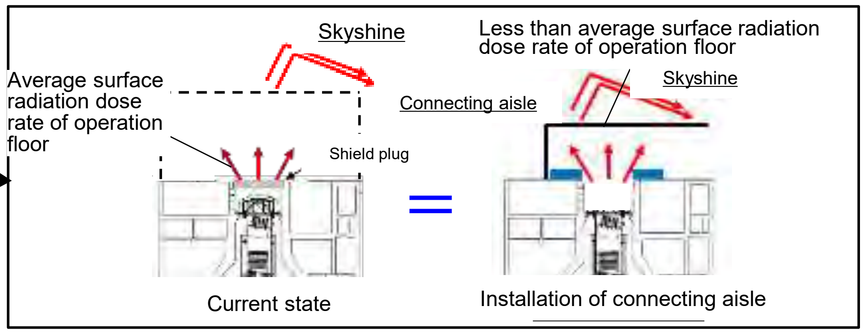
【Study policy】

① Dose rates in the site boundary during opening the reactor (not moving the reactor internals toward the operation floor) are equivalent to effects of the operation floor at the moment.

② Dose rates of the connecting aisle surface during opening the reactor (not moving the reactor internals toward the operation floor) are less than the surface dose rate.

③ In case that the reactor internals are moved to the operation floor (inside the connecting aisle), dose rates of the site boundary are less than 35μSv/yr.*1 .





【Conditions of preliminary calculation】

- Dose rates of the operation floor surface (average value): [Unit 1]125mSv/h, [Unit 2]120mSv/h, [Unit 3]105mSv/h
- Dose rates in the reactor after opening the RPV head [Unit 1]30Sv/h, [Unit 2&3]：55Sv/h,
- Dose rates in the site boundary: Less than current dose (as of February 2020)
- Distances from each Unit to the site boundary: 800m
- Connecting aisle: [Inside dimensions] 14,400 x 37,500 x H22,000mm(tentative values), iron

【Results of preliminary calculation】

	Dose rates of operation floor surface(average value) [mSv/h]	Dose rates of inside the reactor after RPV head open [Sv/h]	Specifications of connecting aisle	
			Shield thickness [mm]	Mass [ton]
Unit 1	125	30	190	3,844
Unit 2	120	55	220	4,443
Unit 3	105	55	220	4,443

According to a preliminary calculation of shield thickness, dose rates in the site boundary is more than 35μSv.
⇒In case that only surrounding of the structure is provided additional shields at maximum of 130mm (approx. 120ton), dose rate would be much less than 35μSv.

Shield thickness could be possibly reduced.

*1：This value is per 1 plant and calculated by the Professional Standard, 1mSv/yr., and dose rate of the site boundary in the implementation plan, 0.89 mSv/yr.

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Comparative evaluation on transport method of removal of the whole structure in integrated state

As a result of study on the feasibility of ensuring airtightness and shield thickness of the connecting aisle, candidate plans were re-compared.

Bold and underlined letters: Significant issues

Methods	Advantage	Disadvantage	Issues	Assessment
Plan A (Transport canister method)	● Contamination ranges are small. (In case that airtightness of the gate is possible.) ● The mass is assumed to be small.	● Complicated removal and transport. ● Large number of equipment	● **Feasibility of gate airtightness on the container and well.** ● Difficult maintenance. Specifically, lifting machine for installation of the container. ● Lifting machine cannot be stored in or on the container. ● **Difficult emergency recovery of removal device**	Not applicable
Plan B (Connecting aisle method)	● Less equipment (less maintenance) ● Simple removal and transport ● Layout of equipment required for maintenance can be installed far from the place on the well.	● Contamination ranges are large. ● The mass of equipment is large.	● Heavy loads for the reactor building	Acceptable
Plan C (Connecting aisle ＋Transport canister method)	● The canister with shielding function enables a smaller thickness of the connecting aisle, therefore, the mass reduction may be possible.	● As airtightness of the container on the operation floor cannot be ensured, contamination would spread. ● Complicated removal and transport ● Large number of equipment	● The height in dimensions increases because the container and rack are required. Therefore, the connecting aisle would be larger (concerns about seismic performance).	Acceptable

As a result of the above comparison, Plan B was adopted as the most priority and the detailed study will start in next fiscal year.

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

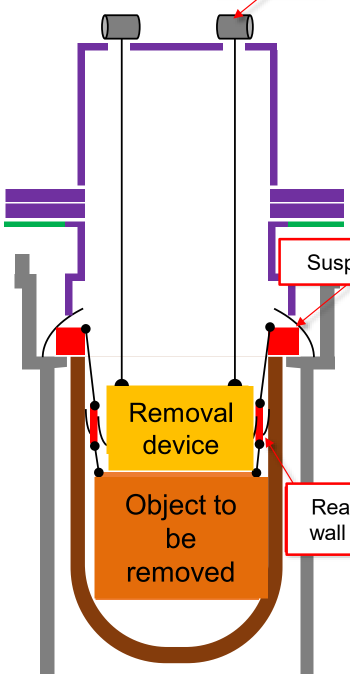
■ Study of specific plan 1 (Removal and transport of the whole structure): Study of Study of method to remove from the reactor

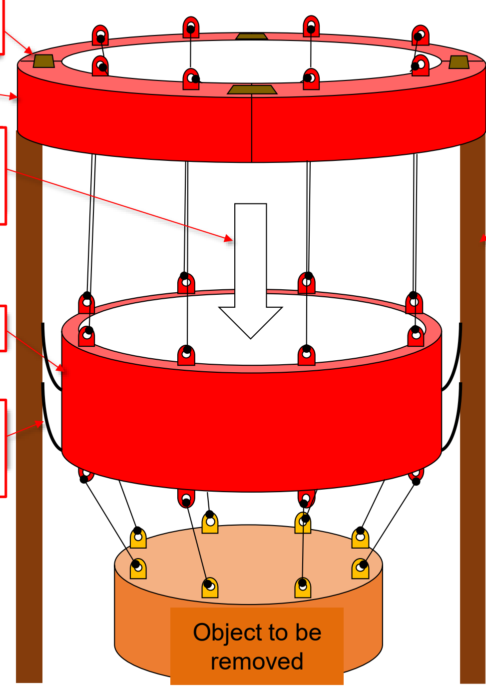
The study of method for lifting the reactor internals from the reactor to the operation floor level was performed (the transport method is based on the study results in the previous pages).

【Concept of method for removing from the reactor 】

- ✓ Removal and suspending functions are distributed (emergency recovery in the state of maintaining fall prevention for target objects, and implementation of device maintenance)

  ⇒Major component consists of two devices: Removal device and suspending device.
- ✓ Removal device: Cutting of the reactor internals, and wire implementation for fall prevention of removed objects
- ✓ Suspending device (suspension rings and reactor wall rings): Suspending function to prevent falling target objects (reactor internals
- ✓ Prevention of spreading contamination from the lower part of each device (RPV inner seal)





Example of the RPV inner seal *

*Development Results by the Fundamental Technology Project in FY 2016-2017

7. Implementation items of this project

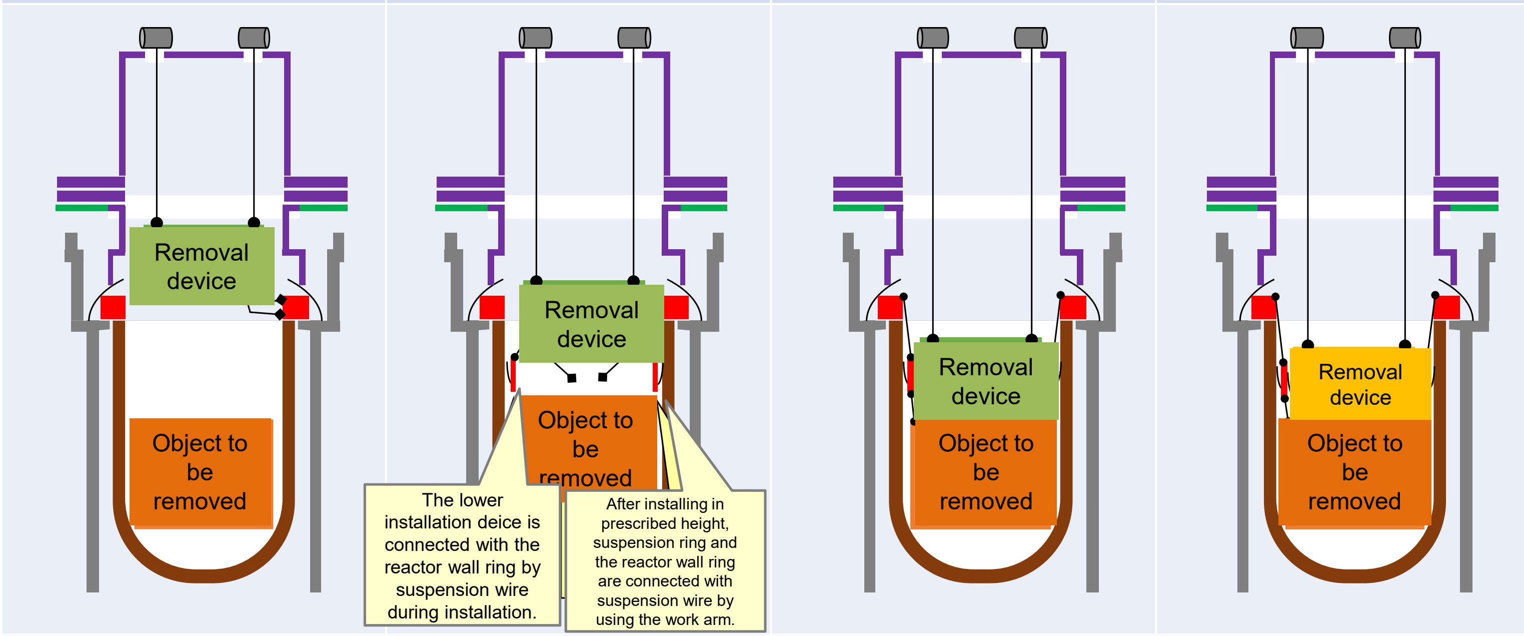
【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Study of method to remove from the reactor

On a basis of concepts in the previous pages, the removal procedures were studied.

Step 1	Step 2	Step 3	Step 4
Suspension ring installation	Reactor wall ring installation	Connection with removal object	Removal device installation



Step 1	Step 2	Step 3	Step 4
• A suspension ring that is divided into the structures is installed and assembled on the bulk head (external diameter of the suspension ring is larger than inner diameter of the transport container). • The bulk head is connected with the suspension ring.	• A plate spring of external periphery of the reactor wall ring is connected with the RPV inner surface. • The upper part of the reactor wall ring is connected by a suspension wire.	• A suspension jig that will be removed is connected with a new reactor wall ring by a suspension wire.	• A plate spring of external periphery of removal device is connected with the inner surface of the reactor wall ring.

IRID

7. Implementation items of this project

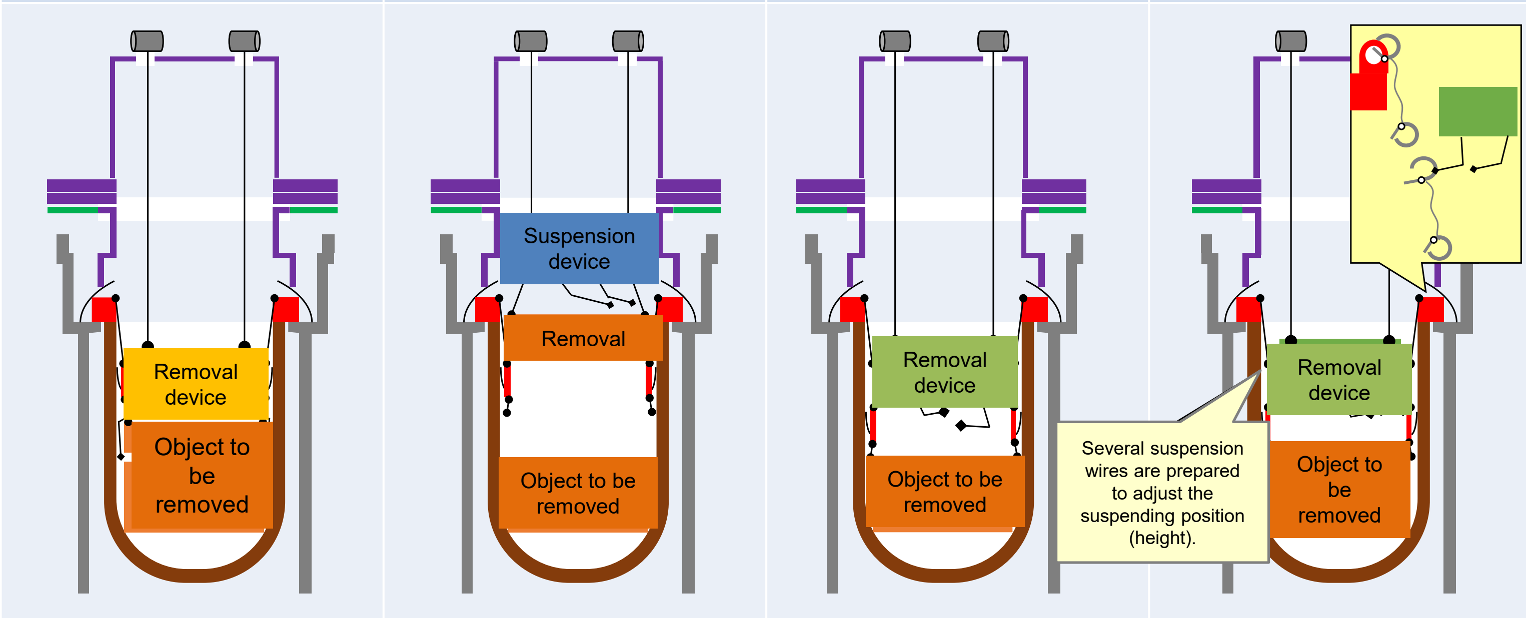
【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Study of method to remove from the reactor

On a basis of concepts in the previous pages, the removal procedures were studied.

Step 5	Step 6	Step 7	Step 8
Cutting of removal object	Pull-up of removal object	Reactor wall ring suspension	Suspension wire extension



Step 5	Step 6	Step 7	Step 8
• The removal object is cut by using a cutting tool that is equipped with the removal device. • The removal device is suspended and then transported.	• The suspension device is installed and connected a jig with suspending wire that is cut from the lower device. • The suspending wire that is connected the lower reactor wall ring and removal objects is disconnected by using a suspension arm. The whole object including the suspension device is pull out.	• The installation device is transported, and connected the lower installation device and the upper reactor wall ring with a suspending wire. • The connection with the suspension ring and the reactor wall ring is disconnected by using the installation arm. The installation device including the reactor wall ring is lowered.	• A wire suspending from the ring is extended and connected with the reactor wall ring.

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

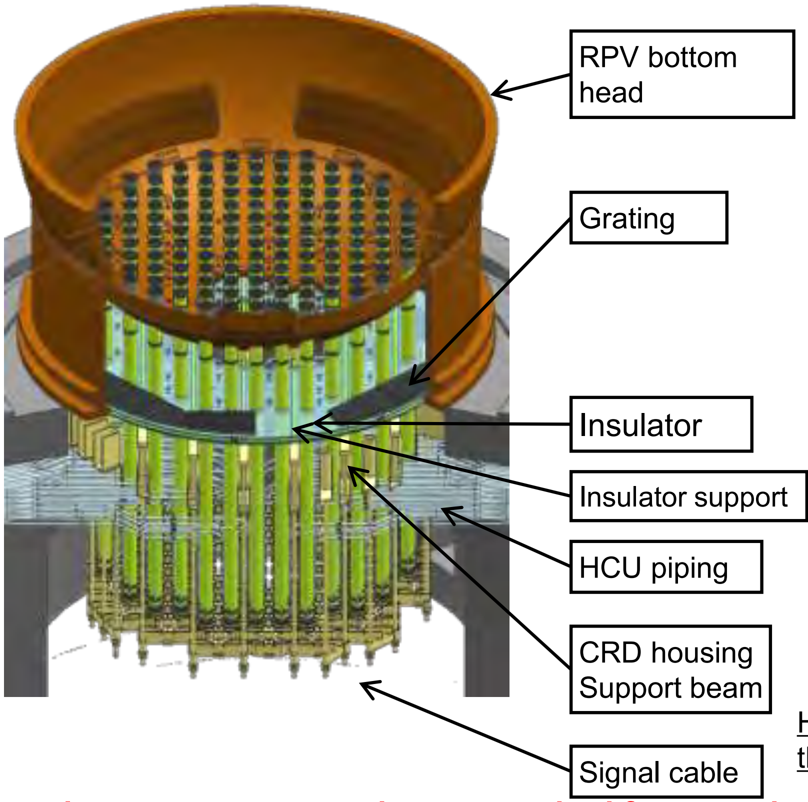
■ Study of specific plan 1 (Removal and transport of the whole structure in integrated state): Study on method to remove from the reactor

In FY 2018, element tests for the reactor bottom were conducted (stored in the unit canister (UC).

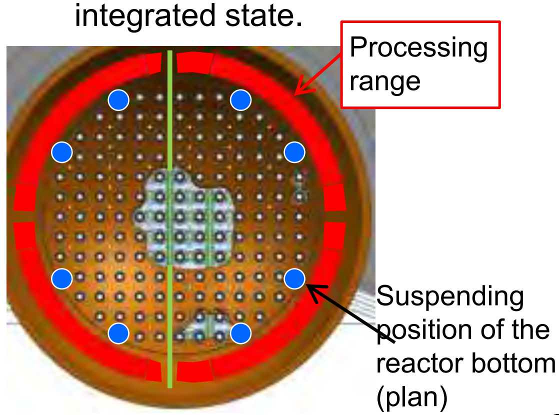
⇒To comparably evaluate the removal method of the whole structure and the conventional cutting method, element tests that are similar to the above test for the reactor bottom are being planned.

To conduct element tests, procedures of the reactor bottom removal method in an integrated state were studied.

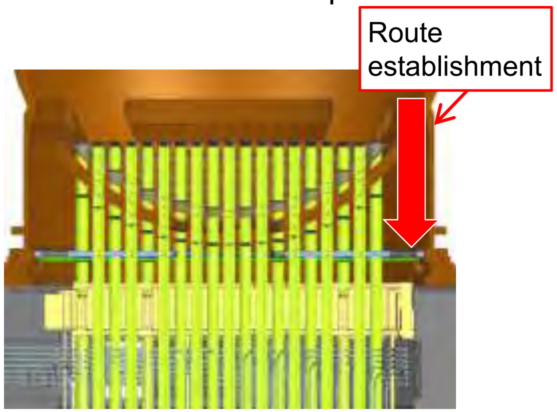
【A concept of the method for removing the reactor bottom 】



- ✓ Installation of the RPV opening to access the lower part
- ✓ After opening the RPV, fall prevention system is installed.
- ✓ Accessing from the opening, the structures are cut. (grating, insulator, insulator support, HCU piping, signal cables and CRD housing support beam)
- ✓ After implementing fall prevention measures, the bottom head was removed from the RPV and then the reactor bottom is suspended in an integrated state.



Horizontal view of planned opening of the RPV bottom head



Cross sectional view of opening plan of the RPV bottom head

Based on summary procedures, a method for removing each structure will be clarified and element tests will be conducted in next fiscal year.

7. Implementation items of this project

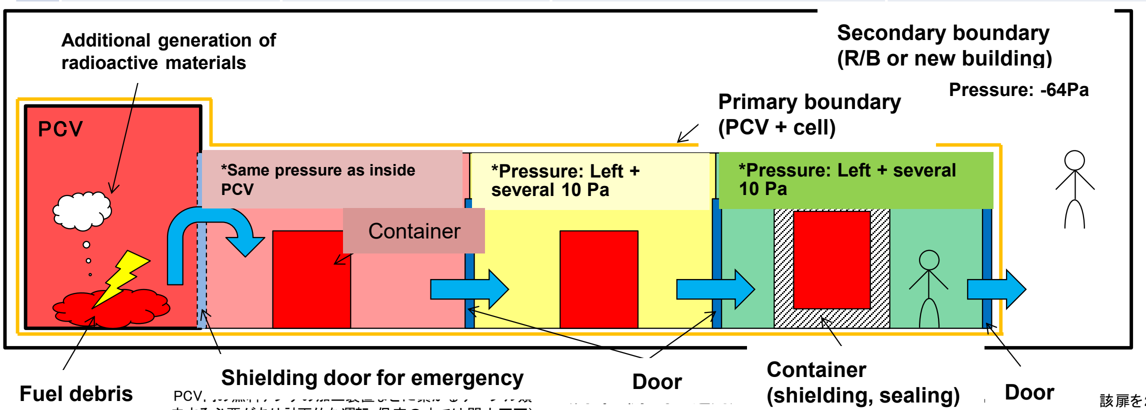
【 1) ① Development of interference removal technology】

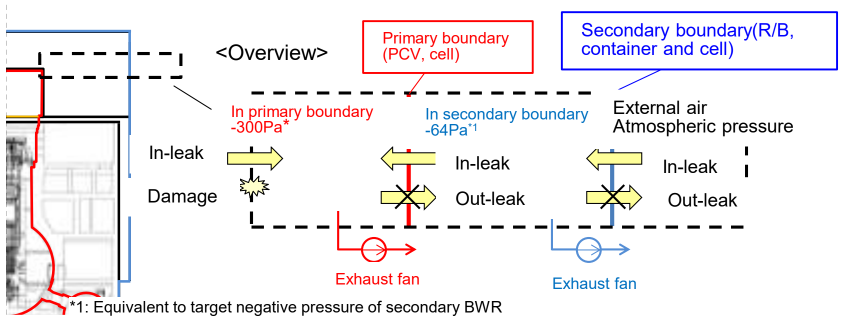
a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: A basic policy

- The following work procedures and facility layout plan were set.
  - Interference objects should be as large as possible to transport. In that case, the shielding of the objects should be reduced by decontamination or divided into appropriate size to transport in combination with shielding (it will be conducted at DS pool or spent fuel pool (SFP)).
  - The reactor well should be ensured shielding and confining before removing the shield cover. A concept of confinement area should be followed by the results in the previous fiscal year; The primary/secondary boundary will be established, the primary boundary will be subdivided and dynamic boundary will be applied by negative pressure.
  - After removing large-scale structure, the area for cutting will be unnecessary. To minimize confinement area for contamination, area setting should be modified.
  - Fuel debris should be stored into the transport container at the location as near as the RPV and then transported. Necessary work for storage including drying, sorting and storing in the canister should be performed in the another building away from the reactor building. Reduction of weight should be promoted by reduction of cell functions.

	Target	Functions	Conditions for achieving goal	Necessary equipment (major dynamic component)
Gas phase	Primary boundary (PCV, cell))	Prevention of leaking from primary boundary to secondary boundary	The primary boundary is maintained at negative pressure rather than in secondary boundary.	Exhaust fan (installation of primary boundary gas control)
	Secondary boundary (R/B, container and cell)	Prevention of leaking from secondary boundary to environment (external air)	The secondary boundary is maintained at negative pressure rather than external air.	Exhaust fan (installation of secondary boundary gas control)





*1: Equivalent to target negative pressure of secondary BWR
*2: -100Pa negative pressure comparing to secondary boundary
(Tentatively, difference pressures of cells in reprocessing facility are referred. However, conditions of the container are different from the cell. Effective difference pressures are required for future study result.

Conceptual diagram of boundary (formation image)

✓ The primary and secondary boundary are maintained at negative pressure.

✓ A policy of the primary boundary has several stages considering prevention of the spread of contamination. (Pressure setting for the PCV side are lower. Considering maintenance of the double door, a door is designed with three-protection door).

✓ Installation of isolation door at outer side of PCV is considered for emergency.

該扉を2重扉[外側]の位置づけで運用)

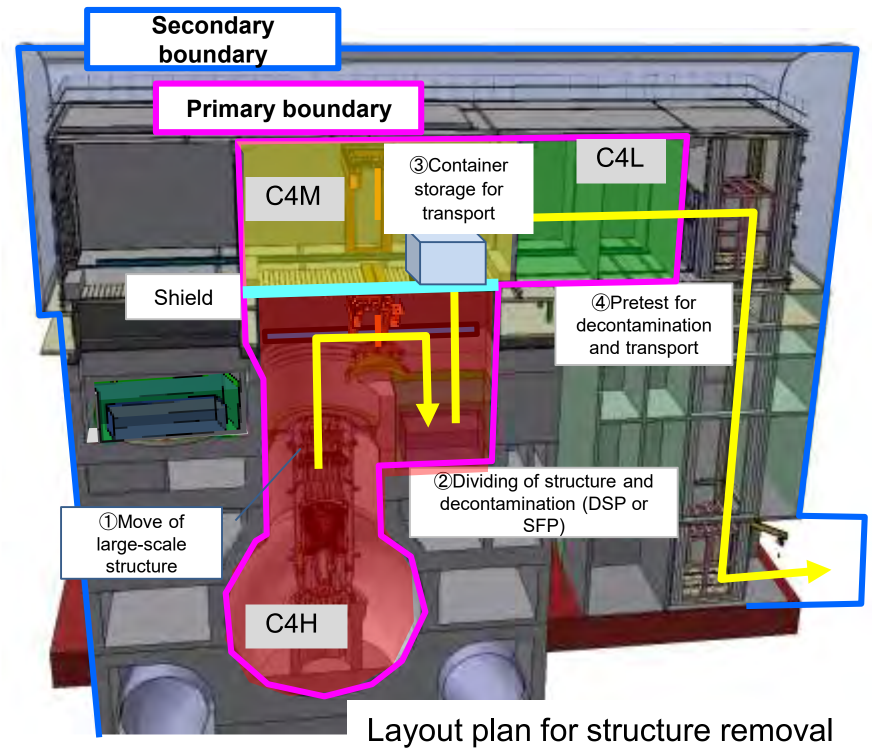
7. Implementation items of this project

【 1) ① Development of interference removal technology】

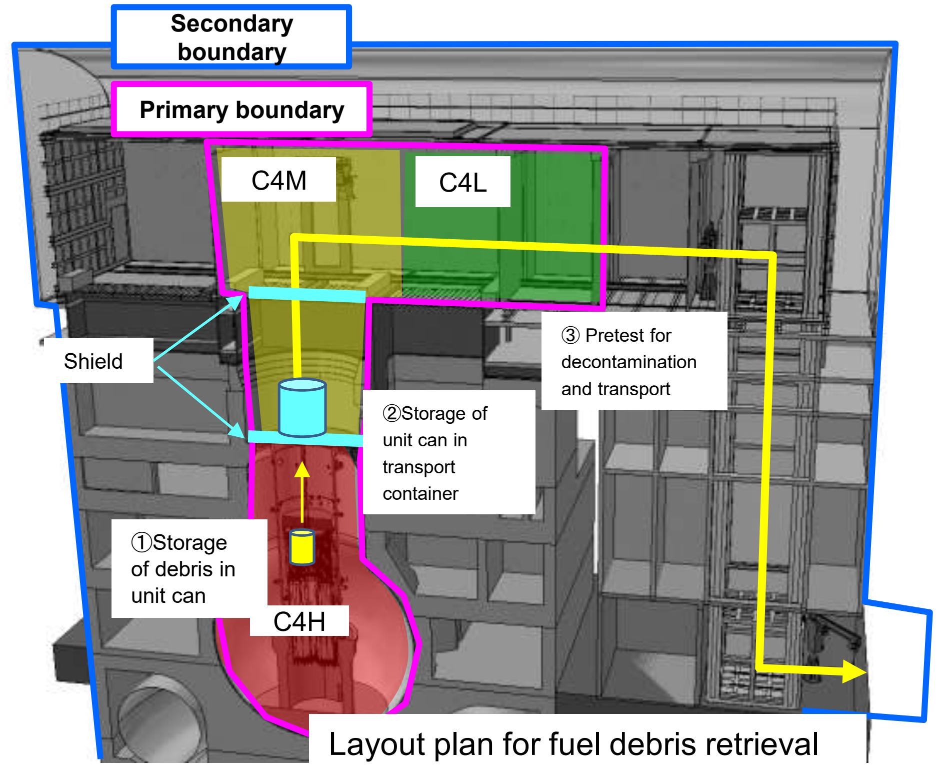
a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: A basic policy

- Prevention measures for the spread of dust during removing the large-scale structure (a basic policy of confinement (ensuring gas-phase boundary))
  - According to a basic policy, an overall layout plan is developed for removal work of the structure (interferences) and fuel debris retrieval work.
  - Firstly, the structure is removed to the DSP or SFP and divided, and then divided structures are transported after decontamination. The load of the building can be reduced by installation of shielding right above a pool (currently, the load to be reduced is estimated to be around 1000-1500 tons (fewer than half of the previous value).
  - After removing the structure, the overall layout is changed and the well is decontaminated by installation of shielding on the upper PCV.
  - The DSP and SFP are under preparation for temporary placement of equipment and the transport container, and for maintenance. The overall layout will be discussed in future.



Layout plan for structure removal



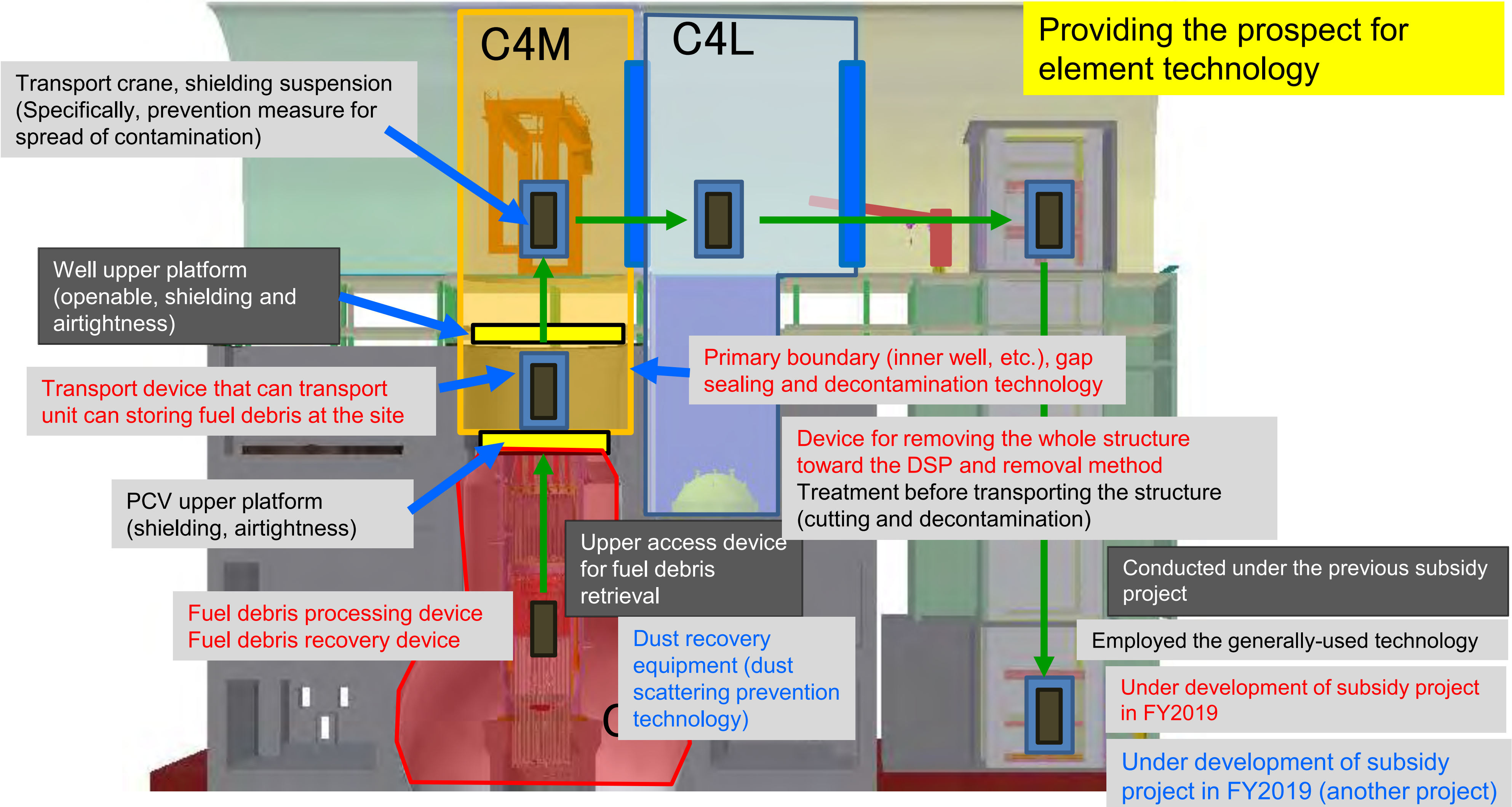
Layout plan for fuel debris retrieval

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning



7. Implementation items of this project

No.44

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

Issues and development policy (development issues in element technology were clarified and development policy was established)

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

ID	Element technologies	Issues of development	Development policy
1	Transport device (canister)	• Method for ensuring airtightness: Connection part and remote operation part (lid and lifting machine)*1 • Hydrogen control during transportation and criticality control method • Development of basic requirement specifications (standards (site transport standards, etc.), fuel debris specifications and work plan for workers)	Studied by the subsidy project in FY2019 and 2020. 7.1)②d. Method for transporting the unit can from the R/B.
2	Well of upper platform	• Devices required for installation before starting removal work of the reactor internals and fuel debris retrieval work. • Verification of movable shielding operation and airtightness performance during suspending operation.	Element test were completed. 【It can be designed.】
3	PCV upper platform	• Open-close method and its mechanism in the limited space such as the reactor well. • A method for fixing the PCV flange and fixing procedures • Connection with mobile cell and fuel debris retrieval device (airtightness structure) • Maintenance method and procedures	Studied by the subsidy project In FY2019 and 2020 (to be planned in 2020)
4	Gap sealing for inside the well, decontamination technology	• Necessary work before starting removal work of the reactor internals • Work for the well internal to build the primary boundary • Sealing technology for the gate plug gap and the construction method, decontamination of the well and technology for extending the PCV	Studied by the subsidy project in FY2019 and 2020 (existing technology can be applied to decontamination).
5	Method for removing the whole structure (including decontamination and cutting)	• Selection of the transport method for large-scale structure, study of procedures, lifting machine and suspension tool • Setting of decontamination ranges • Calculation of weight of shielding, available transport crane and estimation of minimum divided structures • Cutting technology for complicated structures such as dryer unit and separator. 7.1)①a. Technology that the reactor well can be a boundary	Studied by the subsidy project In
6	Fuel debris processing and recovery device	• Achieving of processing speed far beyond existing technology and investigation of processing technology that exceeds the range of existing technology • Selection of processing and collecting methods according to type of debris (specifically, nuclear fuel that has not been studied • Release of fission products (FP) and its responding method 7.1)①a. Technology for removing shield cover	The subsidy project has completed. Studied by the subsidy project In FY2019 and 2020, (continued, conceptual design and element tests continue)
7	Dust recovery equipment	• A collecting head that can collect dust generated from near the processing points, and study on the hood. • Considering maintenance performance, concepts of water dust collecting system, collecting effects, and maintenance plan are developed. Another subsidy project (development of dust collection technology) engages in.	Studied by the subsidy project In FY2019 and 2020 (conceptual study and element tests)
8	Upper access device for fuel debris retrieval	• A concept of access device that is improved maintenance pe[r...] • Development of the maintenance method	Element tests have done. 【Designing actual device】

7. Implementation items of this project

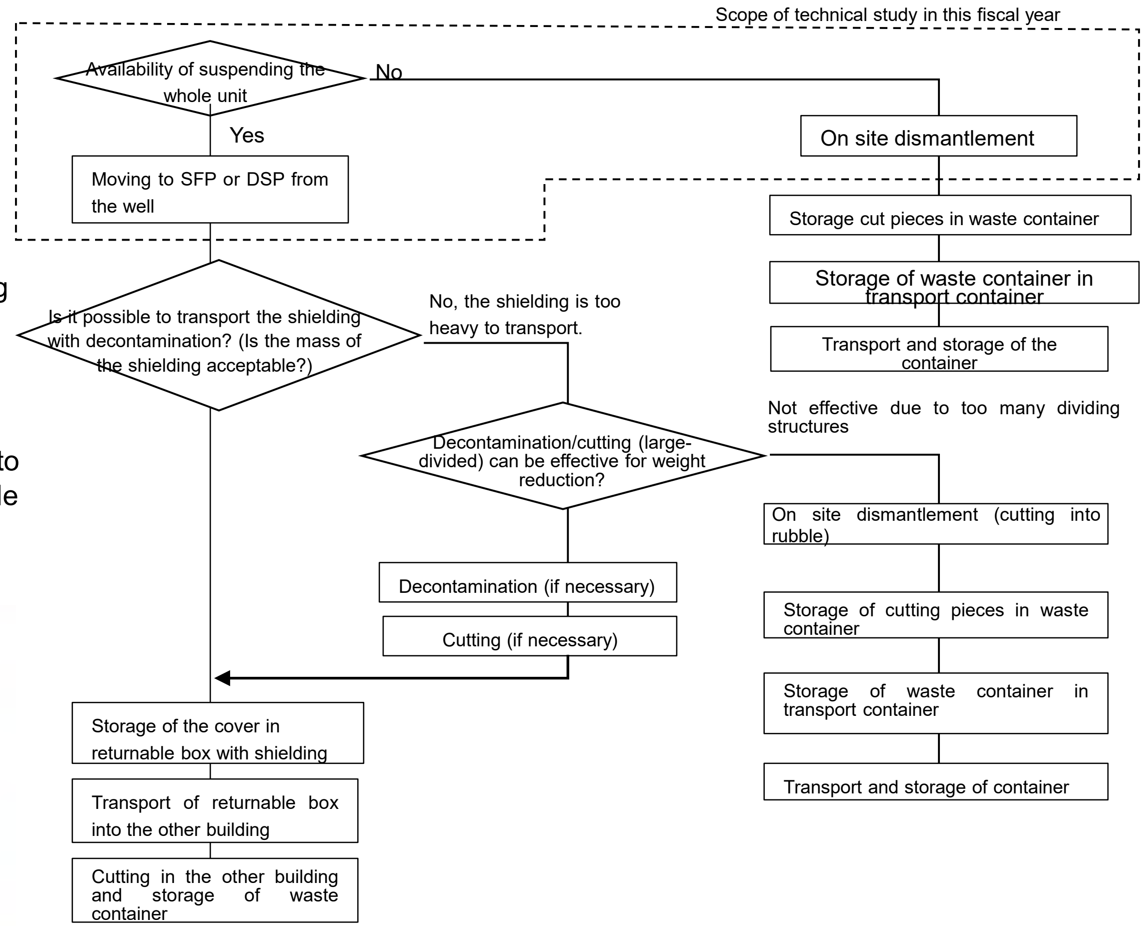
【 1) ① Development of interference removal technology】

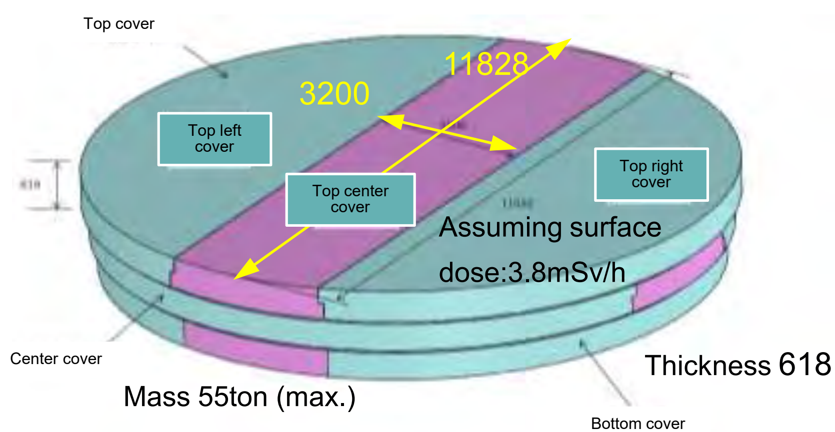
a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

● Technology for removing the whole shield cover into the DSP (or SFP)

- It will be stored in a waste container and placed in the premises of Fukushima Daiichi.
- Various plans are considered; Cutting in the R/B and stored in the canister, cut and storage of the canister in the other building after removing the whole unit, and dividing and transporting the large-scale structure in the R/B and then cutting in the other building.
- On the other hand, a critical process should be shorten and therefore, operations in the R/B (cutting, etc.) and transportation should be minimized.
- Decontamination shall be considered, if effective, when transporting from the building.
- Finally, several plans will be selected among plans for removal of the whole unit, the divided large structure and cutting/decontamination, considering different states of each unit.
- Element technologies will be studied to achieve a target according to each scenario. In this fiscal year, a method for suspending the whole unit and a dismantlement method on site will be considered.





7. Implementation items of this project

【1) ① Development of interference removal technology】

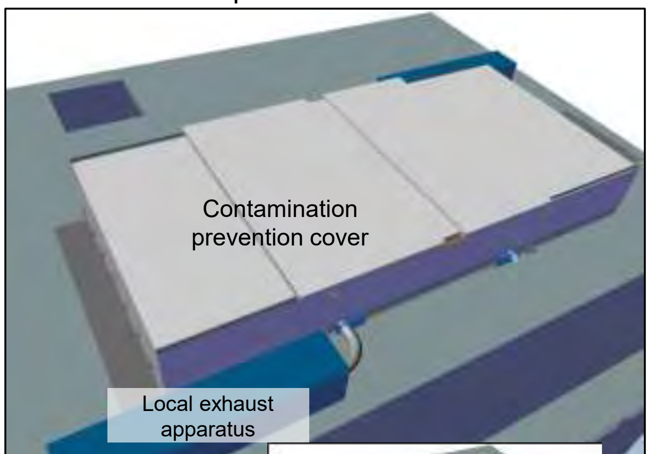
a. Removal and transport methods for large-scale structures by accessing from the top

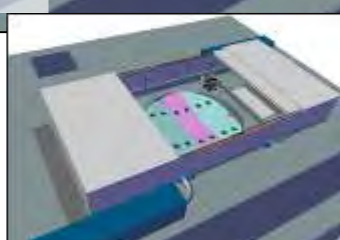
■ <u>Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning</u>

● Technology for removing the whole shield cover)

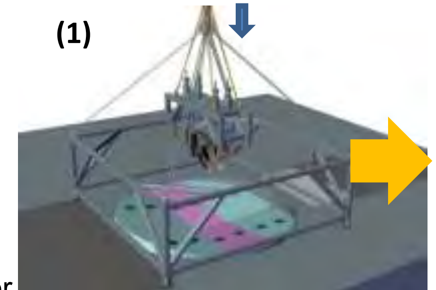
Sequence plan for removal and transport

- Moving of the shield cover on the well for dividing cutting, decontamination and packing
- Candidate destination is the DS pool or fuel pool.
- A transport work should be completed inside the cover to prevent from spreading contamination and to shield. Therefore, a crane that can transport into the cover should be implemented.



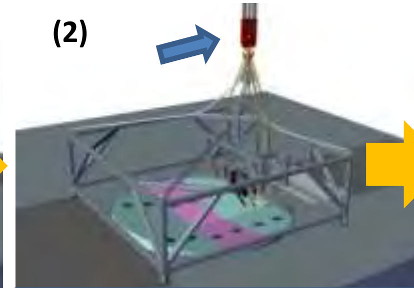


(1)



Firstly, a deflection restraining frame is grounded to control deflection around a robot by a wire tension.

(2)

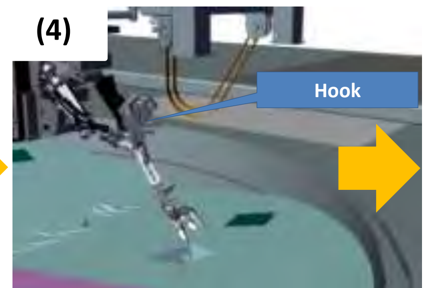


Transfer a robot to the upper cover

(3)

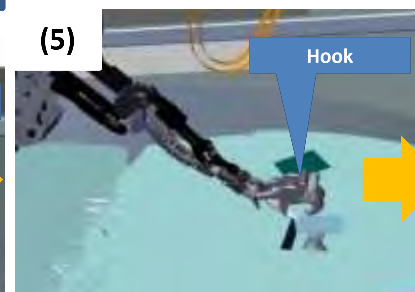
Remove a bail cover by using a robot (work range of robot: 3m radius)

(4)



Handle a slinging hook by using a robot

(5)

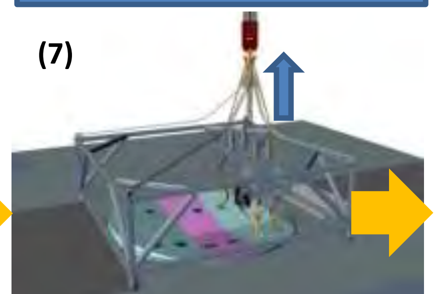


Handling of slinging hook by using a robot

(6)

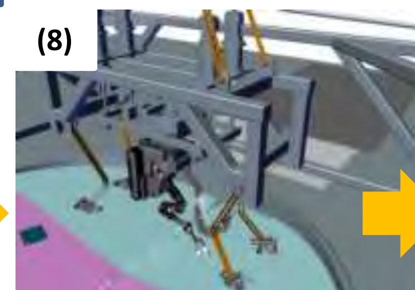
Pull a hook

(7)



Handle the shielding cover when lowering the deflection frame.

(8)



Hook on four points, following the same procedure.

(9)

Handle the shielding cover when lowering the deflection frame.

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

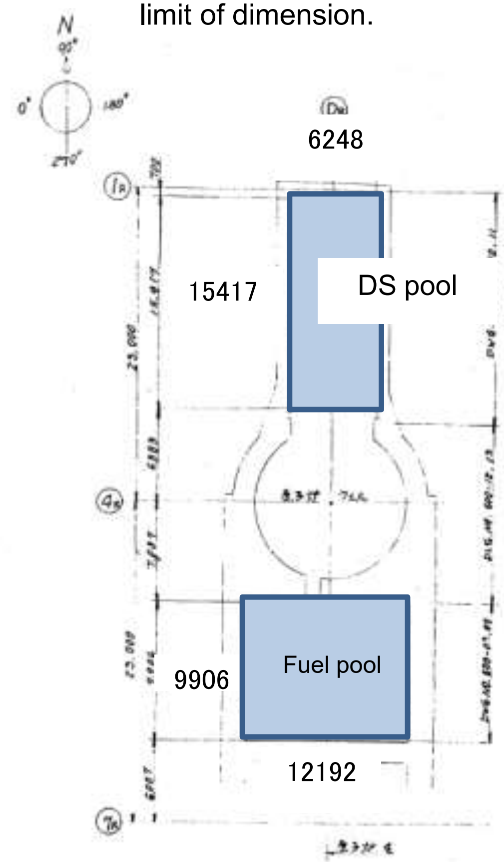
■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

● Technology for removing the whole shield cover toward DSP (or SFP)

Applicability and issues for Unit 1 through 3, related to suspending move of the shield cover

Methods and target	Unit 1	Unit 2	Unit 3
Shielding cover and surrounding conditions	All the shield cover has fallen and the lower part (the third layer from the top) has also fallen on the well, which contacted the PCV top head. The well wall liner was damaged (fallen off). Water is accumulated in the well seal bellows. Maximum dose of the upper surface: Approx. 2 sv/h. The middle lower side: Approx. 1 Sv/h.	Damages are not identified from observation of the surface of the upper shield cover. It is estimated to be sound.	Damages were found in the upper of the shield cover (the first layer from the top) and the concave surface was confirmed in the center. The condition of the lower part is uncertain.
Reference of information	TEPCO HD website 2019.8.29	TEPCO HD website 2019.1.31	TEPCO HD website 2014.2.27
Acceptability of application	△ It is hard to assess acceptability of application because of difficult assessment of the soundness.	○ Assessment reveals the soundness.	△ It is hard to assess acceptability of application because of difficult assessment of the soundness.
Minimum conditions for application of the method for suspending the whole unit	・The shield cover has the strength (it can endure suspending transport). ・Amount of dust dispersion from the damaged part is with acceptable range.		・The shield cover has the strength (it can endure suspending transport). ・Amount of dust dispersion from the damaged part is with acceptable range. ・The lower part should not fall when suspending the upper cover.
Issues for assessment of applicability	Establishment of assessment method for the soundness (confirmation of the soundness for reinforcement arrangement inside the shield cover) Confirmation of the conditions including the lower part	Appearance investigation up to the lower part	Establishment of assessment method for the soundness (confirmation of the soundness for reinforcement arrangement inside the shield cover) Confirmation of the conditions including the lower part

The most promising destination for an entire shield cover to be removed to is the DS pool, considering the limit of dimension.



7. Implementation items in this project

【 1) ① Development of interference objects removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ <u>Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning</u>

● Technology for dismantling the shield cover on the well (on site)

Applicability of the method of removing the whole shield cover for unit 1 and 3 has many issues, therefore comparative study of the dismantlement method on site (cutting) was conducted.

Method	Water jet method (Method 1)	Wall saw method (disc blade)(Method 2)	Chipping method(Method 3)
Wet/ dry	Wet crushing method	Wet crushing method (low water amount)	Dry crushing method
Assuming construction capability	0.2m3/a day	3.2m/a day (0.35 m depth)	0.3m3/a day
Characteristics	1) Small reaction force 2) No effect on work even in buckling part.	1) The depth of cut can be controlled 2) Concrete and reinforcing steel can be cut at the same time.	1) General-purpose heavy machine can be used for construction. 2) Drainage water is not generated.
Image of implementation	1) Reaction force is small. 2) Abrasive is sprayed on reinforcing steels. 3) To avoid a sudden fall of the damaged part, it is repeatedly crushed from the top.	1) Reaction force of a small type heavy machine construction is larger than chipping method. 。 2) To avoid falling cut parts, grasping method is applied.	1) Cut pieces are grasped by jig or collected by vacuum suction. 2) To avoid a sudden fall of the damaged part, it is repeatedly crushed from the top.
Major issues	1) Waste water treatment apparatus is required to treat large amount of water. 2) Particulate water injection would cause poor visibility.	1) Dust and flipped stones would generate. 2) Another construction method is required for internal corner. 3) It is necessary to move blade and install a jig to accept reaction force.	1) Micro cracks would generate due to vibrating and beating. 2) Dust and flippered stones would generate. 3) Reinforcing steel cutting is required for long hours.
Risks of falling on the well (specifically, on the well seal bellows)	It is hard to collect drainage water, abrasive and fallen crushed materials. In addition, the damage prevention measure for the bellows is required.	Fall prevention measures for cut pieces and debris from processing is required.	Fall prevention measures for processing pieces are required.
Reaction force	Small	Large	Medium
Dust dispersion	Work under the contamination prevention cover		
Secondary waste	Drainage volume: Large Abrasive volume: Large Both of drained water and abrasive are collected.	Drainage volume: Small Wasted blade volume: Small	Wasted jig volume: Small
Construction days	Long	Short	Medium
Assessment	This method is not reasonable because large amount of waste water would generate and the construction period is longer. However, if another method causes trouble, (i,.e. Stacks due to a rock pocket), it might be effective during spot period.	Dust and flipped stones can be prevented by the protection cover. If the method 3 is applied for the internal corner, this method can be applicable.	Dust and flipped stones can be prevented by the protection cover. If the method 2 is applied for cutting of a reinforcing steel in advance, the construction period would be shorter.

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

● Technology for removing the whole shield cover

Summary

- A conceptual study of removing the shield cover that interferes with the top access method was performed.
  - In addition to a conventional plan that the shield cover is cut and stored in the waste container and then transported, various plans were clarified; A plan for transporting the whole unit from R/B and other operations are performed outside the building including cutting the cover, and another plan for transporting divided large-scale structures from the R/B (after reduction of weight) and the other operations are performed outside the building including cutting.
  - Procedures and branch points for selecting scenarios of each plan (a flow chart) were defined. The applicability of the method differs depending on units.
  - For the plan for suspending the whole unit from the reactor well, a conceptual design of device and the work procedures were performed.
  - For the plan for cutting in the R/B, a list of cutting method was created and comparative evaluation for each plan was performed.
  - To suspend the whole shield cover, it is necessary to study acceptability of feasibility for suspending the shield plug including the upper as well as the lower part, and on-site investigation data is also required and significant.
- Major issues that should be studied under a subsidy project in FY 2020.
  - Removal procedures for each unit are clarified. A plan for removing the whole unit was created and therefore a cutting method on the reactor well will be developed, specifically prevention measures for collapsing the lowest part and falling plugs and debris will be developed.
  - Decontamination and paint treatment method to prevent spreading contamination adhered on the wall of the well after removing a plug
  - Criteria for acceptability of the whole unit suspension method are required to determine. After that, transport device for the whole unit suspension will be designed.
- Response to construction and engineering in future

  Collection of practical information to assess the whole unit suspension method (specifically, state of reinforcing steel, risks of fall, expected radiation doses when suspending and contamination conditions for estimation of radiation emission, etc.)
  - To consider cell configurations during removal, the time of installation for the shielding and scale of the shielding (thickness), contamination state of inner surface of the well and the surface of the cover will be surveyed.

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

- Development of sealing technology for the opening part to establish a boundary of the reactor well

- Basic requirement functions
  - Confinement of radioactive materials by building a boundary
  - Requirement conditions for the sealing part (target values)
    - Differential pressure: Leakage amount for differential pressure design will be set in future.
      (Calculated from estimated flow rates in the system to maintain negative pressure in a boundary (-100Pa) and the ratio of the PCV surface area to the opening part.)
    - Differential pressure design: Differential pressure design will be set in future, which is required the sealing part to be sound.
    - Defect of the sealing part can be detected.
    - Negative pressure of the primary boundary during maintenance (differential pressure during normal operation) should be maintained.
  - Reduction of radiation exposure for workers
    - Measures to achieve requirement functions: Planning of a complete remote operation.
    - Requirement conditions for the sealing part: The sealing part can be installed/replaced by remote operation.
- Conditions of environmental requirements
  - Radiation dose: (After installation of PCV flange platform): 5-10mSv/h
    (Before installation of PCV flange platform): Approx. 100 Sv/h
  - Temperature： -7～40℃
  - Humidity： Outside the boundary: Equivalent to external air
    Inside the boundary: ≦99%
  - Lifetime of design：50 years (Consumables can be replaced during maintenance.)

7. Implementation items of this project

【 1) ① Development of interference removal technology】

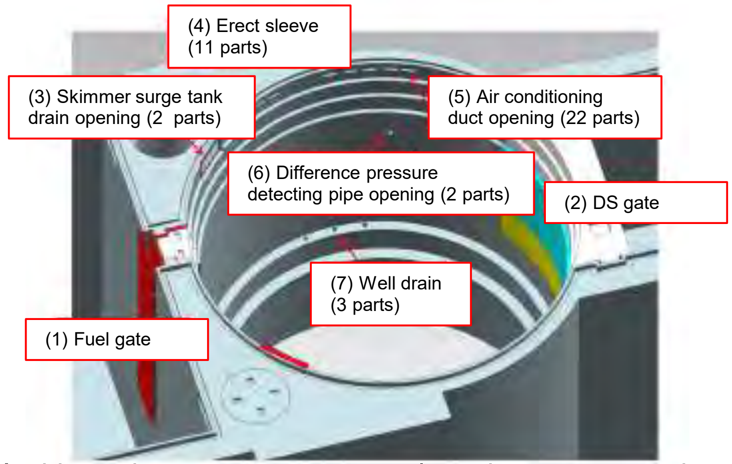
a. Removal and transport methods for large-scale structures by accessing from the top

■ <u>Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning</u>

● Development of sealing technology for the opening part to establish a boundary of the reactor well

- Required sealing parts are identified.

#	Name of parts	Studied
1	The reactor well air-conditioning duct opening part (23 parts)	○
2	The reactor well side duct opening part of a skimmer surge tank (2 parts)	○
3	The differential pressure detection tube opening part of the reactor well interruption part (2 parts)	○
4	A gap between a slot and a slot plug (Officially, one side: 13mm)	○
5	G1/G2 gate tube drain of the slot part (1 part)	
6	A gap between D/S pit cannel and D/S plug (Officially, one side: 13mm)	○
7	A gap between the well cover and the upper stand of the reactor well (Officially, one side: 13mm)	
8	A gap between the well cover and the other covers (Officially, 13mm)	
9	A gap between the well cover and the upper stand of the slot plug (Officially, 13mm)	
10	A gap between the well cover and the upper part of the D/S plug (Officially, 13mm)	
11	The main part of the well sealing bellows (In case of damage)	
12	The well sealing bellows and the welding part of the reactor well lower liner (in case of damage)	
13	The welding part of the well sealing bellows and the PCV flange (in case of damage)	
14	The reactor well lining plate (in case of damage)	
15	The welding part of the reactor well lining plate (in case of damage)	
16	The erecting sleeve of the upper part of the reactor well air-conditioning duct (11 parts)	○
17	A screw hole for handrail on the reactor well cab liner ⇒ No penetration at t25	
18	The well drain of the lower stand of the reactor well (3 parts)	○



In this study, seven parts were selected as representative structures from the left chart. The well cover related parts (7 parts) are to be replaced with a new well cover that is considered for leakage after removal, and another parts that have potential damage in welding parts (5 parts) are to be blocked depending on the damaged conditions or evenly sealed with grout.

- A policy of response to Level 2 and 3 to evaluate radiation exposure.

Level classification	Evidence	Index of sealing performance (Ex. Flow rates)	Detection method	Prevention for accident occurrence	Recovery for event occurrence
Level 1	Achieving a flow rate of **m3/h at differential pressure **Pa.	**m3/h			
Level 2	** times of Level 1	**m3/h			
Level 3	When running out of sealing	****m3/h			

Based on the sealing structure developed in FY2019, the structure of each sealing part will be created in FY2020.

7. Implementation items of this project

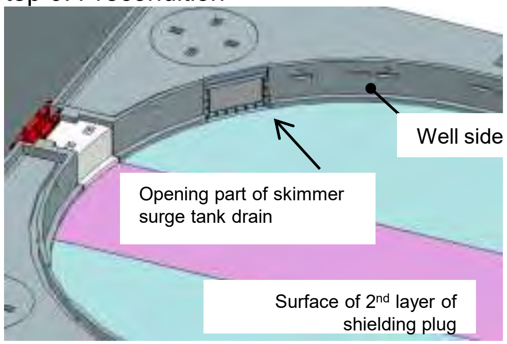
【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

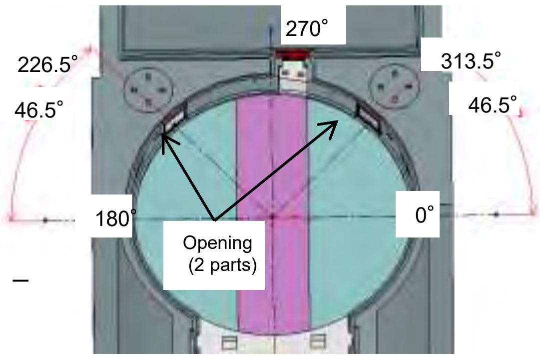
■ <u>Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning</u>

● <u>Development of sealing technology for the opening part to establish a boundary of the reactor well(process chart for sealing)</u>

Step 0: Precondition

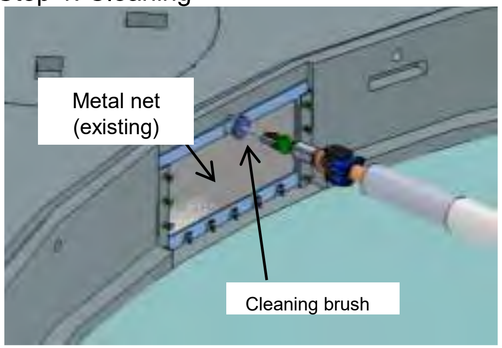


・The 1st layer of the shield plug is removed and the surface of the second layer completes decontamination and cleaning.
・Metal net is installed in front of drainage.
・Damages and deformation are not seen



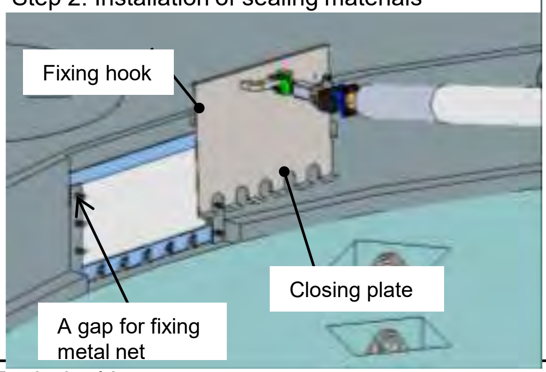
Technical issues
・Access route plan
・Plan of a monitoring method
・Clarification of requirement functions for self-driving robot

Step 1: Cleaning



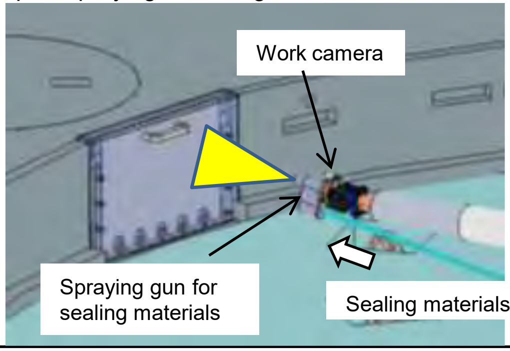
Technical issue
・Setting of required cleaning levels

Step 2: Installation of sealing materials



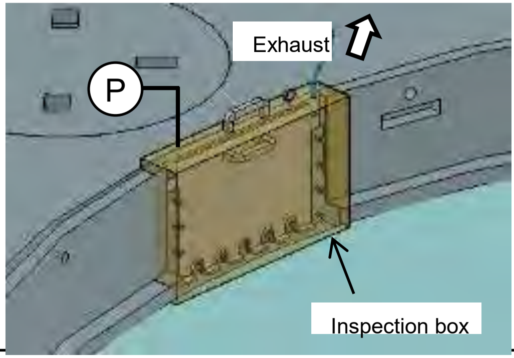
Technical issue
・Acceptable value setting of clearance amount

Step 3: Spraying of sealing materials



Technical issues
・Understanding of available construction hours
・Establishment of spraying procedures
・Establishment of reasonable evidence to determine to judge work completion

Step 4: Inspection



Technical issues
・Structure of inspection box
・Method for identifying a leakage point

7. Implementation items of this project

【 1) ① Development of interference removal technology】

a. Removal and transport methods for large-scale structures by accessing from the top

■ Study of specific plan 2 (combination with removal of divided large-scale structures and decontamination: Element technology required for confirming feasibility planning

● Development of sealing technology for the opening part to establish a boundary of the reactor well

Summary

- Sealing technology for the opening part to establish a boundary of the reactor well was studied, which is required for the top-access fuel debris retrieval method.
- The existing opening parts were surveyed and identified issues to be discussed.
- General-use sealing technologies were surveyed and then sealing technology for each opening part was selected.
- A work flow chart for remote operated device was created as a implementation plan for selected sealing technology.
- The following items will be studied and implemented in fiscal year 2020.
    - Listing of issues based on the work step planning
    - Maintenance plan for sealing, rescue plan in case of radiation leakage in the sealing part and monitoring planning to avoid leakage in advance
    - A policy of solutions to identified challenges including maintenance and rescue, and test and analysis plans
    - A boundary establishment method except for sealing of the opening part; Ex. Comparison of extension pipes installed from the PCV flange

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

- Purpose of Development
  - To conduct studies related to the method of establishing the access route from the equipment hatch to the CRD opening, which is necessary for fuel debris retrieval.

- Issues that must be resolved
  - Increase in scope of remote operation and enhancement of work efficiency.
  - Method of handling cables of the various devices used within PCV.

- Approaches to development
  - Drafting of work procedures from accessing the inside of PCV to removing interferences.
  - Study of the methods of removing interferences that are on the access route from the equipment hatch to the CRD opening, and element tests.
  - Development of the method for installing utilities for the devices used inside PCV.

- Expected outcome
  - Work procedures from accessing the inside of PCV to removing interferences.
  - Method of establishing the access route from the equipment hatch to the CRD opening.
  - Method for installing utilities for the devices used inside PCV.

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Preconditions of the study

- ✓ PCV and expanded building (*1) can be connected by means of a passage (access tunnel). Further, the access tunnel is installed by launching it remotely from outside the R/B.
- ✓ The yard has been prepared for access tunnel installation, measures pertaining to underground structures have been taken and structures on the ground have been removed.
- ✓ The work of removing interferences from inside PCV and the work of fuel debris retrieval is carried out using multiple remote operation devices. Devices are assembled inside PCV as required.

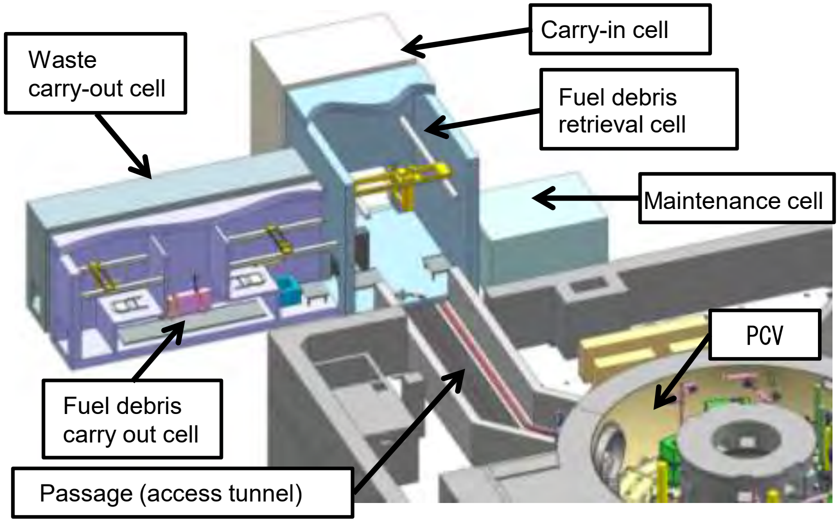


Image showing how the PCV and expanded building are connected

(*1): Since the detailed functions of the expanded building are still being studied, it is defined as a facility with preliminary treatment functions for storage including fuel debris drying.

7. Implementation items of this project

[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Study Flow

: Reported this time

Policy for initiatives for the current fiscal year in response to issues from the past fiscal year

- Outside the pedestal: Verification of feasibility of the work of installing utilities for implementing the work of assembling remote operation devices
- Inside the pedestal: Verification of feasibility of interference removal method / fuel debris retrieval method using the CRD platform

Study of work outside the pedestal

Study of work inside the pedestal

- Installation of common utilities for remote operation devices on the grating on the first floor outside the pedestal

Issues faced in making work outside the pedestal possible and related studies (including tests)

Issues faced in making work inside the pedestal possible and related studies (including tests)

- Verification of feasibility by means of element tests related to installation of common utilities

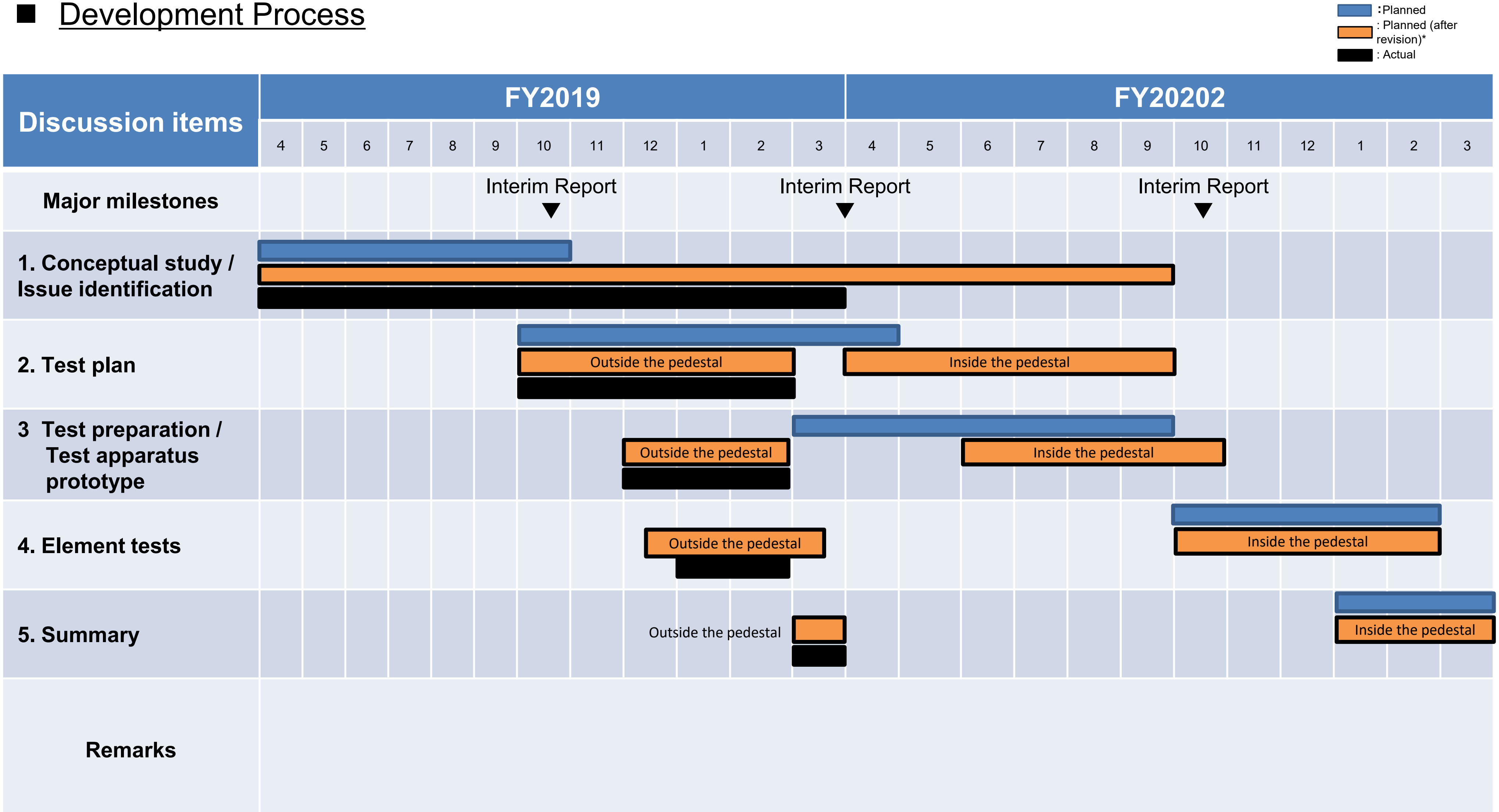
Scope of implementation under the subsidy project

Site situation investigation results

Actual construction plans

7. Implementation items of this project
[1) ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ <u>Development Process</u>



* The plan was revised to reflect the study progress status and the results of element tests.

7. Implementation items of this project
[1) ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Overview of the method to be studied

✓ The PCV and expanded building are connected by means of a passage (access tunnel). The access tunnel is installed by launching it remotely from outside the R/B.

- ➢ The floor load inside R/B can be reduced by using the access tunnel.
- ➢ If the layout of the access tunnel interferes with other work, the interference can be prevented by changing the route of the access tunnel (highly flexible layout plan).
- ➢ Amongst the existing penetrations, the equipment hatch is used as the access point for the access tunnel.

✓ The work of removing interferences from inside PCV and the work of fuel debris retrieval is carried out using multiple remote operation devices. Devices are assembled inside PCV as required.

✓ This method is applicable regardless of the unit and whether the interference is inside or outside the pedestal.

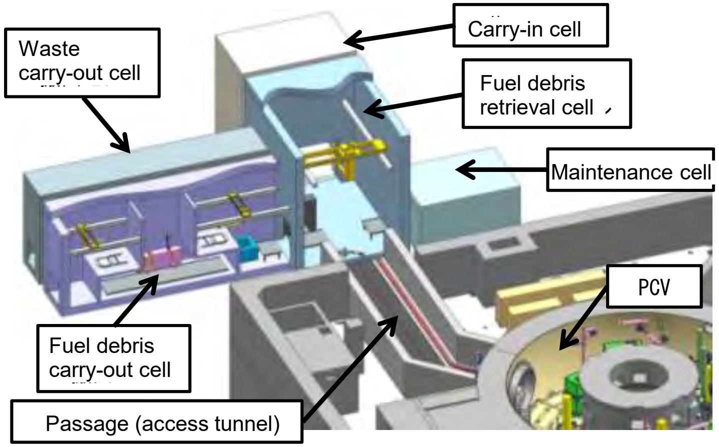
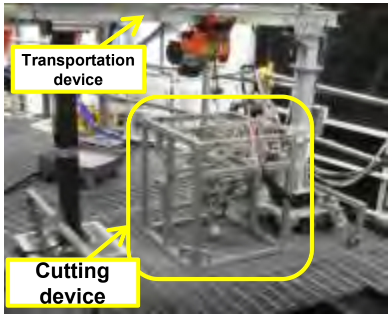


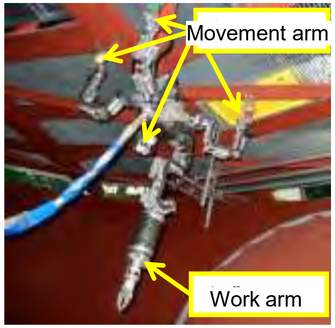
Image showing how the PCV and expanded building are connected

[Example of remote operation device]

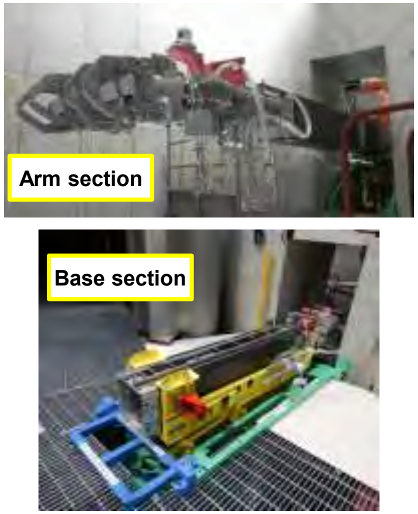
Flexible work arm (crawler, dual arm type)



Transportation device and cutting device



Flexible work arm (multi-arm type)



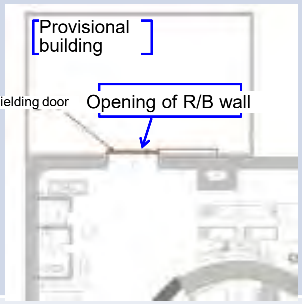
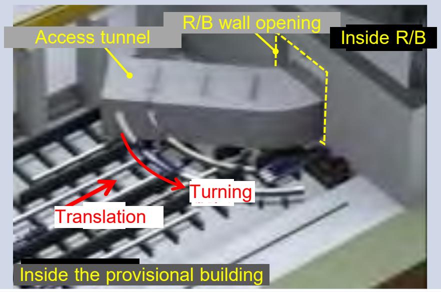
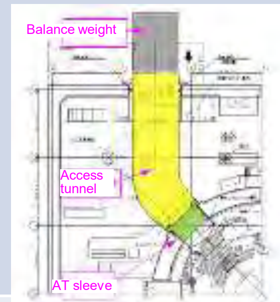
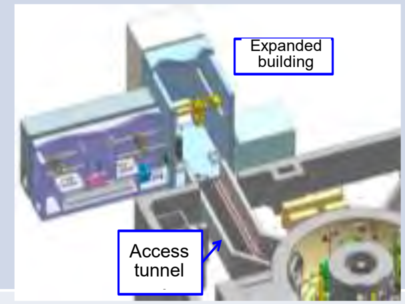
Device for removing interferences from inside the pedestal

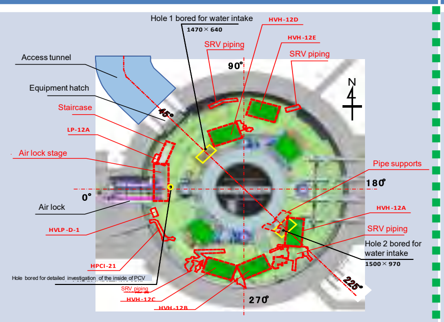
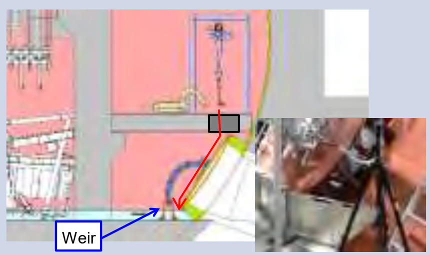
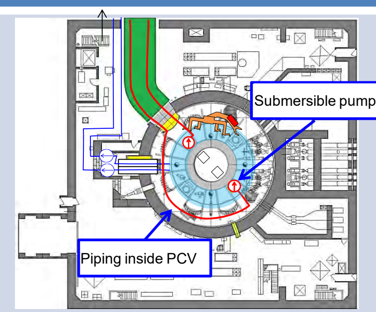
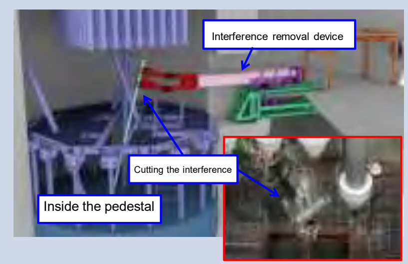
7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Main work steps

✓ Following is a series of the main work steps from preparatory work to fuel debris transportation. [dotted box]: Studied in FY2019-20

Work step	① Construction of provisional building Opening up the R/B wall	② Launching the access tunnel	③ Connection of the access tunnel	④ Construction of expanded building
Step diagram				
Remarks*	• Conceptual study has been conducted. • Since it is presumed that existing technology can be used, the following steps are being studied on a priority basis.	• Feasibility has been verified through element tests. (FY2017-18) • A turning element test simulating actual weight is planned.	• Element tests related to the method of welding the sleeve and PCV are planned to be implemented as part of this project. (FY2020)	• Detailed study by the operator's engineering department is underway.

Work step	⑤ Removal of interferences outside the pedestal (Establishment of access route inside D/W)	⑥ Installation of weir for preventing spread of contamination	⑦ Laying of pipes in the D/W Installation of submersible pump	⑧ Removal of interferences from inside the pedestal
Step diagram				
Remarks*	• Interferences from inside the D/W (first floor) are removed. • Element tests related to the tasks from accessing the basement floors to the work of removing the piping have been implemented. (FY2017-18)	• The D/W basement floor is accessed. • A weir for preventing spread of contamination is installed. • Preliminary tests related to installing the weir around the jet deflector (J/D) have been implemented. (FY2017-18)	• Construction of the water circulation system • Element tests related to laying of pipes and pump installation have been implemented as part of the water circulation PJ. (FY2019)	• Element tests related to the method of interference removal using a beam have been implemented. (FY2017-18) • Interference removal element tests using the CRD platform are planned to be implemented. (FY2020)

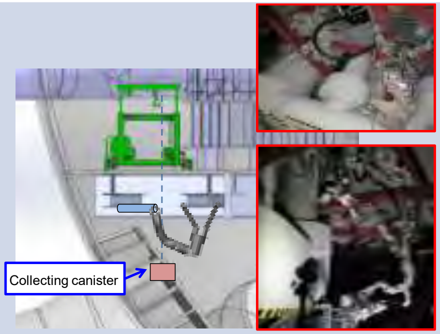
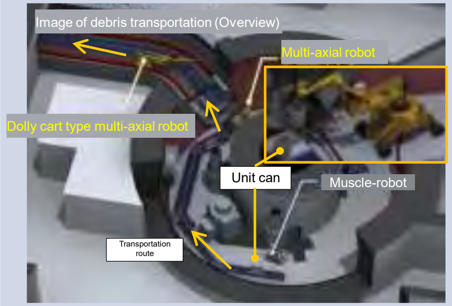
* Items that have been underlined are being implemented as part of other projects or by the engineering department.

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Main work steps

: Studied in FY2019-20

Work step	⑨ Fuel debris retrieval	⑩ Fuel debris transportation
Step diagram		
Remarks*	• The figure illustrates an example of work carried out outside the pedestal. • Work inside the pedestal is carried out by means of the interference removal device. • Element tests related to the method of fuel debris retrieval using a beam have been implemented. (FY2017-18) • Element tests related to fuel debris removal using the CRD platform are planned to be implemented. (FY2020)	• Conceptual study has been conducted. • Although technological development is necessary for transportation work in this step, if the preceding steps are not feasible, this step won't need to be carried out, and hence the preceding steps are being studied on a priority basis.

Steps ③, ⑤, ⑥, ⑧, ⑨ are being studied as part of this subsidy project.
(The other steps are either being studied as part of other projects or by the engineering department, or element tests for those steps have already been implemented.)

✓ Detailed development content for step ③ is described under “3) (i) ② Technology for ensuring confinement functions in connection parts”. (Slide 260 to 270)

✓ Detailed development content for steps ⑤, ⑧, ⑨ is described under “1) Development of interference removal technology” in this section. (next slide onwards)

✓ Detailed development content for step ⑥ is described under “1) ② Development of various technologies other than interference removal technology”. (Slides 88 to 107)

7. Implementation items of this project
[1) ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Overall strategy for the work of removing interferences from outside the pedestal

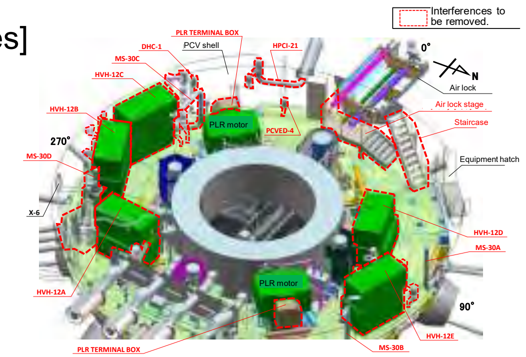
✓ During the work of removing interferences from outside the pedestal, the work of providing utilities for removal work is carried out in parallel with the interference removal work.

⇒ Verifying whether or not providing utilities is feasible, is as important as confirming whether or not the interference itself can be removed. (Since the feasibility of provision of utilities has an impact on the interference removal method)

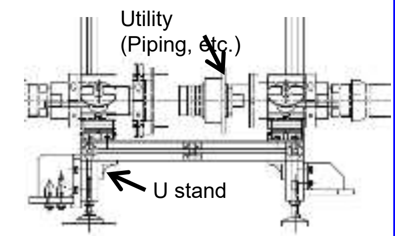
⇒ As part of this project, efforts will be made to verify the feasibility of providing utilities prior to interference removal.

[Procedures for interference removal and for providing utilities]

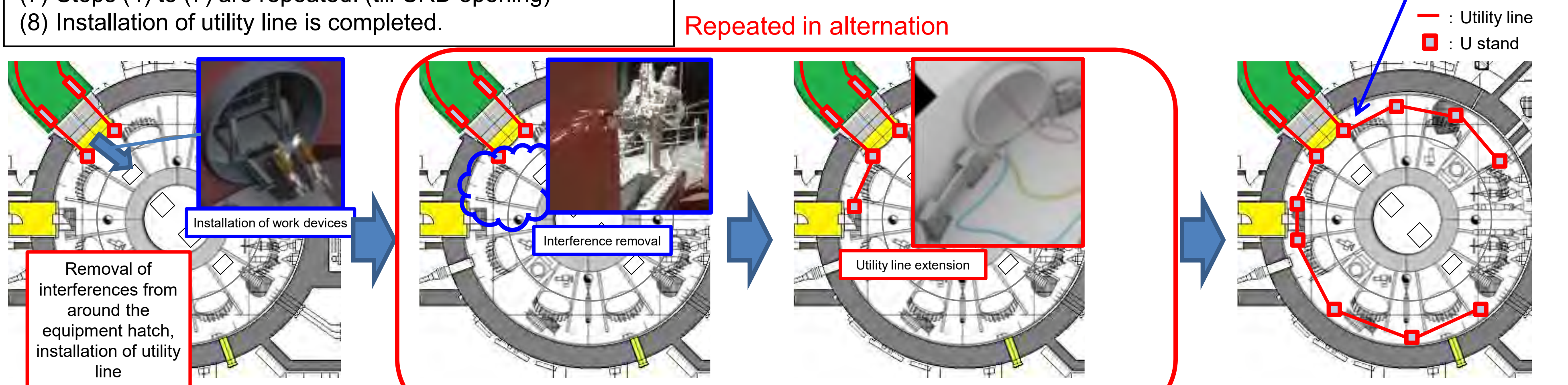
(1) Work devices are installed through the equipment hatch.
(2) Interferences from around the equipment hatch (inner side of PCV) are removed.
(3) Utility (hydraulic pressure / electric) line is installed around the equipment hatch.
(4) The cable connection of the work device is changed over (reconfigured) to the installed utility line.
(5) Surrounding interferences are removed.
(6) Utility line is extended.
(7) Steps (4) to (7) are repeated. (till CRD opening)
(8) Installation of utility line is completed.



Interferences to be removed from outside the pedestal (first floor)



Utilities, such as piping, etc. are connected on the utility stand (U stand)



Installation of work devices

Interference removal

Utility line extension

Utility line installation completed

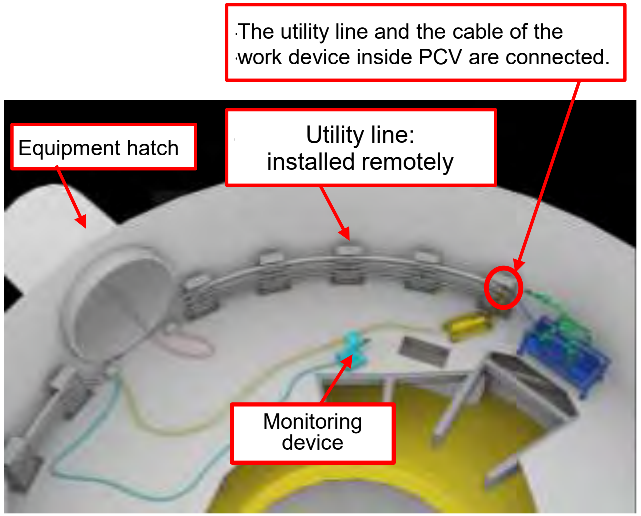
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Study of the method of installing common utilities

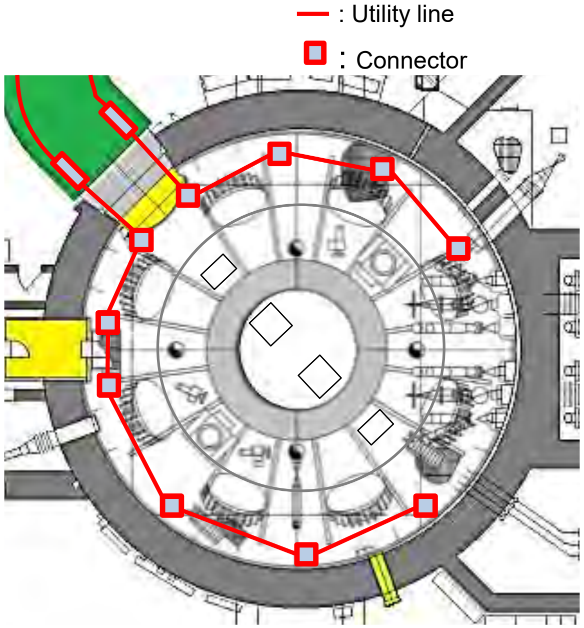
Installation of common utilities around the area outside the pedestal was studied as a proposed solution for the issue identified last year, namely, enabling remote operation of the construction of removal devices and surrounding equipment of the remote operation devices used inside the PCV.

[Concepts of common utilities]

- Water (hydraulic pressure) and electricity, which is the drive source of the remote operation device used inside PCV, is supplied.
- The work of installing the utility line is carried out by means of remote operation devices (flexible work arm, etc.) that operate independently.
- The remote operation devices used for the work of removing interferences from within and outside the pedestal, and for the fuel debris retrieval work are connected to the connectors near the work place and utility (hydraulic pressure / electricity) is supplied.
- Since one end of the cable of the remote operation device is connected to the connector near the work place rather than that at the equipment hatch (expanded building), there is no need to manage long cables.



Conceptual diagram of common utilities



Scope of installation of common utilities (planned)

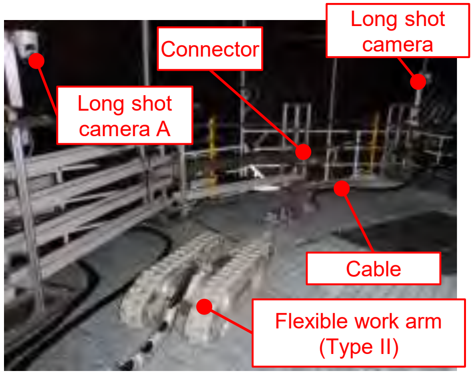
7. Implementation items of this project
[1] ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

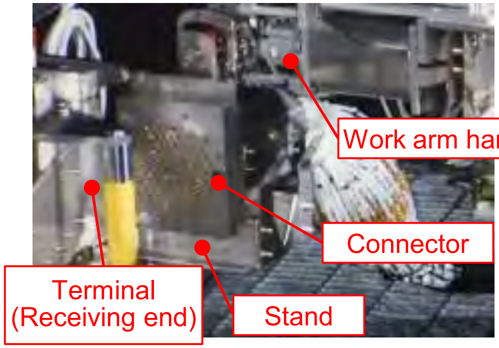
■ Study of the method of installing common utilities

Preliminary tests pertaining to the connection for installing the common utilities, using the flexible work arm, are implemented.

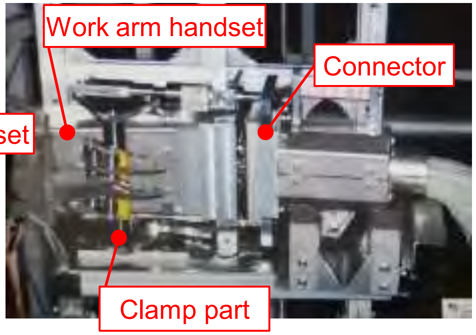
[Preliminary test conditions pertaining to the connection with the connector under a simulated environment of the area outside the pedestal]



Initial layout



Connector installation status



Connector clamp status

Items for Verification	Procedure	Criteria	Results
Is the connection possible?	Hold and convey the connector with the flexible work arm, and when the positions of the terminal and connector match, fix it with a clamp. Carry out work based only on the image on the camera.	・The connector should not fall while holding and conveying. ・One should be able to fix the clamp after the positions of the terminal and connector match.	Good
Confirmation after connection	After the connection work is completed, check the connection part between the terminal and the connector by means of the image on the camera.	The connection part between the terminal and the connector should not be deformed.	Good
Is there any leakage?	After the connection is made, pass water through the pipe inside the terminal.	There should be no leakage from any of the pipes.	Good

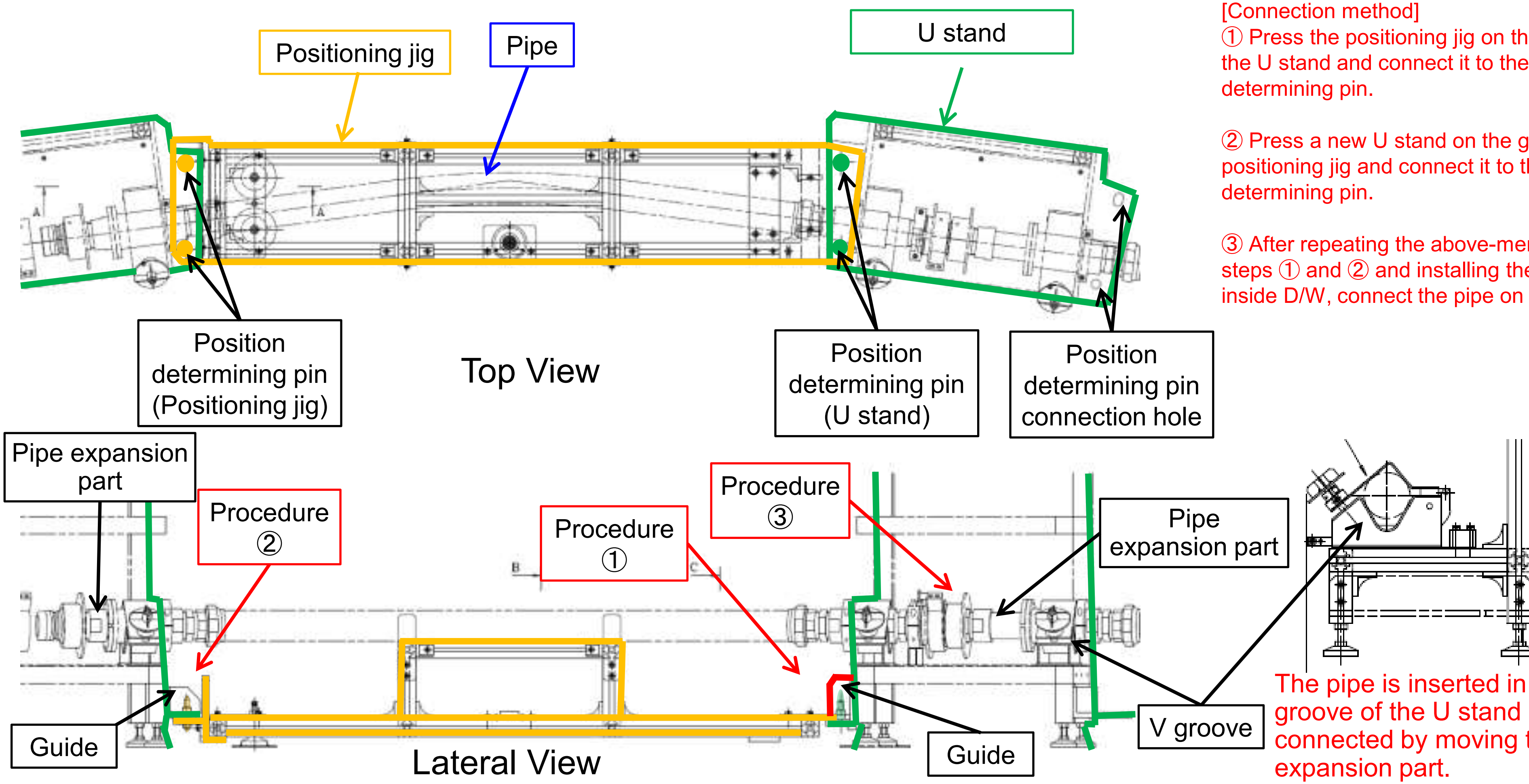
- ✓ It is confirmed that the connector can be connected through remote operation.
- ✓ There are still Issues such as the method of determining the position and the method of verifying completion of connection. Solutions for the issues were studied. (Refer to the following slide)

7. Implementation items of this project [1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Study of the method of installing common utilities

The configuration of common utilities studied based on the results of the preliminary tests, is as follows:



[Connection method]
① Press the positioning jig on the guide of the U stand and connect it to the position determining pin.

