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

Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures

Accomplishment Report FY2017

April 2018

International Research Institute for Nuclear Decommissioning (IRID)

1. Purpose and Goal of "Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures"

[Purpose of upgrading of fundamental technology for retrieval of fuel debris and internal structures]

Investigations to date suggest that nuclear fuel, melted down with reactor internals, formed fuel debris and accumulated in the Reactor Pressure Vessel (RPV) and the Primary Containment Vessel (PCV) on 1F.

It will be a correct assessment that fuel debris in the RPV and PCV is in a sub-criticality state. Nevertheless, the entire nuclear plant's condition is different from the intended original design and is unstable due to damage in the reactor building (R/B), RPV and PCV from the accident; therefore, it is necessary to stabilize the plant by retrieving the fuel debris and keeping it in a sub-critical state as well as to prevent the diffusion of radioactive materials.

Given the above-mentioned circumstances, the project's goal is to begin fuel debris retrieval, by 2021 or earlier, from any of the units chosen as the first target of this work. The project target is based on the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4" (hereinafter referred to as Mid-and-Long-Term Roadmap).

The program objectives are: to facilitate the smooth decommissioning and contaminated water treatment of the Fukushima Daiichi Nuclear Power Station by supporting the development of necessary technologies according to the "Mid-and-Long-Term Roadmap" as well as the "Progress status of R&D projects and direction for next period" (39th meeting, Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment), and to improve the level of science and technology in Japan.

Specifically, technologies to realize methods and equipment used to remove fuel debris and reactor internals will be developed to support the selection and implementation of methods and technologies for fuel debris and reactor internals removal. Focus will be given on top entry and the side entry methods for the technical development of fuel debris retrieval methods.

[Overall development goal]

The program will be executed with the aim of commencing fuel debris retrieval in fiscal 2021 on any of the units chosen as the first target of this work based on the "Mid-and-Long-Term Roadmap."

2. Achievements of Projects Implemented Previous Fiscal Year (Years 2015-2016)

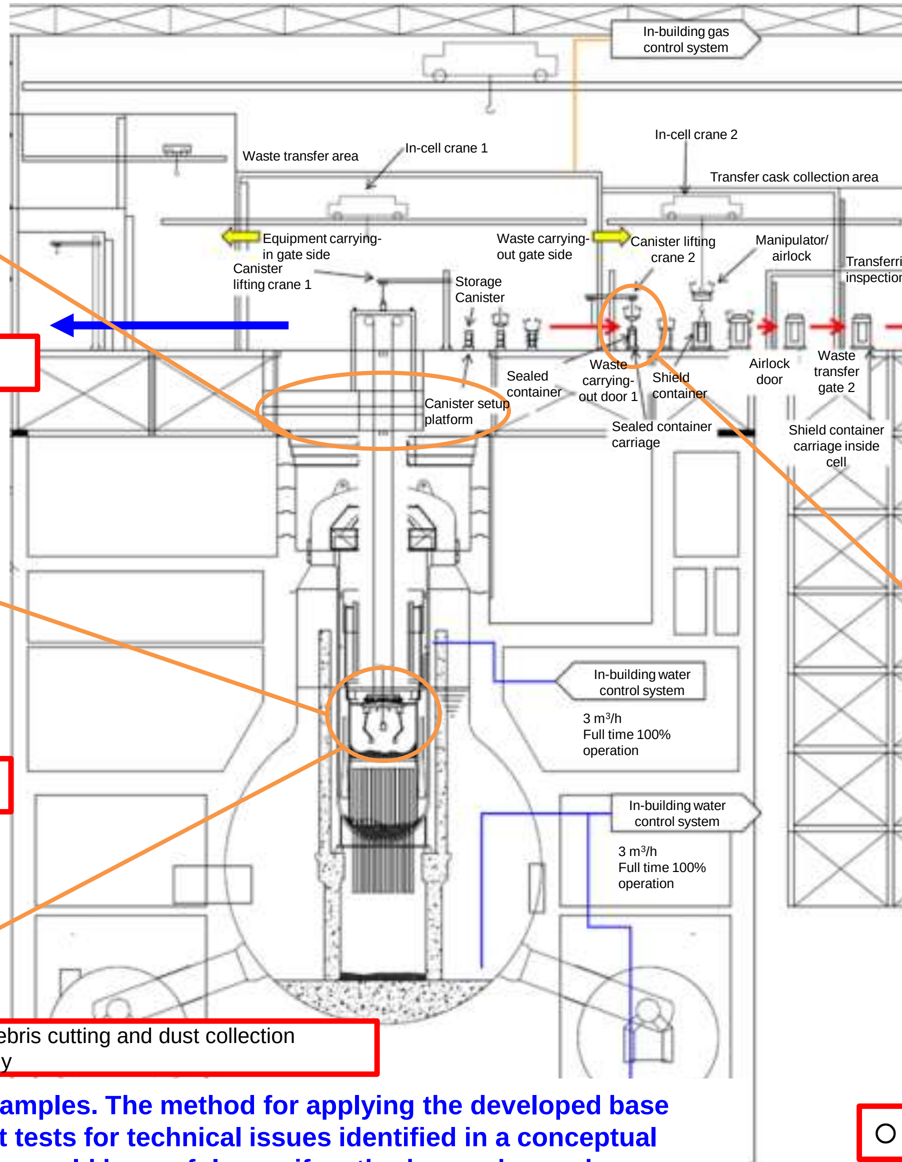
Application Examples of Developed Basic and Fundamental Technology(1/3)

Example of method

○ Tests for platform and cells

○ Tests for RPV access equipment

○ Fuel debris cutting and dust collection technology



: Device traffic line

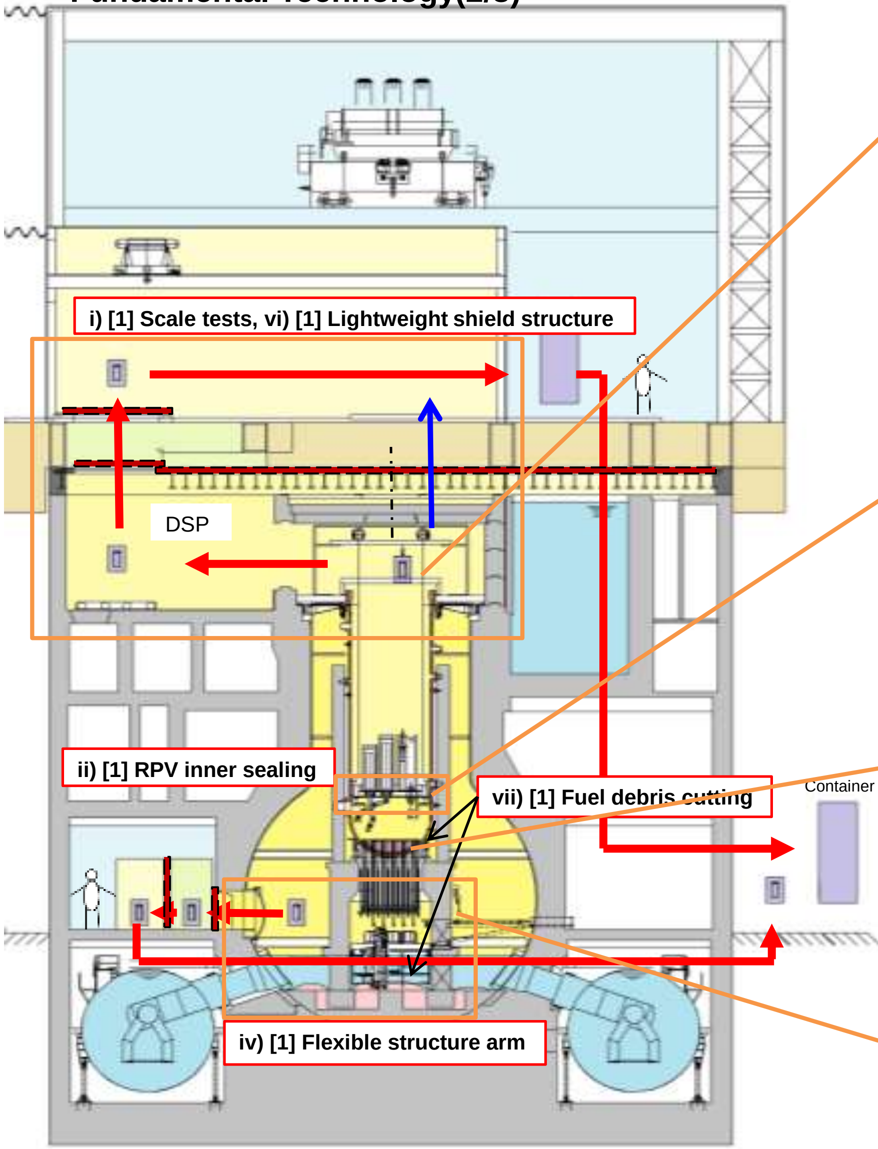
: Fuel debris flow line

○ Tests for canister handling equipment

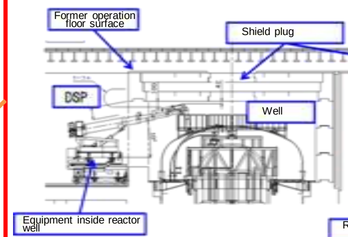
Applications shown in the figure are only examples. The method for applying the developed base technologies may be reviewed later. Element tests for technical issues identified in a conceptual study were performed so that the test results would be useful even if methods are changed.

2. Achievements of Projects Implemented Previous Fiscal Year (Years 2015-2016)

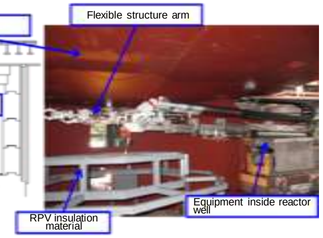
Application Examples of Developed Basic and Fundamental Technology(2/3)



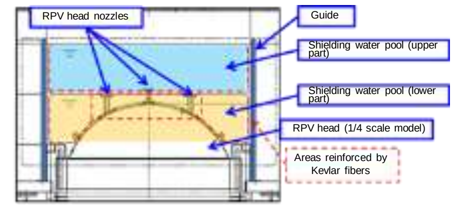
○ Scale tests, development of lightweight shield structure



PCV head handrail dismantlement



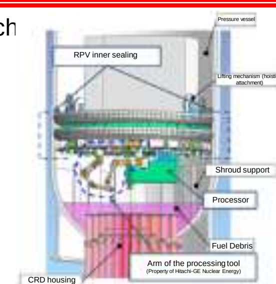
Verification test for accessibility to the RPV insulation material for dismantlement



The shielding water pool installed over the RPV head

○ Development of RPV inner sealing tech

Full-scale mock-up of RPV internal structures



RPV inner sealing

Installation of RPV internal structures

○ Development of fuel debris cutting tech

Common test facility processing status

Collected core

⌀48 non-core bit

Impregnated bit

○ Development of flexible structure arm (Partial submersion-the side entry method)

Crane parts transportation status (pillar)

Horizontal cutting

Power supply connector connection

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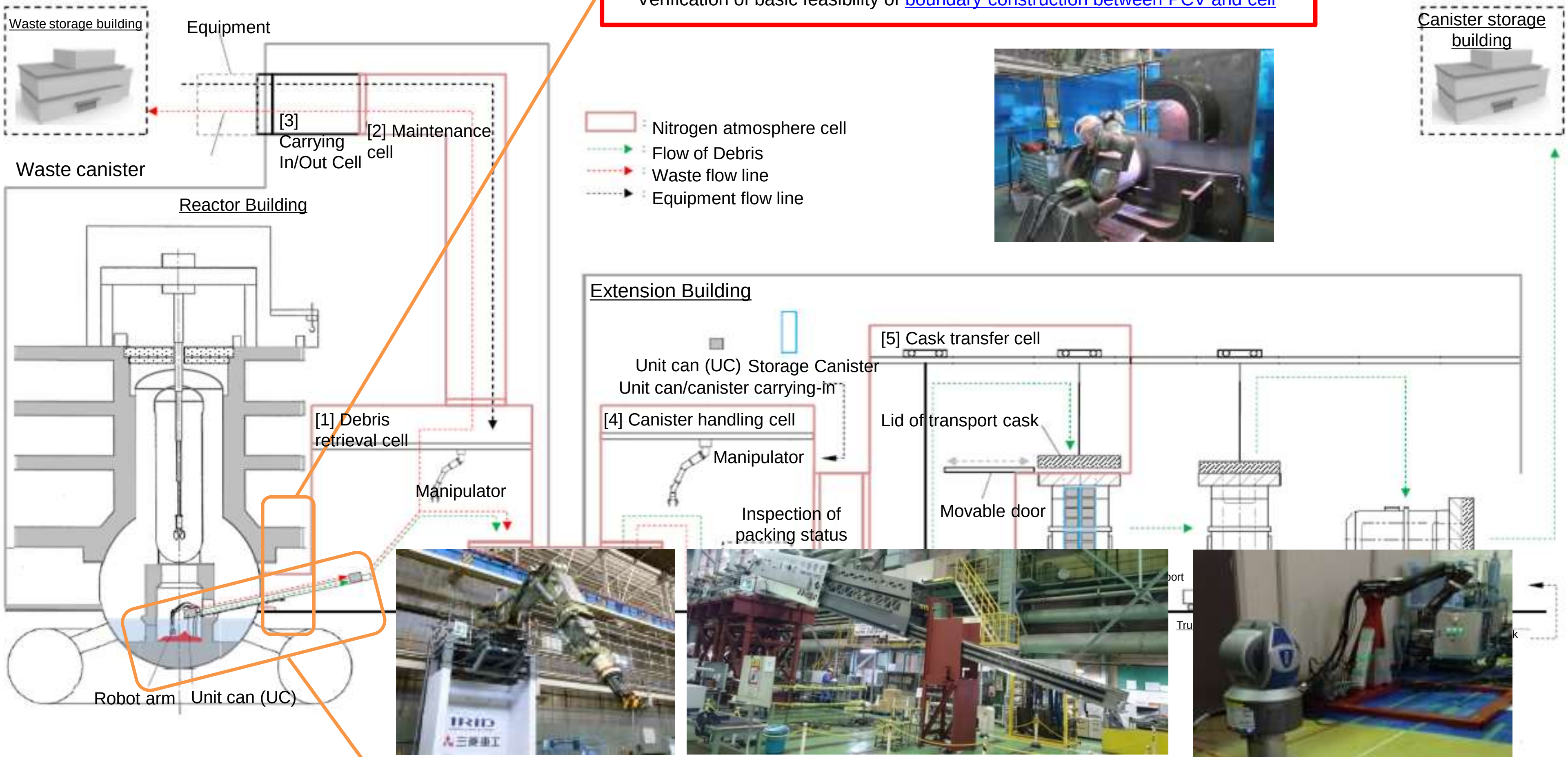
2. Achievements of Projects Implemented Previous Fiscal Year (Years 2015-2016) No.4

Application Examples of Developed Basic and Fundamental Technology(3/3)

○ Tests of PCV welding equipment for remote welding work for sealing
Verification of basic feasibility of boundary construction between PCV and cell

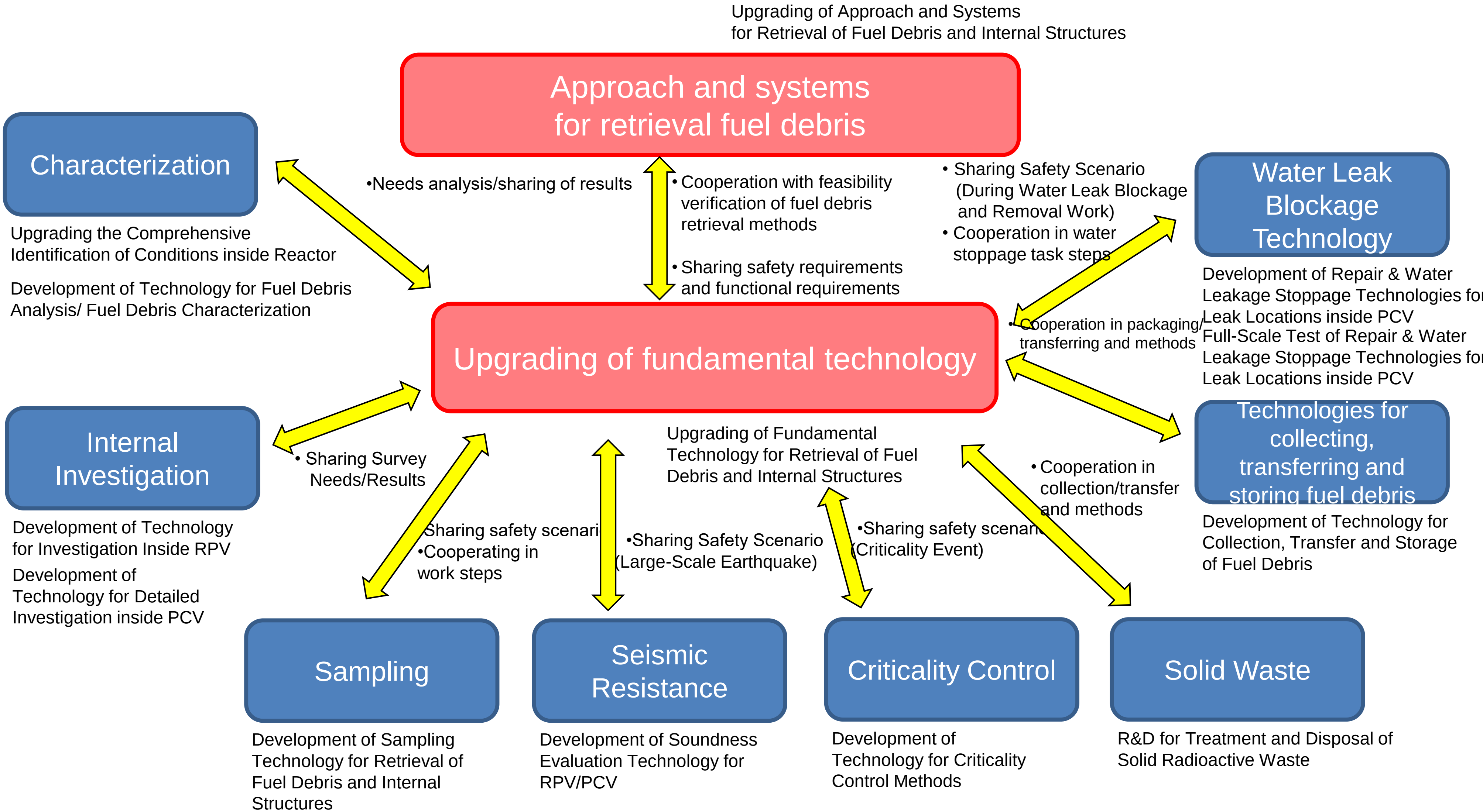


○ Tests for access equipment inside the pedestal
Verification of basic feasibility of robot arm and access rail

○ Tests for a hydraulic manipulator
Acquisition of basic data to build control logic
Fundamental test for robot arm development

3. Project Overview

3.1 Collaboration with Other Projects



3. Project Overview

3.2. Basic Policy of Fundamental Technology Development

Main action policies for matters arising in connection with implementing the project plan are as described below.

[Basic Policy]

Policies for fundamental technology development shall be established based on the "Technological Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of TEPCO Holdings, Inc." (hereinafter referred to as "Strategic Plan 2017"), which was formulated by the Nuclear Damage Compensation and Decommissioning Facilitation Corporation. Details of the program and development themes shall be determined according to suggestions of the Strategic Plan 2017.

3. Project Overview

3.2. Basic Policy of Fundamental Technology Development

[Suggestions of Strategic Plan 2017]

1. The technology development plan shall be formulated based on the following understanding about the fuel debris retrieval project: it is a comprehensive program encompassing preparatory work, waste removal, treatment and storage, and post-removal work. It requires total optimization through careful considerations, including coordination with other work conducted on site.
2. Fuel debris retrieval methods with high potential shall be selected first as primary development program targets. Then, the program shall be carried out by a step-by-step approach with flexibility to reflect information obtained during the program's progress.
3. The development program shall be carried out on the premise that a combination of various methods will be needed to retrieve fuel debris successfully.
4. The focus will be on the partial submersion method when conducting preliminary engineering and R&D activities.
5. Methods to retrieve fuel debris that accumulated in the PCV bottom shall be given top priority. Then, the development program shall be reviewed regularly based on knowledge and experiences obtained from these activities.
6. The method to access inside PCV laterally (side-entry method) shall be studied first as a route to access fuel debris at the PCV bottom. The points to note in construction using this method are as follows:
   - Reducing the radiation dose at the work site
   - Establishing water level control technology
   - Establishing cell connection technology and securing areas

- **Study and development will be conducted by focusing on technologies required to retrieve fuel debris at the PCV bottom by "Partial submersion-the side entry method."**
- **Study and development of common technologies by methods that are not dependent on collection/cutting and dust collection technologies will also be conducted by focusing on technologies required to retrieve fuel debris at the PCV bottom by "Partial submersion-the side entry method".**
  (Example: Collection of fuel debris in particle or powder form, MCCI debris processing)
- **The development program shall be designed with consideration to relevant information, including those obtained by investigating inside the PCV. The various methodological choices will be prepared with contingencies in case a single technology and method is insufficient, and flexible combinations of different technologies and methods are required.**

3. Project Overview

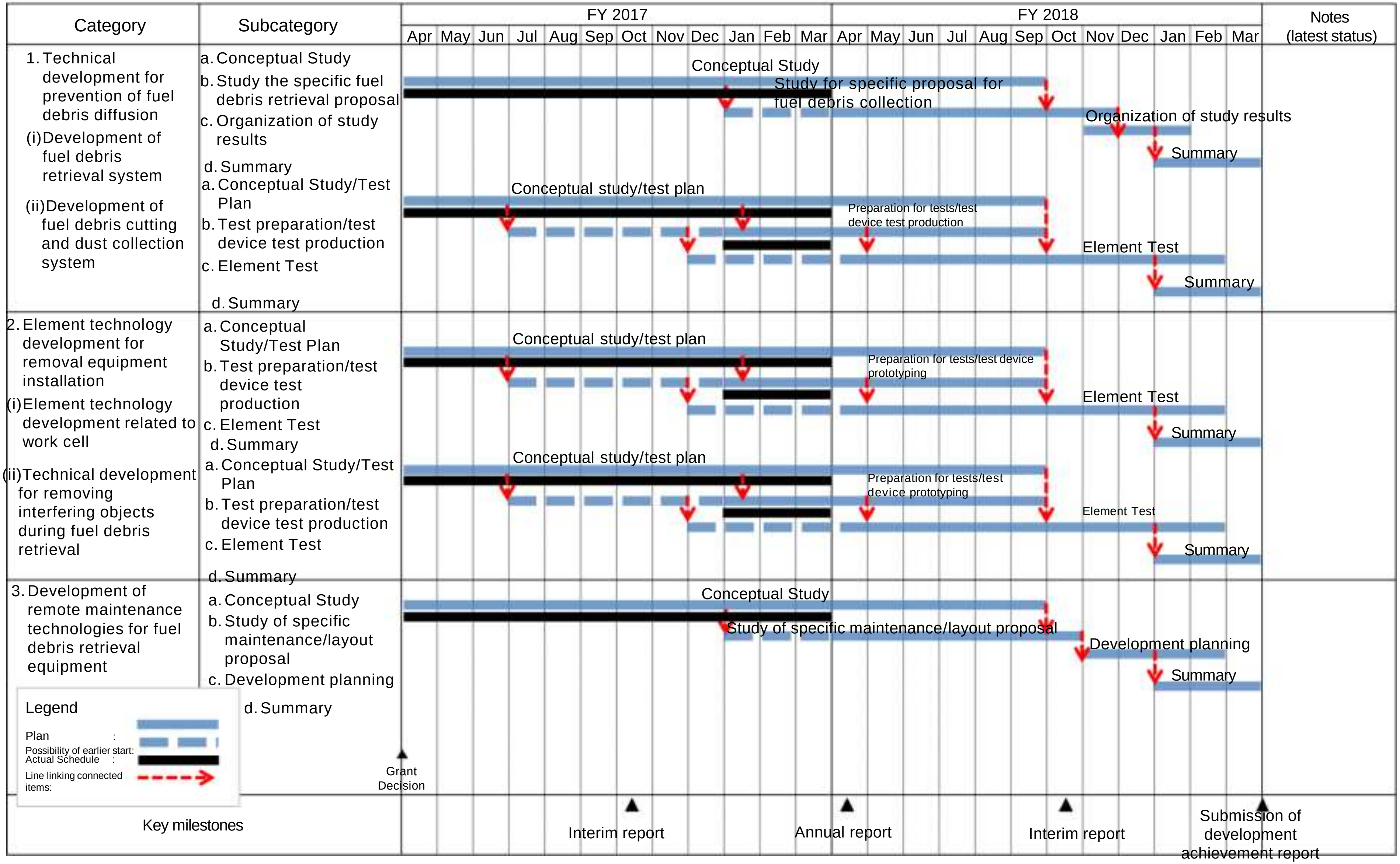
3.2. Basic Policy of Fundamental Technology Development

Based on the policies listed in the previous sections, implementation policies for each development item are determined as follows:

Publicly offered development items	Implementation policy	Reference
1) Technical development to prevent fuel debris diffusion [1] Development of a fuel debris collection system	While retrieval technologies are applicable to different types of work in common, study and development shall focus on technologies applicable to retrieving fuel debris at the PCV bottom (including fuel debris fragments generated by cutting) using a the side entry method, which is likely to be used for the actual retrieval project.	Slide No.12
[2] Development of a fuel debris cutting/dust collection system	While cutting and dust collection technologies are applicable to different types of work in common, study and development shall focus on technologies applicable to cutting and collecting fuel debris in the PCV bottom using a the side entry method.	Slide No. 37
[3] Development of methods to prevent fuel debris diffusion	The diffusion of fuel debris from the PCV bottom to vent pipes and the S/C may occur during fuel debris retrieval. Technologies to prevent such diffusion shall be studied and developed.	Slide No.53
2) Element technology development for installing retrieval equipment [1] Element technology development related to work cell	Technologies to connect cells and PCV without leaking radioactive materials shall be studied especially closely and developed, including alternate methods to achieve the safe confinement of such materials. In addition, technologies for transporting and installing cells and the estimate of the cells' impact on the reactor building (R/B) shall also be studied and developed; the former is related to worker exposure and the latter is related to ensuring safety in an emergency.	Slide No.61
[2] Technical development for removing interfering objects during fuel debris retrieval	Study and develop methods for removing interfering objects that block access to fuel debris in the PCV bottom by a the side entry method. Methods and technologies applicable to the dismantlement of interfering objects through top entry shall be studied first. Then, further development shall be implemented on those that are found essential and difficult to be embodied.	Slide No.94
3) Development of remote maintenance technologies for fuel debris retrieval equipment	First, the basic remote maintenance approach shall be based on internal cell facilities for a the side entry method. Then, the plan of study and development of maintenance equipment shall be formulated.	Slide No.174

4. Project Schedule

Schedule for Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures



5. Subsidized Project Scope

[Purpose]

For FY2017-2018, the program will be implemented with focus on design study and element tests based on the fuel debris retrieval policy announced in September 2017 and with consideration of the policy's applicability; the program will be implemented with a view to developing the equipment to be used in the actual debris removal work so that the work will enter a practical phase.

[Main scope of this project]

1) Technical development for prevention of fuel debris diffusion

Effective, flexible collection technologies applicable to different fuel debris conditions, and technologies to collect dust generated during the removal work, will be developed to prevent diffusion of dust and other materials produced during fuel debris retrieval.

2) Element technology development for installing retrieval equipment

Develop remote technologies for each task that are assumed during fuel debris retrieval because the site is highly radioactive, so many of the tasks must be controlled remotely.

3) Development of remote maintenance technologies for fuel debris retrieval equipment

Fuel debris retrieval equipment/devices and systems (including the fuel debris cutting and dust collecting systems, containers and work tables, monitoring system, and robot arms to manipulate the equipment) need to be maintained remotely as a rule by because they are installed in a highly radioactive area. This requires reviewing maintenance methods for fuel debris retrieval equipment and systems, evaluating feasibility, identifying issues, and studying a reasonable action policy with actual equipment.

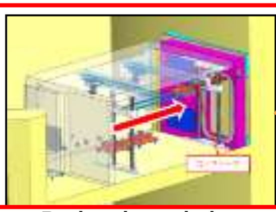
6. Implementation Details

6.1 Development Plan

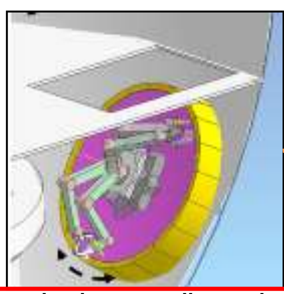
Project development plan is shown in the figure below. Detailed implementation items are listed on the next and subsequent pages.