② Press a new U stand on the guide of the positioning jig and connect it to the position determining pin.

③ After repeating the above-mentioned steps ① and ② and installing the U stand inside D/W, connect the pipe on the U stand.

The pipe is inserted in the V groove of the U stand and connected by moving the pipe expansion part.

The applicability of remote operation in the above-mentioned configuration will be verified by means of element tests*.

*Refer to the table on Slide 71 for details on the contents of the element tests.

7. Implementation items of this project
[1] ① Development of interference removal technology]

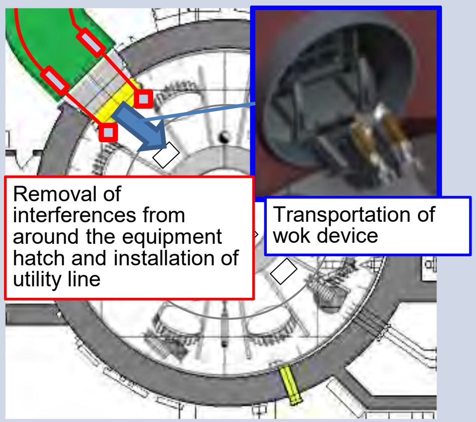
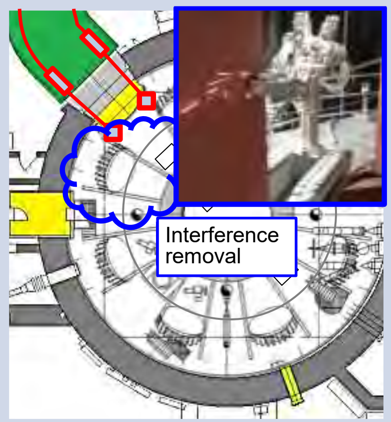
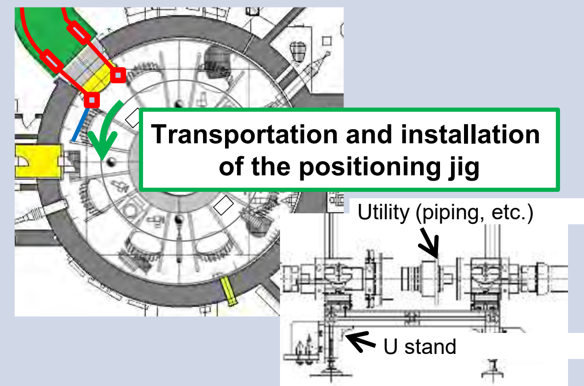
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Work steps for removal from outside the pedestal

✓ The work steps for removal from outside the pedestal, which includes the installation of common utilities, were sub-divided, work contents were specified and issues were identified.

[Step ④] Construction of the expanded building (Refer to Slide 59)

: Items to be verified by means of the element tests

<table>
<tr><th>Work step</th><th>1. Work device transportation, interference removal (around the equipment hatch), utility installation</th><th>2. Removal of interferences from inside D/W (first floor)*</th><th>3-1. Utility line extension*
(Installation of positioning jig)</th></tr>
<tr><td>Step diagram</td><td>
</td><td>
</td><td>

Conceptual diagram of U stand</td></tr>
<tr><td>Details</td><td>The work device is brought in from the equipment hatch and the interferences around the equipment hatch (inner side of PCV) are removed. Thereafter a utility line (hydraulic pressure / electricity) that is extended from the access tunnel is installed around the equipment hatch (inner side of PCV).</td><td>The cable connection of the work device is moved over to the utility installed in the previous step. Thereafter, the surrounding interferences are removed.</td><td>The positioning jig for installing the U stand is brought in up to the designated location and installed using the work device.</td></tr>
<tr><td>Issues</td><td>• Method of pulling the utility extending from the access tunnel.</td><td>(Element tests concerning whether or not the connector can be connected and the interferences can be cut off by means of remote operation, have been implemented. [FY2015-16])</td><td>• Whether or not the positioning jig can be held with the work device
• Transportation of positioning jig using the work device
• Accuracy of installing at the target position
• Whether or not the positioning jig can be fixed</td></tr>
</table>

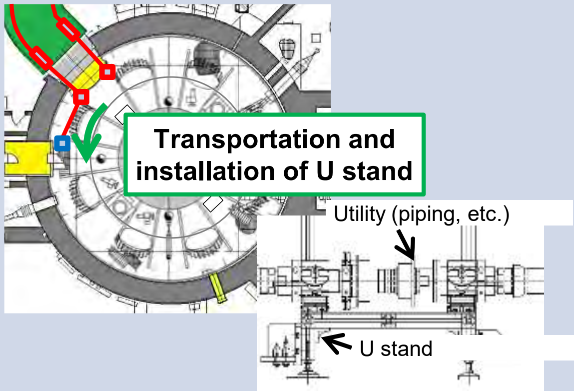
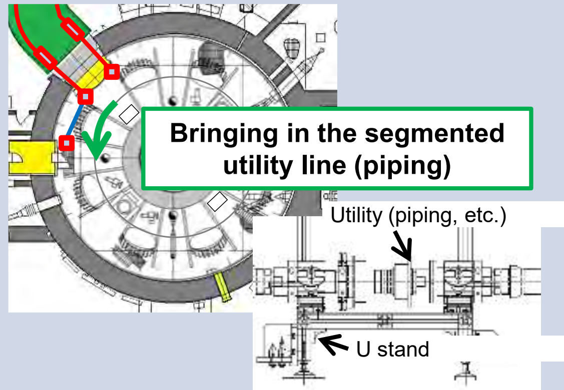
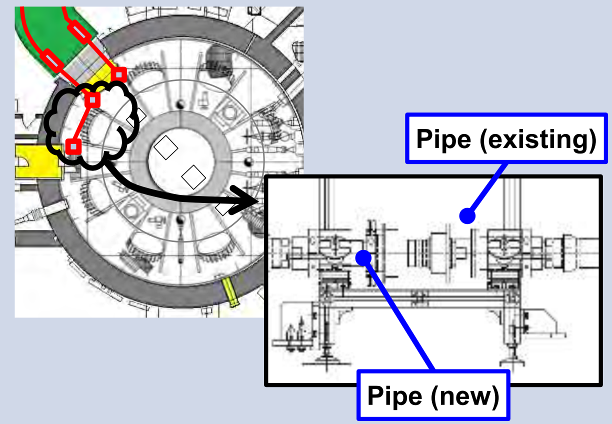
*Since the utility line is installed (extended) while removing interferences from the first floor, steps 2 → 3-1 to 3-4 are repeated. (Until the area near the CRD opening is reached)

7. Implementation items of this project
[1] ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Work steps for removal from outside the pedestal

:: Target of element tests

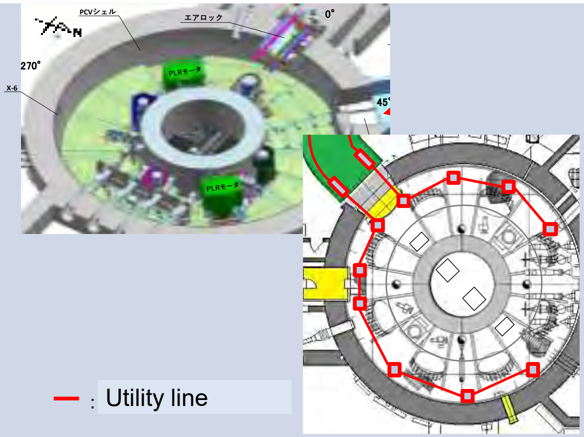
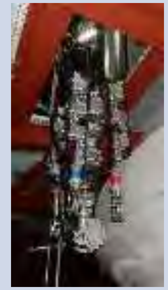
Work step	3-2. Utility line extension* (Installation of U stand)	3-3. Utility line extension* (Bringing in the segmented utility line)	3-4. Utility line extension* (Connecting the segmented utility line)
Step diagram	 Conceptual diagram of U stand	 Conceptual diagram of U stand	
Details	The U stand is transported to the designated location and installed using the work device.	The segmented pipe is brought in to the designated location using the work device.	The segmented pipe is fixed on the U stand and connected to the existing pipe.
Issues	• Whether or not the U stand can be held with the work device • Transporting U stand using the work device • Accuracy of installing at the target position • Whether or not U stand can be fixed	• Transportation of utility line using the work device • Accuracy of temporary positioning at the target position	• Fixing of the pipe on the U stand • Connection with the existing pipe using the work device

*Since the utility line is installed (extended) while removing interferences from the first floor, steps 2 → 3-1 to 3-4 are repeated. (Until the area near the CRD opening is reached)

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ <u>Work steps for removal from outside the pedestal</u>

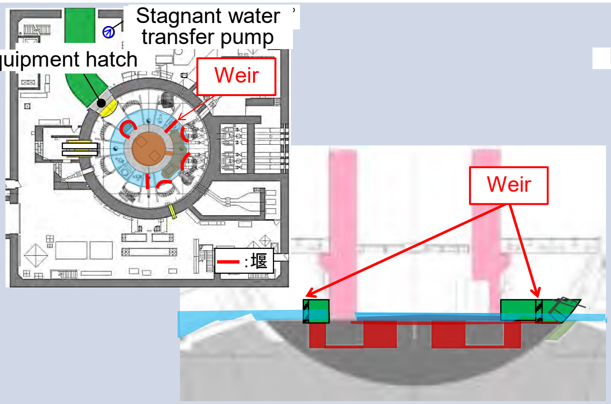
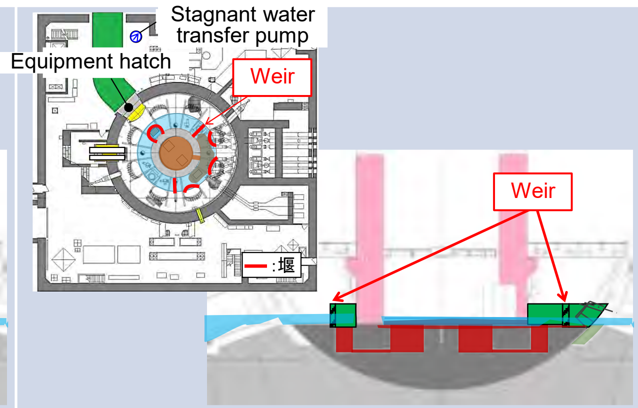
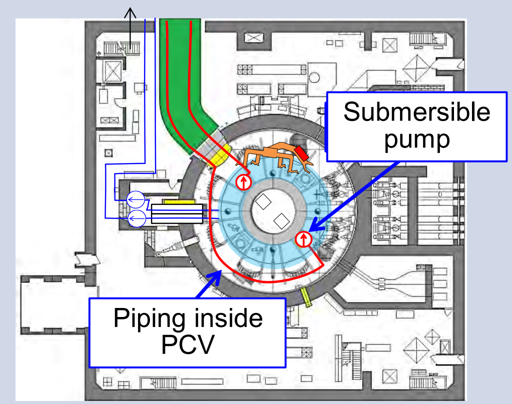
Work step	4. Completion of interference removal from inside D/W (first floor) and laying of the utility line	5. Creating an opening in the grating, lifting and lowering the interference removal device	6. Removal of interferences from inside D/W (basement floor)
Step diagram	 — : Utility line	 Device for making openings  Interference removal device for the basement floor	
Details	By repeating steps 2 → 3-1 to 3-4, the interferences on the first floor inside D/W are removed and the utilities for the work device are installed around the area outside the pedestal.	The grating is cut, and the interference removal device is installed on the basement floor.	Since the submersible pump is to be installed in the pit, the interferences in the vicinity of the pit such as the existing pump, etc. in the pit are removed. If there are deposits, the deposits are removed.
Issues	(Same as Steps 2 to 3-4)	(Element tests concerning the tasks of cutting the grating, making an opening and installing the interference removal device on the basement floor have been implemented. [FY2017-18])	(Element tests concerning removal of interferences from the basement floor have been implemented. [FY2017-18])

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Work steps for removal from outside the pedestal

: Target of element tests**

Work step	7-1 Installation of weir for preventing the spread of contamination* (Formwork installation)	7-2 Installation of weir for preventing the spread of contamination* (Dry mortar injection)	8. Deployment of piping inside D/W and installation of submersible pump
Step diagram	 (The figure indicates the image of installation of weirs in Unit 1.)	 (The figure indicates the image of installation of weirs in Unit 1.)	
Details	The folded weir (formwork) is brought in through the opening in the grating using the interference removal device, etc. for the basement floor. Thereafter, it is spread and installed on the basement floor.	Dry mortar is injected in the folded weir that is now spread, with the help of the remote operation device (flexible work arm, etc.).	Pipes are deployed inside D/W and submersible pump is installed inside the pit.
Issues	• Whether or not the formwork (folded) can be carried in through the opening (1200 x 600mm) • Whether or not the formwork can be spread on the basement floor	• Whether or not dry mortar can be injected into the spread formwork • Whether or not the dry mortar can be transported to the basement floor within the time period before it starts hardening	(Element tests concerning laying out of pipes, installation of pumps are planned to be implemented as part of the water circulation PJ. [Implemented in FY2019])

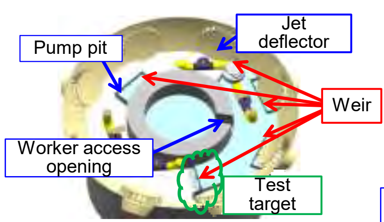


Image of installation in Unit 1

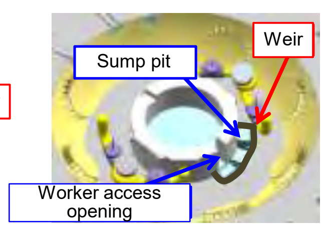


Image of installation in Units 2 & 3

* Steps 7-1 to 7-2 are repeated until the desired weir is built for each unit.

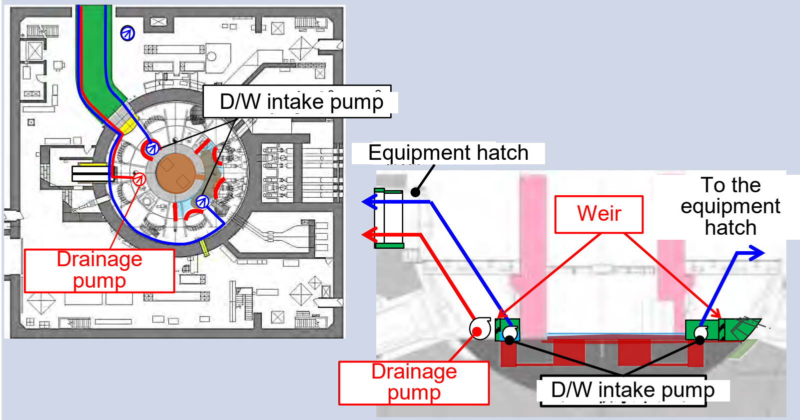
IRID

** Details of the test contents related to work steps 7-1/7-2 are described separately in section 7. (1) ② c "Method of preventing spread of contamination into S/C" (Slide 88 onwards).

7. Implementation items of this project
[1) ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Work steps for removal from outside the pedestal

: Target of element tests

Work step	9. Installation of drainage pump on the outer side of the weirs
Step diagram	
Details	A submersible pump is installed on the outer side of the weirs. Further, installation of submersible pump on the inner side of the weirs has been completed in the previous step (Step 8). The submersible pumps are operated after installation.
Issues	(Same as Step 8)

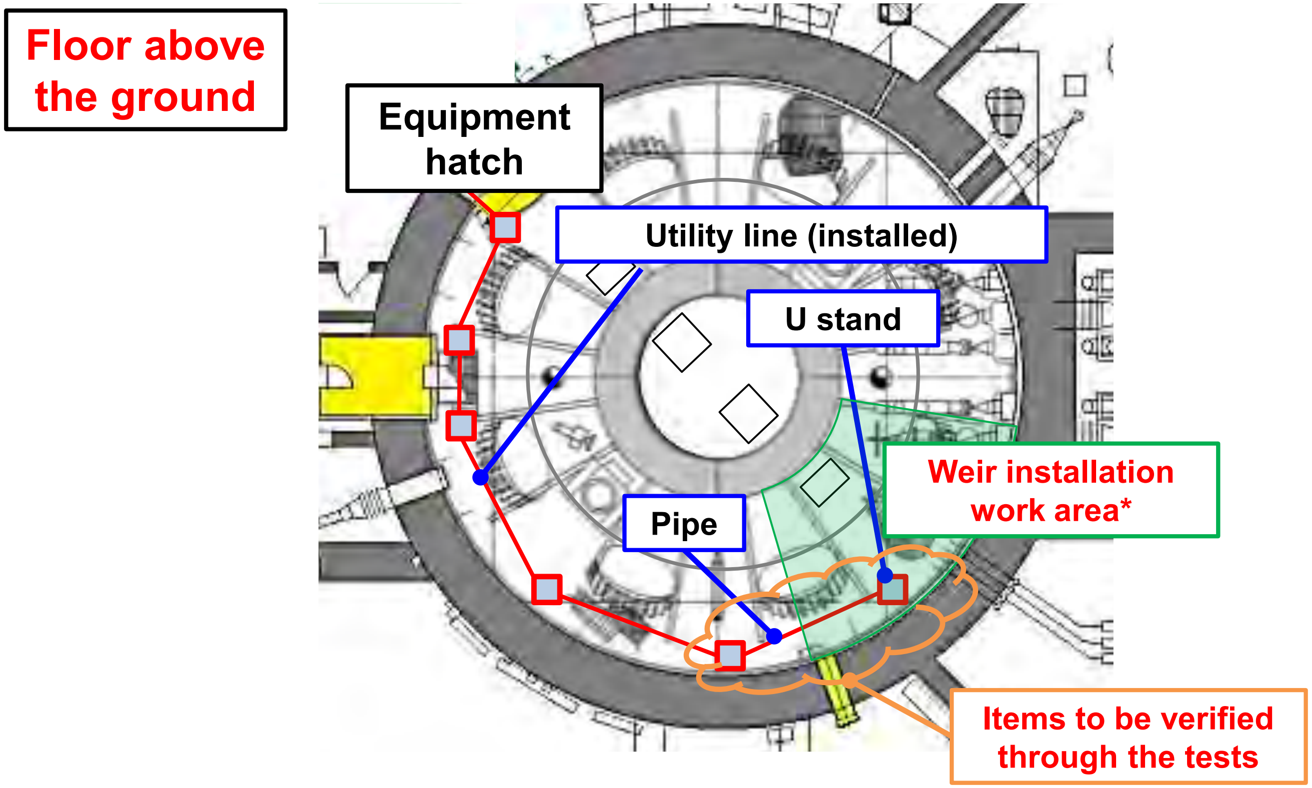
[Step ⑧] Removal of interferences from inside the pedestal

(Refer to Slide 59)

b. **Method of removing interferences from within and outside the pedestal by accessing from the side**

■ Scope of simulation in element tests

✓ Element tests concerning the work of installing common utilities are implemented for resolving the issues identified until the previous slide.
✓ Since the work of installing common utilities is a repetition of extension work, the final installation location is simulated and it is assumed that the utilities up to the previous stage have been installed.



Scope of simulation in the common utility installation test

*The details of the contamination spread prevention weir are described separately in Section 7. (1) ② c "Method of preventing spread of contamination into S/C" (Slide 88 onwards).

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Element test items and criteria

ID	Test item	Relevant work steps*1	Test outline and procedures	Criteria	Remarks
1	U stand assembly	3-1 3-2	(1) Lift the positioning jig with the gantry-type lifting machine. (2) Transport the positioning jig to the target position (existing U stand). (3) Lower the positioning jig while pushing it against the existing U stand guide and fix the jig to the existing U stand. (4) Lift the U stand with the gantry-type lifting machine. (5) Transport the U stand to the other end of the positioning jig installed in step (3). (6) Lower the U stand while pushing it against the guide at the other end of the jig, and fix the U stand to the other end of the positioning jig installed in step (3).	• The positioning jig can be lifted. • The positioning jig and U stand can be transported to the target position. • The positioning jig and U stand can be fixed together.	
2	Connection of the utility lines	3-3 3-4	(1) Place the segmented pipes on the transport cart. [Manual work] (2) Transport the pipes to the vicinity of the U stand by the transport cart. (3) Install the pipes on the U stand with the gantry-type lifting machine. (4) Fix the pipes to the U stand and connect them with the flexible work arm.	• The pipes can be transported to the target position by the transport cart. • The pipes can be installed from the transport cart on to the U stand. • The pipes can be connected with the flexible work arm.	

#1: Refer to the work steps on Slides 65 to 69

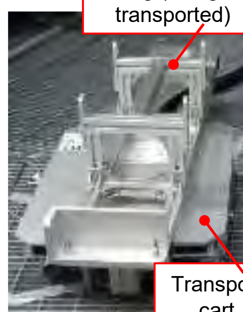
[Devices used for the element tests]

Holding the jig and assisting in the work

Flexible arm for remote operations*

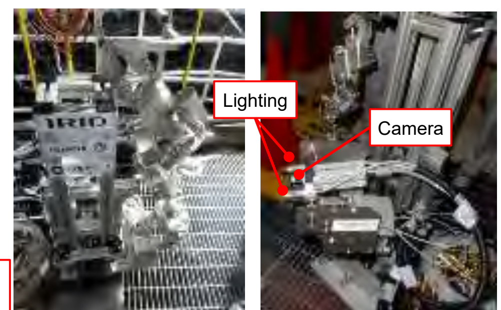
Transporting and installing the jigs

Gantry-type lifting machine



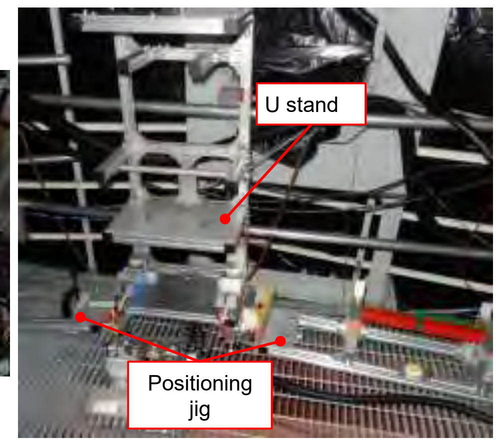
Transporting the jigs

Transport cart



Work monitoring

Camera cart

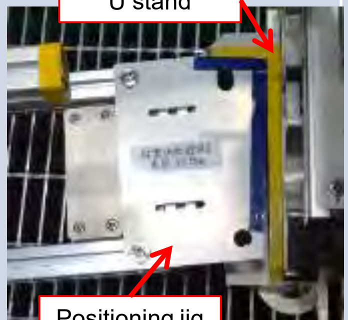
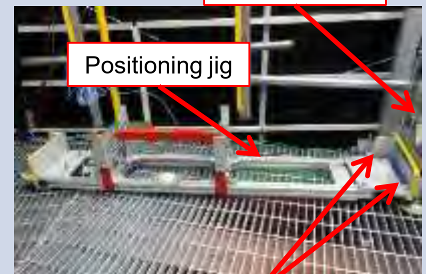


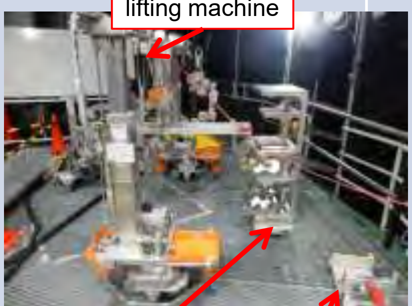
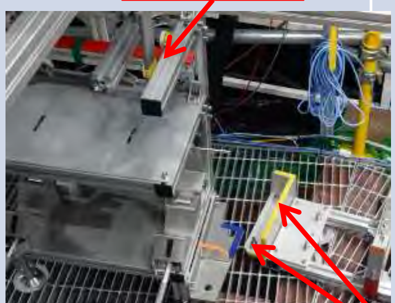
U stand and positioning jig

*There are several variations in flexible arms for remote operations. The above specification is an example of a crawler-type flexible arm.

7. Implementation items of this project
[1) ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ <u>Test procedure (Assembling the stand)</u> #Verified by a preliminary test

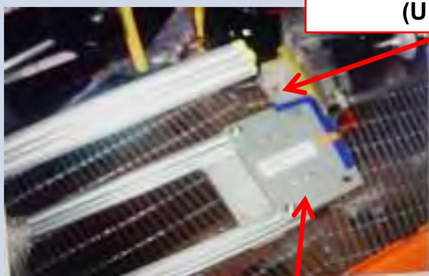
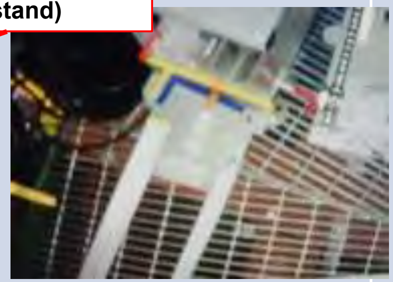
STEP	1. Carrying in the positioning jig	2. Connecting the jig to the U stand positioning pin	3. Verifying that the connection is complete
Illustration of operation		 	

STEP	4. Carrying in the U stand	5. Connecting the U stand to the positioning pin of the positioning jig	6. Verifying that the connection is complete
Illustration of operation		 	

7. Implementation items of this project
[1) ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Element test results (Assembling the stand)

STEP	1. Carrying in the positioning jig	2. Connecting the jig to the U stand positioning pin		3. Verifying that the connection is complete
Illustration of operation				

STEP	4. Carrying in the U stand	5. Connecting the U stand to the positioning pin of the positioning jig		6. Verifying that the connection is complete
Illustration of operation				

It was confirmed that the positioning jig and U stand can be installed and connected remotely

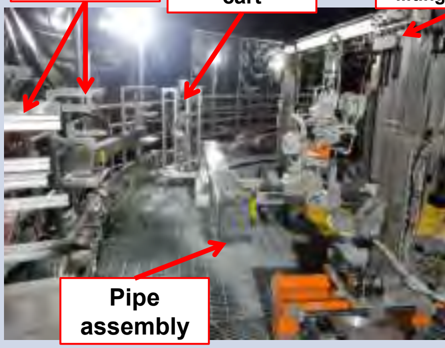
7. Implementation items of this project
[1] ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

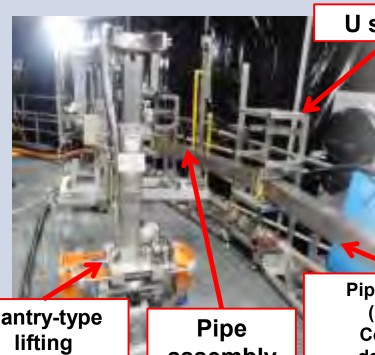
■ <u>Test procedure (Connection of the utility lines)</u> #Verified by a preliminary test

STEP — Illustration of operation

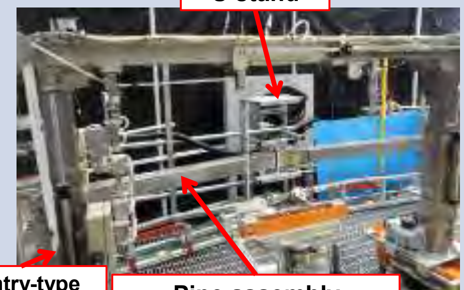
1. Preparing the pipes [Manual work]



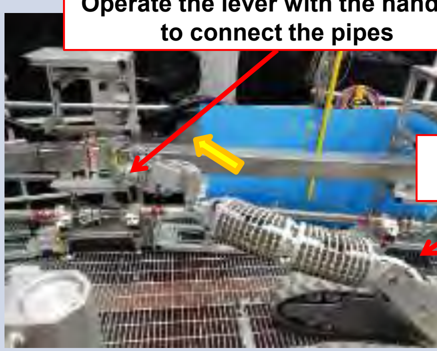
2. Transporting the pipes



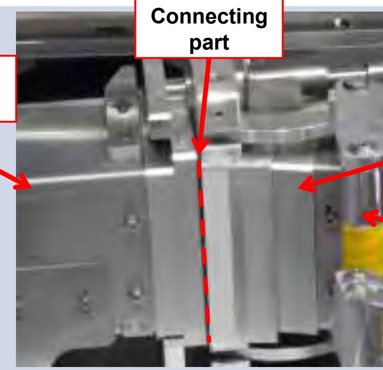
3. Installing the pipes



4. Connecting the pipes



5. Verifying that the connection is complete

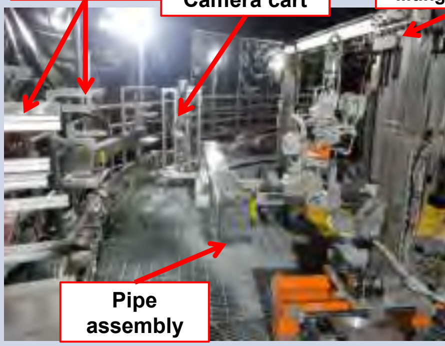


7. Implementation items of this project
[1] ① Development of interference removal technology]
b. Method of removing interferences from within and outside the pedestal by accessing from the side

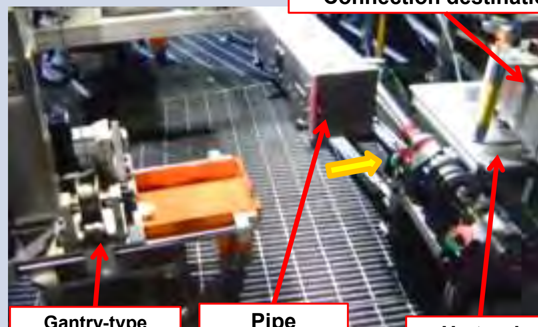
■ Element test results (Connection of the utility lines)

STEP — Illustration of operation

1. Preparing the pipes [Manual work]



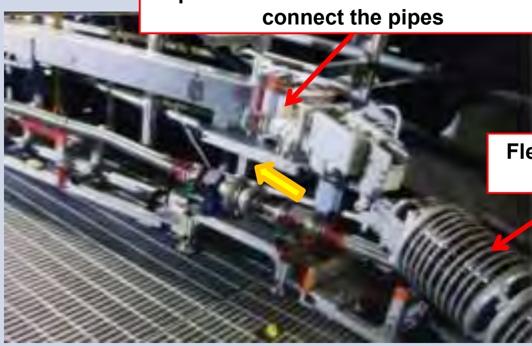
2. Transporting the pipes



3. Installing the pipes

STEP — Illustration of operation

4. Connecting the pipes



5. Verifying that the connection is complete

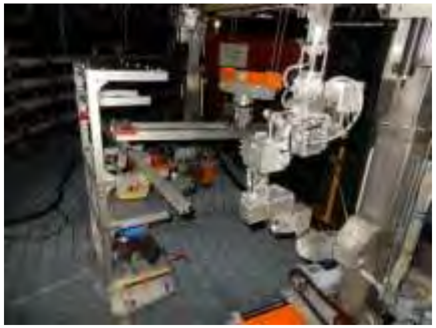
It was confirmed that the utility lines (pipe assembly) can be installed and connected

7. Implementation items of this project
[1] ① Development of interference removal technology]

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Summary of element test results

ID	Test items	Test outline and procedures	Test results		Remarks
1	Assembling the stand	(1) Lift the positioning jig with the gantry-type lifting machine. (2) Transport the positioning jig to the target position (existing U stand). (3) Lower the positioning jig while pushing it against the existing U stand guide and fix the jig to the existing U stand. (4) Lift the U stand with the gantry-type lifting machine. (5) Transport the U stand to the other end of the positioning jig installed in step (3). (6) Lower the U stand while pushing it against the guide at the other end of the jig, and fix the U stand to the other end of the positioning jig installed in step (3).	• It was confirmed that the positioning jig can be lifted with the gantry-type lifting machine. • It was confirmed that the positioning jig and U stand can be transported to the target position with the gantry-type lifting machine. • It was confirmed that the positioning jig and U stand can be fixed together.	Good	
2	Connection of the utility lines	(1) Place the segmented pipes on the transport cart. [Manual work] (2) Transport the pipes to the vicinity of the U stand by the transport cart. (3) Install the pipes on the U stand with the gantry-type lifting machine. (4) Fix the pipes to the U stand and connect them with the flexible work arm.	• It was confirmed that the pipes can be transported to the target position by the transport cart. • It was confirmed that the pipes can be raised from the transport cart by the gantry-type lifting machine and can be installed on the U stand. • It was confirmed that the pipes can be connected with the flexible work arm, using the pipe connecting jig.	Good	




Assembling the stand


Connection of the utility lines

The feasibility of the work of establishing common utilities (assembling the stand, connection of the utility lines), while satisfying all the criteria, was confirmed.

b. Method of removing interferences from within and outside the pedestal by accessing from the side

■ Identified issues and response policies

No.	Issues	Details	Response policy
1	Method of handling the unevenness on the grating (floor surface)	In this test, a U stand whose height was manually adjusted was installed on a flat grating, but there is a difference in levels in the actual grating, which causes an error during assembly work such as alignment of pipes, etc.	Enable the U stand adjuster to expand and contract by means of remote operation. Lay a scaffold on the grating to ensure a level surface.
2	Method of monitoring during work (Camera and lighting arrangement)	It is difficult to check the alignment of low-lying locations, such as the contact surface of U stand and positioning jig.	Conduct a detailed study on the camera and lighting arrangement so that each task is easily visible, for example, mounting a camera on the tip of the operation device and confirming the task at hand (in the engineering work plan for actual operation). Also conduct studies on structures that can be indirectly verified. (The improved effect due to the remodeling of the camera cart has already been verified)
3	Handling device cables	Manual assistance has to be provided for the extra length of the cables outside the simulated test range (between equipment hatch to around 270°).	Study remote handling methods since devices and cables are crowded in a narrow environment. (The effectiveness of handling the extra length with a cable feeding cart has already been verified)

7. Implementation items in this project

1) Development of fuel debris retrieval methods

② Development of various technologies other than interference removal technology

A system for supporting the operation of the remote operation devices, technology for preventing the spread of contamination outside PCV and technology believed to be needed for establishing the access route, considering the construction of a shielding structure for exposure reduction in the reactor building (R/B), will be developed besides the technology for removing interferences.

The following will be included as the main development and study items. Element tests will be conducted as required to identify problems and organize them.

a. Development of remote operation support method in environments with low visibility and narrow spaces.

・Creation of an environment model (test version) and simulator are underway.

b. Methods to prevent the spread of contamination to the suppression chamber (S/C).

・Element tests will be performed concerning the method of carrying in segmented formwork as a way of building weirs remotely.

c. Conceptual study on the establishment of an access route for installation of cells and method of reducing impact on R/B and other buildings.

・A structural study on determining the concrete details for reducing the load on R/B floor is underway.

d. Method of transporting the unit can from the R/B.

・ A conceptual study on how to carry out the fuel debris in unit cans is underway.

7. Implementation items of this project [1) ② Development of various technologies other than the interference removal technology]

a. Development of remote operation support method in environments with low visibility and narrow spaces

- Need for development

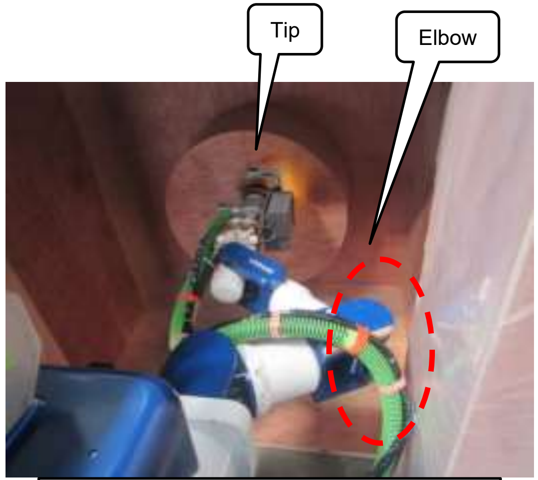
[General technologies]
- **Operator carries out the operation looking at the “tip” of the manipulator**
- **The movements of other joints such as the manipulator’s “elbow” and “shoulder” are left to take their own course ⇒ “Elbow”and “shoulder” are likely to interfere with movements.**

[Methods developed in the subsidy projects so far]
- **The manipulator can be moved in any direction by pointing to the “elbow”“shoulder” one at a time**

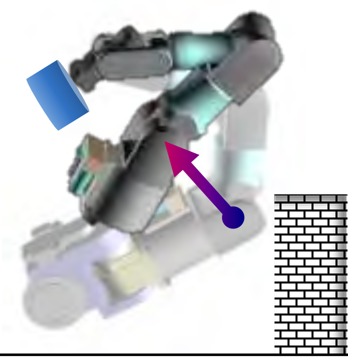
[New issues]
- **Which part of the manipulator is likely to interfere?**
- **Which axis of the manipulator should be moved in which direction to avoid the interference?**

⇒ It is difficult to monitor all movements from a limited perspective/ field of vision
⇒ One operator cannot operate many joints such as “tip", "elbow", and "shoulders" simultaneously (it is also difficult for several people to operate in cooperation with each other)

[Purpose of this development]
- **To automate the movements to avoid "elbow" and "shoulder" interference so that the operator can focus on the movement of the manipulator “tip”**



Verification of workability of X-6 penetration (Decontamination project)



Picture of an operation performed by avoiding interference of “elbow” and “shoulder”

7. Implementation items of this project

[1) ② Development of various technologies other than the interference removal technology]

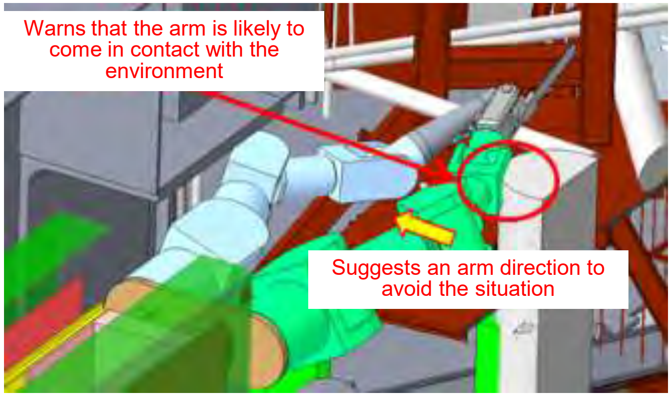
a. Development of remote operation support method in environments with low visibility and narrow spaces

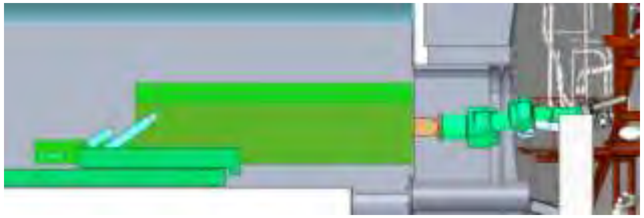
- Purpose of development
  - To develop a control method that can reduce the workload of the operator who remotely operates the robot and improve the efficiency of the operation in environments with low visibility and narrows spaces.

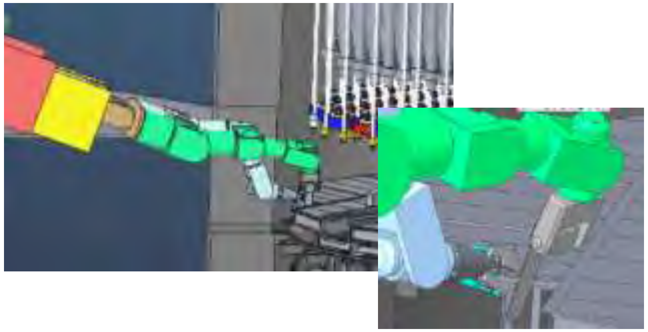
- Issues to be solved
  - In the PCV environment which has low visibility and narrow spaces, remote operation of the access device while avoiding contact and with a limited field of vision, is a heavy burden on the operator. Hence remote operation technology to assist the operations is essential.
  - The existing technology allows efficient robotic operations by teaching the robot, but it is expected that it will take time for the operator to operate the robot inside the PCV where the situation is unclear and keeps changing.

- Approaches to development
  - Conceptual study of the interference avoidance methods
  - Development of an interference avoidance program (manipulator control software)
  - Verification of effectiveness through element tests

- Expected outcome
  - Avoidance of interference with devices operating inside the PCV
  - Reduction in the operator's load by enabling operations in a short time







7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

a. Development of remote operation support method in environments with low visibility and narrow spaces

- **Study flow**

Organization of issues pertaining to remote operations

Conceptual study of interference avoidance methods

Development of an interference avoidance program (manipulator control software)

Verification of effectiveness through element tests (simulator)

Results of this fiscal year

Generation of environmental map, application to the interference avoidance program

Application to mockup test robots

Evaluation of effectiveness and feasibility through elemental tests (Mockup test)

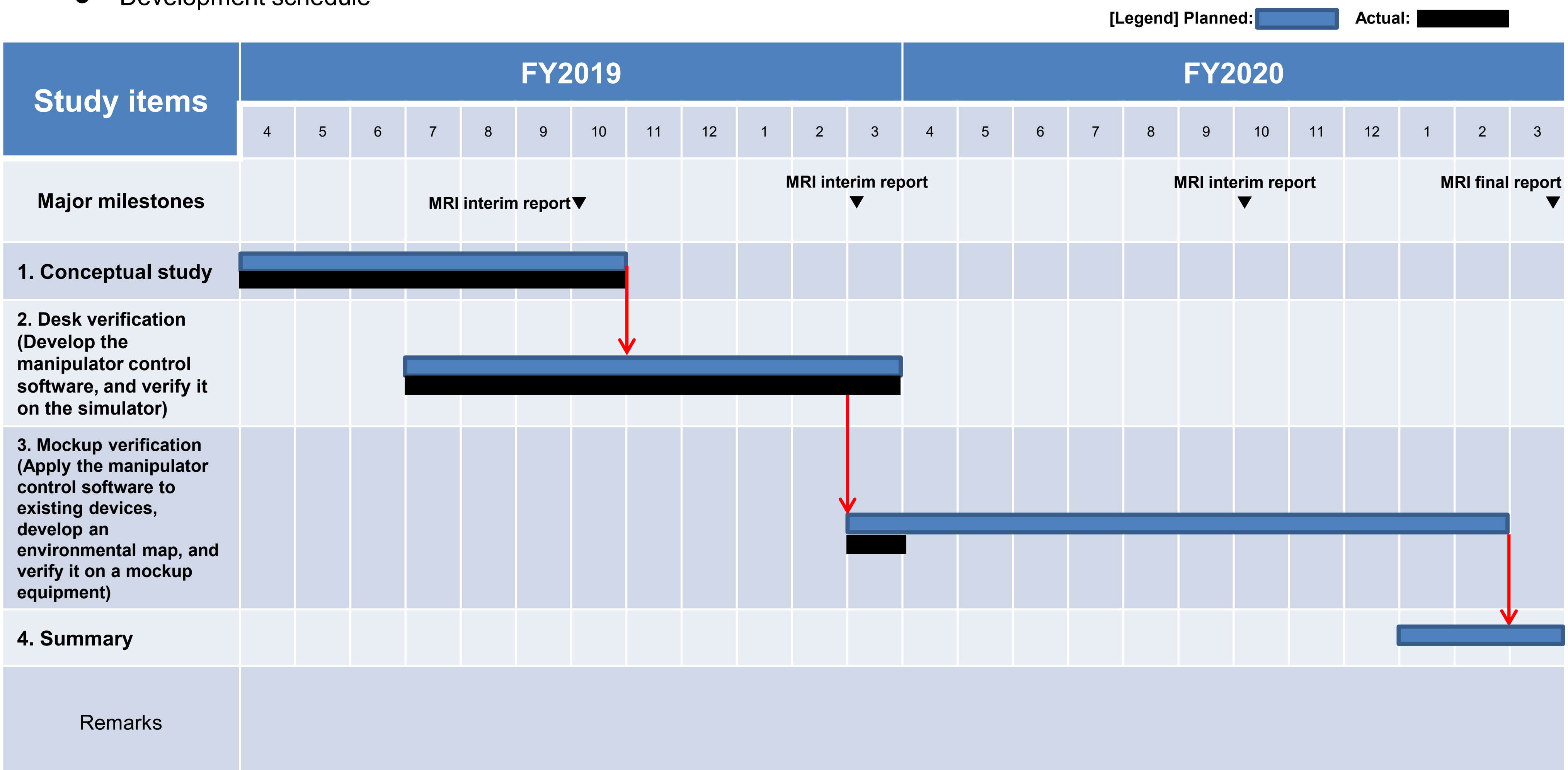
Identification of future issues and response policies

7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

a. Development of remote operation support method in environments with low visibility and narrow spaces

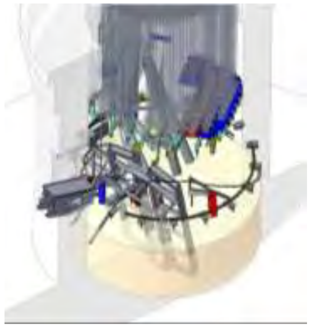
- Development schedule



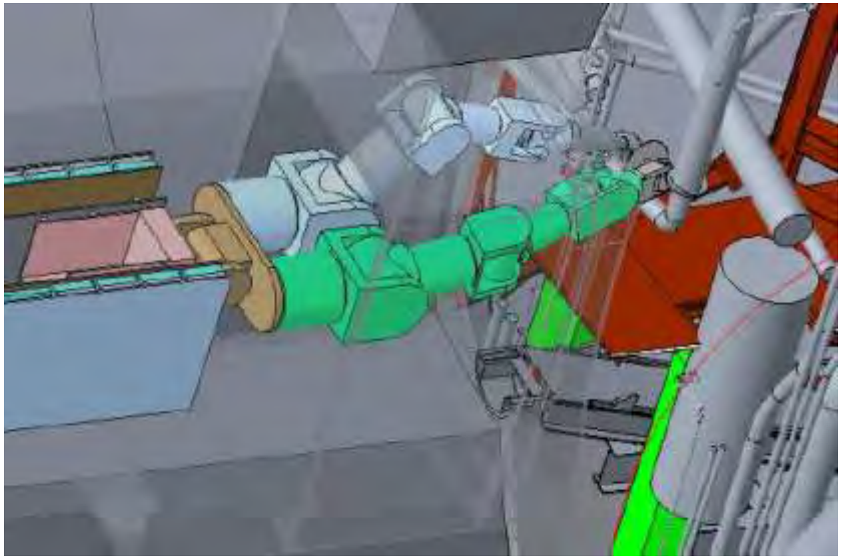
7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

a. Development of remote operation support method in environments with low visibility and narrow spaces

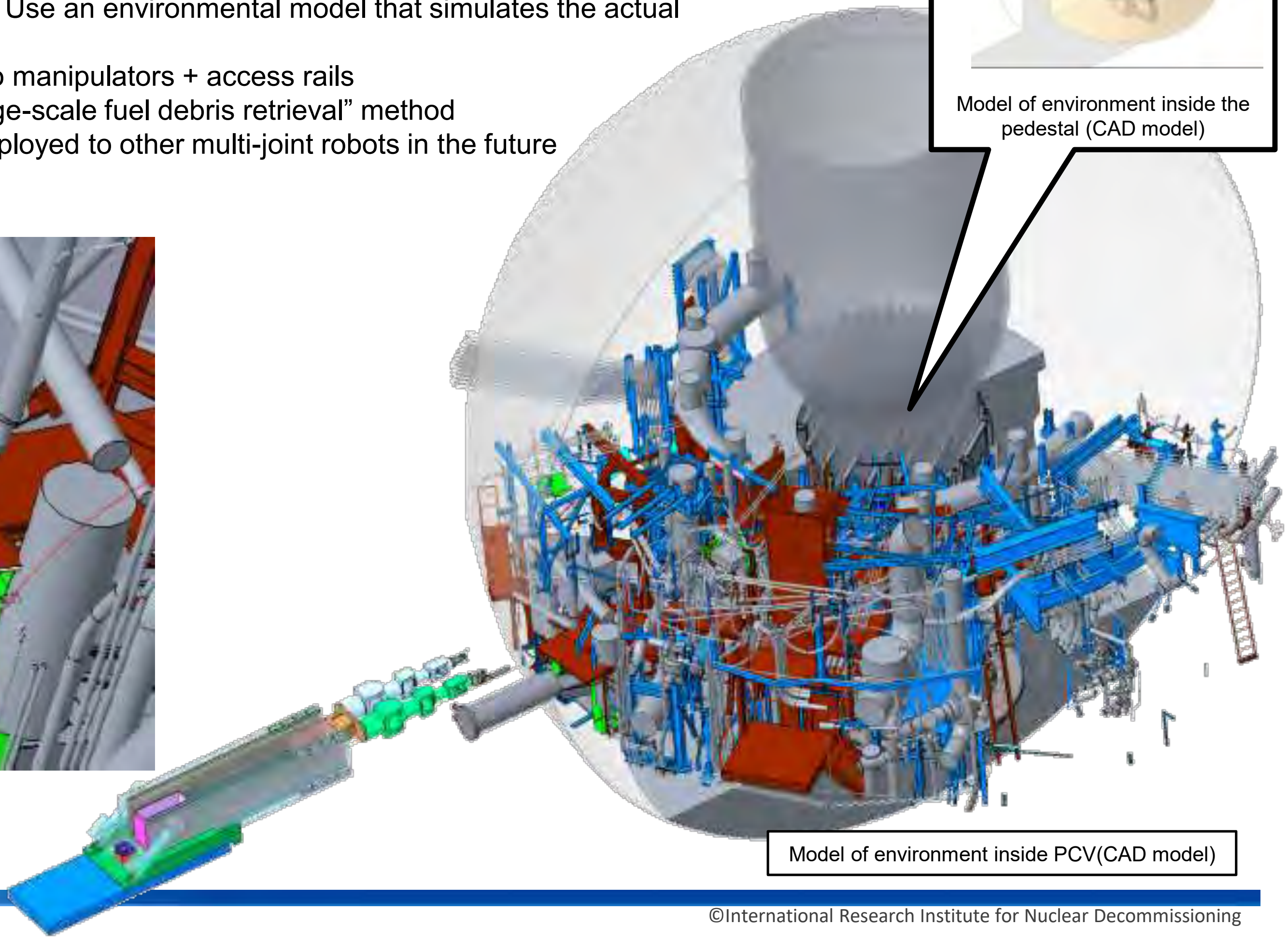
- Preconditions for study
  - Set “Work of removing interferences from inside PCV” as the task.
    ← To perform operations remotely while avoiding contact in environments with low visibility and narrow spaces.
    ← For difficult environments where the situation is unclear and keeps changing as the work progresses
  - The target of the study is Unit 2 and 3. Use an environmental model that simulates the actual situation as much as possible.
  - For instance, the robot model uses two manipulators + access rails
    ← Follow the current study on the “Large-scale fuel debris retrieval” method
    ← Aim for a mechanism that can be deployed to other multi-joint robots in the future



Model of environment inside the pedestal (CAD model)



Interference removal work (CAD model)

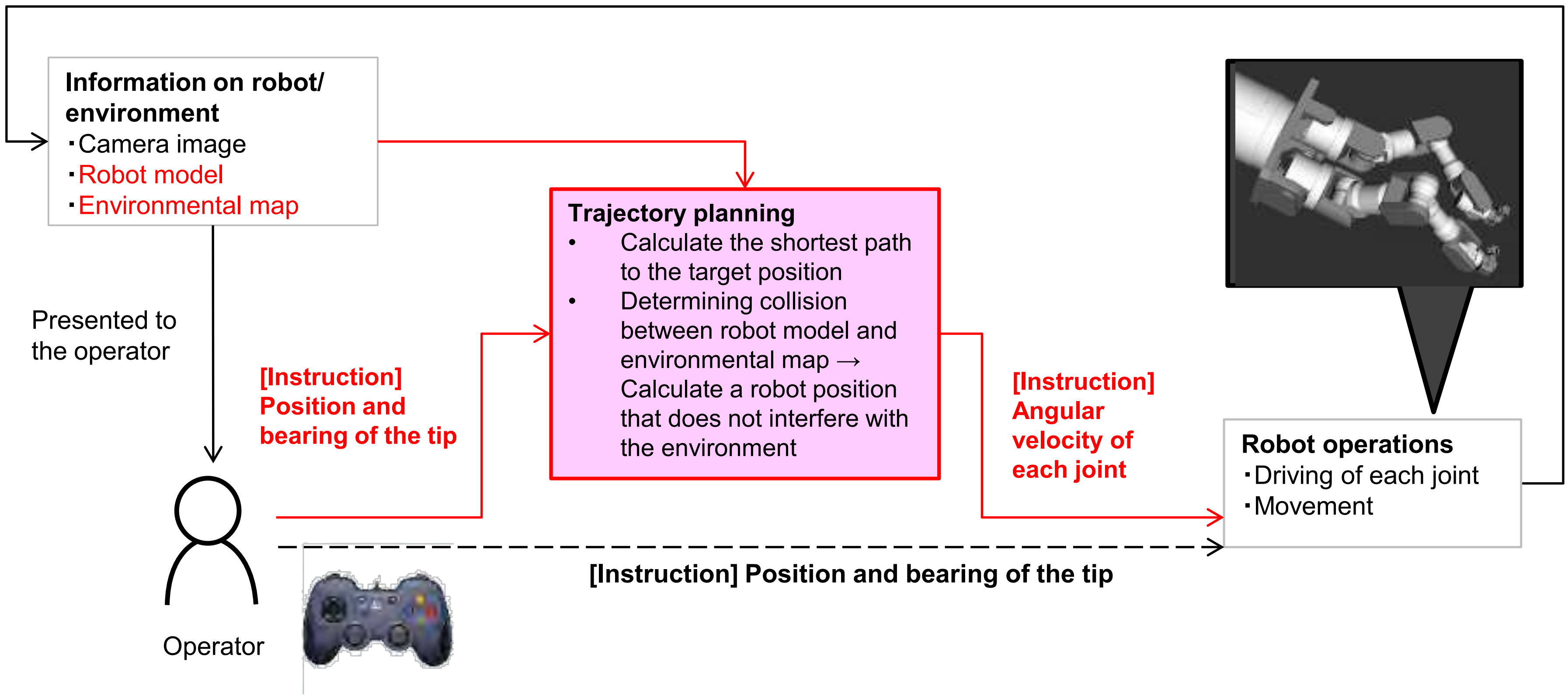


Model of environment inside PCV(CAD model)

a. Development of remote operation support method in environments with low visibility and narrow spaces

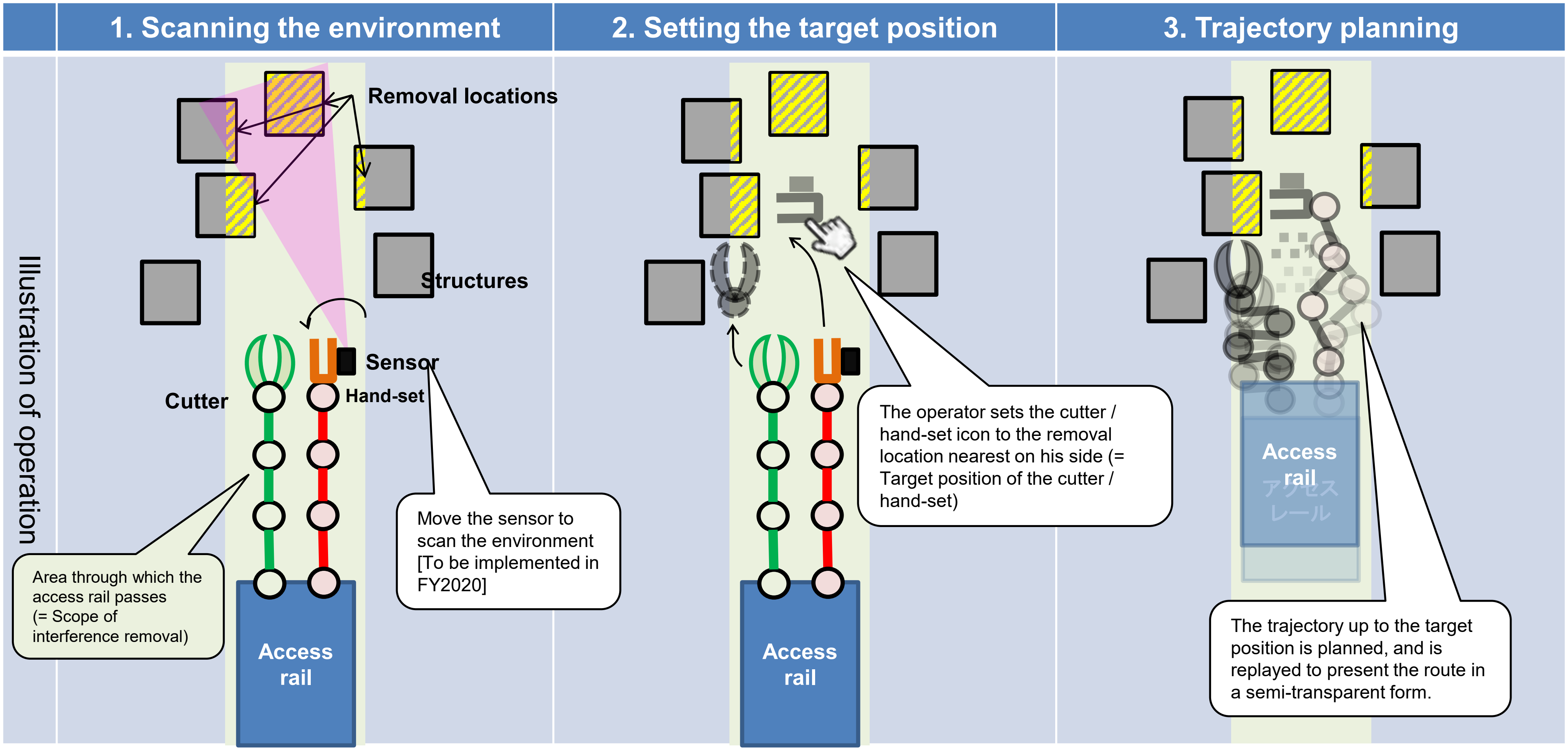
- Conceptual study (Control flow)

  - Manipulator control flow for which a conceptual study was conducted
    - Incorporate movements as needed to "automatically avoid interferences" based on robotic movements through operator-controlled remote operations (manipulator tip operations)



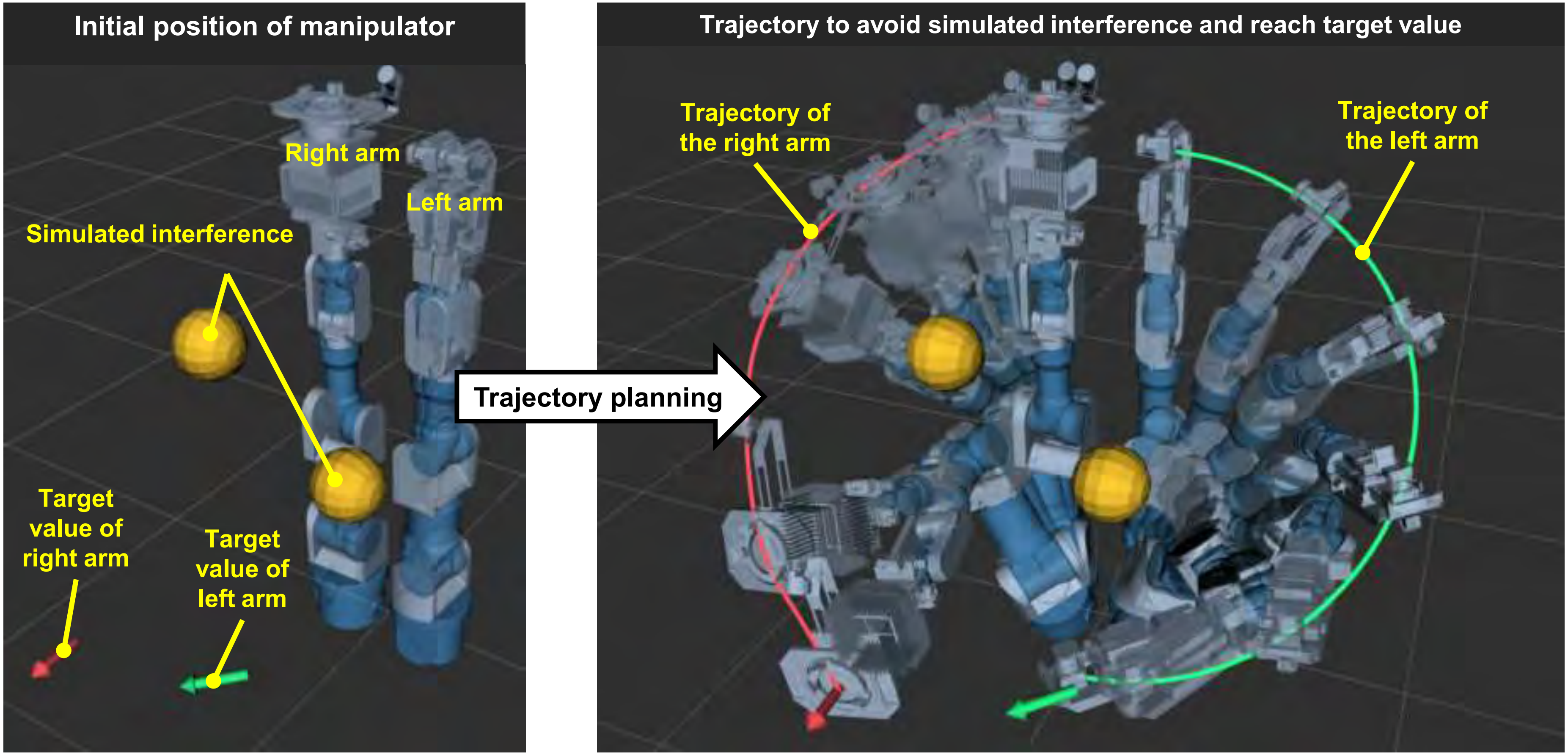
7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
a. Development of remote operation support method in environments with low visibility and narrow spaces

- Conceptual study (Work procedure)



a. Development of remote operation support method in environments with low visibility and narrow spaces

- Verification by means of a simulator



7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

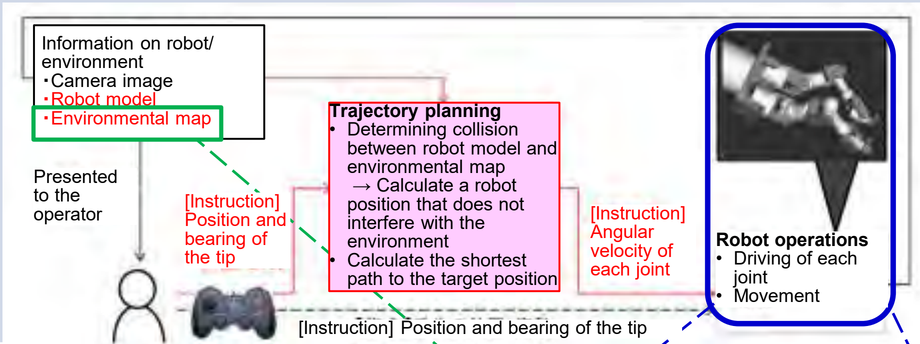
a. Development of remote operation support method in environments with low visibility and narrow spaces

● Implementation items

	FY2019	FY2020

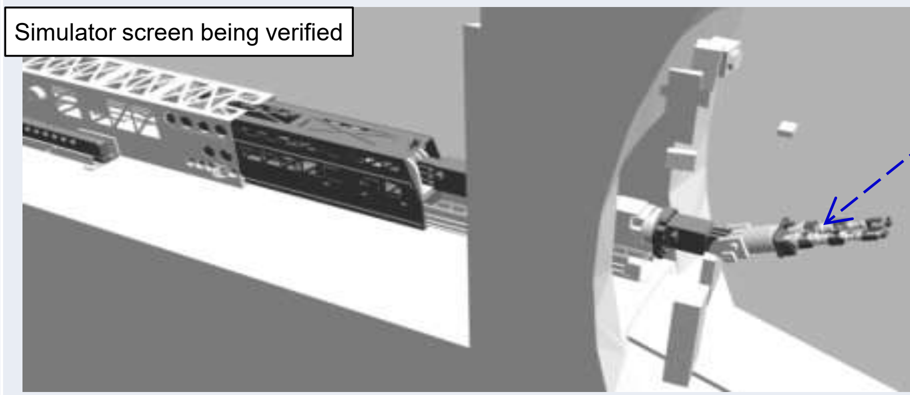
System configuration

[Status of progress in FY2019]
・Interference avoidance program created
・Parameter tuning underway

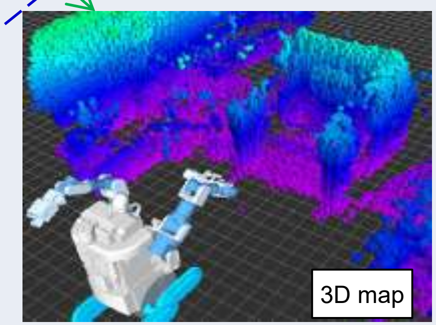


Implementation items

Simulator screen being verified



Operation and verification of the robot model on the simulator
- Derivation of optimal values for the frequency of trajectory planning
- Determination of optimal values of various parameters



3D map

Dual-arm manipulator

Operation and verification of the actual machine in the mockup
- Generation of a mockup environmental map and confirming for collision
- Confirming the validity of simulator verification by using an actual machine

[1) ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

- Purpose of development
  - Further improvement of workability considering remote installation of weirs
  - Performance evaluation of remotely installed weirs

- Issues to be solved
  - Determining the specific work steps considering leakage in the weirs
  - Expanding the scope of remote operations and improving work efficiency

- Approaches to development
  - Study of more efficient work steps for remote installation
  - Planning of element tests for confirming the feasibility based on work steps
  - Verification of workability through element tests, and evaluation of the amount of leakage from the weirs
  - Conceptual study on the long-term integrity of weirs considering the risk of leakage after the installation of weirs

- Expected outcome
  - More efficient work steps for remote installation
  - Workability verification results through element tests, and evaluation results of the amount of leakage from weirs
  - Results of the conceptual study on the long-term integrity of weirs considering the risk of leakage after the installation of weirs

[1) ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Preconditions

✓ The PCV and expanded building are connected by a passage (access tunnel), and interferences outside the pedestal have been removed.

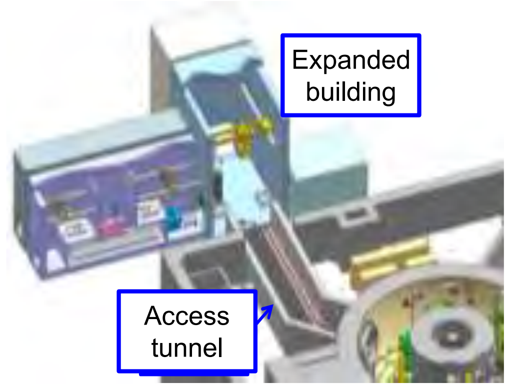
(An access route has been established inside the D/W)

✓ The deposits around the locations, where the weirs will be installed, have been removed.

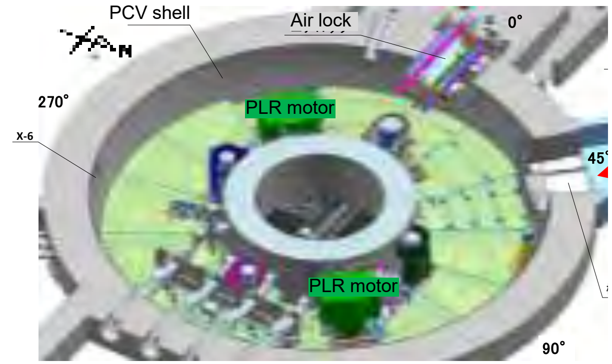
✓ The D/W water level is below the current Unit 2 level, that is, below the lower end of the vent nozzle.

■ Development objectives

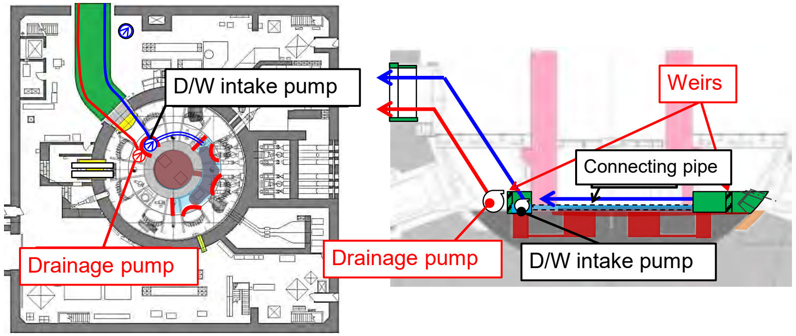
✓ To prevent leakage to the S/C, etc., in combination with drainage from pumps installed inside and outside the weirs.



Expanded building and access tunnel



Status of removal of interferences outside the pedestal



Pump installation position (Example)

[1] ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Study flow

: Reported this time

Policy on initiatives of the subsidy project in the present term in response to the outcomes and issues of the subsidy project in the previous term

- Comparison between proposed methods for preventing the spread of contamination to the jet deflector
  → Selection of the weir installation method
- Study on specific water stoppage methods
  → Identification of methods for constructing weirs by pouring mortar.
- Verification of feasibility of the methods for constructing weirs
  →Verification of feasibility of constructing weirs by pouring mortar (however, issues in execution identified)

Comparative study of streamlined weir construction methods

- Comparative study of the two methods, sandbag method and method of carrying in segmented formwork.

Detailed study of the adopted weir construction method

- Conduct a detailed study of the method of carrying in segmented formwork.

Elemental test for weirs

Scope of implementation in the subsidy project

Survey results of site conditions

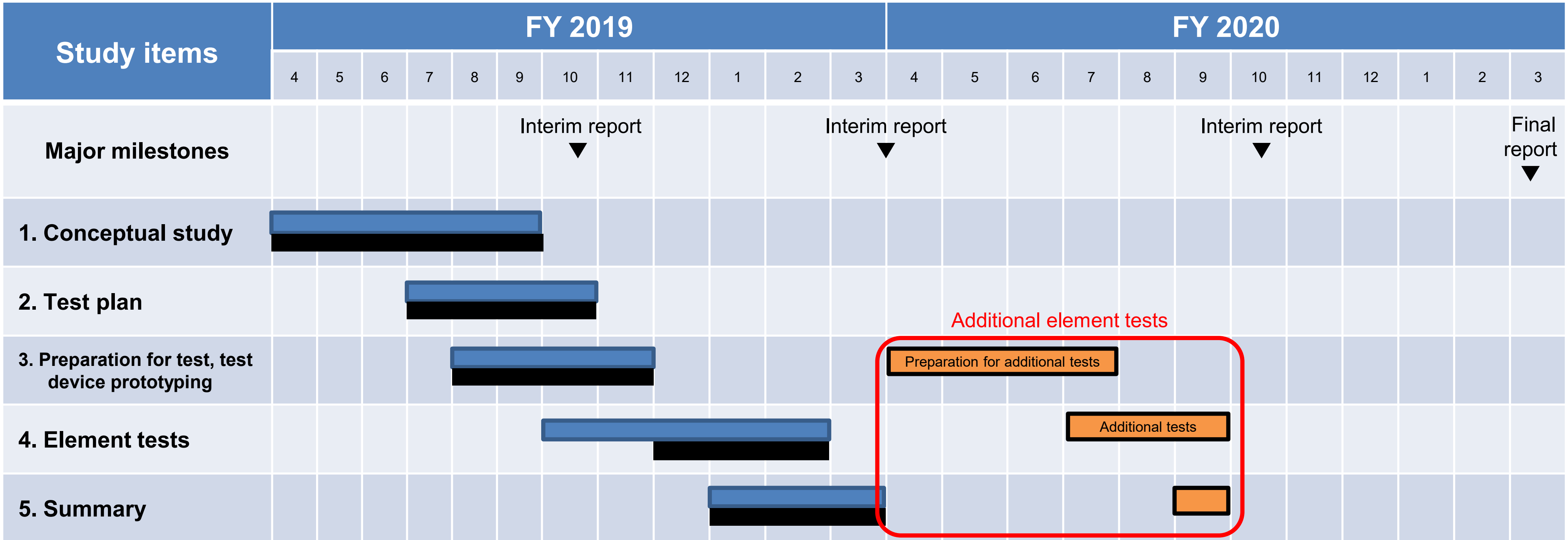
Engineering work plan for actual operations

7. Implementation items of this project

[1) ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

- Development schedule



Remarks: **Additional element tests to be conducted to verify the response policy for issues identified in the element tests.**

7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Results of studies conducted until the previous fiscal year

- Comparison between proposed methods for preventing the spread of contamination to the Jet Deflector
  → Selection of the weir installation method
- Study on specific water stoppage methods
  → Identification of methods for constructing weirs by pouring mortar
- Verification of feasibility of the methods for constructing weirs
  → Verification of feasibility of constructing weirs by pouring mortar
  (Following issues were identified)

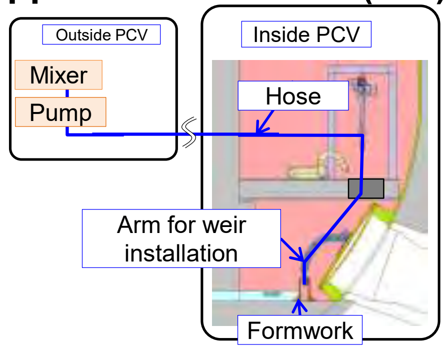


Image of pouring mortar for constructing weirs

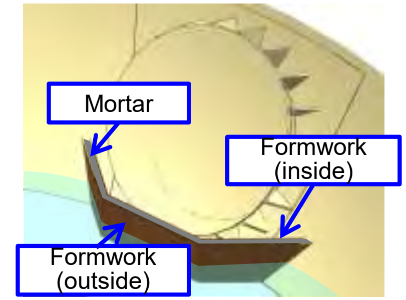
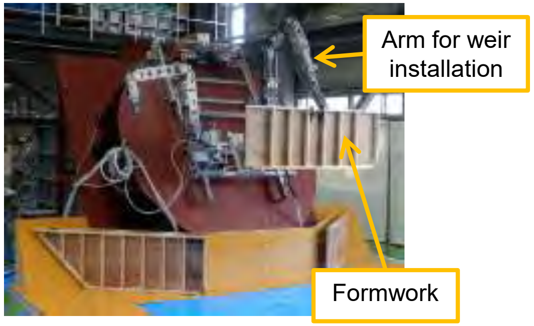


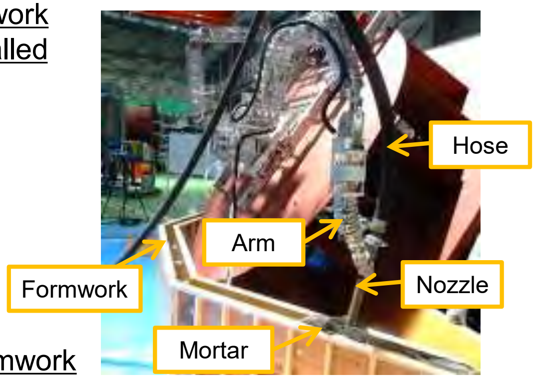
Image of weirs for preventing spread of contamination

Issues identified through the tests and corresponding response policies

ID	Issues	Response policy
1	It was difficult to arrange the hose that pours mortar, at the designated position above the formwork. (In the current setup, the hose needs to be lowered straight down and the opening of the grating has to be larger.)	Other easier methods of creating weirs shall be studied, including whether or not it is possible to use standalone weirs (e.g., sandbags) to build weirs, and element tests shall be conducted. (Tests to verify the ability to install weirs by remote operation devices, tests to verify the ability of weirs to stop water, etc.)
2	After the weirs are installed, pumps and piping may be needed to drain the water on the outside of the weirs.	Together with the tests mentioned above, tests to verify the ability to install pumps and piping for draining water on the outside of the weirs shall be conducted.
3	There is a risk of leakage after weirs are installed.	In order to ensure long-term integrity, remote operation repair methods shall be studied.



Weir formwork being installed



Mortar being filled in a weir formwork

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

A comparative study was conducted on remote operation methods for constructing weirs to prevent the spread of contamination to the S/C.

		Conventional method	[Streamlining plan 1] Sand bag method	[Streamlining plan 2] Method of carrying in segmented formwork
Features		Formwork is installed and an impermeable material (mortar) is injected into the formwork. [The water-added mortar is pumped with a hose]	Impervious bags are stacked up [Bags filled with dry mortar are stacked up]	Several foldable formworks (mesh type) are used. After carrying in the formworks, they are unfolded and installed, and an impermeable material (dry mortar) is injected into the formwork.
Evaluation	Impermeability	○	▲ Depends on the stacking method. The bags must be stacked without gaps.	△ Complete impermeability is difficult, but difference in water levels can be ensured
	Remote operability	▲ Positioning of the hose, installation of the formworks	▲ Implementation of the method of stacking the bags without gaps	△ Formwork arrangement and installation
	Ability to slide along an uneven surface	○	△ Sliding is limited even if the bags are pressed against each other	△ Depends on leakage of dry mortar from the formwork
	Long-term integrity (Frequency of maintenance)	○	△ Depends on the material of the bag	○
Comprehensive evaluation		▲	▲	△

[Legend] O: Good, △: Some issues present, ▲: Issues present (Issues are bigger as compared to △)

- ✓ The sand bag method and the method of carrying in segmented formwork were studied as the methods for solving the issue of remote operability, which was a major issue with the conventional method.
- ✓ The issues with the sand bag method are how to remotely stack the bags so that there are no gaps and the ability to slide the bags along the uneven surface of the floor.
- ✓ The issues with the method of carrying in segmented formwork (method of injecting dry mortar in the foldable formworks (mesh)) are the feasibility of work under the constraint of the mortar curing time, and selection of optimum roughness and material for the mesh bag.

Conventional method

Sand bag method

Method of carrying in segmented formwork

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Possibility of adopting Streamlining Plan 1 and 2

✓ Ability to slide along the floor (uneven surface):
- With the sand bag method, the sliding ability is limited even if the bags are pressed by an external force. The methods used for improvement, such as reducing the impervious material in the bags, do not satisfy the required functions, and hence this method cannot be used.
- In the method of carrying in segmented formwork, by using mesh bags, the ability to slide along uneven surfaces can be ensured.

✓ Remote operability:
- With the sand bag method, it is difficult to achieve remote stacking without gaps, which is almost the same as the conventional method (the major issue with the conventional method is remote hose positioning).
- In the method of carrying in segmented formwork, remote-controlled carrying in and installation is possible by adopting an X-frame structure that is easy to fold and unfold.

✓ Impermeability:
- With the sand bag method, since impermeability depends on the stacking method, ensuring impermeability is difficult.
- For the method of carrying in segmented formwork, the preliminary tests have confirmed that the water level difference can be ensured (On a separate note, it is necessary to check the feasibility of working under the constraint of mesh mortar curing time).

⇒ The method of carrying in segmented formwork shall be adopted.

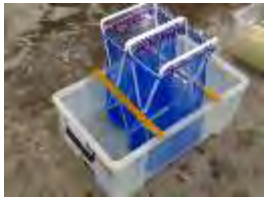
Manual

Remote

Comparison of sand bag stacking methods

Ability to slide along uneven surfaces (sand bag)

Formwork: Folded



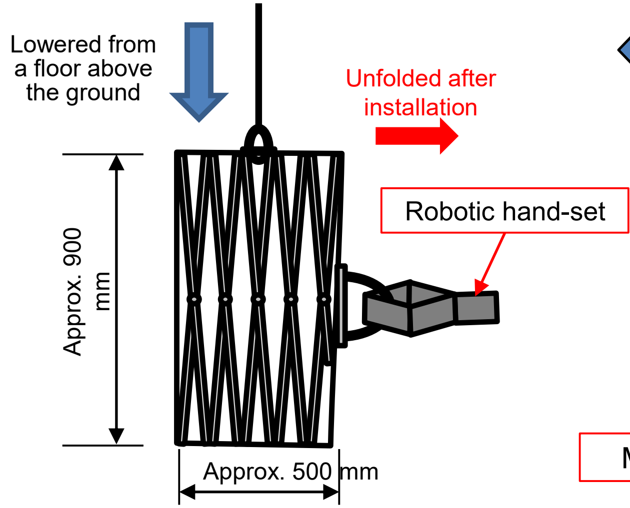
Formwork: After unfolding

Status of drainage after mortar curing

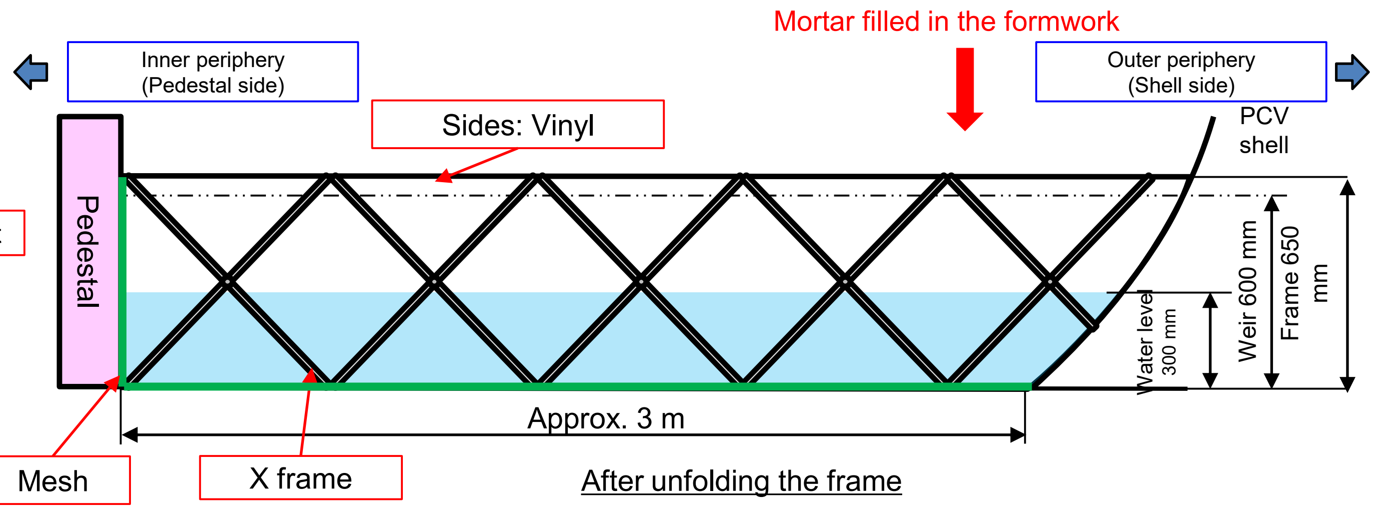
7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

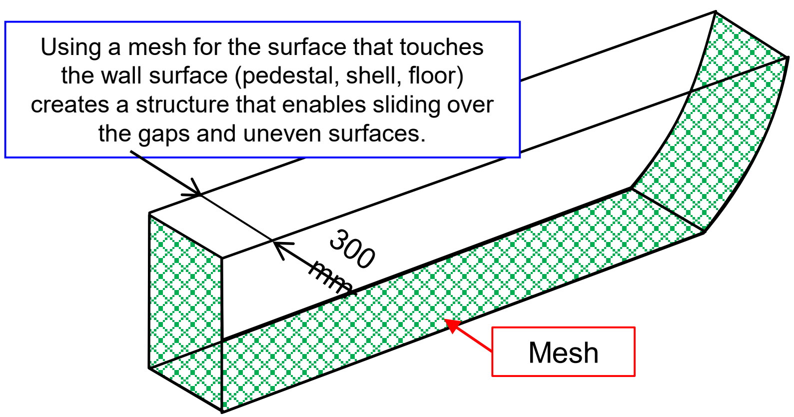
The construction of weirs by the method of carrying in segmented formwork, which was studied in detail, is illustrated below.



When lowered from a floor above the ground



After unfolding the frame



Preliminary test*1

Frame being unfolded

Completely unfolded frame

*1: Prototype created with vinyl on the entire surface, as the preliminary test was conducted for the purpose of confirming the unfolded structure.

Validity of remote operation in the above structure to be confirmed by element tests#

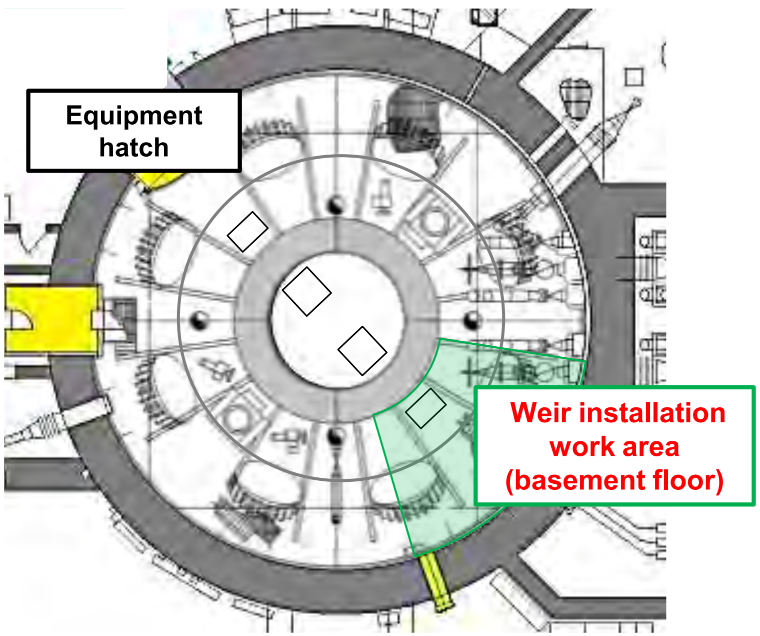
#For details on the content of the element tests, refer to the table on Slide 97.

7. Implementation items of this project [1) ② Development of various technologies other than the interference removal technology]

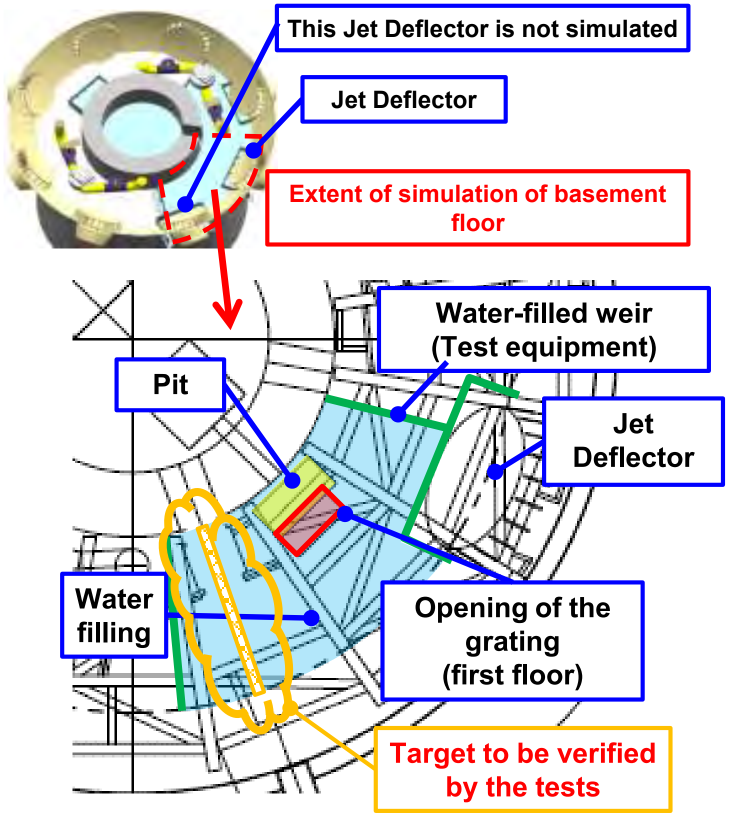
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Extent of simulation in element tests

- ✓ Element tests pertaining to the construction of weirs are conducted for solving the issues identified in the work steps shown on Slides 65 to 69.
- ✓ Weir construction work involves underwater installation work during the actual operation, and hence the tests are conducted under water-filled conditions. In order to confirm impermeability on to the floor and wall surface, the simulation is conducted by installing weirs touching the pedestal outer wall and PCV inner wall.



First Floor



Basement floor

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Element test items and criteria

ID	Test items	Applicable work steps#1	Test outline and procedures	Criteria	Remarks
1	Carrying in and unfolding the formworks	7-1	(1) Lift the formwork with the gantry-type lifting machine. (2) Move the gantry-type lifting machine to a position above the existing opening. (3) Use the winch of the gantry-type lifting machine to lower the formwork to the basement floor. (4) Use the flexible work arm (basement floor) to hold the formwork and hoist the winch of the gantry-type lifting machine. (5) Use the flexible work arm to unfold the formwork.	• The gantry-type lifting machine can be positioned above the opening. • The formwork can be carried in from the opening (1200 x 600 mm). • The formwork can be unfolded.	
2	Injection of dry mortar	7-2	(1) Use the flexible work arm to position the hose (to inject dry mortar) directly above the formwork. (2) Move the hose with the flexible work arm to inject dry mortar into the formwork#2. (2) Drain the water between the weir and the simple weir (for testing). [Manual work] (3) Measure the amount of leakage. [Manual work]	• Dry mortar can be injected into the formwork. • The mortar solidifies. • A water level difference can be created inside and outside the weirs by draining water. • There is no leakage from the weirs. (Goal)	#2: Mortar is injected into the hose manually

#1: Refer to the work steps on slides 65 to 69.

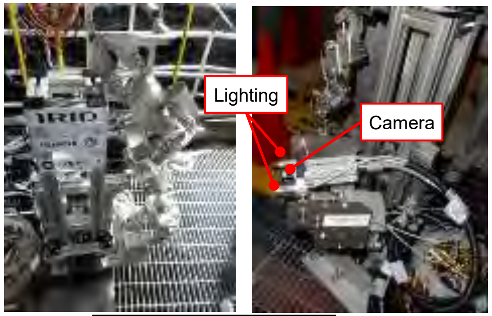
[Devices used for the element tests]

Holding the jig to assist in the work

Flexible arm for remote operations*

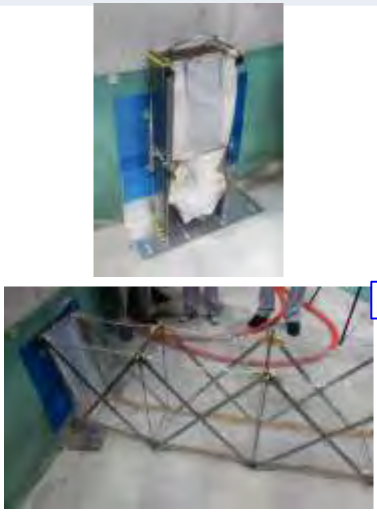
Transporting and installing the jigs

Gantry-type lifting machine

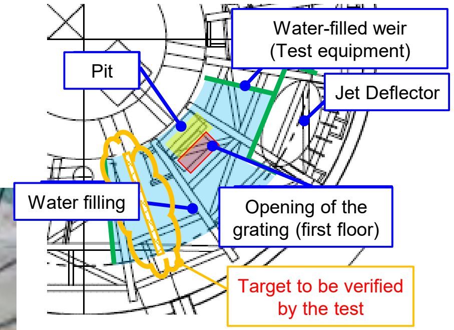


Work monitoring

Camera cart



Formwork



Schematic image of test

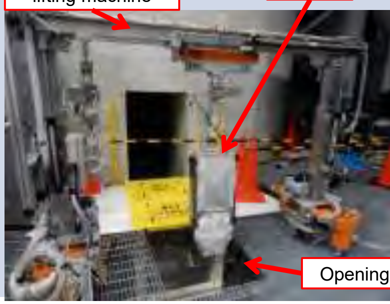
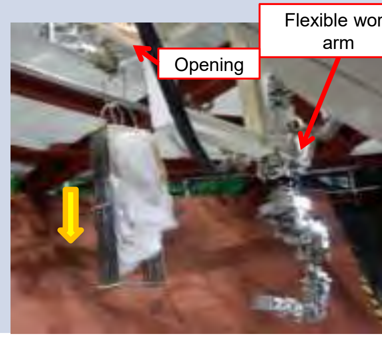
*There are several variations in flexible arms for remote operations. The above specification is an example of a crawler type flexible arm.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Test procedures (Carrying in and unfolding the formworks) #Verified by a preliminary test

ID	Test items	Applicable work steps	Test outline and procedures	Criteria	Remarks
1	Carrying in and unfolding the formwork	7-1	(1) Lift the formwork with the gantry-type lifting machine. (2) Move the gantry-type lifting machine to a position above the existing opening. (3) Use the winch of the gantry-type lifting machine to lower the formwork to the basement floor. (4) Use the flexible work arm (basement floor) to hold the formwork and hoist the winch of the gantry-type lifting machine. (5) Use the flexible work arm to unfold the formwork	• The gantry-type lifting machine can be positioned above the opening. • The formwork can be carried in from the opening (1200 x 600 mm). • The formwork can be unfolded.	