Methods for removing interfering objects by fuel debris retrieval equipment using the side entry method

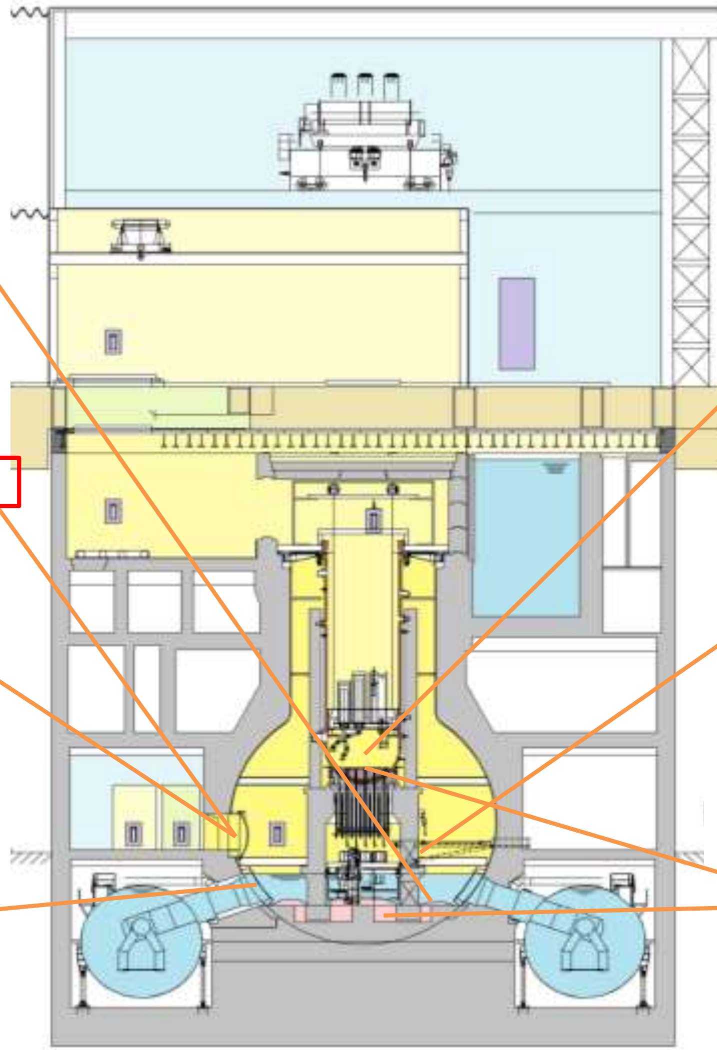
Work cell sealing method (inflate sealing)

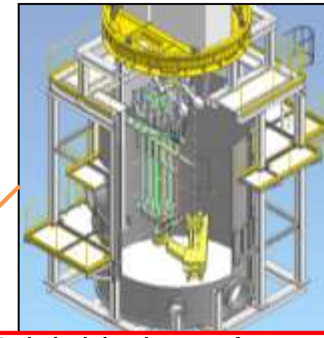


Boring through the biological shielding wall



Preventing contamination spreading to the suppression chamber





Technical development for removing interfering objects and the RPV bottom part

Verifying maneuverability by a combination of a robot arm and access rail

Processing method to minimize fuel debris diffusion

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

Fuel debris is assumed to have accumulated in the primary containment vessel (PCV) in various forms (such as rubble, polluted sludge, and fine powder). Therefore, development of the system will provide effective retrieval methods and systems to handle different debris forms. The transportation and temporary storage system to send removed fuel debris to canisters and other containers needs to be developed in this theme as well.

Specifically, the following methods and technologies need to be studied to prepare a suitable fuel debris retrieval method and system. Additionally, issues need to be identified and addressed by performing element tests when necessary.

a. Means and methods of collecting fuel debris (such as suction and grabbing)

- Information on fuel debris distribution and characteristics are under review.
- Details of suction and grabbing methods are under consideration, based on the information obtained from the above-mentioned work.

b. Method to store fuel debris in unit can

- Identify the specific method for packing fuel debris in unit cans based on results of studies listed in Paragraph a.

c. Fluid control method for fuel debris (such as dewatering or desiccation)

- Methods of controlling the fluid of the fuel debris may be accompanied by hydrogen generation. The relationship between the control methods and hydrogen generation is being studied.

d. Method to store unit cans in canister and to transfer them

- A unit can will be designed as a cylindrical can of ⌀200 mm in principle.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

- Purpose of development
  - Fuel debris is assumed to have accumulated in the primary containment vessel (PCV) in various forms (such as lump, granular, and powder). Therefore, development of the system will provide effective collection methods and systems to handle different debris forms.
- Issues to be resolved
  - Find specific fuel debris properties and volumes (ratio of lumps, powder and power debris)
  - Clarification of powdery debris suction and collection method
- Development approach
  - Presumption of total fuel debris amount to be removed
    - ✓ Estimation of fuel debris properties, distribution and processing methods
    - ✓ Estimation of fuel debris properties and amount after processing
  - Clarification of retrieval processes such as grabbing and suction
    - ✓ Survey of, and benchmark for, collection equipment
    - ✓ Trade-off of collection systems
  - Study of interface conditions with the plant operation systems and infrastructure
  - Study of system for collecting and transferring to canister
- Expected results
  - Feasibility of fuel debris collection work
  - Specifications of particle-shaped fuel debris retrieval system
  - Fuel debris collection rate (throughput)

6. Implementation Details

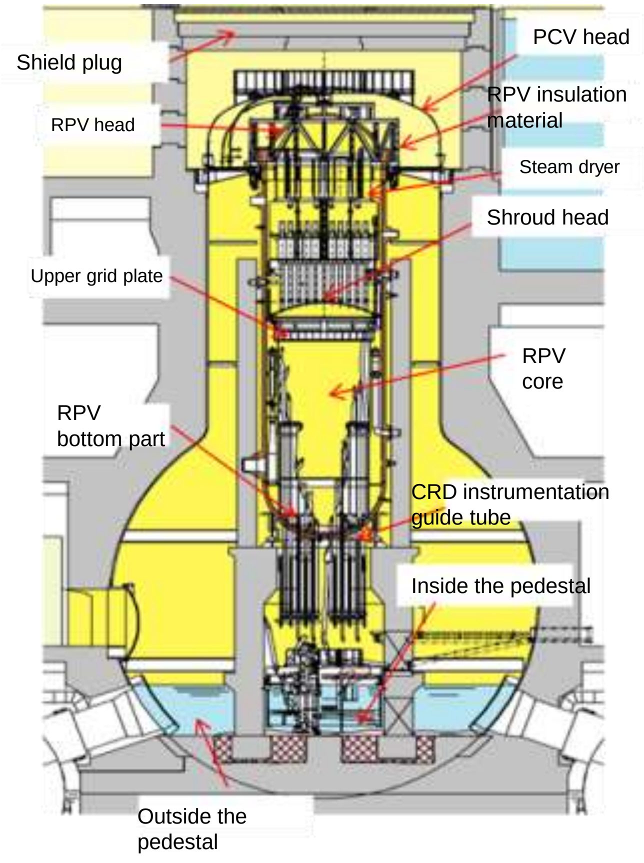
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Information on fuel debris distribution and characteristics in Unit 1 are under review to find specific fuel debris properties and volume.



No.	Position of distribution	Characteristics	General state	Features	Mass [t]	Debris properties	
					MAAP	Size	Composition
1	RPV core	Fuel rod stubs	All fuel assemblies may have melted down, but some could remain	Some fuel assemblies remain without melting down	0-3	4 m or less	Fuel: UO_2 Cladding: Zry-2
		Powdery, Grained	Adhered to or stacked on residual structures	Molten core materials are rapidly cooled down into small pieces		A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
2	RPV bottom part	Powdery, Grained	Most of the debris in this area consists of crust	Molten core materials are rapidly cooled down into small pieces	7-20	A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Lumps form	Crust contains Zr alloy and ZrB and partially rigid and tough	Slowly cooled to form lumps		Thickness A few dozen cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Crust (bedrock)		Debris formed by mixed and solidified molten metals and oxide fuel		Thickness 0.1-1 m	$(U,Zr)O_2$, $(Zr,U)O_2$ $Zr(O)$,Fe
3	CRD/instrumentation guide tube	Structure and adhered debris	Debris adhered in gaps inside and on the outer surface of tubes	Debris clogged the flow passage of lower SUS tubes from the bottom end of the pressure vessel		Penetration depth 10 and a few cm	$(U,Zr)O_2$, $(Zr,U)O_2$, SUS
4	Inside Pedestal	MCCI/powdery Grained	The debris forms multiple layers; most are likely to consist of MCCI debris lumps Large amounts of brittle debris with high porosity accumulated	Molten reactor core materials leaked out of RPV, dispersed, and quenched Crust fractured during MCCI and broken into small fragments due to ejection of molten corium	120-209	50 μm - 20cm	$(U,Zr)O_2$, $(U,Zr)SiO_2$
		MCCI Crust		Ejected materials containing metal components adhere to the wall surface. Debris on the floor has a hollow structure, and the crust in the upper part is porous, with fewer metal components.		Thickness 0.1-1 m	$(U,Zr)O_2$, $(U,Zr)SiO_2$,SiO_2
		MCCI in lump form		Upper part consists of rigid corium with high porosity Lower part is rigid with a low porosity Metallic balls are in the central area and near the wall		A few dozen cm or more	$(U,Zr)O_2$, $(U,Zr)SiO_2$,SiO_2
		Metal layer		Debris distributed relatively uniformly in the bottom of the MCCI		Under study	Fe, $FeSiO_2$ Fe-Zr
5	Outside Pedestal	MCCI/powdery Grained	The layer separation inside the pedestal is unclear; there is a crust and MCCI in a lumpy form.	Grainy debris has leaked from the pedestal	70-153	50 μm - 20cm	$(U,Zr)O_2$, $(U,Zr)SiO_2$
		MCCI Crust/lump MCCI debris		Corium leaked from the pedestal reacted with the concrete and solidified Slightly rich in metal component		0.5 m or less	$(U,Zr)O_2$, $(U,Zr)SiO_2$,SiO_2 $FeSiO_2$

6. Implementation Details

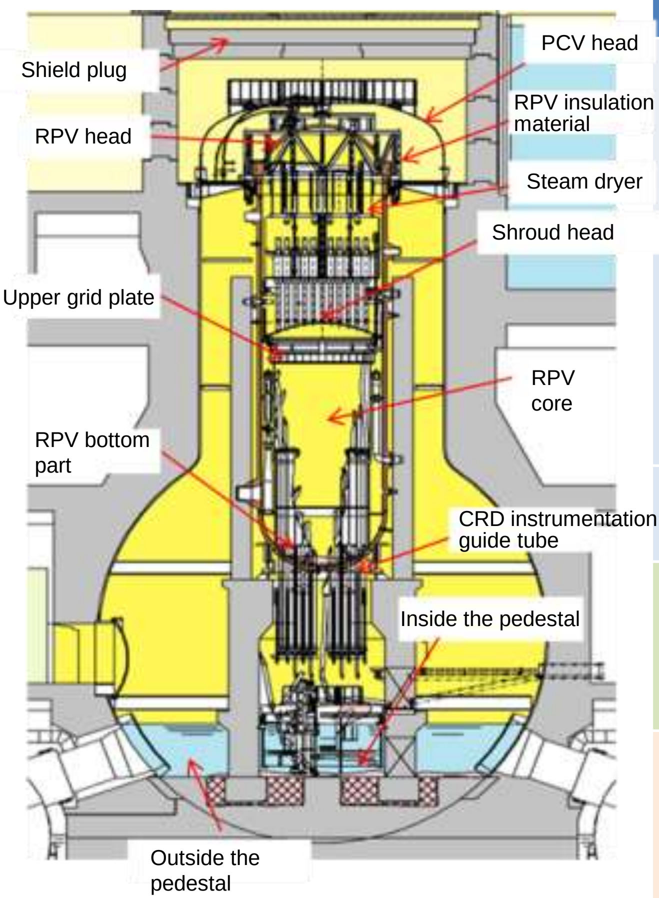
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Data on fuel debris distribution and properties in Unit 2 are under review to identify specific fuel debris properties and volumes.



No.	Position of distribution	Characteristics	General state	Features	Mass [t]	Debris properties	
					MAAP	Size	Composition
1	RPV core	Fuel rod stubs	Fuel assemblies remain in the reactor core periphery	Upper fuel assemblies in the reactor core periphery have melted down, and a few fuel pellets remain there The molten material is 25% metal components	0-51	4 m or less	UO_2, ZrO_2, $(U,Zr)O_2$, Zr(O)
		Powdery, Grained	Adhered to or stacked on residual structures	Molten core materials are rapidly cooled down into small pieces		A few µm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
2	RPV bottom part	Powdery, Grained	Debris exists in the center of the RPV bottom. The main component of the debris is estimated to be UO_2 (Some debris forms a pellet) Some CRGT remained without melting	Molten core materials are rapidly cooled down into small pieces	25-85	A few µm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Lumps form		Slowly cooled to form lumps		Thickness A few dozen cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Crust (bedrock)		Debris formed by mixed and solidified molten metals and oxide fuel		Thickness 0.1-1 m	$(U,Zr)O_2$, $(Zr,U)O_2$ Zr(O),Fe
3	CRD/instrumentation guide tube	Piping	Debris adhered in gaps inside and on the outer surface of tubes	Debris clogged the flow passage of lower SUS tubes from the bottom end of the pressure vessel		Penetration depth 10 and a few cm	$(U,Zr)O_2$, $(Zr,U)O_2$, SUS
4	Inside Pedestal	Powdery, Grained	Because of early water injection, most of the molten debris solidified without forming MCCI There may be MCCI is in the sump pit	Molten reactor core materials leaked out of RPV, dispersed, and quenched Shows little reaction with concrete	102-223	50 µm - 20cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe
		Lumps form		Solidified debris in lump form is distributed uniformly There may be MCCI in the sump pit		Thickness 15 cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$
5	Outside Pedestal	Powdery, Grained	Solidified debris leaked from the pedestal Most is powdery or grainy	Grainy debris has leaked from the pedestal	3-142	50 µm - 20cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe
		Lumps form		Corium leaked from the pedestal reacted with the concrete and solidified Slightly rich in metal component		Penetration depth 0.25m or less	UO_2, Zr(O) $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$

6. Implementation Details

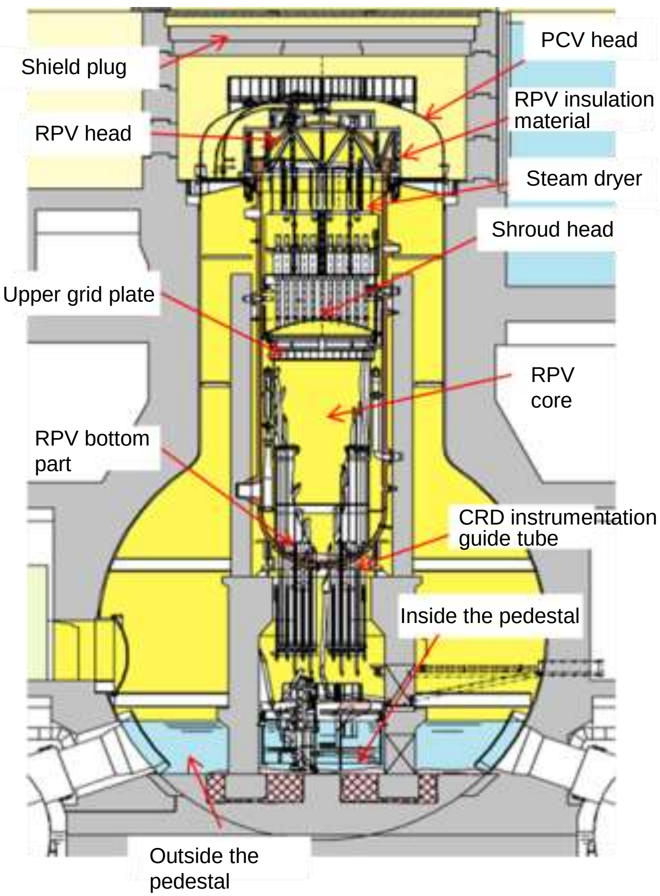
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Information on fuel debris distribution and characteristics in Unit 3 are under review to identify specific fuel debris properties and volume.



No.	Position of distribution	Characteristics	General state	Features	Mass [t]	Debris properties	
					MAAP	Size	Composition
1	RPV core	Fuel rod stubs	Almost all the fuel melted down, and some undamaged fuel assemblies remain in the reactor core periphery. (MAAP)	The top part of fuel assemblies in the reactor core periphery melted down, and a few fuel pellets remain there	0-31	4 m or less	UO_2, ZrO_2, $(U,Zr)O_2$, $Zr(O)$
		Powdery, Grained	Adhered to or stacked on residual structures	Molten core materials are rapidly cooled down into small pieces		A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
2	RPV bottom part	Powdery, Grained	Both the MAAP and the SAMPSON code indicate small amounts of debris in the lower plenum	Molten core materials are rapidly cooled down into small pieces	21-79	A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Lumps form		Slowly cooled to form lumps		Thickness A few dozen cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Crust (bedrock)		Debris formed by mixed and solidified molten metals and oxide fuel		Thickness 0.1-1 m	$(U,Zr)O_2$, $(Zr,U)O_2$ $Zr(O)$,Fe
3	CRD/instrumentation guide tube	Piping	Debris adhered in gaps inside and on the outer surface of tubes	Debris clogged the flow passage of the lower SUS tubes from the top end of the pressure vessel		Penetration depth 10 and a few cm	$(U,Zr)O_2$, $(Zr,U)O_2$, SUS
4	Inside Pedestal	Powdery, Grained	Because of early water injection, most of the molten debris solidified without forming MCCI There may be MCCI is in the sump pit	Molten reactor core materials leaked out of RPV, dispersed, and quenched Shows little reaction with concrete	92-277	A few μm - a few cm	UO_2, $Zr(O)$ $(U,Zr)O_2$, Fe
		Lumps form		Solidified debris in lump form is distributed uniformly There may be MCCI in the sump pit		Thickness 15 cm	UO_2, $Zr(O)$ $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$
5	Outside Pedestal	Powdery, Grained	Solidified debris leaked from the pedestal Most is powdery or grainy	Grainy debris has leaked from the pedestal	0-146	50 μm - 20cm	UO_2, $Zr(O)$ $(U,Zr)O_2$, Fe
		Lumps form		Corium leaked from the pedestal reacted with the concrete and solidified Slightly rich in metal component		Penetration depth 0.20 m or less	UO_2, $Zr(O)$ $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

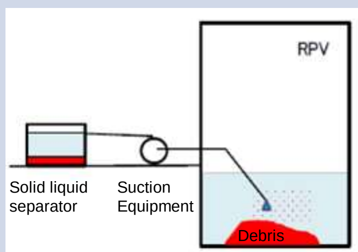
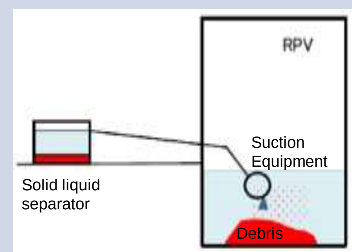
[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Clarification of preconditions to achieving the suction of debris

During pre-staging, before starting detailed studies of a suction and collection system for powder and particle debris, the preconditions for debris suction were set as follows:

[1] Diameter of collected debris	⌀0.1-⌀10 mm
[2] Specific gravity of sucked debris	Specific gravity: 2-11
[3] Debris suction velocity	2 m/sec
[4] Debris suction lift	Approx. 5 m: Unit2 is assumed on the maintenance side
[5] System installation place	Considering footprint, equipment exchange, and maintainability

	Direct suction on bottom surface		Suction of debris with water	
Image				
Applicability/ Remarks	[A]	• Minimum footprint on robot arm • The maximum load capacity of robot arms won't be affected by the suction head	Somewhat Applicable	• Difficulty in carrying the pump in PCV (Difficulty in repair work in case of failure) • The maximum load capacity of robot arms may need to be increased

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Study on method of collecting debris by suction

During pre-staging, before starting detailed studies of a suction and collection system for powder and particle debris, technology mapping was performed on applicable equipment (such as filter systems and pumps).

The filter technology mapping is performed with focus on:
[1] Separation method using difference in specific gravity
[2] Separation method using difference in particle size
[3] Separation method using chemical properties, and other methods

As with the filter, the following types of pumps are focused on individually in the technology mapping of the pump:
[1] Non-positive-displacement pumps (turbine type)
[2] Positive-displacement pumps
[3] Other pumps

6. Implementation Details

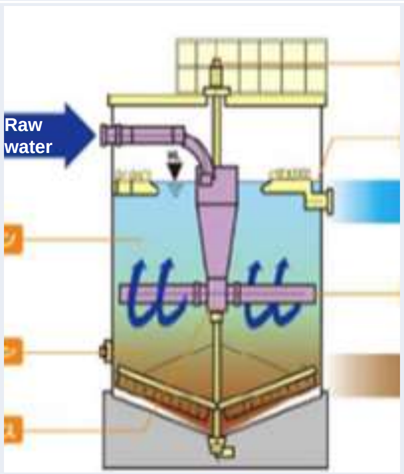
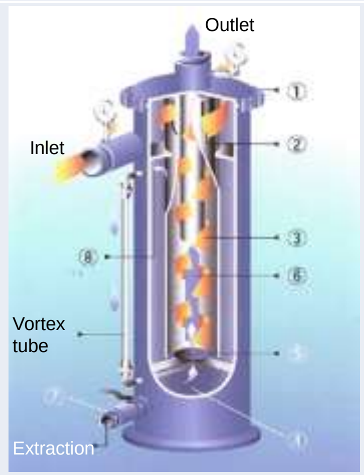
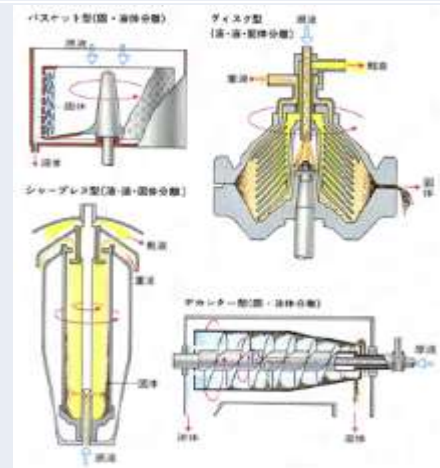
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Filter technology mapping: [1] Gravity filtration

Type	Sedimentation separator	Liquid Cyclone	Centrifugal separator (spin-dryer)
Principles and Features	A type of separator that allows particles to settle out due to differences in specific gravity between particles and liquid in the tank containing stagnant water and discharges supernatant liquid as processed water. The tank may have an additional structure in it to increase separation efficiency. The advantage of this type is its wide range of applicable particle sizes. A flocculating agent is often added to facilitate particle sedimentation.	A type of separator that causes swirl flow of fluid that flows in it so that particles in the fluid are separated by centrifugal force. It has a simple structure. The separation efficiency is higher with large specific gravity.	A type of separator that turns a rotor at a high speed so that particles contained in the liquid are separated from the liquid by centrifugal force. The structure, such as the mechanism to discharge particles, tends to be complex.
Schematic Drawing			
Major application	This method is widely used to treat drinking water, sewage, and general industrial wastewater to separate SS (suspended solids).	This method is used to treat general industrial wastewater and is now being used to treat sewage (as an alternative for the primary sedimentation tank).	Used in production facilities for solid-liquid separation.
Applicability/ Remarks	Somewhat Applicable: Secondary wastes increase because of the flocculating agent. Low maintainability due to many drives.	[A]: High maintainability with less drives	Not Applicable: Structure is complex with many moving parts. Low maintainability.

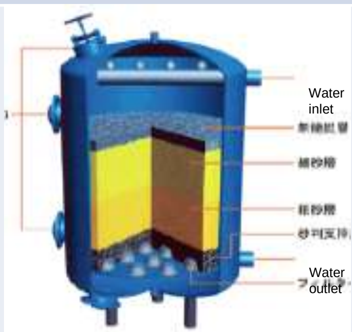
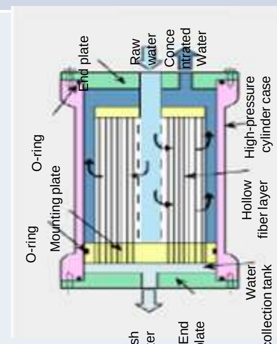
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Filter technology mapping: [2] Particle size filtration

Type	Sand filter/media filter	Auto strainer	MF/UF membrane filtration	RO membrane filtration
Principles and Features	Raw water is run through a tank filled with filler material, and the filler material mesh captures particles contained in the raw water. The captured particles are detached from the filler material and collected by backwashing. High pressure water filters are also included in this type. The equipment is called Sand Filtration Tower if the filler is sand or anthracite, or it is called the Media Filter if the filler is polymer material.	Swirl flow is caused in a tank with an installed screen, and the particles are filtered when the cross flow caused by the swirl passes through the screen. The swirl flow washes the surface of the screen and prevents it from clogging. The particle sizes to be filtered can be changed by changing the mesh size of the screen.	Raw water is run through a porous membrane in one direction, and water that passes through the membrane is collected. Particles larger than the size of the aperture are blocked and filtered by the membrane. An organic and inorganic membrane are used.	Pressurized, raw water is run though a water-permeable membrane in one direction so that only water molecules can pass to the other side of the membrane. Thus, filtered water is collected. Dissolved molecules can be separated.
Schematic Drawing				
Major application	The sand filtration tower is widely used to treat drinking water, sewage, and general industrial wastewater to separate SS (of low concentration).	It is used in the seawater intake system at power plants. It is a proven application for a 1F stagnant water treatment system.	A filtering system with an organic membrane is used to treat general industrial wastewater and power plant wastewater. Inorganic membranes are applied to 1F (ALPS).	This system is widely used as a seawater desalination system. Applied to cooling water desalination system on 1F.
Applicability/ Remarks	**Somewhat Applicable** Contrary to fewer drives, secondary wastes increase due to media exchange.	**[A]** High maintainability with fewer drives.	**Somewhat Applicable** This system has fewer moving parts, and it can capture fine particles. The inorganic membrane provides radiation resistance.	**Not Applicable** This system has fewer moving parts, and it can capture fine particles (including ions). Particle filtration does not require this level of performance. If an organic membrane is used, radiation resistance may be insufficient.

6. Implementation Details

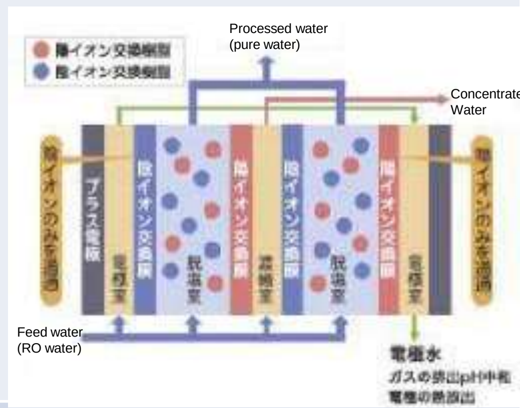
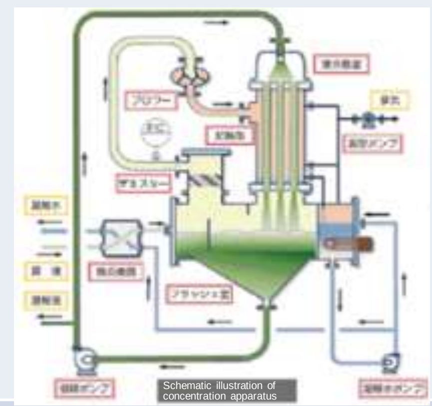
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Filter technology mapping: [3] Chemical filtration

Type	Adsorption Vessel	Electrodialysis	Evaporative concentration apparatus
Principles and Features	Raw water is run through a tower filled with adsorbent so that contents dissolved in the raw water, such as molecules and ions, are adsorbed and removed by chemical and electrochemical actions. Different types of adsorbents including, the following, are used depending on the process purpose: activated carbon (for organic materials), ion-exchange resin (for cation and anion), chelating resin (for heavy metals), zeolite (for cesium, etc.), and tannic acid.	Two electrodes are disposed on the both ends of a set of ion-exchange membranes inside the equipment. Voltage is applied to the electrodes so that raw water ions are moved, separated and concentrated.	Raw water is vaporized so that it is separated into clean distilled water and concentrated raw water. Atmospheric or vacuum vaporization methods may be used.
Schematic Drawing		 	
Major application	There are many application cases for feed water and wastewater treatment.	This method is used for the removal of acid and alkali from waste liquid.	This method is used for liquid waste treatment at nuclear power stations (including 1F of this station).
Applicability/ Remarks	**Not Applicable** Not suitable for particle filtration If material is soluble into ions, this method is applicable. Better maintainability because of less drives. Secondary wastes increase because the adsorbent needs to be exchanged periodically.	**Not Applicable** The structure is complex. In addition, the resistance to radiation may be insufficient because the dialysis membrane (separation membrane) is made of organic resin.	**Not Applicable** The evaporative concentration apparatus is provided primarily to separate soluble materials (separation into concentrated raw water and distilled water). This method is unsuitable for removing particles because they accumulate as sludge and reduce heat-transfer performance. If particles are water soluble, this method is applicable.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

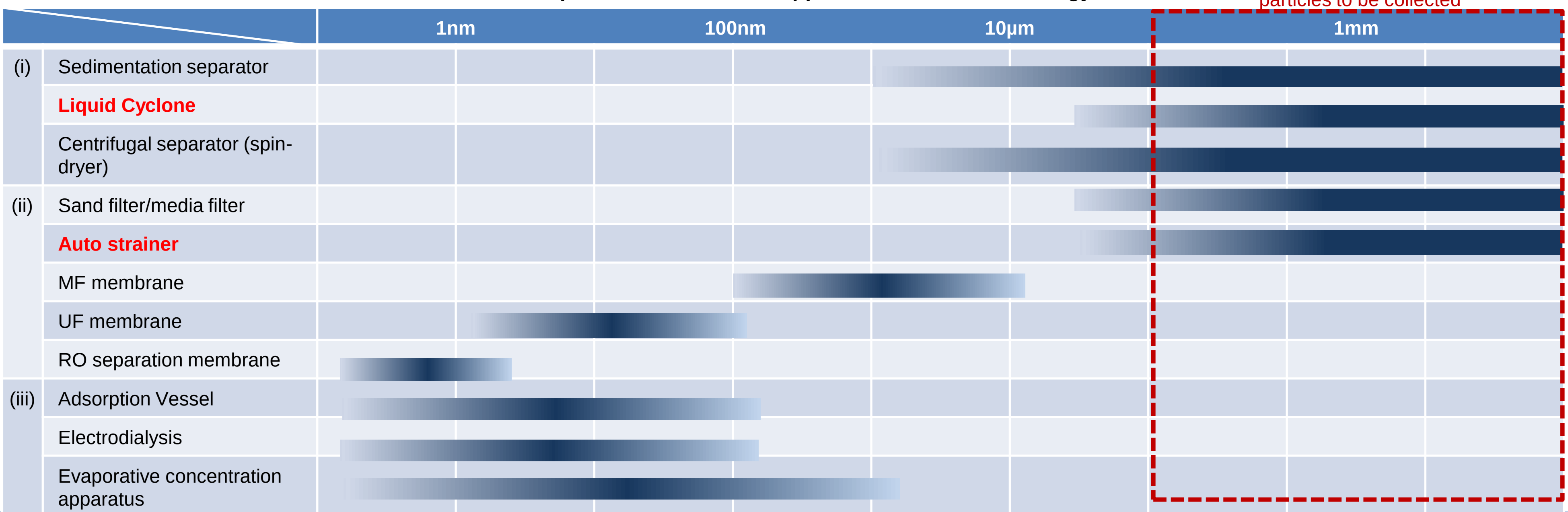
Filter technology mapping : [4] Summary

After applying the results of the studies above to the size of debris to be removed, the following guidelines are obtained:

- If a method using specific gravity differences is chosen, the cyclone-type solid-liquid separation method seems advantageous for particle filtration because of its high maintainability and high radiation resistance. For a method using particle sizes, the auto strainer appears promising.
- None of methods studied in the section of "Use of chemical properties and other principles" is suitable for removing particles.
- The auto strainer can be categorized in the same group as the cyclone-type solid-liquid separator because it uses swirl flow. In debris collection, a liquid cyclone separator should be studied.