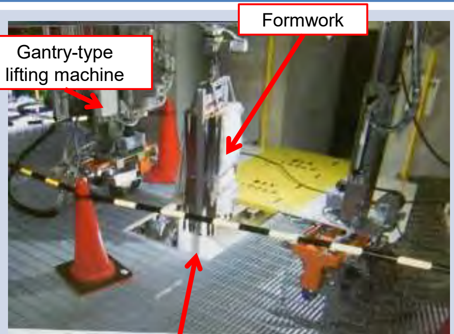
STEP	1. Lifting the formwork with the gantry-type lifting machine → 2. Moving the gantry-type lifting machine above the opening	3. Lowering the formwork	4. Transferring the formwork
Illustration of operation			

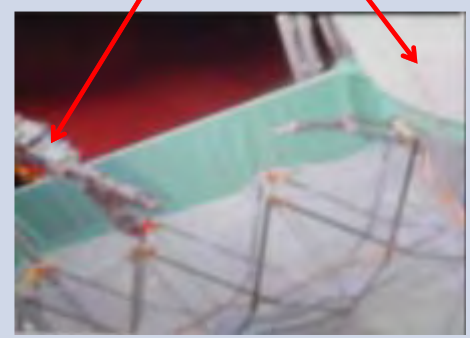
STEP	5. Unfolding the formwork			
Illustration of operation				

7. Implementation items of this project [1) ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Element test results (Carrying in and unfolding the formwork)

STEP	1. Lifting the formwork with the gantry-type lifting machine → 2. Moving the gantry-type lifting machine above the opening	3. Lowering the formwork	4. Transferring the formwork
Illustration of operation			

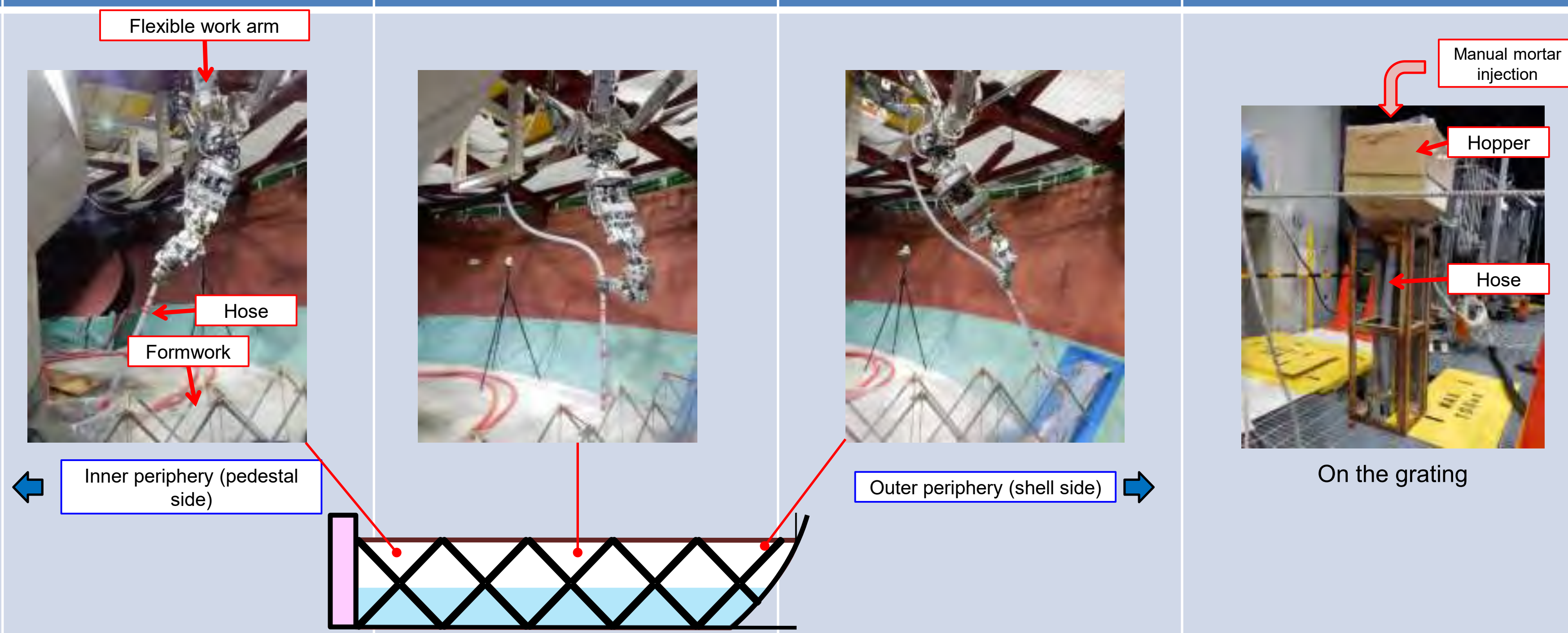
STEP	5. Unfolding the formwork			
Illustration of operation				

It was confirmed that the formwork can be carried in and unfolded.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ <u>Test procedures (Injection of dry mortar)</u> #Verified by a preliminary test

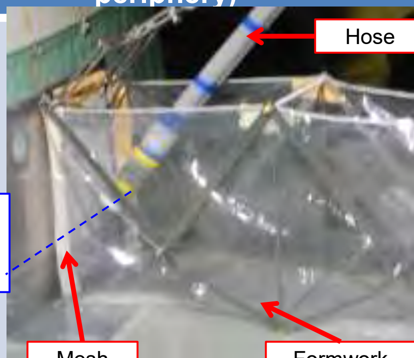
ID	Test items	Applicable work steps	Test outline and procedures	Criteria	Remarks
2	Injection of dry mortar	7-2	(1) Use the flexible work arm to position the hose (to inject dry mortar) directly above the formwork. (2) Move the hose with the flexible work arm to inject dry mortar into the formwork#2. (2) Drain the water between the weir and the simple weir (for testing). [Manual work] (3) Measure the amount of leakage. [Manual work]	• Dry mortar can be injected into the formwork. • The mortar solidifies. • A water level difference can be created inside and outside the weirs by draining water. • There is no leakage from the weirs. (Goal)	#2: Mortar is injected into the hose manually

STEP	1. Positioning the hose over the formwork			
Illustration of operation				

On the grating

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

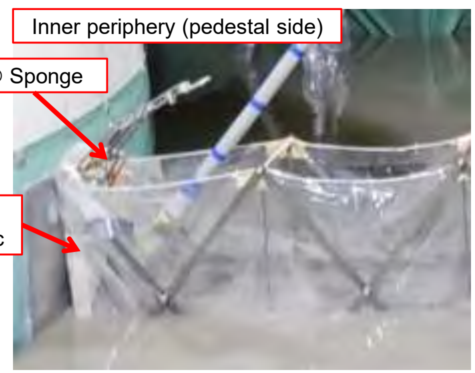
■ Element test results (Injection of dry mortar)

STEP	1. Positioning of hose (inner periphery)	2. Injecting mortar
Illustration of operation		 

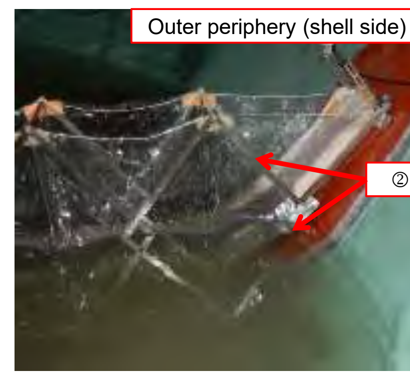
It was confirmed that hose positioning and mortar injection is possible, but there was a large outflow of cement from the gaps between the formwork and the wall surface.

⇒ The test was suspended, the mesh sieves were opened, and the test was resumed after measures were taken for the gaps with the wall surface.

[Countermeasures]
① Attach a non-woven fabric on the outside of the mesh (sieve size 1 mm).
② Close the gaps with the wall with a sponge.
(Either on the outer or inner periphery)



State of the weir on the inner periphery



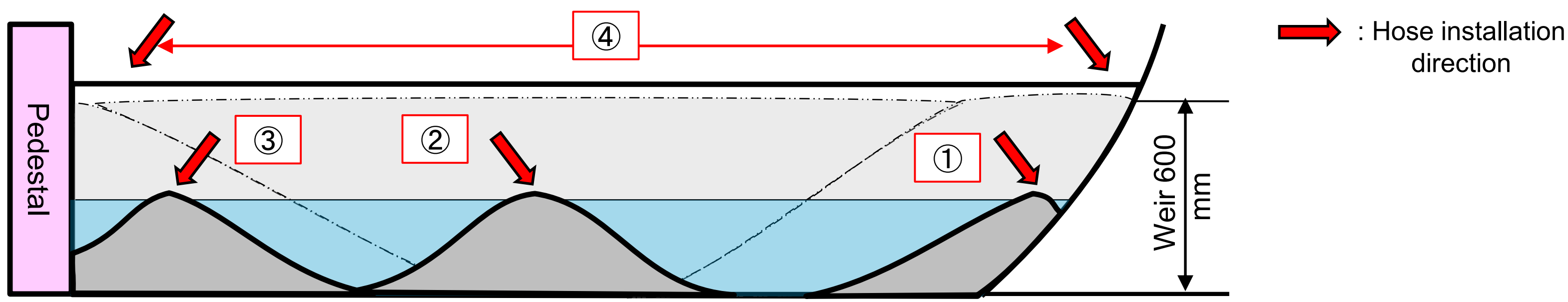
State of the weir on the outer periphery

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ <u>Element test results (Injection of dry mortar)</u>

- ✓ After taking measures for gaps as described on the previous slide, mortar injection was continued and completed. (See the next slide for the injection status)
- ✓ For the mortar injection spots, the following procedures were carried out while observing the accumulated mortar.

No.	Injection position	Details	Standard
①	Outer periphery bottom	Mortar is injected so that the gaps with the wall surface are filled and the bottom surface is covered.	Mortar is injected until the top of the mortar mound emerges in the air.
②	Centre bottom	Mortar is injected so that the mesh at the bottom is covered.	Mortar is injected until the top of the mortar mound emerges in the air.
③	Inner periphery bottom	Mortar is injected so that the gaps with the wall surface are filled and the bottom surface is covered.	Mortar is injected until the top of the mortar mound emerges in the air.
④	Entire area in the air	Mortar is injected throughout so that the height is 600 mm.	Mortar is injected while confirming the mortar accumulation emerging in the air.



<u>Mortar injection position and accumulation status (estimated)</u>

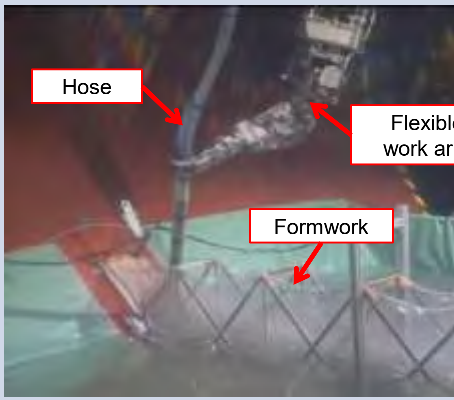
7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ <u>Element test results (Injection of dry mortar)</u>

✓ After taking the measures described on the previous slide, mortar injection was continued and completed.

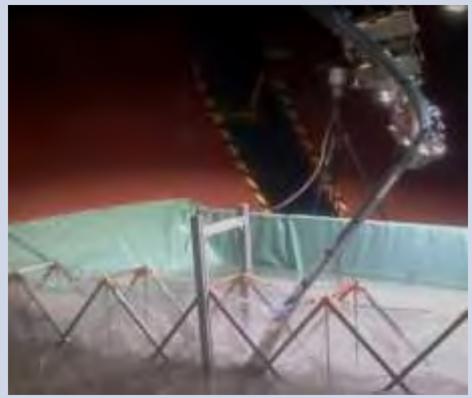
STEP: 1. Hose positioning, mortar injection (① Outer periphery)

Illustration of operation



STEP: 2. Hose positioning, mortar injection (② Centre part)

Illustration of operation

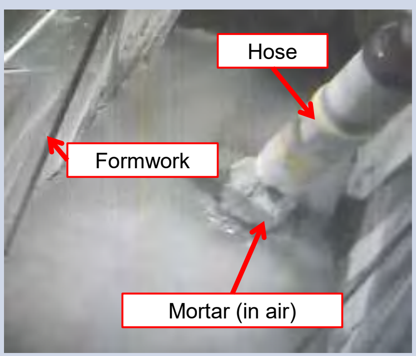


STEP: 3. Hose positioning, mortar injection (③ Inner periphery)

Illustration of operation

STEP: 4. Mortar injection monitoring status (③ Inner periphery)

Illustration of operation



STEP: 5. After completion of mortar injection

Illustration of operation

7. Implementation items of this project

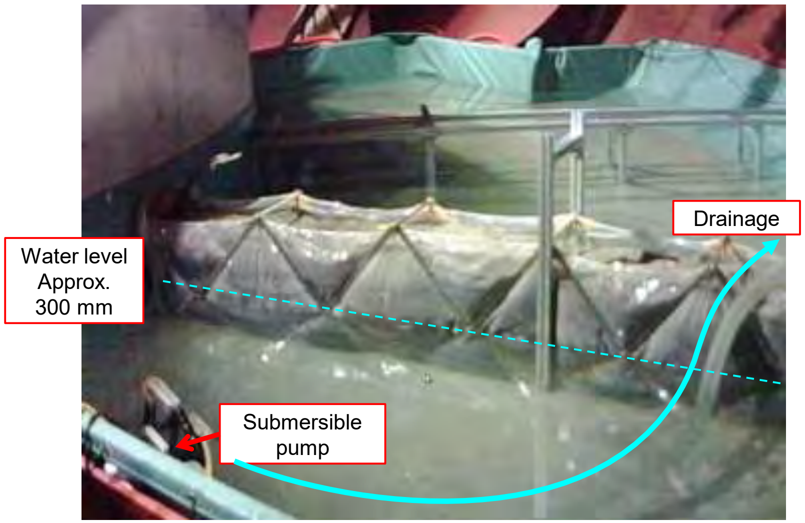
[1) ② Development of various technologies other than the interference removal technology]

b. Methods for preventing spread of contamination to the suppression chamber (S/C)

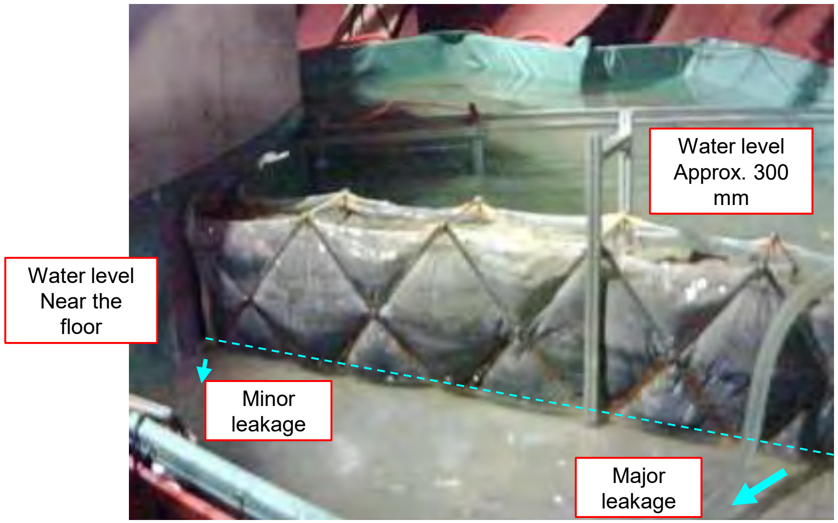
■ Element test results (Injection of dry mortar): Status of verification of leakage

✓ It was confirmed that after the curing of mortar, different water levels could be achieved inside and outside the weirs by draining the water, but there was a major leakage from the outer periphery of the weirs and the difference in water levels was lost soon (approximately 10 minutes).

→ Specifically on the outer periphery, the gaps were filled up with sponge, but the amount of leakage was large because the mesh bags did not swell enough to adhere firmly to the wall surface.



Before draining water outside the weir



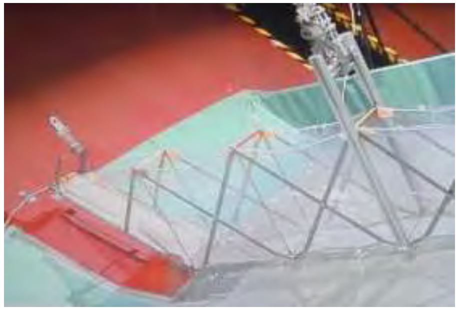
Immediately after draining water outside the weir

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Summary of element test results

ID	Test items	Test outline and procedures	Test results		Remarks
1	Carrying in and unfolding the formwork	(1) Lift the formwork with the gantry-type lifting machine. (2) Move the gantry-type lifting machine to a position above the existing opening. (3) Use the winch of the gantry-type lifting machine to lower the formwork to the basement floor. (4) Use the flexible work arm (basement floor) to hold the formwork and hoist the winch of the gantry-type lifting machine. (5) Use the flexible work arm to unfold the formwork.	• It was confirmed that the gantry-type lifting machine can be positioned above the opening. • It was confirmed that the formwork can be carried in from the opening (1200 x 600 mm) into the basement floor with the gantry-type lifting machine, and that the formwork can be held with the flexible work arm (basement floor). • It was confirmed that the formwork can be unfolded using the flexible work arm (basement floor).	O	
2	Injection of dry mortar	(1) Use the flexible work arm to position the hose (to inject dry mortar) directly above the formwork. (2) Move the hose with the flexible work arm to inject dry mortar into the formwork#1. (2) Drain the water between the weir and the simple weir (for testing). [Manual work] (3) Measure the amount of leakage. [Manual work]	• It was confirmed that the hose can be positioned with the flexible work arm (basement floor), and that dry mortar can be injected into the formwork. • It was confirmed that the mortar injected under water solidifies. • The mortar could be injected into the formwork, but a large amount of cement flowed out from the mesh. • Different water levels could be achieved inside and outside the weirs by draining the water, but there was a major leakage from the weirs and the difference in water levels was lost soon.	▲	#1: Mortar is injected into the hose manually


Carrying in formwork


Unfolding formwork


Injecting dry mortar


Outward appearance of weirs

It was confirmed that the criteria pertaining to remote operability were fulfilled, but there are issues in the structure and impermeability of the weirs.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ Identified issues and policy of response

No.	Issue	Details	Response policy
1	Method of closing the gap between the formwork and the wall	If the gap between the formwork and the wall surface is large, it cannot be filled completely and the mortar does not adhere to the wall, so the water cannot be stopped.	The roughness of the mesh sieve shall be studied again and **additional element tests shall be conducted.**
2	Method of preventing the outflow of cement from the mesh	Since the mesh sieve is coarse, the cement component of mortar flows out.	**Additional element tests shall be conducted** in addition to the above improvements.
3	Method of repair when a leak occurs	It is necessary to conduct repairs if the amount of leakage increases over a long period of time, but repairs are difficult with the current method.	Desk study shall be performed and then **additional element tests shall be conducted.** This will also be studied as a backup method for cases when water cannot be stopped as in this element test.
4	Method of confirming the status of mortar injection	It is difficult to monitor the mortar injection status from outside the formwork. (This test was conducted by manually installing a camera near the hose.)	The issue shall be handled through detailed arrangement of cameras and lighting (during actual operation).

Additional element tests to be conducted for No. 1 to 3.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
b. Methods for preventing spread of contamination to the suppression chamber (S/C)

■ <u>Additional element test plan</u>

- ✓ An element test is being planned to check the items listed in the below table.
- ✓ The structure will be reviewed focusing on "adhesion" between the wall surface and formwork and "measures against outflow" from the mesh, the preliminary tests will be performed, and then the following element test will be conducted.
- ✓ The element test will be performed on a scale that takes into account the effect along the length of the weirs.

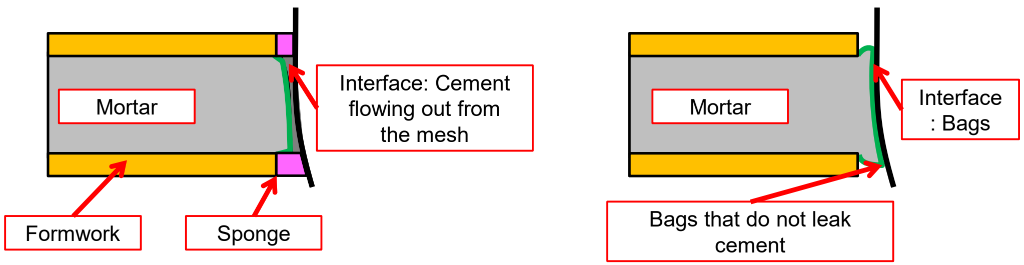


Illustration of a preliminary test

Items to be confirmed by means of the additional element test

No.	Check items	Criteria
1	Adhesion to the wall surface	If there is a gap between the formwork and the wall surface, can the water be stopped if the mortar adheres to the wall surface?
2	Adhesion of the formwork intersection	At the intersection of the two formworks, can the water be stopped if the weirs adhere firmly to each other?
3	Ability to slide along an uneven floor surface	Can the water be stopped even if the floor surface is uneven?
4	Repair method in the event of leakage	If there is a leakage in the above interface, can it be repaired? (Assuming work from the upstream side.)

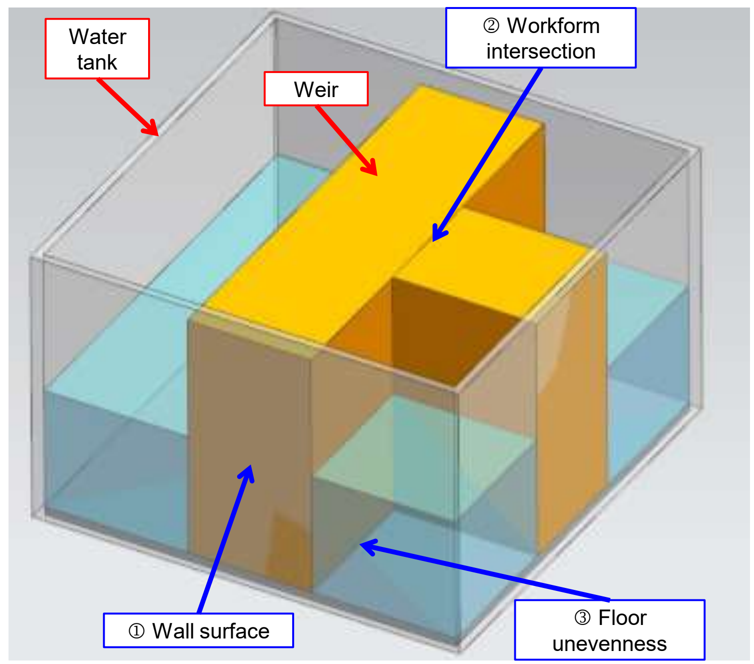


Illustration of a specimen for the additional element test

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

- Purpose of development
  - To refine the planned implementation method for verifying feasibility, by reconsidering the proposed configuration and layout of the fuel debris retrieval equipment, in addition to studying the method of implementation that resulted from the studies conducted until last year, along with studying the progress of other projects, the safety aspect, constraints of the installation location, etc., in preparation for the designing stage.
- Issues to be solved
  - It is necessary to reduce the weight of the equipment to satisfy the allowable load value for the floor surface inside and outside the R/B.
  - It is necessary to optimize the equipment layout to avoid interference with existing equipment outside the R/B, which are difficult to remove.
- Approaches to development
  - Detailing and reorganization of study conditions for reducing the equipment weight and optimizing the installation area
  - Study of ideas on how to reduce the equipment weight and optimize the area
  - Study of the methods of installation, carrying in, and fitting of retrieval facilities
  - Study for determining the specifics of the retrieval method and evaluation of its feasibility
- Expected outcome
  - Refinement of the feasible configuration, layout plan, and retrieval method for the fuel debris retrieval facilities

7. Implementation items of this project

[1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

- **<u>Study flow</u>**

Organization of study conditions from issues and problems based on the results of the subsidy project in the previous term

↓

Study of proposed countermeasures to solve issues and problems

↓

Results of this fiscal year

Determining the specifics of the access route establishment plan

↓

Evaluation of the feasibility of the access route establishment plan

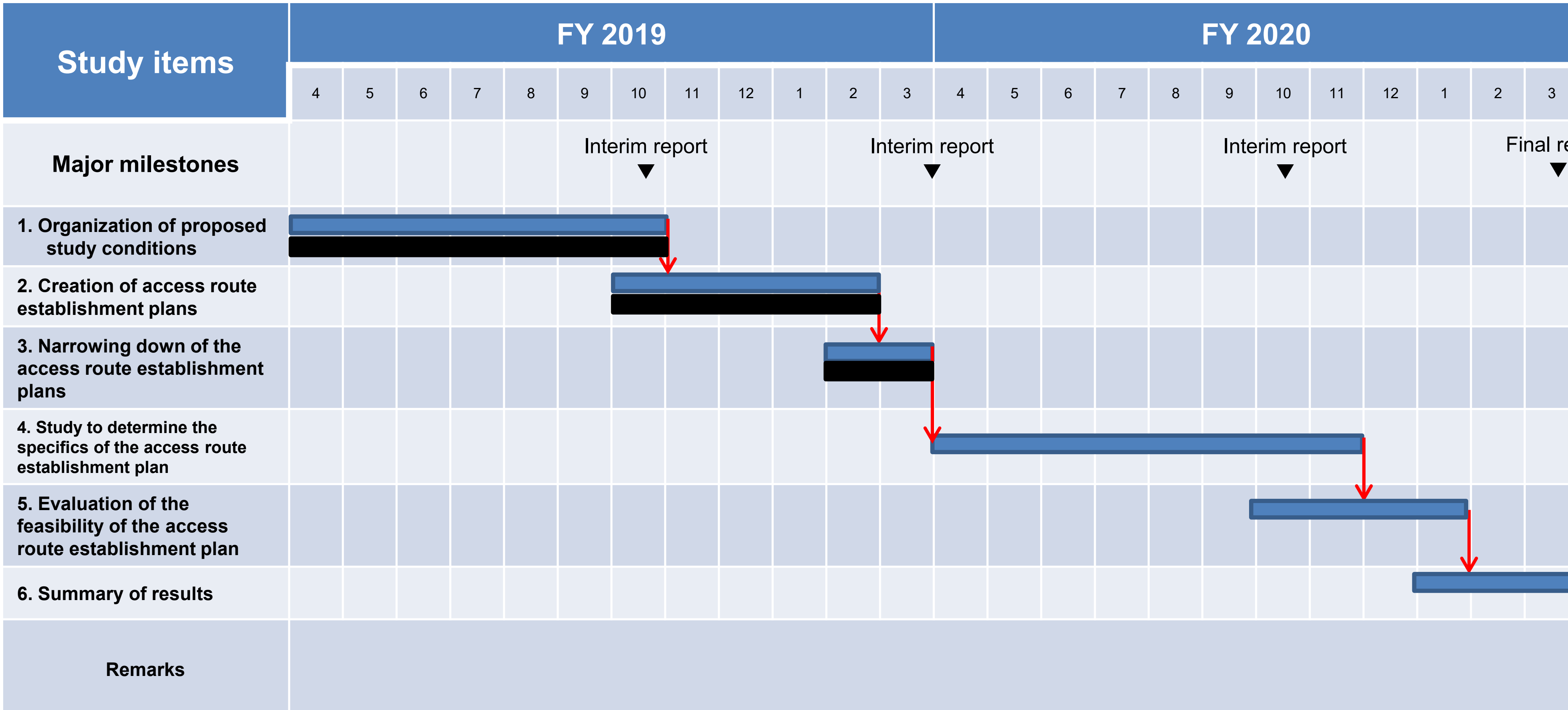
↓

Identification of future issues and response policies

7. Implementation items of this project [1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

■ <u>Development schedule</u>



7. Implementation items of this project [1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

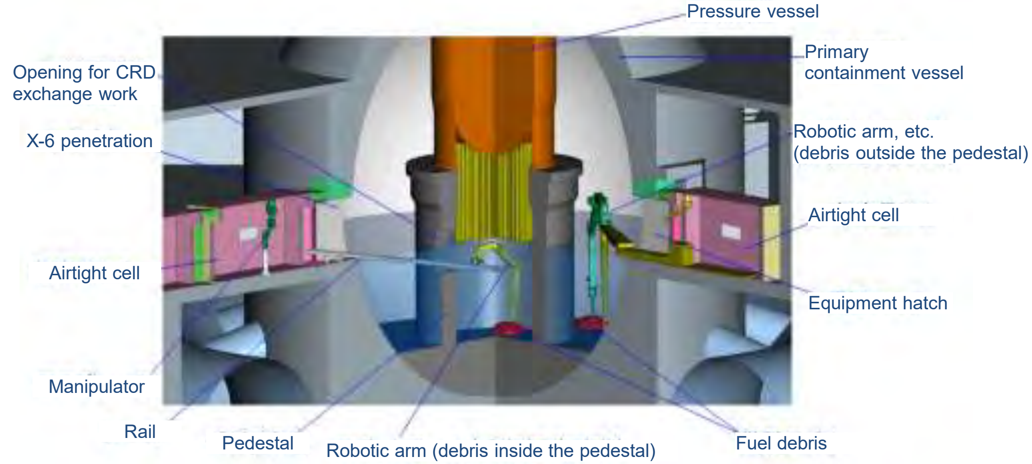
[Main outcomes up to the previous year]
With respect to the method of collecting fuel debris by securing the boundary with cells and accessing the debris from the side of the PCV with the robotic arm, the configuration and layout plan of the fuel debris retrieval facility was devised with the below development concept.

<u>Concepts of development (Aims of development)</u>

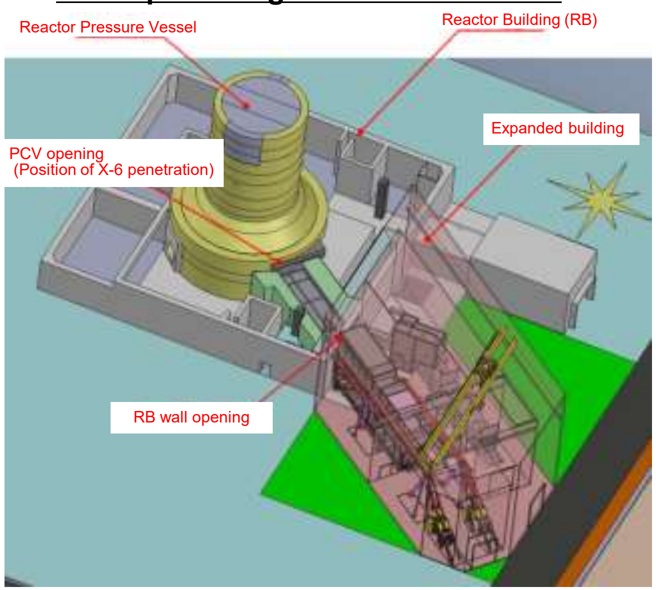
○ Consideration of access with the shortest distance
→Study of methods to quickly access fuel debris based on the idea of carrying in large equipment into the PCV with minimal interference removal

○ Adoption of the cell structure cultivated at the Rokkasho Reprocessing Plant (RRP)
→Based on the technology that has a proven track record in reducing worker exposure, a highly reliable system configuration was created adding the latest findings

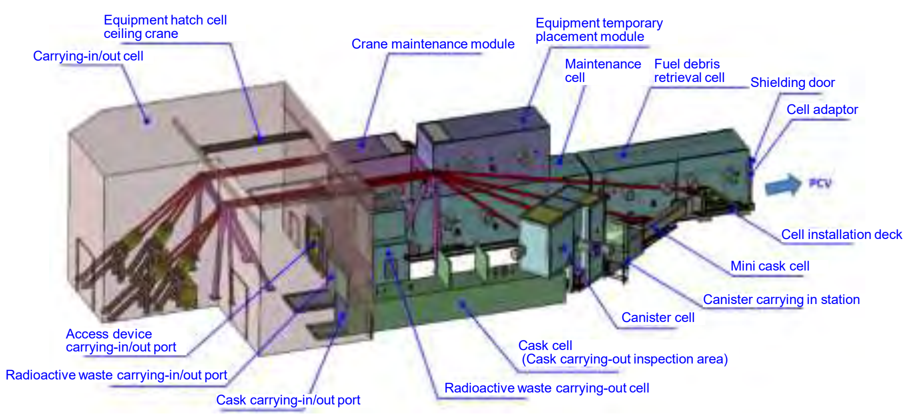
○ Utilization of remotely operated manipulators for which knowledge is available in the field of maintenance and reprocessing of light water reactors
→Study of methods taking into account the special environment based on realistic work / maintenance plan considering actual results



<u>Conceptual diagram of access route</u>



<u>Facility layout plan up to the previous fiscal year</u>



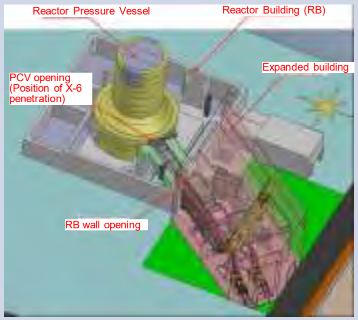
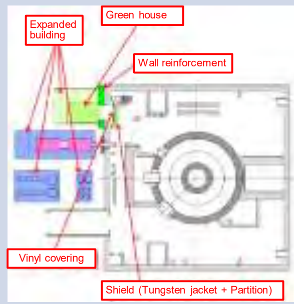
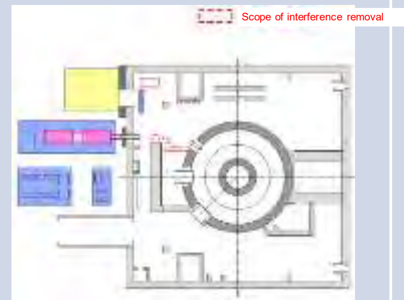
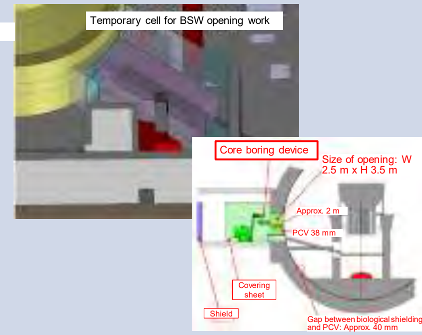
<u>Facility configuration plan up to the previous fiscal year</u>

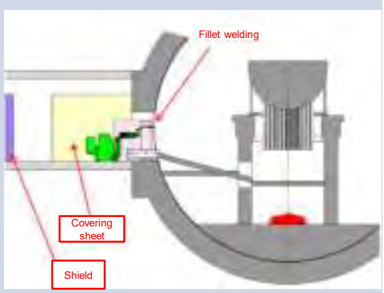
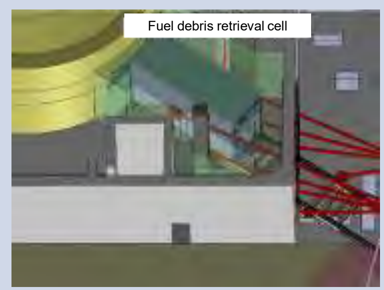
7. Implementation items of this project [1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

: Scope of study in FY2019-2020

Overview of work steps(1/2)

Work step	Installation of expanded building	Work to open R/B wall	Removal of interferences inside R/B	BSW opening
Illustration of steps				
Remarks	• A brief study of scale was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018		• The opening method developed by Toshiba in FY2017-2018 is planned to be applied.

Work step	Welding of cell adapter	Installation of shielding door	Installation of fuel debris retrieval cell	Installation of external R/B cell
Illustration of steps				
Remarks	• Element technology was developed in FY2016-2017	• A conceptual study was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018

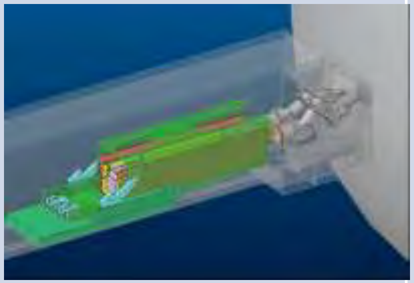
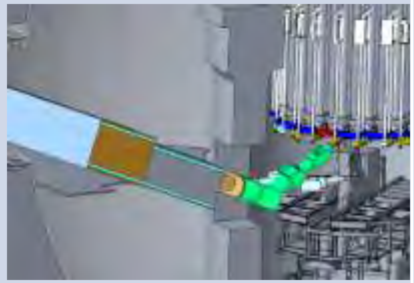
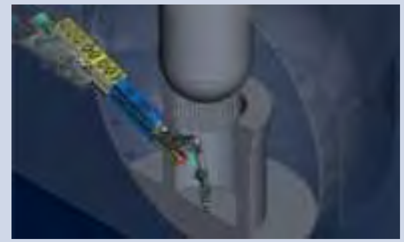
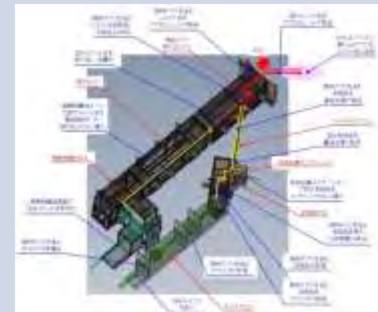
7. Implementation items of this project

[1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

Overview of work steps(2/2)

: Scope of study in FY2019-2020

Work step	PCV wall opening	Removal of interferences inside PCV	Fuel debris retrieval	Carrying out fuel debris
Illustration of steps				
Remarks	• A conceptual study was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018	• A conceptual study was conducted in FY2017-2018

To solve the issue that the R/B floor load will exceed the allowable value due to the weight of the fuel debris retrieval cell to be installed in the R/B, in this subsidy project, studies will be conducted to review the access method, the equipment layout inside the fuel debris retrieval cell, and the cell fixing method with the intention of reducing the size and weight of the fuel debris retrieval cell.

7. Implementation items of this project

[(1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

[Issues / problems based on the results of the previous fiscal year]

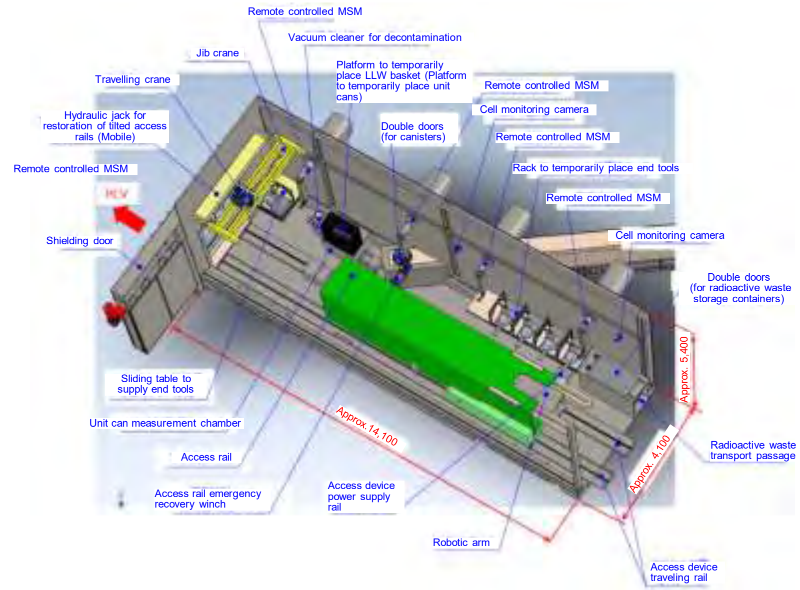
① Increase in the size of the cell due to the relatively large access device

② Increase in the weight of the cell due to the increase in the number of shields to be installed

③ By conducting a study on a suspension bridge-shaped cell installation platform and bringing the cell load inside the R/B out of the R/B, the R/B floor load can be reduced (zero by offsetting)

④ However, a relatively heavy load is applied to the columns and anchor fixing parts of the suspension bridge-shaped cell installation platform, corresponding to the cell load inside the R/B.

⑤ There are existing structures such as underground tanks near the R/B, and a study found that it would be difficult to construct the strong foundation necessary to support the load applied to the columns and anchor fixing parts

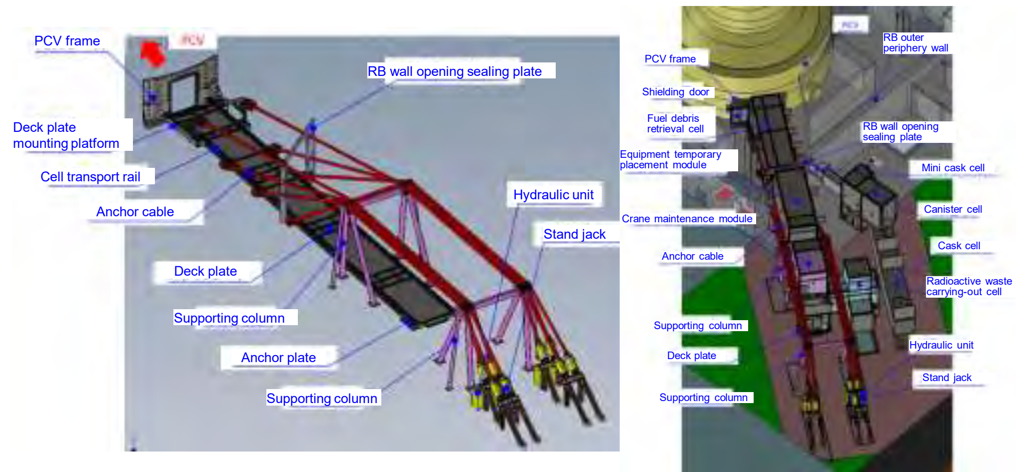


Structural drawing of the fuel debris retrieval cell up to the previous fiscal year

Load reduction measures other than suspension bridge-shaped cell installation platform were required for R/B first floor.

[Study policy and goals]

- Aim to reduce the R/B floor load by reducing the cell's weight and distributing the load by the cell's weight.
- Prevent local concentration of load outside the R/B by eliminating the suspension bridge-shaped cell installation platform



Schematic diagram of suspension bridge-shaped cell installation platform up to the previous fiscal year

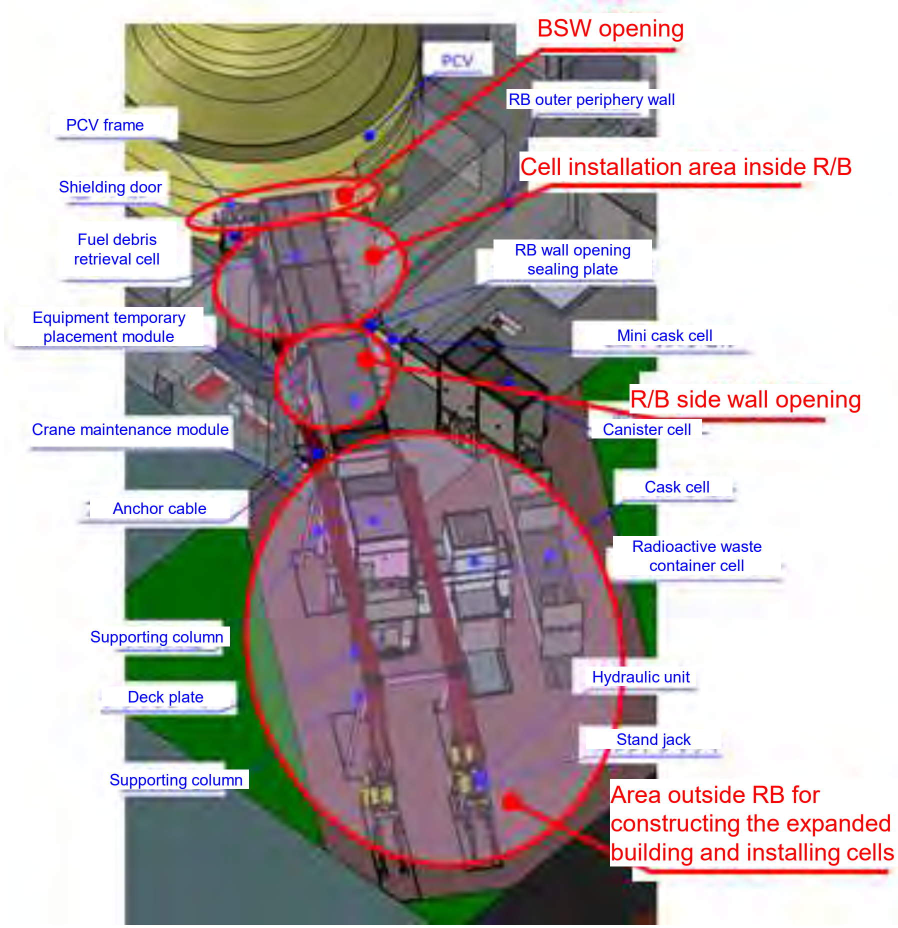
7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

■ **Pre-conditions**

- The ground has been levelled in the area for the cells and expanded building outside R/B and the cells and the expanded building can be set up.
- An opening is provided on the side wall of the R/B, and cells can be carried into the R/B and installed.
- Interferences in the specified area of the R/B have been removed, and the cell installation area has been secured.
- An opening is provided in BSW, and the area for connecting cells to PCV is secured.



■ **Development objectives**

- Aim to reduce the R/B floor load by reducing the weight of the cells and distributing the load resulting from the weight of the cells.
- Prevent local concentration of load outside the R/B by eliminating the suspension bridge-shaped cell installation platform.

[1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

Study items for reducing the size and weight of the cell in R/B (fuel debris retrieval cell)

Purpose	Study items	Overview
To reduce the weight of the cell	① Changing the access method	Eliminate the access rail method and use a fixed rail method to reduce the cell height.
	② Reducing the height of the cell	Reduce the cell height by reviewing the configuration and layout of the equipment in the cell.
	③ Studying the shield mounting range of the cell	Reduce the weight of the shield by limiting the fuel debris transportation system area.
	④ Reducing the shield thickness	Reduce the weight of the shield by reducing the shield thickness within a reasonable range.
To distribute load resulting from the weight of the cell	⑤ Distributing the floor load by using an installation platform	Distribute the floor load resulting from the cell using the platform provided at the bottom of the cell.

- The results of studies conducted on the cells outside the R/B in the subsidy projects up to the previous fiscal year indicate no major problem. Therefore, in order to reduce the load due to the installation of cells inside and outside the R/B, a study will be conducted focusing on reducing the size and weight of the fuel debris retrieval cells installed inside the R/B.

7. Implementation items of this project [1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

Flow of future studies

① Study on downsizing of the access device
② Study on downsizing of cells

↓

③ Study on the mounting range of the shield
④ Study on the shield thickness

↓

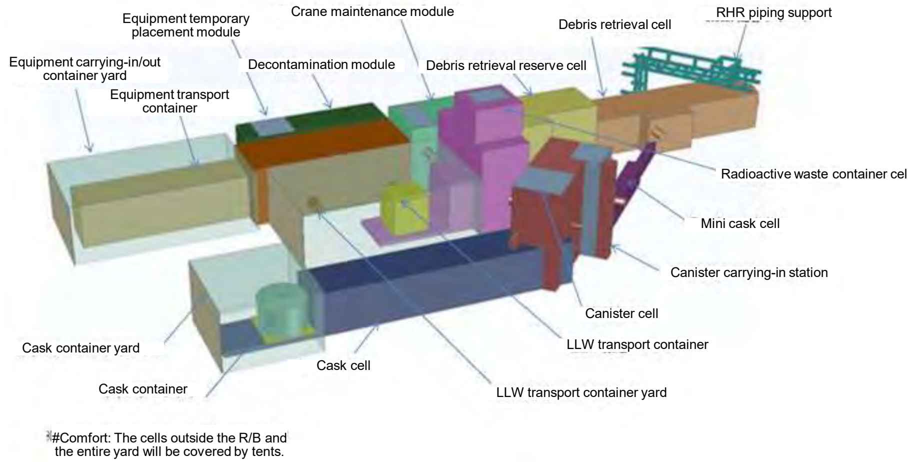
⑤ Study on the distribution of floor load by using an installation platform

↓

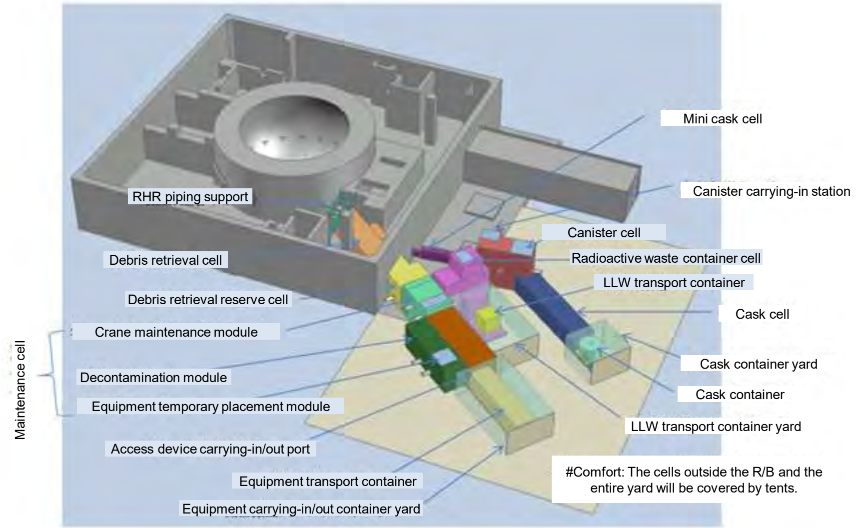
Evaluation of cell size, weight and estimated floor load

↓

Evaluation of the effectiveness and feasibility of the review plan from the viewpoint of fuel debris retrieval work, facility operations, facility layout, installation work, maintenance etc.



Schematic image of facility configuration review



Schematic image of facility layout review

7. Implementation items of this project

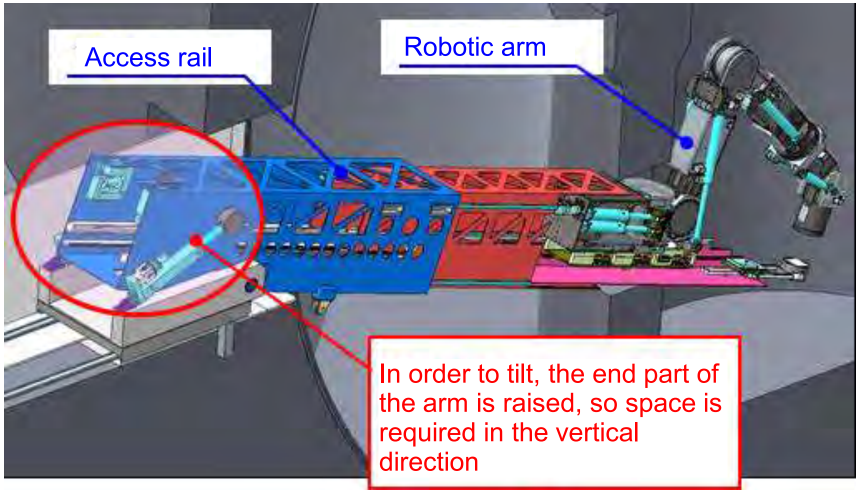
[1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

① Changing the access method

Access device-related issues up to the previous fiscal year

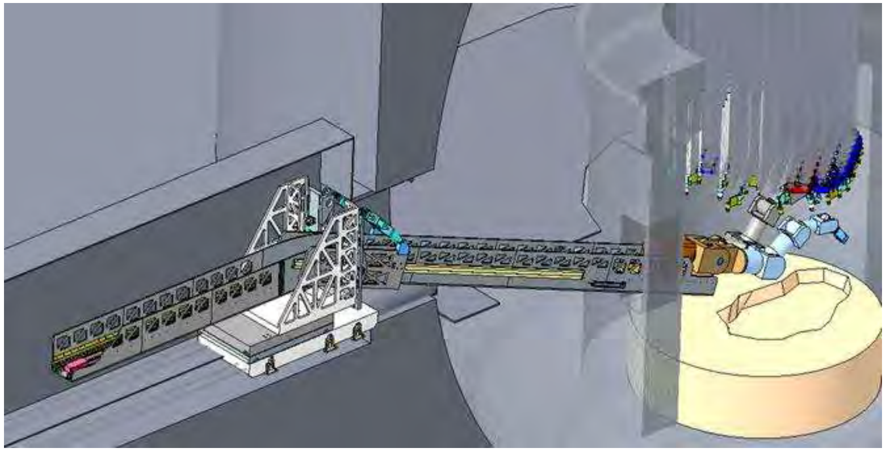
- The method involves tilting and extending the access rail to secure an access route, and a space is required vertically in the cell for tilting.
- A relatively large space is required in the cell to move a relatively large access device in and out of the PCV.



Schematic diagram of the access device up to the previous fiscal year

Study policy

- Reducing the height-wise space of the cell by eliminating the access rail and adopting the fixed rail method
- Reducing the space required for carrying the access device in/out by stopping the use of the largest access rail (on contraction: 8.7 m x 1.9 m x 2.5 m; 24 ton)
- Determining the specifics of the structure, installation method, robotic arm, and unit can transportation methods for a fixed rail as an alternative to the access rail, and verifying their feasibility.



Conceptual diagram of the fixed rail method

Future response

- The specifics of the study item will be verified in the next fiscal year.

7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

② Reducing the height of the cell

Cell-related issues up to the previous fiscal year

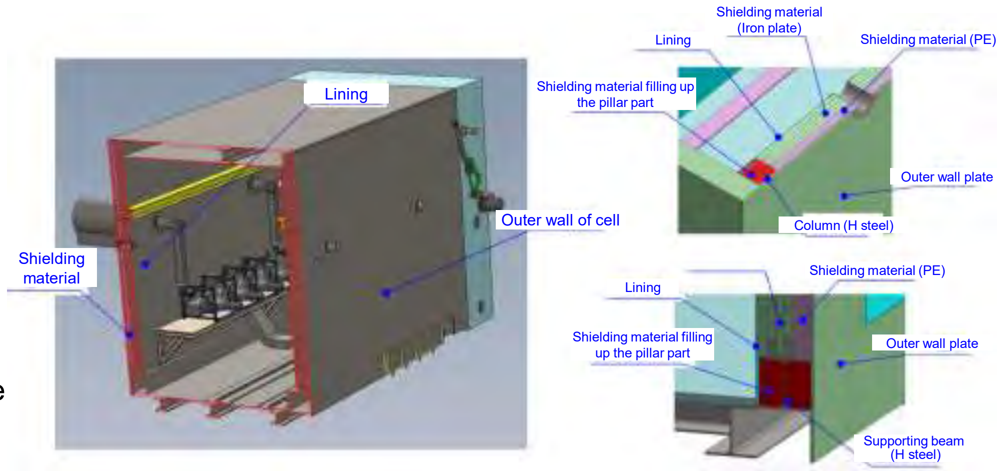
- The weight of shields including structural materials (360 tons) accounts for most of the weight of the fuel debris retrieval cell (382 tons).
- Shields are installed on the sides of the cell to protect workers, and reducing the cell height is effective for reducing weight.
- In order to collect the unit cans from the access rail, it was necessary to lift the unit cans from the top of the inclined access rail, and it was necessary to provide a travelling space for the crane on the top.

Study policy

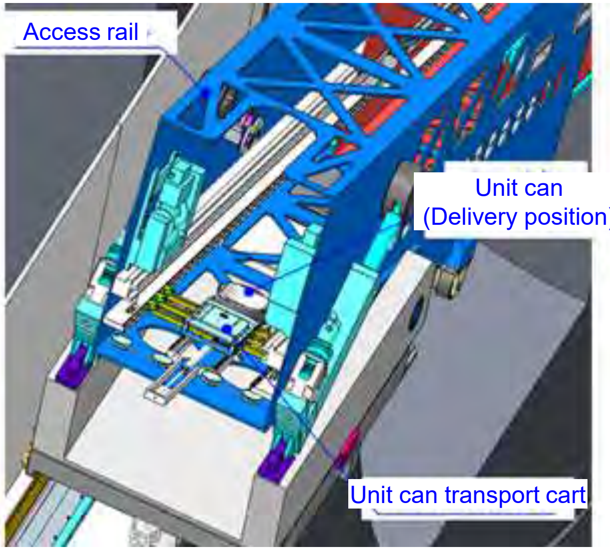
- Due to the elimination of the access rail, it is necessary to review the method of collecting and transporting the unit cans from the access rail.
- In order to reduce the cell height, review the method of collecting the unit cans using a ceiling-mounted traveling crane.

Future response

- The specifics of the study item will be verified in the next fiscal year.



Structural drawing of the shielding material in a fuel debris retrieval cell up to the previous fiscal year



Structural drawing of the unit can transport cart up to the previous fiscal year

7. Implementation items of this project

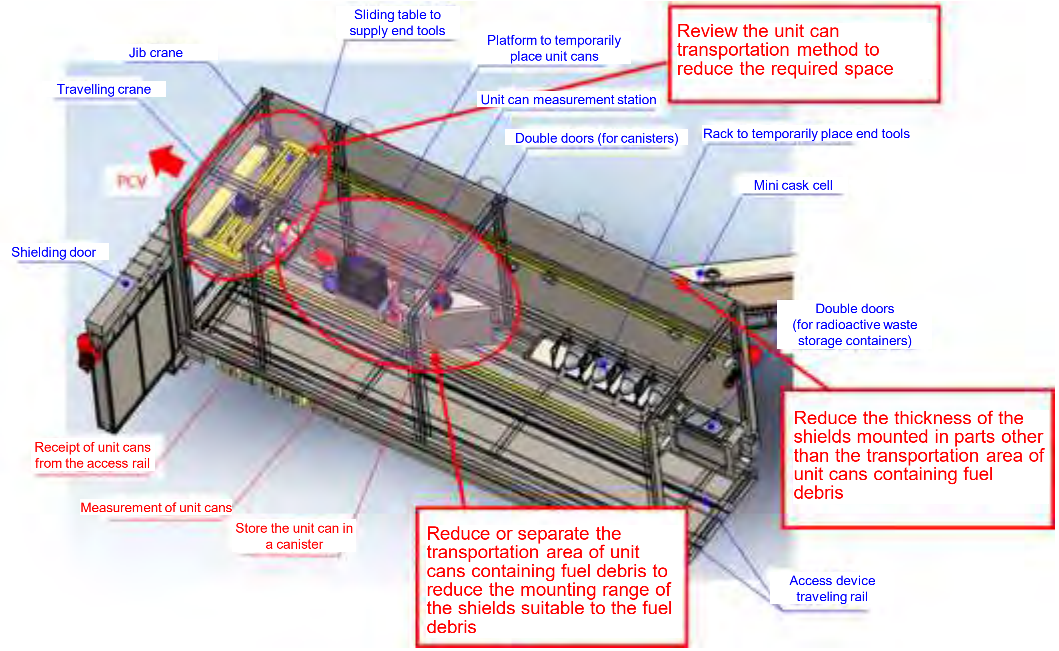
[1) ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

③ Studying the shield mounting range of the cell

Shield-related issues up to the previous fiscal year

- It is necessary to install a thick shield suitable to the source strength for fuel debris.
- Inside the cell, fuel debris was being handled in unit cans without the shielding effect.
- In the fuel debris retrieval cell, it was necessary to secure a relatively large space for handling a large access device.
- It was also necessary to install a thick shield suitable to the fuel debris over the entire side surface of the cell.
- As a result, the shield mounting area became larger and the cell weight increased.



Conceptual diagram on the study of the shield mounting range

Study policy

- Reduce the handling area of fuel debris and the mounting area of the thick shield suitable to the fuel debris by reviewing the unit can handling method.

Unit can

Assumed unit can specifications

- External dimensions: Φ210 mm x 200 mm
- Dry weight: 10 kg
- Maximum debris storage capacity: 50 kg
- Average debris storage capacity: 15 kg
- Maximum gross weight: 60 kg

Future response

- The specifics of the study item will be verified in the next fiscal year.

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

④ Reducing the shield thickness

Shield thickness-related issues up to the previous fiscal year

- The shield thickness was being specified conservatively.
- The shield thickness can be reduced to some extent by reviewing the conditions within a reasonable range

Response

- Review the source conditions within a reasonable range
- Review the criteria for dose rate around the cell within a reasonable range
- Review the considered source study conditions taking into account the operating conditions

Primary study results

- Required shield thickness (2 cm iron + 5 cm PE + 21 cm iron ⇒ iron 2 cm + PE 5 cm + iron 18.5 cm)
- Shield weight reduced by approximately 12% in the same mounting area

Future response

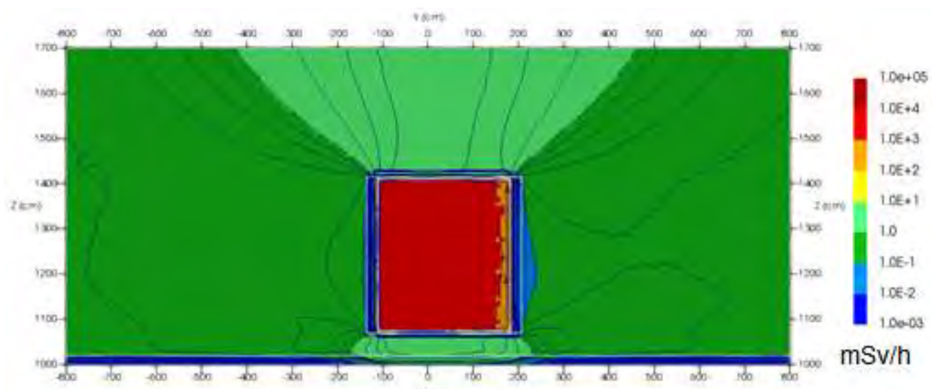
- Reduce the cell weight further in combination with other items.

Source conditions inside the PCV

	FY2017 study	Current study
Form of source	Φ 5 m, height 20 m	Same as on the left
Fuel debris (UO2) weight	78 ton (Unit 1)	107 ton (Unit 2)
Source	Unit 1 - Cooling 10 years (JAEA-Data-Code-2012-018)	Same as on the left
Neutron spectrum	Watt type Pu-239	Same as on the left
Effective neutron multiplication factor	0.7	0.6

Source conditions of unit cans

	FY2017 study	Current study
Unit Can shape (1 can)	Φ 21 cm, height 20 cm	Same as on the left
Number of unit cans	1	4
Fuel debris (UO2) weight	50 kg	60 kg (15 kg × 4 cans)
Neutron spectrum	Watt type Pu-239	Same as on the left
Effective neutron multiplication factor	0.7	0.6



Analysis result in normal times

7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

c. Conceptual study for establishing an access route for installation of cells and method of reducing impact on R/B and other buildings

⑤ Distributing the floor load by using an installation platform

Issues related to the cell installation platform up to the previous fiscal year

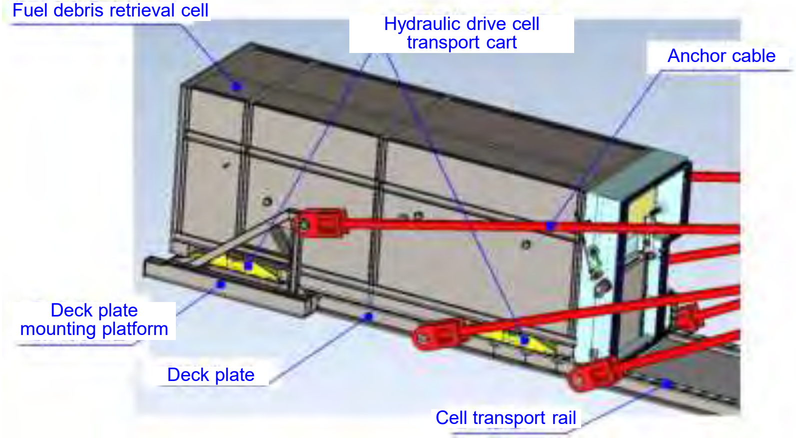
- Allowable load value on R/B first floor
- The design for R/B does not take into account the installation of heavy objects such as cells that were considered up to the previous fiscal year.
- The methods like the cell mounting platform, used up to the previous fiscal year, is advantageous from the viewpoint of reducing the floor load.
- However, dealing with earthquake load and displacement will become complicated and difficult.

Study policy

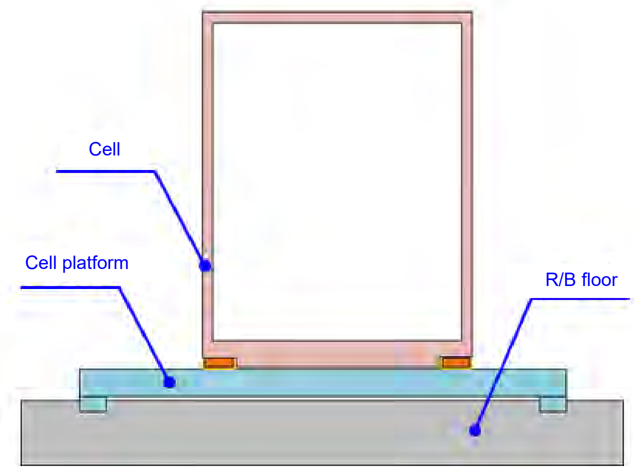
- Study the method of installing and fixing the cell to the R/B floor together with distributing the cell load properly by providing a platform at the bottom of the cell.
- Although an orthodox method that does not draw attention, it is a realistic method that makes it relatively easy to deal with load and displacement during an earthquake

Future response

- Reduce the floor load in combination with other items.



Schematic diagram of the cell mounting platform up to the previous fiscal year

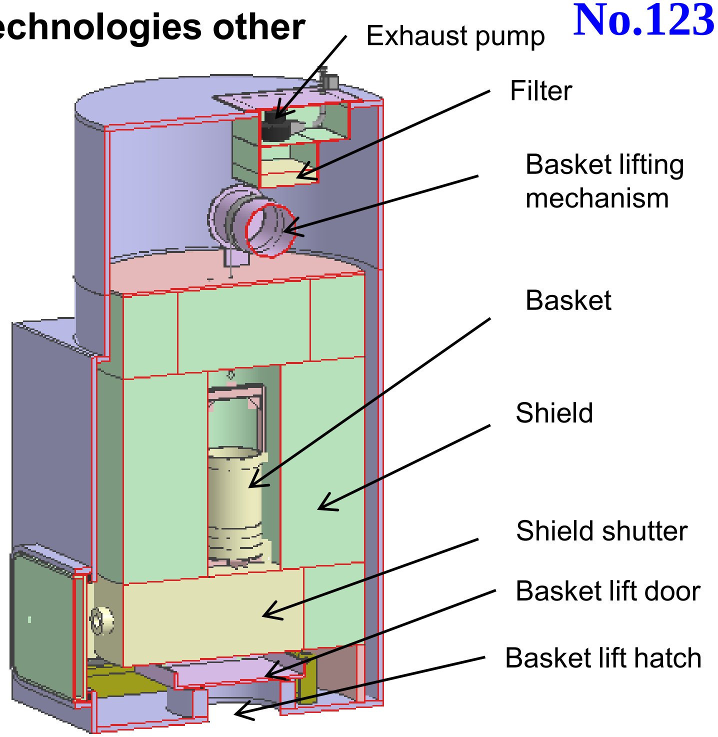


Schematic diagram of a cell platform

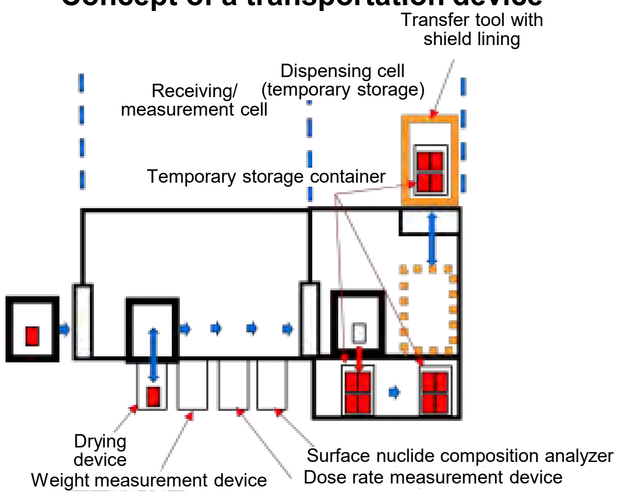
7. Implementation items of this project [1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

- Purpose of development
  - ➢ Develop a method for transporting unit cans to a building away from the R/B.
- Issues to be solved
  - ➢ If the treatment for carrying-out fuel debris storage containers, such as sealing, is performed in a building away from the R/B, a confinement device for transporting the containers to the building is required.
  - ➢ Conceptual study on the confinement device and verification of its feasibility is necessary.
  - ➢ The concept of a building that performs confinement treatment on fuel debris storage containers has not been studied.
- Approaches to development
  - ➢ Conduct a study on transportation of unit cans to a building away from the R/B.
    - Primary evaluation of the transportation time, formulation of confinement device specifications
    - Identification of technology development items, assessment of feasibility through element tests and analysis (Hydrogen generation, cooling, shielding, etc.)
  - ➢ Study the concept and requirement specifications for a building that will perform treatment required for fuel debris storage presuming the application of a confinement device.
  - ➢ Study the required number of treatment systems taking into account the maintenance, normal inspection, failure, etc. of confinement device and building equipment.
- Expected outcome
  - ➢ Establishment of a device to transport fuel debris in unit cans is expected.



Concept of a transportation device



Treatment building to store fuel debris (Schematic image)

d. Transfer method for unit cans from R/B

■ Study flow

Problems and issues in existing design, aiming at improvements

- Work procedure in existing study
- Study of building layout
- Solutions to issues
- Ideas for fuel debris transportation

⇩

Conceptual study of the design to be improved

- Conceptual study of facilities combined with fuel debris retrieval method and layout
- Combination of transportation device and building boundary at each step
- Basic functional requirements
- Safety functions required for the transportation of unit cans storing fuel debris
- Basic design conditions based on safety requirements
- Basic design conditions based on handling requirements
- Defining design specifications and issues

⇩

Response to technical issues

- Confinement mechanism for the door part
- Prevention of hydrogen explosion
- Evaluation of handling work steps, facility layout, and work schedule

⇩

Summary (Outcomes of FY2019 / Plan for FY2020)

7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]
d. Transfer method for unit cans from R/B

Development schedule

Study items	FY 2019												FY 2020											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Major milestones							Interim report ▼					Interim report ▼								Interim report ▼				Final report ▼
1. Formulation of requirement specifications, conceptual design																								
2. Element test plan Element evaluation device specifications																								
4. Preparation for element tests																								
5. Element tests																								
6. Summary																								
Remarks																								

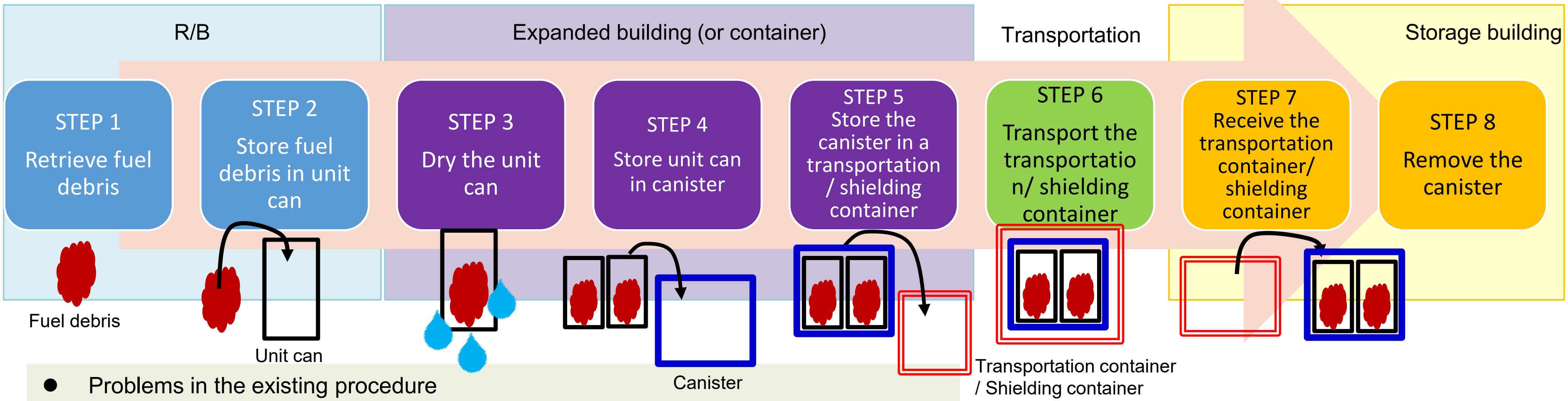
7. Implementation items of this project

[1] ② Development of various technologies other than the interference removal technology]

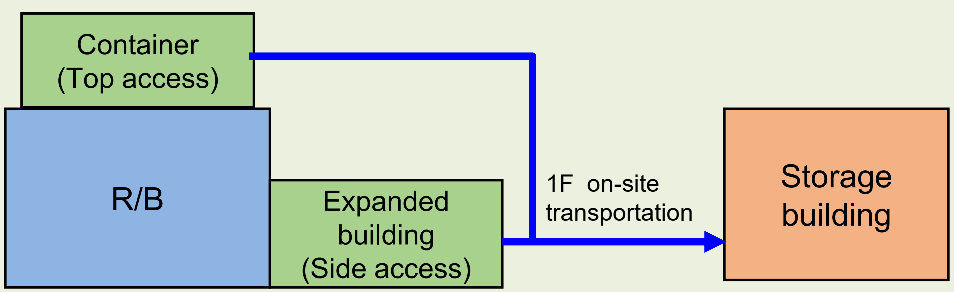
d. Transfer method for unit cans from R/B

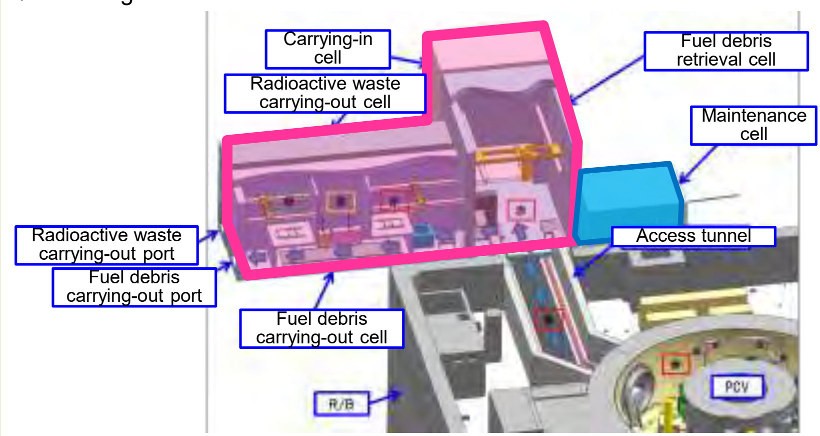
■ Problems and issues in existing design, aim of improvements (Work procedure in existing study)

- Dry the unit can, then store it in a canister, and store the canister in the storage building
- When transporting from the R/B, store in an airtight/ transportation/ shielding container
- Carry out the work before transportation in the expanded building to be constructed adjacent to the R/B or in a container in R/B



- Problems in the existing procedure
  - The expanded building is large in size and affects the site layout
  - Top access container also requires a 3000 to 5000 ton shield
  - Expanded building (container) is required for each top/ side access in each Unit



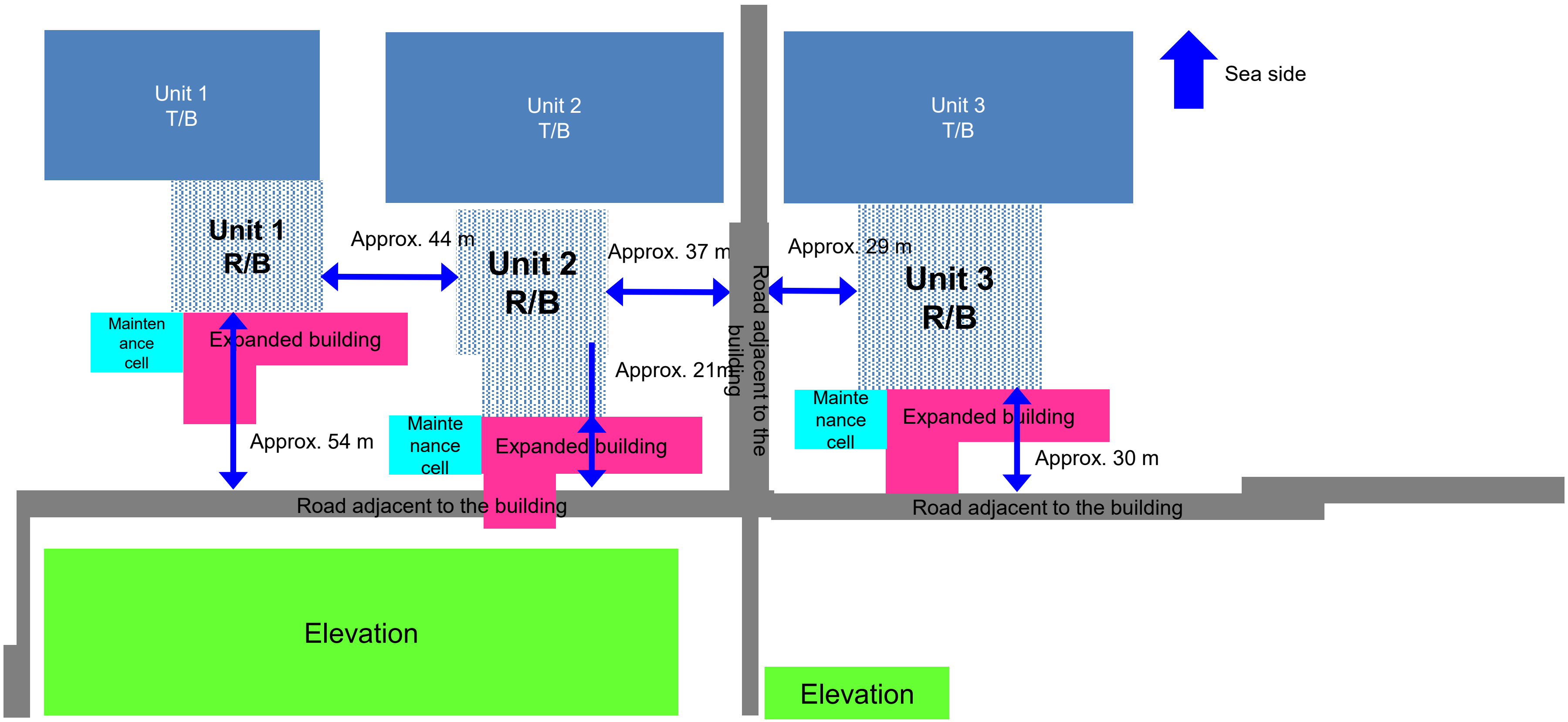


Example of expanded building

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
d. Transfer method for unit cans from R/B

■ Problems and issues in existing design, aim of improvements (Study of building layout)

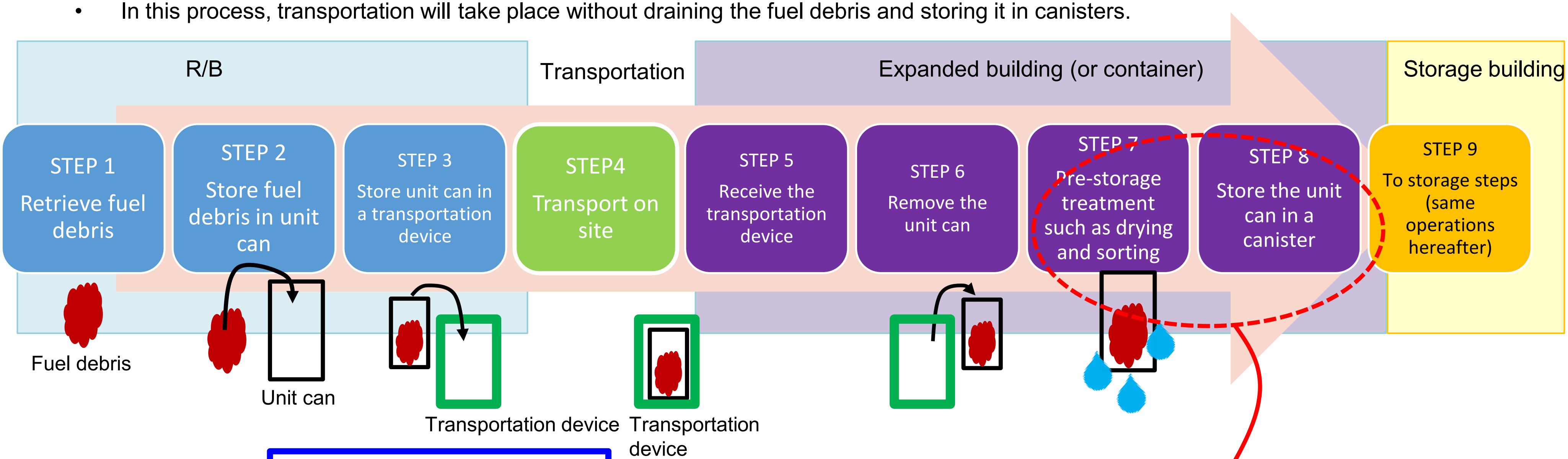
- The effect of the establishment of an expanded building in 1F-1 to 3 was studied.
- If an expanded building is placed in the mountain side area of each Unit, a large area will be occupied by the expanded building, and problems such as inability to carry out other work (for example, installation of a crane for carrying-in/out large objects) are assumed.

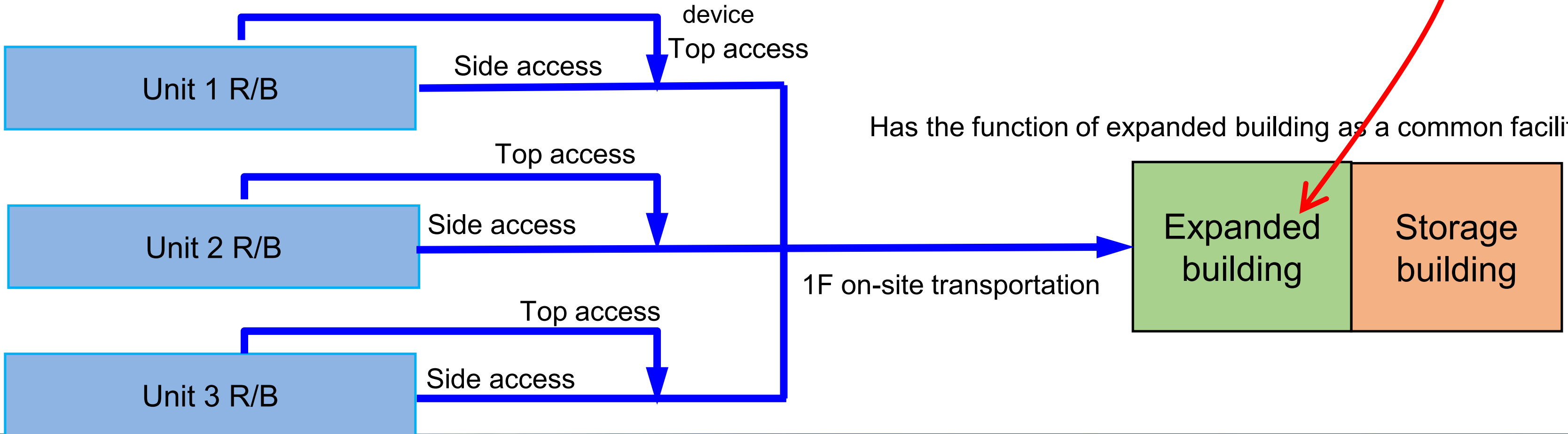


7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]
d. Transfer method for unit cans from R/B

■ Problems and issues in existing design, aim of improvements (Solutions to issues)

- Establish the expanded building away from the R/B and transport on-site.
- The established expanded building shall be a common facility for Units, top/ side access.
- In this process, transportation will take place without draining the fuel debris and storing it in canisters.





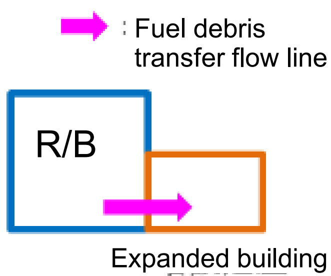
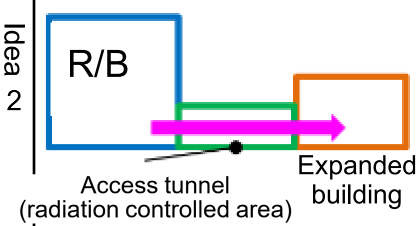
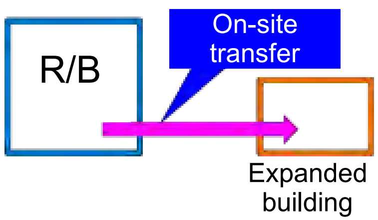
7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Problems and issues in existing design, aim of improvements (Ideas for fuel debris transportation)

・For transportation to the remotely established expanded building, Idea 2 which links the site with a controlled area (trench, etc.), and Idea 3 which transports the cans on site shall be considered.

・ Idea 3 has great merits, but it involves development elements, so a conceptual study will be conducted in this project.

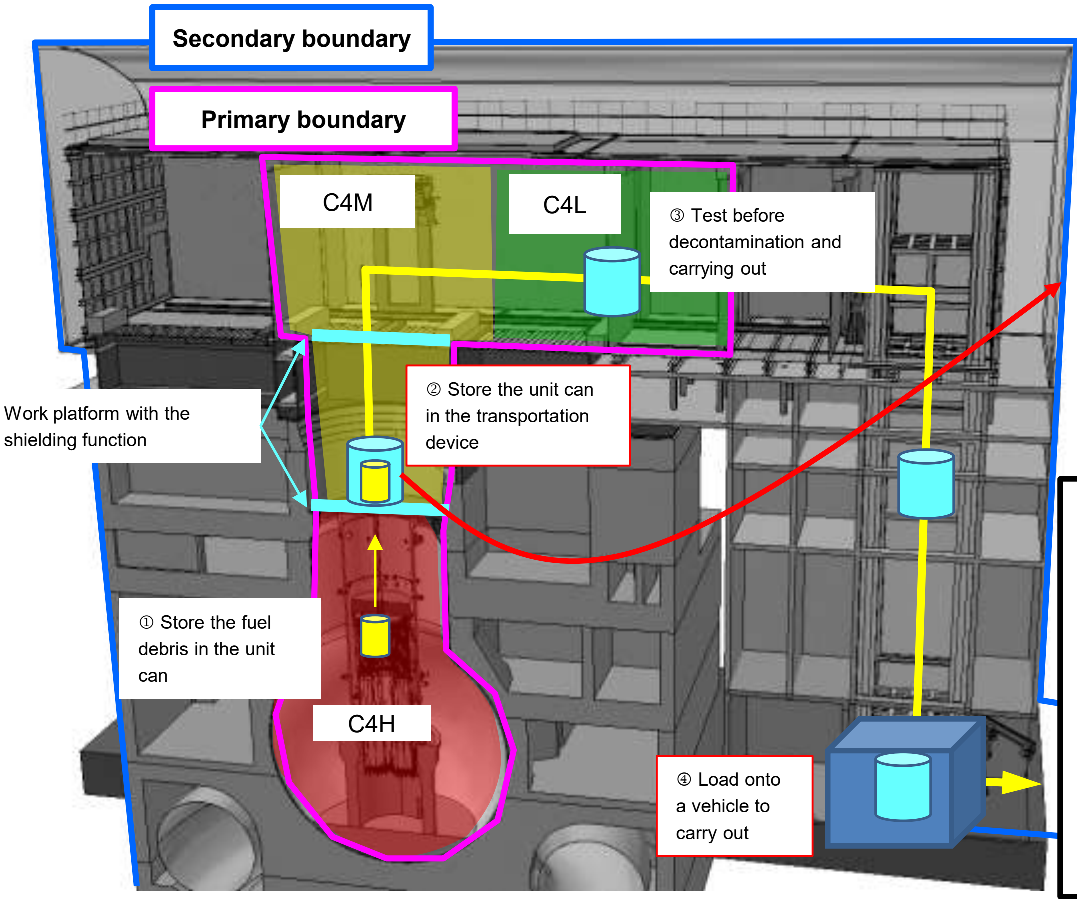
	Schematic image	Overview	Merit/ Demerit	Development elements
Idea 1		[Existing study idea] Dry the fuel debris and perform various container storage operations in the expanded building adjacent to the R/B.	[Merits] The drained fuel debris can be dried without being transported on site. [Demerits] Since an expanded building will be provided for each Unit, there are major restrictions on the site layout and containers.	There are no development elements in transportation because the controlled areas are connected.
Idea 2		[Idea of a tunnel] Provide a controlled area (tunnel) between the R/B and the expanded building to transport the unit can as is without drying.	[Merits] Fuel debris can be transported without providing an expanded building around the R/B. [Demerits] A study on the possibility of installing a transportation tunnel (radiation controlled area) for each unit must be conducted.	There are no development elements in transportation because the controlled areas are connected.
Idea 3		[Idea of on-site transportation] ★ Fuel debris transportation system Transport the unit cans on site from the R/B before the drying process.	[Merits] Minimizes the amount of facilities added to the R/B. Great freedom for selecting the installation location of the expanded building.	Development of a device for on-site transportation of unit cans that have not been dried. Conduct a study on a transportation device that can transport unit cans on the 1F site and a transportation system to operate the same.

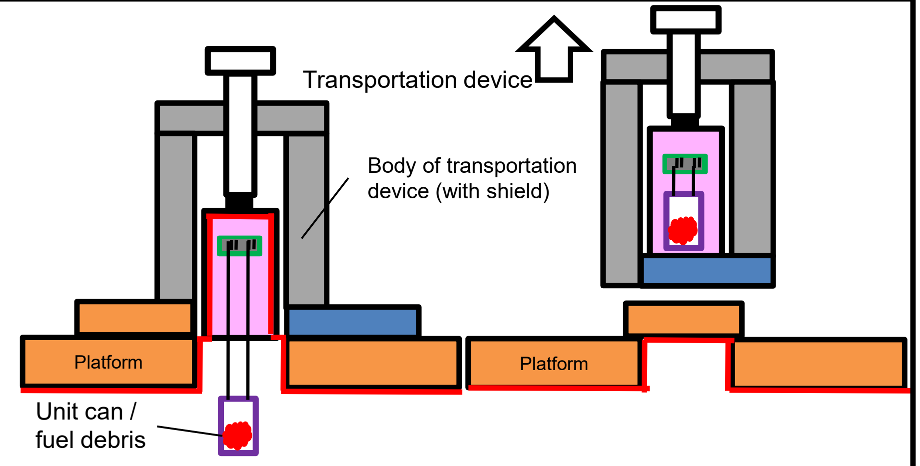
7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Organization of preconditions for the design to be improved (Conceptual study of facilities combined with fuel debris retrieval method and layout)

- To ease the load conditions on the building and container, minimize the shielding on the refueling floor installation cell
- Carry out the unit cans outside the building without using canisters and transport them on site



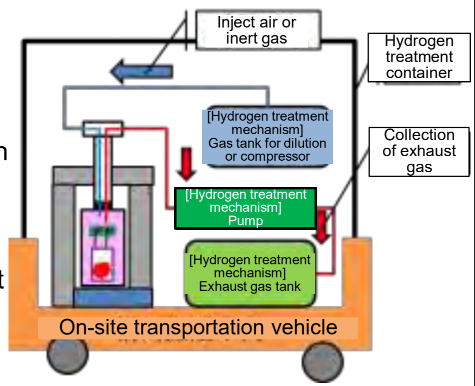


Storing unit cans on a transportation device

- Install a work platform with shield at the top of the PCV
- Connect the transportation device to the platform and insert the unit can

On-site transportation

- Double the confinement by storing the transportation device in a container
- Monitor the hydrogen concentration inside the transportation device
- If it exceeds the standard value, inject air or nitrogen to dilute it
- Diluted gas is stored in the exhaust gas tank

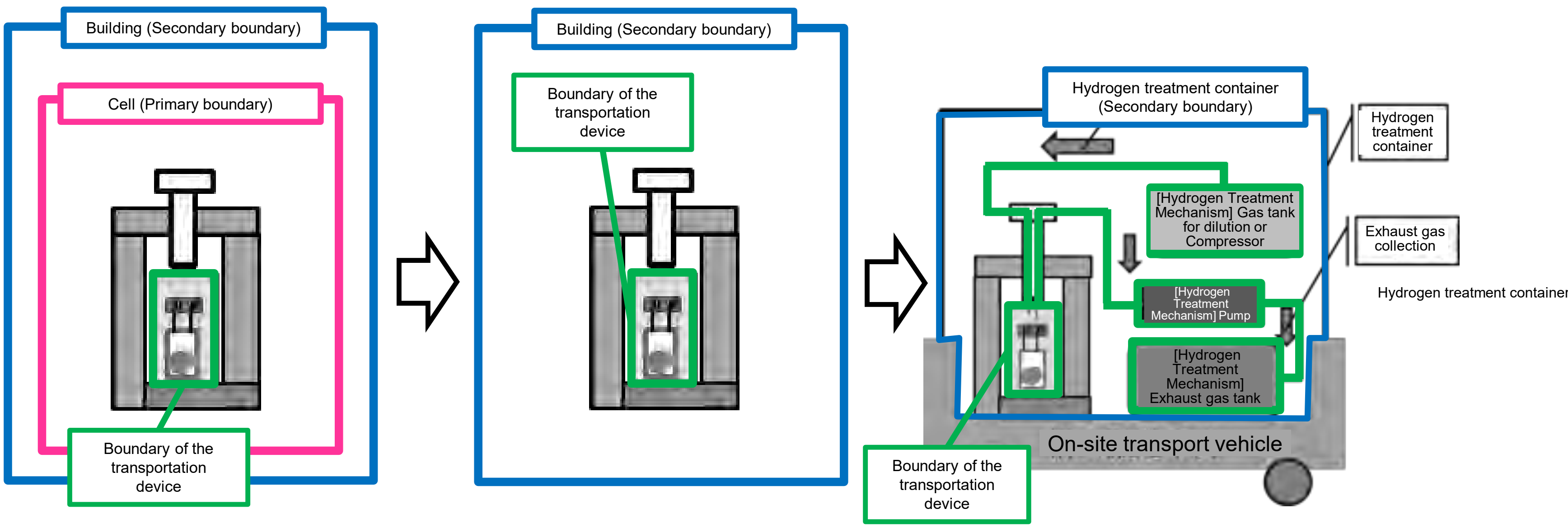


7. Implementation items of this project

[1) ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Organization of preconditions for the design to be improved (Alignment of the transportation device and the building boundaries during each step)



[At the time of transportation within the building cell (Primary boundary)]

Confinement to be executed as follows:
- Main body of the transportation device
- Cell (Primary boundary of the building)
- Building (Secondary boundary)

[Outside the building cell (Secondary boundary)]

Confinement to be executed as follows:
- Main body of the transportation device
- Building (Secondary boundary)

[At the time of transportation within the site]

Confinement to be executed as follows:
- Main body of the transportation device
- Container for transportation

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Organization of preconditions for the design to be improved (Basic functional requirements)

- Work requirements
  - Unit cans containing fuel debris will be loaded and then transported on-site from the R/B to the distantly located expanded building where the unit cans will be lifted out.
- Transportation targets
  - Capacity (Number of unit cans stored): 1 can
  - Unit can: Type 1 mentioned on the right is the basic type.
  (The feasibility of Type 2 will also be studied from the view point of enhancement.)
- Environmental conditions (Set values)
  - Temperature: 0 to 40℃
  - Humidity: 100% or less (with condensation)
  - Environmental dose: 3000 Gy/h or less (Same as the environment inside the reactor))
- Unit can storage function
  - It should be possible to internally store a unit can by lifting it from the reactor (reactor bottom).
  - Lifting height: About 14m (The lifting is assumed to be from the height of the core support plate up to the PCV flange.)
- Transport specifications
  - Number of cans transported in a day: 10 cans (24 hour work)
  - Scope of handling: Buildings
    Limited to inside the R/B and the Expanded building and within the site of the power station.
    (Does not include any handling outside the site.)
  - Access to workers (Presence during work)
    Workers will be present during the inspection prior to carrying out the cans from the primary boundary in C4L.
    The design should be such that the handling work, verification of lid closure, and decontamination work in C4M can be carried out with remote operated devices.