Table Relation matrix between dust particle diameter and applicable removal technology

Preconditioned range of the diameters of particles to be collected



6. Implementation Details

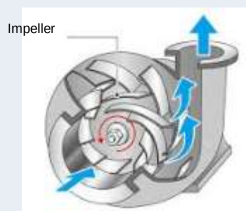
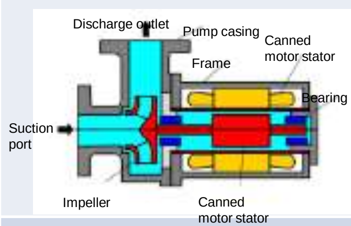
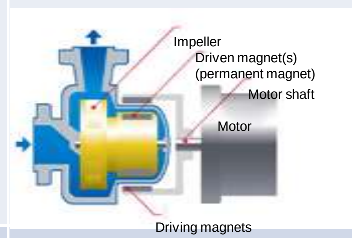
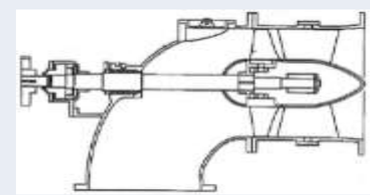
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Technology mapping for pumps: [1] Non-positive-displacement pump (turbine type)

Type	Centrifugal pump	Canned motor pump	Magnet pump	Axial-flow pump
Principles and Features	A type of non-positive-displacement pumps (turbo pumps). Fluid flows because the centrifugal force increases the pressure that the impeller rotation produces in the fluid. This is the most popularly manufactured pump.	A type of non-positive-displacement pumps (turbo pumps). An impeller and a rotor are packaged together in a single housing, like being canned (the name comes from this) so that it can eliminate leakage.	A type of non-positive-displacement pumps (turbo pumps). An impeller and a shaft with driven magnets are put together in a single container, and driving magnets rotate to cause the driven magnets to rotate, so that the impeller also rotates. Like canned motor pumps, no leakage is expected.	A type of non-positive-displacement pumps (turbo pumps). A type of pump that has an impeller is similar to a ship propeller in shape and rotates the impeller to produce thrust in fluid so that the fluid flows in the axial direction. This type of pump is often used for low-lift and high volume pumping compared to centrifugal (turbine) pumps.
Schematic Drawing				
Major application	This type of pump is widely used in a variety of applications, including conveying drinking water and sewage and as process pumps for chemical plants.	Because of the leakage elimination feature, this type of pump is used in fluid conveyance systems where fluid leakage must be prevented, such as in chemical plant systems. It can be designed to handle high pressure fluid compared to a magnet pump.	Because of the leakage elimination feature, this type of pump is used in fluid conveyance systems where fluid leakage must be prevented, such as in chemical plant systems.	This type of pump is often used for river drainage and agricultural irrigation systems because of its high-volume pumping capacity.
Applicability/ Remarks	**[A]** Different models with a variety of specifications are produced for this type of pump, including those used to move earth and sand in dredge work because of their high ability to convey irregular solid contents (of ⌀10 mm or larger) contained in fluid	**Somewhat Applicable** Low ability to convey irregular solid contents (⌀2 mm or so)	**Not Applicable** Fluid pressure cannot be increased much compared to a canned motor pump	**Not Applicable** This type of pump does not meet the debris retrieval system's high pump head and high pumping capacity requirement

6. Implementation Details

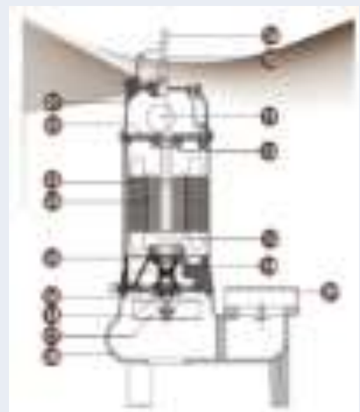
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Technology mapping for pumps: [1] Non-positive-displacement pump (turbine type)

Type	Hydro-turbo pump	Submersible pump	PAAC pump
Principles and Features	A type of non-positive-displacement pumps (turbo pumps). A pump driven by hydraulic pressure. It is designed for use in special conditions where a certain restriction exists, such as no electric power. This type of pump is submerged in the fluid to be pumped.	A type of non-positive-displacement pumps (turbo pumps). The submergible pump is a generic term for pumps equipped with waterproof motors and parts for underwater use. A centrifugal pump is used mostly. Some models are used for pumping sewage (agricultural wastewater and rain water) and water discharge at construction sites; some models can transfer irregular solid objects such as gravel in fluid.	A type of non-positive-displacement pumps (turbo pumps). While this type of pump does not adopt any notable principle, the integrated design of an impeller, shaft and supporting structure (MSU: mobile sub-unit) inside the casing is one of features making this assembly exchangeable from the motor side. In addition, there is an option that offers ability to exchange the assembly remotely.
Schematic Drawing			
Major application	This type of pump is used in food processing machines and explosion-proof environments.	This type of pump is for underwater operations in water treatment facilities, construction sites, and commercial facilities as well as households. This pump is advantageous in that it requires no installation space and its operation noise is lower because it operates underwater.	This type of pump is designed to convey radioactive fluid. It is used in reprocessing facilities.
Applicability/Remarks	Somewhat Applicable •Low ability to convey irregular solid contents (⌀6 mm) •Difficulty in carrying the pump in RPV	Somewhat Applicable •Difficulty in carrying the pump in RPV	Not Applicable •Low ability to convey irregular solid contents (⌀0.3 mm) •Difficulty in carrying the pump in RPV

6. Implementation Details

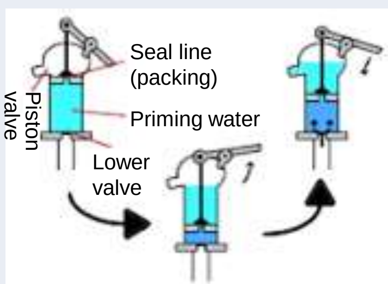
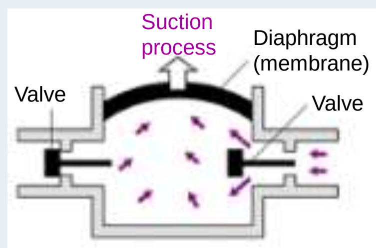
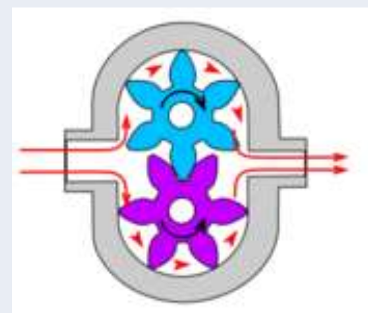
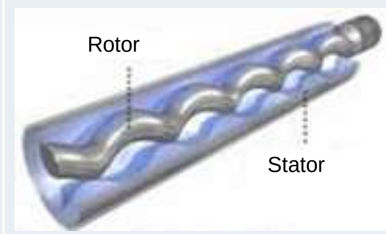
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. <u>Means and methods of collecting fuel debris (such as suction and grabbing)</u>

Technology mapping for pumps: [2] Positive-displacement pump

Type	Piston pump	Diaphragm pump	Gear pump	Mohno pump (screw pump)
Principles and Features	One of positive-displacement pumps. This type of pump conveys fluid by exerting pressure on the fluid to change the volume caused by the reciprocating movement of the piston.	One of positive-displacement pumps. This type of pump conveys fluid by exerting pressure on the fluid by changing in the volume of the diaphragm.	One of positive-displacement pumps. Gears that have design similar to an impeller rotate and engage to convey fluid.	One of positive-displacement pumps Fluid is conveyed by the force caused by changing the volume of gap (cavity) between the cylindrical casing (stator) and the spiral shaft (rotor). Such a change in the cavity volume is caused by the rotation of the rotor.
Schematic Drawing				
Major application	This type of pump is often used for applications where high pressure pumping is required because its discharge pressure can be set high.	Proven application in TMI. This type of pump has a self-suction capability and doesn't cause a problem in case of empty load operation. It can convey high viscosity fluids. It is often used for industrial, chemical, and sanitary applications.	This type of pump is suitable for conveying high viscosity fluids (such as oils) and often used in a hydraulic system.	This type of pump is often used for applications where high viscosity fluids are mainly handled, such as food materials (bean paste, syrup), chemicals (emulsion, solvents), environmental materials (polluted mud, powder activated carbon slurry), and paper-making materials (pulp).
Applicability/ Remarks	**Not Applicable** High-pressure pumping is not what the fuel debris retrieval system demands.	**Somewhat Applicable** The self-suction capability of this pump is 4 m and short of 5 m.	**Not Applicable** Low ability to convey irregular solid contents	**Not Applicable** Low ability to convey irregular solid contents

6. Implementation Details

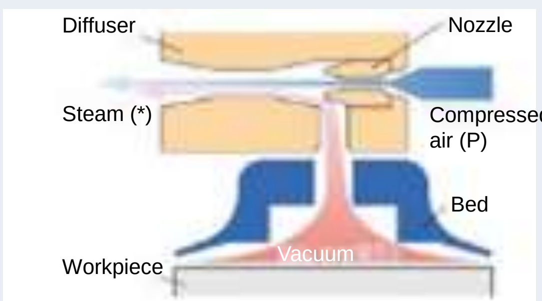
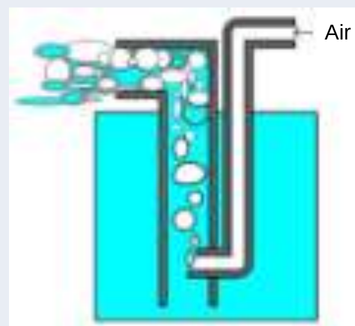
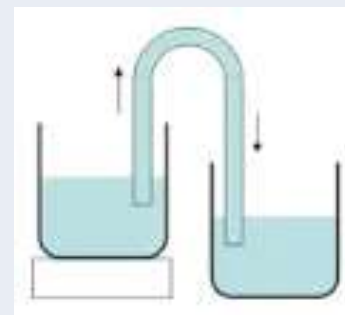
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Pump technology mapping: [3] Other pumps

Type	Ejector/vacuum pump	Airlift pump	Siphon method
Principles and Features	This type of pump is categorized in a special pump group. It has a driving fluid inlet port, a driven fluid inlet port, and a discharge port. The driving fluid injected from its inlet port causes negative pressure, so the driven fluid is aspirated through its inlet port. Both the injected driving fluid and the aspirated driven fluid are expelled from the discharge port together. In such a way, the driven fluid is conveyed. This kind of pump has a low failure rate because it has no active component, but its energy efficiency is lower than other mechanical pumps.	This type of pump is categorized in a special pump group. Compressed air is injected into a tube disposed in a fluid vertically near its bottom end so that difference in specific gravity occurs in the fluid between the inside and outside of the tube. Air bubbles occur and rise along the tube; the rising bubbles cause the fluid to be sucked from the opening of the tube at the bottom end. This type has low failure rate because of no active component but a low pump head because of driving force relying on only rising bubbles.	It may not be accurate to call this method a pump. This method relies on the principle that a fluid flows from the start point to the end point continuously, without pumping, as long as the start point is higher than the end point. This principle applies even if a passage connecting the two points runs through an even higher position than the start point, provided the passage is made of a tube with no hole, and the tube is filled with the fluid all the time.
Schematic Drawing			
Major application	This type of pump is often used for applications where vacuum is required, such as deairing, defoaming, and distilling.	Proven application in TMI. This type of pump is often used to convey removed soil at dredging work sites, to pump hot well water, and so on.	Waterworks
Applicability /Remarks	**Somewhat Applicable** • High maintainability with low failure rate. • Compact size and high ability to handle irregular solid contents.	**Somewhat Applicable** ・The fluid driving force may be insufficient since the water depth at the concerned unit is not as much as that at TMI. ・It will be difficult to install this type of pump because 1F is narrow.	**Not Applicable** ・No restriction on acceptable irregular solid contents. ・No active component ・Large scale facility

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

Pump technology mapping: [4] Summary

- In the non-positive-displacement pump (turbine type) category, a centrifugal pump seems advantageous because it can convey irregular solid contents.
- Although a diaphragm pump is promising in the positive-displacement pump category, its pump head does not meet the 5 m requirement set in the preconditions.
- The centrifugal pump type is selected as a primary candidate because it meets preconditions. Further study towards actual design will be implemented based on this decision. As an alternative, application of other type, such as a submergible or vacuum pump, should also be studied.

Table - Debris Suction Pump Evaluation (showing [B] or higher ratings from technology mapping)

		Acceptable size of irregular solid contents (⌀10 mm or more)	Suction pump (5 m and higher)	Possibility to carry in PCV	Evaluation results
(i)	Centrifugal pump	[A]	[A]	[A] (Only hose)	[A] Required specifications of a pump set in the preconditions
	Canned motor pump	Somewhat Applicable (⌀2 mm)	[A]	[A] (Only hose)	[B] Applicable depending on debris diameter.
	Hydro-turbo pump	Somewhat Applicable (⌀6 mm)	-	Not Applicable	[B] Applicable depending on debris diameter. Also applicable if the PCV can be carried in. However, difficulty anticipated in maintenance in the PCV.
	Submersible pump	[A]	-	Somewhat Applicable	[B] Applicable if the PCV can be carried in. However, difficulty anticipated in maintenance in the PCV.
(ii)	Diaphragm pump	[A]	Somewhat Applicable (4m)	[A] (Only hose)	[B] Applicable depending on suction pump. Pulsation requires attention.
(iii)	Ejector vacuum pump	[A]	[A]	Somewhat Applicable	[B] Applicable if the PCV can be carried in.