Table. Specifications of the unit can to be transported (Set based on information from the canister project)

	Type 1	Type 2
External dimensions	Φ206×h403 mm	Φ386×h403 mm
UO2 weight (Maximum), #1	41.5 kg	150 kg
Moisture content %	30%	30%
Amount of hydrogen generation, #1	0.5 L/hr	1.7 L/hr
Amount of oxygen generation	0.25 L/hr	0.85 L/hr
Size of fuel debris	Particle diameter of 0.1 mm or more	

#1: In this project, the specifications have been provided for 1 unit can although in the canister project, the specifications have been formulated for collectively transporting 2 unit cans

d. Transfer method for unit cans from R/B

■ Conceptual study of the design to be improved (Safety functions required for the transportation of unit cans storing fuel debris)

Safety functions	Contents
Leakage prevention	Prevention of exposure of workers or public to radioactive materials due to leakage from the transportation device
Shielding	Prevention of exposure of workers or public to radiation
Subcriticality maintenance	Maintenance of subcriticalities
Cooling or heat removal	Prevention of safety inhibitors due to a rise in the temperature of the fuel debris
Functions necessary to maintain the safety functions	Appropriate structural strength so as to maintain the necessary safety functions such as leakage prevention and subcriticality maintenance, etc. considering the handling of the transportation device
	Prevention of explosion of the generated hydrogen
	Maintenance of confinement function etc. to deal with aging degradation such as corrosion or degradation of material during the period of usage
	Fire prevention with powder metal such as zircaloy, etc.
Basic requirements for functional maintenance (General common matters)	Maintaining functions under usage environment conditions
	Essential reliability and multiplexing and diversification as and when necessary
	Equipment with which necessary inspections and maintenance can be executed
	Equipment for the necessary monitoring functions
	Equipment with which the necessary operations, especially, the necessary site operations can be executed
	Equipment with which appropriate counteraction is possible against any hazard (internal or external)

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Conceptual study of the design to be improved (Basic design conditions based on the safety requirements)

Safety principles		Functional requirements	Design policies
Prevention of excessive release of radioactive materials	Confinement of radioactive materials	Prevention of leakage of contaminants during storage and handling of the unit cans containing the fuel debris	・In addition to the confinement area (primary boundary) in the form of the main body of the transportation device (including the hydrogen treatment mechanism), the main body of the transportation device and the hydrogen treatment mechanism will be stored in a container (secondary boundary), and the container will be handled at the time of carrying out of the controlled area. ・The exhaust gas stored in the tank of the hydrogen treatment mechanism will not be released in the air outside the controlled area, but will be passed through the vapor treatment system of the R/B or the Expanded building.
			・There is a possibility that a positive pressure is formed in the transportation device main body during abnormal circumstances following hydrogen generation, hence by managing negative pressure in the container, the release of contaminants outside the container will be prevented even if the contaminants are released from the transportation device main body. ・By installing ventilating and air conditioning equipment inside the container, the gas inside the container will be purified even if there is any release of contaminants from the transportation device main body. Moreover, the designing will be such that it will be possible to carry out decontamination inside the transportation device main body and the container by remote devices.
			There will be two doors at the opening of the container and even if one door is open, the other should be closed. Thus, there will always be a double partition together with the confinement of the main body of the transportation device.
			Enable the replacement of the seal parts to ensure their integrity considering the aging degradation such as corrosion or degradation of material during the period of usage.
			Appropriate seismic class settings or fall prevention measures will be carried out for the handling equipment so that the transportation device does not suffer an impact due to falling or tumbling etc. during handling. Acceleration etc. will be studied in future.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Conceptual study of the design to be improved (Basic design conditions based on the safety requirements)

Safety principles		Functional requirements	Design policies
Prevention of excessive release of radioactive materials	Prevention of abnormal additional generation of radioactive materials	Prevention of additional nuclear fission reaction	The sub-criticalities of the fuel debris are maintained due to the geometrical shape of the main body of the transportation device. Appropriate seismic class settings or fall prevention measures will be carried out for the handling equipment so that the transportation device does not suffer an impact due to falling or tumbling etc. during handling so as to not cause serious damage during handling by which the criticality prevention function might be lost.
		Prevention of abnormal heat dissipation	The structure should be such that the integrity can be maintained (the permissible temperature range of the seal is maintained) by heat dissipation of the main body of the transportation device.
		Prevention of abnormal diffusion of radioactive materials by cutting (Not applicable)	
Prevention of excessive exposure due to radiation		Implementation of radiation shielding in such a way that the workers can directly access the external part of the transportation device main body.	Install a shield structure so that the radiation dose will be 2 mSv/h or less on the outer surface of the transportation device main body.
			Confine the contamination such that work outside the main body of the transportation device becomes possible.
Prevention of excessive exposure or internal exposure of workers		Design for reduction of exposure of workers	Specify appropriate settings for shielding, contamination, and dose classification, carry out remote maintenance to reduce exposure, and use on-site fuel debris transportation flow lines.
		Operation management for reduction in exposure of workers	Use operation methods, maintenance plans, and work management in order to reduce exposure.
Prevention of a fire or explosion due to retained hydrogen		Management of hydrogen density or oxygen density to maintain the lower limit of hydrogen explosion	The structure should not retain hydrogen. Use the hydrogen treatment mechanism to dilute the hydrogen such that its density can be maintained at less than the design value. The exhaust gas due to dilution will be released in the tank connected to the main body of the transportation device, which will be its primary storage during transportation.

d. Transfer method for unit cans from R/B

■ Conceptual study of the design to be improved (Basic design conditions based on the handling requirements)

Safety principles	Functional requirements	Design policies
Remote operability	It should be possible to set up the main body of the transportation device on the work platform by remote operation	Positioning, installation and fixation of the transportation device on the platform should be possible by remote operation.
		The opening lid of the platform and the transportation device can be opened and closed by remote operation.
		The transportation device can be decontaminated by remote operation.
Confinement of radioactive materials	In case of an emergency, the worker should be able to access the platform (outside the main body of the transportation device)	Prevent leakage of radioactive materials from the interface between the platform and the main body of the transportation device. Moreover, set up a seismic class to enable prevention of leakage of radioactive materials even during an earthquake.
	In order to be able to carry out the main body of the transportation device, it should be possible to decontaminate the outer surface	In order to carry out the main body of the transportation device from the primary boundary, the structure should be such that the outer surface of the main device body can be decontaminated.
Maintenance	Remote maintenance	Remote maintenance and replacement of consumables should be possible for the devices on the PCV platform part.
		Equipment that is always accessible to workers should be able to be manually maintained and the consumables replaced.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Conceptual study of the design to be improved (Defining design specifications and issues)

Identification of design specifications and issues based on design policies and regulation compliance policies

As regards the detailing and refinement of design specifications, the plans will be formulated after reflecting on the details of actions to deal with future technological issues.

	Design specifications for transportation device	Issues that need to be verified by studies and tests in particular	Studies under this PJ
Confinement	• The leakage from the transportation device, and the leakage from the part connecting the platform and the transportation device is below the limit value. • The confinement is maintained without damaging the transportation device in view of the assumed events during handling.	・It is necessary to study a structure wherein transportation within the site is possible while both "Confinement" and "Prevention of contamination" is carried out for the door part which will open and close during the storage or lifting out of the unit cans. ・A structure in which operations including the opening and closing of the door can be done by remote operations, is necessary.	• Planning and risk evaluation of work flow. As regards the events which carry a risk, verify the presence of structural strength required to maintain confinement by means of simulation or testing, etc. • Feasibility study by means of formulating a device concept and conducting seal testing, etc.
	• Outer surface of container: 0.4 Bq/cm^2 or less #1	• Nothing specific (the structure should be such that the decontamination of the locations assumed to be contaminated at the design stage, is easily possible)	• The structure should allow easy decontamination.
Criticality prevention	• The shape of the unit can should be maintainable without damaging the transportation device in view of the assumed events during handling.	• Nothing specific (Note that it is necessary to study the interface conditions after the basic design of the unit can is completed)	• Planning and risk evaluation of work flow. As regards the events that carry a risk, ensure the structural strength to maintain the shape by means of simulation or testing, etc.
Heat removal	• The material of the transportation device should maintain the temperature such that no function is lost.	• Confirm the feasibility of the structural design	• Confirm by means of simulation, etc.
Shielding	• Surface of the transportation device: 2 mSv/h • Distance of 1 m from the surface: 0.1 mSv/h	• Confirm the feasibility of the structural design	• Confirm by means of simulation, etc.
Hydrogen explosion-prevention	• A state where the levels are kept sufficiently below the lower hydrogen explosive limit (4vol%) should be maintained. In order to maintain this, high-pressure gas should not be used while transporting within the 1F site premises.	• Measures to prevent rise in pressure inside the main body of the transportation device following hydrogen generation → If high pressure-resistant specifications are used, the transportation device becomes larger in size (+ weight increases). Study systems which can reduce the density of hydrogen while avoiding rise in pressure. • It is necessary to have a structure wherein the density of hydrogen inside the transportation device can be monitored remotely and hydrogen treatment is possible through remote operations during routine work.	• Verify the feasibility of the hydrogen treatment system through desk studies or testing, etc. by injecting air or inert gases such as nitrogen.

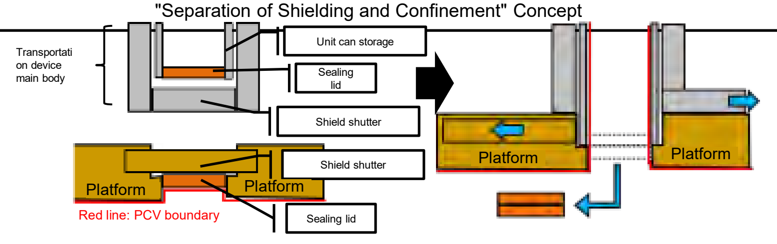
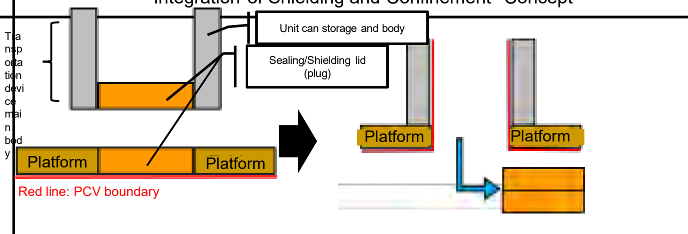
#1：Cited from the Atomic Energy Society of Japan (AESJ) " Safety Design and Inspection Criteria for Transfer Container for Spent Fuels, New Mixed Oxide Fuels, and High Level Radioactive Wastes: 2013"

7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Response to technical issues (Confinement mechanism for the door)

- Separation or integration of shielding and confinement functions for the structure of the door. Moreover, three kinds of door structures are planned as per the door opening operation mechanism.
- All have their own merits and demerits, and evaluation will be carried out by continuing the studies, such as assigning priority levels to the evaluation items or testing the seals, etc.

Evaluation items [Legend] ◎: Especially excellent as compared with other concepts ○: Superior than △, but inferior to ◎ △: Too many issues compared to other concepts		"Separation of Shielding and Confinement" Concept		"Integration of Shielding and Confinement" Concept
				
		[Linear method] The sealing lid is attached and detached by the direct movement of the rail.	[Swing method] The sealing lid is attached and detached by the arc-like movement caused by the arm installed inside the PCV.	[Plug method] The sealing lid (plug), which has the thickness of the shield, is attached and detached by the arm installed inside the PCV.
Ability to handle	Occupied area on platform (footprint)	○	○	◎ It can be expected to become compact as compared to the other concepts since the plug will include both the shielding and the confinement functions.
	Weight of the door	○ Since the clamping mechanism of the sealing lid is needed, the weight increases as compared to the swing method.	◎	△ It becomes heavier due to the thickness of the shield provided to the sealing lid.
	Weight of the entire equipment installed on the platform	△	△	○ As compared to other concepts, comparatively lightweight with few equipment components
	Speed of the door opening/closing operation	Evaluation scheduled	Evaluation scheduled	Evaluation scheduled
Nuclear safety	Shielding function	○	△ The interface of the platform with the shield must be estimated.	△ As the arm rises gradually over the PCV, it becomes a source of radiation and hence it is necessary to add dose reduction measures.
	Confinement function	Evaluation scheduled	Evaluation scheduled	Evaluation scheduled
	Risk of door falling	○	○	△ It is necessary to study the fixing mechanism to be used when the arm is handling the plug and study the fall risk reduction measures.

7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

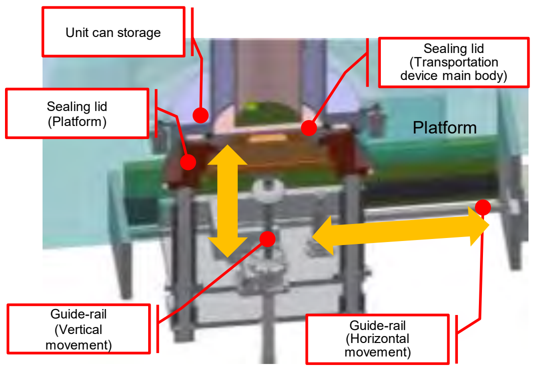
■ Response to technical issues (Confinement mechanism for the door)

- A structural image for each method is shown below.

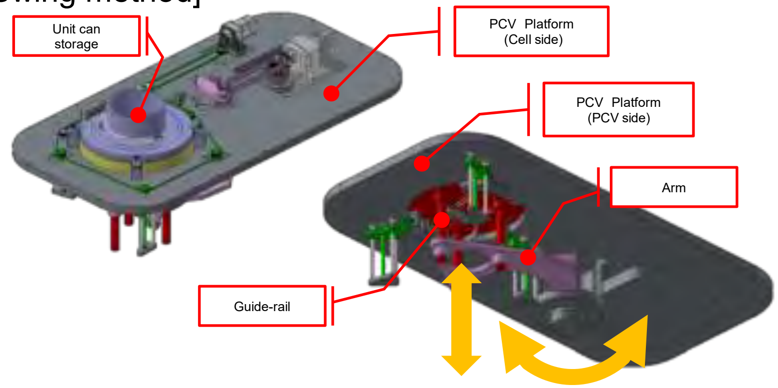
Each structure is likely to change in future with the progress in design

"Separation of Shielding and Confinement" Concept

[Linear method]

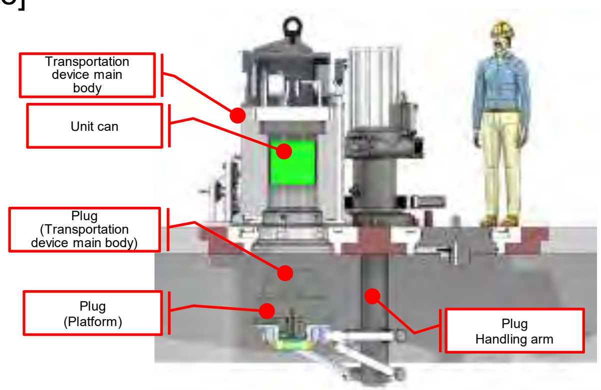


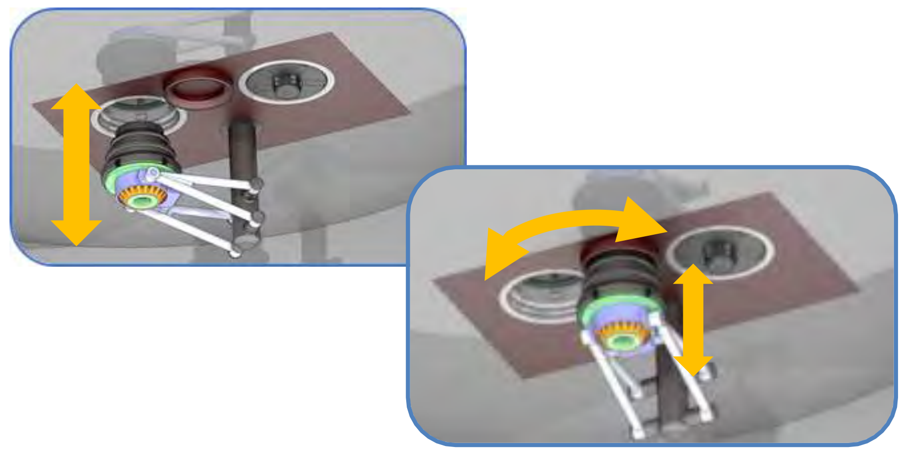
[Swing method]



"Integration of Shielding and Confinement" Concept

[Plug Type]





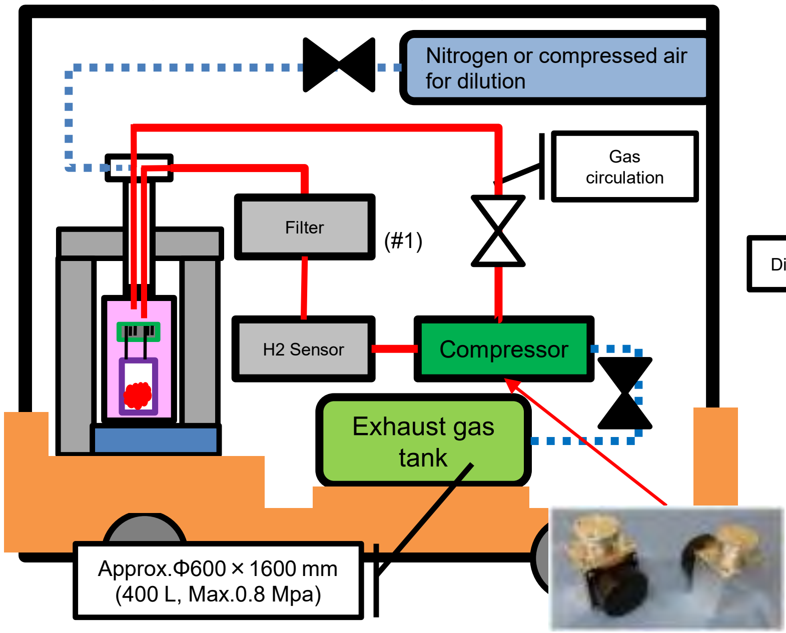
7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Response to technical issues (Prevention of hydrogen explosion)

- Maintain the hydrogen density below the explosion lower limit (4Vol%) and manage it below the set value (2.5Vol%)
- Always monitor the density of hydrogen in the main body of the transportation device. If a standard value is exceeded, gas will be injected for dilution. After purification, the exhaust gas will be stored temporarily in the waste gas tank by the compressor. It is assumed that the exhaust gas tank can store at the most for seven consecutive days. Also conduct a study on reducing the size of the tank (add as needed when diluting).
- Exhaust gas which is thus stored will be passed through the heating, ventilating and air-conditioning system of the transportation destination or R/B.

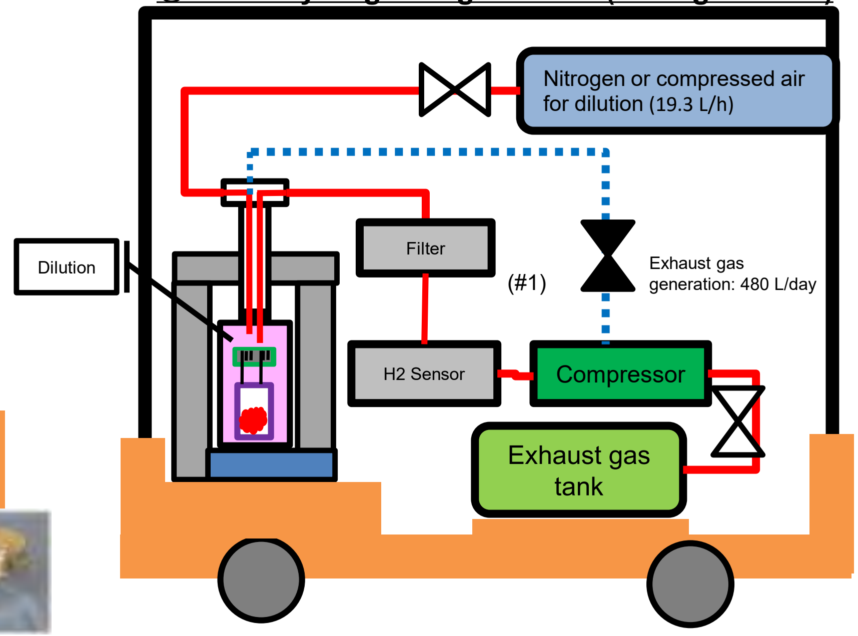
① During routine monitoring



#1: Also conduct a study on installing a filter inside the main body of the transportation device considering a rise in the radiation

Piston-type vacuum / pressurized airtight compressor

② When hydrogen is generated (During dilution)

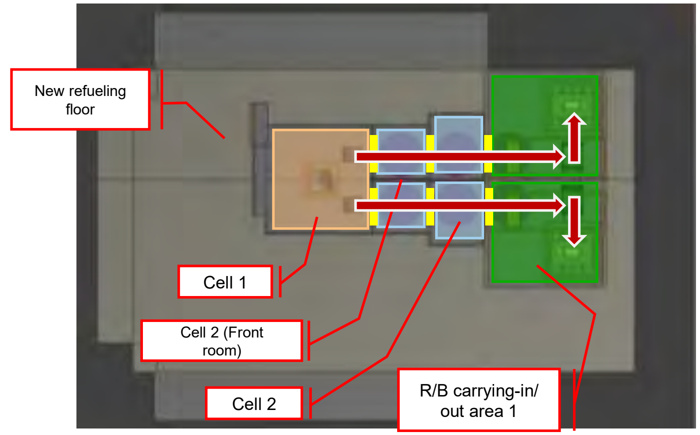


7. Implementation items of this project
[1] ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Response to technical issues (Evaluation of work steps, equipment layout ,and work schedule during handling)

- Goal: To transport 10 unit cans per day
- Select a series of handling work sequences such as transportation between cells using cranes and vehicles, opening/ closing operations between the cell partitions, inspection prior to carrying out, etc.
  Evaluate the overall handling time by allotting working hours for each task.
- Plan the overall handling plan for a day taking into account the prohibition of opening of the partition doors simultaneously or the settings for the waiting time when multiple transportation equipment are in use.
- The cans can be carried out in about 2.5 hour intervals. Assuming 10 vehicles a day with a target time of 2.4 hours or less, two carrying out routes will be established. Note that if the movement of one vehicle is focused on, the handling work inside the R/B will require 11.5 hours, so altogether ten transportation devices will be needed.



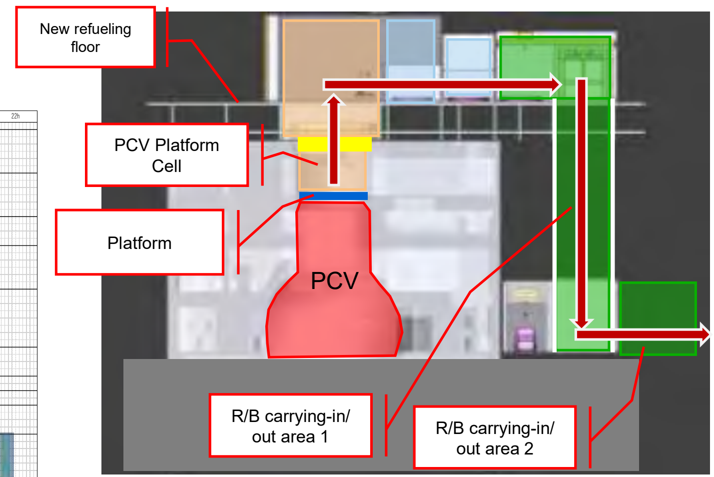
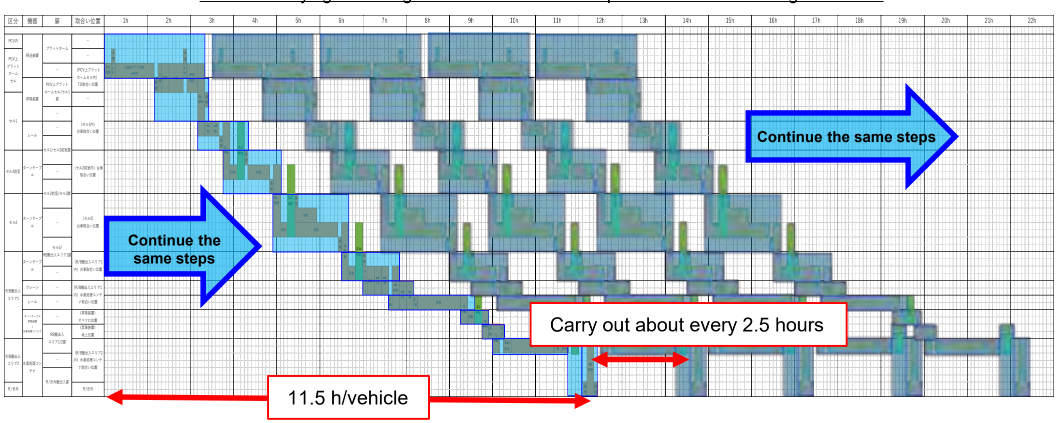


Table 1. Carrying out timing chart for fuel debris transportation device focusing on the line



7. Implementation items of this project
[1) ② Development of various technologies other than the interference removal technology]

d. Transfer method for unit cans from R/B

■ Summary

- Results in FY2019
    - The building cell layout was determined based on the plan for fuel debris on-site transportation by transportation devices.
    - The basic functional requirements for transportation were determined based on the assumed parameters of the unit cans/ fuel debris.
    - The basic functional requirements for safety were determined based on the nuclear safety and related regulations.
    - The design policies were formulated and the technical issues were identified based on the above-mentioned basic functional requirements for transportation and safety.
    - The conceptual design for the important technical issues of doors (double doors) and hydrogen treatment mechanism was prepared.
    - The evaluation and feasibility of fuel debris transportation throughput using the transportation devices was confirmed.

- Details of the implementation schedule for FY2020
    - Narrowing down of the concept of door (double doors) and its feasibility evaluation by means of analysis and seal unit testing, etc.
    - Feasibility evaluation of the concept of hydrogen treatment mechanism by means of element testing, etc. (prototyping of element composition)
    - Preliminary analysis of the strength reinforcement of the transportation device main body in anticipation of safety analysis.
    - Analysis and testing to evaluate the structural feasibility of the winch used for unit can collection.
    - Structural designing and feasibility evaluation of the unit can grasping mechanism, study of the procedure for the handling operations, and formulation of a plan for issues and countermeasures. Study of problem events in particular.
    - Study of facility layout inside the R/B with a view to further improving the fuel debris transportation throughput.

7. Implementation items of this project

2) Development of technology for handling of fuel debris

(i) Technological development for fuel debris collection and storage systems

In addition to the molten-damaged fuel from the RPV, there is a pile up of various states of fuel debris (loose fuel debris, sludge, particulate (powdered) fuel debris, fuel debris due to processing such as crushing/cutting etc.) at various places on the structures such as the pedestal bottom etc. inside the PCV. For efficient fuel debris retrieval, a collection method and a method and system for storage in containers will be developed according to the state of the fuel debris, and as and when necessary, the feasibility will be verified by means of element tests.
During the element tests, data to evaluate the collection efficiency will be acquired and this data will be used for evaluating the fuel debris retrieval efficiency considering the location and state of the fuel debris. Moreover, a conceptual study will be undertaken considering assurance of safety and on-site applicability for the storage methods and systems, which can improve the retrieval efficiency.

The following are the main development study items, and issues will be identified and consolidated by carrying out element tests as and when necessary:

a. <u>Development of particulate fuel debris suction and collecting system</u>

- The optimal shape of the pump strainer is being studied.
- A method of detecting the fullness of the separator without using a pressure gauge/ flowmeter is being studied.

b. <u>Development of technology for transferring fuel debris and wastes</u>

- The retrieval method is being planned by presuming the state and properties of the fuel debris.

7. Implementation items of this project

[2) (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

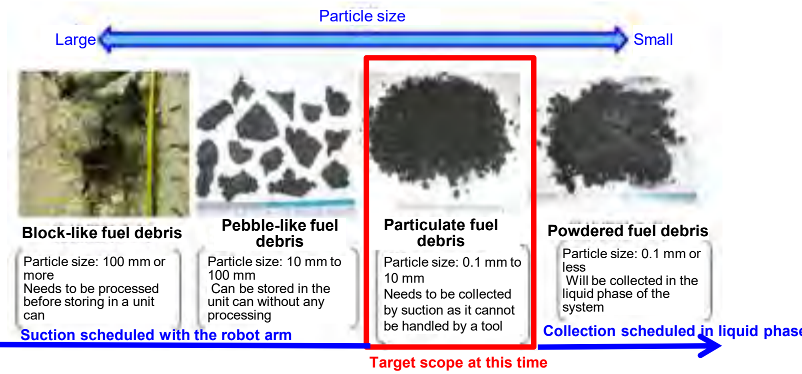
- Purpose of developing a suction and collecting system for particulate fuel debris
    - ➢ The suction and collecting system for particulate fuel debris is being developed with an aim to collect the particulate fuel debris that is difficult to catch with the robot arm or in liquid phase so as to prevent missing out on any fuel debris.

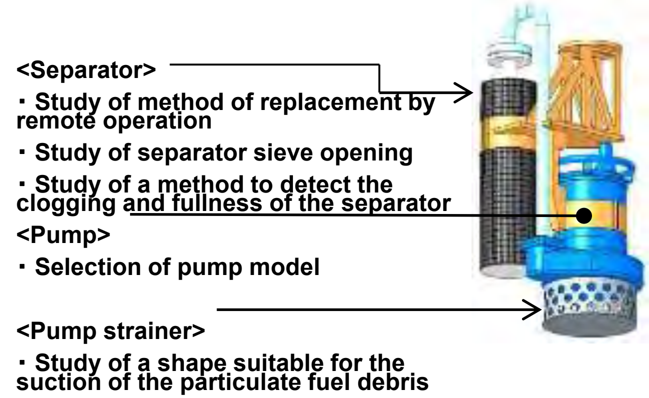
- Issues to be solved
    - ➢ Determining the details of the specifications, equipment, maintenance and operability etc. considering the 1F environment.

- Approaches to development (from the main issues identified during the previous term of the subsidy project)
    - a) Study of a pump strainer shape suitable for this system
    - b) Study of a method to detect the fullness of the unit can (separator)
    - c) Study of a method for replacing the unit can (separator)
    - d) Study of a suitable pump model for suction from the air
      (A pump model for suction under water has been studied.)

  Based on the above results, feasibility of the system will be studied by performing element tests.

- Expected outcome
    - ➢ Specifications with details determined for the suction and collecting system for particulate fuel debris suitable for the 1F environment.





Suction and collecting system for particulate fuel debris　Study issues

7. Implementation items of this project
[2) (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

- **Study flow**

Results and issues in the subsidy project in the previous term

The following issues have been selected presuming suction and collection from water:
・Since the strainer (suction port) of the submersible pump has been designed empirically as per the manufacturer's know-how, it is difficult to say whether it is a suitable shape for the suction and collection of the particulate fuel debris.
・ The method of detecting the fullness of the particulate fuel debris unit can (separator) is undecided.
・ The method of replacing a filled unit can (separator) is undecided.

Approach towards the issues to be handled during the subsidy project of the current term

・Solutions for the issues identified during the subsidy project of the previous term will be studied.
・A suction and collecting system for particulate fuel debris, applicable even in an environment (in air) where some of the fuel debris has been exposed to air, will be studied.

(Suction from water)
Study of the shape of the strainer

(Suction from air)
Study of the suction device

(Common equipment to be used under water/ in air)
Study of methods to detect the fullness of the separator

Study of methods to replace the separator

Results of this fiscal year

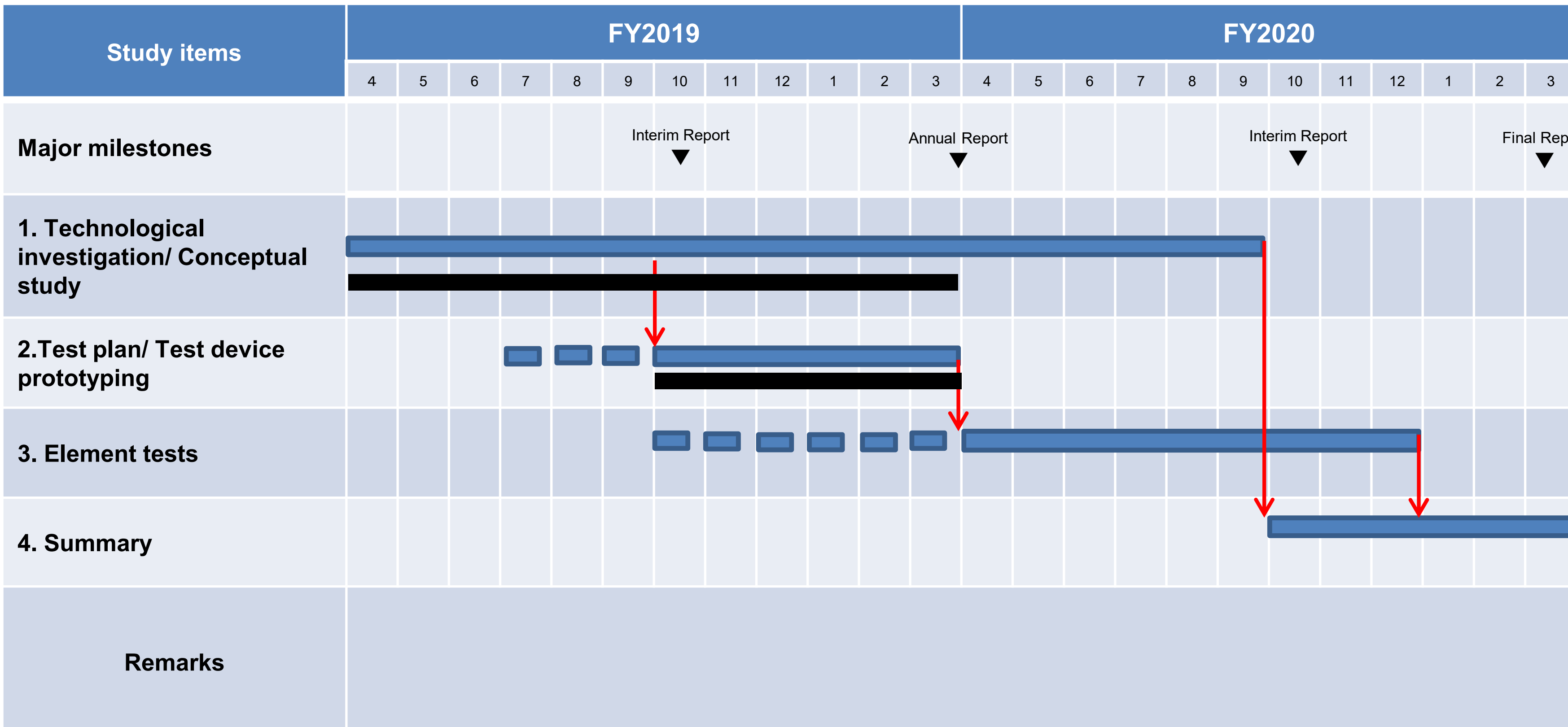
Verification of the feasibility of the study results by means of element tests

Identification of future issues and response policies

7. Implementation items of this project
[2] (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

■ Development Schedule

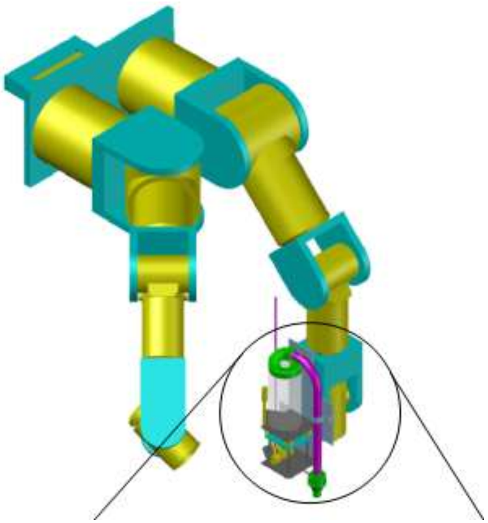


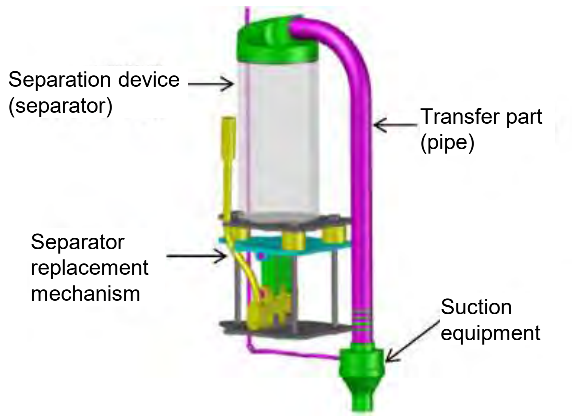
7. Implementation items of this project
[2] (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

- **Preconditions for study**
  - The robot arm should be able to access the particulate fuel debris.
  - At the time of suction from water, the water level necessary (roughly about 20 cm) for operating the submersible pump should be available.
  - The collection equipment (separator) that is filled with the particulate fuel debris will be removed by the manipulator inside the cell after the robot arm is stored in the cell.
  - The maintenance of the particulate fuel debris suction and collecting system will be also carried out by the manipulator inside the cell.

- **Development objectives**
  - Development of a suction and collecting system which will efficiently collect the particulate fuel debris (0.1 mm to 10 mm) believed to exist at the bottom of the reactor.





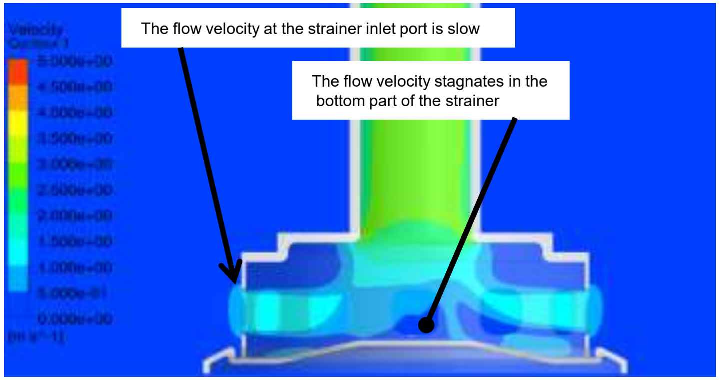
7. Implementation items of this project
[2] (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

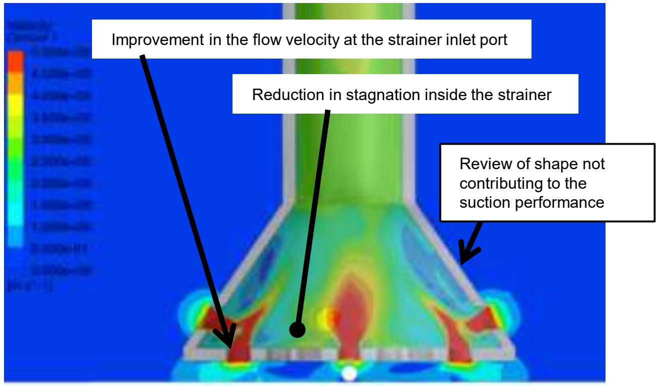
a) Study of the shape of the pump strainer suitable for the suction and collecting system for particulate fuel debris

- In order to perform suction and collection of the particulate fuel debris in a stable manner, the strainer shape satisfying the following was studied:
  - In order to prevent clogging of the pump, solid objects that are larger than the predetermined size should not be sucked.
  - Suction occurs at a flow velocity of 2.7 m/s or more, which is terminal settling velocity x 1.5 times
  - The sucked particles do not remain in the strainer.
- As a result of the study, it was possible to develop a strainer shape that satisfies the above-mentioned conditions (Refer to the lower right side figure).
- For information, the results of the flow analysis done on the manufacturer standardized strainer are given in the lower left side figure.

Image of the submersible pump strainer



Flow analysis results of the manufacturer standardized strainer (suction port)



Flow analysis results of the modified strainer (suction port)

7. Implementation items of this project

[2) (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

b) Study of the method to detect the fullness of the unit can (separator)

- The method that measures the changes in the discharge pressure or the flow rate of the pump to detect the fullness is a method that detects fullness indirectly and not directly, hence, the issues of erroneous detection or accuracy remain.
- Here, a method that directly detects the fullness of the separator using a robot-arm mounted camera for monitoring, was studied.
- The method studied involved making holes on the top part of the separator and when the separator was filled with fuel debris, the fuel debris seemed to spout out from the holes at the top of the separator and this would be monitored by the camera (lower left side figure).

c) Study of the method to replace the unit can (separator)

- One-touch installation/ removal mechanism with toggle mechanism + spring was examined as the structure which can enable easy replacement by remote operations. (Lower right side figure)

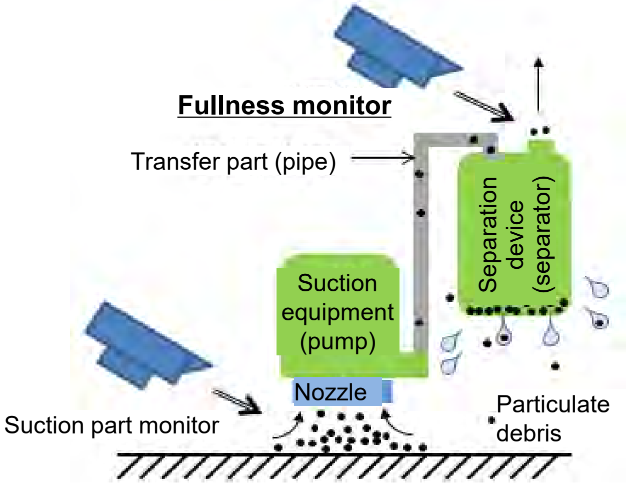
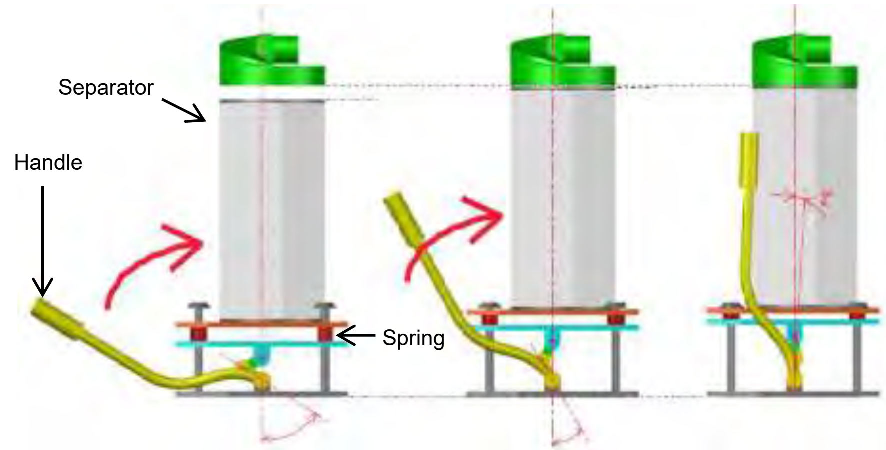


Image of the separator fullness detection method



Separator replacement mechanism concept

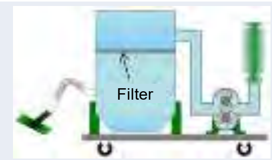
7. Implementation items of this project

[2) (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

d) Study of a pump model suitable for suction from air

- Screening was conducted for the selection of a pump model suitable for suction from air.
- Ejector pump which uses the compressed air as the driving source was selected from the screening results.

Model		Ejector pump (Driving source: Compressed air)	Ejector pump (Driving source: High-pressure water)	Vacuum suction type
Principles and Features		This type of pump is categorized as a special pump. It has three ports, namely, a driving fluid inlet port, transportation fluid inlet port, and discharge port, and the driving fluid injected from its driving fluid inlet port gives rise to negative pressure which causes suction. Reliability is high because it has no moving element.		Negative pressure is generated inside the container by means of the piston type or the root type of pump and the fluid is sucked using this negative pressure. There is a large number of maintenance parts as compared to the ejector pump.
Schematic drawing				
Power		Compressed air (Nitrogen (100 m^3/h) used for in-leak prevention is assumed to be the driving source)	High-pressure water (Circulating water (10 m^3/h) from the liquid phase is assumed to be the driving source)	Electricity (Supplied by a cable via the robot arm)
Ability to remove solid objects (Desk study)	**From air**	Specific gravity of 11 and particle size of approximately 10 mm is presumed	Specific gravity of 11 and particle size of approximately 0.1 mm is presumed	Specific gravity of 11 and particle size of approximately 10 mm is presumed
	Under water	Not clear	Specific gravity of 11 and particle size of approximately 5 mm is presumed	Not clear
Resistance to radiation		Resistant to radiation (metallic)		Consists of components which have poor resistance to radiation
Draining		Even if water is sucked or transferred, draining is possible by the separator in the latter stage		It is necessary to separately study the method of draining since there is no discharge mechanism for water.
Evaluation		• It is necessary to consider the impact on the gaseous phase inside the PCV, but it can be applied in the range which will not cause any impact.	• As per the information from the catalog, since the suction performance (flow velocity) in air is clearly low, and it cannot suck the target particles, so this pump was eliminated from consideration.	• It is necessary to study the maintenance of negative pressure, the method of draining, water-proofing, and maintenance methods and there are a lot of developmental issues, so this pump was eliminated from consideration.

7. Implementation items of this project

[2] (i) Technological development for fuel debris collection and storage systems]

a. Development of particulate fuel debris suction and collecting system

● Results of the conceptual study for this fiscal year

➢ The status of study for suction under water or in air are as follows.
➢ In the next fiscal year, element tests are scheduled after studying the pump suction port for "Suction from air".

Items	Suction from water	Suction from air	Notes
Selection of suction equipment	Submersible pump selected	Ejector pump selected (Driving source: Compressed air)	
Study of pump suction port	An appropriate strainer shape was evaluated through CFD analysis	Not yet (The study is scheduled for the next fiscal year with the method applied for suction from water)	
Separator fullness detection method	The method of detecting the fullness with a surveillance camera was designed	Same as left	・Equipment used in common for water and air ・Study scheduled for a shape which can collect a size of 0.1 mm or more
Separator replacement method	One-touch installation/ removal mechanism with toggle mechanism + spring was studied	Same as left	・Equipment used in common for water and air
Evaluation	To be carried out in the next fiscal year	To be carried out in the next fiscal year	

7. Implementation items of this project
[2) (i) Technological development for fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

- Purpose of development
  - For efficient fuel debris retrieval, a collection method, and a method and system for storage in containers will be developed according to the state of the fuel debris, and as and when necessary, the feasibility will be verified by means of element tests.
- Issues to be solved
  - Determining the specific collection procedures and devices to be used for the assumed variety of fuel debris
  - Feasibility verification of planned work procedures and devices
  - Refinement and shortening of work time evaluation accuracy
- Approaches to development
  - Study of collection methods (procedures and necessary devices) by consolidating the various forms of fuel debris, such as slag, particulate matter, pellets, damaged fuels, etc., as a precondition (study of collection methods depending on the state such particle size or fuel rod stubs, etc.)
  - Consideration of shortening of work time, maintenance during operations, response during breakdowns, etc.
  - Study of investigation and adoption of cutting methods (processing ability and dust evaluation etc.), and element tests as and when necessary
  - Study of feasibility of the methods of processing-grasping-unit can storage and carrying out
  - Evaluation of falling of debris during work and study of necessary functions
  - Coordination with other project "Development of Technology for the Retrieval of Fuel Debris and Internal Structures (Development of Technology for Dust Collection System of Fuel Debris)"

Presumptions and classification of the fuel debris properties

Creation of a presumptive diagram of the status inside the reactor based on the existing study results, and use this as the precondition for this study

Planning the retrieval method depending on the properties

Planning the retrieval methods for each of the presumed states of the fuel debris

Selecting the processing method and providing information for the development of collection technology

Planning the composition of the devices to be used

Creation of conceptual diagrams for work systems and devices by studying not just the usage state of the devices, but also the procedures and compositions for the replacement of consumables or maintenance, etc.

Element tests

Measurement of retrieval methods, work time, and collection efficiency by the retrieval element tests of simulated fuel debris.

Reflection in the conceptual diagram and procedure chart for the device. Estimation of the fuel debris retrieval period (review of existing results)

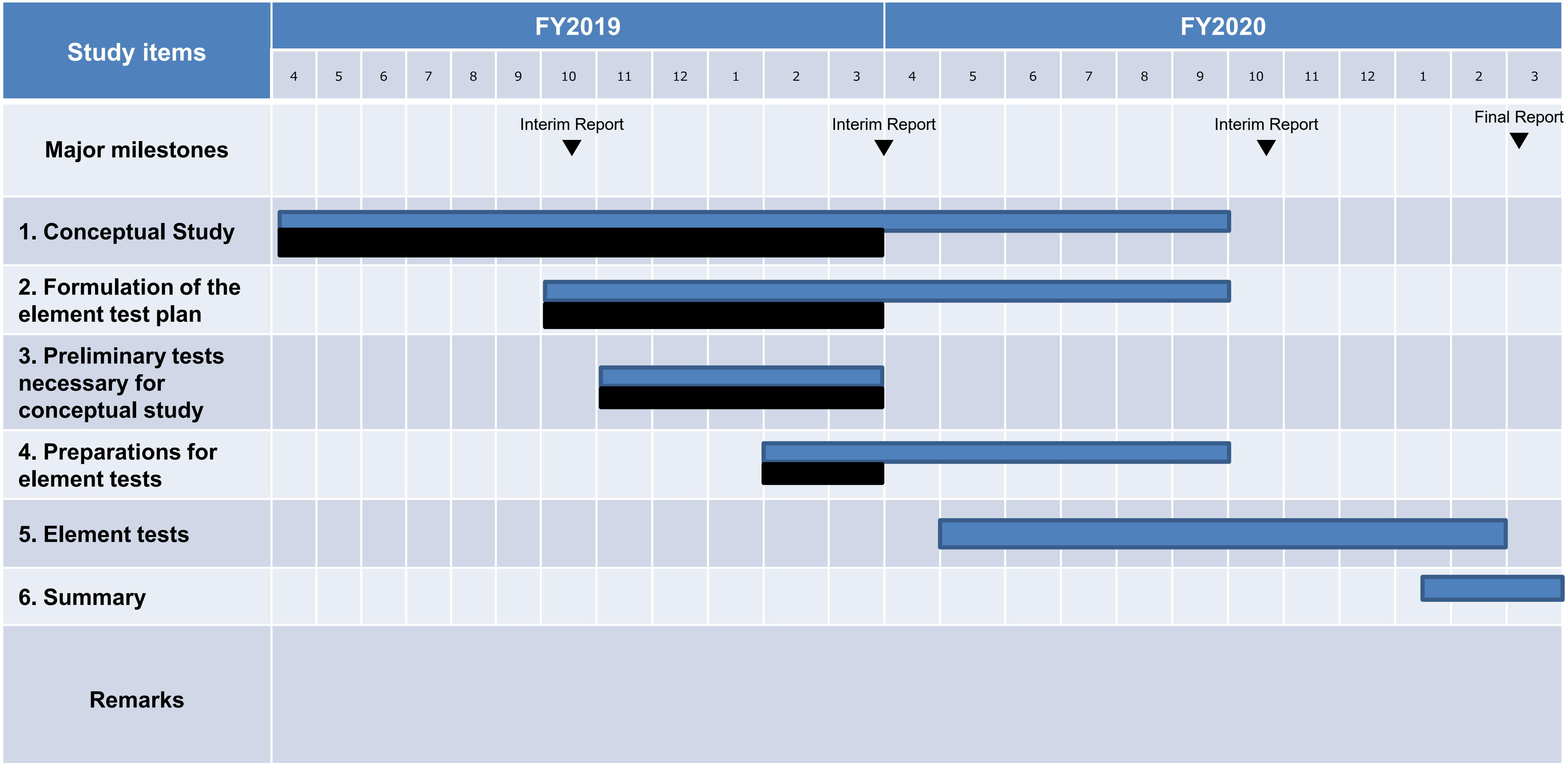
- Expected outcome (TRL：3)
  - Conceptual planning of the collection methods (procedure and necessary devices) depending on the state of the fuel debris (slag, particulate matter, pellets, damaged fuel etc.)
  - Feasibility evaluation of the planned methods by means of element tests
  - Estimation about the work time and the assumed debris retrieval period

7. Implementation details of this project

[2] (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■ <u>Development schedule</u>

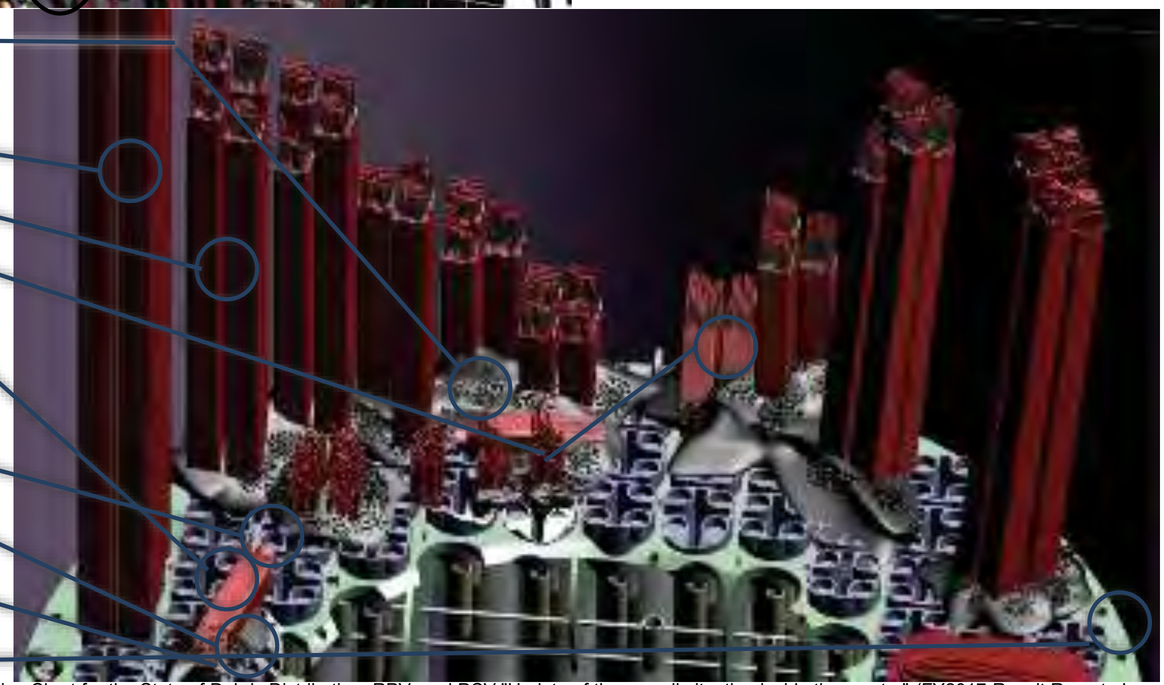


b. Development of technology for transferring fuel debris and wastes

■Preconditions of the study (Estimation of the state of fuel debris inside RPV: Around the upper grid plate and reactor core)
Creation of a presumptive diagram for the retrieval study by putting together the existing estimated results

Undamaged fuel assemblies
Undamaged control rods
Openings due to melting around the center
Creep deformation around the center No adherence of molten fuel
No damage No adherence of molten fuel

Powdered/particulate fuel debris (including abrasives) or fuel pellet deposits on the fuel rods or the reactor core support plates	Burnt pellets
	Particulate slag fuel
	Abrasives
There are fuel assemblies which can fall from the outer area into the central area and collide with the processing/ collection devices	No damage
	Mostly standing upright
	Inclined and touching the surroundings
	Toppled
	Damaged. There are no fuel debris adhesions
Fuel support metal fittings remain on the reactor core support plates	Fuel debris adherence on the inside
	Adherence to the reactor core support plate
Surrounding structures melted and solidified on the reactor core support plates	
Melted fuel debris which has entered between the reactor core support plates and the shroud body	



Presumptive Chart for the State of Debris Distribution, RPV, and PCV "Update of the overall situation inside the reactor" (FY2017 Result Report; June 2018)
Created on the basis of the presumptions about the fuel debris distribution at Units 1 to 3 "Technical Strategic Plan FY2018 for the Decommissioning of Fukushima Daiichi Nuclear Power Station"

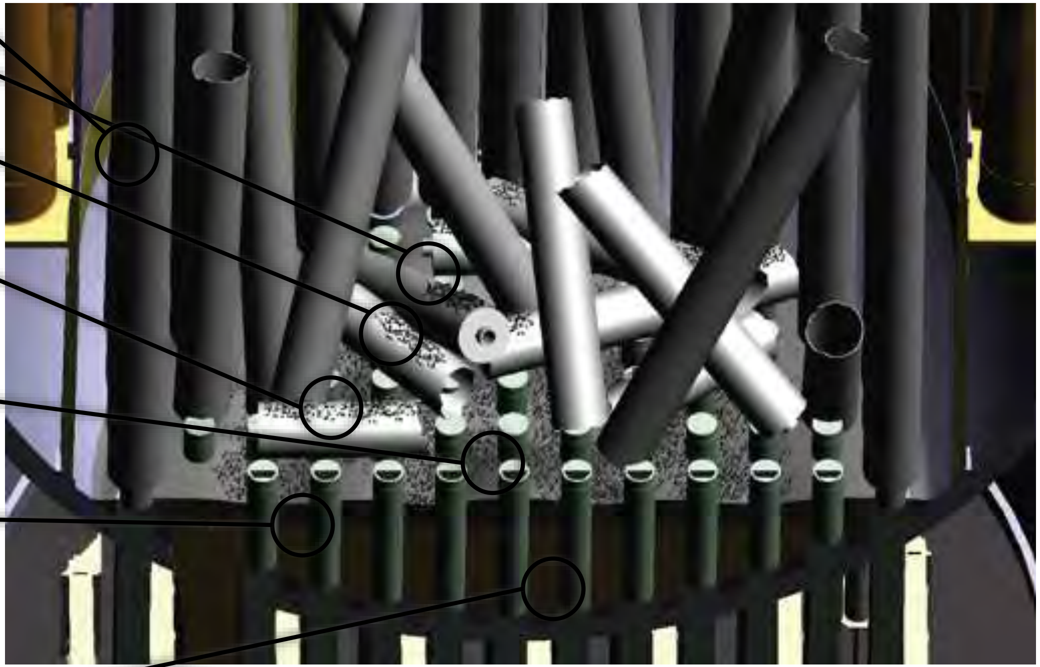
7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■Preconditions of the study (Estimation of the condition of fuel debris inside the RPV: Lower plenum and reactor bottom)

Upright position: No damage	
Collapsing on top of one another	Adhesion of a little molten fuel debris
	Adhesion of a lot of molten fuel debris
Scattered pellets/claddings and structures (handles/fuel support metal fittings)	Non-fused
	Fused
Granulated cooled and hardened molten objects (metal rich)	Non-fused
	Fused
Crusted fuel debris	Exists independently
	Fused with other structures (CRD/ bottom head)
Molten metal: Pool shaped	Metal rich
	Ceramic rich
Ball-shaped molten metal	Metal rich
	Ceramic rich



Presumptive Chart for the State of Debris Distribution, RPV and PCV "Update of the overall situation inside the reactor" (FY2017 Result Report; June 2018)
Created on the basis of the presumptions about the fuel debris distribution at Units 1 to 3 "Technical Strategic Plan FY2018 for the Decommissioning of Fukushima Daiichi Nuclear Power Station"

7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■ Preconditions of the study (Classification by type of the fuel debris conditions inside the RPV)

Classification of Fuel Debris			Mass (t)		Composition	Porosity	Hardness	Melting point
Vicinity of the upper grid plate	Undamaged fuel assemblies and internal structures	Undamaged fuel assemblies	51					
		Undamaged control rods						
		Undamaged upper grid plate						
	Damaged upper grid plate	Damaged or deformed upper grid plate						
Fuel debris on the upper part of the reactor core support plates (Fuel rod stubs)	There are fuel rods with shapes maintained (identifiable as fuel rods)	Upright fuel rod stubs with little damage		17	UO_2 ZrO_2 $(U,Zr)O_2$ Zr(O)	Up to10%	Fuel 6 GPa Cladding 1 to 3 GPa	Fuel 2850℃ Cladding 1850℃
		Greatly damaged fuel rod stubs						
		Fuel rod stubs that are damaged but are supported by surrounding structures						
		Toppled fuel assemblies						
In the vicinity of the reactor core support plates and the fuel support metal fittings	Fuel support metal fittings remaining on the reactor core support plate	Undamaged fuel support metal fittings		17				
		Undamaged reactor core support plate						
		Damaged fuel support metal fittings that have melted and solidified in the surroundings						
		Damaged reactor core support plates that have melted and solidified in the surroundings						
	Deposited fuel debris	Block-like fuel debris piled up without adhesion		17	$(U,Zr)O_2$ $(Zr,U)O_2$	Up to 88%	6 to 10 GP	2500 to 2700℃
		Pebble-like fuel debris piled up without adhesion						
		Powdery/ particulate fuel debris piled up without adhesion						
	Melted and solidified structures or fuel	Fuel debris adhering to the reactor core support plates						
		Block-like fuel debris that has melted and solidified between the shroud and the reactor core support plates						
In the vicinity of CRGT (From the reactor core support plates up to the reactor bottom)	CRGT and the control rod drive mechanism which are either standing or collapsed due to damage	CRGT that is undamaged and standing upright	85	15				
		CRGT that has collapsed but has little damage						
		CRGT that has collapsed and has fuel adhering to it						
Reactor bottom	Block of fuel debris that has solidified at the bottom of the reactor	Fuel debris that has melted and solidified on the internal structures		35	$(U,Zr)O_2$ $(Zr,U)O_2$ ZrO Fe	Up to 88%	6 to 17 GPa	1075 to 2700℃
	CRD housing	CRD housing present without damage						
	Deposits at the bottom of the reactor	Block-like fuel debris piled up without adhesion						
		Pebble-like fuel debris piled up without adhesion		35	$(U,Zr)O_2$ $(Zr,U)O_2$	Up to 30%	6 to 10 GPa	2500 to 2700℃
		Powdery/ particulate fuel debris piled up without adhesion						

b. Development of technology for transferring fuel debris and wastes

■**Planning the collection methods according to the types of fuel debris inside the RPV**

- Policies for planning the collection methods
  - Fuel debris with a size of 200 mm or less to be collected without any processing
    - Fuel debris with a size of 10 mm or more to be picked up (buckets, jamming adsorption pads etc.)
    - Fuel debris with a size of 10 mm or less to be suctioned, etc.
  - Melted and solidified blocks
    - Priority to be given to breaking down the debris with a chisel (spiky hammer) that has a simple operation and a fast processing speed, or to breaking the brittle parts with bucket-like tools, but prepare the following alternate plans assuming a scenario where the debris cannot be broken down due to accessibility or its physical properties.

      ⇒Disc Saw (Less powder dust and simple operation)

      ⇒Core boring⇒Reactor core may not be stable (might collapse), so consider using it in combination with ultrasonic waves ⇒Widening of opening with a splitting implement.

      ⇒Laser (and gouging)
  - Fuel assemblies and fuel rods
    - Draw the fuel assembly or fuel rod, which is not damaged and can be removed as is, into long mobile cells
    - Priority to be given to cutting out (while tearing out) the damaged fuel using a hydraulic cutter or bucket-like tools, but prepare the following alternate plans assuming a scenario where the material is hard and cannot be cut.

      ⇒ Cutting out small parts with a disc saw
  - Structures
    - The melted and solidified internal structures to be chipped off and cut with an ultrasonic chisel, etc.

      ⇒ Disc saw to be used for the block-like fuel support metal fittings or the reactor core support plates

      ⇒ Laser or AWJ to be used for the thick shroud or the CRGT etc.

      ⇒ Hydraulic cutter to be used for the thin upper grid plate

7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■Planning the collection methods according to the types of fuel debris inside the RPV

Targets	Core boring Ultrasonic core drill	Disc Saw		Hydraulic cutter	Bucket	Chisel hammer	AWJ	Laser cutting Laser gouging
		Circular saw*1	Cutting wheel grindstone*2					
Undamaged fuel assemblies	Collected without processing							
Undamaged control rods		○					△	◎
Undamaged upper grid plate		○					△	◎
Damaged or deformed upper grid plate		○					△	◎
Upright fuel rod stubs with little damage			○	◎				
Greatly damaged fuel rod stubs			△	○	◎			
Fuel rod stubs that are damaged but supported by surrounding structures			◎	○				
Toppled fuel assemblies			△	○	◎			
Undamaged fuel support metal fittings	Collected without processing							
Undamaged reactor core support plate		○					△	◎
Damaged fuel support metal fittings that have melted and solidified in the surroundings			◎				△	○
Damaged reactor core support plates that have melted and solidified in the surroundings			◎				△	○
Block-like fuel debris piled up without adhesion			◎			○		
Pebble-like fuel debris piled up without adhesion	Collected without processing							
Powdery/ particulate fuel debris piled up without adhesion	Collected without processing							
Fuel debris adhering to the reactor core support plates			◎		△	○		○
Block-like fuel debris that has melted and solidified between the shroud and the reactor core support plates								◎
CRGT that is undamaged and standing upright		○					△	◎
CRGT that has collapsed but has little damage		○					△	◎
CRGT that has collapsed and has fuel adhering to it			◎				△	○
Fuel debris that has melted and solidified on the internal structures	△		○		△	◎		
CRD housing maintaining its shape		○					△	◎
Block-like fuel debris piled up without adhesion			◎			○		
Pebble-like fuel debris piled up without adhesion	Collected without processing							
Powdery/ particulate fuel debris piled up without adhesion	Collected without processing							

#1 : The targets are processed by cutting
#2 : The targets are processed by grinding with an abrasive coating

◎ : Processing method with highest applicability
○ : Processing method with high applicability
△ : Processing method which may be applicable, but has issues

b. Development of technology for transferring fuel debris and wastes

■Planning the collection methods according to the types of fuel debris inside the RPV

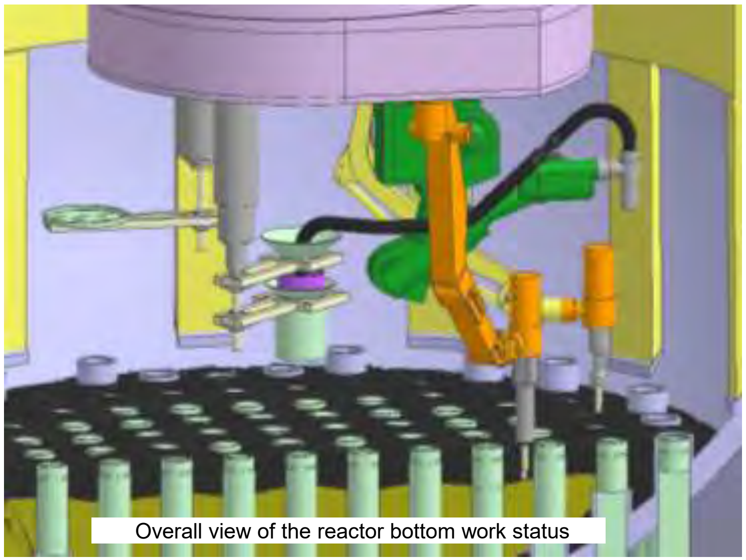
- **Basic requirement functions**
  - **The tip tools (processing tools and collection tools) should be able to access the entire internal area of the pressure vessel below the height of the upper grid plate (specific limitations will be formulated in FY2020).**
  - **The tip tools can be attached/ detached and replaced inside the PCV.**
  - **For maintenance such as replacement of consumables, etc., the tip tools shall be carried out from the platform at the top of the PCV. Therefore, the tools should be able to pass through the opening for carrying out the unit cans.**
  - **The power at which a manipulator can operate is given below (the payload of a general power manipulator is 2000 N or less)**
    - **Processing tool mass should be 500 N and the reactive force during processing should be 1000 N or less.**
  - **The following utilities can supply to the reactor core and the reactor bottom**
    - **Power supply: 3φ, 200 V, 10 A**
    - **Water: Approx. 1 m^3/h**
    - **High-pressure air: (The pressure and flow rate will be formulated in FY2020 by referencing the existing study results of the gaseous phase system)**
- **Environmental requirement conditions**
  - **Dose rate: Inside the reactor, reactor bottom: 3000 mSv/h**
  - **(After setting up the PCV flange platform): 5 to 10 mSv/h**
  - **Temperature: -7 to 40℃**
  - **Within the boundary: ≤ 99%**
  - **Design life: 50 years (However, the consumables can be replaced during maintenance.)**

7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

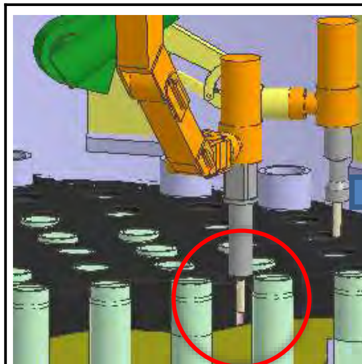
b. Development of technology for transferring fuel debris and wastes

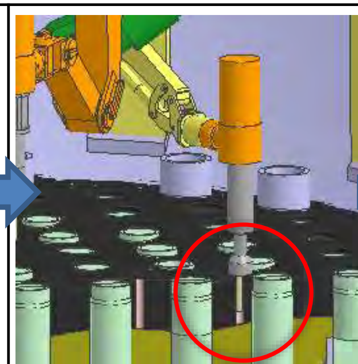
■ Planning the collection methods according to the types of fuel debris inside the RPV

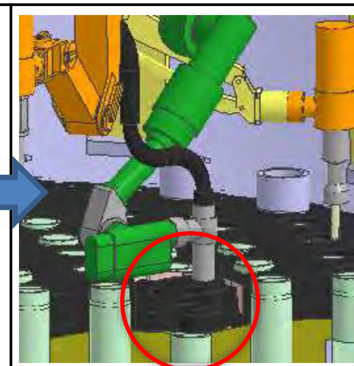

Overall view of the reactor bottom work status

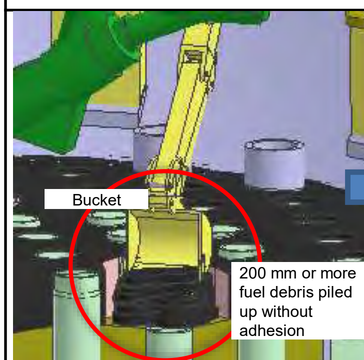
●Study of the collection method
Suitable processing collection tools were selected by using the assessment model diagram. A step diagram was created by using these tools and a comprehensive study was conducted with respect to the effectiveness, workability, and efficiency of the collection method.

● Content of future studies: Selection of issues
- Feasibility of the interface between the tools
- Confirmation of visibility by means of camera arrangements, etc.
- Identification and rescue method of assumed problems
- Feasibility of comprehensive maintenance

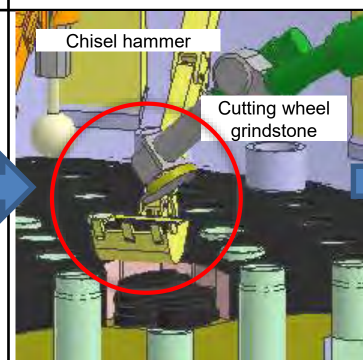

Opening of holes with the ultrasonic core drill


The opened hole is enlarged with a splitting implement and fuel debris is crushed.

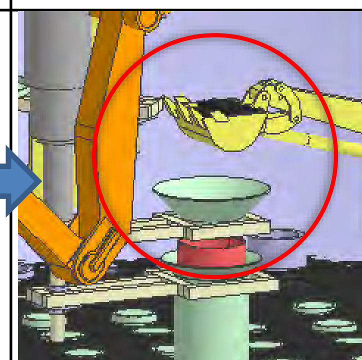

The crushed small-diameter fuel debris is collected with the suction device



The large fuel debris amongst the ones crushed with the splitting implement are picked up



The picked up fuel debris is broken down with the cutting wheel grindstone


The debris is crushed to a size that will fit into a unit can and then stored in the unit can

Example of reactor bottom work step diagram

7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■ **Planning the collection methods according to the types of fuel debris inside the RPV**

Investigation of the processing capability of the processing technologies being considered

The cutting process is carried out by using the tools normally suitable for metals or ceramic respectively.

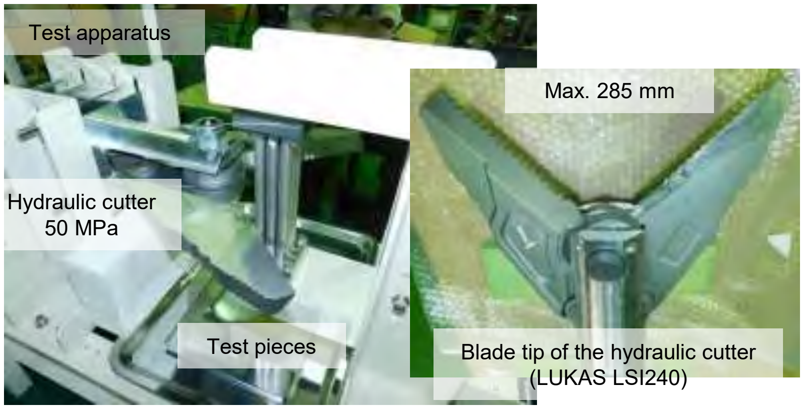
Based on the estimation of the conditions inside the reactor, element tests were carried out for the cutting process using the same tools for composite materials containing metals and ceramics, and the issues were identified.

Tools	Targets	Issues	Test details
Hydraulic cutter	Remaining fuel rods or fuel rod stubs	➢ Possibility of cutting the fuel rods or stubs containing a mixture of both metals (claddings) and ceramics (fuel pellets), and understanding the behavior during cutting ➢ The effect on the behavior during cutting due to the variations in the shape of the cutting blade	➢ Possibility of processing with hydraulic cutter ➢ Identification of issues during the cutting of fuel rods
Cutting wheel grindstone	Fuel-rich fuel debris	➢ Can the fuel-rich fuel debris containing both metals (internal structures) and ceramics (molten fuels) be processed with the same tools, under the same processing conditions and at the same time? ➢ Tool life when metal and ceramics are processed at the same time	➢ Possibility of processing with a cutting wheel grindstone ➢ Processing speed and tool life ➢ Issues when processing with cutting wheel grindstone
Chip Saw	Metal-rich fuel debris	➢ Can the metal-rich fuel debris containing both metals (internal structures) and ceramics (molten fuels) be processed with the same tools, under the same processing conditions and at the same time? ➢ Tool life when metal and ceramics are processed at the same time	➢ Possibility of processing with chip saw ➢ Processing speed and tool life ➢ Issues when processing with a chip saw

■ Planning the collection methods according to the types of fuel debris inside the RPV

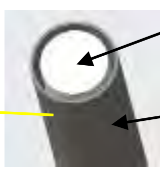
Investigation of the processing capability of the processing technologies being considered (Hydraulic cutter)

- Used tools and test apparatus
  - Commercially available handy hydraulic cutter was used.



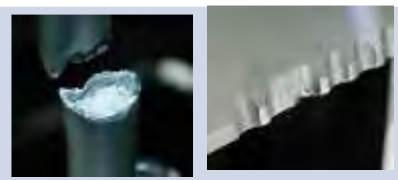
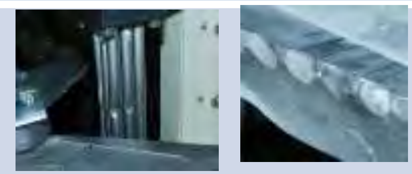
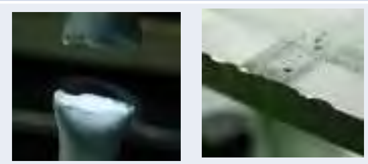
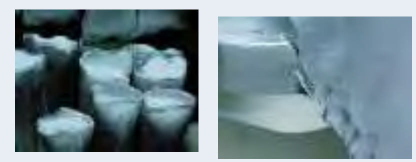
- Test specimen
  - Application to the residual fuel and the fuel rod stubs was assumed
  - The fuel rods were simulated. One in nine rods were compressed bydifferent strength

3 x 3 test specimen



Reference: Compressive strength of ceramics

Zirconia	Approx.4000 MPa
Mullite	Approx.160 MPa
(Reference) UO_2	Approx.1000 MPa

Test specimen	One orthogonally cut test specimen	3x3 orthogonally cut test specimen
Zirconia Soundness and hardness are assumed	 Could be cut (10 secs required) The blade tip was damaged and deformed. Zirconia was crushed into pebble-like pieces.	 Of 9 rods, only 1 rod could be cut. 4 rods out of the remaining 8 could not be cut although zirconia was crushed. The blade tip was damaged and deformed.
Mullite Assumed to become brittle under harsh conditions	 Could be cut (8 secs required) There was no significant damage to the tip of the blade. Mullite was crushed into powder.	 Could be cut (10 secs required). Minor damage caused near the base of the blade.

- It was confirmed that processing is possible with the hydraulic cutter, since the cladding was cut by shearing while the fuel was crushed due to the compressive strength.
- It is estimated that the hydraulic cutter is effective when the fuel is brittle.
- In case the fuel is not brittle, then it is estimated that initially crushing the fuel pellets with bucket-like crushing tools etc. and then carrying out the processing with a combination of tools, is effective.

7. Implementation details of this project

[2] (i) Technological development of fuel debris collection and storage systems]

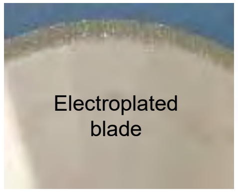
b. Development of technology for transferring fuel debris and wastes

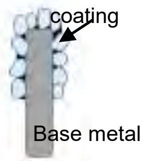
■ Planning the collection methods according to the types of fuel debris inside the RPV

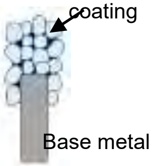
Investigation of the processing capability of the processing technologies being considered (Cutting wheel grindstone)

Tool diameter	200 mm
Feed speed	4 mm/min
Rotating speed of tool	2000 rpm
Cutting fluid	Not used and only a rust inhibitor added
Target processing depth	17 mm

- Used tools
  - Two types of diamond abrasive coating tools for ceramic processing
  - A vertical slicing device was used for precision processing

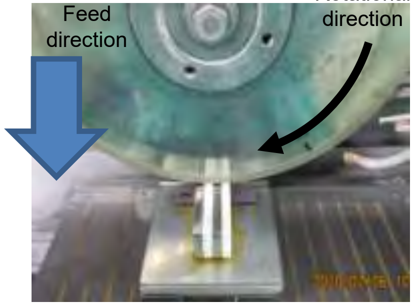




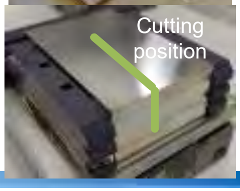


	Abrasive coating strength	Abrasive coating	Features
Electroplated blade	Strong	Single layer	Abrasive coating is strongly retained
Metal blade	Somewhat strong	Multi-layer	If there is wear and tear, the lower layer of the abrasive coating is exposed.

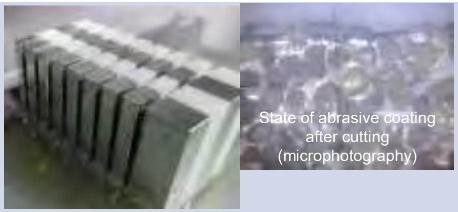
- Test specimen
  - Four laminated layers of SUS304 (t5 mm) plates and zirconia plates (t5 mm)
  - Changes in the direction of lamination and processing (notch)



Vertical



Horizontal

	Vertical	Horizontal
Electroplated blade	 If processing is continued, the abrasive coating is lost and this leads to clogging.	 An abnormal noise was generated during processing and the processing stopped. Abrasive coating is lost and this leads to clogging.
Metal blade	 Processing ability is excellent. Due to the wearing out of the grindstone, the diameter shortens.	 Processing ability is excellent. Even if the grindstone wears out, processing ability continues.

- It was confirmed that the electroplated blade and the metal blade could be used to cut the test specimen laminated with metal and ceramic even when the cutting fluid was not used.
- It is estimated that the tool life of the metal blade is longer that is approx. 19,000 mm^2.
- Processing speed (cross-sectional area) is 80 mm^2/min.

7. Implementation details of this project

[2] (i) Technological development of fuel debris collection and storage systems]

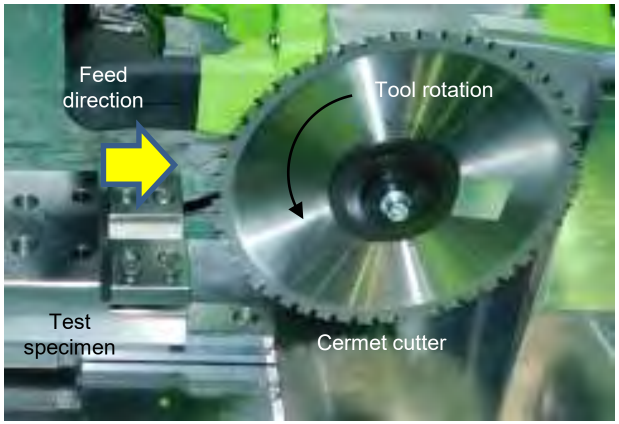
No.164

b. Development of technology for transferring fuel debris and wastes

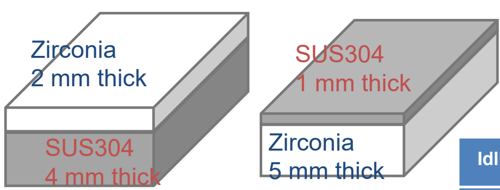
■ Planning the collection methods according to the types of fuel debris inside the RPV

Investigation of the processing capability of the processing technologies being considered (Chip Saw)

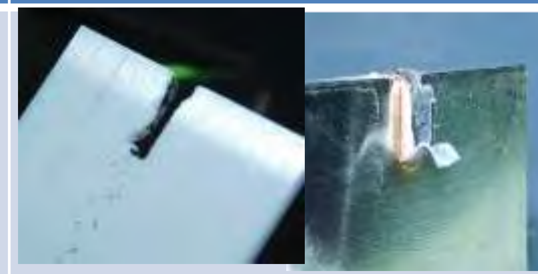
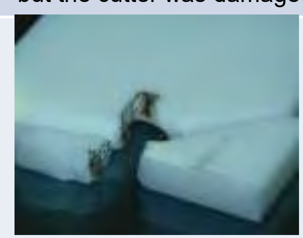
- Used tools
  - Commercially available dry cermet cutter was used.



- Test specimen
  - Simulation of the melted solidified fuel (zirconia) and simulation of the laminated structure of metal (SUS304)



Metal-rich Ceramic-rich

Test specimen	Feed 12 mm/min	Feed 60 mm/min
Metal-rich	 Possible to process metal, zirconia was fragmented.	 There were notches in both zirconia and metal, but the cutter was damaged as well.
Ceramic-rich	 Zirconia cracked, metal had notches and the chip corners were lost.	 Zirconia cracked, chip corners were lost and the base metal of the cutter was also damaged. 

Idling speed	3500 rpm
External diameter of saw blade	185 mm
Thickness of saw blade	1.6 mm
Number of blades	48

- It was confirmed that cracks developed at the locations hit by the blade and with further progress, the zirconia plate cracked.
- The tip of the blade was damaged by the collision of zirconia and the blade.
- The processing ability with respect to stainless steel decreased due to the damage to the tip and burrs developed.

7. Implementation details of this project

[2) (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■Study of the fuel debris processing and collection procedures

Investigation of the processing capability of the processing technologies being considered - Summary

Tools	Test details	Test results	Identified issues
Hydraulic cutter	➢ Possibility of processing the assumed fuel debris (especially, the fuel rods that remained unmelted) ➢ Identification of issues at the time of cutting the fuel rods	● Claddings were crushed by shearing (plastic deformation) and fuel was crushed by compressive strength. The required time was a few seconds up to about ten seconds ● When hardness level of the fuel is high, it is difficult to cut multiple fuel rods together. Study of the work procedures etc. is necessary.	● Cutting process for objects that are not brittle ➢ Procedures to be combined with crushing ➢ Improvement of cutting power
Cutting wheel grindstone	➢ Possibility of processing the assumed fuel debris (especially, the melted and solidified fuel debris) ➢ Processing speed and tool life ➢ Issues when processing with a cutting wheel grindstone	● It was possible to cut the test specimen consisting of laminated metal and ceramic. The melted and solidified debris consisting of metals and fuels mixed together could be processed. ● The processing speed is slow at 80 mm^2/min for a cross-sectional area. ● Tool life of the metal blade is longer. ● It is estimated that approximately 19,000 mm^2 of area can be processed with the metal blade.	● Procedure to cut out block-like debris ● Processing support technology such as position controls that emulates the unevenness of the fuel debris ● Size or quantity of abrasive coating, types of bonds, introduction of slits, etc.
Chip Saw	➢ Possibility of processing of the assumed fuel debris (especially, the melted and solidified fuel debris) ➢ Processing speed and tool life ➢ Issues when processing with chip saw	● In case of ceramics, with the development of cracks, the processing moved forward with the crushing of the material, but it was found that the tip of the blade also gets damaged similarly. ● Metallic bodies could be processed without trouble, but the processing ability with respect to stainless steel decreased due to the damage to the tip and burrs developed.	● The ability to process ceramics is low, and the grinding stone is more applicable to fuel debris mixed with melted and solidified UO2.

[2] (i) Technological development of fuel debris collection and storage systems]

b. Development of technology for transferring fuel debris and wastes

■ **Planning the collection methods according to the types of fuel debris inside the RPV**

- Summary and future policies
  - An imaginary diagram was created estimating the conditions inside the RPV putting together the information on Units 1 to 3.
    - Information about the existing understanding of conditions inside the reactor and the fuel debris characterization project.
    - The summarized information was used in the study of methods for retrieving fuel debris inside the RPV.
  - Selection of collection methods for each type of fuel debris classified on the basis of shape, presence/ absence of melting, etc.
    - Study of the presumed operating procedures by planning the collection devices to be used inside the reactor based on the collection methods
  - Execution of preliminary tests to verify the feasibility of the hydraulic cutter and the disc saw
    - Assessment of the general scope of applicability by verifying the applicability to the processing of metals or ceramics by the tools used
  - Issues for the future (FY2020)
    - Summarization of issues on the basis of the concept of fuel debris retrieval devices and operating procedures planned currently.
      - Study of the assumed problem events such as falling of equipment or falling of fuel debris during transport, etc., and study of action policies for the same
      - Transportation to the container in which the fuel debris will be stored and transportation of the container
      - Impact on the safety systems (outflow of chips, utility (water and gas) supply and criticality monitoring procedures)
    - The tools on the tip coming in contact with fuel debris were studied in FY2019 and will be summarized in future in a comprehensive configuration diagram.
      - Incorporation of the maintenance policies that are the outcome of the previous year and their reflection in the device maintenance plans
      - Incorporation of the device maintenance plans and the response policies for the problem events, and their reflection in the layout plans
      - Study of cell installation and construction procedures to establish the overall configuration
      - Calculation of the processing abilities necessary for the device plan and for the achievement of goals etc. when the plan is applied, and evaluation of conformity to the desired values

2) Development of Technology for Processing Fuel Debris

(ii) Technological development for the treatment of fuel debris and deposit

① Removal technology for soluble nuclides in circulating cooling water

As regards the removal technology for soluble nuclides believed to flow into the circulating cooling water from the fuel debris, optimal adsorbents were selected after carrying out element tests related to the adsorption technology for the removal of soluble nuclides. The element tests were conducted for alpha nuclides. The conceptual system design of the adsorption removal equipment was carried out based on these results.

The main development study items included the following, and as and when necessary, issues were identified and organized by conducting element tests.

a. Conceptual system design of soluble nuclide removal facility

- The preliminary test necessary for drafting the plan for the adsorption test using alpha nuclides (U and Pu, etc.) is underway.

b. Conceptual design of boric acid conditioning facility

- The deposition behavior assessment test of boric acid ions is underway.

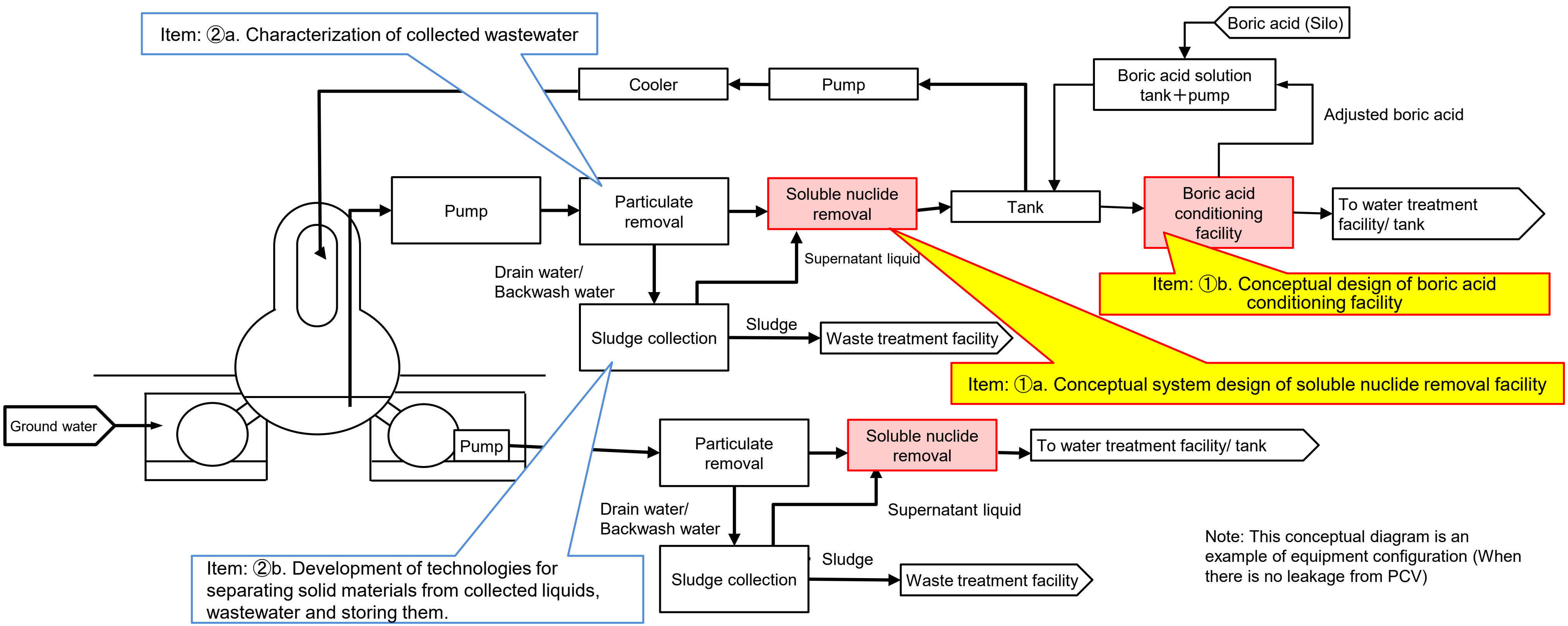
2) Development of Technology for Processing Fuel Debris

(ii) Technological development for the treatment of fuel debris and deposit

① Removal technology for soluble nuclides in circulating cooling water

The conceptual diagram of the contaminated water treatment system for the retrieval of fuel debris is shown below.

: Facilities of these items were tested in this project.



<u>Figure. Liquid system during fuel debris retrieval (conceptual diagram) and implementation targets for element tests</u>

7. Implementation details of this project

[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

a. Conceptual system design of soluble nuclide removal facility

- Purpose of development
  To acquire data in order to select the adsorbent types and amount used for the adsorption removal of alpha nuclides (Pu, U, Np, Am, Cm).

- Issues to be solved
  The data regarding the nuclide adsorption capability of the alpha nuclide adsorbent used at the soluble nuclide removal facility, is insufficient.

- Approaches to development

(1) Preparation for element tests

① Organization of water quality assumed for actual operations

② Study of the form of existence of the alpha nuclides for the assumed water quality

③ Literature research on the adsorbents for the adsorption removal of alpha nuclides other than Am (Pu, U, Np, etc.), and selection of the candidate adsorbent

④ Study of methods to test adsorption (conditions and procedures)

(2) Preliminary tests required for element test planning

② Study of the form of existence of the alpha nuclides for the assumed water quality

(3) Adsorption tests using alpha nuclides (U, Pu, etc.) (Immersion test and circulation test)

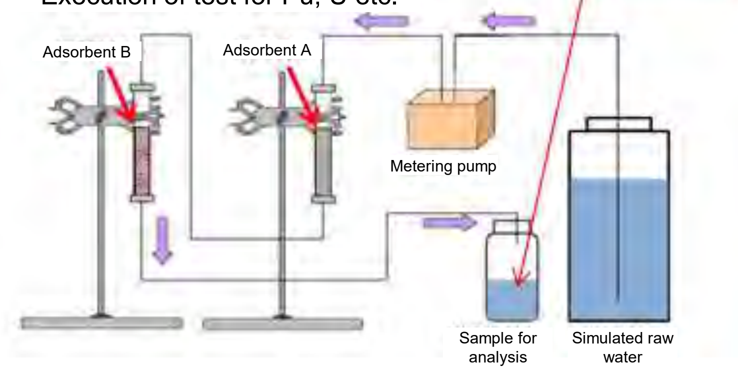
<<Example of the test to verify the nuclide adsorption ability>>

1) Immersion test
- Establishment of high accuracy test procedures
- Execution of test for Pu, U etc.

Measurement of the adsorbed amount by measuring the concentration of adsorbed substances in a canister before/after starting the test

2) Circulation test
- Establishment of a test procedure which can reduce the quantity of nuclides used
- Execution of test for Pu, U etc.

Understanding the initial DF by measuring the changes occurring in the concentration of adsorbed substances with the lapse of time



- Expected outcome
  Data for selecting the alpha nuclide adsorbents to be used at the soluble nuclide removal facility

7. Implementation details of this project

[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

a. Conceptual system design of soluble nuclide removal facility

◆ Study flow

The initiatives until FY2018, the initiatives in this project, and the initiatives after this project are shown in the following flow.

In FY2019, the preconditions for the adsorption tests (for the selection of the candidate adsorbent) were mainly organized with preliminary tests, etc.

[Up to FY2018]

Conceptual study of the liquid phase system

Exposure evaluation

Large share of Pu and Am

Necessity of removal of soluble alpha nuclides

・ALARA
・ (Discharge to water treatment facility)

Temporary settings of the assumed water quality during actual operations

Refer to the water quality of stagnant water inside the PCV of Units 2 and 3

Narrowing down of the applicable candidate technology

Selection of RO membrane removal and adsorption removal. Selecting an appropriate adsorbent is necessary.

Adsorption test plan (Am)

・Test procedures
・Adsorbents to be evaluated

Selection of the applicable candidate adsorbent by lab tests (Am)

・Applicable candidate adsorbent (Am)
・Necessity of test procedure review
・Necessity of evaluation of non-evaluated nuclides

[FY2019 to FY2020 (This project)]

A: Adsorption test plan

[Results in FY2019]
Test plan drafted. Approach to adsorption test priority organized.

・ Test procedures (After review)
・Adsorbent to be evaluated

B: Preliminary test

[Results in FY2019]
The preliminary test for Am, Cm, and U are executed. The feasibility estimations of the Am, Cm adsorption test and the rising tendency of solubility under boric acid solution conditions, are confirmed.

・Form of existence of the alpha nuclides in the liquid phase
・Container adhesion effect

C:Selection of the applicable candidate adsorbent by lab tests (Pu etc.)