6. Implementation Details

6.2. Implementation Details

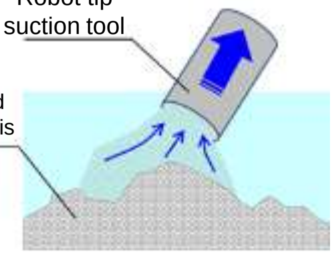
1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

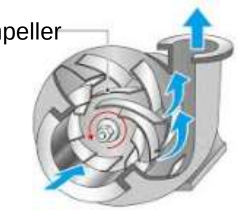
a. Means and methods of collecting fuel debris (such as suction and grab)

○ Example of specific method of collecting powder debris by suction

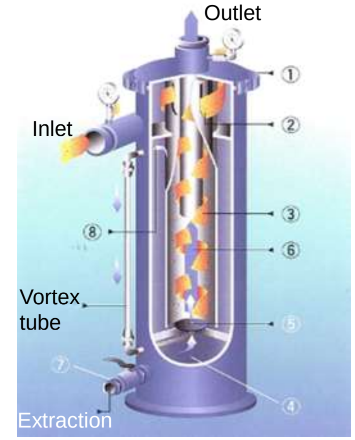
- A suction and collection system for powder debris, combined with each assumed component, is under study for specification
- The study scope will involve a mechanism to suck power-form debris in the PCV, separate and collect powder debris, package the canister, and carry it out.
- Identify future issues from the assumed suction and collection system for powder debris.



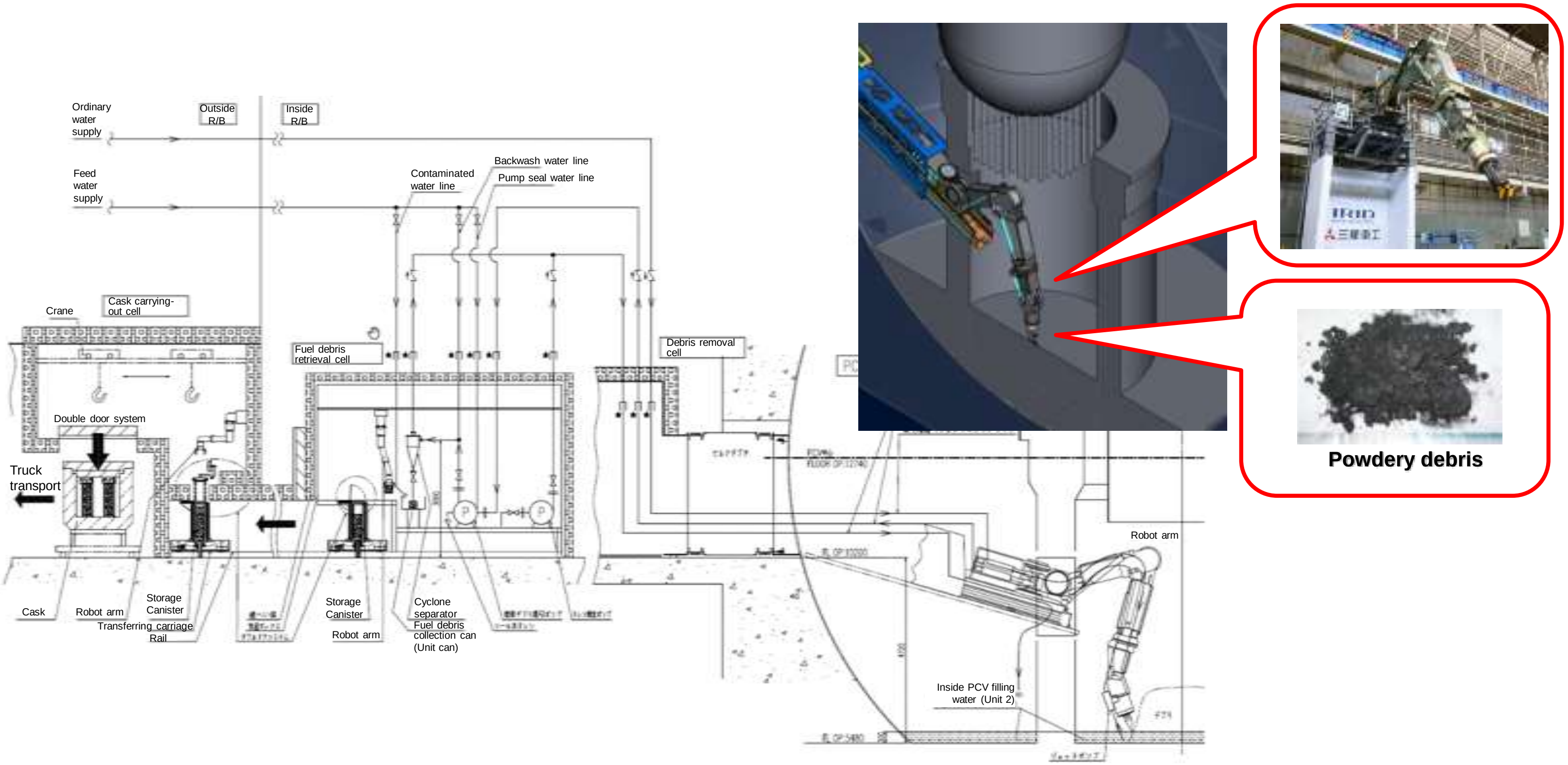
Conceptual drawing of a powder debris retrieval system



Debris suction pump (centrifugal pump)



Debris separator (cyclone-type separator)



6. Implementation Details

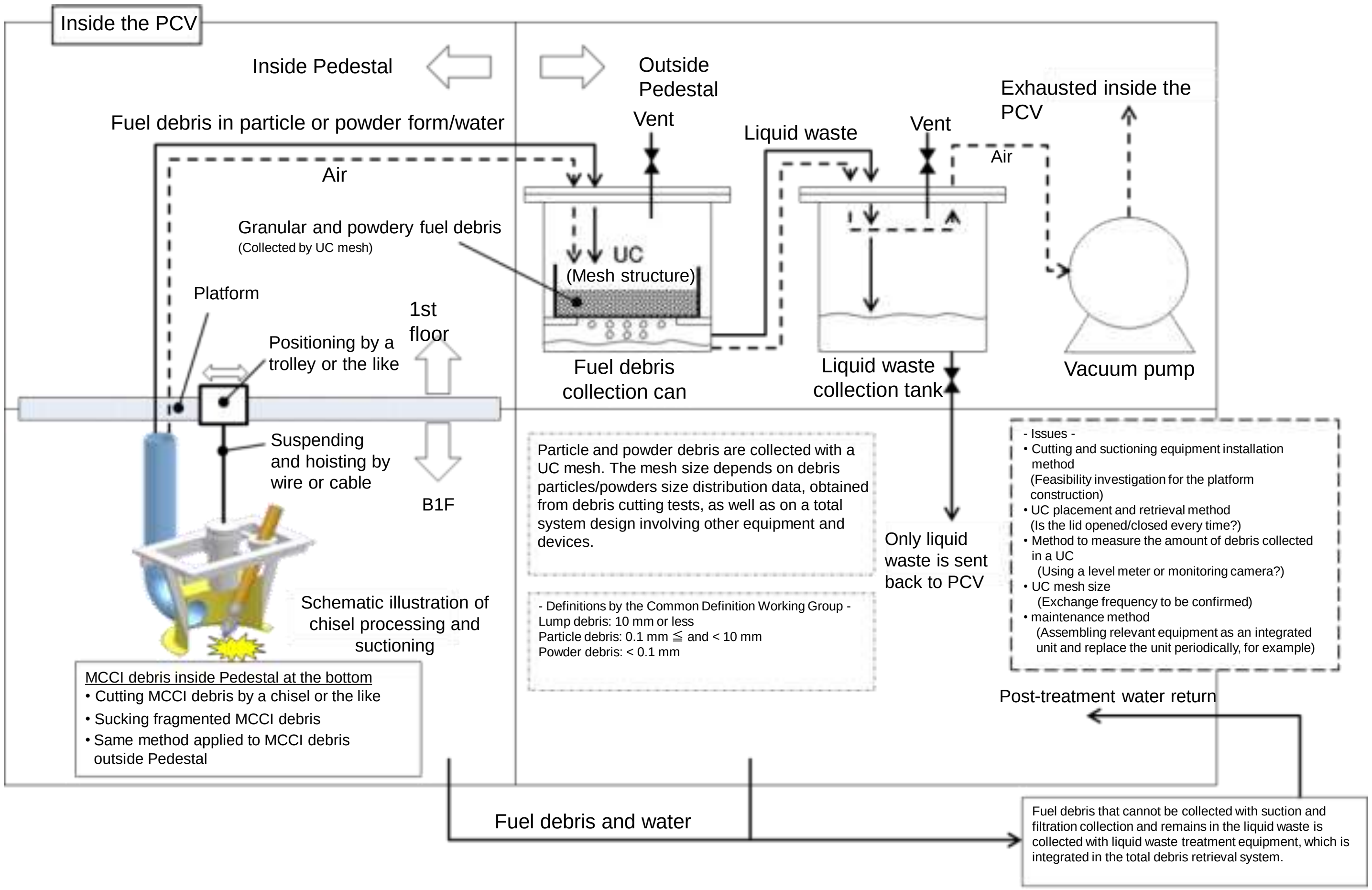
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

a. Means and methods of collecting fuel debris (such as suction and grabbing)

○ Example clarifying the granular debris suction and collection method



6. Implementation Details

6.2. Implementation Details

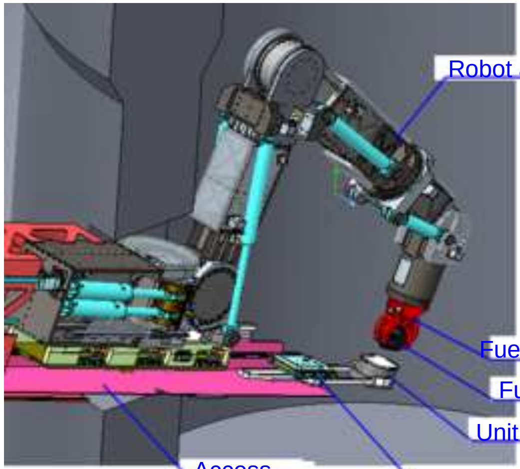
1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

b. Method to store fuel debris in unit can

○ Study of methods of grabbing debris and collecting them into the unit can

- Work procedures to grab cutout debris and put it in the unit, and a mechanism, are under consideration.
- Studying fuel debris processing methods, larger lump debris should be grabbed, and smaller lump debris should be scooped.
- Methods to control the appropriate amount of debris in the unit can is also under consideration.

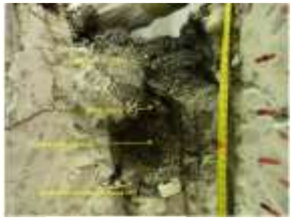


Examples of debris collection tools

Grained debris

Powdery debris

Crust



MCCI in lump form

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

c. <u>Fluid control method for fuel debris (such as dewatering or desiccation)</u>

- In the project for development of technology for collection, transfer and storage of fuel debris, the effects of residual fluid in fuel debris and in the canister are under in terms of sub-criticality, prevention of hydrogen explosion caused by hydrogen generation accompanying radiolysis of fluid (by reducing hydrogen generation), and corrosion control, etc.
- The conceptual study of the fluid control system will be started after discussion and coordination of fluid control method requirements.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

d. Method to store unit cans in canister and to transfer them

○ Assumed specifications of the unit can and the canister

- In the early stage of fuel debris retrieval, a canister of ⌀210 mm is assumed to be used to prevent fuel debris criticality because the debris characteristics are not yet known.
- Accordingly, methods to collect and transfer debris are studied based on the use of the unit can of ⌀ 210 mm first.
- In addition, the use of ⌀400 mm unit can is also considered based on the possibility that the size may be adopted to increase the throughput of retrieval work if the possibility fuel debris criticality is eliminated in the future.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

d. Method to store unit cans in canister and to transfer them

○ Handling of unit cans and canisters

- Unit can: Handled in high-level contaminated areas.
- Canister: Handled in mid-level contaminated areas.
- Cask: Handled in low-level contaminated areas.

○ Issues for carrying-out of unit cans and canisters

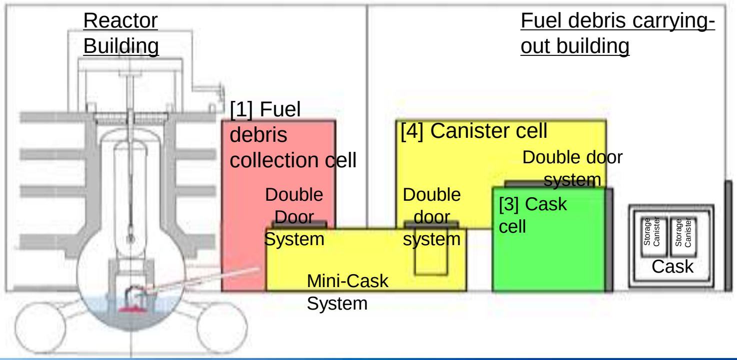
- Fuel debris contains nuclear materials. In the fuel debris retrieval project, a large amount of fuel debris needs to be handled must be transported repeatedly for a long period. Therefore, it is essential to prevent the spread of contaminants that may occur during the debris retrieval process as much as possible (otherwise, contaminants accumulate and spread).
- When the canister is brought in a highly contaminated area to put unit cans into it, there is a risk of contaminants attaching to the canister surface.
- Similarly, there is a risk of contaminating the cask surface when the cask is brought in a mid-level contaminated area to put the canister in it.

To move unit cans/canisters across contaminated areas:

- The contamination level of each unit can/canister's surface must be measured to ensure the outsides are not contaminated.
- If the surface is contaminated, it must be decontaminated to a permissible level.

If monitoring and decontaminating the surface is not implemented, the contamination level in the cells continuously increases, which increases the radiation dose that workers receive during maintenance work.

Monitoring and decontamination of surface contamination is very time-consuming work and reduces throughput significantly



(red)	High-level contaminated area:	Areas where fuel debris and wastes are handled directly.
(yellow)	Mid-level contaminated area:	Areas where fuel debris is contained in the canister and handled indirectly. Or areas directly connected to a high-level contaminated area.
(green)	Low-level contaminated area:	Fuel debris is contained in a sealed container and handled indirectly.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

d. Method to store unit cans in canister and to transfer them

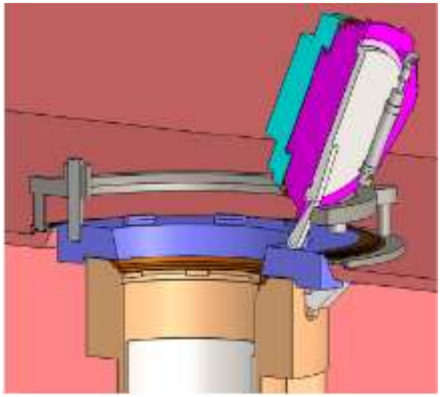
Methods to store unit cans in the canister and to transport the canister outside the reactor building are being studied with consideration of the following requirements:

- The spread of contaminants that may occur in each step of the fuel retrieval process must be minimized.
- Debris and debris containers must be transferred swiftly and efficiently to increase throughput.