Applicable candidate adsorbent #1

Lab test result

D: System conceptual study #2

#1: It is necessary to conduct a performance verification test which finally uses the actual liquid for the selection of the adsorbent. Under this project, the policy is not to narrow down to a single candidate adsorbent, but to make multiple selections.
#2:The study of a conceptual system and the identification of issues shall be performed assuming the application of the adsorption system.

[FY2021 onwards]

Adsorption performance verification test using the actual liquid #3

・Applicable adsorbent
・Differential pressure data during long-term water flow
・Removal performance during long-term water flow
・Adsorbent replacement frequency (amount of waste generated)

System conceptual design

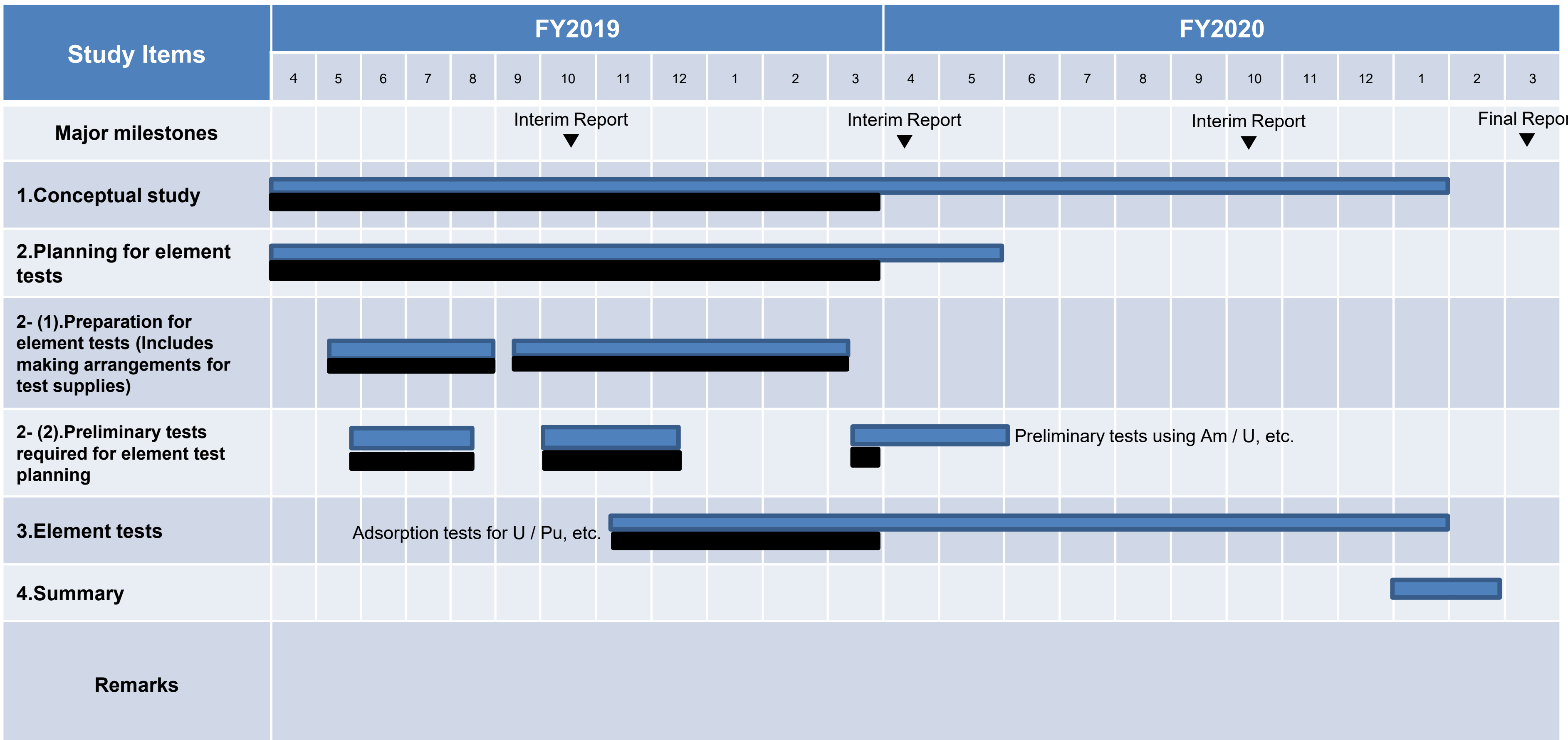
#3: It is considered necessary to conduct tests using the retrieval of fuel debris from the first Unit, which is planned to start in 2021.

7. Implementation items of this project

[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

a. Conceptual system design of soluble nuclide removal facility

◆ Development Schedule



7. Implementation items of this project

[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

a. Conceptual system design of soluble nuclide removal facility

◆ **Selection of a candidate adsorbent: The candidate material was selected based on a literature research and the form of existence of alpha nuclides in the solution.**

① A literature research was conducted and the candidate adsorbent for each nuclide element to be removed was selected.

Alpha nuclides	Candidate adsorbent	Approach to selection (literature research)
Pu	**Clinoptilolite**	In the test results using actual underground water, Kd was present to the order of 10^3
	Chabazite	In the test results using actual underground water, Kd was present to the order of 10^2
Am	**Clinoptilolite**	In the test results using actual underground water, Kd was present to the order of 10^3
	Crystalline silicotitanates	In the test results with 30% diluted seawater (3000 ppm of boron), Kd was present to the order of 10^3
Cm	Not applicable	Though there is literature on adsorbents evaluated in the acidic region, there are no research results evaluated near neutrality
U	**Mordenite**	In the test results with NaCl (10^{-3} mol/l ~ 10^{-1} mol/l) pH 6~7, Kd was present to the order of 10^3
	Activated carbon attached to adsorption site	In the test results with KNO_3 (I = 0.1) pH 7~8, Kd was present to the order of 10^4
Np	**X-type zeolite**	In the test results with 0.1 M NaCl / 0.001 mol/l HCl pH 6, Kd of approximately 800 ml/g was present

② Candidate adsorbents were selected considering the existence form of alpha nuclide to be removed

Existence form of alpha nuclides		Candidate adsorbent	Selection method
Ion	Divalent cation Molecular ions	**Zeolite / Titanic acid / Crystalline silicotitanates**	Selected as an adsorbent that can adsorb cations. In addition, a high adsorption rate was confirmed in the Am test during the last year's subsidized project.
	Trivalent cation	**Zirconium phosphate**	Selected as an adsorbent that can adsorb trivalent ions.
Colloid		**Activated carbon**	As it has excellent adsorption of neutral substances, it is expected to remove molecules that reacted with colloid and organic substances.

7. Implementation items of this project
[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

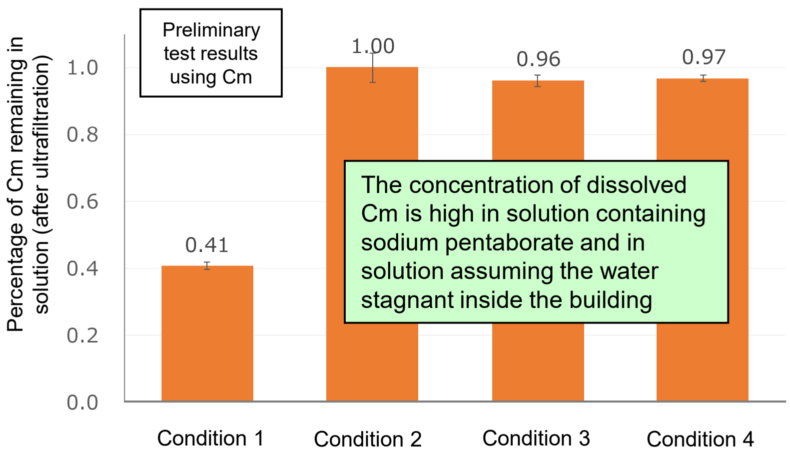
a. Conceptual system design of soluble nuclide removal facility

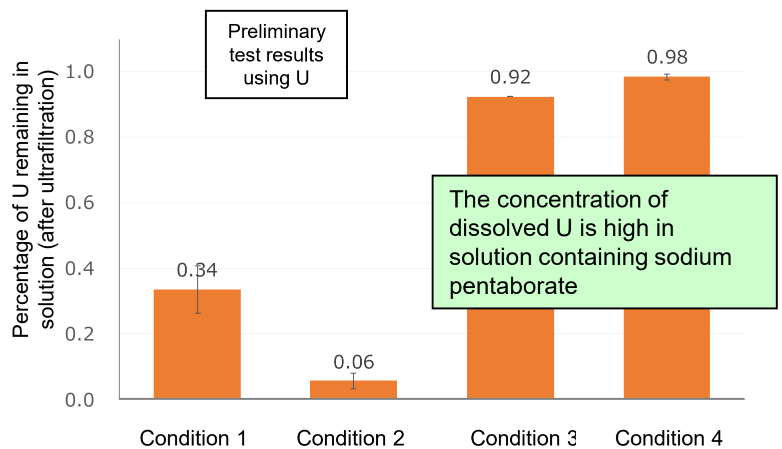
◆ **Preliminary test: Confirms the difference in the degree of dissolution of Am, Cm, and U depending on the assumed water quality. Pu and Np will be evaluated in FY2020.**

List of actual and assumed water quality conditions

Conditions for conducting preliminary tests (applies to test conditions 1–4, outlined in red)

Test solution conditions	Seawater component	Concrete component	Addition of boric acid solution	Conditions: Temperature [℃]	Conditions: Cl ion concentration [ppm]	Conditions: Ca ion concentration [ppm]	Conditions: Boric acid concentration [ppm]	Conditions: pH	Conditions: SS concentration [ppm]	Assumptions
1	No	No	No	10 ~ 40	About 20	< 1	< 1	Near neutral	< 1	Stagnant water inside PCV
2	Yes	Yes	No	10 ~ 40	About 350	About 40	<1	Weak alkali	< 1	Stagnant water inside the building
3	No	No	Yes	10 ~ 40	About 20	< 1	7,000	Weak alkali	< 1	Stagnant water inside PCV (boric acid solution added)
4	Yes	Yes	Yes	10 ~ 40	About 350	About 40	7,000	Weak alkali	< 1	Stagnant water inside the building (boric acid solution added)
5	No	Yes	No	10 ~ 40	About 20	Saturated	< 1	High	< 1	Elution of concrete components into stagnant water inside PCV





7. Implementation items of this project

[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

a. Conceptual system design of soluble nuclide removal facility

◆ **Adsorption test: Adsorption test is being conducted after prioritizing the tests based on the desk evaluation and preliminary test results.**

- Pu, Am, and Cm, that have a high effect of exposure and a low regulatory concentration limit, have a high priority for adsorption removal.
- Seawater components and boric acid-added conditions, that were suggested to increase alpha nuclide concentration in solution in preliminary tests, have relatively high priorities.
- The coexistence of Cs and Sr may reduce the alpha nuclide adsorption performance, so it has the second highest priority. However, U and Np, which have low solubility, have a relatively low priority.
- Although the elution effect of Ca has a high priority for data collection, it is difficult to evaluate Cm and Am as their carriers get sedimented with the increase in pH. The possibility of evaluation for U, Np, and Pu will be confirmed in the preliminary tests in the future.
- The initially planned water flow test is expected to be excluded by conducting high-priority tests.

Alpha nuclide elements	Immersion test (confirmation of adsorption capacity at equilibrium)								Water flow test		
	Circulating cooling water	Coexisting ion effect							DF		Adsorbent life
		Seawater components	Ca (concrete)	Carbonic acid	Cs	Sr	Boric acid	Others	During initial water flow	During long-term water flow	
U	△/x	△/x	(▲/x)	x	(▲)	(▲)	○	▲	▲	x	x
Np	(△/x)	(△/x)	(▲/x)	x	(▲)	(▲)	(○)	▲	▲	x	x
Pu	(◎)	(○)	(○/x)	x	(△)	(△)	(○)	▲	▲	x	x
Am	◎	○	x	x	△	△	○	▲	▲	x	x
Cm	◎	○	x	x	△	△	○	▲	▲	x	x

・Legend ◎: High priority, ○: Relatively high priority, △: Relatively low priority, ▲: Low priority, x: Test evaluation is difficult in this PJ
・ The parentheses indicate assumptions since these tests were conducted before the preliminary test.

7. Implementation items of this project

[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

- **Purpose of development**

  As a safety system, it was necessary to organize the design requirements (equipment needs) essential for criticality control using soluble neutron absorbers and to determine the specific details of the process.
  The data on physical properties when using sodium pentaborate (physical properties of sodium pentaborate, deposition behavior, migration data during evaporation, etc.) will be obtained and the design requirements will be organized.

- **Issues to be solved**

  To obtain the data on physical properties such as deposition behavior of sodium pentaborate.
  To organize the design requirements for criticality control systems considering the data on physical properties of sodium pentaborate.
  To study the requirements for operation and maintenance of the criticality control systems under the actual environment (dose, etc.).

- **Approaches to development**

  Regarding the behavior of sodium pentaborate, literature research and element tests (test assuming actual operations if necessary) will be performed, and the data necessary for design will be acquired.
  The requirements for criticality control systems will be organized using the acquired data.
  The amount of boric acid migrating to the destination (equivalent to the existing water treatment facility) will be suggested and the impact (element test etc. shall be conducted if necessary) will be confirmed.

- **Expected outcome**

  Physical properties data required for actual equipment design
  Concept of criticality control systems using sodium pentaborate
  Amount of boric acid migrating to the destination and its impact

7. Implementation items of this project

[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

[Background: Overview]

- In the subsidized project (Criticality Control Project), initiatives are being taken for development of technology for cases using both soluble and insoluble neutron absorbers as the criticality control methods for retrieving fuel debris.

- As technology developments of Criticality Control Project (FY2018), a system configuration plan was created, issues were identified and studied after tentatively determining the preconditions including the liquid phase system, as the system using soluble neutron absorbers is closely related to the liquid phase system (circulation loop system).

- In continuation to last year, this project will continue to carry out studies aimed at solving the identified issues.

- Identified issues (see next slide for details)

Issue ① : Deposition of sodium pentaborate
Deposition of boric acid inside the system (PCV, circulation loop, boric acid conditioning facility) and its effect on the systems

Issue ② : Amount of sodium pentaborate and pH regulator to be injected
Loss of boric acid inside the system (PCV, circulation loop, boric acid conditioning facility) (increased burden on the boric acid injection system)

Issue ③: Amount of sodium pentaborate migrated
Amount of boric acid migrating to the destination and its impact

Issue ④: Operation and maintenance policy of boric acid conditioning facility
Organizing the operations and maintenance policies under actual operating environment based on issues ① to ③

7. Implementation items of this project
[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]
b. Conceptual design of boric acid conditioning facility

[Challenges of a pentaborate operating system]

Issue ① Deposition of sodium pentaborate

Deposition of boric acid compounds inside the system (PCV, circulation loop, boric acid conditioning facility) and its effect on the systems

- Organizing the deposition conditions for sodium pentaborate with respect to the assumed water quality at each location (literature research, element test)
- Study on the effects of boric acid deposition and countermeasures for the same

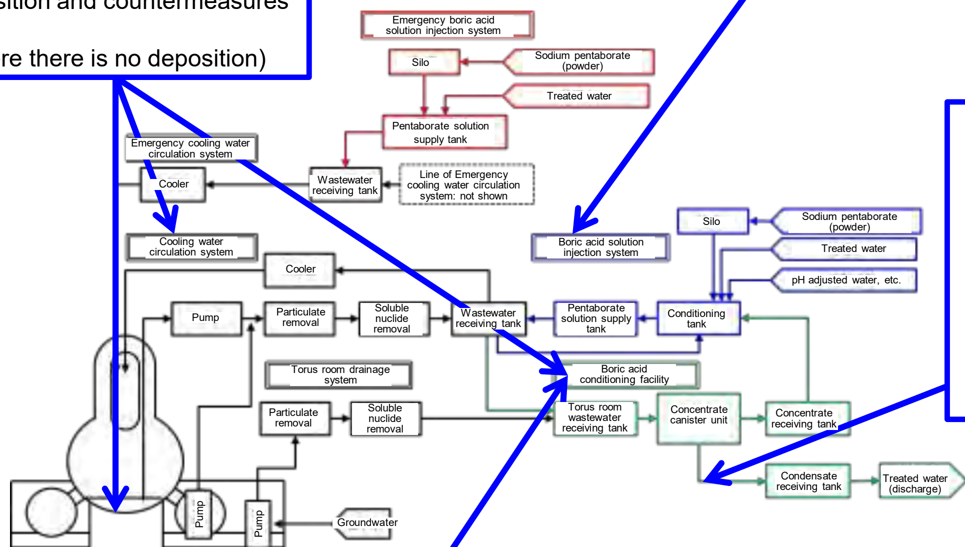
(Study of operating condition range where there is no deposition)

Issue ② Amount of sodium pentaborate and pH regulator to be injected

Loss of boric acid inside the systems (PCV, circulation loop, boric acid conditioning facility) (increased burden on the boric acid injection system)

•Confirmation of deposition conditions, confirmation of boric acid adsorption amount in nuclide removal (confirmed in the previous section a.)

•Evaluation on the amount of loss of boric acid



Issue ③ Amount of sodium pentaborate migrated

Amount of boric acid migrating to the destination and its impact

- Confirmation of boric acid recoverability (element test)
- Checking the amount migrating to the destination and its impact

Issue ④ Operation and maintenance policy of boric acid conditioning facility

Operation and maintenance policy under actual operating environment

- Confirmation of DF performance in boric acid environment (confirmed in the previous section a.)

7. Implementation items of this project [2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

○ Workflow

To prevent insufficient data at the system design stage, the basic physical properties of sodium pentaborate will be organized based on the results of studies conducted in the subsidy projects so far and additional literature research, and the missing data will be collected through element tests.

FY2019 to FY2020 (first half)

Study and investigation of the issues

1.Organizing the preconditions

① Organizing the preconditions for using sodium pentaborate solution
(a) Organizing the criticality control plan
(b) Organizing the assumed conditions
(c) Creation of system function diagram

2.Identifying the test items

② Creation of list of properties of sodium pentaborate solution
(a) Literature research (includes organizing the results of past subsidy projects)
(b) Creation of physical property list

[Preliminary test]
Confirmation of missing physical properties

③ Material balance evaluation under the conditions assumed in 1F (Identifying the concerns)
(a) Conditions for material balance evaluation
(b) Results of material balance evaluation

④ Study on measures for addressing the concerns

[Preliminary test]
Confirmation of evaluation conditions / evaluation results related to the concerns

⑤ Organizing the insufficient data / technical issues (test items) from the viewpoint of 1F design

Study and investigation of the issues

FY2020

Organizing the requirement specifications for operations

3. Drafting the element test plan / 4. Element tests

⑥ Element tests
(a)Setting of test conditions ….Setting the conditions based on the results of material balance evaluation.
(b)Drafting of testing method ….Drafting the testing method using the literature research results in ①
(c)Element tests

⑦Creating the list on physical properties of sodium pentaborate solution for the 1F design

○ **Goal**
Implementing the important processes required in criticality control using soluble neutron absorbers: Organizing the design requirements (equipment needs), determining the specific details for the configuration of facilities

7. Implementation items of this project
[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

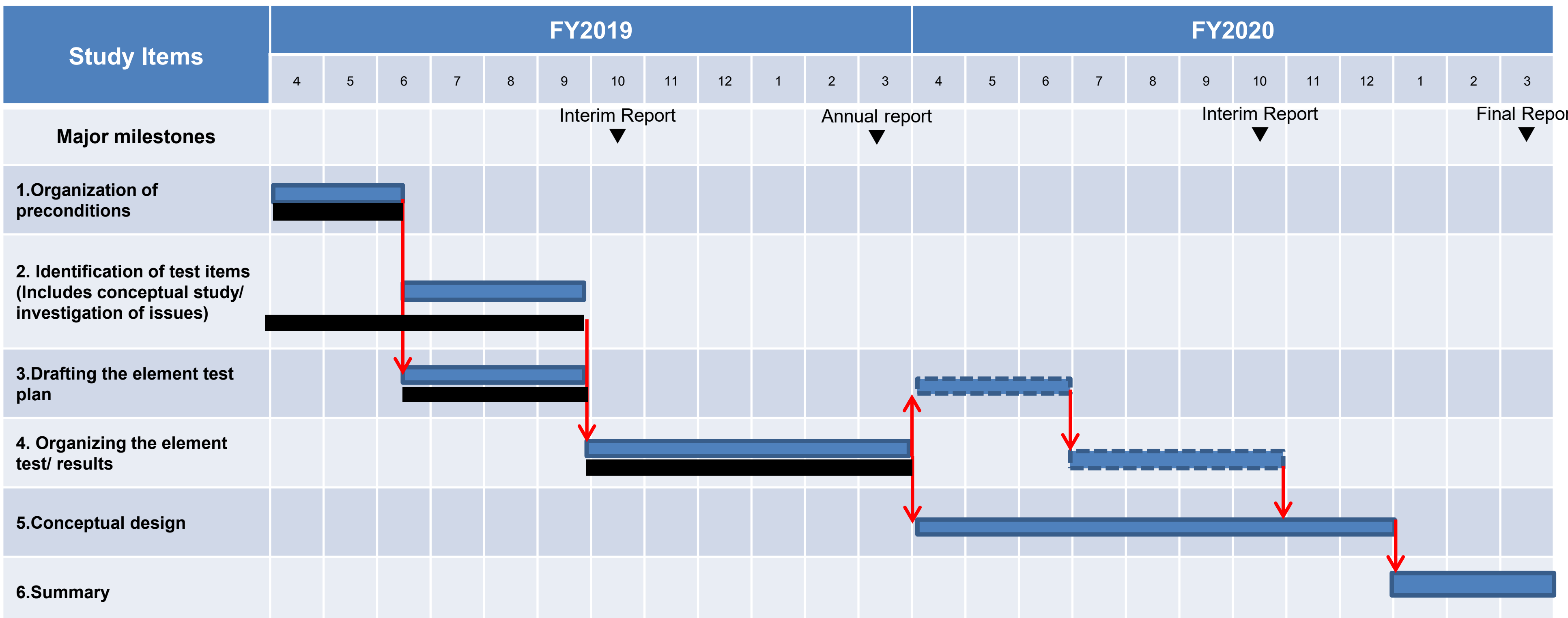
b. Conceptual design of boric acid conditioning facility

◯ Future Plans

<Plan for FY2020>

- Evaluation of deposition element test results using Ca and B deposits and Na/B ratio change.
- Additional tests shall be performed if required.
- At the same time, countermeasures for the deposits shall be studied.

◯ Schedule



7. Implementation items of this project [2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

① Organizing of preconditions for using sodium pentaborate solution

In addition to studying the development issues in using sodium pentaborate solution, the following was studied for organizing the preconditions.

● **Organizing the Criticality Control Plan**

・ Safety requirements

Prevention of generation of abnormal radioactive materials due to nuclear reaction

・Functional requirements

Level 1: Maintaining subcriticality within the control criteria values

Level 2: Preventing criticality by detecting the approach to criticality of the assumed abnormality and stopping the retrieval operation

Level 3: Detecting criticality and stopping the operation immediately.

・ Means of achievement

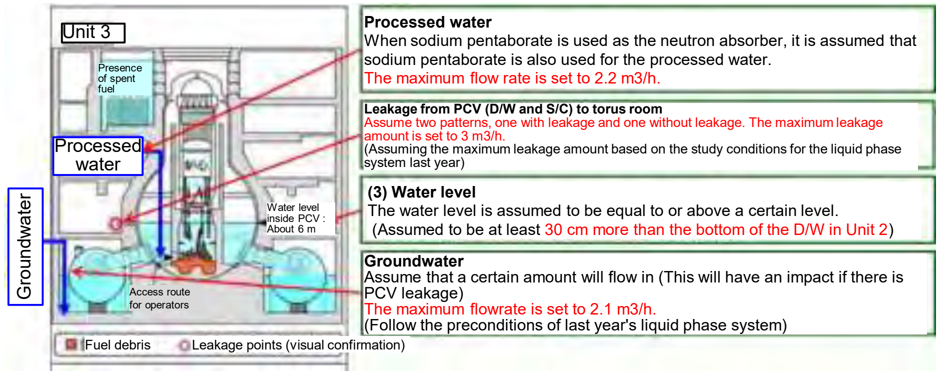
Maintaining subcriticality using neutron absorber (sodium pentaborate solution) and stopping abnormalities

● **Organizing the assumptions**

● **Creation of system functions diagram**

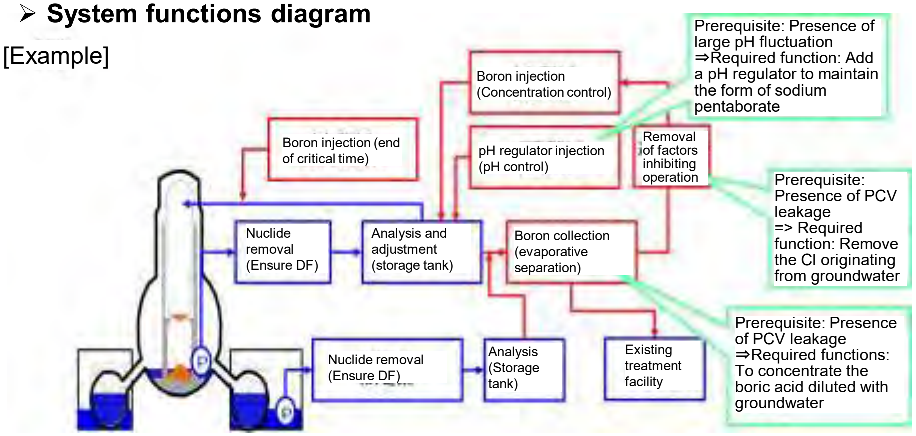
To organize the material balance evaluation conditions assumed in 1F based on the preconditions

➢ **Example of assumed conditions (around PCV)**



➢ **System functions diagram**

[Example]



7. Implementation items of this project
[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

② Organizing the physical properties of sodium pentaborate solution

Studies on the physical properties of sodium pentaborate solution and literature research on deposition were carried out.

● Study results

(i) Ca ion: Possibility of formation of deposits in coexistence with approximately 200 mg/L of Ca ions

(ii) Mg ion: Possibility of formation of deposits in coexistence with approximately 350 mg/L of Mg ions

(iii) Na/B ratio: Possibility of formation of deposits when the NaB ratio (molar ratio) deviates from the ra ... orate it is us

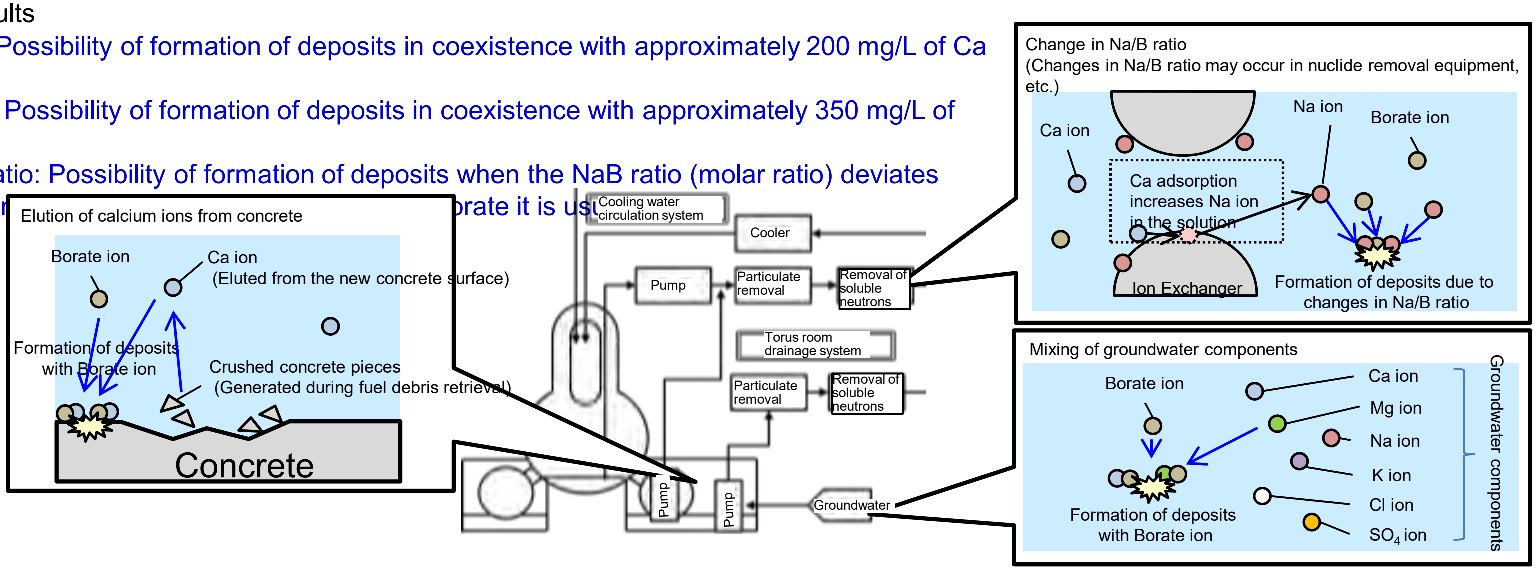


Figure. System during fuel debris retrieval, and contaminants from concrete and groundwater

③ Material balance evaluation under the conditions assumed in 1F

Based on the preconditions, the conditions for material balance evaluation assumed in 1F are organized, and material balance evaluation is carried out for items of concern such as usage amount of B.

Determine the need for data acquisition by evaluating the level of impact, and deploy it in the test plan.

7. Implementation items of this project
[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

④ Study on measures for addressing the concerns
⑤ Organizing insufficient data / technical issues (test items) from the viewpoint of 1F design

Based on literature research, etc., the initiating events, event progression and issues, countermeasures, and test items related to the concerns that may be expected when using sodium pentaborate solution, were organized.

● Organizing the results related to deposition

Initiating events | **Possible event progression** | **Issues, countermeasures and test items**

Initiating event: Cutting of fuel debris

Cutting of fuel debris → Elution of Ca ions (Generated from concrete) → Deposition reaction of Ca ion and Borate ion

Initiating event: Contamination of groundwater

Contamination of groundwater → Increase in Na ions ➡ Change in Na/B ratio → Deposition due to change in form of borate ion in solution (formation of low solubility compound)

Form	Chemical formula	Solubility (g/L as B)
Sodium pentaborate	$Na_2B_{10}O_{16} \cdot 10H_2O$	49 (30℃)
Boric acid	H_3BO_3	12 (30℃)
Sodium tetraborate	$Na_2B_4O_7 \cdot 10H_2O$	7.8 (30℃)

Contamination of groundwater → Increase in Ca / Mg ions → Deposition reaction of Ca/ Mg ions and borate ions

Issues, countermeasures and test items

[Issues]
・Reduction of boric acid concentration
・Blockage due to deposition
・Impact on system equipment
(increased burden on filter)
(Degraded performance of coolers, etc.)

[Countermeasure]
・Prevention of deposition by operation management
→ Control of Ca ions/ Mg ions
→ Adjustment of Na/B ratio
・Removal of deposits

[Test items]
・Checking the criteria for operations management
→ Allowable limits for Ca ion and Mg ion
→ Allowable limit of Na/B ratio
・Checking the removal method of the deposits
→ Composition of the deposits, etc.

7. Implementation items of this project
[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

⑥ Element test

[Purpose]
- **To confirm the deposition behavior of sodium pentaborate solution, and study the countermeasures (Control criteria for preventing deposition, method for maintaining boric acid concentration, etc.)**

[Issues]
- **The Ca ions, Mg ions, etc., contained in concrete may react with borate ions to form deposits. The impact in this case (concentration range, temperature range, and impact of coexisting ions) is unclear.**
- **The borate ions may form deposits due to an increase in low-solubility boric acid compounds due to changes in Na/B ratio. The impact in this case (dissolution / deposition range) is unclear.**

[Implementation Details]
- **Confirming of dissolution / deposition behavior of sodium pentaborate in the event of coexistence with Ca ions, Mg ions, and other impurities**
- **Confirming of dissolution / deposition behavior during change in Na/B ratio**
- Study on the methods for removing deposits
- Study on the control methods for impure ions and Na/B ratio

[Goal]
- Determination of control criteria for concentration of impure ions (specifically Ca, Mg), Na/B ratio, etc.
- Drafting of countermeasures for deposits

7. Implementation items of this project
[2) (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

⑥ Element test

[Test condition range and expected outcome]

Table　Test Conditions

Items	Testing range	Remarks
B concentration (mg/L as B)	510 ~ 10000	
Na/B ratio	0.06 ~ 1.0	Set based on the literary fact of possibility of deposition at 25℃
Ca ion concentration (mg/L)	0 ~ 800	Set based on the saturated concentration of Ca $(OH)_2$
Mg ion concentration (mg/L)	0 ~ 800	Set by assuming equivalence to Ca

Table　Diagram on control criteria values

Items	Control values	Remarks
B concentration (mg/L as B)	510 ~ 10000	
Na/B ratio	XX ~ XX	Range where there is no deposition at 20℃
Ca ion concentration (mg/L)	< XX	Range where there is no deposition at 20℃
Mg ion concentration (mg/L)	< XX	Range where there is no deposition at 20℃

[Testing Method]
- Prepare the specified solution and stir it for the specified amount of time and temperature
- After the specified time, filter the solution and separate the filtrate, filter and beaker cleaning solution.
- Perform component analysis of filtrate and filter (B, Na, Ca, Mg, etc.)

[Evaluation method]
- Analyze the target components in the solution and in the collected solids, and determine the amount of deposition of the added elements and boron components
- Find the concentration range of each component where there is no deposition of boron components.

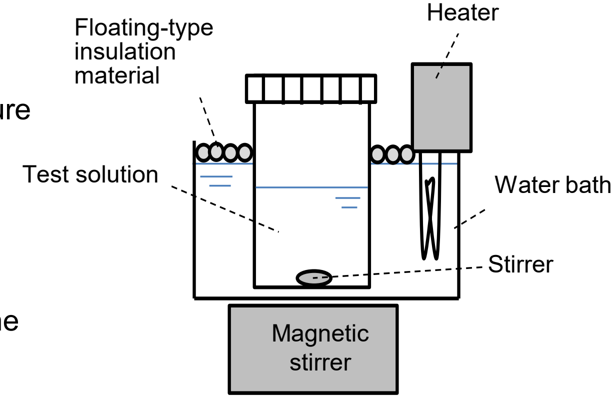


Figure. Test equipment

7. Implementation items of this project
[2] (ii) ① Removal technology for soluble nuclides in circulating cooling water]

b. Conceptual design of boric acid conditioning facility

⑥ Element test

[Effect of Ca ions]
- While adding Ca $(OH)_2$, deposition was confirmed at 380 mg/L or higher Ca.
- The Ca/B molar ratio of deposits was approximately 0.3. Based on the literature information, the deposits are assumed to be $Ca_2B_6O_{11} \cdot 13H_2O$.

[Effect of Na/B ratio]
- Deposition was seen when Na/B ratio was < 0.1.
- Most of the deposits are B, and based on the literature information, the deposits are assumed to be H_3BO_3.
- The tests are progressing as planned, and the results are also being obtained as per the plan.

<Test conditions>
Solution: sodium pentaborate 6000 mg/L as B
(Testing underway for cases where sodium pentaborate concentration is changed)
Temperature: 20 ℃

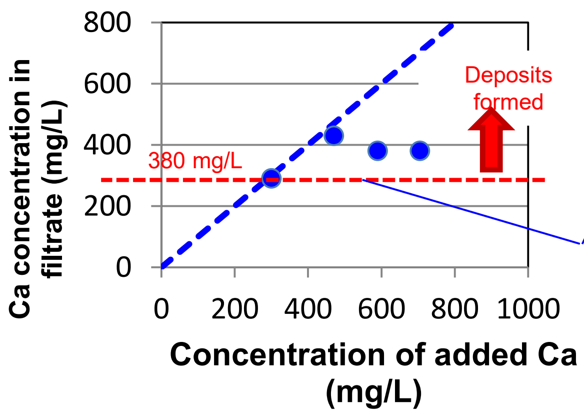


Figure.1 Overview of deposition test results by adding Ca

Appearance of deposits when 590 mg/L as Ca is added

Appearance of deposits when Na/B ratio is 0.08

<Test conditions>
Solution: With sodium pentaborate 6000 mg/L as B, adjust Na/B ratio by adding boric acid or sodium hydroxide
(Testing underway for cases where sodium pentaborate concentration is changed)
Temperature: 20 ℃

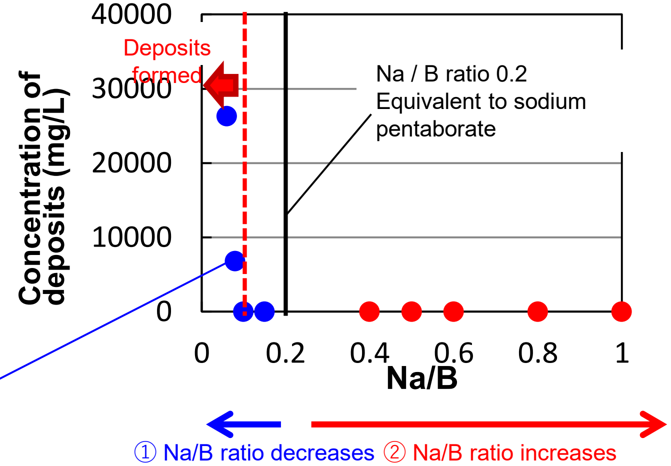


Figure.2 Impact confirmation test for change in Na/B ratio

7. Implementation items in this project

2) Development of technology for processing fuel debris

(ii) Technological development of treatment for fuel debris and deposit

② Treatment technology for deposits collected from inside PCV

When collecting deposits containing fuel debris that is present at the bottom of PCV, wastewater containing deposits is generated. Also, during the fuel debris retrieval operation, wastewater containing solid matter is generated when the filter of the circulating water system is backwashed. When handling and storing these, it is necessary to separate the solid components from the liquid from the viewpoint of safety, volume reduction, and the like. Therefore, regarding the treatment technology for separating solid material from the wastewater and storing it, technology considering storage efficiency, remote operations, maintenance, etc., was developed and a conceptual system of the wastewater treatment equipment was designed.

The main development study items included the following, and the issues were identified and organized by performing element tests wherever required.

a. <u>Characterization of collected wastewater</u>

・ A differential pressure countermeasure test was partially conducted on an intermediate removal filter, which is a candidate device for removing insoluble nuclides.

b. <u>Development of technologies for separating solid material from wastewater and storing it</u>

・ As a technology for separating solids from collected wastewater, the applicability of separation using sedimentation separation is being verified.

7. Implementation items in this project

2) Development of technology for processing fuel debris
(ii) Technological development of treatment for fuel debris and deposit
② Treatment technology for deposits collected from inside PCV

The conceptual diagram of the contaminated water treatment system during fuel debris retrieval is shown below.

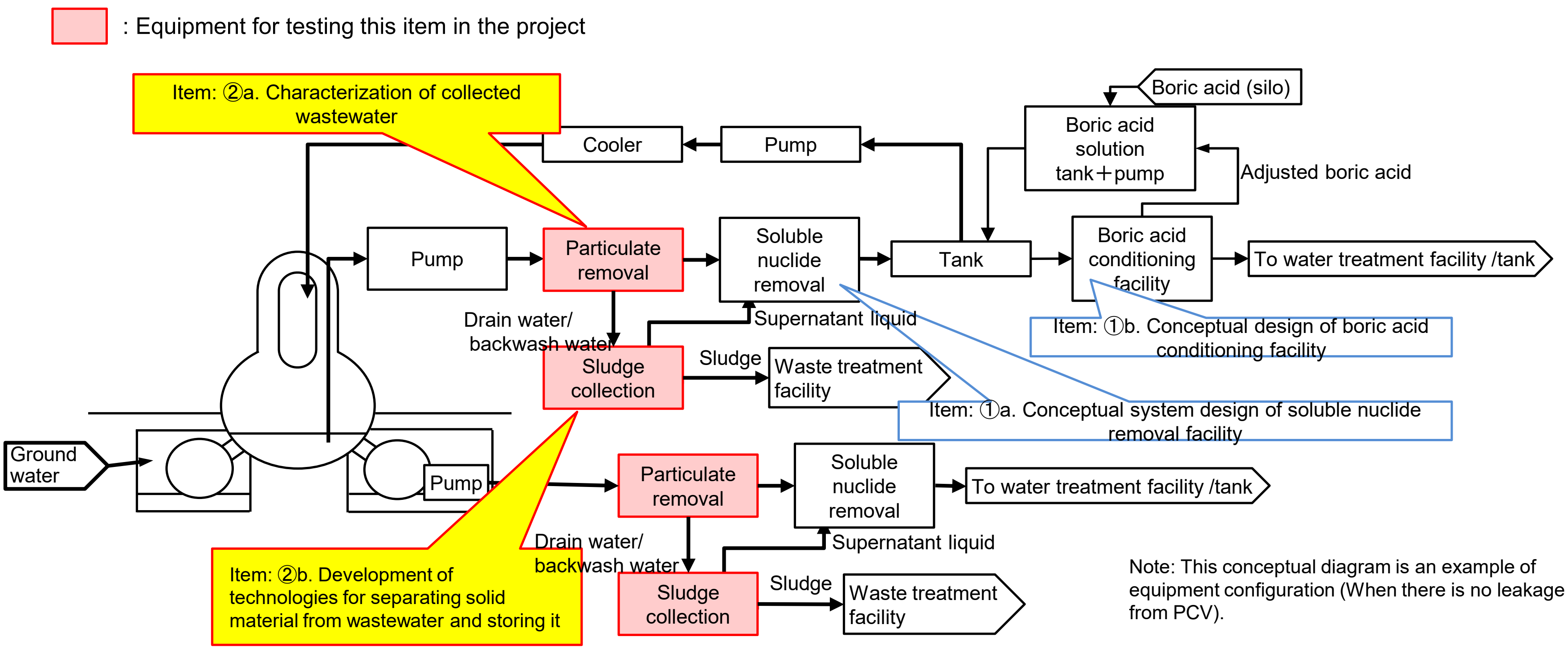


Figure. Liquid system during fuel debris retrieval (conceptual diagram) and implementation targets for element tests

7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

- Purpose of development

  In order to select the particulate collection equipment to be used in the insoluble nuclide removal facility, data such as particulate collection rate, differential pressure behavior, and properties of wastewater was acquired by performing a filter water flow test.

- Issues to be solved
  - Particulate collection technology to be used has not been selected.
  - Optimization of particulate collection equipment design is required.
  - There is insufficient data on the backwash performance, etc. of particulate collection equipment for long-term water flow.

- Approaches to development

  ① Filter load optimization test
  ② Backwash conditions optimization test
  ③ Impact assessment test of insoluble criticality inhibitor (conducted as needed)
  ④ Long-term water flow test

- Expected outcome

  Design optimization and acquisition of operational data on particulate collection equipment candidates to be used in particulate removal equipment.

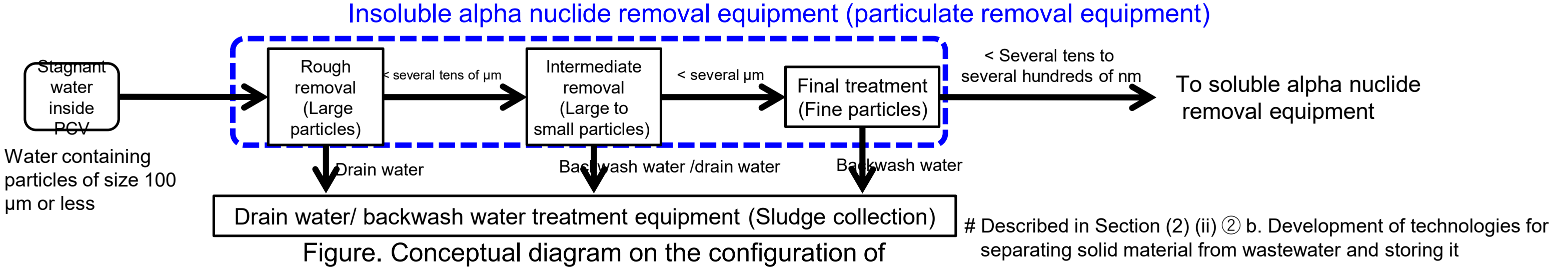


Figure. Conceptual diagram on the configuration of particulate removal equipment system

7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

➢ **Study Flow: In this project, design optimization of the candidate equipment identified in the previous subsidy project and acquisition of long-term operation data was performed and was reflected in the conceptual system design.**

FY2019 | FY2021

Previous subsidy project | This PJ | After FY2021

Previous subsidy project

- Study on the liquid-phase particulate removal concept flow
- Study on technology benchmarking
- Candidate device applicability confirmation test

This PJ

- Optimization of particulate collection candidate equipment design
- Acquisition of operational data for long-term water flow
- Conceptual system design

After FY2021

- Confirming the properties of actual liquid
- Conceptual design based on the properties of actual liquid
- Basic design and detailed design

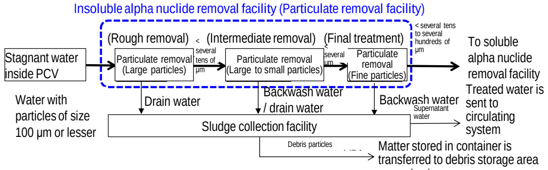


Figure. Conceptual flow of liquid-phase particulate removal system

Table: Test results of FY2018

	Rough removal	Intermediate removal	Final treatment
Equipment	Auto strainer Liquid cyclone	Auto strainer Inorganic filters#1	Inorganic filters #1
Collection rate	High	High	High
Increase in differential pressure	Minimal	Large (High frequency of backwash)	Less

#1: Candidates for Inorganic filters include sintered metal filters and ceramic filters.

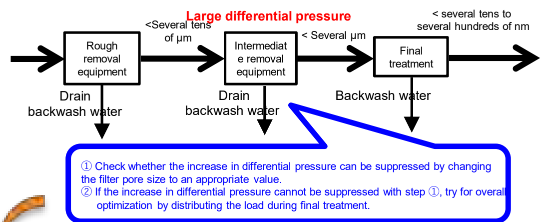


Figure. Illustration of the study on intermediate removal optimization

INPUT the optimized conditions

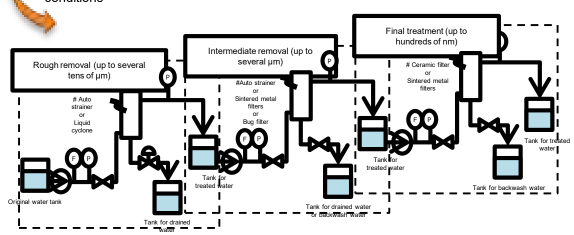


Figure. Illustration of long-term water flow test

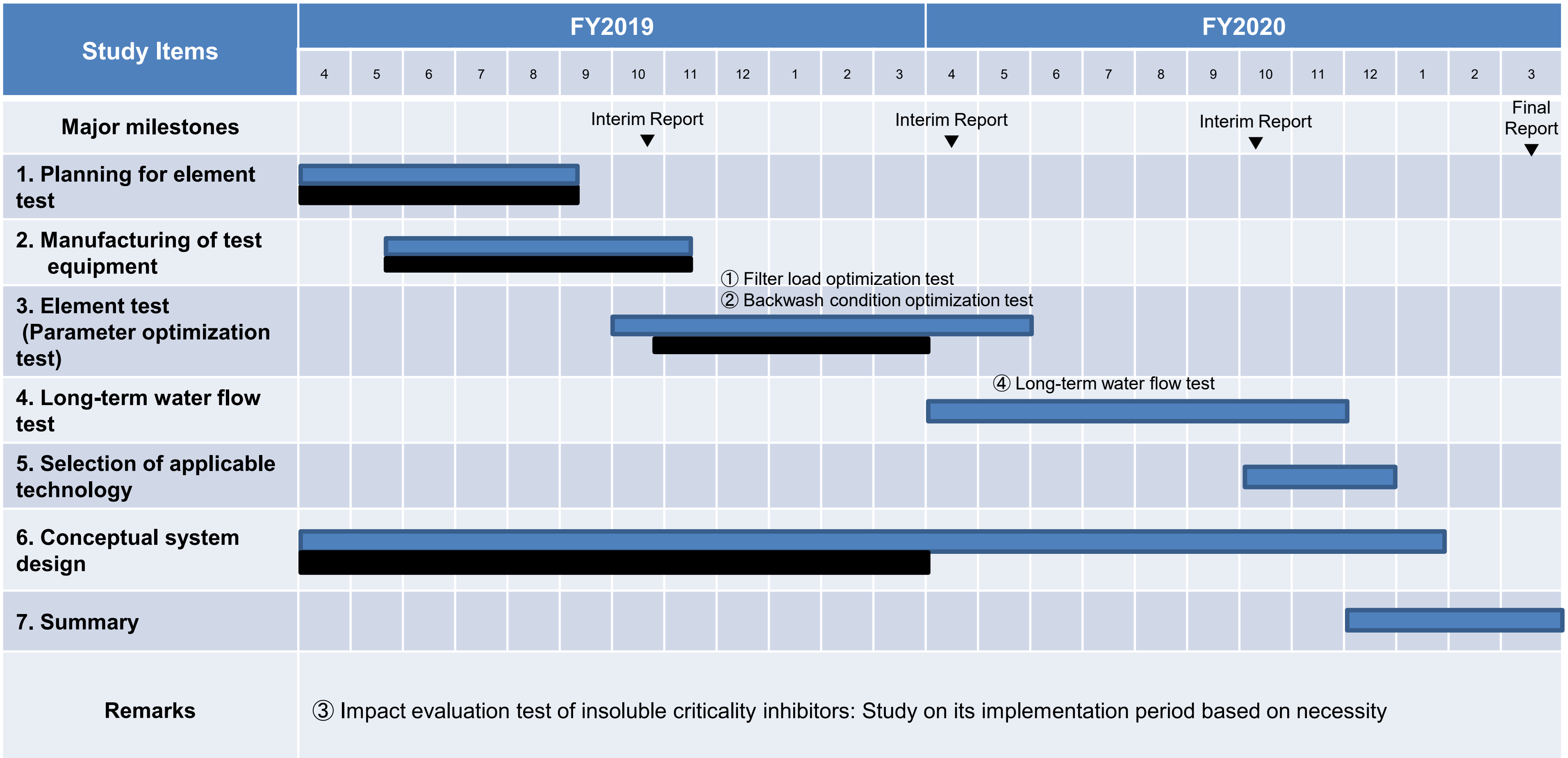
Specific approaches after FY2021 will require coordination with operator's engineering department.

7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected iquids, wastewater

■ Development Schedule



7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

➢ Preconditions

✓ **Applicable particulate collection equipment candidates**

The selections were made as shown in the table below based on the test results up to the previous year, and literature research.

Table: Filter water flow test List of particulate collection equipment

No.	System	Particulate collection equipment	Mesh size of filter	Remarks
1	Rough removal	Auto strainer	50 µm	Select the same mesh size as used in the FY02018 subsidy project
2	Intermediate removal	Auto strainer	10, 20 µm	As the differential pressure increased significantly when using auto strainer with a mesh size of 5 µm, the test was conducted using filters with a larger mesh size.
		Sintered metal filters	2, 5, 10, 20 µm	As the differential pressure increased significantly with the sintered metal filters with a mesh size of 2 µm, the test was conducted using filters with a larger mesh size.
3	Final treatment	UF membrane (Ceramic filter)	10, 50, 100 nm	As the increase in differential pressure was gradual for UF membranes with mesh sizes of 50 and 100 nm, tests were also conducted for a 10 nm UF membrane.

Current report

✓ **Simulated particle composition**

The components of fuel debris are roughly divided into fuel components, structural material components, and concrete components. The composition of particles used for simulating each component were set as shown in the table below.

Table: Filter water flow test Simulated particle composition

No.	Simulation target		Simulated particles	
	Particle composition	Relative density	Particle composition	Relative density
1	Uranium dioxide	Approx.11	Tungsten carbide	Approx.15
			Tungsten dioxide	Approx.11
2	Core internals	Approx.8	SUS316L	Approx.8
3	Concrete	Approx.2 to 3	Silica sand	Approx.3

7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

➢ Preconditions

✓ **Filter water flow test - Testing Conditions**

The common conditions for the filter water flow test were set as shown in the table below based on the liquid conditions of the water to be treated.

Table: Filter water flow test - Testing Conditions

No.	Items	Conditions	Remarks
1	Temperature	Room temperature (approximately 25℃)	The temperature was set to room temperature as it was considered that the removal performance had less dependency on temperature.
2	pH	Neutral (unadjusted)	Though the particles may aggregate, deposit, and dissolve due to the impact of pH, the factors that change in such cases are particle size and SS concentration. Since the particle size and SS concentration are evaluated as test parameters in this development, it is considered that data contributing to the performance evaluation can be obtained even if the actual pH and the test pH are different.
3	Sodium pentaborate	0 ppm	Not added, as the effect of sodium pentaborate was considered to be small based on the results of the subsidy project in FY2018.
4	Salt content	0 ppm	The operation during fuel debris retrieval varies depending on the presence or absence of PCV leakage. However, even under the condition of PCV leakage with high salt concentration where the salt concentration is about several hundred ppm of chloride ions, its contribution to the density and viscosity of the fluid is small, and hence not considered.
5	SS concentration	30 ppm ~ 300 ppm #	The basic condition was set to 100 ppm, the accelerated test condition was 300 ppm, and the condition considered for rough removal was 30 ppm.
6	Particle size	0.1 μm ~ 100 μm	Estimated particle size collected with non-soluble nuclide removal equipment
7	Flow rate	3 ~ 10 m^3/h #	The basic condition was set to 10 m^3/h considering the current rate of coolant injection as 3 m^3/h, and anticipating the amount of water expected to be used in the retrieval operation.

The test conditions were adjusted so that the load on the filters is the same (Example: Flow rate 10 m^3/h x SS concentration 100 ppm ≒ Flow rate 3 m^3/h x SS concentration 300 ppm)

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

➢ Test results

- ✓ The test was conducted under the condition of changing the filter pore size (5 → 20 μm) and eliminating the maintainability of SS concentration (100 ppm → 30 ppm), but there was no change in the differential pressure increase time (liquid flow time).
- ✓ When the particle size was set to 50 to 0.1 μm, which is the assumed size in the actual water system, the increase in differential pressure was mitigated, but the particle collection rate decreased.
- ✓ The impact of the decrease in particle collection rate needs to be evaluated because it will be a load during the final treatment in the subsequent stage.

Table: Summary of FY2018-2019 test results

	FY2018	FY2019	
Equipment	Auto strainer	Auto strainer	
Filter pore size	5 μm	20 μm (close to the pore size of rough removal where the differential pressure was relatively small)	
Particle size	5 μm each	50 μm each	Mix of 50 ~ 0.1μm (Assumption in actual water system)
Flow rate	10 m^3/h	10 m^3/h	
SS concentration	100 ppm (Not considering rough removal)	100 ppm, 30 ppm (Considering the presence or absence of rough removal)	30 ppm (Considering rough removal)
Particle collection rate	Approximately 90%		**About 30% (The remaining about 60% will become the load for final treatment)**
Increase in differential pressure	Large (Liquid flow time approx. 10 sec)		**Small (Liquid flow time approx.10 min[#1])**

#1: Value estimated from differential pressure trend (calculated by creating an approximation curve from the test data)

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

a. Characterization of collected liquids, wastewater

➢ **Summary**

- ✓ In the current test, a prospect of approximate liquid flow time of 10 min was obtained. However, as the frequency of backwashing is high even under these conditions, it is presumed that measures such as adding multiple intermediate removal systems is necessary while implementing intermediate removal.

➢ **Future plans**

- ✓ Load optimization test for final treatment.
- ✓ Study on adding multiple intermediate removal systems.
- ✓ Long-term water flow test by combining rough removal, intermediate removal (if necessary) and final treatment

Table: Relationship between duration of liquid flow and amount of drain / backwash water (reference)

Duration of liquid flow	Amount of drain / backwash water #1 (m^3/y)	Frequency of drain / backwash (times/y)	Concentration rate #2 (times)
10 sec	2207520	3153600	0.04
10 min	36792	52560	2.4
1 h	6132	8760	14
24 h	256	365	343

#1: The assumed total amount of drained and backwash water per 1 time is 700 L.
#2: Amount of water flow per year (10 m^3/h x 24 h/d x 365 d/y = 87600 m^3/y) ÷ amount of drained or backwash water

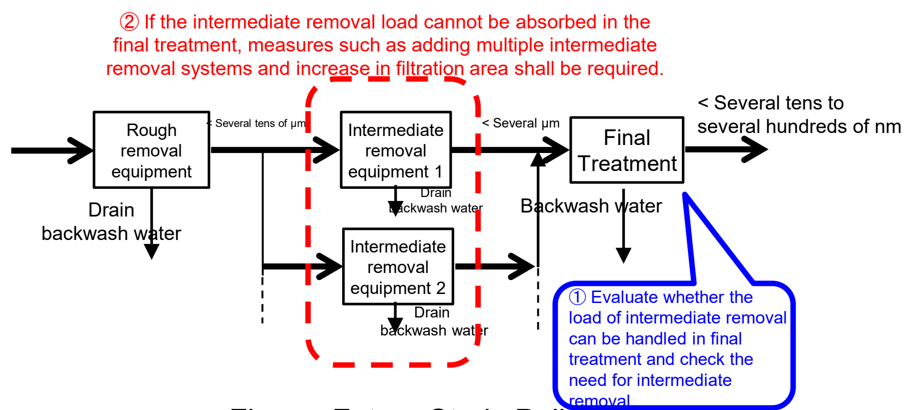


Figure. Future Study Policy

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

- Purpose of development
  - The technology for the separation of solid materials present in wastewater generated from particulate removal equipment, was selected.
  - The practical applicability of the selected technology for solid-liquid separation was evaluated through element tests.
- Issues to be solved
  - It takes some hours to several tens of hours for the fine particles contained in the wastewater to settle naturally, and it is necessary to develop a technology that promotes solid-liquid separation.
  - Insufficiency in the data required to identify the equipment considering the storage, remote operations, maintenance, etc., of separated solid materials.
- Approaches to development
  - Selection of technology for solid-liquid separation through literature research.
  - Selection of aggregating agents through literature research.
  - Preliminary tests for the selection of aggregating agents.
    - ① Confirming the sedimentation separation effect of aggregating agents using simulated wastewater (beaker scale test)
    - ② Evaluating the effects of aggregating agents on adsorbents (batch test)
    - ③ Designing and manufacturing of testing facility (sedimentation separation tank)
  - Element tests to confirm the actual applicability of sedimentation separation tank.
    - ④ Aggregation sedimentation test using the sedimentation separation tank
    - ⑤ Evaluating the effects of aggregating agents on adsorbents (batch test, column water flow test)
- Expected outcome
  - Evaluation of the results on actual applicability of aggregation sedimentation technology by the addition of aggregating agents.
  - Conceptual design of sedimentation separation tank and acquisition of operational data.

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

➢ **Study Flow: In this project, the applicability of aggregation sedimentation was confirmed using a beaker test, and the operation and operability was tested using device testing.**

FY2019 (Start of this PJ)

FY2020

FY2021 (End of this PJ)

After FY2021

Selection of technology for separation (See table below) → Aggregation sedimentation beaker test → Device testing and conceptual design → Confirmation of actual liquid properties and conceptual design → Basic / detailed design

(Results)
・Aggregation sedimentation
・Applicability of inorganic aggregating agents

(Results)
・Applicability of aggregation sedimentation
・Candidates for aggregating agents

(Results)
・Equipment / process concept
・Operation and operability

Table Features of solid-liquid separation method and applicability to sludge collection (Summary of literature research)

Solid-liquid separation method	Features	Applicability to sludge collection
Aggregation sedimentation	**・Separability mainly depends on surface properties of the particles (charge, etc.).** **⇒ There is redundancy even when the particle size fluctuates slightly.** ・Aggregating agents are basically inorganic in consideration of their contact with fuel debris. ・The effect of aggregating agents on the adsorption systems in later stages is unknown.	○
Centrifugal separation	・The structure is simple, and maintainability is excellent. ・Separability strongly depends on particle size and relative density.	△
Filtration	・Separability strongly depends on particle size. ・Separation of fine particles might be accompanied by a significant increase in differential pressure. ・Excellent for dehydration (filter press, etc.).	△
Floatation	・Strongly dependent on the relative density of the particles (it does not float if the relative density is high). ・It is necessary to study the recovery method of floating particles.	x

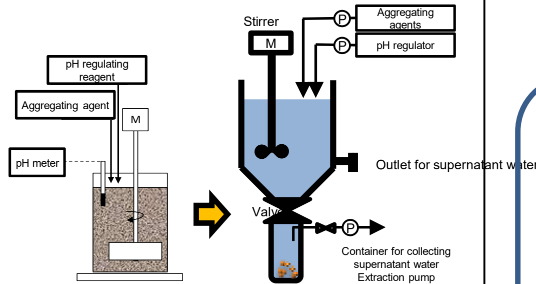


Illustration of beaker test **Illustration of device test**

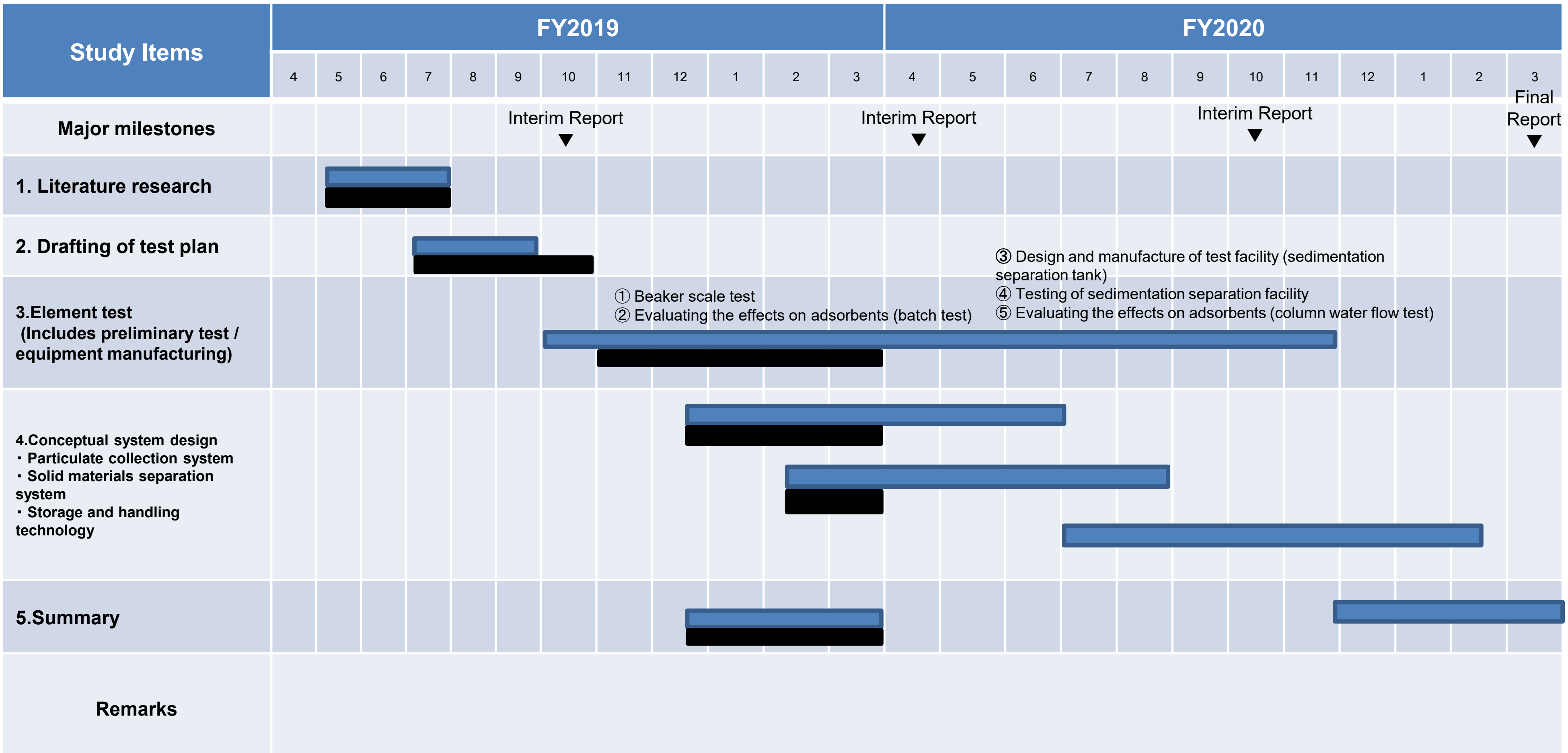
Items to be confirmed in the tests
・Time for sedimentation, sludge volume and impact on the adsorbent
・Impact of parameters such as pH, water temperature, presence or absence of boric acid, etc.

Specific approaches after FY2021 will require coordination with operator's engineering department.

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

➢ Development Schedule



7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

➢ Test details and preconditions

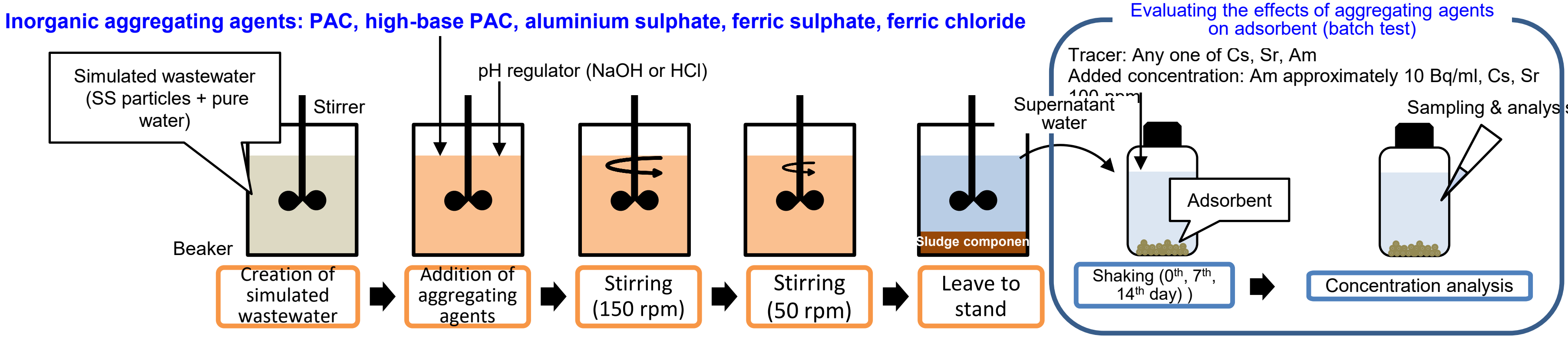


Figure. Illustration of beaker scale sedimentation separation test and batch test for evaluating impact on adsorbent

Table: Preconditions for beaker scale sedimentation separation test

No.	Items	Test conditions	Basis for setting the conditions
1	Concentration of aggregating agents	100 ~ 1500 ppm	Set based on the value recommended by the manufacturer.
2	SS type	① SiO_2 only (standard condition) ② Three component mixture (WC, SUS, SiO_2)	① Only SiO_2 was set as a conservative condition (which is difficult to settle). ② For comparison, the test was also conducted with the condition of three-component mixture simulating the actual wastewater.
3	SS particle size	0.1 ~ 100 μm (Standard condition: 0.1 μm)	Set based on the particle size range of the particulate collection facility used in the previous stage.
4	SS concentration	2000 ~ 20000 ppm (Standard condition: 10000 ppm)	With 10000 ppm as the base, which is 100 times more concentrated than the inlet condition (100 ppm) of the particle recovery equipment in the previous stage, the fluctuating conditions are evaluated as parameters.
5	pH	7 ± approx.2 (Standard condition: 6 ~ 7)	The fluctuating conditions are evaluated based on the value 7 recommended by the manufacturer.
6	Temperature of water	10 ~ 40 ℃ (Standard condition: 25 ℃)	Standard condition is 25℃, taking seasonal fluctuations into consideration.
7	Impact on adsorbent	Adsorbent for Cs and Sr: Titanium silicate Adsorbent for alpha nuclide (Am) : Activated carbon	A typical adsorbent is selected from the results of previous studies. Tested with supernatant water with an aggregating agent added concentration of 1000 ppm (set from the previous beaker tests).
8	Sodium pentaborate	0 ~ 7000 ppm as B	Evaluate the effects of mixing boric acid in treated water.

7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

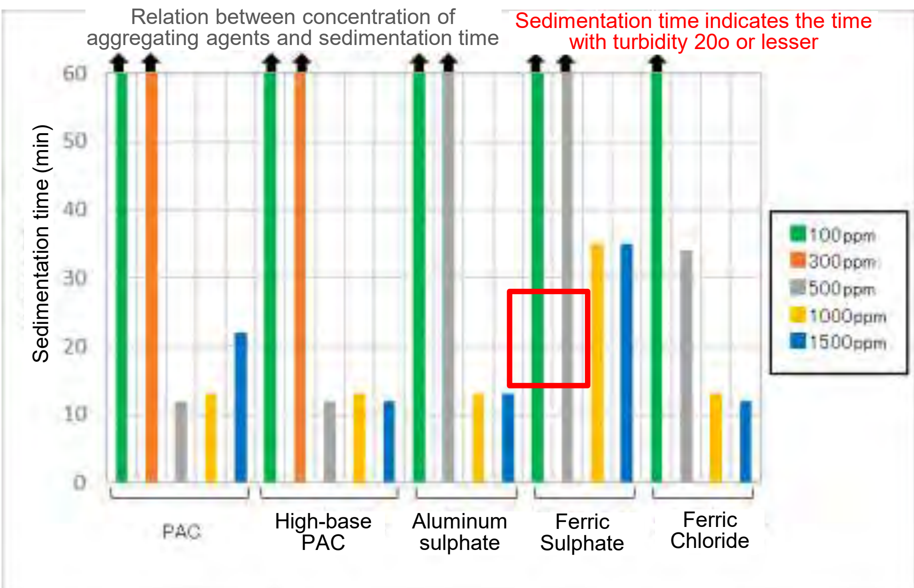
➢ Test results (example)

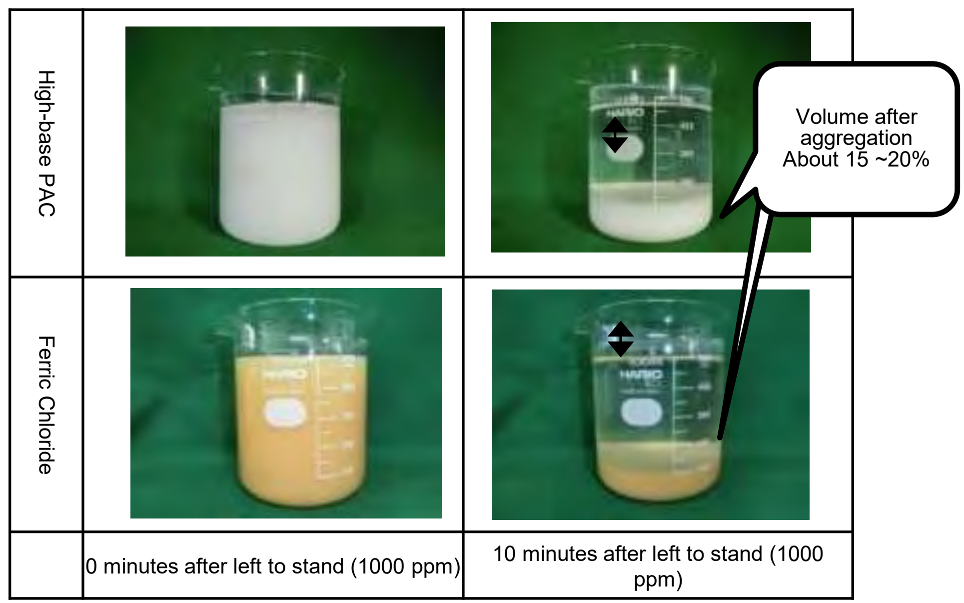
- ✓ Evaluation of the concentration of added aggregating agents and sedimentation time in boric acid-free system
- ✓ **All aggregating agents underwent aggregation sedimentation with an added concentration of 1000 ppm or more (sedimentation time was within 40 minutes).**
- ✓ PAC and high-base PAC sedimented well even at an added concentration of 500 ppm.
- ✓ Sedimentation time increased with PAC of 1500 ppm (If the amount added is too large, the sedimentation time becomes longer).

<Test conditions>

Concentration of aggregating agents: 100 ~ 1500 ppm, concentration of wastewater, silica sand (SiO_2) 0.1 μm 10000 ppm, Boric acid (B) 0 ppm, pH of wastewater (when adjusting pH after adding aggregating agents): 7±0.5

Temperature of water: 25℃, stirring speed / time: strong stirring 150 rpm x 5 min → weak stirring 50 rpm x 15 min, liquid volume 440 mL





7. Implementation items of this project

[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

➢ Test Results (Summary)

- ✓ The effectiveness of aggregation sedimentation in a boric acid-free system was confirmed.
- ✓ In the future, appropriate aggregating agents shall be selected by evaluating the effect of adding boric acid.

Table Test result summary of beaker scale sedimentation separation test

No.	Items	Test conditions	Test results
1	Concentration of aggregating agents	100 ~ 1500 ppm	・All of the aggregating agents showed aggregation sedimentation with added concentration of 1000 ppm or more. ・The relative merits and demerits of the aggregating agents is as shown below when determined based on sedimentation time and added concentration of the aggregating agents From the top: high base PAC, PAC ≒ ferrous chloride, aluminum sulphate, ferrous sulphate ・The standard added concentration is set to 1000 ppm for the parameter tests other than No.2
2	SS type	① SiO_2 only (standard condition) ② Three-component mixture (WC, SUS, SiO_2)	・Aggregation sedimentation was seen under both conditions ① and ②. Sedimentation time was about the same. ・The volume of the aggregated material is less in the case of the three-component mixture (presumed to be consolidated as it contains particles with a large relative density).
3	SS particle size	0.1 ~ 100 μm (Standard condition: 0.1μm)	・Sedimentation time is about 10 to 15 minutes at 0.1 μm and about 5 minutes at 1 μm or more. ・Larger particle size is more favorable for aggregation sedimentation.
4	SS concentration	2000 ~ 50000 ppm (Standard condition: 10000 ppm)	・Good sedimentation can be seen up to 20000 ppm (sedimentation cannot be seen for 50000 ppm) ・High-base PAC has a shorter sedimentation time with increasing SS concentration.
5	pH	7 ± approx.2 (Standard condition: 7±0.5)	・The suitable pH range for high-base PAC is pH 6 ~ 8.5, and ferric chloride is pH 4.5 ~ 7.1. ・Assuming that the actual pH is neutral to alkaline, it may be possible to reduce the amount of pH regulator used for high-base PAC.
6	Temperature of water	10 ~ 40 ℃ (Standard condition: 25 ℃)	・No impact was seen in this temperature range (the result was the same as the standard 25 ℃).
7	Impact on adsorbents	Adsorbent for Cs and Sr : Titanium silicate Adsorbent for alpha nuclide (Am) : Activated carbon	・No major change in adsorption performance even when supernatant water was added (removal rate was almost 100%)
8	Sodium pentaborate	0 ~ 7000 ppm as B	・Testing in progress.

Boric acid-free system

2.Progress of technology development (Element test results)

2) (ii) ②b. Development of technologies for separating solid material from wastewater and storing it

- **Summary of FY2019**
  - ✓ The applicability of separation using aggregation sedimentation was confirmed in a boric acid-free system.
- **Future plans**
  - ✓ To confirm the applicability of aggregating agents in boric acid-added system and conceptual process design based on those results.
  - ✓ To confirm the operability using aggregation sedimentation device testing, identify the issues, and study the countermeasures.

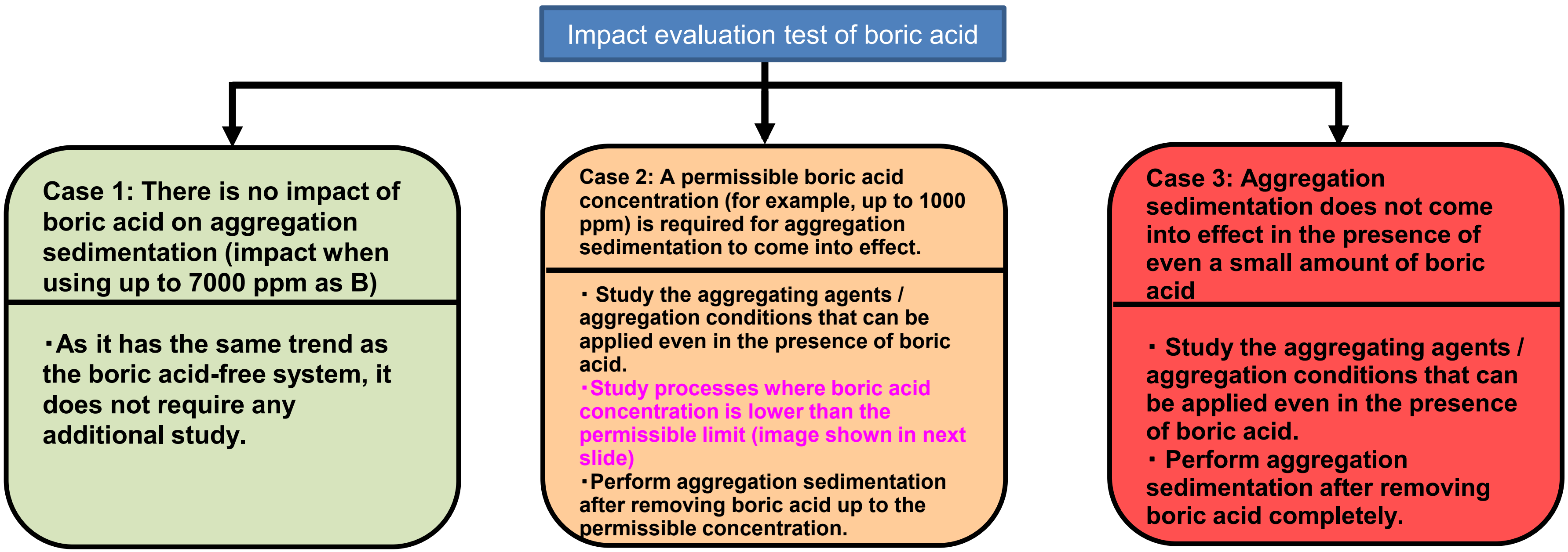


Figure. Trifurcation of study cases based on the impact of boric acid

2.Progress of technology development (Element test results)

2) (ii) ②b. Development of technologies for separating solid material from wastewater and storing it

➢ **Proposal for a conceptual system (reference) for the case with permissible boric acid concentration**

✓ Aggregation sedimentation may be applicable by using the external water that does not contain boric acid, for backwash water.

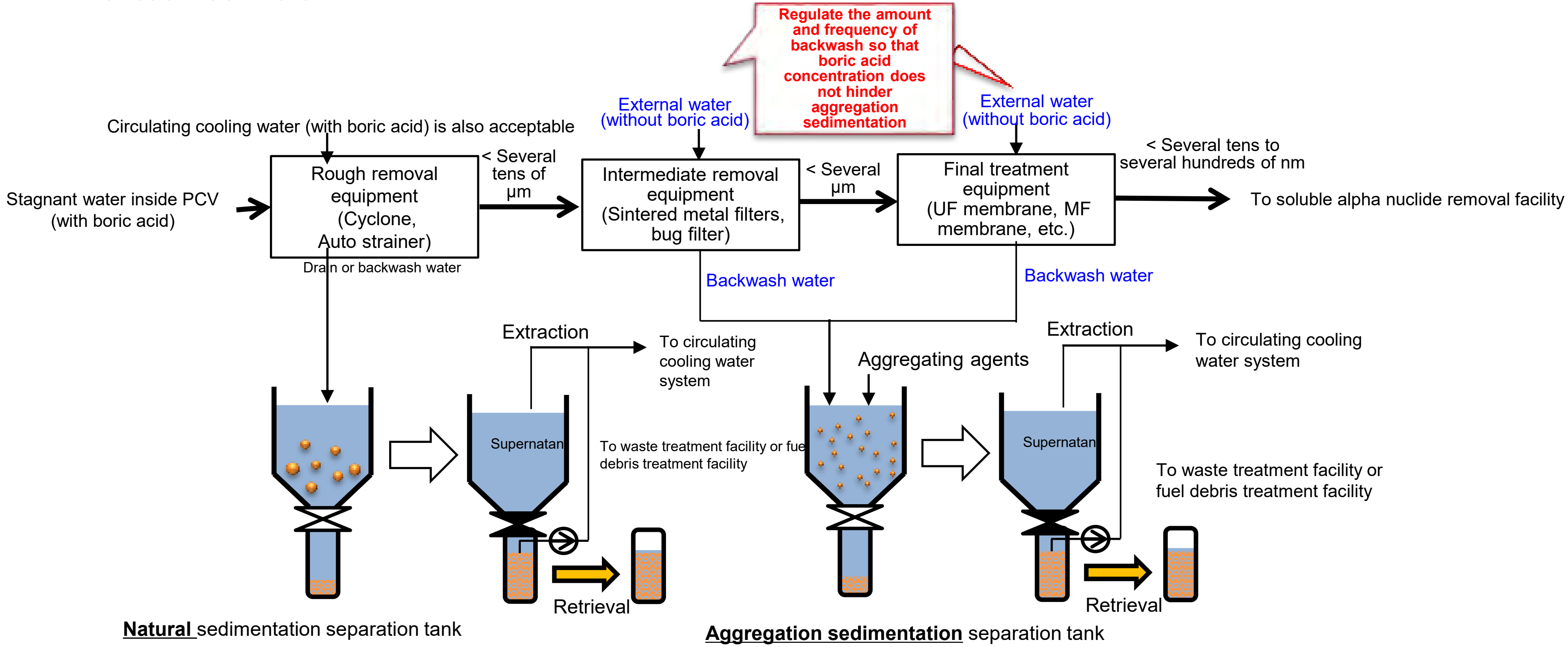


Figure. Conceptual plan for the aggregation sedimentation system (for the case with permissible boric acid concentration)

7. Implementation items of this project
[2) (ii) ② Treatment technology for deposits collected from inside PCV]

b. Development of technologies for separating solid material from wastewater and storing it

- **Design and manufacture of testing device (sedimentation separation tank)**

  ✓ The conceptual diagram of a testing device was created and the required equipment was identified.

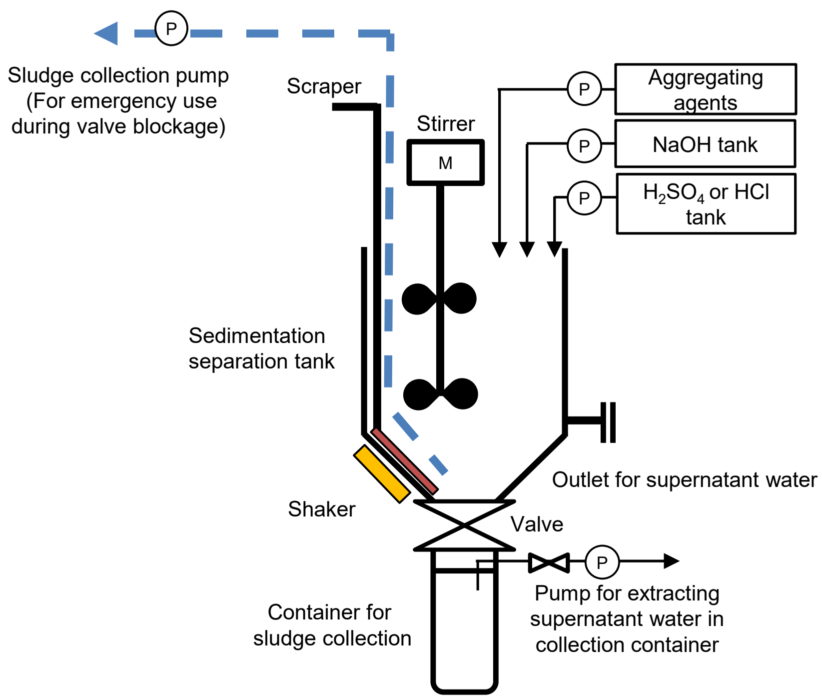


Figure. Conceptual diagram of testing device

Table: Proposal for testing device specifications

No.	Equipment name	No of units	Remarks
1	Sedimentation separation tank	1	The tank height is set based on the sedimentation time in beaker test.
2	Container for sludge collection	1	Made of acrylic. The shape, dimensions, and capacity are set with reference to the beaker test results and canisters.
3	Gate valve	1	Electrically-operated gate valve
4	Tank	3	Aggregating agents reagent x 1, pH reagent x 2
5	Pump	5	For supplying aggregating agents x 1, for supplying pH reagent x 2, for extracting supernatant x 1, for extracting sludge x 1
6	Stirrer	1	Set based on the stirring speed in the beaker test
7	Scraper	1	Manual type. To remove particles adhering to the tank.
8	Shaker	1	For removal of particles adhering to the tank and to prevent valve blockage
10	Pipe	1	For transferring water before and after treatment
11	pH meter	1	Assumed to have the same specifications as in the beaker test.
12	Turbidity Meter	1	Assumed to have the same specifications as in the beaker test.
13	Rack	1	For installing the facility

7. Implementation items in this project

2) Development of technology for processing fuel debris

(iii) Survey on sorting technology for fuel debris and radioactive wastes

The technologies required for sorting the fuel debris and radioactive wastes retrieved from inside the PCV were surveyed.

Study on the sorting methods and their feasibility were evaluated in coordination with related projects such as “Development of Technology for Containing, Transfer and Storage of Fuel Debris” and “R&D for Treatment and Disposal of Solid Radioactive Wastes”.

① Study on the formulation of scenarios related to sorting

- The preconditions (sorting requirement) were organized, and the sorting requirement flow was studied.

② Study on the required sorting technology

- The locations for applying each decided sorting method were organized and the necessity for survey on technologies was studied.
- Surveys on technologies were conducted and the applicability to sorting was studied.

③ Evaluating the technical feasibility of the fuel debris sorting scenarios

- Based on the technology survey results, the technical feasibility of each sorting point was evaluated and sorting scenarios considering the feasibility were formulated.

7. Implementation items of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

- Purpose of development
  - Sorting (separating) fuel debris and radioactive wastes to reduce the amount stored as fuel debris
  - Evaluating the feasibility of technology that can sort fuel debris and radioactive wastes
- Issues to be solved
  - Identifying methods for sorting fuel debris and radioactive wastes
  - The procedures (scenario) for sorting fuel debris and radioactive wastes, and locations where sorting must be applied have not been decided yet.
- Approaches to development
  - Organization of the sorting requirements from the perspective of retrieval, transportation, and storage
  - Creation of a plan for sorting method of fuel debris based on the requirements organization results
  - Identification of the treatment and measurement techniques required for sorting fuel debris
  - Survey on treatment and measurement techniques required for sorting fuel debris
  - Creation of a plan for the scenarios and locations for application of fuel debris sorting
  - Organization of the development issues and difficulty levels required for sorting fuel debris and radioactive wastes
- Expected outcome
  - Identification of the sorting method for fuel debris and radioactive wastes
  - Identification of the development issues required for sorting fuel debris and radioactive wastes

7. Implementation items of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study flow

Survey on sorting requirements from each project

Questionnaire survey on the purpose, target, sorting details, implementation method, location of application, required technology, issues assumed in the requirements, related projects, etc.

↓

Classification and organization of sorting requirements

The study targets were set after the following classification and organization:
① Requirements to be studied in each project
② Requirements to be studied in design as interface conditions
③Sorting requirements subject to study

(① and ②: Excluded from study targets)

↓

Study of sorting requirements flow

A flow chart that logically and mechanically arranged all sorting requirement points considered from the viewpoint of sorting requirements and the location of application, was created

↓

Organizing the plans for sorting scenarios

Multiple sorting scenario plans were created from the sorting requirements flow chart based on the evaluation of advantages and disadvantages of each sorting point and the assumption on technical feasibility.

↓

Identification of measurement technology required for sorting

Regarding the measurement technology, which is required as the deciding method, the location of application was classified based on the size of the background and the targets for technology survey were identified.

↓

Survey on technologies

Surveys were conducted on visual (image) determination technology, PCV nuclear material distribution estimation technology, and nuclear material measurement technology, and their applicability was evaluated.

↓

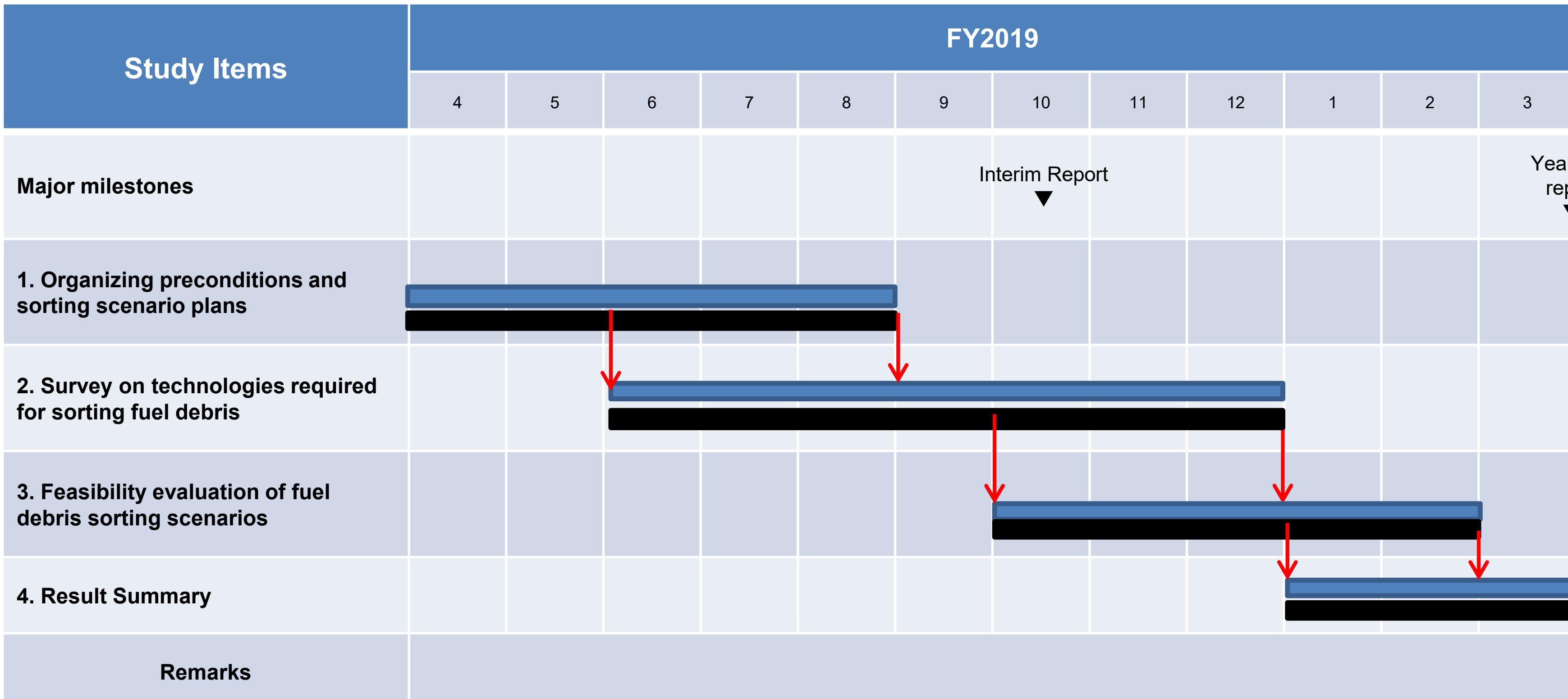
Evaluating the technical feasibility of the fuel debris sorting scenarios

Based on the results of technology surveys, the technical feasibility of each sorting point was evaluated and sorting scenarios considering the feasibility were formulated.

7. Implementation items of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ <u>Development Schedule</u>



7. Implementation items of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Organising the preconditions (sorting requirements)

From the identified sorting requirements, the sorting requirements to be studied (purpose, targets, sorting location, determination method, criteria, expected issues, advantages and disadvantages of sorting, etc.) were organized.

● Sorting requirements to be studied

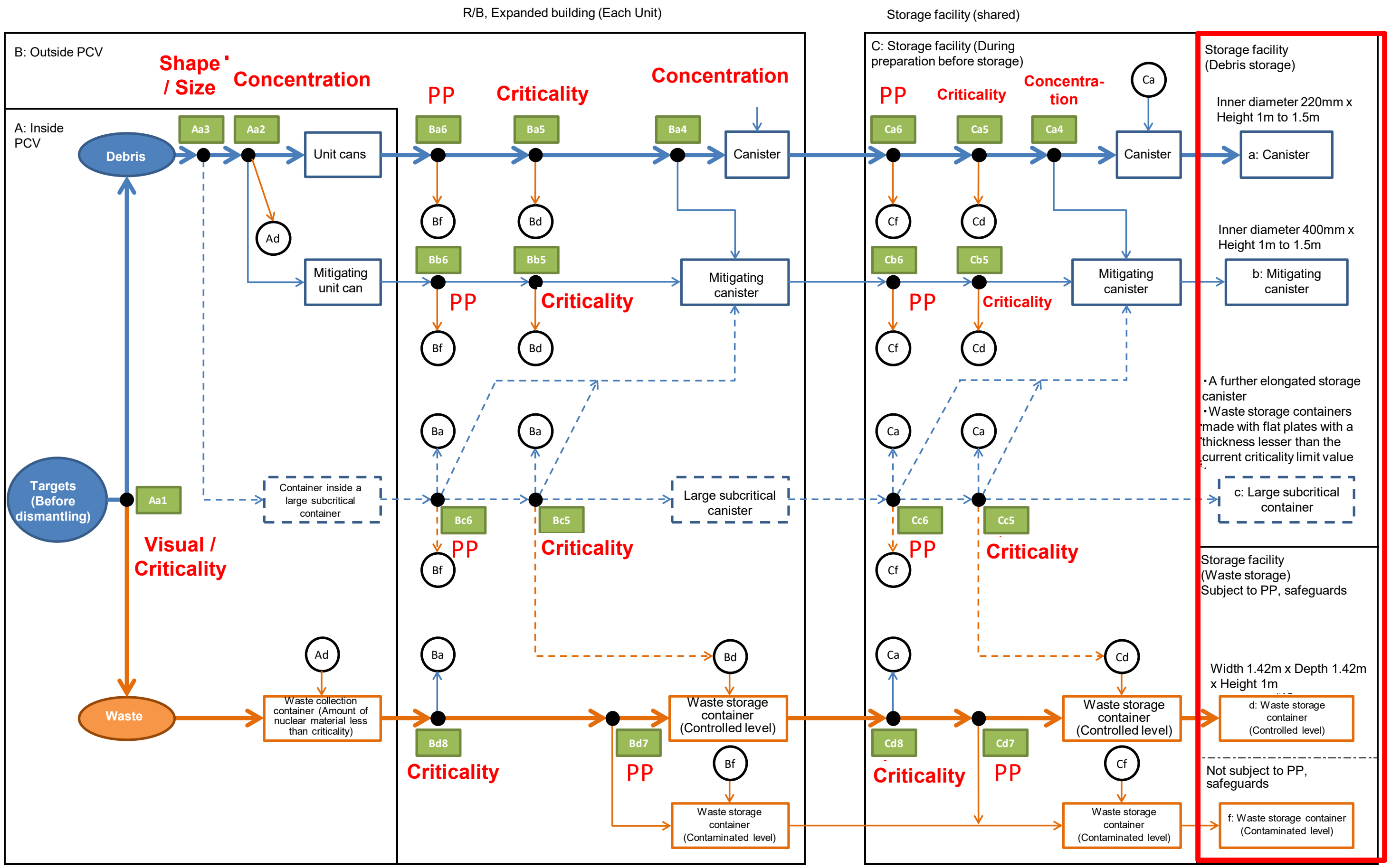
No.	Purpose	Goal and sorting details	Sorting location	Required technology
1	Ensuring criticality safety	Items containing significant nuclear fuel material are stored in shape-controlled containers (canisters) to ensure criticality safety.	A: Inside PCV	Nuclear material measurement for visual (image) determination, nuclear material distribution estimation and criticality safety control
2	Increase in retrieval throughput	Collected materials with a small amount of nuclear material are stored in mitigation canisters that are larger than the storage canisters.	A: Inside PCV	Measurement of nuclear material for measurement of fissile material concentration
3		Collected materials with large amount of target materials are stored in large-size subcritical containers.	A: Inside PCV	Visual understanding of shape and dimensions
4	Reduction in storage scale of fuel debris	Collected materials with a small amount of nuclear material are stored in mitigation canisters that are larger than the storage canisters.	B: Outside the PCV of each unit C: Storage facilities	Measurement of nuclear material for measurement of fissile material concentration
5		Collected materials with a small amount of nuclear material are stored in waste containers.		Measurement of nuclear material for criticality safety control
6		Collected materials that are not covered by safeguards are stored in waste containers.		Measurement of nuclear material for deciding the termination of safeguards, PP
7	Streamlining of waste storage and management	Sorting of waste into waste covered by safeguards and waste not covered by safeguards	B: Outside the PCV of each unit C: Storage facilities	Measurement of nuclear material for deciding the termination of safeguards, PP
8		Confirmation of the fact that the amount of nuclear material contained in the waste does not exceed the subcritical limit.	A: Inside PCV B: Outside the PCV of each unit C: Storage facilities	Measurement of nuclear material for criticality safety control

7. Implementation items of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ <u>Summary of study results on the formulation of scenarios for sorting (Sorting Requirements Flow Chart)</u>

A logical and mechanical arrangement according to the logistic flow of all possible sorting requirement points, considered from the viewpoint of sorting requirements and location of application



<u>Preconditions</u>

① Inside PCV, the fuel debris and wastes are put in the inner container
② Outside PCV, the inner container is placed in corresponding outer container (canisters, waste storage canister, etc.)
③ As large-size subcritical container is a new concept that has not been studied so far, it is indicated by a dotted line.

Sorting points are indicated by ●.The sorting points indicate the sorting location and order and do not necessarily mean that sorting is performed at those points. If sorting is completed on the upstream side, it need not be implemented on the downstream side.

<u>Notations used for sorting points</u>
1st digit: Area symbol
2nd digit: Line symbol
3rd digit: Sorting requirement number

7. Implementation items of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Summary of study results on the formulation of scenarios for sorting

● Sorting classification results and criteria (Tentative plan)

Sorting classification	Sorting requirement number	Criteria (tentative)				
		(Neither of the items on the right is satisfied)	U-235 concentration in fuel debris: less than or equal to the reactivity equivalent to 1.5 wt%	*1 Debris that is difficult to store in a canister	Amount of nuclear material is 3.7 kg / container or less	*2 Amount of nuclear material is less than or equal to the amount to terminate safeguards and nuclear material protection target
a: Canister (Inner diameter 220 mm, height approximately 1 m)	1	O	-	-	-	-
B: Mitigating canister (Inner diameter 400 mm) *3	1, 2, 4	-	O	-	-	-
c: Large-size subcritical containers	1, 3	-	-	O	-	-
d: Waste storage container (controlled level)	1, 5, 7, 8	-	-	-	O	-
f: Waste storage container (contaminated level)	1, 5, 6, 7, 8	-	-	-	O	O

*1: As the results of past evaluations in the Canister Project show that canisters with an inner diameter of 400 mm can be used when the weight ratio of U-235 to the fuel debris is approximately 1.7 wt% or less on the assumption that the fuel debris is composed entirely of U-235 and U-238, this value is set to 1.5 wt% providing a margin to the 1.7 wt%.
*2: Set by equally dividing the minimum critical mass (approximately 30 kg) into 8 waste storage containers, considering the arrangement and stacking during storage
*3: The large-size subcritical containers are at the idea stage, and no concrete specifications have been defined.

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting (Identification of targets for technology survey)

Regarding the determining methods identified while organizing sorting requirements, the location of application was classified based on the size of the background affecting the difficulty level of the decision and the target of each technology survey was set. (O shown in the table below refers to survey targets)

No.	Determining (measurement) technology	Standard for applicable location and background			Remarks
		A: Inside PCV (Before storing the container) Several 10 ~ Several 100 Sv/h	B: Outside PCV of each unit (RB, expanded building) Several mSv/h level	C: Storage facility (During preparation before storage) 500 μSv/h or less (Amber zone)	
1	Visual (image) determination ・Comparison by means of identification sample*1 ・Determination through image processing (Includes AI)	O (1-A)	O (1-B)	O (1-C)	*1) Shape data for structures etc., which provide information for visual determination
2	Estimation of nuclear material distribution inside PCV	O (2-A)			Create distribution diagram based on the results of disaster behavior analysis and sampling analysis ⇒ Directly investigate the technology for measuring distribution
3	Measurement of nuclear material (Nuclide, concentration)				
	① For measuring the concentration of nuclear fissile material	O (3①-A)	O (3①-B)	O (3①-C)	・For determining the feasibility of storage in a mitigating canister
	② For criticality safety control	O (3②-A)	O (3②-B)	O (3②-C)	・For determining the feasibility of storage in a waste storage container
	③ For decision on termination of PP and safeguards		O (3③-B)	O (3③-C)	・For the determining the targets for PP and safeguards

Note) Since the symbols in the lower row represent the applicable locations, the symbols are a combination of determination (measurement) technology number and symbol for the applicable locations (A, B, C)

7. Implementation details of this project
[2] (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting (Technologies subject to technology survey)

The existing determination (measurement) technologies were investigated and the principle, performance, usage environment, device configuration/size, measurement time (measuring speed), usage results, applicable locations and issues were organized in a survey form.

●: Estimations

Technologies surveyed	Purpose of determination (measurement) assuming application											
	Visual (Image) determination			Estimation of distribution	Concentration measurement			Criticality safety control			PP, safeguards	
	1-A	1-B	1-C	2-A	3①-A	3①-B	3①-C	3②-A	3②-B	3②-C	3③-B	3③-C
Reflectance measurement	●	●	●	-	-	-	-	-	-	-	-	-
Image determination	●	●	●	-	-	-	-	-	-	-	-	-
Passive alpha ray measurement	-	-	-	●	●	●	●	●	●	●	-	-
Passive gamma ray measurement	-	-	-	●	●	●	●	●	●	●	-	-
Passive neutron measurement	-	-	-	●	●	●	●	●	●	●	-	-
Active X ray measurement	-	-	-	-	●	●	●	●	●	●	-	-
X ray transmission	-	-	-	-	-	●	●	-	●	●	-	-
Cosmic rays scattering measurement	-	-	-	-	-	●	●	-	●	●	-	-
Active neutron measurement	-	-	-	-	-	-	-	-	●	●	●	●
Passive neutron measurement + gamma ray measurement	-	-	-	-	-	-	-	-	●	●	●	●
Passive/Active neutron measurement + gamma ray measurement	-	-	-	-	-	-	-	-	●	●	●	●

7. Implementation details of this project

[2] (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting (Main measurement technology survey form (1/4))

Table-1 Measurement technology survey form

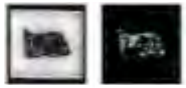
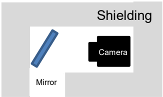
Technology name	Reflectance measurement technology (Hyperspectral camera)	
Principle	･Acquire reflectance distribution of the object surface with hyper camera and compare the spectrum with various materials measured earlier in order to identify the material. ･Since information obtained is limited to the surface, evaluate the material of the structural surface (such as adhesion/non-adhesion of fuel component) broadly by application to relatively less damaged structures.  RGB image Pseudo-color image Figure 1: Example of material evaluation of ore Source: https://www.klv.co.jp/hyperspectral/case_study_case_study06.html  Figure 2: Spectrum of Uranium ore Source: Preliminary study on the detection of radioactivity with airborne remote sensing system	
Performance	Resolution	･To the extent to which the rough composition distribution of concrete, metal etc. on the surface to be measured can be understood ･Since the data is only for the surface of the target to be measured, it is not possible to measure the weight of the fuel composition and percentage of UO2 in the material to be measured. ･In case the damage of the target to be measured is relatively low, it may be possible to estimate the target to be measured by comparing this image with the design diagram of the structure.
	Lower limit of measurement	Evaluation with absolute value is difficult
Usage environment (background)	Details not known (Shield is required)	
Device configuration / size	[Device configuration] ･Camera and mechanism for its operation are mandatory ･Since camera is not radiation resistant, shield is required ･Data is transferred with a cable [Size] ･Since it depends on the size of the shield, evaluation by radiation resistance test is required ･Camera unit (Nano-Hyperspec manufactured by Headwall): Approx. 76mm x 76mm x 120mm (Mobile mechanism and shield are excluded)  Figure 3: Example of the appearance of the camera (Nano-Hyperspec manufactured by Headwall)  Figure 4: Image of the structure	
Measuring size (Measuring speed)	Several seconds per image ※The angle of view depends on the lens	
Usage results	We have a record of general ore sorting, but no record of UO2 and debris management.	
Applicable locations	1A, 1B, and 1C. However, tasks such as opening the lid after container storage, etc. are required.	
Issues	･Information related to interior composition of the structure is not acquired (×) ※If used only for general confirmation of surface condition (composition distribution), then △ ･Shield design and evaluation of radiation resistance are required (△) ･Development of the operating mechanism for camera is required (△) ･Study on the types of lighting, layout optimization is required (△) ･Evaluating the influence of spectral changes due to moisture, etc. is required (△) ･Advance creation of spectral data for the material to be measured such as Uranium, etc. is required (△)	

Table-2 Measurement technology survey form

Technology name	Image determination technology (Determination of structure using camera image, 3D shape)	
Principle	･Identify the type of the structure by comparing the image capturing the appearance of the object with a visibility camera, and the external shape of the object measured by the TOF (Time Of Flight) laser scanner method using laser light etc., with the external photographs of the structure and drawing data. ･Application is limited to the less damaged structure in order to compare with drawing data and external photographs of the structure, but the type of the structure might be identifiable using commercial sensors (recognition process is separate).  Figure 1: Example showing image recognition using in-vehicle camera Source: https:/jp.mathworks.com/discovery/image-recognition.html  Figure 2: Example of shape fitting Source: https:/jp.mathworks.com/discovery/image-recognition.html	
Performance	Resolution	･Identification of structure type with characteristic differences in appearance (shape/size) is possible. ･Objects with damages are not applicable since appearance (shape/size) and drawing data are compared.
	Lower limit of measurement	Depends on the surrounding conditions and target to be measured.
Usage environment (background)	Shield is required in high-dose environment since semiconductor sensor is used. Shield is not required in case of radiation-resistant camera.	
Device configuration / size	[Device configuration] ･Camera, laser scanner, and mechanism for operating them are required. ･Requires the process of identifying the structure from the appearance image and shape. ･Since semiconductor sensor (camera, laser scanner) is not radiation-resistant, shield is required (excluding when radiation-resistant camera is used). ･Data is transferred with a cable. [Size] ･Since it depends on the size of the shield, evaluation by radiation resistance test is required ･Radiation-resistant camera unit: Approx. Φ41mm x 250mm ･Laser scanner unit (FARO FOCUS 150): Approx. 230mm x 183mm x 103mm ※Mobile mechanism and shield are excluded  Figure 3: Example of radiation-resistant camera (Diakront STS-40M)  Figure 4: Example of the appearance of a laser scanner (FARO FOCUS 150)	
Measuring size (Measuring speed)	Visibility camera: 1 second or less per image (Angle of view depends on the lens) Laser scanner: Several minutes to several tens of minutes (Varies depending on measurement range and measuring pitch)	
Usage results	･Image recognition using in-vehicle camera ･A part of image evaluation acquired by PCV internal investigation (Unit 3)	
Applicable locations	1A	
Issues	･Not applicable to damaged objects (×) ･It is possible that identification with similar structures is not allowed (×) ･Shield design and evaluation of radiation resistance are required (△) ･Developing the operating mechanism for camera/laser scanner is required (△) ･Study on identification process is required (△) ･Training data (learning data) is required (△) ･Study on the types of lighting, layout optimization is required (△)	

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting (Main measurement technology survey form (2/4))

Table-7 Measurement technology survey form

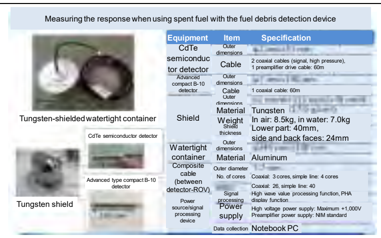
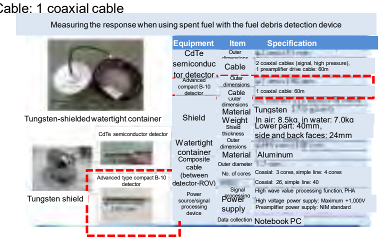
Technology name	·Passive gamma ray measurement technology (CdTe sensor)
Principle	・Measurement of the charge generated from the interaction between CdTe semiconductor and gamma rays ・Conversion of the charge into the energy given to CdTe semiconductor by using the conversion coefficient prepared in advance ・Evaluation of gamma ray emitting radionuclides incident from energy distribution ・Estimation of the presence or absence of nuclear fuel and its amount from the presence or absence of gamma ray flux and its amount originating from Eu-154
Performance	Resolution: 12.9keV @662keV Lower limit of measurement: Depends on measuring time Ex: 8.6×10^{-3} /cm^2/s @1274keV
Usage environment (background)	Actual value at the time of measurement of spent fuel assembly: 19.4Gy/h
Device configuration / size	
Measuring time (Measuring speed)	Depends on measuring environment Ex: Actual value at the time of spent fuel assembly measurement: 3 minutes or above
Usage results	・Operation was confirmed in a radioactive environment using spent fuel assembly ・To be used mounted onto ROV in 1F-1PCV internal detailed investigation
Applicable locations	・2-A (Sensor scanning required) ・3(2)-A, 3(2)-B, 3(2)-C (Must be combined with other technologies and the results of pre-analysis/analysis)
Issues	・Shielding and collimator design in accordance with applicable environment (△) ・Method of conversion into Uranium weight (△) ・Concentration measurement for isotopic elements (×: 3 (1)-A, B, C) ※In case of combined usage with other technologies, results of pre-analysis/analysis in estimating the presence of target to be measured and concentration levels (△)

Table-16 Measurement technology survey form

Technology name	Passive neutron measurement technology (Advanced type compact B-10 sensor)
Principle	・Measurement of charge (wave height value) which is correlated with the energy of charged particles generated by nuclear reaction between B-10 and thermal neutrons ・Measurement of wave height spectrum, determining any area as a neutron measuring area and acquiring values ・Evaluation of thermal neutron flux from the values by using thermal neutron sensitivity acquired in advance ・Estimation of the presence or absence of nuclear fuel and its amount from the presence or absence of thermal neutron flux and its amount
Performance	Resolution: — Lower limit of measurement: Depends on measuring time (Thermal neutron sensitivity: 0.2cps/nv)
Usage environment (background)	Dose rate tolerance: 650Gy/h Cumulative dose rate: 1MGy or above (Constrained by accessory cables)
Device configuration / size	Outer dimensions: Φ7mm x 100mm Cable: 1 coaxial cable 
Measuring time (Measuring speed)	Depends on measuring environment Ex: Actual results when measuring spent fuel assembly (implemented in internal detailed investigation of PCV PJ): Approx. 1 minute
Usage results	・Operation was confirmed in a radioactive environment using spent fuel assembly ・To be used mounted onto ROV in 1F-1PCV internal detailed investigation
Applicable locations	・2-A (Sensor scanning required) ・3(2)-A, 3(2)-B, 3(2)-C (Must be combined with other technologies and the results of pre-analysis/analysis)
Issues	・Shielding and collimator design in accordance with applicable environment (△) ・Method of conversion into Uranium weight (△) ・Concentration measurement for isotopic elements (×: 3 (1)-A, B, C) ※In case of combined usage with other technologies, results of pre-analysis/analysis in estimating the presence of target to be measured and concentration levels (△)

7. Implementation details of this project

[2] (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ <u>Study results on technologies required for sorting (Main measurement technology survey form (3/4))</u>

Table-19 Measurement technology survey form

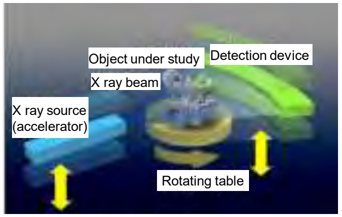
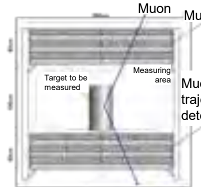
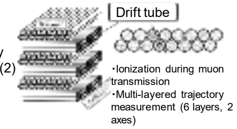
Technology name	X ray transmission (High energy X ray CT method)	
Principle	･Imaging principle is the same as medical X ray CT. ･Imaging is carried out by rotating the target to be measured using a rotating table. ･Seismic tomography for high density material and large structures is possible using accelerator (LINAC) as the X ray source. ※1 http://www.hitachi.co.jp/products/healthcare/products-support/catalog/industrial_ct/pdf/HiXCT-BR-070_j.pdf ※2: Uesaka, et al.: Collection of Theses, Atomic Energy Society of Japan 2019	
Performance	Resolution	Image resolution: 0.4mm ※1
	Lower limit of measurement	–
Usage environment (background)	In a normal environment (Assuming the use outside the PCV of each unit and at storage facilities)	
Device configuration / size	<Given below is the information concerning ※1> Configuration: X ray source (accelerator), rotating table, X ray detector (line sensor) Size: Approx. 4m x 4m (includes footprint, maintenance area) Weight of the target to be measured: Maximum 100kg Height of the target to be measured: Maximum 1,000mm X ray transmission capacity: Iron 320mm, concrete 1,080mm (When 9MV X ray source is used) Others: Install collimator on the front of the X ray detector to reduce the impact of scattered rays which cause measurement error (image degradation).  	
Measuring time (Measuring speed)	10 to 15 seconds per section (※1) (when 3G imaging (single rotation imaging system), single energy) → When a unit can was measured (inner height 360mm), 3,600 to 5,400 seconds (approx. 1 to 1.5 hours)	
Usage results	･Observation of internal conditions of waste drum (※1) ･Fuel assembly inspection (rotation and translational imaging method) Iwami, et al.: JAEA-Data/Code 2014-012 ･Various non-destructive inspections (Machine components such as automobile engines etc. (※1), bridge (※2) etc.)	
Applicable locations	3①－B、3①－C、3②－B、3②－C	
Issues	･Only density distribution information is obtained from cross-sectional imaging by single energy X ray, but it is possible to acquire elemental information by a method (※2) using multi-energy X ray and identify the nuclear material such as Uranium etc., iron and concrete (△) ･Isotopic identification is not possible. Must be combined with other measurements, evaluation methods etc. such as isotopic ratio measurement etc. (△) ･Reduction of impact of debris-derived gamma rays on measuring accuracy. (△) ･BG reduction (△)	

Table-20 Measurement technology survey form

Technology name	Cosmic ray scattering measurement technology (Muon scattering method)	
Principle	･When a cosmic ray muon passes through a substance, the composition in the substance is analyzed from the magnitude and spread of the scattering angle by utilizing the property of scattering at an angle according to the atomic number of the object the ray passes through. ･If the atomic number of the material is high, scattering angle is also high; Uranium can be selectively evaluated when compared to iron etc., but isotopic analysis is not possible ･Source is not required since cosmic rays are used. ･3 dimensional distribution can also be acquired, albeit roughly  Figure 1 Detection of 20kg Uranium sphere in 14 tons of iron [1]LA-UR-04-3985, Information Extraction from Muon Radiography Data	
Performance	Resolution	Uranium: Diameter 8cm, weight 20kg [1] ※Depends on the size of the container, air dose rate in the environment, and measuring time
	Lower limit of measurement	About 1 to 10kg when measuring Uranium alone ※Depends on the size of the container, air dose rate in the environment, and measuring time
Usage environment (background)	Assuming use in the lowest possible background ※The upper limit of air dose rate changes depending on the size of the detector.	
Device configuration / size	[Device configuration] Made of 2 muon trajectory detectors, and scattering spot and scattering angle are measured from the trajectories acquired by the muon trajectory detectors at the upper and lower levels. [Size] Size is approx. 2.5m x 1.5m x 3m (power supply panel and control panel are not included). ※Optimization required since this depends on environmental dose rate and measuring time.  Figure 2: Example of device configuration  Figure 3: Configuration of detector	
Measuring time (Measuring speed)	Approx. several minutes to an hour per measurement of 1 unit ※Varies due to effective measurement area of detector and air dose rate	
Usage results	･Security scanner ･Results of measuring spent fuel containing casks (MC-10 cask for PWR) under low dose rate Phys. Rev. Applied 9, 044013,"Verification of Spent Nuclear Fuel in Sealed Dry Storage Casks via Measurements of Cosmic-Ray Muon Scattering"	
Applicable locations	3①－B、3①－C、3②－B、3②－C	
Issues	･Muon measuring efficiency is reduced by the impact of gamma rays from debris and BG. If a shield is added, the effect of gamma rays is like to be reduced, but since the precision of the fuel detection system would then deteriorate, it is necessary to conduct a study on optimization (△) ･Identification of isotope and measurement of concentration levels cannot be performed, so it is necessary to conduct a study on the derivation method from average concentration level (△) ※It is possible to increase measuring accuracy and degree of certainty by combining the techniques for measuring isotopic ratio and degree of burn-up (Burn-up monitor etc.) ･It is necessary to conduct a study on long-term operation and maintenance methods under 1F environment (radioactivity, dust, vibrations etc.) (△)	

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting (Main measurement technology survey form (4/4))

Table-21 Measurement technology survey form

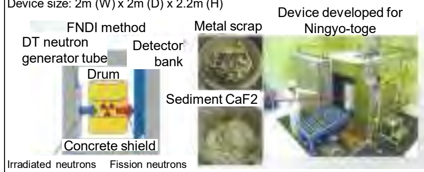
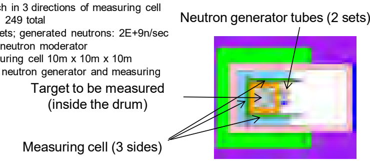
Technology name		Active neutron measurement technology (Fast Neutron Direct Interrogation (FNDI) method)
Principle		(1) Sample is irradiated with fast neutrons from neutron generator. (2) Thermal neutrons inside the system of measuring device and sample are slowed down. (3) Nuclear fission material contained within the sample induces nuclear fission and neutrons are emitted. (4) Measurement is carried out with neutron detector installed in measuring system. (5) Nuclear material weight is computationally estimated by measuring the extinction time for fission neutrons.
Performance	Resolution	Total amount of nuclear material (U-235, Pu-239, Pu-241) can be measured. Measurable in a comparatively shorter time. Can be applied to large and high density containers because fast neutrons are used. Resolution is not known.
	Lower limit of measurement	Unknown
Usage environment (background)		Assuming use in the lowest possible background
Device configuration / size		Device configuration (1) Neutron detector bank (includes neutron detector, moderator etc.) (2) Neutron generator (DT tube) (3) Signal processing unit (4) Calculator for computational estimation It is a structure in which a detector bank is installed around the debris canister. In addition, it is necessary to provide a moderator for decelerating the fast neutrons and a shield for reducing the radiation level in the surroundings when the neutron generator is operating, which makes the size considerably large. Device size: 2m (W) x 2m (D) x 2.2m (H) 
Measuring time (Measuring speed)		Measuring time varies in accordance with required detection limit. In general, it is about 1 hour in total for background measurement of measuring cell, carrying-in of canister, measurement, carrying-out.
Usage results		JAEA Ningyo-toge Environmental Engineering Center Measuring device for measurement and management of Uranium waste (JAWAS-N)
Applicable locations		3②-B、3②-C、3③-B、3③-C
Issues		Major issue is identifying the status of debris inside the canister.

Table-23 Measurement technology survey form

Technology name		Passive/active neutron and gamma ray measurement technology (Gamma spectrometry for volume compressed drum and neutron measuring device)
Principle		Based on the measuring results obtained with: 1. Gamma spectrum measuring device 2. Passive neutron measuring device 3. Active neutron measuring device Will evaluate: a. Gross U and Pu amounts b. Alpha activity (Pu, Cm, gross alpha) c. Beta activity (Cs-137, Sr-90, Y-90, Pu-241) d. Decay heat
Performance	Resolution	Amount of nuclear fissile material Statistical error obtained from measuring result: approx. 10% Calibration error: approx. 30%
	Lower limit of measurement	Detection limit 100mg of U-235 + Pu-239 + Pu-241 in total 100g of U-235 + U-238 + Pu-239 + Pu-241 in total
Usage environment (background)		The gamma spectrum measuring device must be limited to sufficiently low background. The level of gamma rays from the surroundings and target to be measured must be reduced so that the neutron measuring device is maintained at a max. 2rad/h due to the properties of the detector. Therefore, locations with high surrounding background levels are not suitable.
Device configuration / size		Drum to be measured: Diameter approx. 1m; Height approx. 1.5m Gamma spectrum measuring device: High purity Ge detector Drum rotating and vertical driving device Installation space: Not known Neutron measuring device: 83 neutron directors each in 3 directions of measuring cell (finite length: 1,000mm); 249 total Neutron generators: 2 sets; generated neutrons: 2E+9n/sec Measuring cell made of neutron moderator Installation space: Measuring cell 10m x 10m x 10m (Auxiliary equipment for neutron generator and measuring device are not included)  Conceptual diagram of neutron measuring device
Measuring time (Measuring speed)		Gamma spectrum measuring device: 15 to 45min. Neutron measuring device: 45 to 60min.
Usage results		La Hague volume compression facility
Applicable locations		3 (2)-B, 3 (2)-C, 3 (3)-B, 3 (3)-C (However, the device being large-sized, it is considered difficult to install in R/B and it is assumed that it will be installed in storage preparation facility and new expanded building which may be designed in accordance with the device.)
Issues		Measurement target is the hull-end piece evacuated from the retreatment plant and the background of the contents is known. On the other hand, the fuel debris contents cannot be identified, so a major problem is how to evaluate critical parameters while evaluating density, material etc. Accordingly, in order to understand these uncertain and unknown elements, it is highly likely that there is a need for additional installation of instrumentation devices to be able to estimate and evaluate the status of distribution and density of the contents as in case of tomography. (△) As a result, the size of the device is expected to increase. (△)

7. Implementation details of this project

[2] (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting

O: Prospects for application
△: Feasible
x: Not feasible at this stage
-: Not applicable

A: Inside PCV (Before storage in the container)
B: Outside PCV of each Unit (RB, expanded building)
C: Storage facility (During preparations before storage)

●Evaluation of each surveyed technology (1/3)

Technologies surveyed	Performance ① Resolution ② Lower limit of measurement	Main specifications ① Radiation tolerance or performance in the environment used ② Equipment size ③ Measuring time	Main issues	[1] Visual (Image) determination	[2] Estimation of nuclear material distribution inside PCV	[3①] For measuring the concentration of nuclear fissile material	[3②] For criticality safety control	[3③] For decision on termination of PP and safeguards
						Concentration of U-235 in fuel debris: Reactivity equivalent to 1.5 wt% or less	Mass of nuclear material 3.7 kg / container or less	Not yet determined
Reflectance measurement	①To the extent that rough surface composition distribution can be understood ② Evaluation by absolute value is difficult	① Details not known (Shield is required) ② 76 x 76 x 120 mm ③ Several seconds per image	･Relevant internal information is not available ･Creation of spectrum data for material to be measured	*1 A: x B: x C: x	-	-	-	-
Image determination	① Types of structures with characteristic differences are identifiable ② -	① Shield is necessary ② Approx.230 x 183 x 103 mm ③ Camera: 1 second or less per image; laser scanner: ~several tens of minutes	･Not applicable to damaged objects ･Learning data is required	*2 A: △ B: △ C: △	-	-	-	-
Passive alpha ray measurement (Alpha camera)	*3 ① Position resolution: About 2 cm ② Alpha radioactivity: 4 Bq/cm^2	① Details not known (Shield is required) *3 ② 400 x 300 x 250 mm ③ From several seconds to several minutes, maximum 1000 seconds per image	･Effects of high dose gamma ray and beta ray emission ･Relevant internal information is not available	-	*1 A: x	-	-	-
Passive alpha ray measurement	① - ② Depends on measuring time	① Dose rate tolerance: 350 Gy/h ② Sensor size 3 x 3 mm ③ Depends on measuring environment	･Alpha ray sensitivity ･Method for conversion into uranium weight ･Measurement of isotope concentration	-	*1 *4 A: △	A: x B: x C: x	*1 *4 A: △ B: x C: x	-

*1: There is a possibility to acquire relevant surface information
*2: Identification of nuclear material is not possible. However, might support sorting by shape measurement etc.
*3: Currently under development in Solid Radioactive Waste PJ. Provisional values.
*4: Combination with other sensors and techniques required

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting

● Evaluation of each surveyed technology (2/3)

O: Prospects for application
△: Feasible
x: Not feasible at this stage
-: Not applicable

A: Inside PCV (Before storage in the container)
B: Outside PCV of each Unit (RB, expanded building)
C: Storage facility (During preparations before storage)

Technologies surveyed	Performance ① Resolution ② Lower limit of measurement	Main specifications ① Radiation tolerance or performance in the environment used ② Equipment size ③ Measuring time	Main issues	[1] Visual (Image) determination	[2] Estimation of nuclear material distribution inside PCV	[3①] For measuring the concentration of nuclear fissile material	[3②] For criticality safety control	[3③] For decision on termination of PP and safeguards
						Concentration of U-235 in fuel debris: Reactivity equivalent to 1.5 wt% or less	Mass of nuclear material 3.7 kg / container or less	Not yet determined
Passive gamma ray measurement	①12.9keV @662keV ②Depends on measuring time	①19.4Gy/h (Actual values at the time of spent fuel assembly measurement) ②Detector size Φ7x51 mm ③Depends on measuring environment	･Shield/collimator designing ･Method for conversion into uranium weight ･Measurement of isotope concentration	-	*4 A: △	A: x B: x C: x	*4 A: △ B: △ C: △	-
Passive neutron measurement	①- ②Depends on measuring time	①Dose rate tolerance: 650 Gy/h ②Detector size Φ7x100mm ③Depends on measuring environment	･Directivity ･Method for conversion into uranium weight ･Measurement of isotope concentration	-	*4 A: △	A: x B: x C: x	*4 A: △ B: △ C: △	-
Active X ray measurement	①- ②Uranium in the order of μg is detectable	①Laboratory analysis is presumed ②Unknown ③Unknown	･Measurement under high BG environment ･Measurement of isotope concentration ･Sample removal method	-	A: x	A: x B: x C: x	A: x B: x C: x	-
X ray transmission	①Image resolution: 0.4 mm ②-	①Normal environment level ② (Footprint) 4 x 4 m ③10 ~ 15 sec/Section (Unit can: 1 ~ 1.5 Hr)	･Distinguishing iron/concrete from uranium etc. ･Reduction of impact of gamma rays originating from BG and fuel debris	-	-	*5 A: - B: △ C: △	*6 A: - B: △ C: △	-

*4: Combination with other sensors and techniques required
*5: Estimate the weight of nuclear material. The conversion of U-235 concentration needs to be re-evaluated by assuming the concentration and composition ratio.
*6: Must be re-evaluated by correcting the total weight of the measurement target.

7. Implementation details of this project

[2] (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting

● Evaluation of each surveyed technology (3/3)

O: Prospects for application
△: Feasible
x: Not feasible at this stage
-: Not applicable

A: Inside PCV (Before storage in the container)
B: Outside PCV of each Unit (RB, expanded building)
C: Storage facility (During preparations before storage)

Technologies surveyed	Performance ① Resolution ② Lower limit of measurement	Main specifications ① Radiation tolerance or performance in the environment used ② Equipment size ③ Measuring time	Main issues	[1] Visual (Image) determination	[2] Estimation of nuclear material distribution inside PCV	[3①] For measuring the concentration of nuclear fissile material	[3②] For criticality safety control	[3③] For decision on termination of PP and safeguards
						Concentration of U-235 in fuel debris: Reactivity equivalent to 1.5 wt% or less	Mass of nuclear material 3.7 kg / container or less	Not yet determined
Cosmic rays scattering measurement	①Uranium: Diameter 8 cm, weight 20kg ②About 1 ~10 kg for uranium alone	①Upper limit of air dose rate in the range of approximately 0.3 ~ 0.5 mSv/h *7 ②2.5m x 1.5 m x 3 m ③Several minutes to one Hr per unit	・Effects of gamma rays from BG and fuel debris ・Isotope identification, derivation of concentration level	-	-	*5 A: - B: △ C: △	*6 A: - B: △ C: △	-
Active neutron measurement	①Unknown (Total quantity of nuclear material is measurable) ②Unknown	①Usage at low BG is presumed ②2 m x 2 m x 2.2 m ③ About 1Hr (BG measurement, carrying in, measurement, carrying out)	・Identifying the status of material stored in the container	-	-	-	*8 A: - B: △ C: △	*9 B: △ C: △
Passive neutron measurement + gamma ray measurement	①30% of measured values by comprehensively evaluating all error factors ②Unknown	①To the extent that the waste drum can be operated by manipulator ②Unknown ③Unknown	・Identifying the status of material stored in the container	-	-	-	*8 A: - B: △ C: △	B: x C: x
Passive/Active neutron measurement + gamma ray measurement	①Statistical error approx.10%, Calibration error approx.30% ②U235+Pu239+ Pu241: 100 mg Above-mentioned + U238: 100 g	①Unsuitable for high BG areas ② (Installation space: Measuring cell) 10 m x 10 m x 10 m ③Gamma spectrum measurement: 15 ~ 45 minutes, neutron measurement: 45 ~ 60 minutes	・Identifying the status of material stored in the container ・Increased size of equipment	-	-	-	*8 A: - B: △ C: △	*8 *9 B: △ C: △

*5: Estimate the weight of nuclear material. The conversion of U-235 concentration needs to be re-evaluated by assuming the concentration and composition ratio.
*6: Must be re-evaluated by correcting the total weight of the measurement target.
*7: Performance when the target is loaded into the canister with shielding function
*8: Evaluation was conducted on the premise that the composition ratio of fissile material nuclides is known.⇒ Combined usage of other measurement techniques such as estimating the degree of burn-up in fuel debris.
*9: It is necessary to re-evaluate the detection limit and measurement error when fuel debris is the measurement target.

7. Implementation details of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Study results on technologies required for sorting

O: Technology that can be applied
△: Feasible technology
x: No feasible technology at this stage

●Summary

No.	Determination (measurement) technology	Application location		
		A: Inside PCV (Before storage in the container)	B: Outside PCV of each Unit (RB, expanded building)	C: Storage facility (During preparations before storage)
1	Visual (Image) determination	(1-A) △Image determination	(1-B) △Image determination	(1-C) △Image determination
2	Estimation of nuclear material distribution inside PCV	(2-A) △Passive alpha ray measurement △Passive gamma ray measurement △Passive neutron measurement		
3	Measurement of nuclear material (Nuclides, concentration)			
	①For measuring the concentration of nuclear fissile material	(3①-A) x	(3①-B) △X ray transmission (High energy X ray CT method) △Cosmic rays scattering measurement (Muon scattering method)	(3①-C) △X ray transmission (High energy X ray CT method) △Cosmic rays scattering measurement (Muon scattering method)
	② For criticality safety control	(3②-A) △Passive alpha ray measurement △Passive gamma ray measurement △Passive neutron measurement	(3②-B) △Passive gamma ray measurement △Passive neutron measurement △X ray transmission (High energy X ray CT method) △Cosmic rays scattering measurement (Muon scattering method) △Active neutron measurement (FNDI method) △Passive neutron measurement + gamma ray measurement △ Passive /active neutron measurement + gamma ray measurement	(3②-C) △Passive gamma ray measurement △Passive neutron measurement △X ray transmission (High energy X ray CT method) △Cosmic rays scattering measurement (Muon scattering method) △Active neutron measurement (FNDI method) △Passive neutron measurement + gamma ray measurement △Passive /active neutron measurement + gamma ray measurement
	③For decision on termination of PP and safeguards	-	(3③-B) △Active neutron measurement (FNDI method) △Passive /active neutron measurement + gamma ray measurement	(3③-C) △Active neutron measurement (FNDI method) △Passive /active neutron measurement + gamma ray measurement

7. Implementation details of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Evaluation of technical feasibility of fuel debris sorting scenarios (Evaluation of sorting scenarios)

① Preconditions

- Do not consider sorting with the same content in multiple locations. (If sorting is performed on the upstream side, do not perform sorting on the downstream side.)
- The storage facility (during preparations before storage) has a lower background than outside the PCV of each unit (RB, expanded building), it is easy to secure the installation space for the sorting equipment, and installability of sorting equipment is higher on the storage facility side.
- It is likely that measurement of nuclear material inside PCV is difficult when compared to other locations and it is also assumed that handling sorting (Aa1) of fuel debris and wastes inside PCV by mere visual (image) determination might be difficult.

② Formulation of sorting scenarios from the perspective of feasibility

- Scenario A: Scenarios in which sorting is performed at the earliest possible stage
- Scenario B: Scenarios focusing on the installability of sorting equipment
- Scenario C: When sorting (Aa1) of fuel debris and waste inside PCV is difficult ① (Sorting at the earliest possible stage)
- Scenario D: When sorting (Aa1) of fuel debris and waste inside PCV is difficult ② (Focus on installability of sorting equipment)

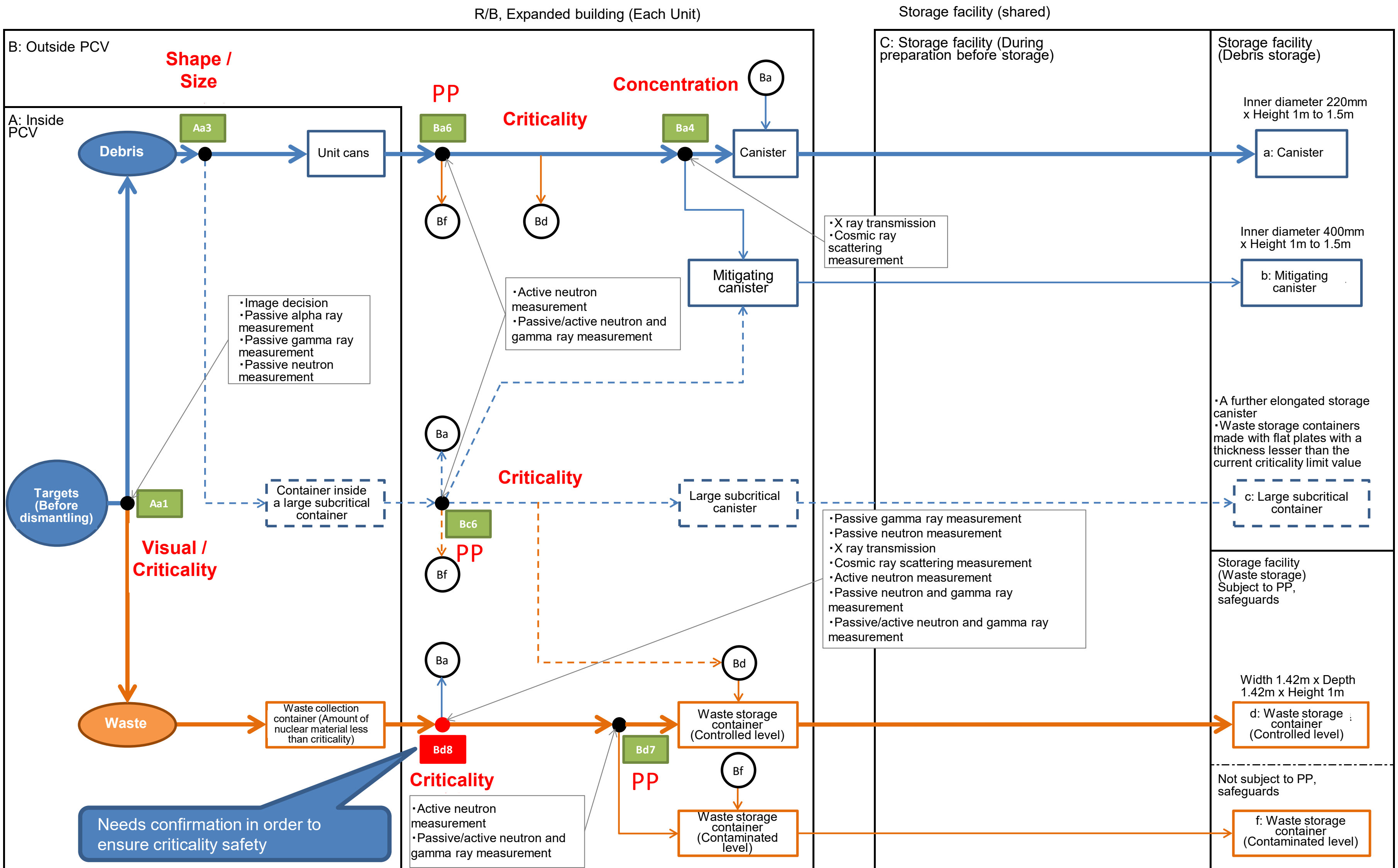
7. Implementation details of this project

No.222

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ **Evaluation of technical feasibility of fuel debris sorting scenarios (Evaluation of sorting scenarios)**

Scenario A: Scenarios in which sorting is performed at the earliest possible stage

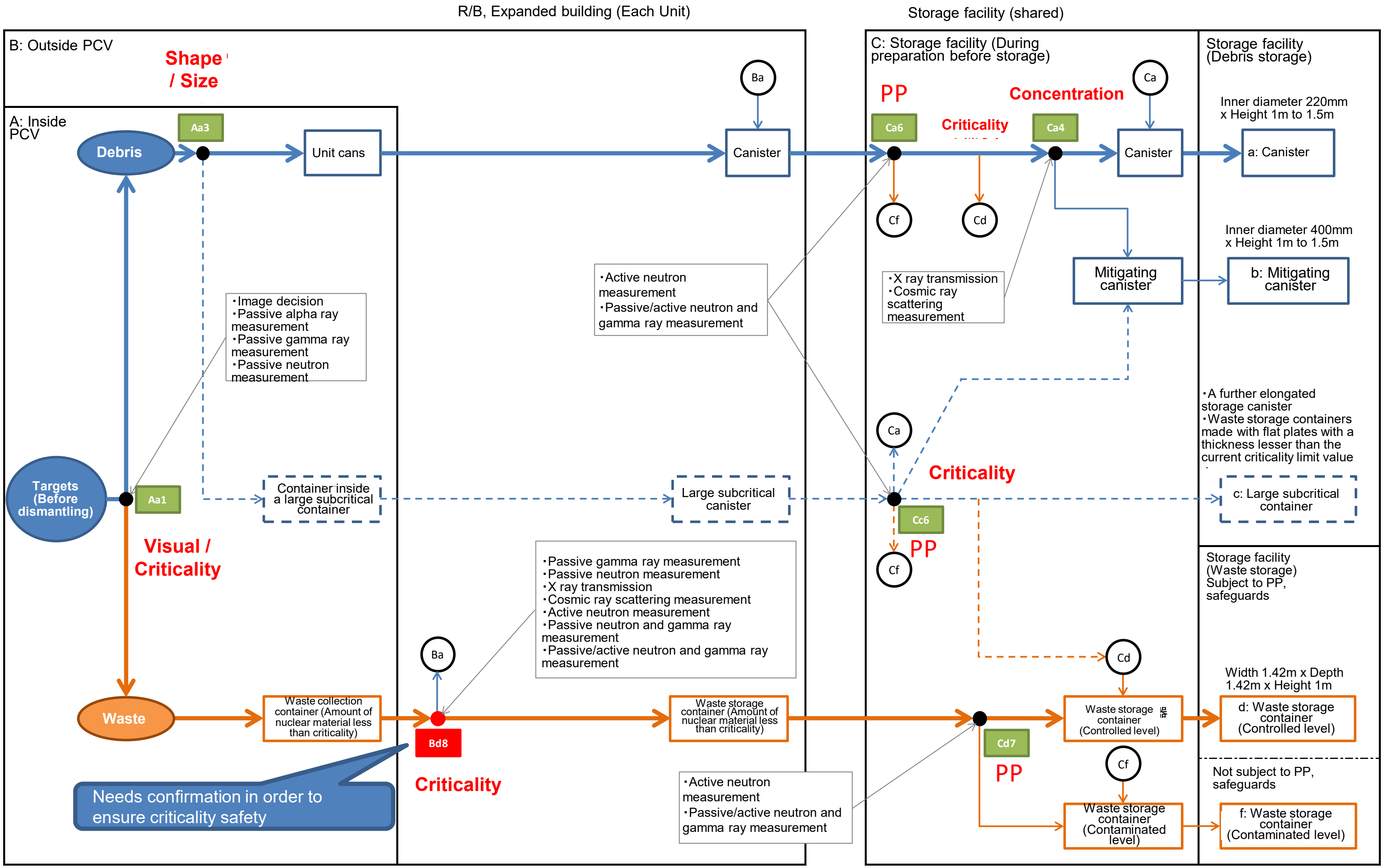


7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ **Evaluation of technical feasibility of fuel debris sorting scenarios (Evaluation of sorting scenarios)**

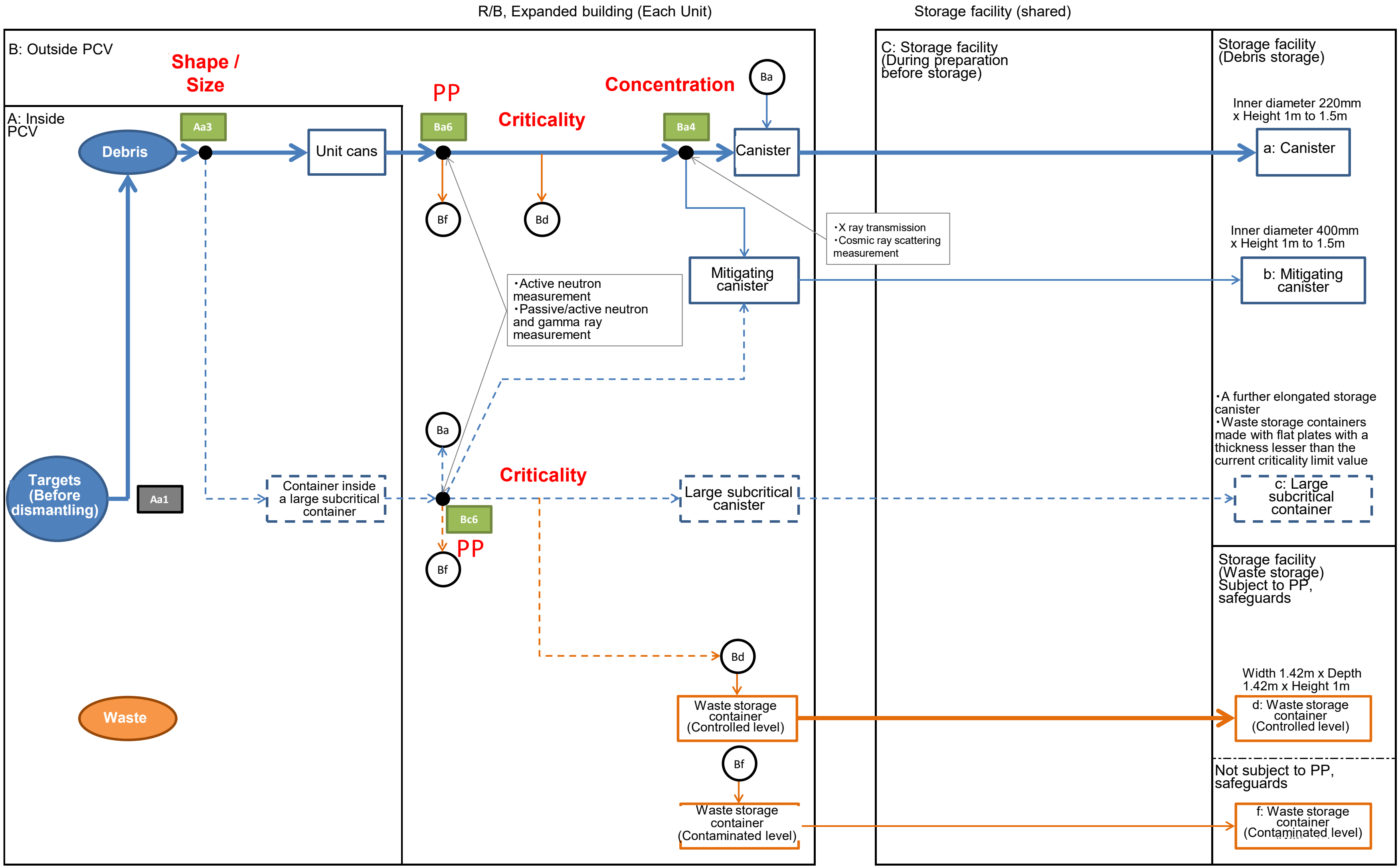
Scenario B: Scenarios focusing on the installability of sorting equipment



7. Implementation details of this project
[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ **Evaluation of technical feasibility of fuel debris sorting scenarios (Evaluation of sorting scenarios)**

Scenario C: When sorting (Aa1) of fuel debris and waste inside PCV is difficult
① (Sorting at the earliest possible stage)

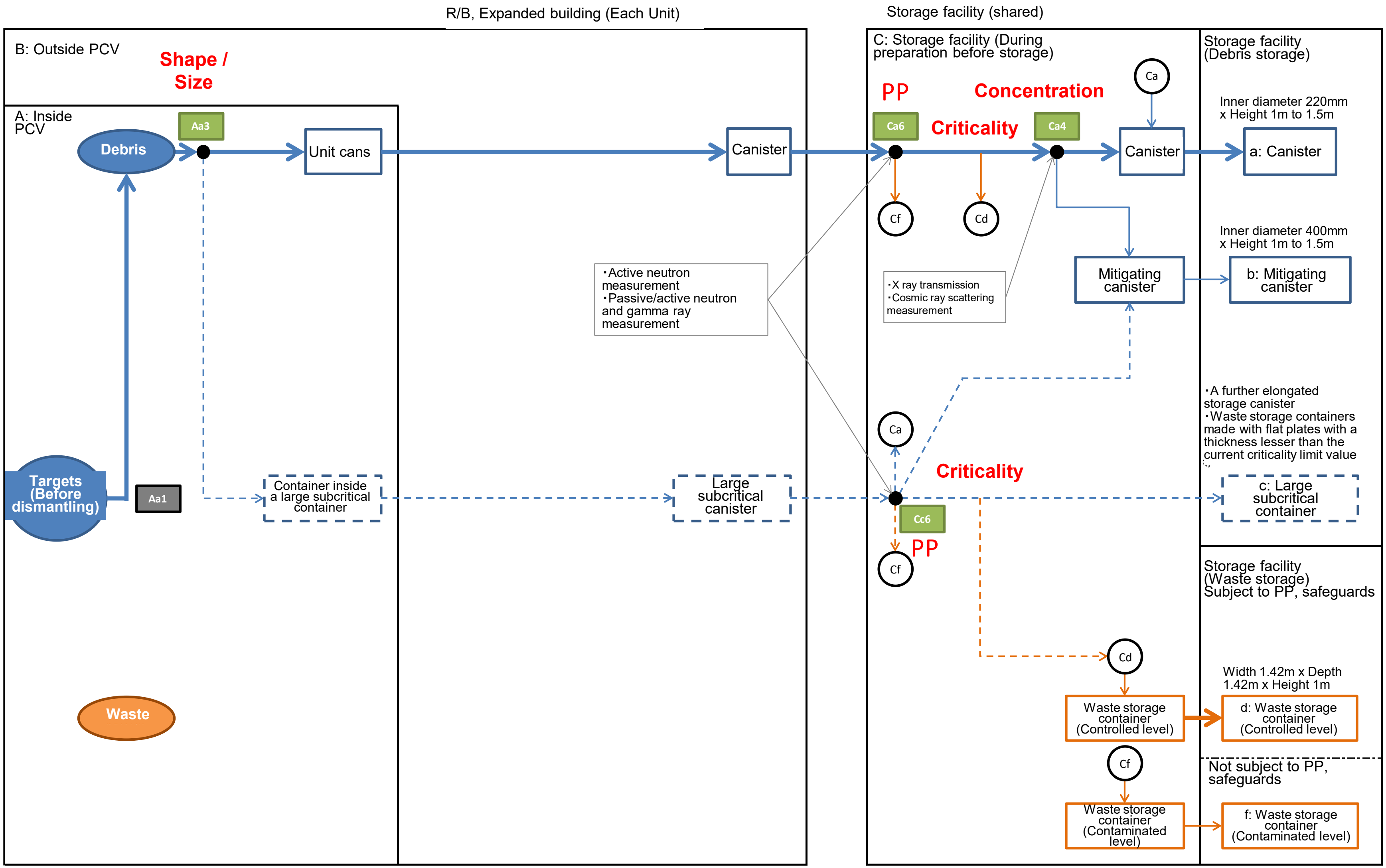


7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ **Evaluation of technical feasibility of fuel debris sorting scenarios (Evaluation of sorting scenarios)**

Scenario D: When sorting (Aa1) of fuel debris and waste inside PCV is difficult ② (Focus on installability of sorting equipment)



7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ **Evaluation of technical feasibility of fuel debris sorting scenarios (Comparison of sorting scenarios)**

Sorting scenario (Main application location)		Merits	Drawbacks	Evaluation
Scenario A A: Inside PCV B: Outside PCV	Sorting at the earliest possible stage	➢ Hot cell can be shared ➢ Amount of transferred material can be optimized since sorting is completed before transportation	➢ Requires sorting equipment for every Unit ➢ Since fuel debris retrieval equipment and sorting equipment coexist, there may be problems in securing a place for installation	➢ Sorting has major benefits such as optimization of transferred amount, but issues associated with installability of equipment are expected ➢ Difficulty level of sorting inside PCV is high
Scenario B A: Inside PCV C: Storage facility	Focus on installability of sorting equipment	➢ Sorting equipment can be shared ➢ It is easier to secure the installation site for sorting equipment when compared with Scenario A	➢ Storage facility requires hot cells ➢ Less effective in reducing the amount of material transferred in canisters when compared to Scenario A	➢ Has merits such as sharing of equipment and installability, but less effective in reducing the amount of material transferred in canisters ➢ Difficulty level of sorting inside PCV is high.
Scenario C (B: Outside PCV)	When sorting (Aa1) of fuel debris and waste inside PCV is difficult ① (Sorting at the earliest possible stage)	➢ Work inside PCV is less when compared to Scenarios A and B ➢ Sorting points are less when compared to Scenario A ➢ (Merits are same as Scenario A)	➢ Delivered quantity of unit cans is more when compared to scenarios A and B ➢ Ba6 treated quantity increases when compared to Scenario A ➢ (Drawbacks are same as Scenario A)	➢ Sorting work inside PCV is less, but issues associated with installability of equipment are expected
Scenario D (C: Storage facility)	When sorting (Aa1) of fuel debris and waste inside PCV is difficult② (Focus on installability of sorting equipment)	➢ Work inside PCV is less when compared to Scenarios A and B ➢ Sorting points are less when compared to Scenario B ➢ (Merits are same as Scenario B)	➢ Delivered quantity in case of unit cans is more when compared to scenarios A and B ➢ Ca6 treated quantity increases when compared to Scenario B ➢ Storage facility requires hot cells ➢ Amount transferred in canisters is the highest of all the scenarios	➢ Sorting work inside and outside PCV is the least and the level of difficulty is low, but it is less effective in reducing the volume of unit cans delivered and amount of material transferred in canisters

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Summary (Issues and future action)

Issues

① The technology survey revealed that at present there is no technology that can be applied to sorting technology as is, and in case of technology that may be feasible, it is necessary to take countermeasures for each issue, for example, understanding the properties of the measurement target and correcting the measurement errors. <Measurement technology>

② Since it is highly difficult to measure nuclear material inside PCV, combination of multiple techniques is required to implement sorting. <Measurement technology>

③ When loading into a waste container, some kind of confirmation method for safety is definitely required in order to “Secure” criticality safety and this method of measurement needs to be developed. <Measurement technology>

④ The amount of fuel debris stored can be reduced in any scenario. However, sorting inside PCV is effective for reducing retrieval workload and sorting at an earlier stage (inside or outside PCV) will be effective in achieving an improved effect of reduction in the amount of transported material. On the other hand, sorting at an early stage has a lot of installability issues pertaining to setup of background level, space for installation etc. and leads to conflicting effects. <Scenario>

⑤ Sorting itself leads to increase in costs and it is necessary to evaluate the relative advantages and disadvantages of cost reduction effects of fuel debris storage and waste storage by sorting. <Scenario>

7. Implementation details of this project

[2) (iii) Survey on sorting technology for fuel debris and radioactive wastes]

■ Summary (Issues and future action)

Future course of action

Matters to be taken up in future for implementation of sorting

① For finalizing the scenarios, it is necessary to decide on implementation of scenario and decide on the stage at which sorting is to be carried out. It is necessary to select the scenarios based on the overall plan for fuel debris retrieval and a study by operators is required. <Scenario>

② It is essential to develop the technologies for image determination and nuclear material measurement required for each scenario. It is difficult to judge the applicability by conducting technological survey focusing on published information and literature. Hence, for future development, it is important to study matters such as measuring instruments, shield structure, data analysis technologies etc. together with the vendors. <Measurement technology>

③ In this study, scenarios were examined assuming the implementation of sorting. In future, it will be necessary to verify the effectiveness of sorting by determining the concrete details of the specifications, layout study, economic evaluation etc. of sorting equipment. <Scenario>

7. Implementation items in this project

3) Development of technology for ensuring safety while retrieving fuel debris

(i) Development of element technology for confinement functions

① Technology for prediction of dust behaviors in PCV

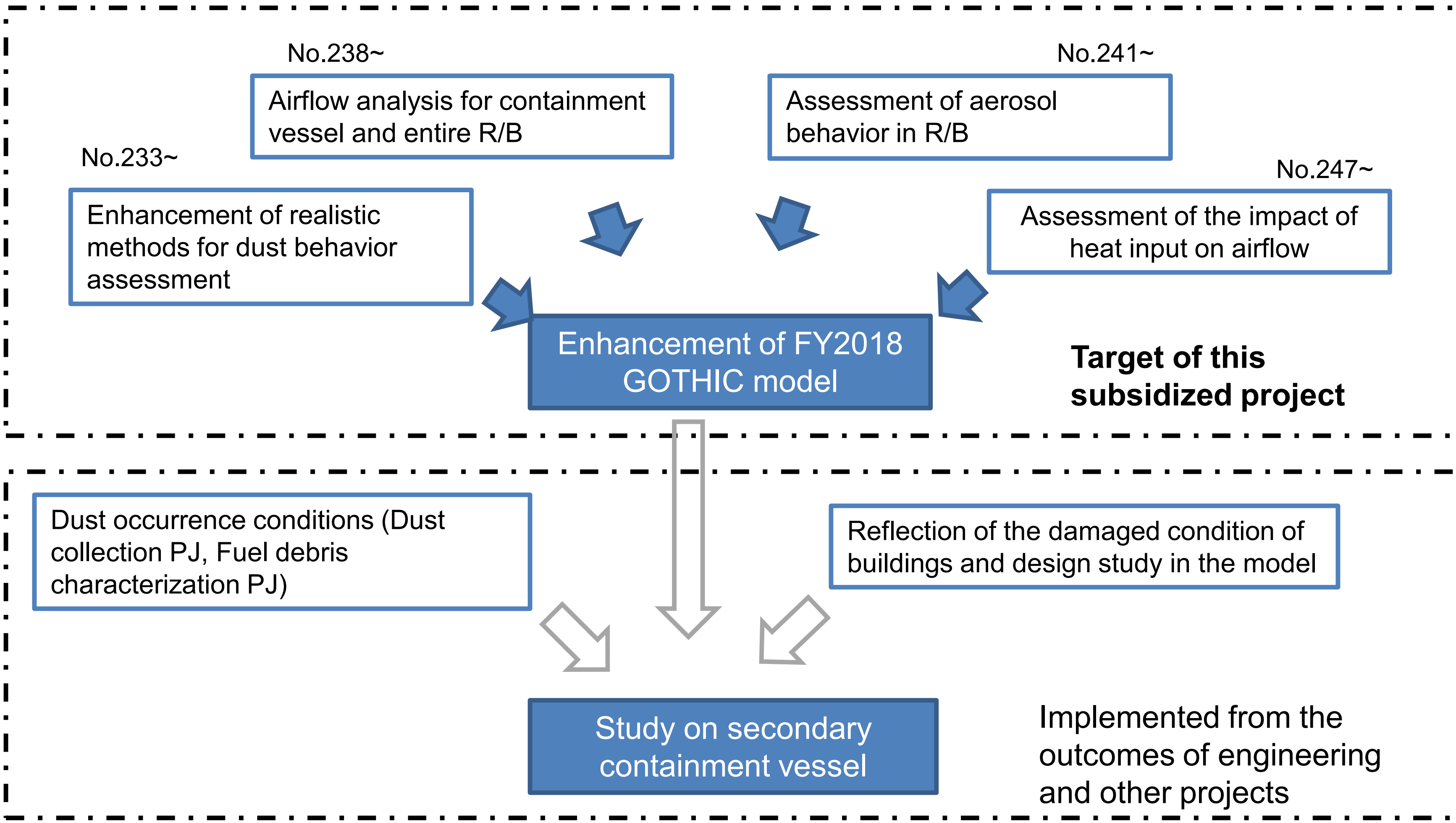
Confinement function is essential to ensure the safety of the public and workers. The project aims at conducting research and development towards combined technology for the analysis of aerosol behavior and airflow analysis inside PCV, which is essential for predicting the behavior of the dust containing alpha nuclides produced during fuel debris processing, and also aims at enhancing the analysis model for predicting the behavior inside R/B. In this way, this project aims at conducting a study on predicting the effects of removing aerosol contained in the dust, selecting appropriate monitoring technology and monitoring positions.

Main study items for development include the following:

a. Airflow analysis

- Realistic dust behavior evaluation techniques were enhanced.
- Airflow analysis was performed for containment vessel and entire R/B.
- Evaluation was conducted to find out the impact of heat input on airflow.

7. Implementation details of this project
[3] (i) ① Technology for prediction of dust behaviors in PCV]



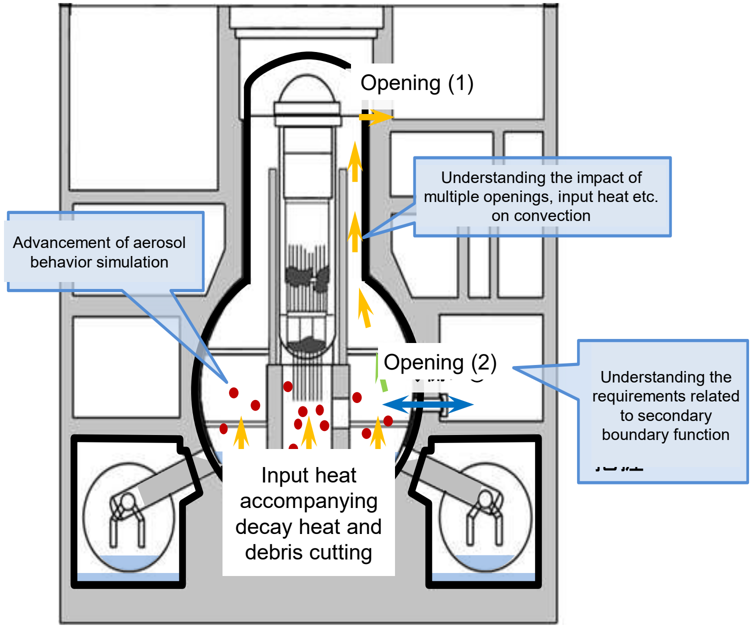
7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]

- Purpose of Development
  - ➢ From the study conducted in the previous subsidy projects, a method for predicting dust behaviors inside PCV using the GOTHIC code was created and the possibility of applying it to system design was obtained. Our goal this year is to study the issues that were not studied last year and to achieve the following two items:
    - Formulation of requirement specifications (ventilation rate, negative pressure) for R/B air tightness and gas management system, to secure the confinement function of radioactive dust in the event of an abnormality
    - Identification of effective monitoring positions from the viewpoint of reducing the exposure to the public and workers while monitoring within the R/B, in the event of an abnormal dust leak from PCV

- Issues to be solved
  - ➢ Study on evaluation methods considering resuspension in the aerosol removal mechanism.
  - ➢ Study of impact on airflow analysis considering the R/B.
  - ➢ Study of the effects on airflow due to the heat input during decay heat / fuel debris processing.

- Approaches to development
  - ➢ Advancement of realistic dust behavior evaluation method
  - ➢ Airflow analysis in containment vessel and entire R/B
  - ➢ Evaluating the behavior of aerosol in R/B
  - ➢ Evaluating the impact of input heat on airflow

- Expected outcome
  - ➢ Requirement specifications (ventilation rate, negative pressure) for R/B air tightness and gas management system to secure the confinement function in the event of an abnormality
  - ➢ Identification of effective monitoring positions from the viewpoint of reducing the exposure to the public and workers while monitoring within R/B, in the event of an abnormal leak from PCV



7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]

■ <u>Development Schedule</u>

Study Items	FY 2019											
	4	5	6	7	8	9	10	11	12	1	2	3
Major milestones							Interim Report ▼					Year-end report ▼
1. Advancement of realistic dust behavior evaluation method												
2. Airflow analysis in containment vessel and entire R/B												
3. Evaluating the behavior of aerosol in R/B												
4. Evaluating the impact of input heat on airflow												
5. Summary												
Remarks												

7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]
① Advancement of realistic dust behavior evaluation method (1/5)

✓ Implementation items for this year [I] - Creation of evaluation methods considering dust removal mechanisms other than gravitational sedimentation -

・Applying the knowledge related to dust removal mechanisms other than gravitational sedimentation

→ Investigation was conducted on each of the GOTHIC removal mechanisms and phenomenon analysis models. As a result of the investigation, it was found that the aerosol behavior in the environment inside the 1F containment vessel can be evaluated by appropriately considering gravitational sedimentation.

・Conducting study on appropriate spatial dust concentration distribution evaluation methods after considering various removal mechanisms

→ While evaluating spatial concentration distribution, the results show that the mesh sensitivity (especially in the gravitational direction) is high when gravitational sedimentation is dominant. By changing to a model with fine mesh, it has been possible to properly evaluate the dust floating in the air (and amount transferred through exhaust).

✓ Implementation items for this year [II] -Confirming the effect of dust removal using a moist environment-

・Confirming the effect of accelerated removal using particle growth

→ The growth of particles in a moist environment happens only in the case of hygroscopic aerosols. As it is considered that the dust generated by fuel debris retrieval does not include hygroscopic particles, it became clear that it is not necessary to pay special attention to the moist environment.

・Confirming the effect of accelerated removal by dropping condensed water

→ The removal effect using the water flowing like raindrops that were observed inside the PCV internal survey was studied. However, this does not work like spray removal and was less effective as well. From this, it was understood that it need not be considered.

7. Implementation items of this project

[3) (i) ① Technology for prediction of dust behaviors in PCV]

① Advancement of realistic dust behavior evaluation method (2/5)

✓ Implementation items for this year [III] - Creation of dust behavior evaluation methods considering resuspension -

・Studying the methods for appropriately simulating the behavior of resuspended dust

→ The GOTHIC V8.3 resuspension model has been created for droplet entrainment at the two-phase flow boundary and it was concluded that it cannot be applied for aerosol analysis at 1F. Though it became clear that a mechanistic model can be incorporated, from the flow rate it became clear that resuspension will not occur. For this reason, it was clear that dust suspension need not be considered.

7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]
① Advancement of realistic dust behavior evaluation method (3/5)

	Mechanism	Controlling factors for the environment	Study on applicability	PCV environment	Airflow analysis handling policy
Natural removal	Gravitational sedimentation	None	Its applicability was confirmed through the validity confirmation conducted in FY2018	–	As it is dominant in natural removal and its applicability has been confirmed, the GOTHIC model shall always be enabled and evaluated.
	Inertial impaction	Stokes number (Flow rate Nozzle diameter)	・Its applicability in the Stk number region (~ 0.3) was confirmed, where the capturing rate of the GOTHIC model is approximately 50% ・ Though inertial impaction is less likely to occur when the Stk number is small, it tends to be non-conservative as it is possible for the GOTHIC model to calculate the removal even in such areas. ・However, as the capturing rate evaluated in the low Stk number region is extremely small (< 1E-5) and is negligible, it has no effect.	Low Stk region (~ 1E-5)	・As the flow rates are such that do not cause inertial deposition inside the PCV environment, the GOTHIC model shall be disabled and evaluated. (As it tends to be non-conservative, there is virtually no problem even when enabled) ・In situations where a high Stk number is expected, it is enabled, as the impact will be large and the applicability can also be confirmed.
	Diffusion deposition	Flow rate	・Diffusion deposition is a phenomenon that occurs near the wall surface (~ 1E-4m). However, even if the aerosol is transported near the wall surface due to turbulence, the effect is limited as the area targeted for diffusion deposition is extremely small with respect to the entire space. ・The diffusion model of GOTHIC is a model that fits the test results assuming in-tube gas-liquid two-phase flow (turbulent flow) and does not simulate a dry state in a large space.	Extremely large space compared to the inside of the pipe, etc.	・Turbulent diffusion acts in limited regions and does not have significant impact in large spaces when compared to gravitational sedimentation. Therefore, it is disabled and evaluated. ・When focusing on turbulence in piping, it shall be enabled and evaluated.
	Thermophoresis	Temperature gradient	・In GOTHIC, it occurs on the surface of the heat sink ・It was confirmed that the GOTHIC model is a model based on the thermal kinetics of the medium gas. Therefore, it is deemed to be applicable in a wide temperature range. ・However, in situations where the temperature difference is extremely small, it has no effect as gravitational sedimentation becomes dominant. ・It may contribute to situation with particles with size to the order of submicron ・It has limited effect in large systems	Expected temperature difference is approximately 5 ℃	・ Though its usability was confirmed, it has no effect in cases where there is almost no temperature difference. So, it can be disabled and evaluated. (Not a problem even if enabled) ・In small systems such as pipes where there is a large temperature difference as well as handling of small particle sizes, it shall be enabled and evaluated.
	Diffusiophoresis	Concentration gradient (Or water vapor condensation rate)	・In GOTHIC, this happens when water vapor condensation occurs on a cold wall surface. ・When calculating the amount of water vapor transferred in an environment with less concentration difference (when diluted water vapor is contained in nitrogen gas), it was confirmed that the value calculated with GOTHIC is several tens of times larger than when evaluated using the diffusion coefficient. ・The reason for this is thought to be that GOTHIC calculates the amount of water vapor transfer from the water vapor condensation rate, but the condensation rate and gas diffusion transfer are different. ・The deposition rates of thermophoresis and diffusiophoresis are generally the same, however, there are concerns on the GOTHIC evaluated values	The expected concentration difference is approximately (0.3 mol / m^{3}) **Note) Difference in saturated water vapor concentration at 5℃**	・As it is not effective in situations where there is almost no difference in concentration (almost no water vapor condensation occurs), it is not necessary to consider it. So, it can be disabled and evaluated. (Even if there is a concentration difference, it should not be enabled as it may overestimate the deposition.)

[3) (i) ① Technology for prediction of dust behaviors in PCV]

① Advancement of realistic dust behavior evaluation method (4/5)

	Mechanism	Controlling factors for the environment	Study on applicability	1F PCV environment	Airflow analysis handling policy
Moisture Effect	Growth of hygroscopic particles	Relative humidity	・Though there is an accelerated removal effect due to the absorption of moisture by the aerosols resulting in increased particle size, it has not been modelled in GOTHIC. ・ Some of the particles with remarkable particle growth are aerosol with deliquescent properties such as sea salt particles, zeolites, silica gel, etc., that absorb moisture. (These absorb moisture even if the relative humidity is less than 100%) ・The particle growth of aerosols other than these (hydrophobic) due to moisture absorption is limited. ・U3O8, Fe oxide, etc., have been reported to have the effect of promoting gravitational sedimentation by changing the shape factor during the aggregation process in a moist environment.	Maximum relative humidity is 100%	・It is unlikely for aerosols with hygroscopicity to be generated due to mechanical cutting. ・Non-hygroscopic aerosols may have some particle growth, but their effects are limited. ・Therefore, as it is not necessary to consider particle growth due to moisture absorption even in a moist environment, no new modeling shall be performed. (However, when considering polydisperse, there are cases where it shall be taken into consideration depending on the aerosol properties)
	Removal using water falling like raindrops	Droplet density Temperature difference	・A spray effect can be considered as a removal mechanism using raindrops ・As a method for aerosol removal using spray, GOTHIC deals with agglomeration of spray droplets and aerosols ・Turbulent diffusion and gravitational sedimentation are considered for agglomeration. ・However, the removal mechanism using spray is generally due to inertial impaction, interception, brown diffusion, and phoresis that are related to airflows around the droplet. ・When the number density of droplets becomes large as in the engineered spray, the target range for removal becomes large and removal effect can be expected. ・In cases where the droplet temperature is low and vapor condensation occurs on the droplet surface, phoresis system removal mechanism works, and a significant capturing rate can be expected.	Low droplet density Small temperature difference (approx. 5℃)	・As the GOTHIC removal model is not based on airflows around the droplet, it is necessary to incorporate the model separately. ・However, with the amount of raindrops caused by cooling water and the amount of evaporation and condensation of drain water, density of droplets is low and spray removal is not possible. ・In addition, when there is no temperature difference between the droplet and the space, the phoresis system removal does not work, and the removal efficiency is extremely small ・Therefore, it is not necessary to consider removal using raindrop-like water that is currently seen, and new modeling shall not be performed.

7. Implementation items of this project

[3] (i) ① Technology for prediction of dust behaviors in PCV]

① Advancement of realistic dust behavior evaluation method (5/5)

Mechanism	Controlling factors for the environment	Study on applicability	1F PCV environment	Airflow analysis handling policy
Resuspension (Dry environment)	Flow rate	・The GOTHIC V8.3 resuspension model has been created for droplet entrainment at the cyclic gas-liquid two-phase flow boundary and is not applicable to dry conditions. ・Though re-scattering of primary particles deposited under dry conditions is unlikely to occur, the fine agglomerated particles re-scatter and form a powder layer when the amount of deposition increases. ・It is considered possible to create a model that evaluates the amount of resuspension based on the mechanical balance between shear stress and adhesive force. ・However, continuous re-scattering does not occur at a flow rate of less than 10 m/s.	・Expected flow rate is less than 0.6 m/s (inside PCV) Less than 0.3 m/s (In R/B) **#99% cumulative value**	・GOTHIC resuspension model cannot be applied ・Though it is possible to incorporate a model to evaluate the re-scattering of agglomerated particles, there is not enough airflow to cause continuous resuspension even in situations where dry aerosols are deposited on dry surfaces. ・ Therefore, no new modeling shall be performed.

7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]
② Airflow analysis in containment vessel and entire R/B (1/3)

✓ Creation of GOTHIC analysis model considering R/B

→ Surveys were conducted on the characteristics of each simulation method of GOTHIC code and construction methods for the building model were studied. Though it was not possible to calculate the transport of aerosols through vertical flow path using the previous surveys, an R/B model using vertical and horizontal flow paths was constructed as transportation accompanied by airflows can be evaluated.

✓ Confirmation on the atmospheric pressure followability of PCV internal pressure taking R/B into consideration, and as a result, the evaluation on the maintainability of negative pressure

→ After the construction of R/B model, the pressure behavior was evaluated under the condition of fluctuating atmospheric pressure and it was confirmed that, like the evaluations in FY2018, the PCV pressure does not follow atmospheric pressure.

✓ Understanding the airtightness of the building using the damage status of R/B

→ The pressure behavior was evaluated with the building damage conditions. If the building is sound, then airtightness can be ensured using negative pressure. Also, even in cases where the operating floor is open to the atmosphere, it was confirmed that it is possible to ensure airtightness using negative pressure by ventilating air from the lower floor and narrowing the flow path to the operating floor.

7. Implementation items of this project

[3] (i) ① Technology for prediction of dust behaviors in PCV]

② Airflow analysis in containment vessel and entire R/B (2/3) ~Analysis Conditions~

[Unit 2: Absence of damage in building]

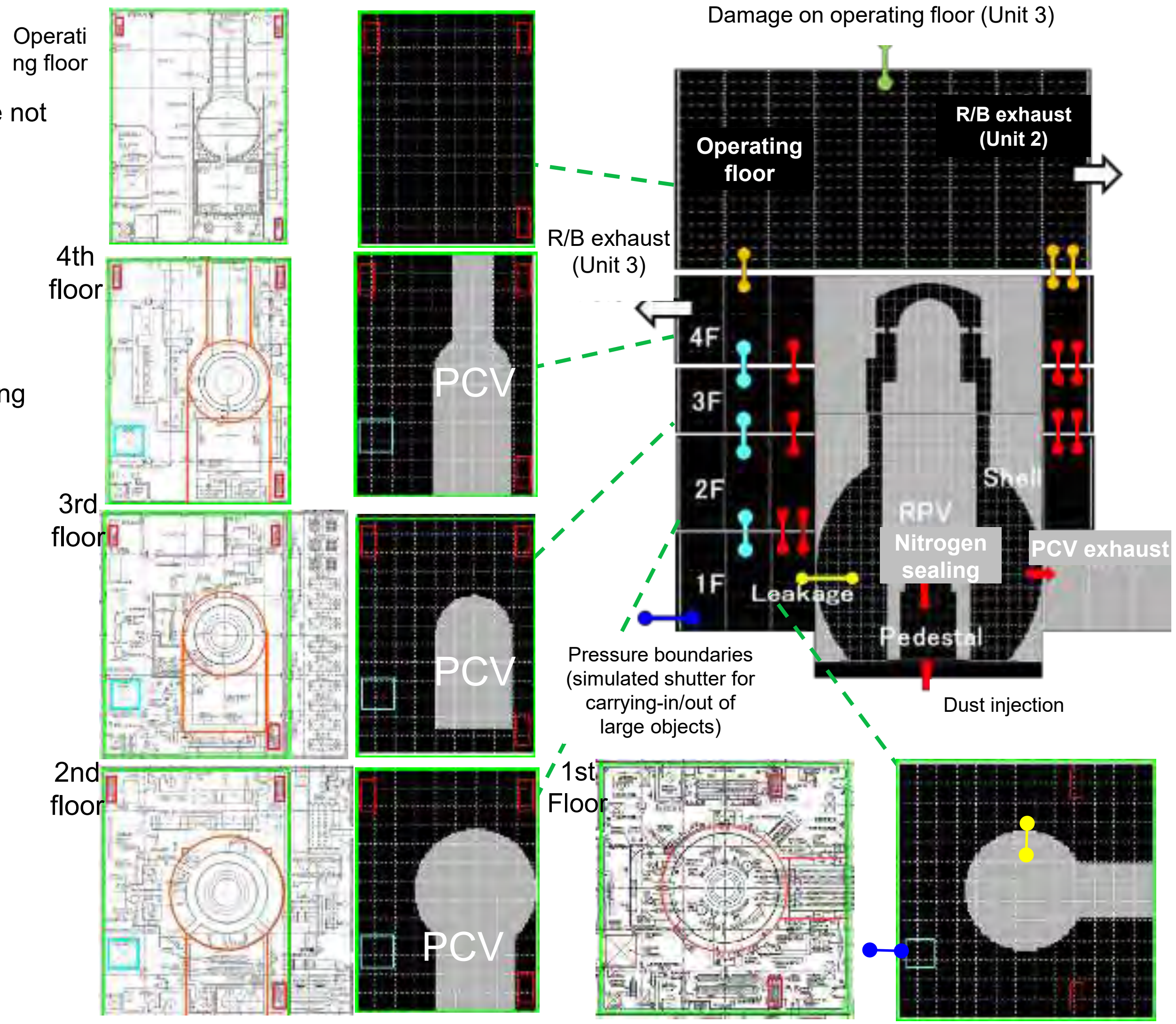
- ✓ Exhaust at 10,000 [m^3/h] from the operating floor (Uniform flow rate boundary)
- ✓ Pressure boundaries due to damage in operating floor are not considered

[Unit 3: Presence of damage in building]

- ✓ Assuming damage in operating floor ceiling (pressure boundary)
- ✓ Exhaust at 10,000 [m^3/h] from the 4th floor of the building (Uniform flow rate boundary)
- ✓ Negative pressure countermeasures for the building are expected to be implemented in the area of the stairs leading from the 4th floor to the operating floor (The flow path area is set to 1/100)

[R/B shared items]

- ✓ Secondary containment on the floors above the ground (1st to 5th floor) are considered as target for modelling
- ✓ The equipment hatch between the building floors is kept open. However, the equipment hatch on the operating floor is closed.
- ✓ The staircase door is open
- ✓ The flow path between floors are staircases and equipment hatches, and each of them are modeled to have vertical flow paths
- ✓ Though the shutter used for carrying equipment in/out remains shut, it is considered as the atmospheric pressure isobaric boundary due to lack of airtightness
- ✓ Areas on each floor (PCV and MS tunnel rooms) that are not included in the free space are closed using blockages



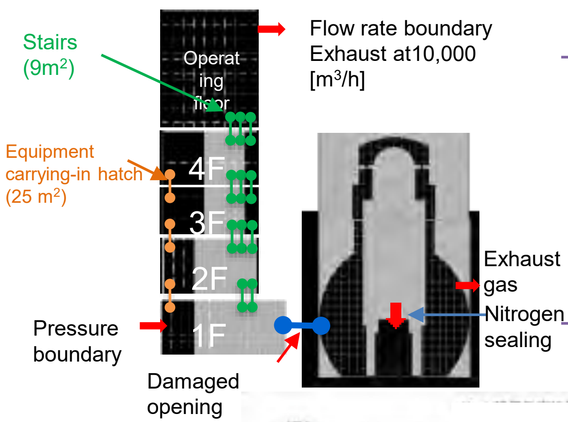
7. Implementation items of this project

[3] (i) ① Technology for prediction of dust behaviors in PCV]

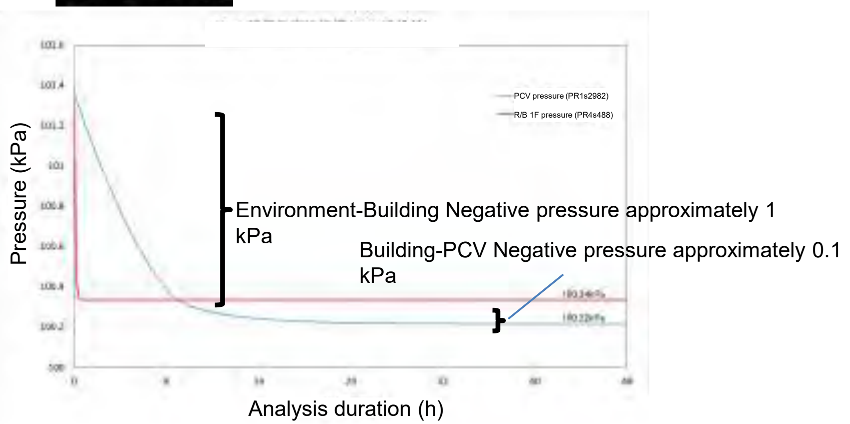
② Airflow analysis in containment vessel and entire R/B (3/3)

- ✓ In cases where the air tightness of the building is ensured (absence of damage in the building), it is possible to create negative pressure in the building by performing exhaust at 10,000 [m^3/h] from the current operating floor. In addition, it is expected that a negative pressure of approximately 0.1 kPa can be achieved inside the PCV as well against the building.
- ✓ When the air tightness of the building was lost (operating floor ceiling and building damaged), exhaust from the operating floor became meaningless and the evaluation was conducted by relocating the building exhaust to the 4th floor. However, the result was that negative pressure could not be created due to the inflow of outside air from the operating floor side.
- ✓ As countermeasures for the building, cross-sectional area of the stairs between the operating floor and 4F was reduced to 1/100 (0.09m^2 x 3) which resulted in creation of approximately 0.1 kPa negative pressure in the building. In addition, it is expected that a negative pressure of approximately 0.1 kPa can be achieved inside the PCV also against the building.

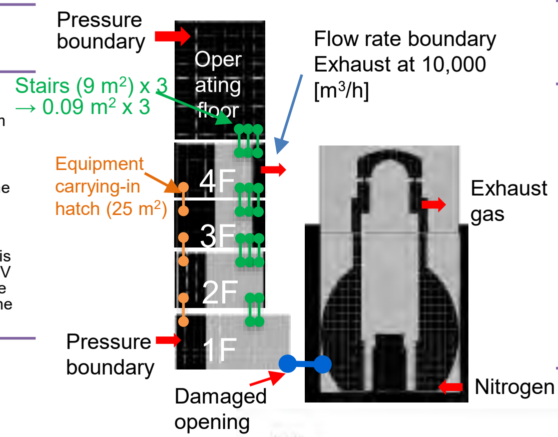
[Absence of damage in building]



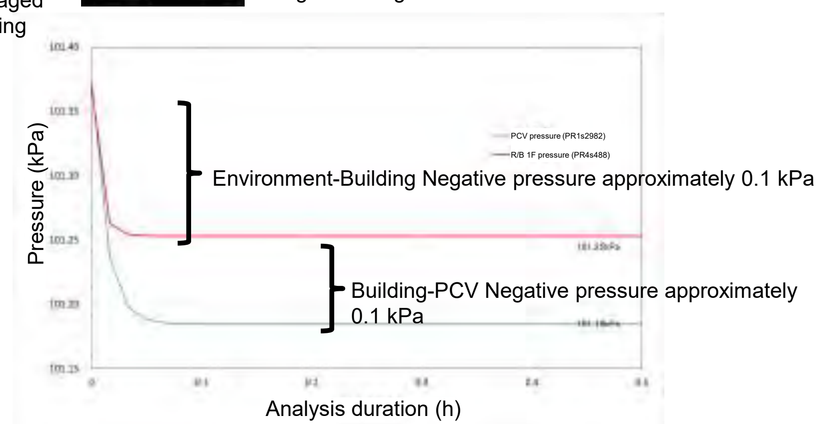
Analysis Conditions	Air flow
Nitrogen sealing	15.6 Nm³/h It is assumed that all nitrogen sealed from the top of the RPV flows out from the bottom of the RPV to the PCV.
Damaged opening	Assuming D/W spherical shell Based on the previous year's study, the area was set to 1. 0 E-4m²
Exhaust air flow from PCV	16.8 Nm³/h Based on the previous year's study, it is the air flow required to achieve the PCV negative pressure of 0.1 kPa when the outside of the PCV is assumed to be the atmosphere



[Presence of damage in building]



Analysis Conditions	Air flow
Nitrogen sealing	1700 Nm³/h Based on the previous year's study, the airflow required for the negative pressure and mitigation of oxygen concentration is sealed in from the bottom of the RPV
Damaged opening	Assuming D/W spherical shell Based on the previous year's study, the area was set to 1. 0 E-2m²
Exhaust air flow from PCV	2000 Nm³/h Based on the previous year's study, it is the airflow required for achieving the PCV negative pressure of 0.1 kPa and for the mitigation of oxygen concentration assuming that the outside of the PCV is the atmosphere



[3) (i) ① Technology for prediction of dust behaviors in PCV]

③ Evaluating the behavior of aerosol in R/B (1/6)

The analysis conditions including the R/B model were set for evaluating the aerosol behavior inside R/B. The behavior of aerosols inside R/B was evaluated by assuming cases such as most severe PCV leakage, continuation of nitrogen sealing and fuel debris cutting after the stoppage of PCV exhaust, etc., in an environment equivalent to Unit 3 where the airtightness of the building has been lost.

✓ Evaluating the behavior at the time of abnormal dust leakage in R/B

The following findings were obtained by conducting the R/B dust behavior evaluation:

- It was confirmed that in areas where the gas flow rate was fast, the amount of dust deposition was small, and in areas where the flow rate was slow (stagnation), the amount of deposition tends to be large. It became evident that the air flow rate is an important parameter.
- From the perspective of leak detection monitoring, it became clear that it may not be possible to measure the air dose rate correctly in areas with large amount of deposition after a certain period due to the background effect of the deposited FP.

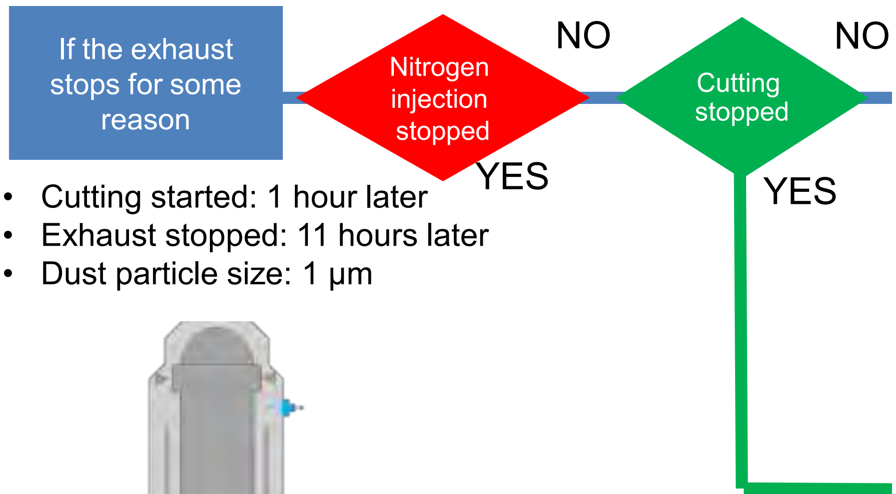
✓ Sensitivity analysis for R/B dust behavior

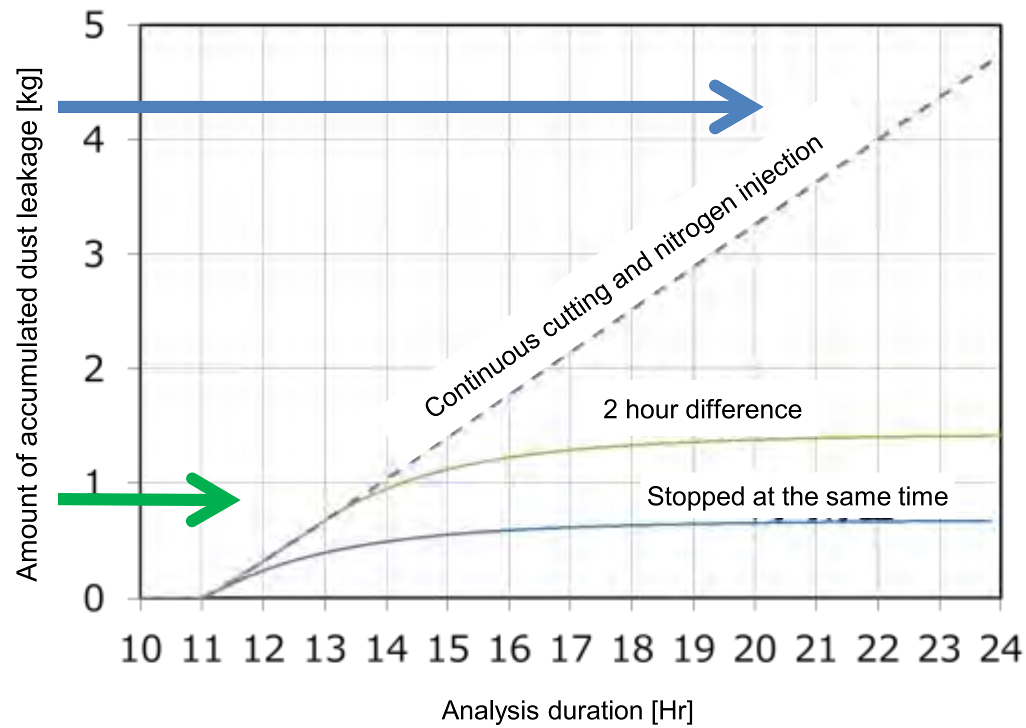
As sensitivity analysis, the following findings were obtained by evaluating the impact of damaged opening position in PCV, impact of response at the time of stoppage of PCV exhaust system and impact of the state of air-conditioning in the building:

- It is possible to prevent the spread of contamination by stopping dust cutting immediately after detecting an abnormal leakage.
- Even in cases where the R/B cannot be maintained in a negative pressure state, exhaust from the building results in the prevention of dust leakage into the environment. As a result, the confinement function may be secured even when negative pressure inside the building is not attempted.
- However, if negative pressure is not attemted inside the building, the contamination on the leaked floor spreads. In addition, as the deposition in the building increases, the dust transfer to the building exhaust decreases.
- If the building exhaust is not performed, the gas leaking from the PCV will cause dust to leak into the environment. Ventilation of the building is indispensable to confine the dust.