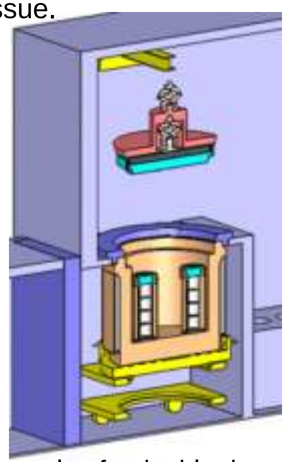
Study example: Double door

By adopting a double door system, the following effects are expected:

- The double-door system adopted to the canister and cask design eliminates the need to carry those containers into a high-contamination area when packing unit cans in the canister and the canister in the cask.
- Risk of contaminant spread is reduced since fuel debris is carried out in sealed containers.
- Throughput increases because surface contamination monitoring and decontamination work can be decreased.
- The remote maintenance of the double door will be an issue.



Example of a double door adopted to the canister



Example of a double door adopted to the cask

6. Implementation Details

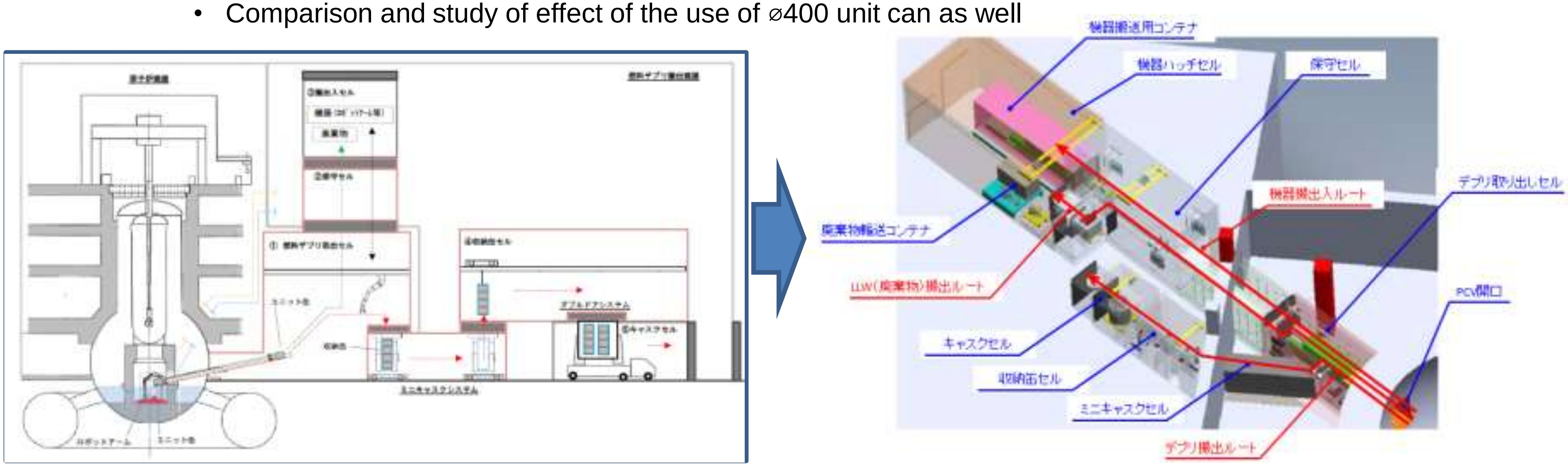
6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

d. Method to store unit cans in canister and to transfer them

- Processes required for unit cans and canisters are listed above.
  - Those processes include unit can transfer, criticality condition measurements, contamination level measurements, unit can storage, and canister transfer
- Identify specific transport equipment required for transporting unit cans
  - The equipment includes cranes, transfer carriages, shielding doors, double doors, and decontamination equipment
- Identify a specific transport process for units can and canisters and deploy it in the installation layout
- The process time will be calculated for each transport step of unit cans and canisters, and throughput for the entire debris retrieval process will be calculated based on the each calculation result as a final outcome
  - Improvement of throughput will also be studied
  - Comparison and study of effect of the use of ⌀400 unit can as well



6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

Cutting methods whose cutting performance data are available through cutting performance test results, including cutting tests of fuel debris simulant ceramics, metal-concrete mixtures, and contaminated structures, will be subjected to cutting performance tests to obtain data, including the amount and particle size distribution of chips generated by those methods. In addition, dust collection systems will be developed to match the cutting methods developed through the above-mentioned activities, and dust collection efficiency data from the developed dust collection systems, with chips and dust generated by these methods will be obtained by tests.

a. Listing of possibly effective processing and cutting methods with consideration of fuel debris characteristics and study of the listed methods

- The review and study of processing and cutting methods that match different fuel debris characteristics is ongoing.
- Effective processing methods will be selected based on the study results.

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

- A processing elements test for chisel processing and ultrasonic core boring are planned.

c. Producing a test facility simulating fuel debris and contaminated structures used for processing tests

- Specifications of simulated fuel debris and contaminated structures used in processing element tests are under study.

d. Study and analysis of dust collection systems used for chips and dust generated during cutting work

- The local dust collection system used to collect chips and dust produced in cutting and processing is under consideration as a measure to prevent fuel debris diffusion.
- Methods to collect chips and dust generated during element tests for cutting methods, and to analyze the collected chips and dust, will be coordinated from now.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

- **Purpose of development**
  - To obtain data necessary to analyze the advantages and disadvantages of processing technologies applicable to fuel debris processing.
    - ✓ Cutting performance (such as cutting speed) and the amounts of chips and dust produced
    - ✓ Development of a dust collection system

- **Development approach**
  - Conceptual study of potentially effective processing and cutting methods with consideration of fuel debris characteristics
  - Selection of a MCCI test facility to be processed (for example, ceramics, metal-concrete mixtures, or contaminated structures)
  - Cutting performance tests (to obtain data, including the amount and particle size distribution of chips and dust generated by cutting work)
  - Development of a dust collection system (including data collection concerning the efficiency of the system to collect the chips and dust generated)

- **Expected results**
  - Determination of processing and cutting methods, each of which fit with different fuel debris characteristics.
  - Cutting performance data to estimate throughput.
  - Study result of local collection system (chips and dust spread prevention).
  - Analyzing results of particle size distribution in processing liquid waste.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

- **Issues to be resolved (essential factors in selecting fuel debris cutting technologies)**

	Requirements	Essential factors in the selection of fuel debris cutting technologies
Safety Requirements *1	Prevent abnormal generation of radioactive materials caused by nuclear reactions	(There is no comparative data since every cutting method entails a risk)
	Prevention of the emission of radioactive materials due to abnormal temperature rise in fuel debris	Input heat input to fuel debris shall be small. (Especially, further assessment is required for thermal processing methods)
	Prevention of abnormal diffusion of radioactive materials caused by cutting fuel debris and structures	Fewer fumes (powders, fine particles, etc.) shall be emitted to the atmosphere.
		Fewer chips and powders shall be emitted underwater.
Task requirements	The method must be capable of processing various types of fuel debris, such as fuel assemblies, including fuel pellets and fuel claddings, reactor internals, pressure vessels, and concrete	The method should not be affected by fuel debris characteristics, such as electric conductivity (conductive or non-conductive), mechanical properties (such as hardness), and thermal properties (melting point, boiling point)
	The time required to retrieve fuel debris must be minimized as much as possible	The processing speed must be high
	The cutting tool head must reach fuel debris lying in narrow areas inside the RPV and PCV	The processing device (especial its head or tip) shall be small
	Little impact on the plant operation systems and infrastructure	Minimum demand of assist gas and other utilities
		Less demand of water supply and less abrasive particles contained in AWJ
	High feasibility of work area	Fewer utilities required and minimum scale of auxiliary facilities
	Availability of technology	Technology can be currently available from a vendor.

*1: Requirements relevant only to fuel debris processing are excerpted from all safety requirements

- Promising processing methods are picked up based on essential selection factors, and element tests are performed for each method.
- Then, the line of processing technologies must be prepared for equipment design and adopted depending on the accessibility of debris locations.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

: methods that received good evaluation for fuel debris processing

a. **Listing of possibly effective processing and cutting methods with consideration of fuel debris characteristics and study of the listed methods**

	Applicable to various fuel debris	Processing speed	Access ability (small head)	Heat input	Fume generation (aerial diffusion)	Amount of chips generated (underwater diffusion)	Downsizing of utilities	Availability	Total evaluation /element tests
Core boring	[A]	Somewhat Applicable	[A]	[A]	[A]	Somewhat Applicable	[A]	[A]	[A] Finished
Disk saw	[A]	[A]	Somewhat Applicable	[A]	[A]	[A]	[A]	[A]	[A]
Wire saw	Somewhat Applicable	Somewhat Applicable	Not Applicable	[A]	[A]	[A]	[A]	[A]	
Hand saw	Somewhat Applicable	Somewhat Applicable	Not Applicable	[A]	[A]	[A]	[A]	[A]	
Ultrasonic core drill	Somewhat Applicable	Somewhat Applicable	[A]	[A]	[A]	Somewhat Applicable	[A]	[A]	[A] Not yet
Hydraulic cutter	Somewhat Applicable	[A]	[A]	[A]	[A]	Somewhat Applicable	[A]	[A]	[A]
Chisel	Somewhat Applicable	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A] Not yet
AWJ	Somewhat Applicable	Somewhat Applicable	[A]	[A]	[A]	Not Applicable	Not Applicable	[A]	[A] Finished
Laser gouging	[A]	Somewhat Applicable	[A]	Somewhat Applicable	[B]*1	Somewhat Applicable	Not Applicable	[A]	[A] Finished
Plasma arc	Not Applicable	Not Applicable	[A]	Somewhat Applicable	Not Applicable	Somewhat Applicable	Not Applicable	[A]	
Plasma jet	[A]	Somewhat Applicable	[A]	Somewhat Applicable	Not Applicable	Somewhat Applicable	Not Applicable	Not Applicable	
Gas	Not Applicable	Somewhat Applicable	[A]	Somewhat Applicable	Not Applicable	Somewhat Applicable	Somewhat Applicable	[A]	
Contact arc	Not Applicable	Not Applicable	[A]	Somewhat Applicable	Not Applicable	Somewhat Applicable	Somewhat Applicable	Somewh Applicab	
Arc saw	Not Applicable	Not Applicable	Not Applicable	Somewhat Applicable	Not Applicable	Somewhat Applicable	Somewhat Applicable	Somewh Applicab	
Consumable electrode WJ	Not Applicable	Not Applicable	[A]	Somewhat Applicable	Not Applicable	Somewhat Applicable	Not Applicable	Somewh Applicab	
Laser boring	[A]	Somewhat Applicable	[A]	[A]	Not Applicable	Somewhat Applicable	Not Applicable	Somewh Applicab	

*1: It was confirmed, based on the outcome of research activities in last fiscal year that the aerial diffusion of chips and dust generated by the laser gouging can be inhibited by washing the chips and dust by water flow, although the process is performed in the atmosphere.

Processing methods for which element tests have not yet been performed are subjected to assessment for selection in terms of the capability to process MCCI debris in the PCV bottom

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. <u>Processing element tests with fuel debris simulant by effective processing/cutting methods</u>

<u>(1) A processing element test with chisels</u>

- General information about chisel processing
    - A processing method to crush target materials by hitting them with a crushing bit attached to the front end of heavy machinery. It is used at civil engineering work sites.
    - This method is widely used.
    - Specifically, it is generally used to bore through bedrock, break rocks into small pieces, and crush concrete.
    - In FY2015-FY2016, preliminary tests to crush concrete blocks, using the combination of a muscular robot and chisel processing, were performed.

Concrete block crushing test by a chisel processing method

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(1) A processing element test with chisels

- Purpose of development
  - ➢ Verification of the chisel processing method's applicability to fuel debris retrieval.
    - ✓ Improvement of efficiency in collecting MCCI debris to about 90%.
    - ✓ Assessment of the feasibility of a high speed processing method applicable to MCCI debris.
    - ✓ Assessment of the feasibility of a dust collection technology applicable to chips and fragments generated by a chisel method.
    - ✓ Investigation of the characteristics of processing liquid waste that contains chips and fragments generated by a chisel method.
- Issues to be resolved
  - ➢ The target duration of the fuel debris retrieval project is 10 years, and fuel debris of 300 kg must be processed daily to achieve this target. However, existing processing methods cannot achieve this goal. Therefore, the feasibility of a high-speed processing method needs to be examined.
- Development approach
  - ➢ Evaluation items in FY2015-FY2016
    - ✓ Phase 1: Applicability evaluation through desk study
    - ✓ Phase 2: Implementation of preliminary tests
  - ➢ Evaluation items in this project
    - ✓ Phase 3: Conceptual study and element test planning
    - ✓ Phase 4: Manufacturing prototype units for testing and implementing element tests

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(1) A processing element test with chisels

- Expected results
  - Feasibility of basic processing methods applicable to MCCI debris
  - Throughput calculation.
  - Result of the size distribution of particles contained in MCCI processing liquid waste.
  - Issues concerning MCCI debris processing.

6. Implementation Details

6.2. Implementation Details

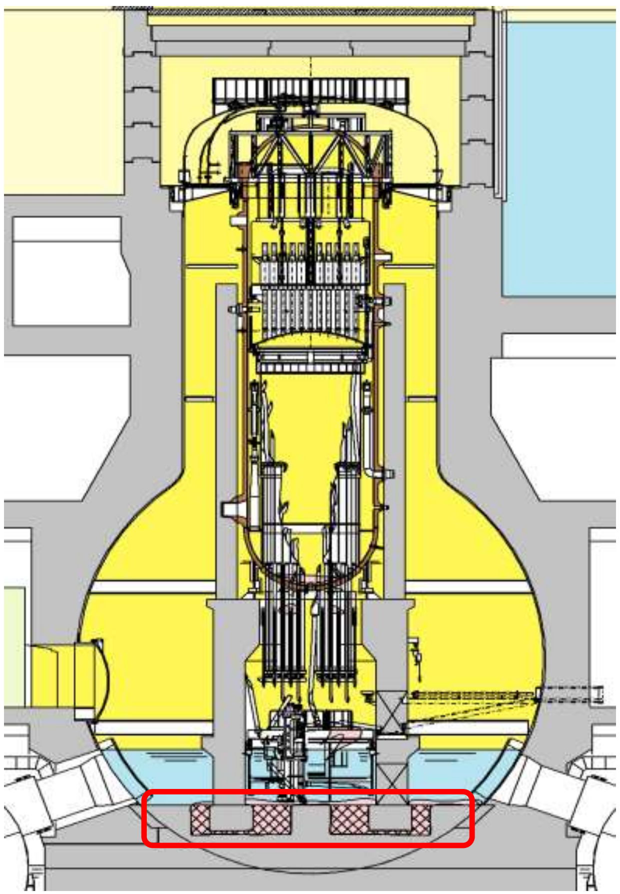
1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(1) A processing element test with chisels

Since relevant analysis results suggest that the chisel processing method is highly capable of handling MCCI debris that constitutes most of the fuel debris, element tests for this method were performed.