7. Implementation items of this project
[3) (i) ① Technology for prediction of dust behaviors in PCV]
③ Evaluating the behavior of aerosol in R/B (2/6)

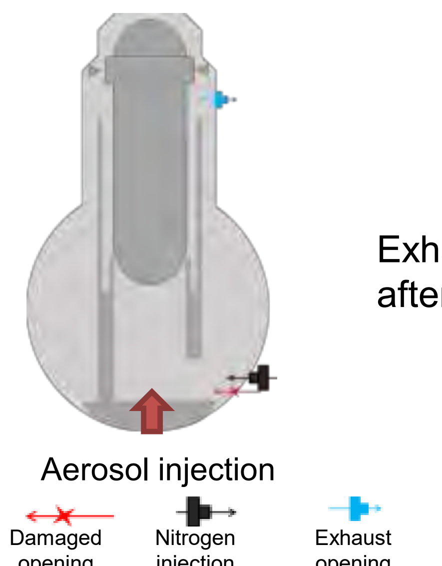
✓ As a result of sensitivity analysis conducted in FY2018 to study the amount of dust leak from PCV, it was found that continuous nitrogen injection and continuous dust cutting while PCV exhaust was stopped was the most severe condition . Therefore, the same conditions are used to evaluate the dust leakage inside the building.





- Cutting started: 1 hour later
- Exhaust stopped: 11 hours later
- Dust particle size: 1 μm

Exhaust stopped after 0h, 1h, 2h

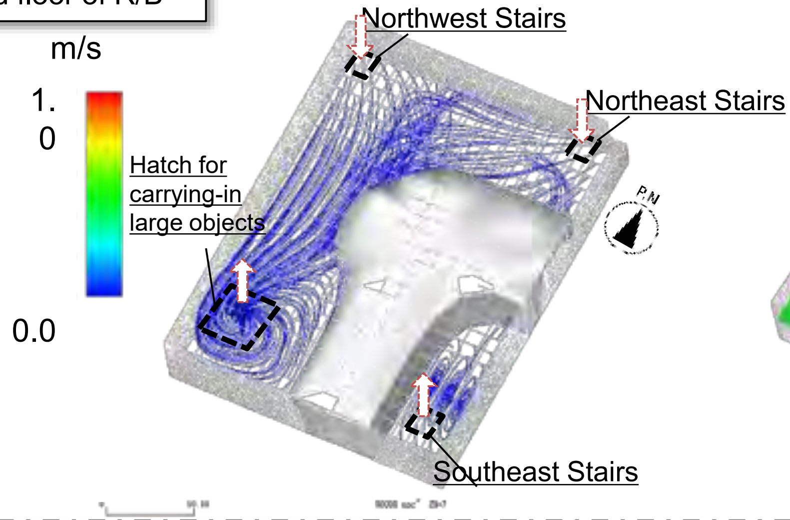


* From the results of technology development research conducted in FY2018 to secure confinement function

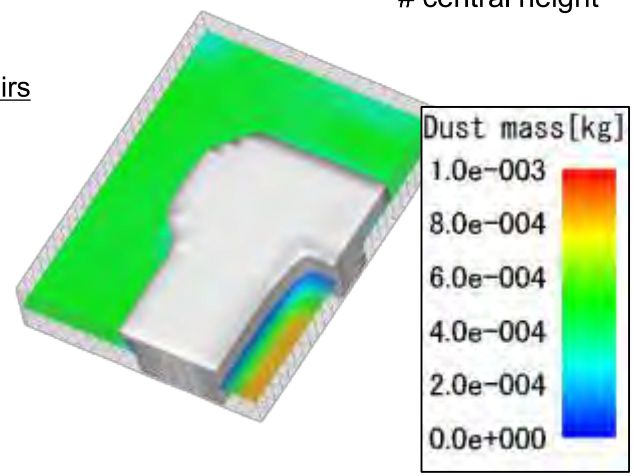
[3) (i) ① Technology for prediction of dust behaviors in PCV]
③ Evaluating the behavior of aerosol in R/B (3/6) ~ Mass distribution of aerosol ~

[Base case analysis result (1st floor to 2nd floor)]

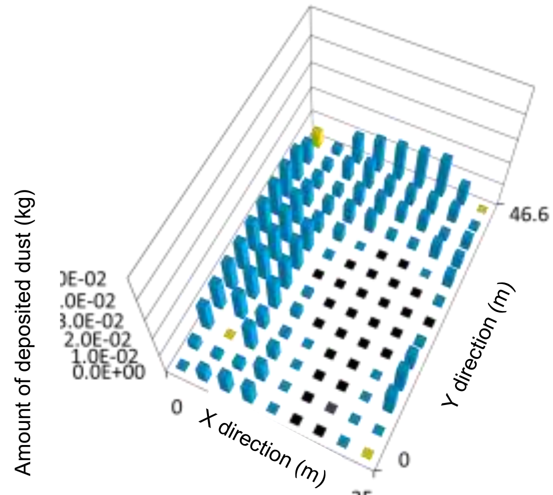
2nd floor of R/B



Amount of airborne dust

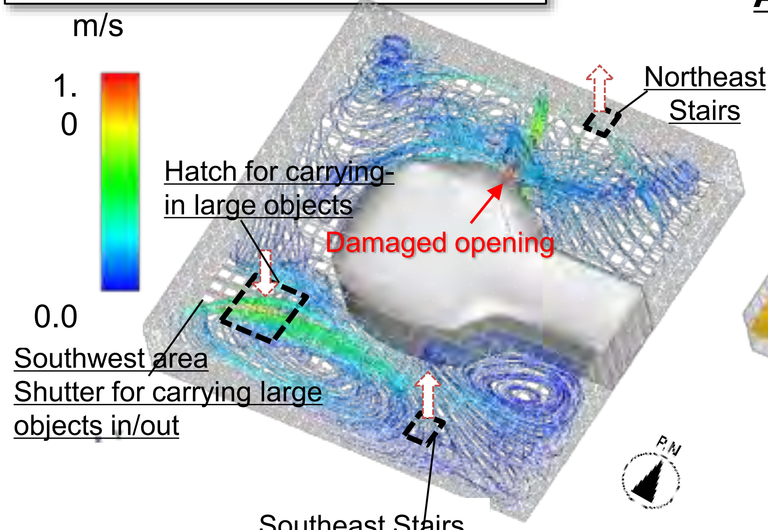


Amount of deposited dust

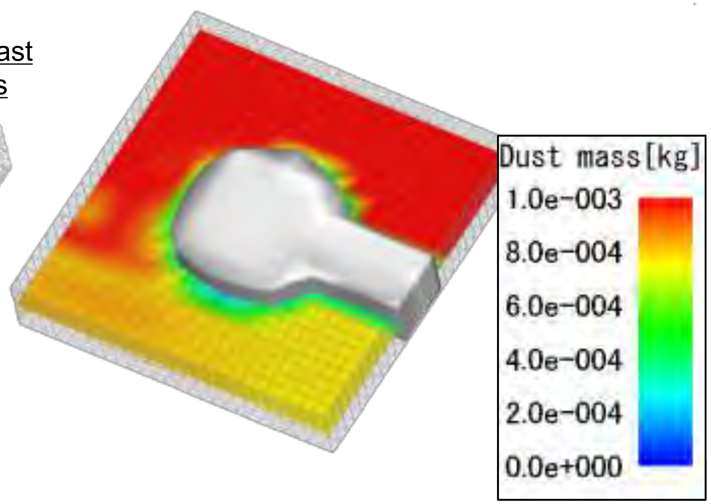


24 hours after dust leakage

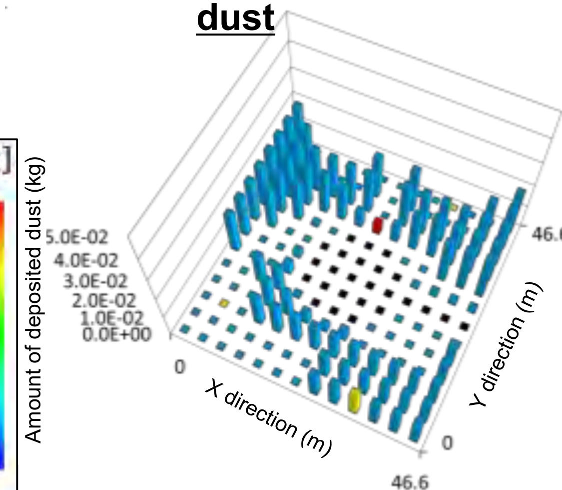
1st Floor of R/B (**Leakage floor**)



Amount of airborne dust # central height



Amount of deposited dust



24 hours after dust leakage

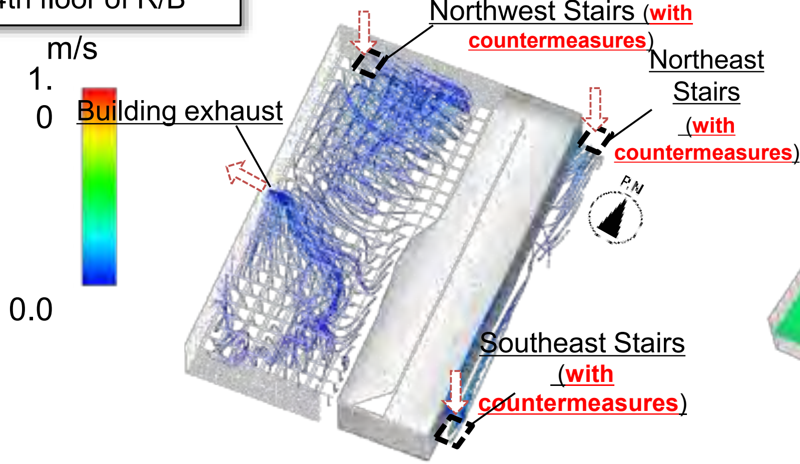
7. Implementation items of this project

[3] (i) ① Technology for prediction of dust behaviors in PCV]

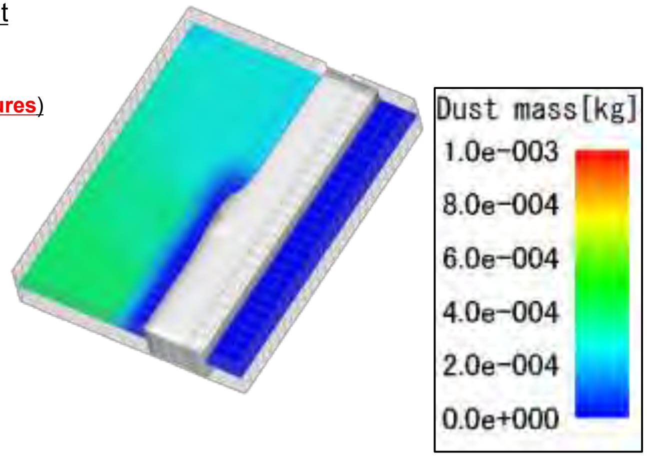
③ Evaluating the behavior of aerosol in R/B (4/6) ~ Mass distribution of aerosol ~

[Base case analysis result (3rd floor to 4th floor)]

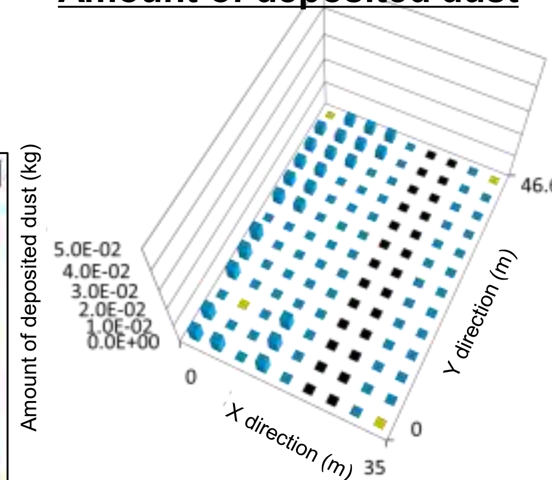
4th floor of R/B



Amount of airborne dust # central height

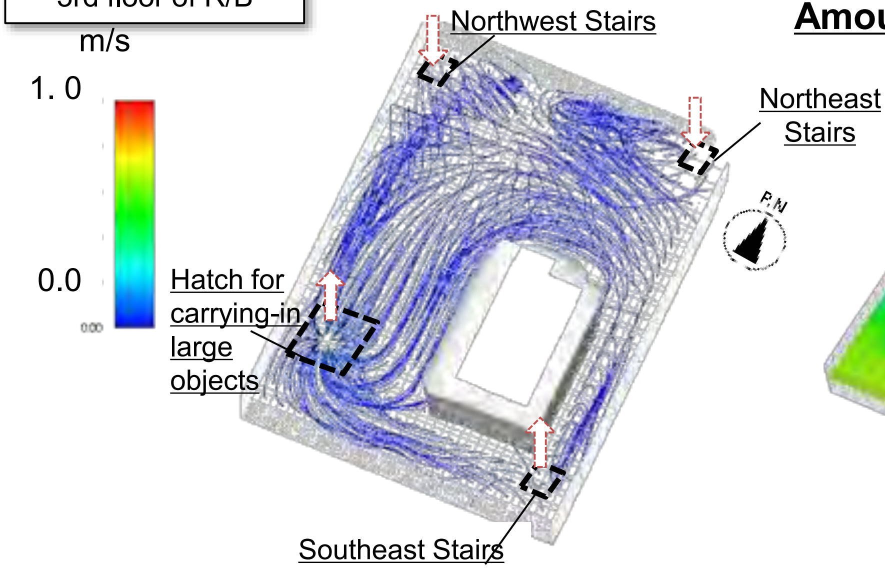


Amount of deposited dust

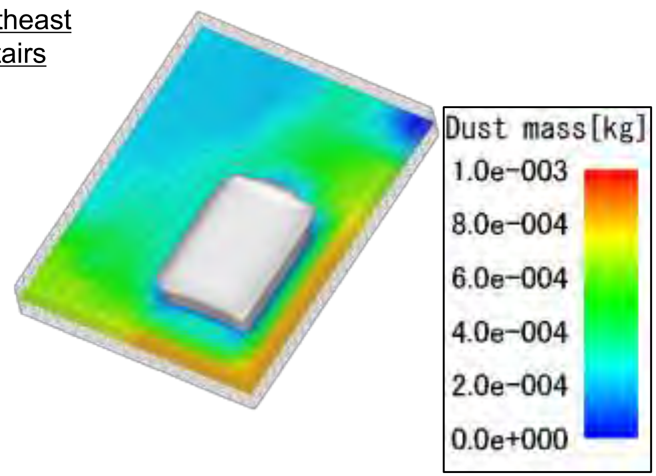


24 hours after dust leakage

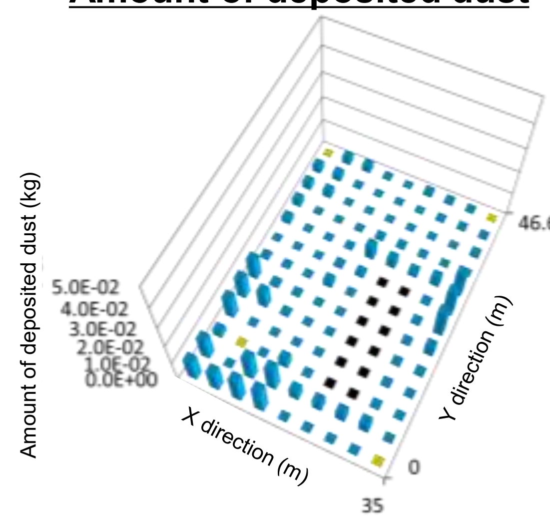
3rd floor of R/B



Amount of airborne dust # central height



Amount of deposited dust



24 hours after dust leakage

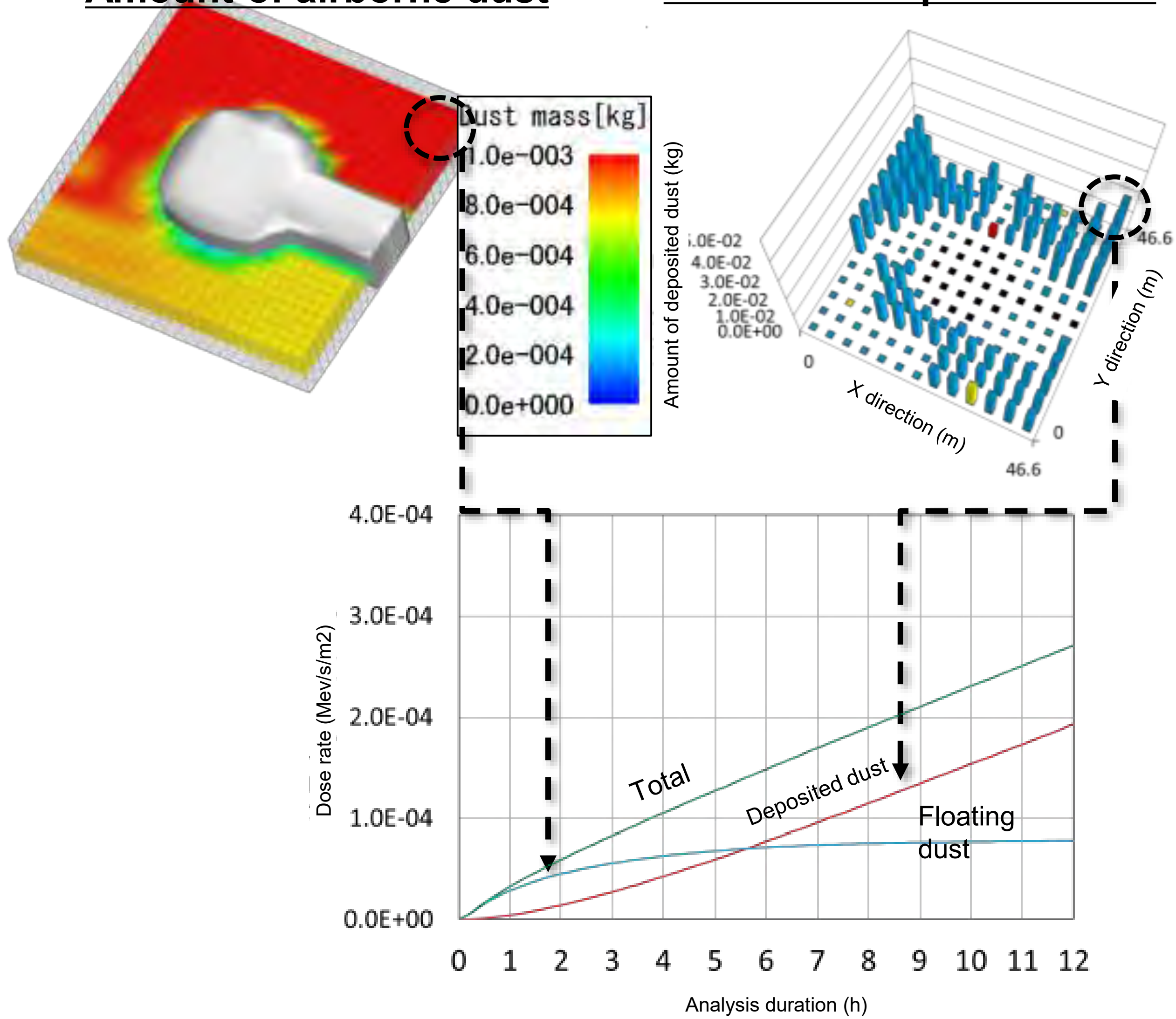
[3) (i) ① Technology for prediction of dust behaviors in PCV]

③ Evaluating the behavior of aerosol in R/B (5/6) ~Monitoring dose rate contribution~

- ✓ When doing a simple evaluation on the dose rate contribution when FP is suspended in a cube with a side of 3m and when all of it is deposited on the floor, <u>the contribution of suspended FP was about 3 times than that of deposited FP.</u>
- ✓ In areas where the deposited amount is the most severe, <u>the dose rate contribution of floating dust is dominant up to 5.5 hours</u>, and after that, the contribution by the deposited dust is high.

- ✓ From a monitoring point of view, in areas with a high amount of dust deposition, <u>the air dose rate may not be measured properly after a certain period of time</u>.

Amount of airborne dust **Amount of deposited dust**



7. Implementation items of this project

[3] (i) ① Technology for prediction of dust behaviors in PCV]

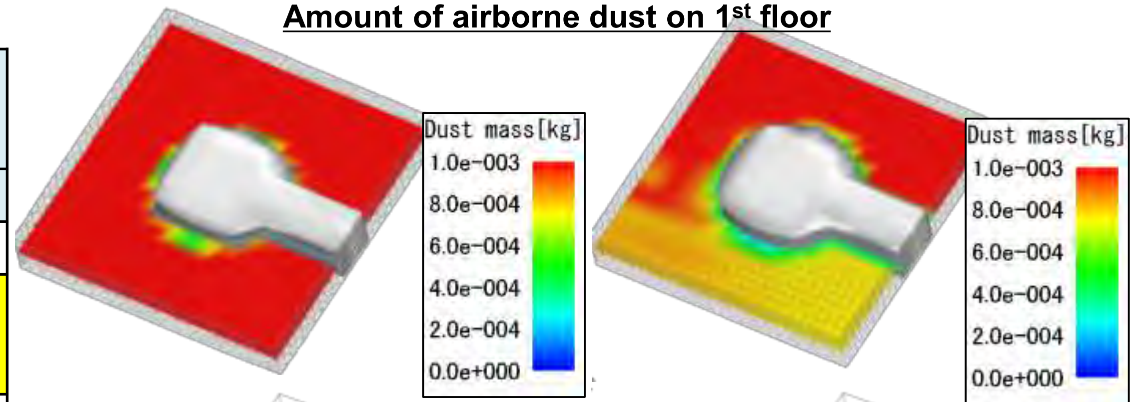
③ Evaluating the behavior of aerosol in R/B (6/6) ~Sensitivity analysis using building countermeasures~

- ✓ **Dust may not be released to the environment** even if negative pressure countermeasures are not implemented.
- ✓ When negative pressure countermeasures are not implemented, **dust inside the building increases** and contamination on1st floor and 2nd floor of the building spreads.
- ✓ By implementing negative pressure countermeasures, it may be possible to reduce the amount of dust inside the building and prevent contamination. However, the **exhaust dust from the building increases.**
- ✓ Furthermore, **if the building exhaust is not performed, dust is released into the environment through the operating floor and the shutter for carrying large objects in/out.**

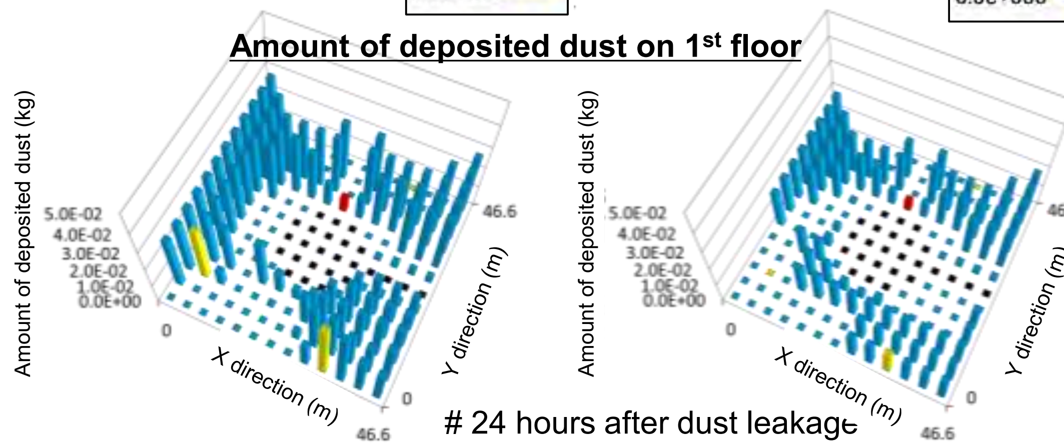
Staircase area		Negative pressure countermeasures implemented	Negative pressure countermeasures not implemented
		0.09 [m^2]	9.0 [m^2]
Negative pressure		0.1 [kPa-diff]	0.0 [kPa-diff]
Intake of outside air through the operating floor		2.0 [kg/s] (Gas)	2.9 [kg/s] (Gas)
Amount of dust exhaust from 4F		5.2 [kg]	2.1 [kg]
Dust mass #	4F	0.3 [kg]	0.2 [kg]
	3F	0.4 [kg]	0.5 [kg]
	2F	0.9 [kg]	2. 4 [kg]
	1F	2. 1 [kg]	3. 8 [kg]
Intake of outside air through the shutter for large objects		0.9 [kg/s] (Gas)	0.04 [kg/s] (Gas)

 # Sum of the floating and deposited amounts

Amount of airborne dust on 1st floor



Amount of deposited dust on 1st floor



24 hours after dust leakage

Negative pressure countermeasures not implemented (0 [kPa - diff])	Negative pressure countermeasures implemented (0.1 [kPa - diff])

④ Effect of heat input on airflows (1/9)

・In cases where the dust and the area near the floor become hot due to the decay heat from fuel debris or due to the cutting of fuel debris etc., the ascending air flow will cause more dust to fly up, possibly increasing the amount of leakage and the amount of dust migrating to the exhaust.
・When a temperature gradient occurs inside PCV and multiple damaged openings are present in the PCV, the chimney effect will cause the airflow to enter and exit through the damaged opening. This is believed to have impact on the dust behavior.

✓ Implementation items for this year [I]

- Study including the method for evaluating the effect of heat input on airflows due to decay heat of fuel debris or cutting of fuel debris -

→ As typical cutting methods, plasma cutting that has a large thermal effect, and laser cutting that has a large amount of assist gas, were selected, and the amount of dust generated and the amount of heat input (heat dissipation at the time of cutting and decay heat of the cutting dust) were evaluated based on the literature. Also, a model adding heat input to airflow was built.

→ Through analysis, the increase in airflow temperature due to heat input was confirmed by taking into account the increase in exhaust airflow due to the blowout of assist gas and heat input.

✓ Implementation items for this year [II]

- Understanding the temperature gradient due to heat input and understanding the relationship between the position of damaged openings and the chimney effect based on it -

→ A sub-volume was added to the GOTHIC model to simulate the gaps between the PCV and building concrete. Two damaged opening locations with different heights and flow conditions were set.

→ When the negative pressure inside the PCV was set from -200 Pa to -300 Pa, there was no leak due to the chimney effect in the gaps between the inside of the PCV and the outside of the PCV. Heat dissipation at the time of cutting is the dominant factor for increasing the pressure inside the PCV.

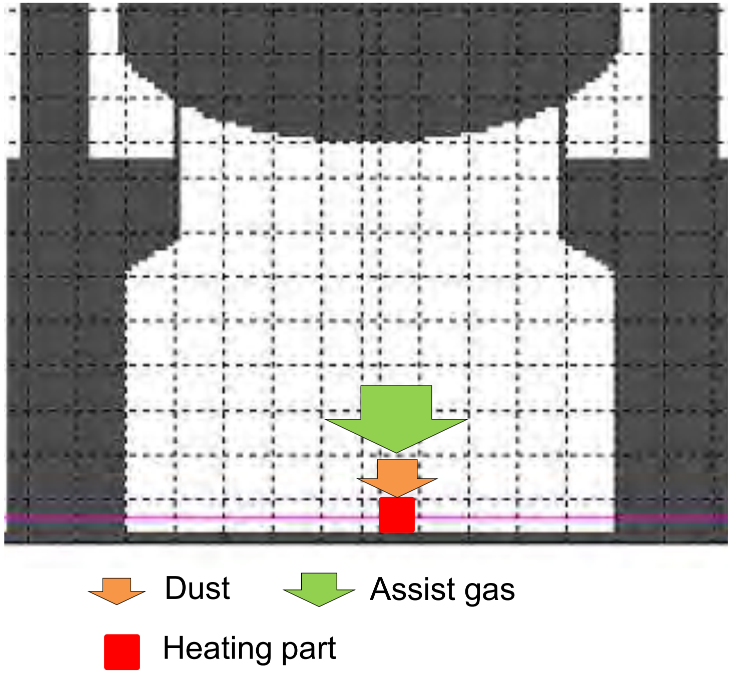
[3] (i) ① Technology for prediction of dust behaviors in PCV]

④ Effect of heat input on airflows (2/9)

- ✓ As cutting methods, plasma cutting that has a large thermal effect, and laser cutting that has a large amount of assist gas, were selected, and the amount of dust generated and the amount of heat input (heat dissipation at the time of cutting and decay heat of the cutting dust) were evaluated based on the literature.
- ✓ A model with addition of heat input was built. The heat loss due to exhaust was added to the flow of plasma gas and assist gas at the fuel debris cutting position.

Study on the proposed parameters for evaluating the effect of heat input

Analysis Conditions	Plasma cutting	Laser cutting
Cutting current / laser output	200 kW (600 A)	6 kW
Operating rate *1	50%, 25%	50%, 25%
Plasma gas / assist gas	Ar, N_2	N_2
Gas flow rate *2	19.5 L/min	175 L/min
Loss of exhaust heat *3	7%	7%
Amount of dust generated (underwater cutting) *2	3.7×10^{-6} kg/s	1.8×10^{-6} kg/s
Size of dust particles *4	0.05×10^{-6} m	1.0×10^{-6} m

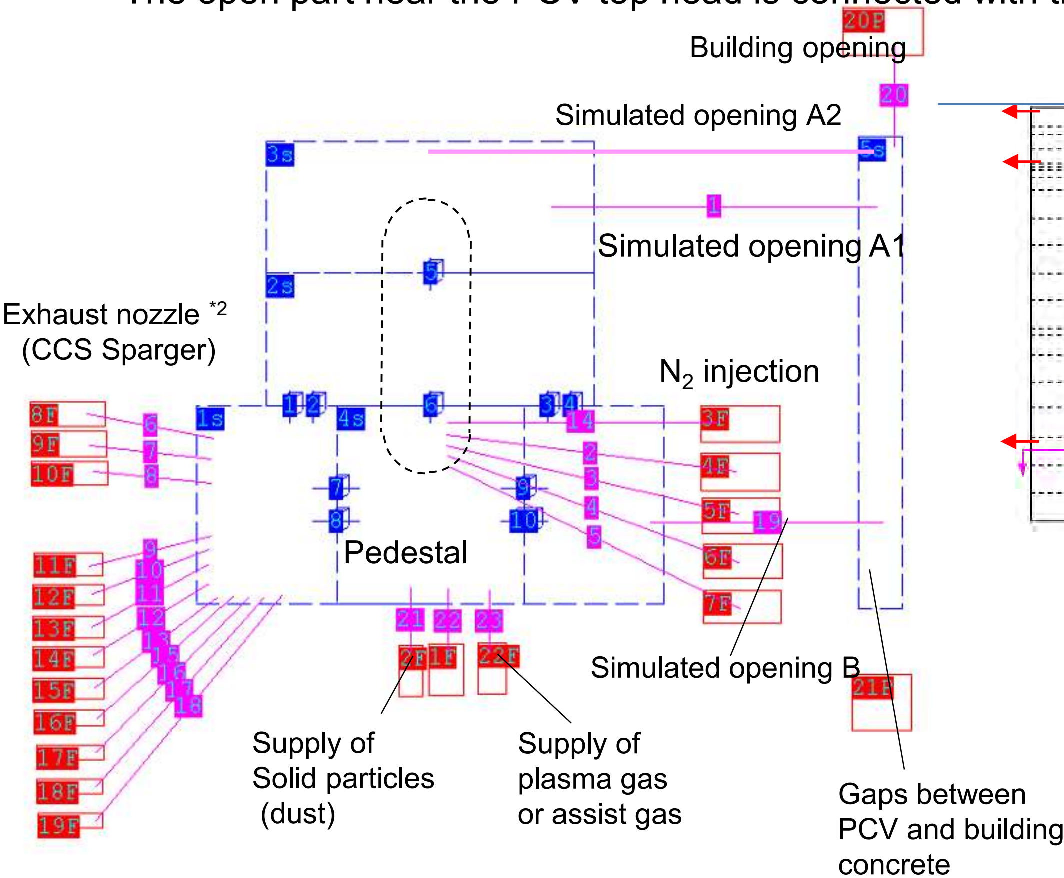


Dust, gas and amount of heat added

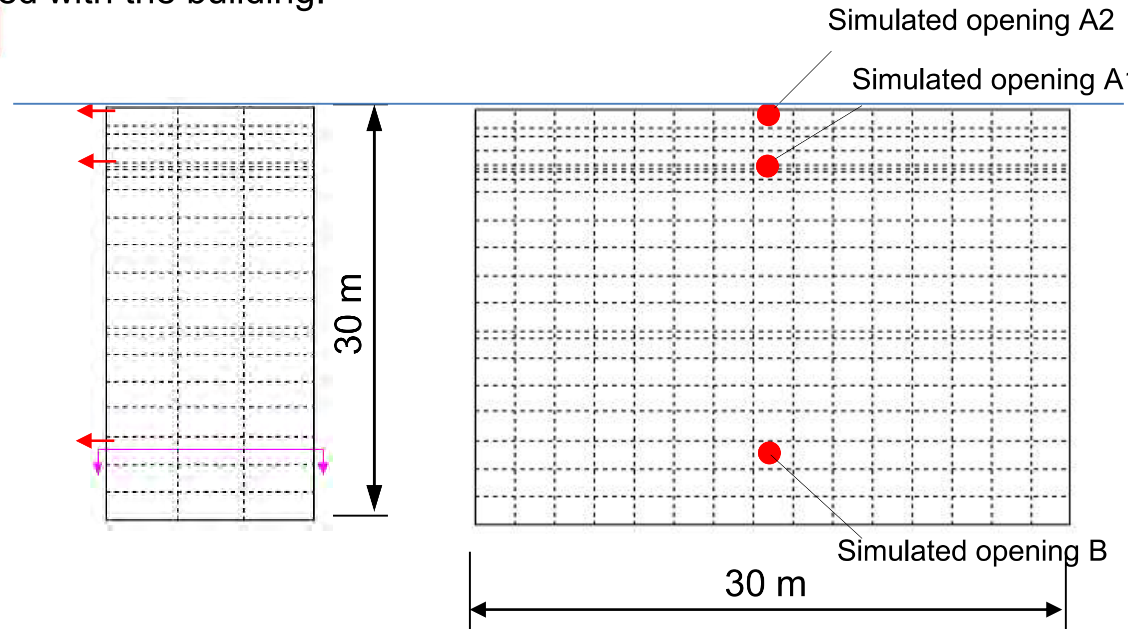
*1: It is the percentage of the net cutting time (50%, quoting the estimated value) excluding the non-heating time such as pulling up and moving the torch, from the working hours.
*2: Value when the operating rate is 50%.
*3: The evaluated value of the exhaust heat loss ratio of plasma gas in the casting field has been used. In underwater cutting, it is assumed that except for the amount of heat that accompanies the exhaust, the rest of the heat gets transitioned to the water that has large heat capacity and subcooling.
*4: The dust particle size distribution during plasma cutting in JPDR dismantling field test is quoted. The dust particle size distribution during SUS304 laser cutting is quoted.

④ Effect of heat input on airflows (3/9)

- ✓ To analyze the chimney effect, a sub-volume simulating the gaps between the PCV and the building concrete is added outside the PCV in the GOTHIC model. For the openings simulating the damaged openings in the upper part, the positions where the height and flow conditions are different (A1: Top head flange, or A2: Top of top head) were studied.
- ✓ The open part near the PCV top head is connected with the building.*1



Control Volume Settings



Sub-volume settings for gaps between PCV and building

*1: The plan was to set up a model that considers gas replacement with the building through pipe opening holes in the case of a leak and increase in temperature in the gaps. However, the results of this analysis confirmed that there was no leakage, so it was decided that it need not be considered.

* 2: In this analysis, the current exhaust system is simulated.

④ Effect of heat input on airflows (4/9)

- ✓ The chimney effect and dust diffusion behavior were evaluated by performing an analysis simulating the fuel debris cutting state.
- ✓ Based on the evaluation [5] of this project, the exhaust flow rate in the analysis was set so that the negative pressure in the PCV became -200 Pa to -300 Pa.

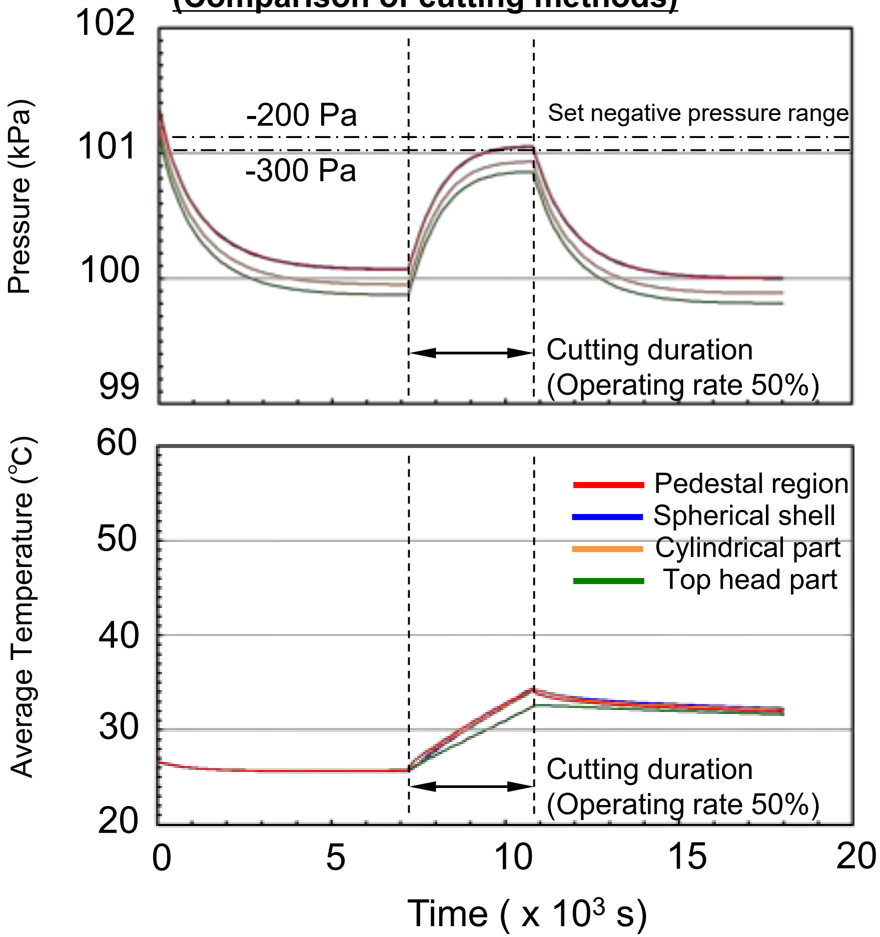
Exhaust flow rate for each cutting method

Case No.	Cutting method	Position of the opening Cutting operating rate	Exhaust flow rate	Maximum pressure during cutting [Negative pressure]
1	Plasma (Underwater)	Top head flange 50%	3.96 kg/min (0.066 kg/s)	101.11 kPa [-215 Pa]
2		Top head flange 25%	3.38 kg/min (0.056 kg/s)	101.05 kPa [-275 Pa]
3		Top of top head 50%	3.96 kg/min (0.066 kg/s)	101.11 kPa [-215 Pa]
4	Laser (Underwater)	Top head flange 50%	2.88 kg/min (0.048 kg/s)	101.11 kPa [-215 Pa]
5		Top head flange 25%	2.88 kg/min (0.048 kg/s)	101.05 kPa [-275 Pa]
6		Top of top head 50%	2.88 kg/min (0.048 kg/s)	101.11 kPa [-215 Pa]
7	Plasma (in air)	Top head flange 50%	11.8 kg/min (0.196 kg/s)	101.04 kPa [-285 Pa]

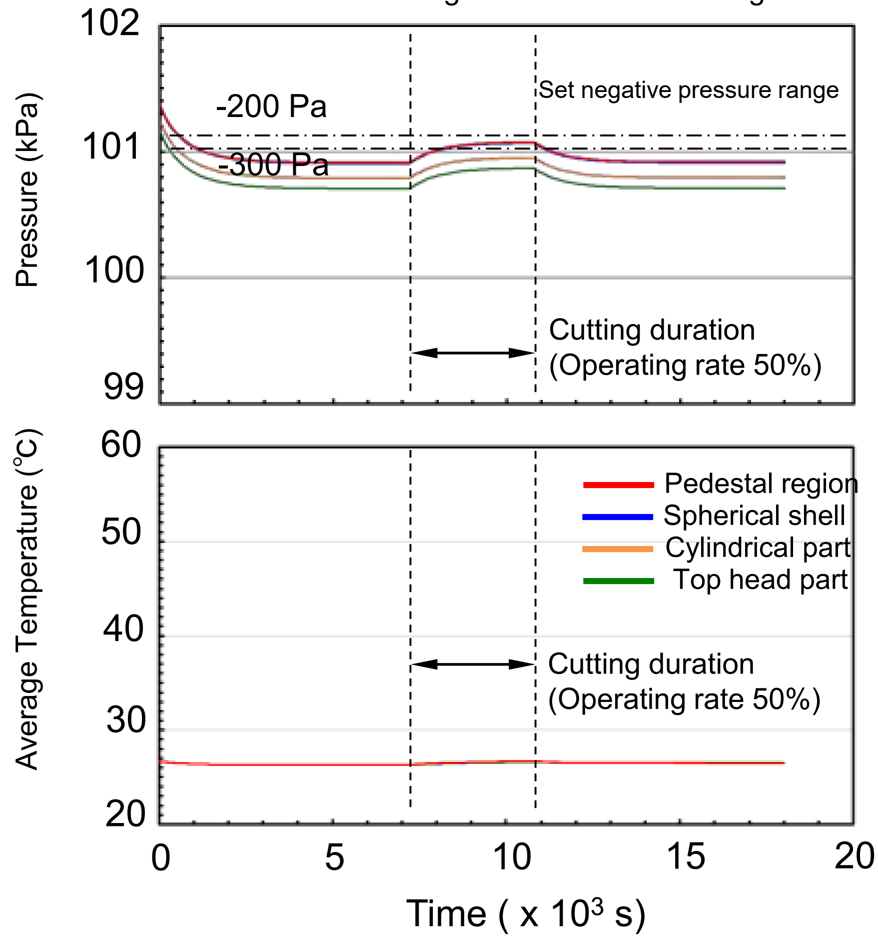
- ✓ Though the plasma gas flow rate (19.5 L/min, at an operating rate of 50%) used for underwater plasma cutting, where a large amount of heat is dissipated, was one order less than the assist gas for laser cutting (175 L/min), the exhaust flow rate for maintaining negative pressure increased by approximately 38%.
- ✓ For plasma cutting performed in air (13. 5 L/min) where the amount of gas generated was relatively low, the exhaust flow rate increased compared to the underwater cutting.
- ✓ It is considered that heat dissipated at the time of cutting is the dominant factor for the increase in pressure inside PCV.

Behavior of PCV internal pressure and temperature while cutting (Comparison of cutting methods)

✓ The analysis of Case 1 took a total of 5 hours, including 2 hours for stabilization of negative pressure for computation, 1 hour for actual cutting and 2 hours for cooling down.



Underwater plasma cutting (Flange opening)

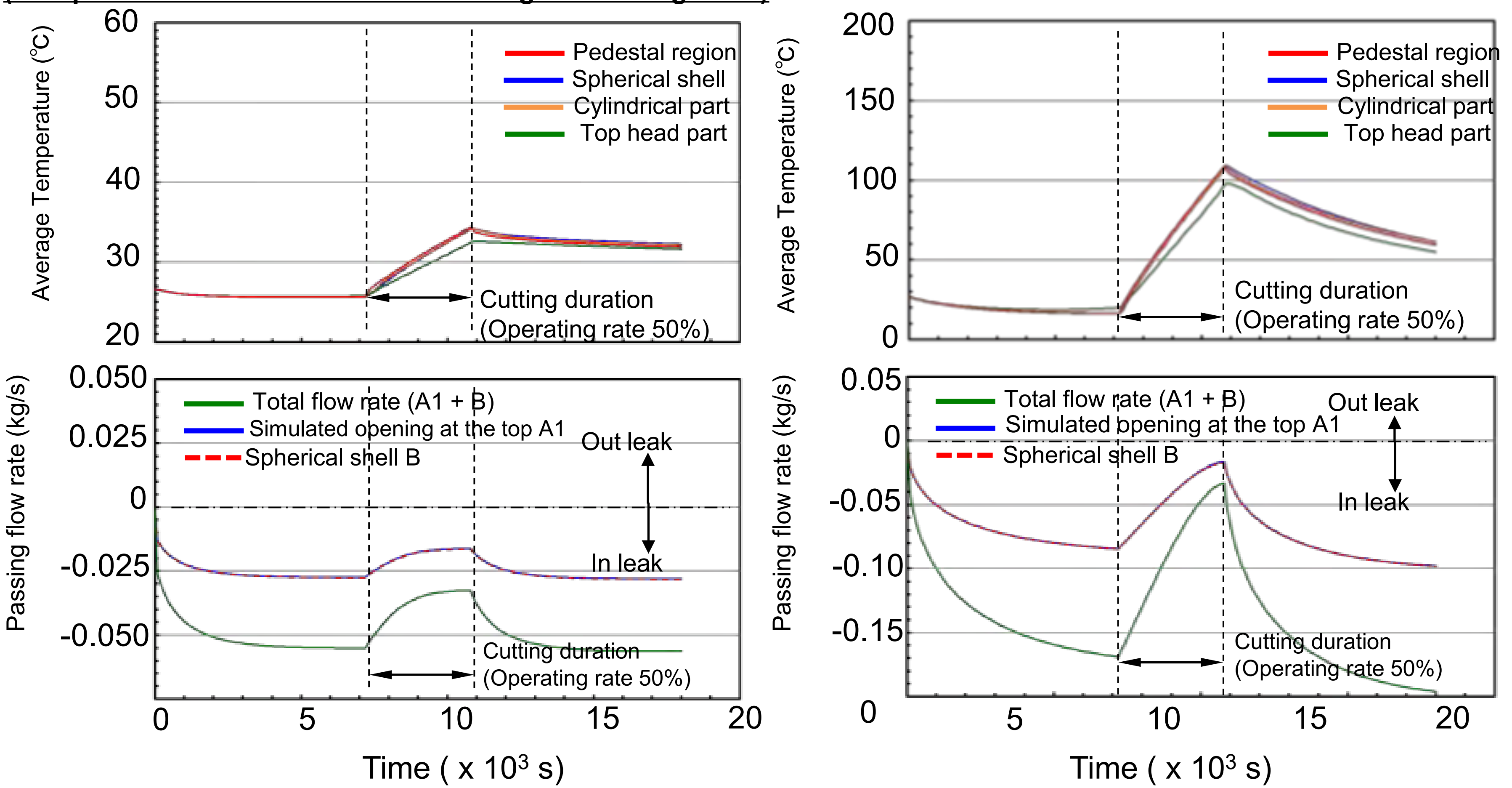


Underwater laser cutting (Flange opening)

- ✓ As there is less change in pressure and increase in temperature in underwater laser cutting, the chimney effect was conservatively evaluated using underwater plasma cutting.
- ✓ The pressure distribution graph did not show any local pressure deviations due to nitrogen sealing, exhaust, in leak from the opening, etc.

④ Effect of heat input on airflows (6/9)

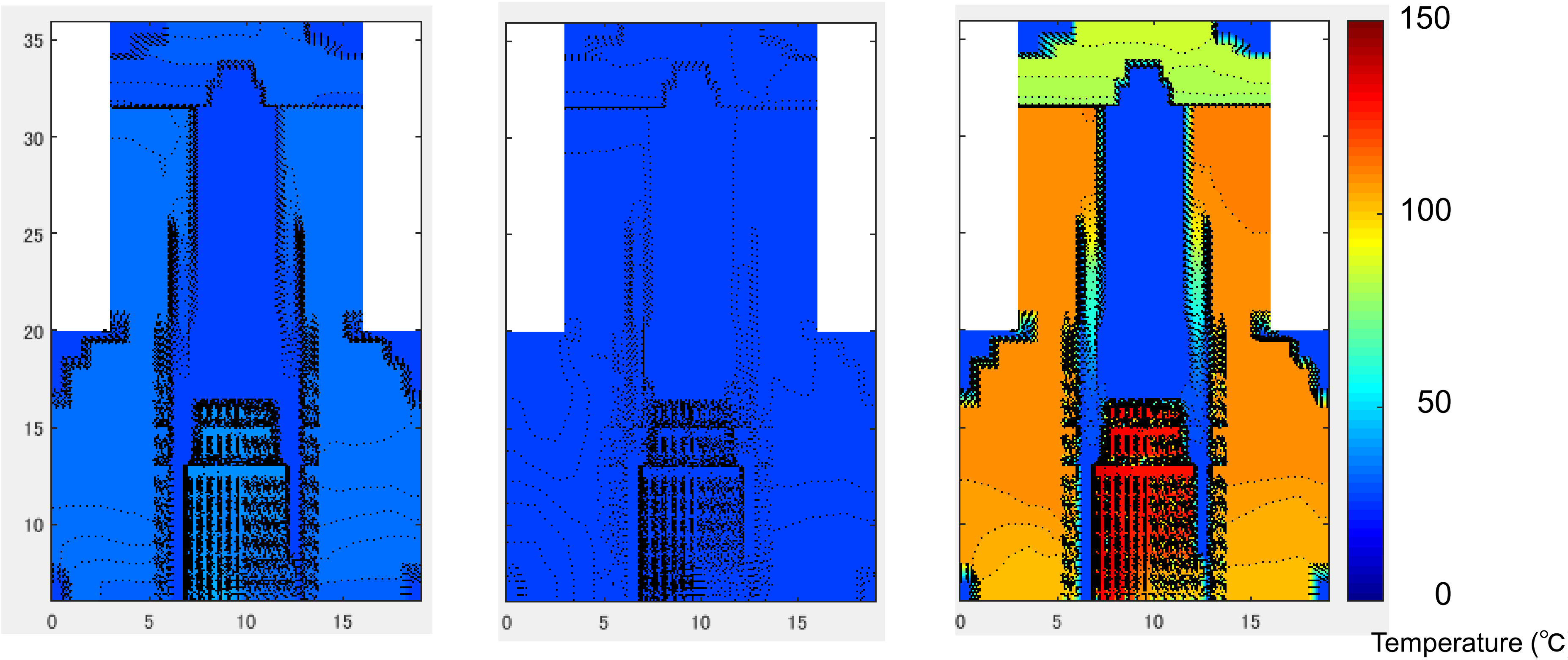
Behavior of temperature and flow rate through openings in various parts of PCV during plasma cutting (Comparison between underwater cutting and cutting in air)



Underwater plasma cutting (Flange opening) **Plasma cutting in air (Flange opening)**

- ✓ In underwater plasma cutting, there were temperature differences in various parts of PCV depending on the heat input, but it did not lead to out leak.
- ✓ In addition, there was almost no difference due to the position of the opening.
- ✓ During plasma cutting in air, the temperature of various parts of PCV increased significantly compared to underwater cutting, but there was no out leak.

Temperature distribution inside PCV during the completion of cutting



Case 1 (10800 s)
・ Underwater plasma cutting
・ Operating rate 50%
・Top head flange opening

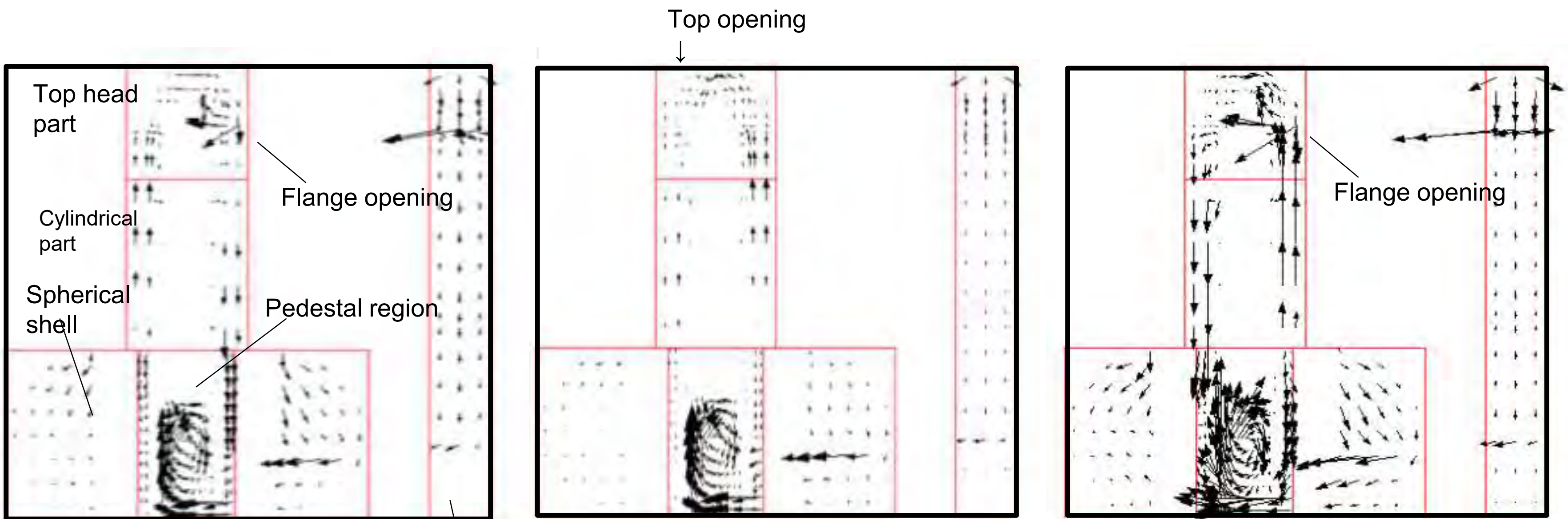
Case 4 (10800 s)
・ Underwater laser cutting
・Operating rate 50%
・Top head flange opening

Case 7 (10800 s)
・ Plasma cutting in air
・Operating rate 50%
・Top head flange opening

- ✓ A height-wise change in temperature was observed due to the difference in heat flow in each cutting method. The pressure distribution was also evaluated, and height-wise pressure changes were observed due to the differences in density.
- ✓ The airflows were compared for plasma cutting underwater and in air where the temperature difference was relatively large.

④ Effect of heat input on airflows (8/9)

<u>Velocity distribution inside PCV at the time of cutting (position of openings and cutting conditions)</u>



Case 1 (9600 s)
・Underwater plasma cutting
・Operating rate 50%
・Top head flange opening

Gap between PCV and building

Case 3 (9600 s)
・Underwater plasma cutting
・Operating rate 50%
・Top of top head opening

Case 7 (9600 s)
・Plasma cutting in air
・Operating rate 50%
・Top head flange opening

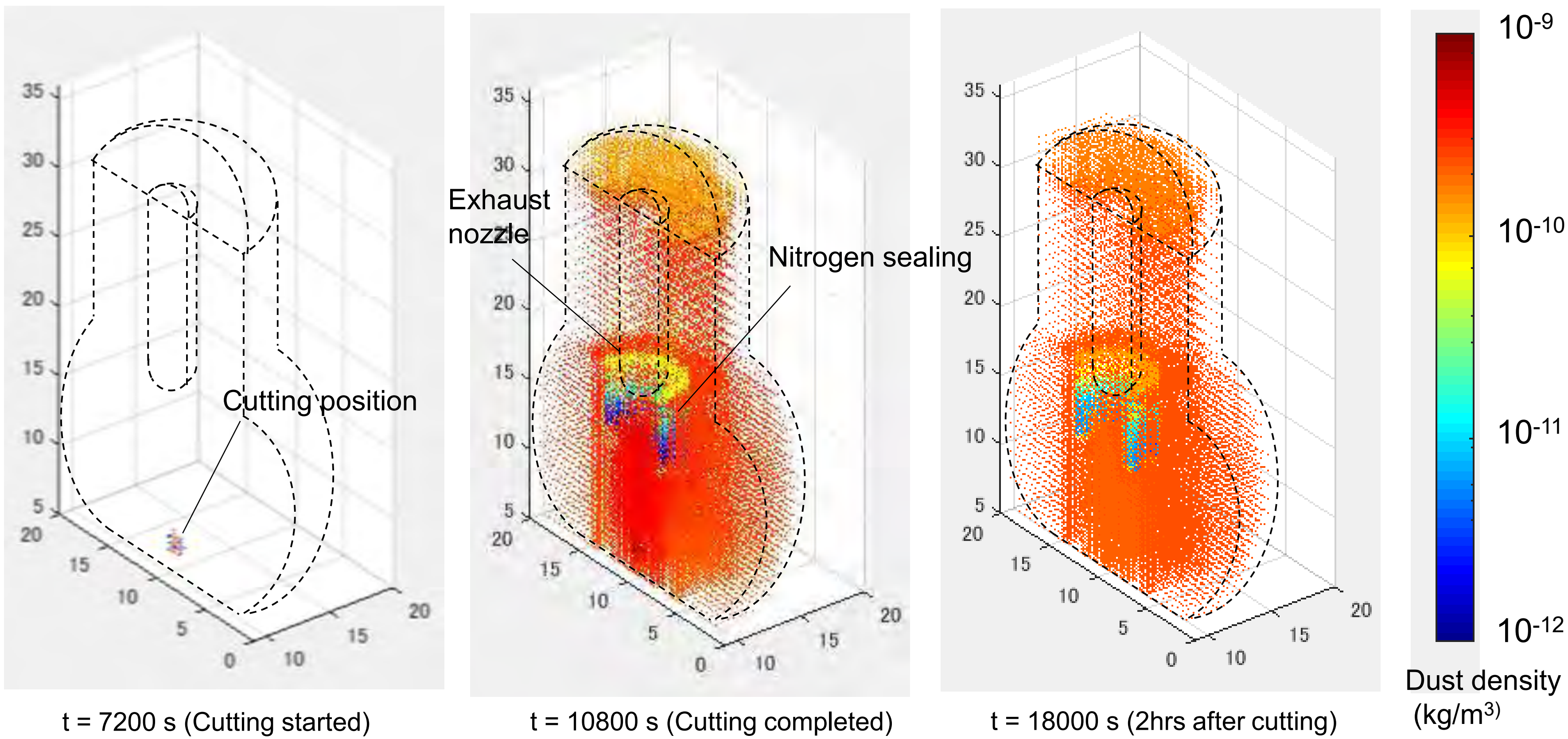
<u>Underwater plasma cutting</u> **<u>Plasma cutting in air</u>**

✓ In-leak flow toward the inside of the PCV was confirmed at the flange opening. For the top opening, the in-leak flow was confirmed from the velocity vector at the gap.

✓ During plasma cutting in air, convection in the PCV cylindrical part and spherical shell became significant, but there was no occurrence of out leak due to the chimney effect.

7. Implementation items of this project [3) (i) ① Technology for prediction of dust behaviors in PCV]
④ Effect of heat input on airflows (9/9)

Dust concentration distribution inside PCV (Underwater plasma cutting, Operating rate 50%, Flange opening)



t = 7200 s (Cutting started) | t = 10800 s (Cutting completed) | t = 18000 s (2hrs after cutting)

- ✓ The dust concentration in the pedestal region was high when cutting was completed. Two hours after the completion of cutting, though the concentration decreased to some extent, dust was distributed throughout the PCV.
- ✓ In addition, there was no significant difference in the top opening conditions compared to flange opening.
- ✓ In underwater plasma cutting, the reduction of dust concentration took some time. When managing the dust concentration in the exhaust, it may be necessary to increase the exhaust flow rate.

⑤ Summary (1/4)

◆ **The following four items of technology development were carried out to evaluate the behavior of dust generated due to fuel debris retrieval. The results of each implementation item are summarized below.**

① Advancement of realistic dust behavior evaluation method

・The validity of the aerosol model in the GOTHIC code and its applicability to 1F were investigated, and it was concluded that the aerosol behavior could be evaluated by considering only gravitational sedimentation.

② Airflow analysis in containment vessel and entire R/B

・The pressure behavior analysis was conducted by creating a new R/B model and by using the presence or absence of damage in the building as a parameter. Even under conditions assuming building damage, it was estimated that negative pressure (air tightness ensured) can be achieved by taking measures such as narrowing the exhaust position and flow path.

③ Evaluating the behavior of aerosol in R/B

・By evaluating the aerosol behavior using the R/B model, the findings for identifying appropriate monitoring positions for detecting abnormal leaks and deposition tendency of aerosols, were understood.

・By performing sensitivity analysis changing the state of air-conditioning in the building, it was estimated that negative pressure inside the building may not always be necessary to secure the confinement function, but exhaust inside the building is mandatory.

④ Effect of heat input on airflows

・A model adding heat input to the airflow was built by studying the amount of dust generated and heat input such as heat dissipation during decay heat and fuel debris cutting.

・The effects of temperature gradient and damaged opening position were evaluated in addition to understanding the required exhaust flow rate for each cutting method through analysis. With this, it was confirmed that the chimney effect does not occur at the assumed negative pressure.

⑤ Summary (2/4)

The results of the following two items that were specified as development items are as follows:

① Requirement specifications for R/B air tightness and gas management system to secure the confinement function in the event of an abnormality

⇒ It can be stated that it is necessary to reduce the flow path area between the operating floor and 4F to 1/100 of the current level (approximately 0.09 [m^2]), with the prerequisite of ventilation rate due to exhaust set to 10,000 [m^3/h] from the 4^{th} floor of the building. In other words, a negative pressure countermeasure plan that narrows down the flow path area between the operating floor and 4F can be one of the requirement specifications for the air tightness and the gas management system of the R/B.

② Identification of effective monitoring positions from the viewpoint of reducing the exposure to the public and workers while monitoring within R/B, in the event of an abnormal leak from the PCV

⇒ Appropriate monitoring positions will be the positions where the flow rate of the gas leaking from PCV is high. The position where the flow rate of the gas leaking from PCV is fast is near the damaged opening in PCV. However, in situations where the location of damage is unknown, the appropriate positions may be the staircase and areas near the hatch, which is the main flow path of leaked gas with a continuous fast flow rate between the floors.

⇒ In order to select an appropriate monitoring technology, measures that do not pick up the background dose from the deposited FP (for example, installing a collimator) are believed to be effective as it is considered necessary to measure the amount of airborne dust from the viewpoint of leak detection.

⑤ Summary (3/4)

◆ **Dust behavior evaluation method was created based on the physical behavior of aerosols considering environment of Fukushima Daiichi**

◆ **By using the results obtained here, various studies have become possible with the following engineering performed for fuel debris retrieval:**

- **Cutting methods and PCV environment during cutting**
- **Image training for cutting work sequence**
- **Optimization of PCV gas management system**
- **R/B countermeasures and optimization of ventilation system for securing the confinement function**
- **System operating conditions that can prevent out leaks and safety margin evaluation during transient**
- **Study on leakage monitoring during abnormality and mitigation measures**

◆ **For individual engineering, conditions that appropriately reflect the results of field surveys and actual tests were set using the analysis methods developed in this PJ. Also, it is necessary to ensure the reliability of analysis by expanding and modifying the model as necessary and comparing it with the test results.**

⑤ Summary (4/4)

◆ **The remaining issues include the following:**

➢ **Issues related to improving the analysis accuracy**
- **Confirming the polydisperse behavior considering particle size distribution**
- **Evaluating the effect of local heat flow behavior below the cell size (CFD, etc.)**

  ⇒ Development of an evaluation method that can appropriately reflect aerosol conditions (particle size distribution, composition, shape factor) and their generation conditions (generated amount, generation rate, etc.) in accordance with the processing method carried out through subsidy projects, based on the results of Dust Collection Project (PJ) and Fuel Debris Characterization PJ.

➢ **Challenges for evaluating the actual equipment**
- **Understanding the state of dust adhesion before the start of cutting by collaborating with the Internal Investigation PJ**
- **Creating the model of actual PCV, R/B in accordance with the retrieval method**
- **Evaluating the physical properties and generated amount of dust by collaborating with the Fuel Debris Characterization PJ**
- **Specifying actual aerosol conditions in accordance with the cutting method, etc.**

⇒ Implemented based on the progress of other PJs and engineering.

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(i) Development of element technology for confinement functions

② Technology for ensuring confinement functions in connection parts

Regarding the new large-sized equipment installed in R/B, such as work cells for fuel debris retrieval, as technology development for securing the confinement function of connection parts with existing structures such as PCV, the structure, methods, inspection, maintenance of sealing materials, etc., of the connection parts were studied, and necessary element tests to confirm the feasibility of the technology were conducted.

The important development study items include the following, and issues shall be identified and organized by conducting element tests, as necessary:

a. Method for connecting PCV and access tunnel.

・The organization of basic requirements for access tunnel connection parts is under progress.

・ Work steps to complete access tunnel connection considering the procedure for removing the shielding plug in front of the equipment hatch, were studied.

7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

- Purpose of Development
  - To study the connection procedures with PCV and the sealing methods of the access tunnels for which the feasibility of the cantilever delivery method has been confirmed.
- Issues to be solved
  - Connection structure with PCV (sealing method) and creation of installation procedures.
- Approaches to development
  - Plan the work procedures starting from the removal of shielding structure in front of equipment hatch to the connection of access tunnel to PCV, considering remote operations.
  - Study on the connecting structures of PCV and sleeve, sleeve and access tunnel, and check the feasibility using element tests.
  - Review the shielding function and conduct conceptual study on weight reduction.
- Expected outcome
  - Work procedures starting from the removal of shielding structure in front of equipment hatch to the connection of access tunnel to PCV, considering remote operation.
  - Confirmation results on the feasibility for connecting structures of PCV and sleeve, sleeve and access tunnel.
  - Results on the shielding function review and conceptual study on weight reduction.

7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

■ Preconditions for access tunnel installation

- ✓ Completion of yard maintenance, underground structure measures and aboveground structure removal for installing the access tunnel.
- ✓ The possibility to build an expanded building that connects to PCV through access tunnel.
- ✓ The possibility of creating an opening on the outer wall of R/B to install the access tunnel. Furthermore, the access tunnel will be laid remotely by delivery from outside the R/B.

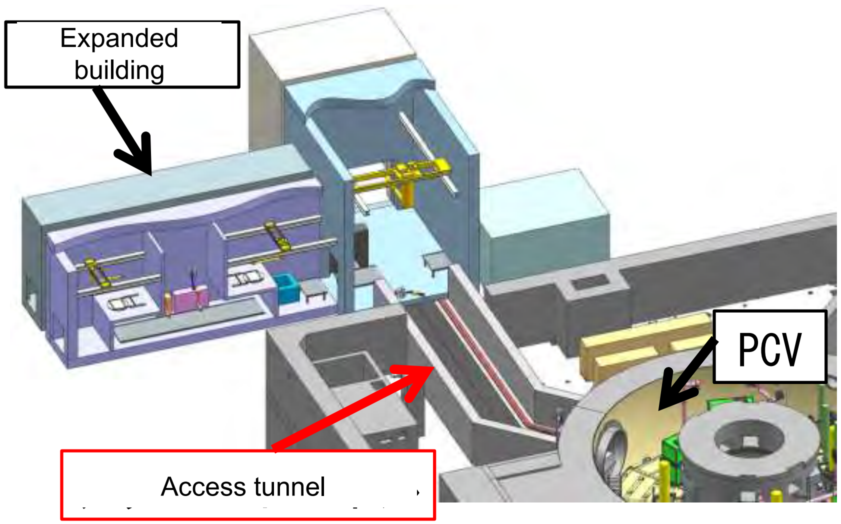


Image showing the connection of PCV and expanded building

7. Implementation items of this project [3] (i) ② Technology for ensuring confinement functions in connection parts]

■ Study Flow

: This report

Outcomes and issues of the subsidy project in the previous term

- Conduct element tests for delivering the access tunnel. Confirm the feasibility of a remote delivering operation.

Study on the connection methods between access tunnel and PCV

- Organize the basic requirement specifications for connection parts between access tunnel and PCV.
- For connection with PCV, conduct a detailed study on the work steps to complete access tunnel connection considering the procedure for removing the shielding structure in front of the equipment hatch.
- Detailed study on the access tunnel sleeve structure.
- Study the proposed connection structures between access tunnel sleeve and equipment hatch.

Element test plan for the connection between access tunnel sleeve and equipment hatch

Connection element tests

Scope of implementation in the subsidy project

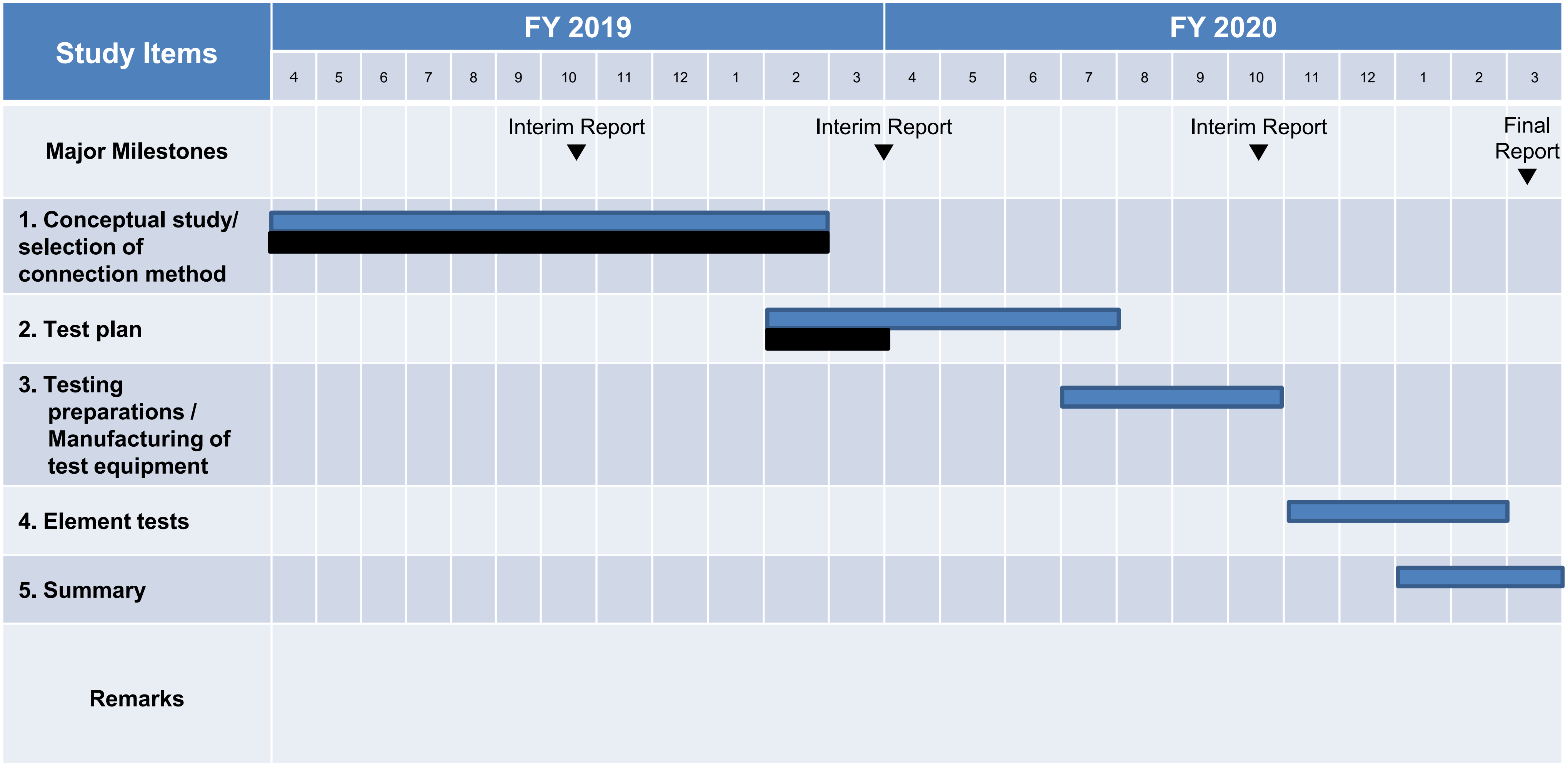
Possibility of delivering the access tunnel with the actual weight

Survey results on site conditions

Actual construction plan

7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

■ Development Schedule



7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

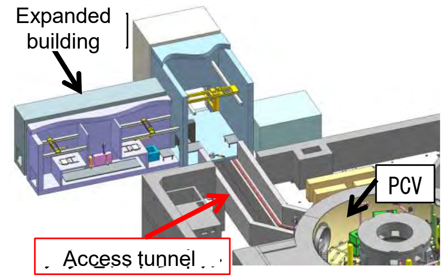
■ Basic requirement specifications for access tunnel connection parts

- ✓ Regarding the access tunnel installation method, element tests on the remote delivery method were conducted and the prospect on feasibility was obtained in previous fiscal years.
- ✓ In this subsidy project (FY2019 - 2020), the connection method with the PCV will be studied.
- ✓ Along with the study on connection parts, organization on the basic requirements for access tunnel connection parts is in progress.
- ✓ After studying the response policy based on the basic requirements in the future, implementation of the required element tests will be planned.

(Element tests are scheduled to be conducted in FY2020)

Table. Basic requirements for the connection parts between PCV and access tunnel [DRAFT]

	Items	Specifications
Basic requirements	Required functionality	Confinement of radioactive materials
	Requirement specification conditions for connection parts	Amount of leakage is ○○ or less when the differential pressure is -100 Pa
		The connection parts must be sound when the designed differential pressure is ○○ Pa.
		The negative pressure (differential pressure during normal operation) at the primary boundary shall be maintained during maintenance.
	Reduction in exposure of workers	Connection work and maintenance work must be completely remotely operated.
	Design Life	50 years
	Maximum horizontal displacement	Can withstand seismic motion (Maximum horizontal displacement: ± ○○ mm)
	Floor load capacity	Shall satisfy the condition of 750 ton/m^2 (load capacity value of the shielding plug installation part).
	Effective diameter of the opening	☐ 1500 mm
Environmental conditions	Dose rate	(R/B 1st Floor) 5 ~ 10 mSv/h (Near the outer wall of the PCV shell) 10 ~ 100 Sv/h
	Temperature	-7 ~ 40 ℃
	Humidity	≤ 100%



Concept of access tunnel

Appearance of confirmation tests on the feasibility of remote delivery (results of previous years)

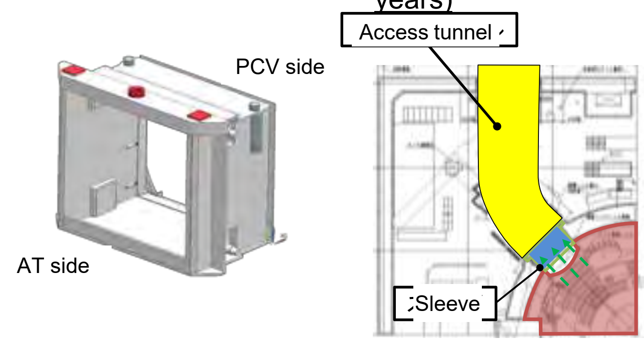


Image of access tunnel sleeve

7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

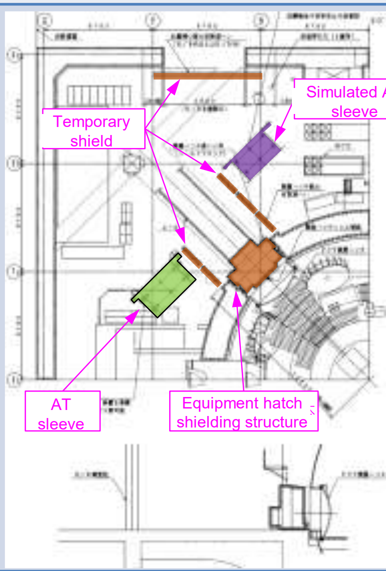
■ Work steps for access tunnel construction

✓ Up to the previous fiscal year, the steps related to delivering the access tunnels from outside the R/B → inside the R/B were mainly studied.

✓ This time, for the connection with the PCV, the work steps up to the completion of access tunnel connection considering the procedure for removing the shielding structure in front of equipment hatch will be studied.

[Diagram on access tunnel installation steps (1/2)]

Step.1

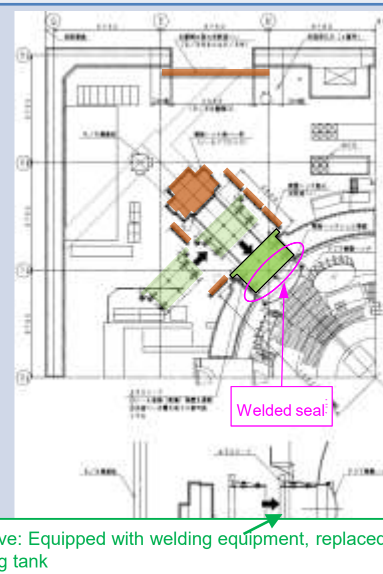


- Carry-in, temporary storage of access tunnel sleeve (hereinafter referred to as AT sleeve)
- Carry-in, temporary storage of simulated AT sleeve
- Installation of shield when pulling out the equipment hatch shielding structure
- Pulling out and removal of equipment hatch shielding structure

Step.2

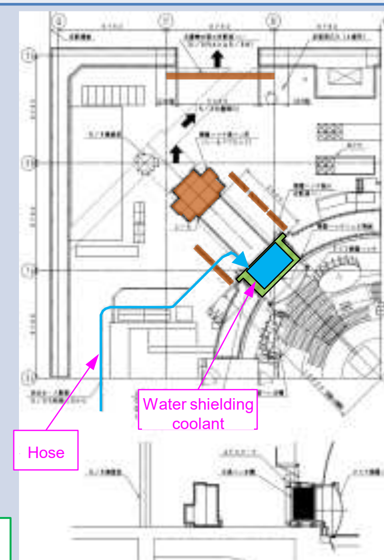
- Performing 3D scan
- Insertion and installation of simulated AT sleeve
- Pretreatment before AT seal welding (rust removal)
- Removal of simulated AT sleeve
- Installation of AT sleeve

Step.3



- Performing 3D scan
- Insertion and installation of AT sleeve
- Welding of AT sleeve seal
- Welding inspection (Inspection items will be studied separately)

Step.4



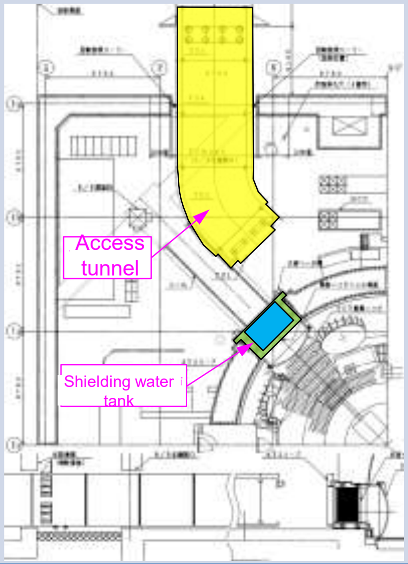
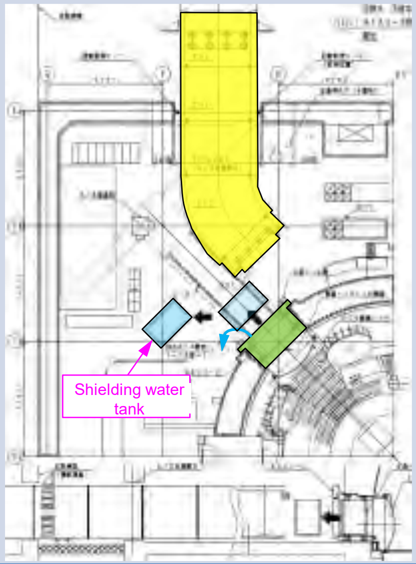
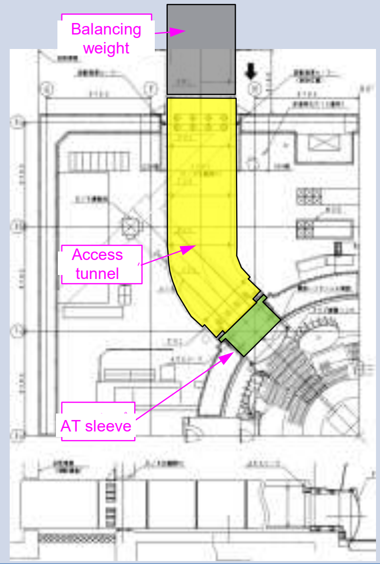
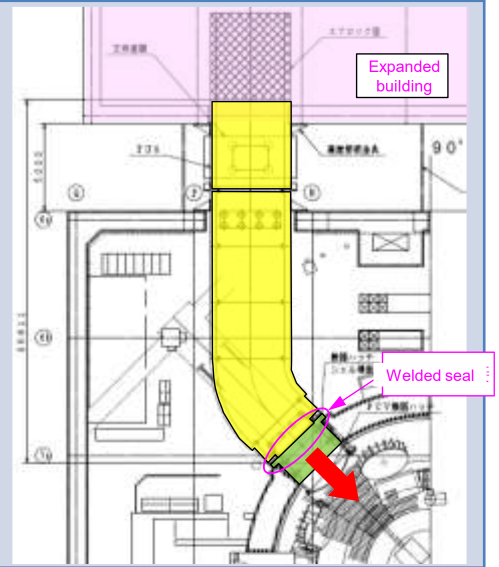
- Injecting water shielding coolant inside AT sleeve
- Dismantling and removal of temporary shield
- Dismantling and removal of equipment hatch shielding structure

(Carrying out from the north opening)

7. Implementation items of this project [3] (i) ② Technology for ensuring confinement functions in connection parts]

■ Work steps for access tunnel construction

[Diagram on access tunnel installation steps (2/2)]

<table>
<tr><th>Step.5</th><th>Step.6</th><th>Step.7</th><th>Step.8</th></tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Installation of temporary building
• AT installation
• AT delivery</td>
<td>• Water shielding drainage inside AT sleeve
• Removal and carry-out of shielding water tank inside AT sleeve
• Connecting AT</td>
<td>• Dismantling the temporary building (partial)</td>
<td>• Construction of expanded building (completion of installation of heating, ventilating and air conditioning system and other equipment)
• AT edge cap removal
• Welding of sleeve with AT
• Opening equipment hatch</td>
</tr>
</table>

7. Implementation items of this project [3] (i) ② Technology for ensuring confinement functions in connection parts]

■ Study on AT sleeve connection methods

➢ AT sleeve structure

✓ Conduct a detailed study on the displacement absorbing mechanism, which is a component of the AT sleeve.

[Setting the amount of displacement at time of earthquake]

It is necessary to secure a displacement of ± 12.5 mm in the horizontal direction.

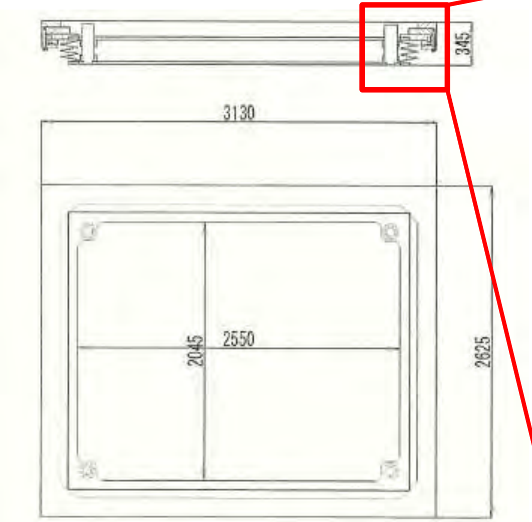
The inter-plane distance at the application part is approximately 350 mm.
As it is difficult to use existing technologies such as bellows structure, study new structures.

Horizontal displacement *

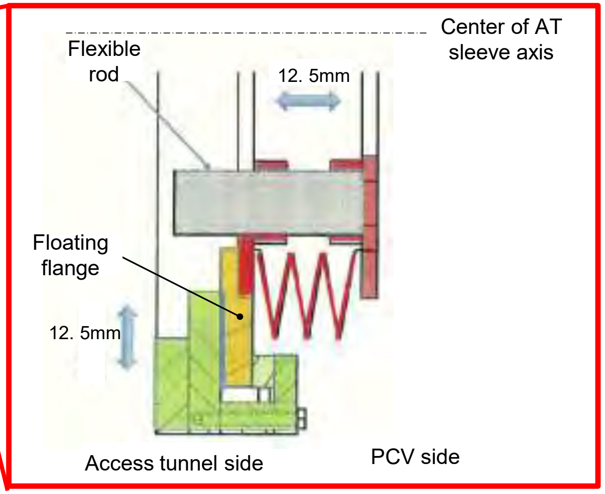
Position	Level from OP [mm]	Evaluation point [mm]	Horizontal displacement [mm]
Top end of hatch	12905	13490	12. 5
Centre of hatch	11260	11180	9
Bottom end of hatch	9675	9760	7

Vertical displacement *

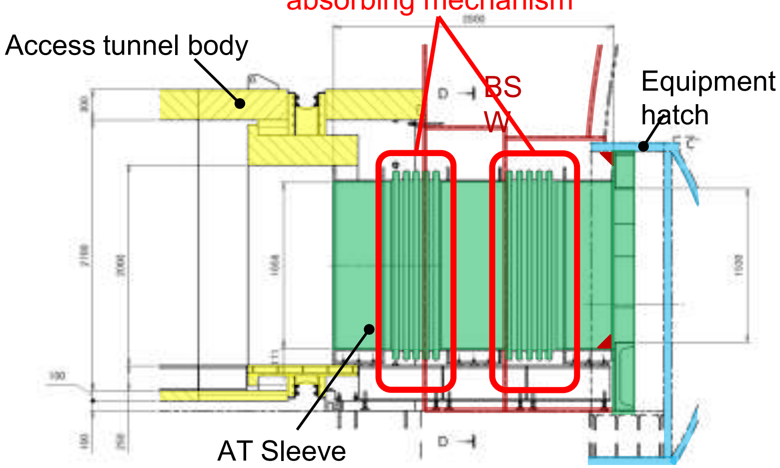
Position	Level from OP [mm]	Evaluation point [mm]	Vertical displacement [mm]
Top end of hatch	12905	13490	0.12



Proposed structure for displacement absorbing mechanism which is under study



Details of displacement absorbing structure



Example of the structure of connection parts between the access tunnel and PCV

In the next fiscal year, the study will continue on the detailed structure in combination with the AT sleeve.

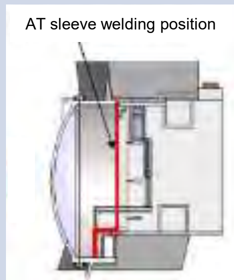
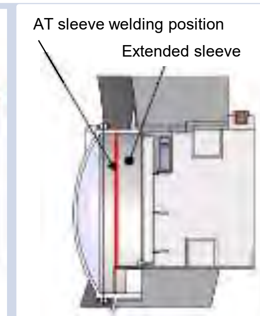
* Set based on the report details of Subsidy Project of Decommissioning and Contaminated Water Management in FY 2015 Supplementary Budgets "Development of Seismic Resistance and Impact Assessment Method on PCV and RPV"

7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

■ Study on the connection method of AT sleeve

➢ Structures connecting equipment hatch and AT sleeve

✓ Multiple welded connecting structures were studied and compared

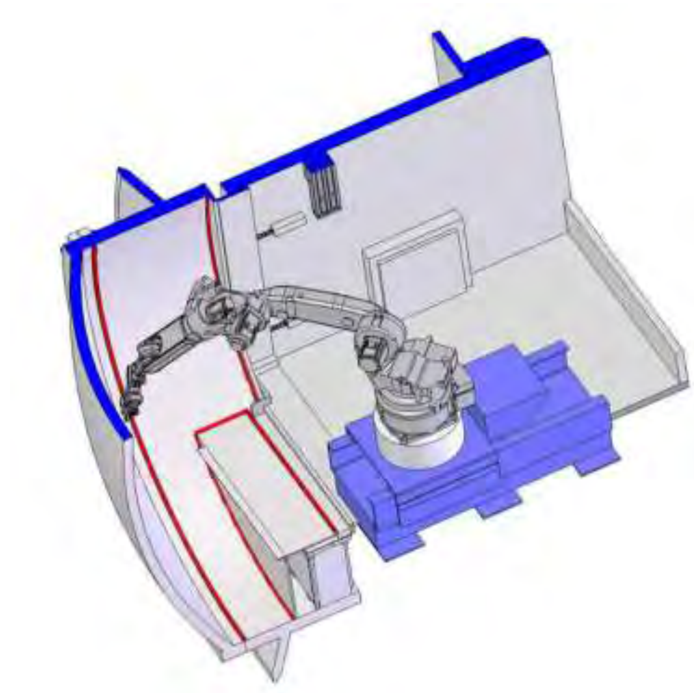
		Case 1	Case 2	Case 3
		 	 	 
		• Partial removal of scaffolding inside the equipment hatch • AT sleeve is welded to the end surface of the equipment hatch shell. • The lower side of the AT sleeve is welded to the inner surface of the equipment hatch shell via the scaffolding seal cover.	• (The scaffolding inside the equipment hatch need not be removed) • AT sleeve is welded to the end surface of the equipment hatch shell. • Place the plate on the scaffold and weld the lower side of the AT sleeve, the inner surface of the equipment hatch and the equipment hatch door.	• Partial removal of scaffolding inside the equipment hatch • A plate that aligns with the AT sleeve is welded on the lower side inside the equipment hatch. • Extended sleeve is added to AT sleeve. • The inner surface of the equipment hatch and the plate that aligns with the AT sleeve are welded.
Confinement of contamination inside the AT sleeve		◎ All connection parts are welded	○ No seal on the door opening / closing part under the plate	◎ All connection parts are welded
Workability	Number of installation steps	△ Scaffolding removal	◎ No scaffolding removal	△ Scaffolding removal
	Number of parts other than AT sleeve	○ Presence of scaffolding seal cover drive mechanism	◎ Plate only	◎ Plate only
	Groove alignment (Inside the equipment hatch)	○ It is necessary to study whether the scaffolding seal cover works well with the equipment hatch.	◎ Assume that the scaffolding plate is just placed	△ Installation accuracy of the alignment plate is required (Level / distance from AT sleeve)
	Welding workability	○ Presence of discontinuous welded structures	○ Relatively easy	◎ Peripheral welding only
Overall evaluation		○	○	△

Cases 1 and 2 will be the main proposals, and studies will be carried out on them in future.

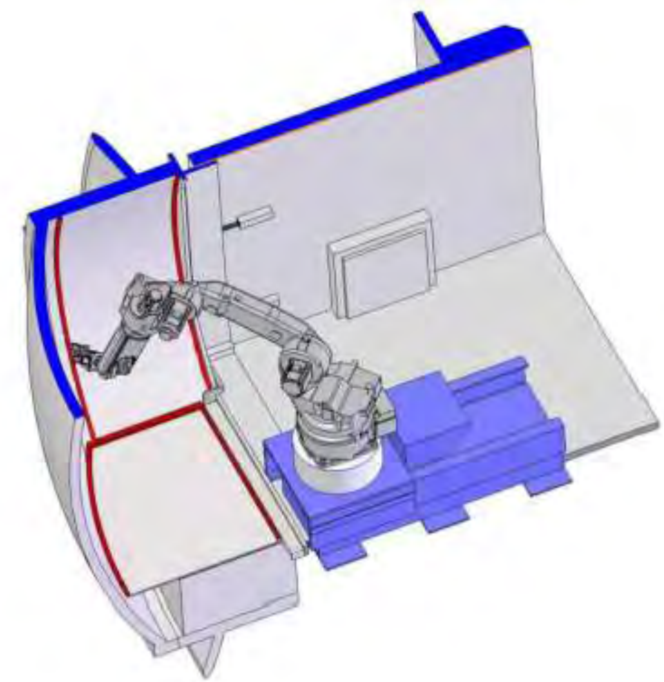
7. Implementation items of this project [3) (i) ② Technology for ensuring confinement functions in connection parts]

■ Study on the connection methods of AT sleeve

➢ Structures connecting the equipment hatch and AT sleeve



Welding position of AT sleeve to equipment hatch (Case 1)



Welding position of AT sleeve to equipment hatch (Case 2)

After deciding the structure of the AT sleeve early next fical year, an element test plan for welded connections will be formulated and conducted in the next fiscal year.

7. Implementation items in this project

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(ii) Development of element technology for prevention and monitoring of criticality

- Overview of technology development for criticality safety control

Current scope

② Criticality approach monitoring

・Monitoring the approach to criticality
(Near the retrieval work area)
・Response before criticality

① Criticality prevention

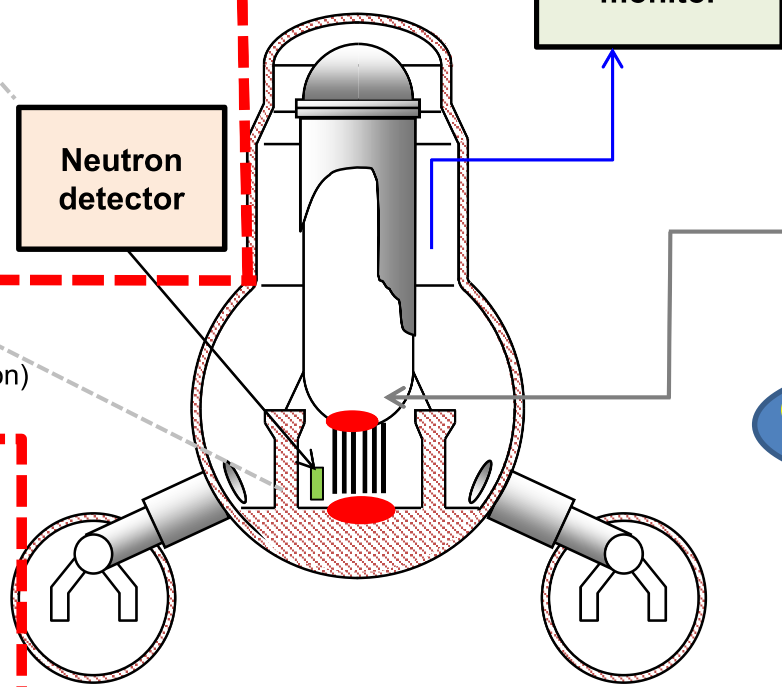
a. Controlling and managing work procedures so that they do not lead to criticality

b. Addition of neutron absorber
① Soluble neutron absorber (boric acid solution)
② Insoluble neutron absorber

B4C Sintered metal material | Glass material with B/Gd | Gd2O3 particles | Water glass / Gd2O3 granulated powder

③ Detection of criticality

・Prompt detection of criticality signs
(entire containment vessel)



④ Mitigation of impact

・Stopping immediately if criticality is reached

7. Implementation items in this project

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(ii) Development of element technology for prevention and monitoring of criticality

① Technological development of criticality monitoring method

Development results till date and implementation details for this fiscal year

Final Goal	Goal to be achieved before actual application	Achievement status	Details for this fiscal year
Creation of subcriticality measurement technology	① Creation of measurement method	Selection of a method that combines the reactor noise method and the neutron source multiplication method (completed) Study on detector sensitivity and placement to reduce measurement error	
	② Formulation of system specifications	Formulation of system specifications for detectors, measurement circuits, etc. (completed)	
	③ Specifications for neutron detector	Formulation of specifications for neutron detector and selection of detectors for prototyping	Study on the specifications of alternative neutron detector candidates (RosRAO / IPL) for size and weight reduction
	④ System design / prototyping	Prototyping of test system consisting of neutron detector, measurement circuit and PC for analysis	
	⑤ Confirmation on the feasibility of subcriticality measurement	Confirmation under homogeneous fuel debris simulated conditions (KUCA test # 1 / # 2) Confirmation under large-scale fuel debris simulated conditions (KUCA test # 3)	Tests for confirming the conditions using non-homogeneous fuel debris / insoluble neutron absorber (KUCA test # 4)
Incorporation into fuel debris retrieval system	① Confirmation of the applicability of neutron detectors to the field	Organization of specification items of the neutron detector unit for transfer with robot arm Formulation of cable handling concept	Study on the structure of neutron detector unit
	② Measures against electromagnetic noise	Evaluation of simulated noise effect, and organization of countermeasures	Study on measures against noise
	③ Study on the criticality approach management procedures	Evaluation on the time required for measurement	Procedures for monitoring the approach to criticality at each step of the debris retrieval method

7. Implementation items in this project

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(ii) Development of element technology for prevention and monitoring of criticality

① Technological development of criticality monitoring method

To prevent the occurrence of criticality due to fuel debris retrieval operation, careful retrieval operation along with monitoring is required. Therefore, the feasibility of subcriticality measurement shall be confirmed by confirming the accuracy of subcriticality measurement in a large and complicated fuel distribution system simulating the state of the Fukushima Daiichi Nuclear Power Station. Also, based on the results of the related “Project of Development of Fundamental Technology for Retrieving Fuel Debris/ Internal Structures (development of small-size neutron detectors)”, the applicability of neutron detectors to the site shall be confirmed. At the same time, the procedures for monitoring the approach to criticality shall be formulated, management procedures including the methods for setting the management parameters, etc., shall be created and the formulation of a demonstration plan for on-site application shall be studied in cooperation with the engineering department of TEPCO .

The following are included as important development study items, and issues shall be identified and organized by performing element tests, as necessary:

a. Confirmation of the feasibility of subcriticality measurement

・A subcriticality measurement test was conducted at the Kyoto University Criticality Assembly (KUCA).

b. Confirmation of the applicability of neutron detectors to the field

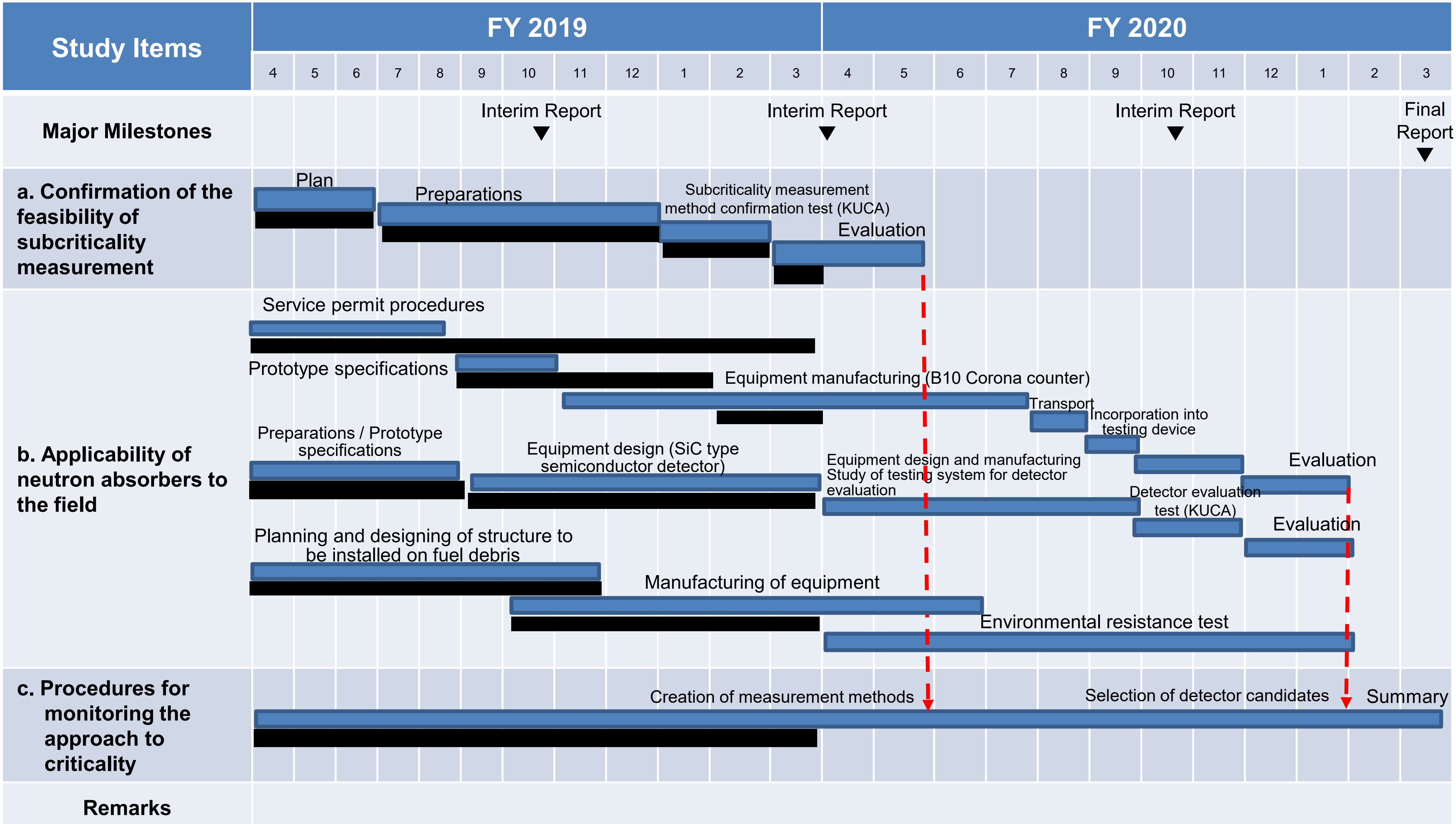
・Neutron detectors found to have good prospects were selected from the perspective of subcriticality measurement.

c. Study on the criticality approach management procedures

・The procedures for monitoring the approach to criticality at each step of the debris retrieval method were organized.

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

- **Development Schedule**



7. Implementation items of this project [3) (ii) ① Technological development of criticality monitoring method]

a. Confirmation of the feasibility of subcriticality measurement

- Purpose of Development
  - To develop methods for measuring the subcriticality of the widely-spread out fuel debris, like that in Unit 2 pedestal.

- Issues to be solved
  - In large fuel debris (which is larger than the minimum critical mass), it is believed that there are parts that are likely to reach criticality locally and parts that are not likely to reach criticality, and there is no knowledge of subcriticality measurement for such a non-homogeneous system.
  - There is a concern about the impact on subcriticality measurement as there is a possibility of injecting insoluble neutron absorbers during fuel debris processing and retrieval.

- Approaches to development
  - A subcriticality system simulating large non-homogeneous fuel debris will be constructed at the Kyoto University Criticality Assembly (KUCA) and a subcriticality measurement test will be conducted using the criticality approach monitoring system. (Figure 1)
  - In addition, a subcriticality measurement test will be conducted in a system in which a neutron absorber is placed between the core and the detector. (Figure 2)

- Expected outcome
  - Errors which should be expected in the subcriticality measurement of fuel debris
  - Methods for measuring fuel debris (detector sensitivity, placement, measurement time)

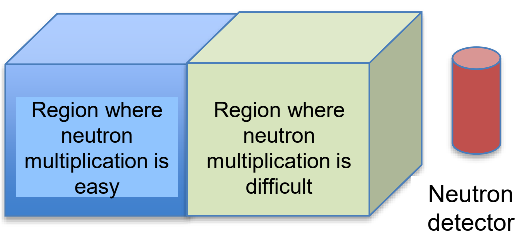


Figure 1 Image showing the testing of non-homogeneous system

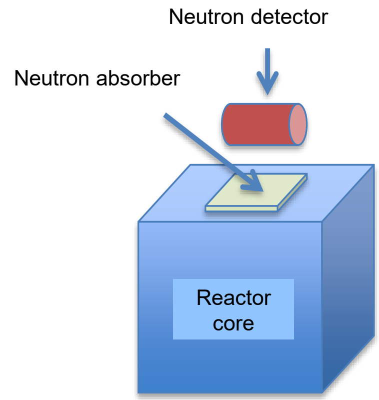


Figure 2 Image showing the test using neutron absorbers

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

a. Confirmation of the feasibility of subcriticality measurement

- Overview of testing facility
  - Kyoto University Criticality Assembly (KUCA) (Figure 1)
  - Fuel: Enriched uranium
  - Moderator: Polyethylene (solid moderator)
  - A desired fuel debris simulated core is prepared by changing the number of enriched uranium cells, the number of polyethylene cells, the number of absorber cells, etc.

- Test period
  February 18 to 27, 2020

- Criticality approach monitoring system
  - Neutron detector: 3 units of B-10 proportional counter type (Figure 2 and 3)
  - The time history of the observed neutron signal is identified and recorded at intervals of 100 nsec (Figure 4).
  - Analysis performed using Feynman-alpha method

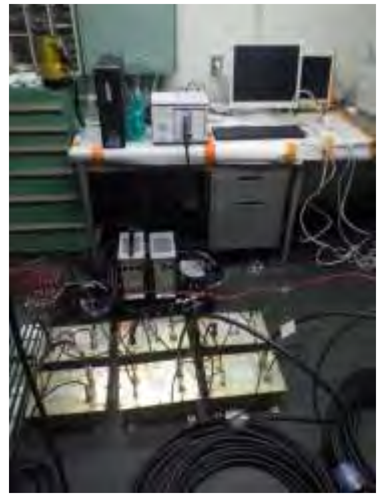
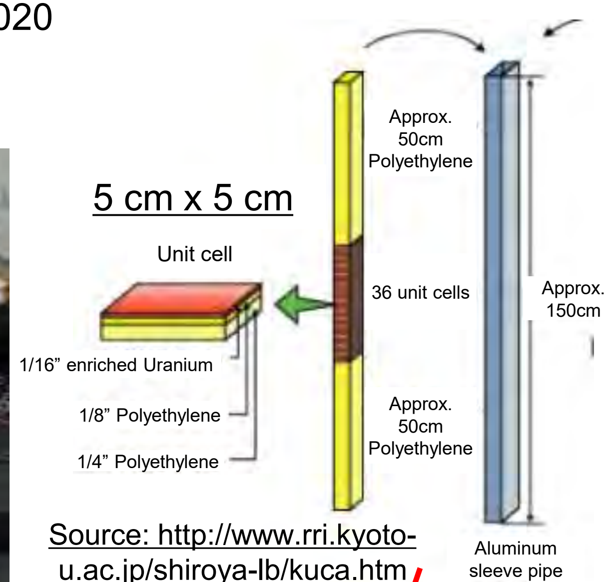


Figure 3 Measuring Equipment



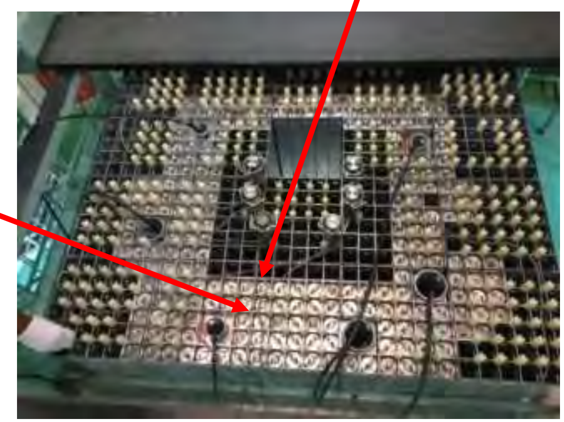


Figure 1 KUCA Criticality Testing Facility

Figure 2 B-10 proportional counter type neutron detector

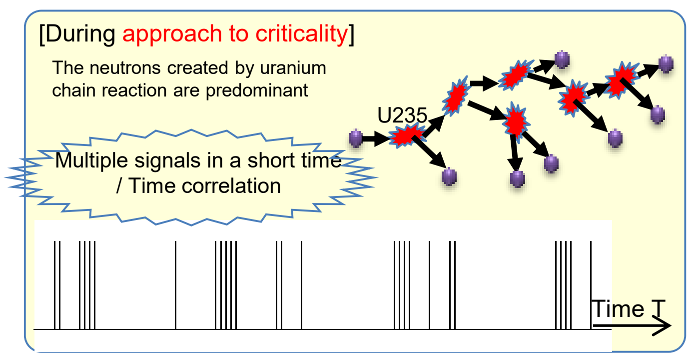


Figure 4 Time series data of neutron signals

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

a. Confirmation of the feasibility of subcriticality measurement

- Purpose of the test
  - To confirm the applicability of subcriticality measurement by Feynman-alpha method to non-homogeneous debris distribution
  - To confirm the applicability of subcriticality measurement to distribution of fuel debris mixed with neutron absorbers.

- Testing method
  - Non-homogeneous distribution containing three types of fuels with different reactivity was simulated by changing the composition of U, polyethylene and graphite (Figure 1)
  - Neutron absorber (LiF) was mixed to one part, and a state where an insoluble absorber is mixed was simulated (Figure 2)
  - Subcriticality was measured by changing the arrangement of the three neutron detectors (Figure 1, 2)

- Test results
  - Neutron signals (time series data) required for the Feynman-alpha method (for this fiscal year, only till data collection) were collected.
  - Analysis and evaluation of the obtained data will be carried out in the next fiscal year

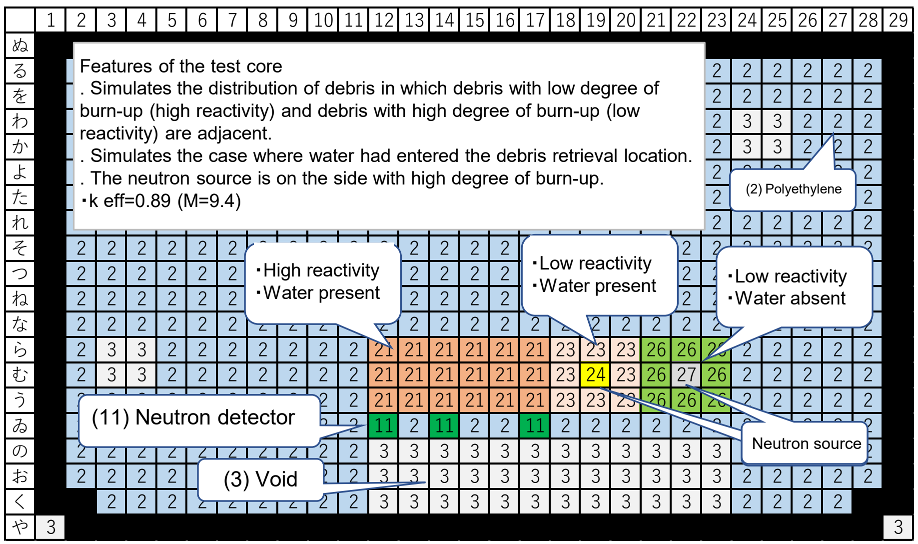


Figure 1 Test core simulating non-homogeneous debris distribution

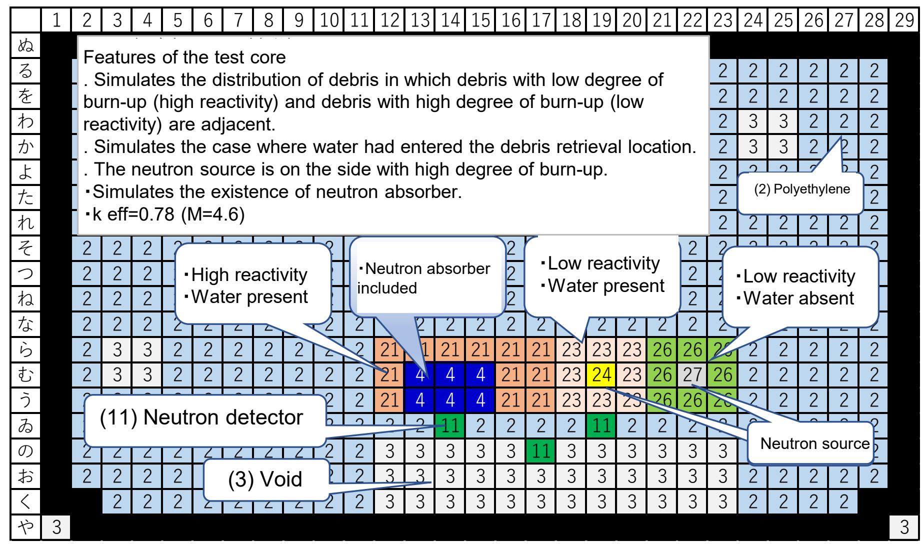


Figure 2 Test core simulating the mixing of neutron absorbers

b. Confirmation of the applicability of neutron detectors to the field

- Purpose of Development
  - To formulate the basic specifications of a neutron detector unit that can be transported by a robot arm and placed on top of fuel debris for measuring the subcriticality of fuel debris. (Figure 1)

(Note) Unit: Refers to an integrated structure including multiple sensors and shield, and in some cases a preamplifier

- Issues to be solved
  - Neutron detectors for measuring the subcriticality of fuel debris are required to have high sensitivity, high time resolution, gamma ray resistance, and electromagnetic noise resistance.
  - The detector needs to be compact and lightweight, so that it can be transported with a robot arm.

- Approaches to development

(b-1) Study on the specifications of alternative neutron detector candidates for size and weight reduction (1: Corona type manufactured by RosRAO)

(b-2) Study on the specifications of alternative neutron detector candidates for size and weight reduction (2: SiC type manufactured by IPL)

(b-3) Study on the structure of detector unit (B-10 / He-3 proportional counter)

(b-4) Study on measures against noise

- Expected outcome
  - Basic design of neutron detector unit
  - Alternative candidates for neutron detector

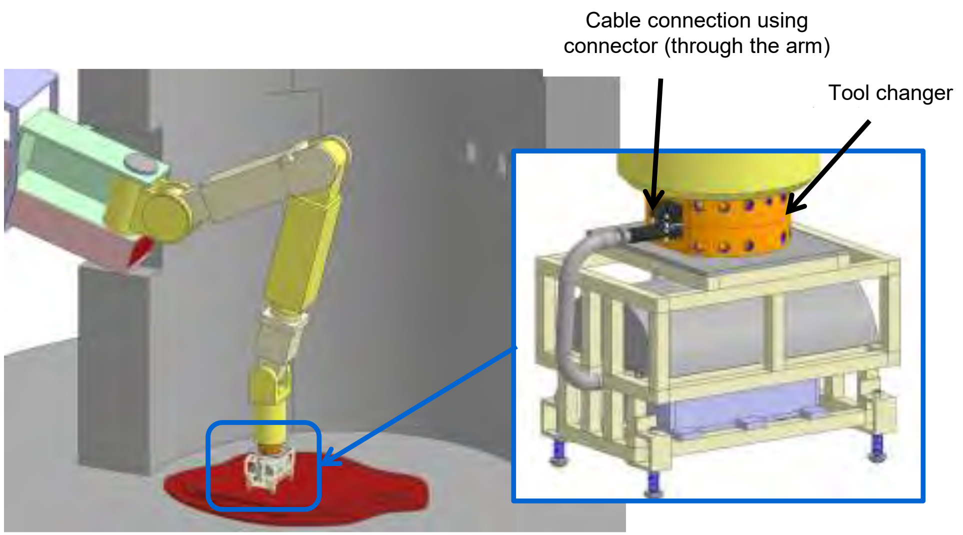


Figure 1 Image of neutron detector unit in side-access retrieval method

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

b. Confirmation of the applicability of neutron detectors to the field

b-1. Study on the specifications of alternative neutron detector candidate for size and weight reduction (1: Corona type manufactured by RosRAO)

- **Implementation details**

Based on the results of the related project "Project of Development of Fundamental Technology for Retrieving Fuel Debris/ Internal Structures (development of small-size neutron detectors)", the specifications of the prototype used for confirming the applicability of the small-size neutron detector (Corona detector) to the field were summarized.

- **Future implementation plan**

The designing and prototyping of a small-size neutron detector will be carried out, and its applicability to the field will be confirmed by a performance confirmation test with the Kyoto University Criticality Assembly (KUCA).

Corona detector

Requirement specification of prototype (detector) for performance testing with KUCA

Items	Requirement specification
Environmental conditions	Temperature: 0 ~ 40 ℃ Humidity: Should not condense Gamma-ray background dose rate: ~100 mGy/hr
Dimension	The size should be accommodated inside the aluminum square pipes making up KUCA, and the sensitive length is set to a core height of 350 mm.
Material	Enclosed gas: Ar, He Neutron converter: ^{10}B and ^{3}He
Thermal neutron sensitivity	2 cps/nv and above (^{10}B type) 15 cps/nv and above (^{3}He type)

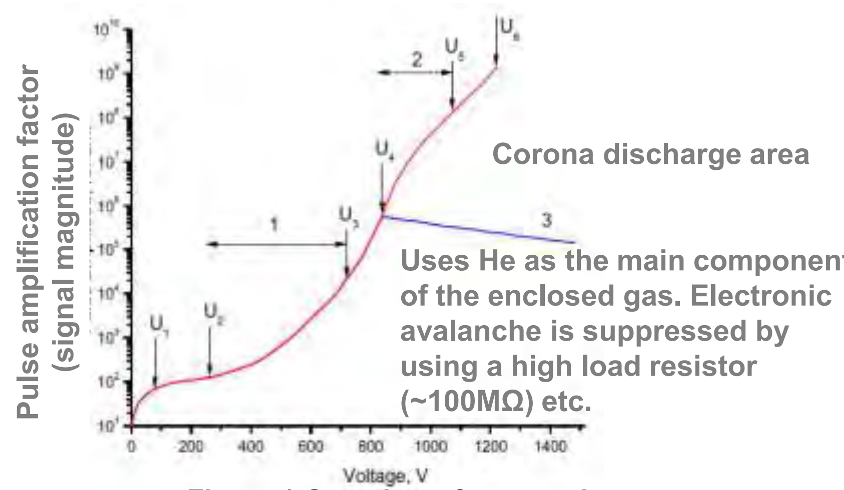


Figure 1 Overview of corona detector

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

b. Confirmation of the applicability of neutron detectors to the field

b-2. Study on the specifications of alternative neutron detector candidate for size and weight reduction (2: SiC type manufactured by IPL)

- **Implementation details**

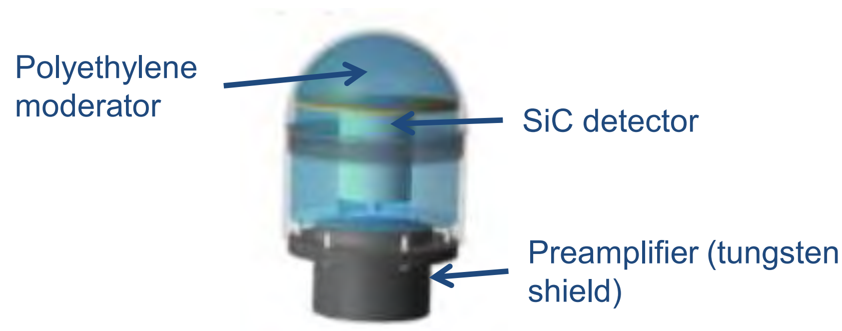
Based on the results of the related project “Project of Development of Fundamental Technology for Retrieving Fuel Debris/ Internal Structures (development of small-size neutron detectors)”, the specifications of the prototype used for confirming the applicability of the small-size neutron detector (semiconductor neutron detector) to the field were summarized.

- **Future implementation plan**

The designing and prototyping of a small-size neutron detector will be carried out and its applicability to the field will be confirmed by performing confirmation test with the Kyoto University Criticality Assembly (KUCA).

Requirement specification of prototype (detector) for performance testing with KUCA

Items	Requirement specification
Environmental conditions	Temperature: 0 ~ 40 ℃ Humidity: Should not condense Gamma-ray background dose rate: ~100 mGy/hr
Dimension	The size should be accommodated inside the aluminum square pipes making up KUCA, and the sensitive length is set to a core height of 350 mm.
Material	Base material: Thin SiC semiconductor Neutron converter: ^{10}B and ^{157}Gd
Thermal neutron sensitivity	As a requirement specification, thermal neutron sensitivity is set to 10 cps/nv, but the specific feasible sensitivity shall be evaluated from the sensitive length, outer diameter size, etc., at the detailed design / manufacturing stage.



(Reference) Proposed detector (detection unit) under study in the Development of Technology for Investigation inside Primary Containment Vessel

b. Confirmation of the applicability of neutron detectors to the field
b-3. Study on the structure of detector unit (He-3 proportional counter)

- **Implementation details**
  - **The design of the detector unit (and neutron detector) was reviewed to address the design / manufacturing issues of the detector unit (#).**

 # The detector unit is intended to be used during the preparation period for fuel debris retrieval and for subcriticality measurement during fuel debris retrieval (see next slide).

Table 1 Issues in the design / manufacture of detector unit, and the response policies

Issues	Response policy for the issues	Overview of implementation in FY2019	Scheduled to be implemented in FY2020
Weight reduction (Target: less than 50 kg)	Improving the radiation resistance by reviewing the design parameters (of the detector) of the He-3 proportional counter.	Study on the design of He-3 proportional counter	To confirm the feasibility of He-3 proportional counter through prototype tests
Response to environmental conditions	Studying structures that can withstand the environmental conditions of 1F. Confirming its ability through prototyping / tests.	Study on the design of detector unit	To confirm the feasibility of detector unit through prototype tests
Reducing the impact of electromagnetic noise	Improving the S/N ratio (signal-to-noise ratio) by incorporating a preamplifier in the detector unit.		
Handling cables through remote operations	By adopting the tool changer method (the cable is laid inside the robot arm), the handling of the cable itself inside the containment vessel is eliminated.	-	To confirm the feasibility of tool changer through prototype tests

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

b. Confirmation of the applicability of neutron detectors to the field

b-3. Study on the structure of detector unit (He-3 proportional counter) (Continued)

- **(Supplement) Operation of detector unit**
  - **The detector unit is used during (A) the preparation period for large-scale retrieval and for (B) daily subcriticality measurement.**

Table 1 Subcriticality measurement / criticality approach monitoring during fuel debris retrieval (large-scale)

Work phase		Measurement details	Measurement frequency (goal)	Measurement time (goal)
A	Preparation period for large-scale retrieval	① The local subcriticality distribution before starting large-scale retrieval measurement using the detector unit. Subcriticality is measured for a long duration only the first time to confirm that the subcriticality is properly obtained.	First time After that, about several tens of times	Once a week Once per hour
B	Before the start of daily retrieval operation	① The detector unit is used to confirm adequately deep subcriticality before starting the daily fuel debris retrieval (the subcriticality and counting rate established as criteria for the measurements in C are to be obtained)	Twice a day	Once per hour
C	During the daily retrieval operation	② A unit detector is used to ensure that the situation is not approaching criticality during daily fuel debris retrieval.	Once per processing or collection task	Once in 10 min
D	When an effective change in neutron source intensity is observed	When a change in the shape of the fuel debris / movement of the detector is observed, the subcriticality and counting rate established as criteria for the measurements in C are to be obtained using ① the detector unit and ② the unit detector.	When required	Once per hour
E	When it is deemed necessary	Subcriticality is measured when it is deemed necessary to identify the extent of subcriticality for some reason (in case of problems).	When required	Once a day

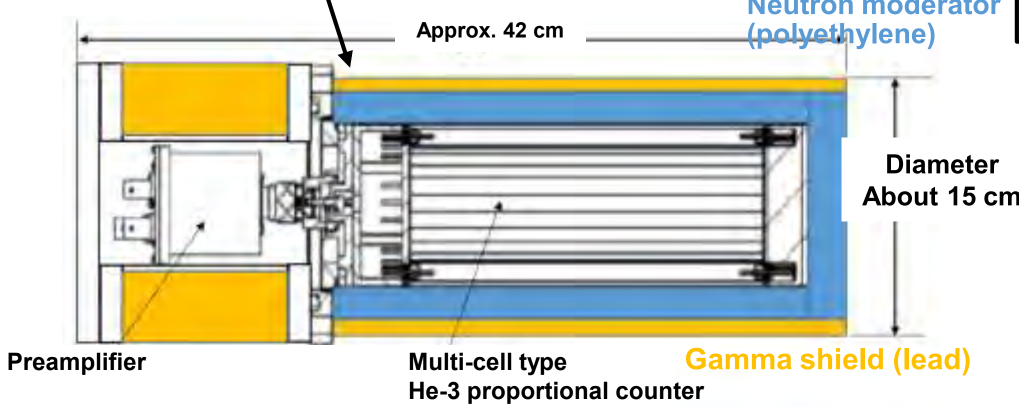
7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

b. Confirmation of the applicability of neutron detectors to the field
b-3. Study on the structure of detector unit (He-3 proportional counter) (Continued)

- **Results obtained so far**
  - ➢ **By reviewing the design parameters of the detector (adopting a multi-cell He-3 proportional counter), the prospect for significant weight reduction was obtained.**
    - **Last year's design plan 120 kg ⇒ Approx. 40 kg (without preamplifier), Approx. 60 kg (with preamplifier)**

- **Future implementation plan**
  - ➢ **To prototype the detector unit (including the detector and tool changer) and confirm the feasibility of the design by testing.**

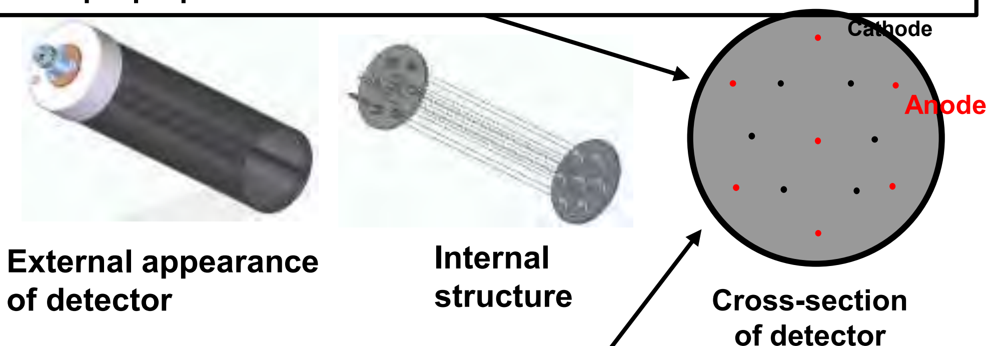
Weight is reduced by thinning the lead shield as the radiation resistance of the detector is improved.



 # The plan is to install a neutron shield (polyethylene) on the top and sides to shield neutrons from fuel debris that is not subject to measurement.

Figure 1 Structure of detector unit (draft)

[Principle]
By arranging multiple anodes and cathodes in one He-3 gas container, it is possible to perform measurements equivalent to multiple proportional counters



Suppressing the impact of noise (pile up) due to gamma rays by increasing the diameter

Figure 2 Principle and structure of multi-cell He-3 proportional counter (draft)

7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

b. Confirmation of the applicability of neutron detectors to the field

b-4. Countermeasures for noise generated from retrieval equipment

- **Background**

In the side-access retrieval method, the cables of the fuel debris retrieval equipment and cables of the neutron detector are likely to pass through the same pedestal opening or PCV penetration (Figure 1), so the neutron measurement system gets impacted by the induced noise due to the proximity of the cables [1].

- **Implementation details**

・By changing the cable between the B-10 proportional counter and preamplifier with a noise-resistant cable covered with a copper mesh shield (Figure 2), it was confirmed that the peak value of the induced noise was reduced by a maximum of one digit (Figure 3).

・By a test in which the retrieval equipment cables and the detector cables were brought close to each other (Figure 4), it was confirmed that their coexistence is possible without the impact of induced noise (Table 1).

- **Remaining issues**

・Noise countermeasures using wraparound from the power system (Independent electrical system, noise removal / suppression)

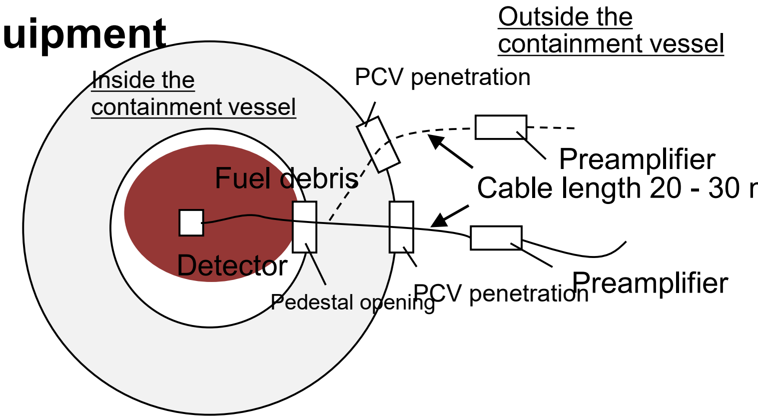


Figure 1 Image of installation in 1F

Simulated noise test

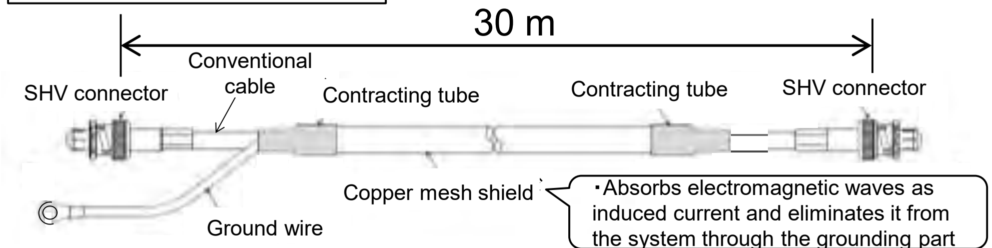


Figure 2 Noise resistant cable

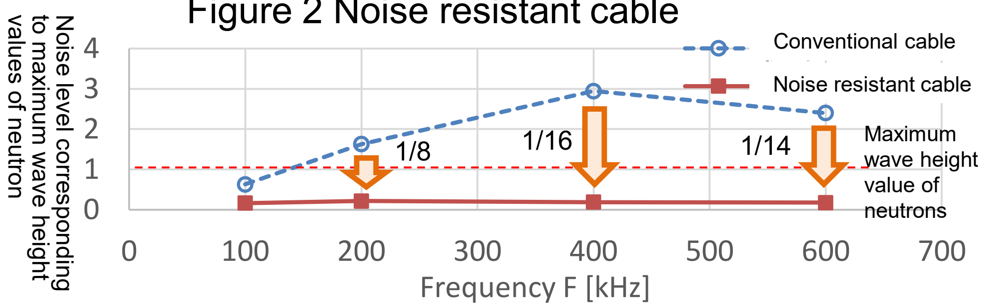


Figure 3 Induced noise reduction effect (when the induced noise current value is 200 mA)

Coexistence test

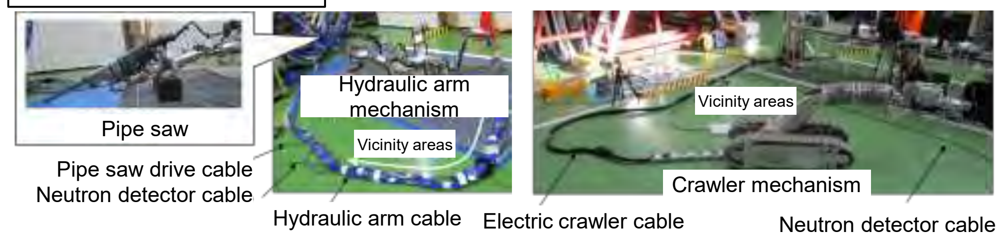


Figure 4. Coexistence test with retrieval equipment

Table 1. Sensitivity reduction rate due to induced noise from the retrieval device

Cable type	Conventional cable	Noise resistant cable
Pipe saw	32 %	0 %
Hydraulic arm	0 %	0 %
Electric crawler	50 %	0 %

[1] IRID, Research report on Subsidy Project of Decommissioning and Contaminated Water Management in FY 2016 Supplementary Budget "Upgrading of Methods and Systems for Retrieval of Fuel Debris and Internal Structures (development of technology for the creation of criticality safety control methods)"

7. Implementation items of this project [3) (ii) ① Technological development of criticality monitoring method]

c. Study on the criticality approach management procedures ~ Coordination with methods ~

- **Implementation details**

To study the criticality approach management procedures during fuel debris retrieval, the criticality safety control method at each retrieval step of each fuel debris retrieval method currently under study (three side-access methods, two top-access methods, figures on next slide) was studied, and the criticality approach monitoring methods to be applied were studied.

- **Future implementation plan**

･To create the concept of criticality approach monitoring system based on the constraints related to the methods and retrieval facilities organized this time.
･To create on-site management procedures by reflecting the requirements and concerns of criticality safety control in the study on methods.

Table. Study on the criticality safety control method at each retrieval step (From the viewpoint of coordinating the methods)

Items	Points to be clarified	Viewpoint
Criticality approach monitoring system	･Steps to be monitored, monitoring method and detector to be used ･Loading and allowable weight of retrieval system	･Getting a clarity on the criticality approach monitoring system study conditions ･Confirmation of consistency with the retrieval procedures
Criticality safety control method (Processing restrictions, etc.)	･Steps that require criticality safety control, and criticality safety control requirements	･Confirmation of consistency with the retrieval procedures
Insoluble neutron absorbers	･Steps that may require the addition of absorbers ･Loading and allowable weight of retrieval system	･Getting a clarity on the study conditions related to loading an absorber injection device on the arm
Notes on criticality safety control	･Items to be noted from criticality safety control point of view	･Getting a clarity on the criticality concerns related to analysis and response to equipment failure modes.

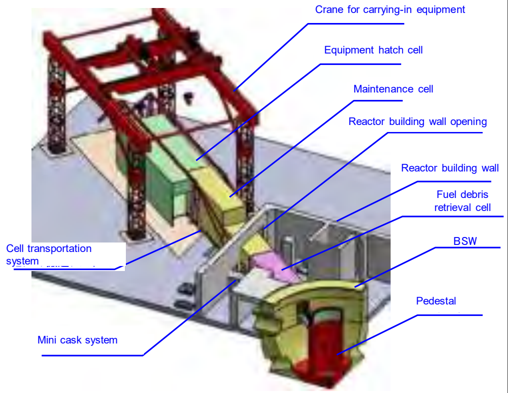
7. Implementation items of this project [3] (ii) ① Technological development of criticality monitoring method]

c. Study on the criticality approach management procedures ~ Coordination with methods ~

Figure Methods under study (Side-access: PLAN-A~ C, Top-access: routes A, B

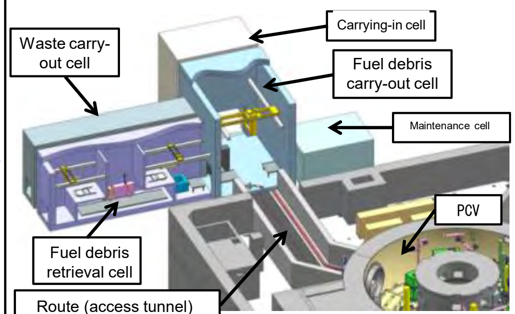
Side access

PLAN-A



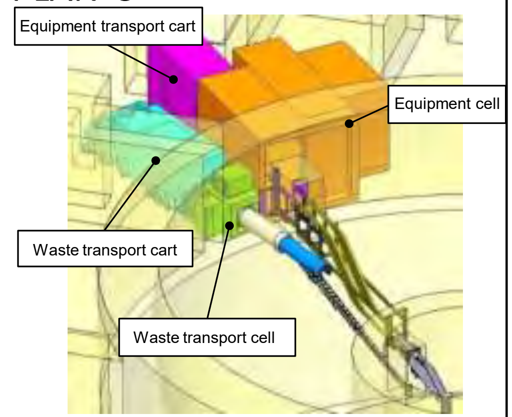
・Access via X-6 penetration
・Large size arm used

PLAN-B



・Access via equipment hatch
・Multiple operating devices used

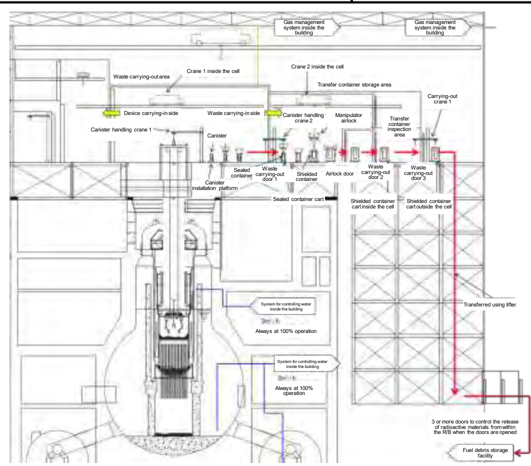
PLAN-C



・Access via X-6 and new opening
・Separate route for carrying-in devices and carrying-out waste

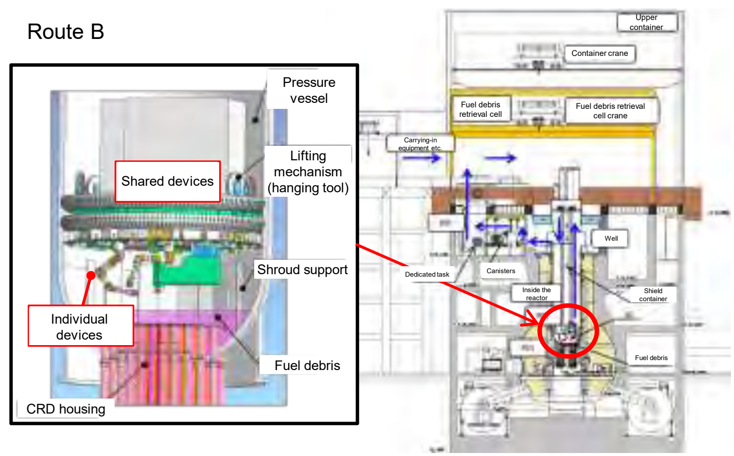
Top access

Route A



・Simple route
・Access to the bottom of the core without removing the shroud, etc.

Route B



・Shielding at operating floor level, debris and interferences carried out through the DSP
・Complete removal of all internal structures via shared devices and individual devices for each target

7. Implementation items of this project [3) (ii) ① Technological development of criticality monitoring method]

c. Study on the criticality approach management procedures ~Concept of criticality approach monitoring~

Criticality approach monitoring is implemented using 3 types of detectors

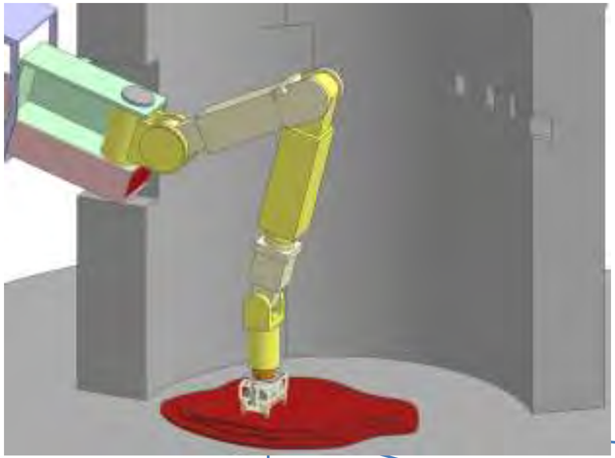
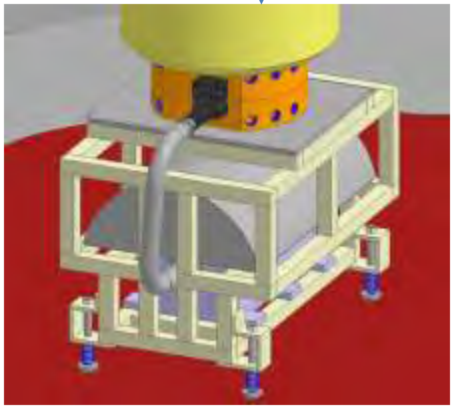
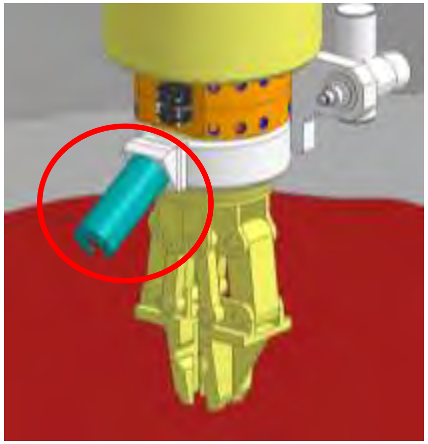


Table. Organization of functionality of the detectors used for criticality approach monitoring

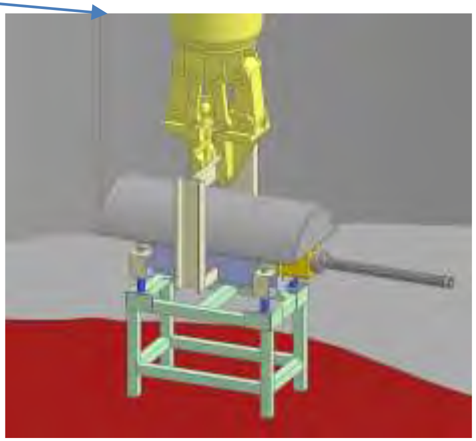
Name	Neutron detector unit	Unit detector	Detector for re-criticality detection
Purpose of use	To understand the pre-job state	To decide on start of processing	To detect unexpected changes
Functionality	Subcriticality measurement	Criticality approach monitoring before and after processing	Continuous monitoring of neutron flux during processing
	Measurement of absolute value of neutron multiplication factor	Measurement of relative change of neutron multiplication factor	
Form	A type that can be installed on fuel debris	Arm mounted type	A type that can be installed on fuel debris
Weight	120 ~ 150kg Currently, size reduction is under study	30 ~ 50kg	Less than or equal to 30 kg
Calculation time	A few days to a week	About 10 minutes	Continuous
Measurement points	One point near the retrieval start point	Moved as appropriate according to the processing position.	Same as on the left



Neutron detector unit
・Includes multiple detectors for high sensitivity
・To locally measure the fuel debris processing location



Unit detector
・Comprises of one detector
・To locally measure the fuel debris processing location



Detector for re-criticality detection
・Comprises of one detector
・Monitors the entire area away from the processing location from a bird's-eye view

c. Study on the criticality approach management procedures ~ Deployment of criticality safety control to retrieval steps ~

・The concept of criticality safety control was deployed to the retrieval steps, and the constraints on monitoring system and points to be noted on criticality safety control were organized.

Example of Criticality Safety Control methods and requirements in the retrieval steps

Step	Sub-steps	Maximum arm mounted weight	Processing restriction / Criticality safety control method	Possibility of pre-filling absorber	Monitoring the approach to criticality			Other criticality prevention measures	Remarks (*2)
					Subcriticality measurement	Monitoring for each fixed amount of processing	Continuous monitoring during processing		
2. Removal of interferences inside PCV and preparation for fuel debris retrieval									
③ Removal of interferences in PCV	4) Processing and cutting of interferences	(Carrying into PCV) ~ 100kg (Arm mounting) ~ 30kg	Absence of deposits presumed to be fuel debris: no constraints	- (*1)	-	-	-	･Preventing the cut pieces from falling towards the deposits in the pedestal ･Preventing heavy objects from falling on top of deposits in the pedestal (Measures to prevent contact with CRD, measures to prevent fall of cutting tools)	
			Presence of deposits (small amount of deformation *1): Limitation on the amount of cutting powder that falls on lower deposits	-	-	-	-		*1 The criterion for determining the amount of deformation is the minimum critical weight (30-60kg)
			Presence of deposits (large amount of deformation): ･ Processing along with criticality approach monitoring ･ Limitation of the amount of cutting powder that falls on lower deposits	○ During approach to criticality	-	Neutron flux measurement and criticality approach monitoring before and after processing and cutting	As a backup, continuous monitoring may be required during processing		

* 1 "-" means not applicable.
* 2 If there are no special notes, it is left

Classification of retrieval method steps (Sub-steps inserted for the steps with criticality)

Constraints on detectors and insoluble absorber injection device

Criticality safety control method, processing restrictions, etc.

Steps in which insoluble absorbers may be applied

Method of performing criticality approach monitoring

Precautions from criticality safety control point of view (mainly measures to prevent the occurrence of incidental events)

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(ii) Development of element technology for prevention and monitoring of criticality

② Development of technology for criticality prevention

Development results till date and implementation details for this year

Final Goal	Goal to be achieved before actual application	Achievement status	Details for this fiscal year
Creation of criticality prevention technology	① Selection of candidates	Selection of candidate materials for insoluble neutron absorbers by confirming basic characteristics, irradiation characteristics, and nuclear characteristics (4 types of candidate materials selected)	-
	② Confirmation of workability and specifications of subcriticality maintaining conditions	Estimation of required injection amount based on the assumed usage Confirmation of workability with fuel debris crushed using chisel, and confirmation of absorber distribution and subcriticality maintenance evaluation (solid type absorber)	
	③ Evaluation of corrosion effects	From the long-term irradiation test, it was found that the hydrogen generation G value is less than the design value, and the diluted seawater in which the absorber component is eluted has a pH of 6 or more.	To evaluate the impact of rust inhibitor effect under irradiation
	③ Evaluation of side effects	The number of canisters and the amount of waste increased by up to approximately 10% for solid absorbers and up to approximately 40% for solidified absorbers.	
Incorporation into fuel debris retrieval system	① Study on the insoluble neutron absorber injection device and operation methods	The method for injecting absorbers was formulated A procedure for injecting absorber for fuel debris processing using chisel was formulated (assuming MCCI fuel debris present under pedestal)	To confirm that it can be injected under water To confirm the impact due to processing
	② Design of absorber injection device	The concept of absorber injecting device was formulated based on the weight / dimensional restrictions of the absorber injecting device and the absorber transfer route restrictions.	
	③ Verification of combination with the retrieval equipment	The absorbers for the fuel debris processing methods for each fuel debris position were organized.	

3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(ii) Development of element technology for prevention and monitoring of criticality

② Development of technology for criticality prevention

The proper use of insoluble neutron absorbers based on the state of fuel debris at the time of fuel debris retrieval, conceptual design of injection device and operational methods of insoluble neutron absorbers shall be studied. In addition, the impact of fuel debris processing on the functionality of insoluble neutron absorbers shall be confirmed using element tests, and those shall be reflected in the study on operational methods. Furthermore, the corrosion effect of insoluble neutron absorbers on structural materials in an environment considering the use of rust inhibitors under irradiation effects shall be studied.

The following are included as important development study items, and issues shall be identified and organized by conducting element tests, as necessary:

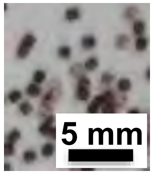
a. Study on insoluble neutron absorber injection device and operation methods
- The possibility of injecting insoluble neutron absorbers in water was confirmed through tests.
- The impact of processing absorbers was confirmed through tests.

b. Study on the corrosion effects considering the use of rust inhibitors under irradiation effects
- The possibility of using a rust inhibitor and a glass material containing B/Gd together was confirmed by an irradiation test.

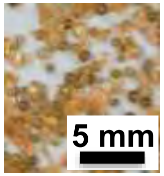
a. Study on insoluble neutron absorber injection device and operation methods

- Purpose of development
  - To develop a device to inject an insoluble neutron absorber so as to prevent fuel debris from approaching criticality.

- Issues to be solved
  - So far neutron absorbers of the solid type or the solidified type (changed from liquid to solid) have been developed (Figure 1). The concept of devices to inject these were studied (Figure 2), but it is unclear whether they can be used under water.
  - By injecting the neutron absorber prior to the processing of the fuel debris, it is assumed that it will be processed together with the fuel debris during the processing operations. Although the impact of processing on the solid type absorbers was confirmed by means of testing, the impact on solidified type absorbers is unclear.



B_4C sintered metal material (Solid)



Glass material with B/Gd (Solid)

Gd_2O_3 particles (Solid)

Water glass/ Gd_2O_3 granulated powder (Viscous)

Figure 1 Insoluble neutron absorber

- Approaches to development
  - Study of the design specifications and the operation method of the absorber injection device.
  - Study of the proper usage of the neutron absorber assuming the state of the fuel debris.
  - Verification of the impact of fuel debris processing on the functionality of the neutron absorber by carrying out element tests wherein the simulated debris injected with a neutron absorber is processed.

- Expected outcome
  - Basic specifications of the neutron absorber injection device
  - Operation method of the neutron absorber

Example of injection device for solids (powder)

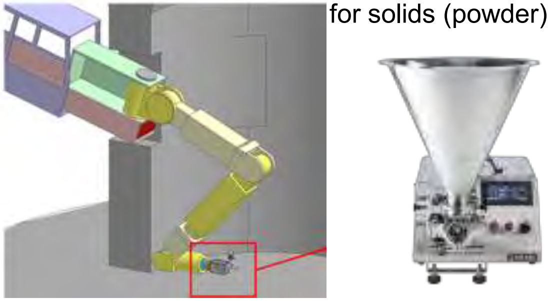
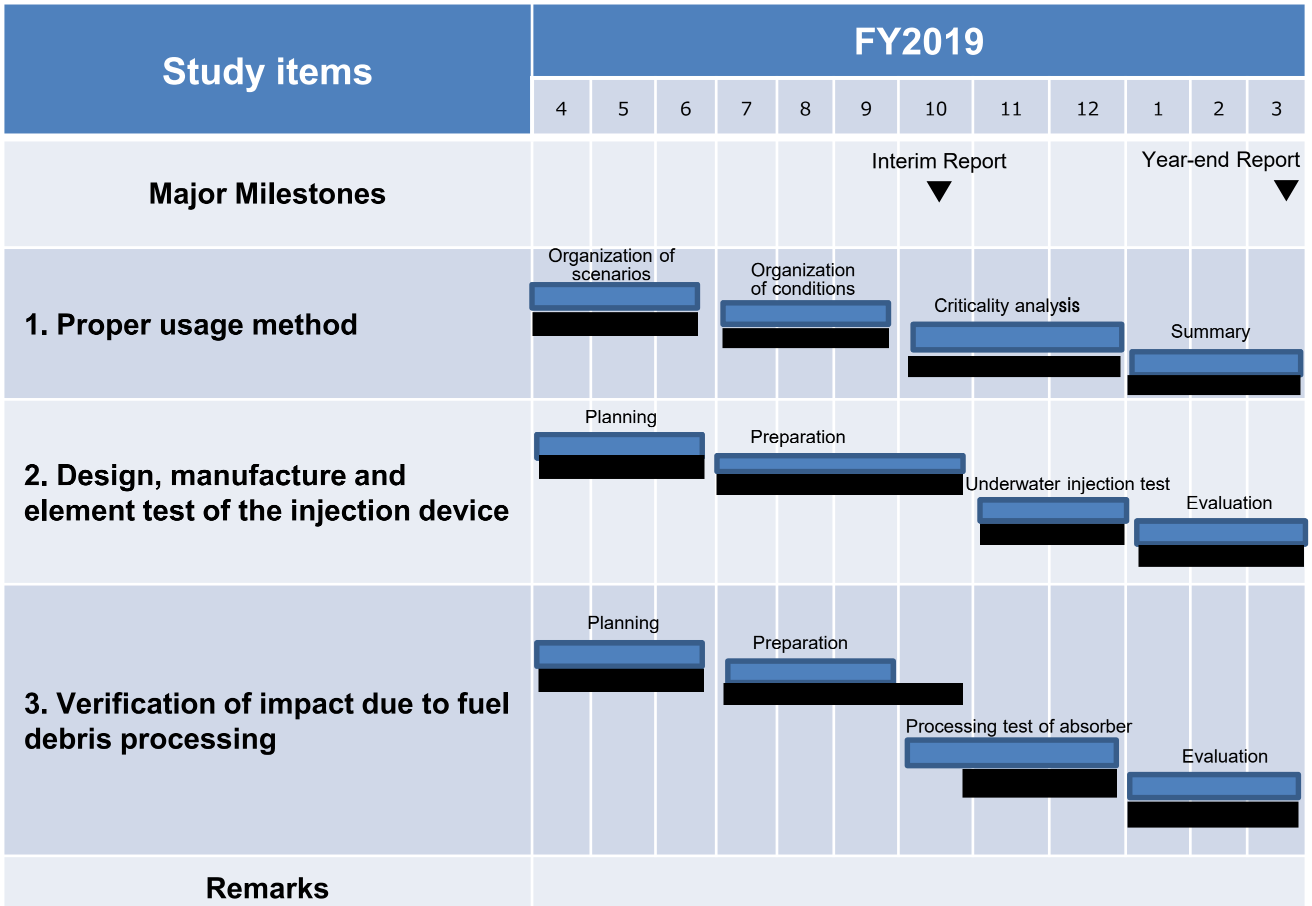


Figure 2 Image showing the absorber injection device mounted on the robot arm

a. Study on insoluble neutron absorber injection device and operation methods

- **Development Schedule**



a. Study on insoluble neutron absorber injection device and operation methods
Proper usage method of the absorber

- The fuel debris is presumed to be in various shapes, such as rod shape or granular shape etc. The type of neutron absorber which is best for the various shapes of fuel debris, should be used.
- The insoluble neutron absorbers are divided into the solid type and the type that has solidified (water glass type) from the liquid state due to lapse of time. The water glass type has fluidity or viscosity immediately after injection, so it is effective when the residual fuel (fuel rod stubs) is standing close together vertically (Figure 5), when the gaps between the fuel debris are small (Figure 3, 4), and when there is a lot of unevenness on the fuel debris surface (Figure 6).

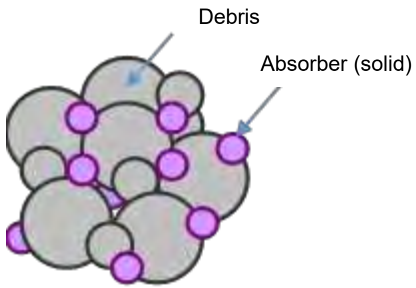


Figure 1 Solid absorber is used for pebble-like fuel debris

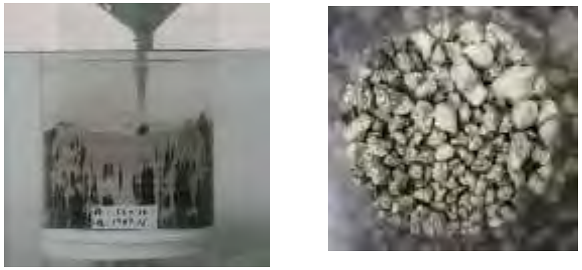


Figure 3 Liquid to solidified absorber is used for pebble-like fuel debris

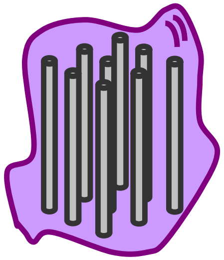


Figure 5 Liquid to solidified absorber is used for rod-shaped fuel debris

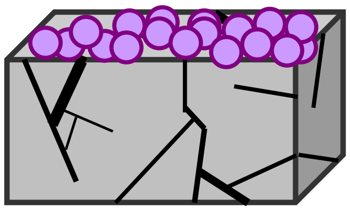


Figure 2 Solid absorber is used for the bedrock-like fuel debris

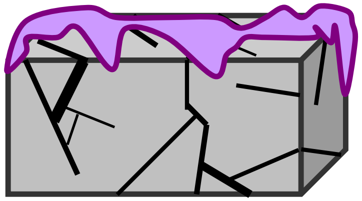


Figure 4 Liquid to solidified absorber is used for the bedrock-like fuel debris

Figure 6 Liquid to solidified absorber is used for fuel debris with large uneven surfaces

a. Study on insoluble neutron absorber injection device and operation methods
Underwater injection test for neutron absorbers

- Purpose of the test
  - The technology which forms the basis for the injection device is presumed to be used in air and there are no results so far regarding its use under water.
  - It is anticipated that as the water depth becomes deeper, it will be difficult to discharge the absorber against the water pressure.
  - To verify whether the solid and viscous insoluble neutron absorbers can be injected under water.
- Testing methods
  - By presuming the water level at Unit 3 of 1F, the test was carried out inside the water tank set up in the Recompression chamber in order to simulate the water pressure (0.5 atmospheric pressure) at 5 m under water. (Figure 1)
  - The injection speed of the absorber was evaluated.

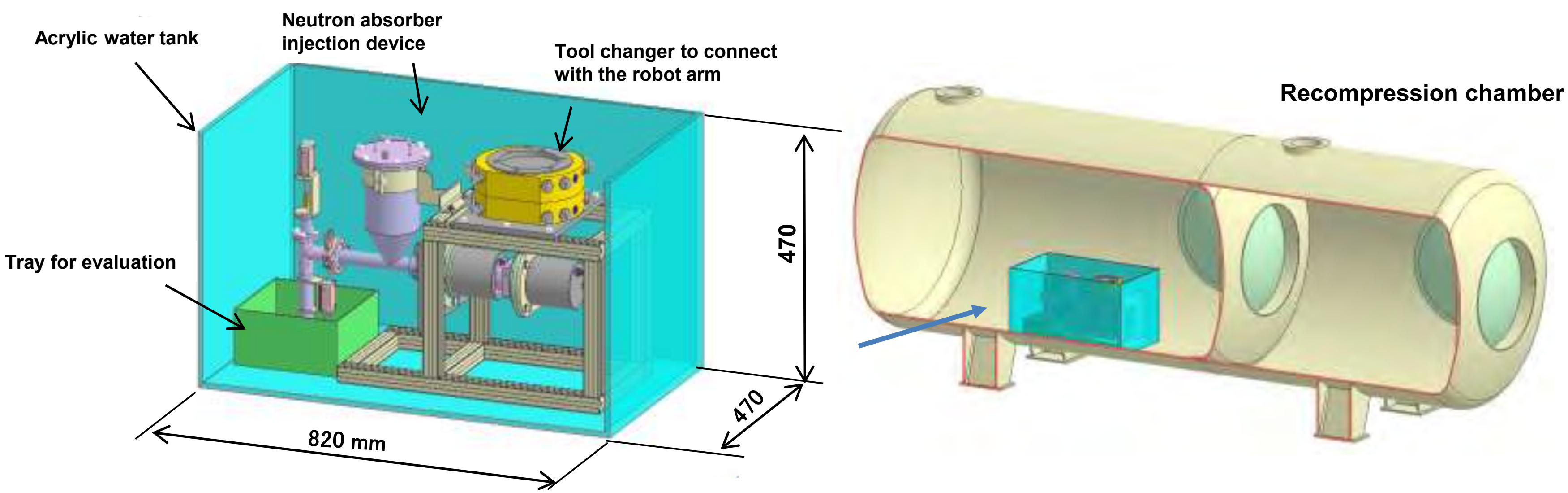


Figure 1 Overview of the test device

a. Study on insoluble neutron absorber injection device and operation methods
Underwater injection test for neutron absorbers (Continued)

- Test results
  - Both solidified type (Gd particles type) and viscous type (water glass type) absorbers could be injected at a stable speed in water with depth equivalent to 5 m. (Figure 1)
  - The intended injection speed could be achieved. (Figure 2)
    Gd particles type: 3.3g/sec
    Water glass type: 2.8L/min
    (Calculated on the assumption that it will take 30 minutes to inject the quantity needed for the 300 kg of fuel debris retrieved in a day)
  - Water resistance performance of the tool changer prototyped for underwater testing was confirmed at a water depth of 5 m. (Figure 3)
    (Static immersion test of 30 minutes based on the JIS waterproofing standard IP7)

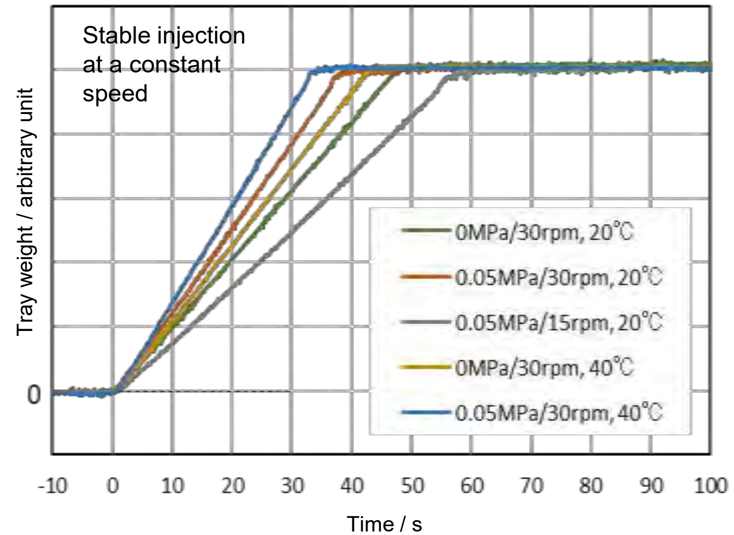


Figure 1 Temporal changes in the amount of absorber injected (Water glass type)

- Issues at the time of actual application
  - When the water glass type absorber was injected, fine particles that did not settle whirled up and the water turned turbid.
    It is necessary to confirm the impact on the water treatment system or the impact on the visibility of the fuel debris processing work.

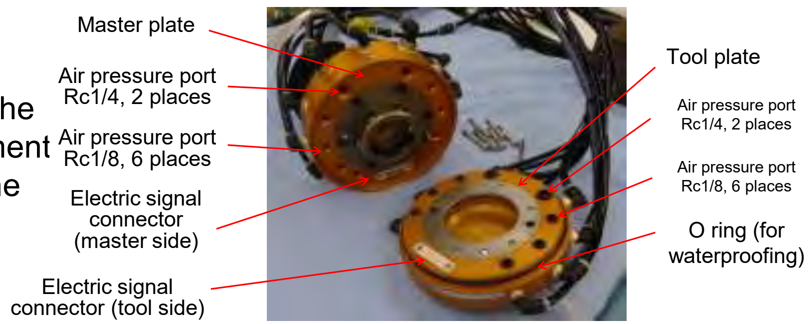


Figure 3 Tool changer prototyped for underwater testing

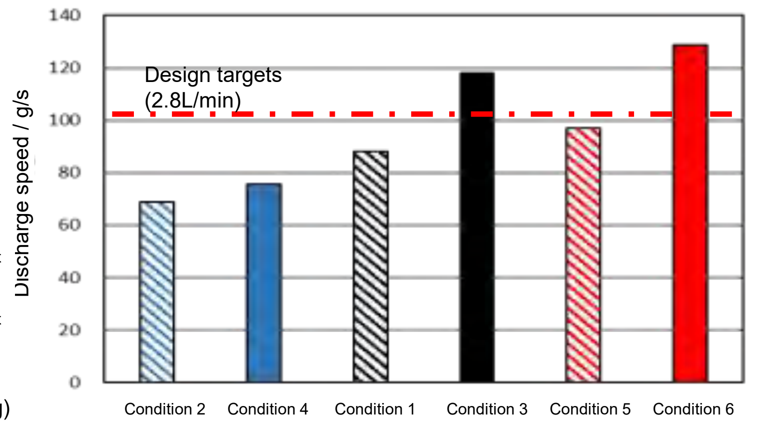


Figure 2 Injection speed of absorber (Water glass type)

a. Study on insoluble neutron absorber injection device and operation methods
Verification of impact due to fuel debris processing

- **Purpose of the test**
  - To assess the impact of processing when the fuel debris is processed with the absorber scattered on the debris (Figure 1).
  - To confirm that the absorber is functioning effectively (the fuel debris and the absorber should mix together after processing).
  - To confirm that the fuel debris processing is performed without trouble even when the fuel debris is covered with the absorber.
  - To examine the size (particle size) of the fine powder of the processed absorber.

- **Testing methods**
  - The MCCI debris was assumed as the simulated fuel debris and a mortar with regulated compressive strength was created.
  - Absorber (water glass type) was dropped on the surface of the simulated fuel debris (Figure 2).
  - The surface of the simulated fuel debris (approximately 5 cm in depth) was crushed (9 places at 5-cm intervals) using a chisel processing device (electric hammer) (Figure 3).
  - Measurements were done under water (particle size measurement) and in air (measurement of mixing).

Figure 2 Water glass type absorber (viscous solidified)

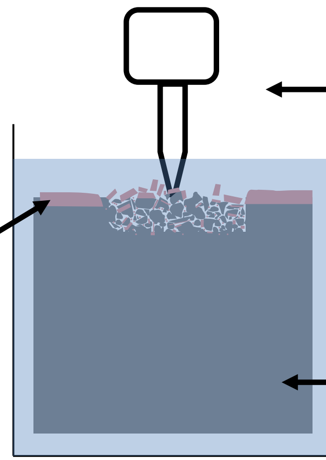


Figure 1 Image of chisel processing

X-Y Positioning jig

Figure 3 Outline image of test device

a. Study on insoluble neutron absorber injection device and operation methods
Verification of impact due to fuel debris processing (Continued)

- Test results
  - The processing at 9 locations required 90 to 150 seconds and no significant difference was noted due to the presence or absence of the absorber.
  - The broken pieces were collected after chisel processing, sorted through a strainer, and their weight was measured to obtain the particle size distribution data (Figure 1). When the absorber was present, there was a tendency that the number of fine particles of size less than 250μm or less increased. This is believed to be because of the minute scattered particles resulting from the crushing or decomposition of the neutron absorber. This result will be presented as an input for the water treatment system design.

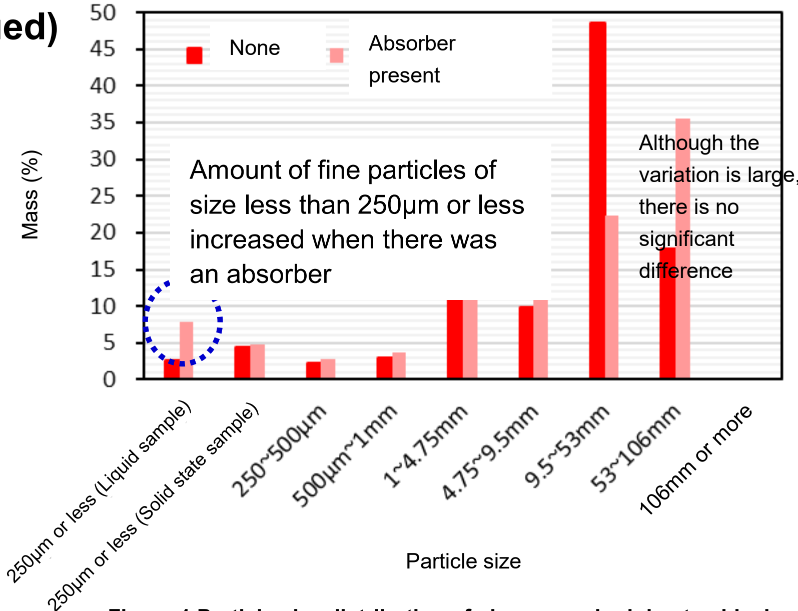


Figure 1 Particle size distribution of pieces crushed due to chisel processing

- The test sample after processing was solidified by impregnation with epoxy resin and on collecting a Φ30 mm sample for analysis by core boring, it was found that the neutron absorber (Gd) had infiltrated (got mixed) deeply (5 to 7 cms). (Figure 2; White part) (Figure 3)

Direction of depth

7cm

Figure 2 Sample for analysis obtained by core boring

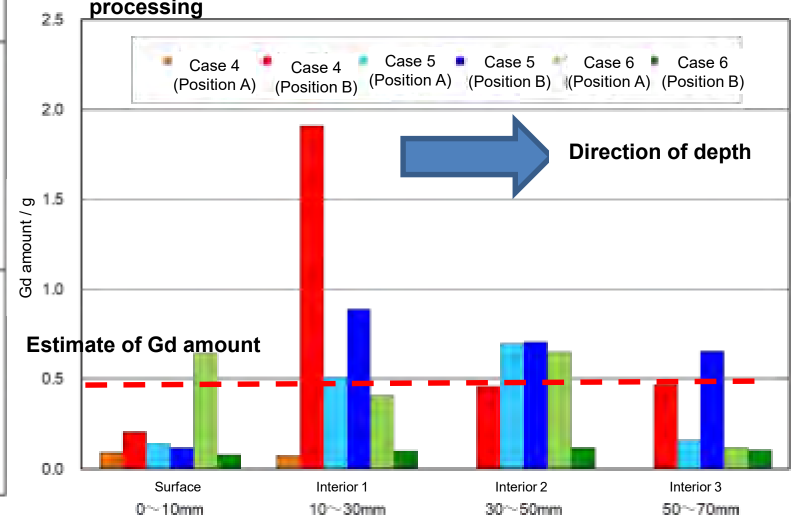


Figure 3 Weight of absorber (Gd) included in the direction of depth after processing

b. Study on the corrosion effects considering the use of rust inhibitors under irradiation effects

- Purpose of development
  - To develop an insoluble neutron absorber to prevent criticality.
- Issues to be solved
  - So far the corrosion effect due to neutron absorbers has been evaluated from the perspective of changes in water quality associated with long-term gamma ray irradiation. The remaining issues arise when the use of a rust inhibitor (Table 2) is considered for controlling PCV corrosion in the reactor water environment.
- Approaches to development
  - Experimental evaluation of the impact on the rust inhibitor effect of neutron absorbers containing rare earths whose effect on the corrosive behavior in a gamma-ray irradiated environment is unknown. (Table 1)
- Expected outcome
  - A combination of rust inhibitor and insoluble neutron absorber that can be applied

Table 2 Rust inhibitor and water quality to be studied

Classification	Rust inhibitor	Water quality to be studied	
		B Concentration (ppm)	pH
I.	$Na_2B_{10}O_{16}$	≧4000	(8-9)
II.	Na_2WO_4 $+Na_2B_{10}O_{16}$	＜4000	(8-9)
III.	ZSMMP	＜(40)	6-8
IV.	ZSCMP	＜(40)	≧10

Values in the parentheses are the result values

Table 1 Dissolution characteristics and secondary impact evaluation status of the selected candidate material

Classification	Candidate material	Dissolution characteristics		During retrieval		Subsequent processes	
		pH	Dissolution components	Fuel debris processing (Chisel)	Rust prevention measures (Desk-top study #)	Canister (Long-term irradiation)	Waste
Solids	B_4C sintered metal material	7 to 9	Fe, B	No effect	No effect	In design	Evaluated
	Glass material with B/Gd	6 to 9	B, Gd, Rare earth type	No effect	Experimental evaluation required	In design	Evaluated
	Gd_2O_3 particles	7 to 9	Gd	Not evaluated	No effect	In design	Evaluated
Liquid to Solid	Water glass/Gd_2O_3 granulated powder	12	Na, Gd, Ca	No effect	Water quality regulation required	In design	Evaluated

ZSMMP: Zinc/Sodium carbonate mixed phosphate, ZSCMP: Zinc/Sodium molybdate mixed phosphate

Desk study based on the pH and dissolution components

b. Study on the corrosion effects considering the use of rust inhibitors under irradiation effects

- **Development Schedule**

Study items	FY2019											
	4	5	6	7	8	9	10	11	12	1	2	3
Major Milestones							Interim Report ▼					Year-end Report ▼
1. Plans				Detailed test plan Selection of QST Takasaki Advanced Radiation Research Institute experimental issues								
2. Test preparations							Setting up of the Test Ancillary Facility Preparation of test specimen and testing solution					
3. Absorber irradiation test								Absorber irradiation test				
4. Evaluation of test results											Evaluation	
Remarks												

b. Study on the corrosion effects considering the use of rust inhibitors under irradiation effects

- Combination with rust prevention measures
  - Evaluation was carried out for the classifications I., II., and III., in which the pH range matches the glass material eluate with B/Gd (Table 3).
- Experimental methods
  - The corrosion test was executed for the PCV carbon steel SGV480 by using the testing solution containing dissolved absorber components (Table 4) by conforming in principle to the testing methods stipulated in the rust prevention measures.
  - The test was conducted at the dose rate of 4 kGy/h which was the same as that stipulated while deciding the rust prevention measures at the QST Takasaki Advanced Radiation Research Institute's gamma ray irradiation facilities.
  - An immersion corrosion test was carried out for uniform corrosion, and an electrochemical test was carried out for oxidation membrane type rust inhibitor for localized corrosion (Classifications I. and II.).

Table 3 Composition and experimental evaluation of the testing solution

Classification	Rust inhibitor		Absorber	Density of artificial sea water	Water quality		Experimental evaluation	
	Elements	Mechanism			B Concentration (ppm)	pH	Uniform corrosion	Localized corrosion
I.	$Na_2B_{10}O_{16}$ 4000 ppm (as B)	Oxidation membrane	Glass material with B/Gd	Diluted 1000 times	4000	8	Immersion corrosion	Electrochemical
II.	Na_2WO_4 5000 ppm +$Na_2B_{10}O_{16}$ 1000 ppm	Oxidation membrane	Glass material with B/Gd	Diluted 1000 times	1000	8-9	Immersion corrosion	Electrochemical
III.	ZSMMP 4000 ppm	Precipitation membrane	Glass material with B/Gd	Diluted 10000 times	0.6 - 0.8	7-8	Immersion corrosion	—

ZSMMP: Zinc/Sodium carbonate mixed phosphate

Table 4 Dissolution components [ppm] from the absorber (Glass material with B/Gd)

B	Ba	Zn	Bi	La	Gd
0.6-0.8	0.4-0.6	0.1-0.2	0.07	0.01	0.01

b. Study on the corrosion effects considering the use of rust inhibitors under irradiation effects

[Test results]

- Uniform corrosion (Immersion corrosion test) (Figure 1)
  - ➢ The amount of corrosion decreased significantly with any of the rust prevention measures, and there was no effect of the dissolved absorber components.
- Localized corrosion (Electrochemical measurement and testing) (Figure 2)
  - ➢ When the dissolved absorber components were present in a gamma ray irradiated environment of dose rate 4 kGy/h, the natural immersion potential increased and changed in the direction in which localized corrosion was likely to occur.
  - ➢ When the progress of localized corrosion was evaluated by setting up conditions based on the measured potential value, it was found that even in the presence of dissolved absorber components, the measured value of the natural immersion potential had a margin of 0.45V or more and no progress in corrosion was seen.
- Coexistence with rust prevention measures
  - ➢ It was confirmed that the dissolved components of glass material with B/Gd could coexist with the Classification I., II., and III. rust prevention measures.

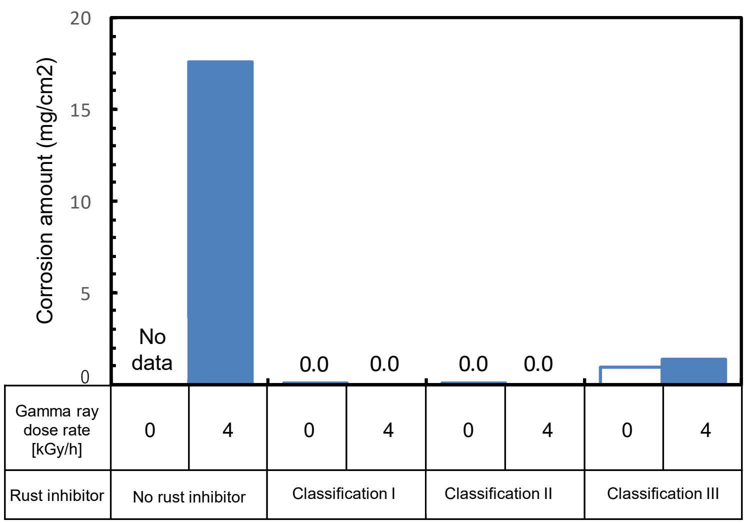


Figure 1 Amount of corrosion based on immersion corrosion test (500 h) (presence of dissolved components of glass material with B/Gd)

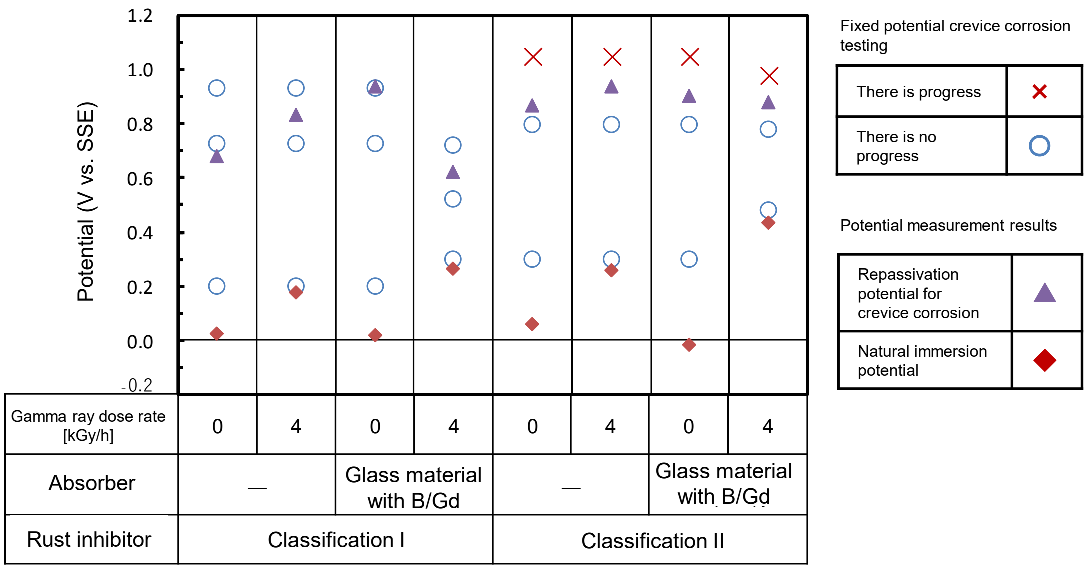


Figure 2 Evaluation of progress of localized corrosion based on electrochemical test
#The data not containing absorber components is cited from the Corrosion Project results

8. Summary

(1) Development of Fuel debris Retrieval method

① Development of technology for removing interferences

- A conceptual study was undertaken for the access routes and methods of carrying out structures with the top-access method. Next fiscal year, the feasibility of the methods will be verified by drafting plans for element tests and by conducting the tests.
- For the side-access method, the feasibility of the method was verified by conducting element tests for the common utilities.

② Development of various technologies other than removal technology for interferences

- As regards the remote operation support method, an environmental model and simulator were created and the robot model was used on the simulator to confirm that interferences can be avoided. Next fiscal year, the effectiveness of the remote operation support methods will be verified by means of a partial mock-up.
- As regards the method of preventing the spread of contamination to the S/C, element tests were conducted for building a weir remotely. The ability of building a weir by remote operation could be confirmed, but issues regarding the ability of stopping water were identified, hence next fiscal year, re-verification will be carried out by means of additional testing.
- In order to reduce the load on the R/B floor, ideas on reducing the weight of the cells inside the R/B were studied by optimizing the settings for the shield thickness required around the cell and reducing the cell height by reviewing the access rail structure. Next fiscal year, the effectiveness and the feasibility of the methods studied will be evaluated.
- As regards the method of transporting the unit cans from the R/B, a conceptual study was conducted on the confinement device (mobile cell) for transporting the fuel debris in unit cans. Next fiscal year, the feasibility of the studied method will be verified by means of element tests.

8. Summary

(2) Development of Technology for Processing Fuel Debris

(i) Technological development of fuel debris collection and storage systems

- As regards the suction collecting system for particulate fuel debris, the shape of the pump strainer was optimized and a pump model was selected according to the application environment. The verification will be conducted by means of element tests next fiscal year.

- For the development of technology for transferring fuel debris and wastes, retrieval methods are being planned presuming the state and characteristics of the fuel debris. Moreover, by carrying out processing element tests for mechanical cutting, issues regarding cutting tools or cutting targets were identified. The targets of application will be organized next fiscal year.

(ii) Technological development of treatment for fuel debris and deposit

① Removal technology for soluble nuclides in circulating cooling water

- The preliminary tests necessary for drafting the plan for adsorption tests using alpha nuclides (U, Pu, etc.) were partially executed, and the container adhesion effect and differences in the dissolution levels were verified by adding Am, Cm, U to the solution having the actually presumed water quality. In future, adsorption testing will be conducted after carrying out similar preliminary tests for Np and Pu too.

- As a result of studying the deposition behavior of boric acid ions, the deposition risk due to the Ca ions or the Na/B ratio changes was confirmed. Details are under study by means of the ongoing element tests.

② Treatment technology for deposits collected from inside PCV

- A differential pressure countermeasures test of the intermediate removal filter which is a candidate device for removal of insoluble nuclides was conducted, and issues and future policies were organized. In the current scope of study (only changes in test conditions for intermediate removal), it was difficult to control the rise in differential pressure during intermediate removal, so distribution of load to the final treatment stage, or creating multiple intermediate removal systems, will be studied in future.

- As a technology for separating solid materials in collected liquids and wastewater, the applicability of separation using aggregation sedimentation was confirmed in a boric acid-free system. In future, operations or applicability verification testing (device testing) will be carried out after confirming the effects of boric acid addition.

8. Summary

(2) Development of Technology for Processing Fuel Debris (Continued)

(iii) Survey on sorting technology for fuel debris and radioactive wastes

- As regards the sorting technology for fuel debris and radioactive wastes, the technical feasibility of each sorting point was evaluated and sorting scenarios were formulated taking feasibility into account.

(3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris

(i) Development of element technology for confinement functions

① Technology for prediction of dust behaviors in PCV

- Advancement of realistic dust behavior evaluation method was implemented to conduct airflow analysis for the containment vessel and entire R/B. The dust behavior evaluation method was established based on the physical behavior of aerosol.
- The airflow analysis was conducted considering the decay heat of fuel debris and heat input during processing. It was confirmed that there was no out leak due to the chimney effect under the assumed negative pressure conditions.

② Technology for ensuring confinement functions in connection parts

- As regards the method of connecting to PCV using the access tunnel, the basic requirements of the connection parts are being organized by studying the work steps. In addition, a comparative study of the connection methods was conducted. Next fiscal year, the feasibility of the method of connecting to PCV by means of welding will be verified by element tests.

8. Summary

(3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris (Continued)

(ii) Development of element technology for prevention and monitoring of criticality

① Technological development of criticality monitoring method

- In order to verify the feasibility of the subcriticality measurements, a neutron measurement test was carried out with the Kyoto University Criticality Assembly, and the gathered data is being analyzed.
- As regards the applicability of the neutron detector to the field, neutron detectors found to have good prospects were selected from the perspective of subcriticality measurement. The structure of the neutron detector unit was designed and it was expected to be much lighter in weight than the earlier ones. Moreover, the effect of a noise-resistant cable was verified after studying countermeasures for noise generated by the processing devices.
- The monitoring methods and limiting conditions of criticality approach and the main points of attention from the viewpoint of criticality safety control were consolidated by organizing the concepts of criticality safety control involved at each step of each of the various fuel debris retrieval methods.

② Development of technology for criticality prevention

- An insoluble absorber injection device was prototyped and tests were conducted and it was confirmed that under water injection at the target speed was possible. Moreover, a test of processing with a chisel was carried out after injection of absorber, and it was confirmed that the fuel debris and absorber get mixed after processing.
- As regards the study on the corrosion effects considering the use of rust inhibitors under irradiation effects, an irradiation test was conducted and it was confirmed that the rust inhibitor and glass material with B/Gd can be used together.

(1) Development of Fuel Debris Retrieval Method	
① Development of technology for removing interferences ・Top-access and transportation methods for removing large-scale structures	As regards the methods to secure an access route by the top-access method (technology for removing interferences, basic specifications of devices and procedures etc.), it should be possible to confirm the feasibility of the methods by means of element tests after conducting studies which take into account remote operations, maintenance or reduction of exposure, etc. (Target TRL at the end of the project: Level 3)
・Side-access method for removing interferences inside/outside of the pedestal	Element test should be completed and the criteria should be fulfilled at the plant with respect to the methods for establishing utilities for the remote equipment, which influence the methods of removing interferences on the route, for the route inside the PCV from the equipment hatch to the CRD opening. Or the issues to be solved and the action policies should be clear. (Target TRL at the end of the project: Level 4)
② Development of various technologies other than removal technology for interferences ・Development of remote operation support method in environments with low visibility and narrow spaces	By developing control methods to avoid interferences by automatic operation of remote-controlled robots with an aim to decrease the work load on the operators and improve efficiency, the effectiveness and feasibility of applying these control methods must be evaluated by means of simulator verification and element tests, etc., and the identification of issues and action policies for the future should be presented. (Target TRL at the end of the project: Level 3)
・Method for preventing the spread of contamination into the suppression chamber (S/C)	As regards the method of preventing the spread of contamination into the suppression chamber (S/C) using weirs, element tests should be completed and the criteria for the element testing should be fulfilled at the plant, or the issues to be solved and the action policies should be clear. (Target TRL at the end of the project: Level 4)
・Establishment of the access route for cell installation and conceptual study of reducing the impact on the R/B	In order to reduce the load both inside and outside the R/B resulting from the installation of a cell, the method of downsizing the cell and the method of cell installation should be evaluated for their effectiveness and feasibility, and the identification of issues and action policies for the future should be presented. (Target TRL at the end of the project: Level 3)

(1) Development of Fuel Debris Retrieval Method (Continued)	
② Development of various technologies other than removal technology for interferences ・A method of transporting the unit can from the R/B.	Conducting a conceptual study regarding the formulation of the safety design or equipment specifications, etc. concerning confinement, criticality prevention, or hydrogen generation countermeasures etc. for the various transport devices used for transporting the unit cans storing fuel debris from the R/B to another building within the premises, and confirming the feasibility of the methods or equipment by means of element tests of the confinement mechanism and the hydrogen treatment mechanism. (Target TRL at the end of the project: Level 3)

(2) Development of Technology for Processing Fuel Debris	
(i) Technological development of fuel debris collection and storage systems ・Development of suction collecting system for particulate fuel debris	By building the proposed suction collecting system for particulate fuel debris, the effectiveness of the suction speed of fuel debris and the ability of mounting the device on the robot arm or the feasibility of the operation methods, etc. shall be evaluated by means of element tests, and the identification of issues and action policies for the future should be presented. (Target TRL at the end of the project: Level 3)
・Process of transferring fuel debris and wastes	As regards the variety of fuel debris (slags, particulate, pellets etc.) presumed till date in the "Upgrading of the Comprehensive Identification of Conditions inside Reactor (FY2017)", by conducting a conceptual study on the necessary devices and series of collection procedures such as cutting, container storage, transport etc. of fuel debris by accessing various locations such as inside the reactor core, bottom of the reactor and the pedestal, the feasibility of the methods or devices should be verified by means of element tests, etc. of the processing or handling devices. (Target TRL at the end of the project: Level 3)
(ii) Technological development of treatment for fuel debris and deposit ① Removal technology for soluble nuclides from circulating cooling water	As regards the soluble alpha nuclides removal facility and the boric acid conditioning facility, the effectiveness and feasibility of the facilities must be verified by means of element tests, etc. based on the results of the conceptual design. (Target TRL at the end of the project: Level 3 to 4)
②Treatment technology for deposits collected from inside PCV	The effectiveness and feasibility of the results of the conceptual design of the wastewater treatment equipment that is related to the separation of solids and liquids and the collection and storage of solids must be verified by means of element tests, etc. (Target TRL at the end of the project: Level 4)
(iii) Survey on sorting technology for fuel debris and radioactive wastes	By formulating scenarios related to fuel debris sorting and conducting surveys of technology necessary for sorting based on the proposed scenarios, the feasibility of the sorting scenarios must be evaluated based on the results of technology survey considering the site environment, and the issues must be identified. (Target TRL at the end of the project: Level 2)

(3) Development of Technology for Ensuring Safety while Retrieving Fuel Debris	
(i) Development of element technology for confinement functions ① Technology for prediction of dust behaviors in PCV	By enhancing the analytical model for predicting the behavior of airflow and aerosol within the boundaries related to the confinement function, more apt methods of evaluation must be studied. Moreover, the requirements for the boundary function (static) and the gas management function (dynamic) of PCV and R/B for ensuring the confinement function must be studied. By predicting the aerosol behavior inside the R/B during times of dust leakage from the PCV, study results regarding the monitoring positions etc. must be presented. (Target TRL at the end of the project: Level 3)
②Technology for ensuring confinement functions in connection parts	As regards the structure and the connection methods of the connection parts between the access tunnel and the PCV (equipment hatch), the criteria of the element test concerning the connection between the access tunnel sleeve and the equipment hatch should be fulfilled, or the issues to be solved and the action policies should be clear. (Target TRL at the end of the project: Level 4)
(ii) Development of element technology for prevention and monitoring of criticality ① Technological development of criticality monitoring method	The applicability of the candidate neutron detector for the measurement of subcriticality must be confirmed. The basic design must be carried out for the structure to be used for installing a neutron detector on top of the fuel debris, and the issues and feasibility must be presented. (Target TRL at the end of the project: Level 4)
② Development of technology for criticality prevention	The corrosion effect which is the secondary effect of an insoluble neutron absorber or the effect associated with fuel debris processing must be confirmed. The basic design must be developed for the device to be used for injecting an insoluble neutron absorber, and the issues and feasibility must be presented. (Target TRL at the end of the project: Level 4)

Terminology (1/3)

No.	Terms	Definition
1	1F	Fukushima Daiichi Nuclear Power Station
2	R/B	Reactor building
3	PCV	Primary containment vessel
4	RPV	Reactor pressure vessel
5	CRD	Control rod drive
6	Operation floor	Operation floor
7	DSP	Device storage pool
8	SFP	Spent fuel pool
9	X-6 penetration	One of PCV piping openings
10	S/C	Suppression chamber
11	Jet deflector	Jet deflector
12	Inflate seal	Inflatable sealing material
13	Cell adapter	A member that connects the cell with the PCV
14	M/U	Mockup
15	BSW	Biological shielding wall
16	MCCI	Molten core concrete interaction
17	UC	Unit can (fuel debris storage container)
18	AWJ	Abrasive waterjet
19	Heating Ventilating Handling Unit (HVH)	Air conditioning unit
20	HCU	Hydraulic control unit

Terminology (2/3)

No.	Terms	Definition
21	CRGT	Control rod guide tube
22	JPDR	Japan Power Demonstration Reactor
23	MAAP	The modular accident analysis program owned by the Electric Research Institute (EPRI), U.S.
24	GOTHIC code	One of the general purpose thermal-hydraulic analysis code developed by EPRI/ZACHRY
25	Chimney effect	The movement of air leakage resulting from air circulation flow through multiple damaged openings due to differences of air density in inside/outside PCV.

Terminology (3/3)

No.	Terms	Definition
1	TRL7	Practical application is complete.
2	TRL6	Onsite demonstration phase
3	TRL5	Actual-scale prototypes are produced, and validation tests are performed in a plant under conditions that simulate the actual environment.
4	TRL4	Functional tests are performed using testing mock-ups as part of the development and engineering processes.
5	TRL3	Development and engineering work is performed within the range of conventional experiences or their combination, or development and engineering work in new areas virtually without past experience.
6	TRL2	Development and engineering work is performed, and the required specifications are developed in areas where there is almost no applicable past experience.
7	TRL1	Basic requirements are identified for the methods and systems to be developed and engineered.