	Type of fuel debris	Major fuel debris	Features	Mass [t]	Fuel debris properties
				MAAP	Size
RPV core	Fuel rod stubs (unmolten fractured fuel)	All fuel assemblies may have melted down, but some could remain	Some fuel assemblies remain without melting down	0-3	4 m or less
	Powdery, Grained	Adhered to or stacked on residual structures	Molten core materials are rapidly cooled down into small pieces		A few μm - a few cm
RPV bottom part	Powdery, Grained	Most of the debris in this area consists of crust	Molten core materials are rapidly cooled down into small pieces	7-20	A few μm - a few cm
	Lumps form	Crust contains Zr alloy and ZrB and partially rigid and tough	Slowly cooled to form lumps		Thickness A few dozen cm
	Crust (bedrock)		Fuel debris formed by molten metals and oxide fuel mixing and solidifying		Thickness 0.1-1 m
CRD/instrumentation guide tube	Structure plus adhered fuel debris	Fuel debris attaching in gaps inside the tubes and on the outer surfaces	Fuel debris clogged the flow passage of lower SUS tubes from the bottom end of the pressure vessel		Penetration depth 10 and a few cm
Inside Pedestal	MCCI/powdery Grained	The debris forms multiple layers; most are likely to consist of MCCI debris lumps	Molten reactor core materials leaked out of RPV, dispersed, and quenched Crust fractured during MCCI and broken into small fragments due to ejection of molten corium	120-209	50 μm-20 cm
	MCCI Crust	Large amount of brittle, highly porous fuel debris accumulated	Ejected materials containing metal components adhere to the wall surface. Debris on the floor has a hollow structure, and the crust in the upper part is porous, with fewer metal components.		Thickness 0.1-1 m
	MCCI in lump form		Upper part consists of rigid corium with high porosity Lower part is rigid with a low porosity Metallic balls are in the central area and near the wall		A few dozen cm or more
	Metal layer		Debris distributed relatively uniformly in the bottom of the MCCI		Under study
Outside Pedestal	MCCI/powdery Grained	The layer separation inside the pedestal is unclear; there is a crust and MCCI in a lumpy form.	There exist grained fuel debris leaked from Pedestal	70-153	50 μm-20 cm
	MCCI Crust/lump MCCI debris		Corium leaked from the pedestal reacted with the concrete and solidified Slightly rich in metal component		0.5 m or less

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(1) A processing element test with chisels

Chisel processing was tested with the MCCI-simulating test facility (provided by Hitachi-GE Nuclear Energy).
Based on the preliminary test result, chisel processing tests and testing equipment are being planned.

No.	Type of chisel	Number of chisels	Processing scene/shape of chisel	Processing result status	Processing speed[*1]	Notes
1	Electrically driven unit	1			28.74 kg/h[*1] (287 kg/day[*1])	
2	Electrically driven unit	1			43.38kg/h[*1] (433 kg/day[*1])	
3	Air driven unit	2	 		255.576kg/h[*1] (2.5 tons/day[*1])	

*1: Data of a processing speed is for reference purposes only since these are preliminary test results with test blocks provided by a vendor. The target processing speed is 300 kg/day. Work time is 10 hours per day.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(2) A processing element test by ultrasonic core boring

- Purpose of development
  - A processing method with less reaction force and less dust diffusion need to be developed.
    - ✓ Features of ultrasonic core boring
      - The reaction force is smaller compared to a standard core boring. (A load of up to 1.5 tons was applied in the element test with a bit of ⌀66 mm performed last fiscal year)
      - Developed for a planetary exploration project. There are successful results for processing various types of hard materials.
      - Compact and lightweight
- Issues to be resolved
  - The applicability of ultrasonic core boring to fuel debris processing must be verified.
    - ✓ Workability (processing speed) of materials including metals (partly expected to be rigid)
    - ✓ Particle size distribution of secondary waste products contained in processing liquid waste
    - ✓ Robustness (in standard use, processing conditions such as type of bit and ultrasonic wave [or sound wave] is changed depending on the characteristics of materials to be processed. Applicability to fuel debris on 1F, whose characteristics are inferred to be heterogeneous, is not specific yet)
    - ✓ The bit shown in the photo on the right has a diameter of about 3 mm. The diameter of a core bit needs to be increased to increase processing speed.

6. Implementation Details

6.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(2) A processing element test by ultrasonic core boring

- Development approach
  - The development process is divided into three phases since applicability to fuel debris on 1F is uncertain.
    - ✓ Phase 1: Applicability evaluation and test planning through desk study
    - ✓ Phase 2: Applicability evaluation by element tests
    - ✓ Phase 3: Prototype tests
  - Before proceeding to the next phase, expert review is provided
- Expected results
  - Processing conditions and performance (processing speed) in processing various materials including metals -> Specification of throughput evaluation
  - Result of particle diameter distribution in processing liquid waste -> Result is input to System Project
  - Issues concerning processing -> Applicability to actual equipment on 1F/development issues

- Development goals
  - Processing speed
    - ✓ The final goal is to achieve a processing speed of 30 kg/hr or higher in the processing test with the test material that simulates MCCI debris in the Pedestal bottom.
    - ✓ The element tests conducted in Phase 2 will assess whether the final target speed or a higher speed can be attained.
  - Mass of processing tools
    - ✓ The target mass of processing tools is 50 kg or less in consideration of the maneuverability of robot arms that hold the handling tools and carry them near fuel debris by remote control.

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. Processing element tests with fuel debris simulant by effective processing/cutting methods

(2) A processing element test by ultrasonic core boring

- Test Conditions
  - Test block (under plan):
    - ✓ Unit test blocks alone and combinations of different unit test blocks

Material	Hardness
Stainless steel	1.5-3 GPa
Zirconia (ZrO_2)	12-14 GPa
Alumina (Al_2O_3)	15-17 GPa
Concrete	-
Stainless steel + ZrO_2 or Al_2O_3	-

    - ✓ Simulated fuel debris (cold)
      - The fuel debris simulant test material shall be made to simulate MCCI debris in the pedestal bottom.
      - Test block specification will be determined from now
  - Measurement of secondary products generated (under plan):
    - ✓ As with the core boring tests conducted up until last fiscal year, measuring the sizes of the particles in processing liquid waste is planned

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. <u>Processing element tests with fuel debris simulant by effective processing/cutting methods</u>

<u>(2) A processing element test by ultrasonic core boring</u>

- Test procedures and criteria

Items	Criteria/targets	Notes
	Element tests/prototype tests	
Processing speed	30 [kg/hr] or higher	300 [kg/day] is targeted
Weight	50 [kg]	Manipulator capacity is taken into account
Boring diameter	Seeking to achieve 75 [mm] or larger	This test corresponds to the core boring test (66 [mm]) conducted in the previous year
Water volume	Target: 0.004 [m^3]	Collection ability is taken into account
Others	Collect and analyze chips and crumbs with a size of 0.1 [μm] or larger	Results are reflected to chip and crumb collection systems

*Criteria/targets may change depending on the progress of study.

7. Implementation Details

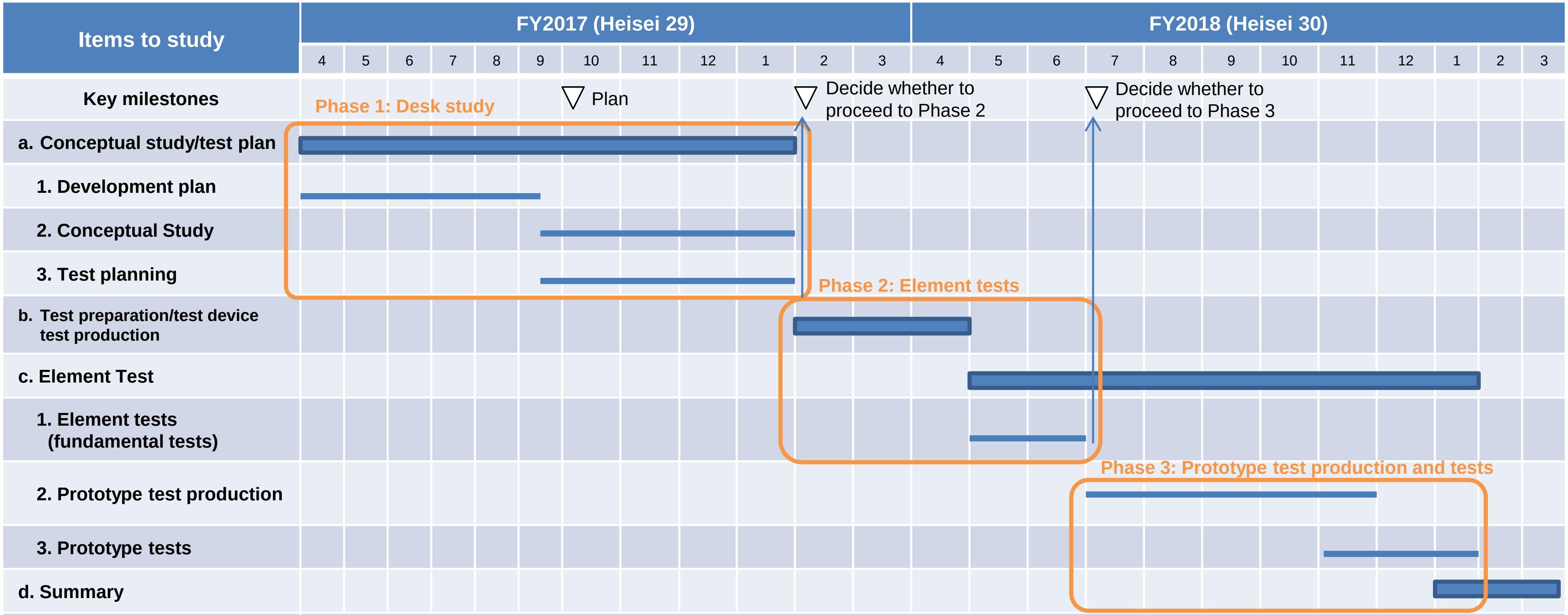
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

b. <u>Processing element tests with fuel debris simulant by effective processing/cutting methods</u>

<u>(2) A processing element test by ultrasonic core boring</u>



Notes	**Expected results**
	[1] Processing conditions and performance (processing speed) in processing various materials including metals -> Specification of throughput evaluation
	[2] Result of particle diameter distribution in processing liquid waste -> Result is input to System Project
	[3] Issues concerning processing -> Applicability to actual equipment on 1F/development issues

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

c. <u>Producing simulated fuel debris and mock-up contaminated structures used for processing tests</u>

- Conceptual study of test facility is underway based on the MAAP analysis result. Test production of the MCCI test facility to be processed is planned in cooperation with the Fuel Debris Characterization Project team.

Requirements of MCCI test facility to be processed

Information on the final solidification state upon completion of MAAP evaluation (FY2015 Report received 14 days later) was reflected. (updated to the latest study status)

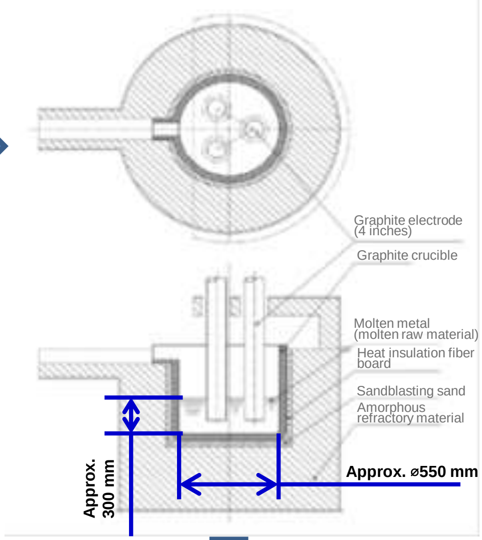
Determination of the components (idea) of MCCI debris simulant test material.

No.	Component	Input quantity (liter)	Composition	Mixing ratio	Density (kg/m³)	Input quantity (kg)
1	Ceramics	2.26	ZrO_2	25%	5.65	3.19
2			CeO_2 (simulating UO_2)	75%	7.2	12.2
3	Metal	1.12	SUS	95%	7.6	8.09
4			Zr or Zry	5%	6.52	0.36
5	Concrete	58.36	Cement	15%	3.5	30.6
6			Aggregate (SiO_2)	85%	2.65	131

Determination of the (proposed) test facility dimensions required for processing tests.

Determination of test facility test production method (proposed).

About the melting test furnace



Schematic illustration of test production of MCCI test facility to be processed

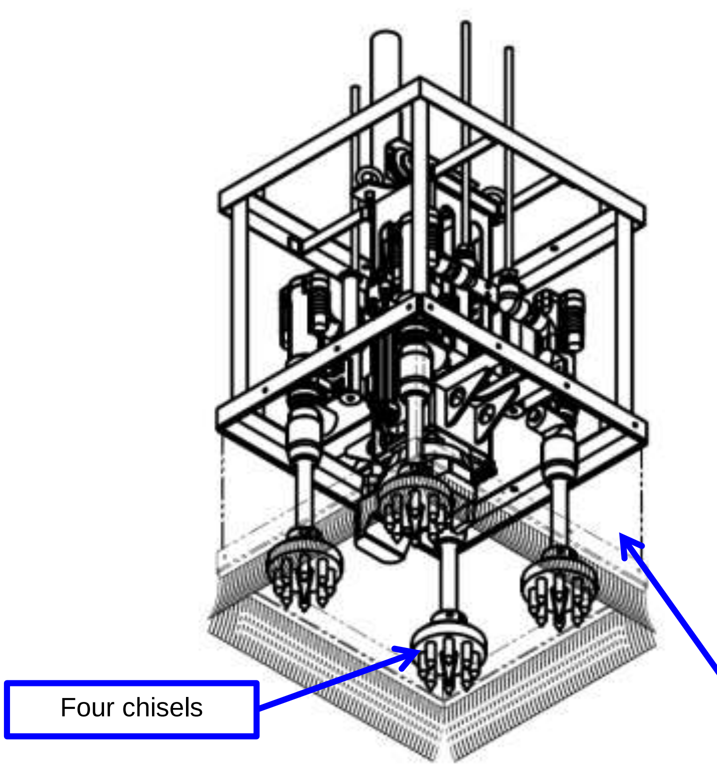
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[2] Development of a fuel debris cutting/dust collection system

d. Study and analysis of dust collection systems used for chips and dust generated during cutting work

- Local collection systems applicable to chisel processing are under consideration.
- Methods to collect chips and dust generated during element tests for cutting methods, and to analyze the collected chips and dust, will be coordinated from now.



Local collection flow of processing

Fuel debris (MCCI) is processed by chisels in the area within the contamination spread prevention sheet.

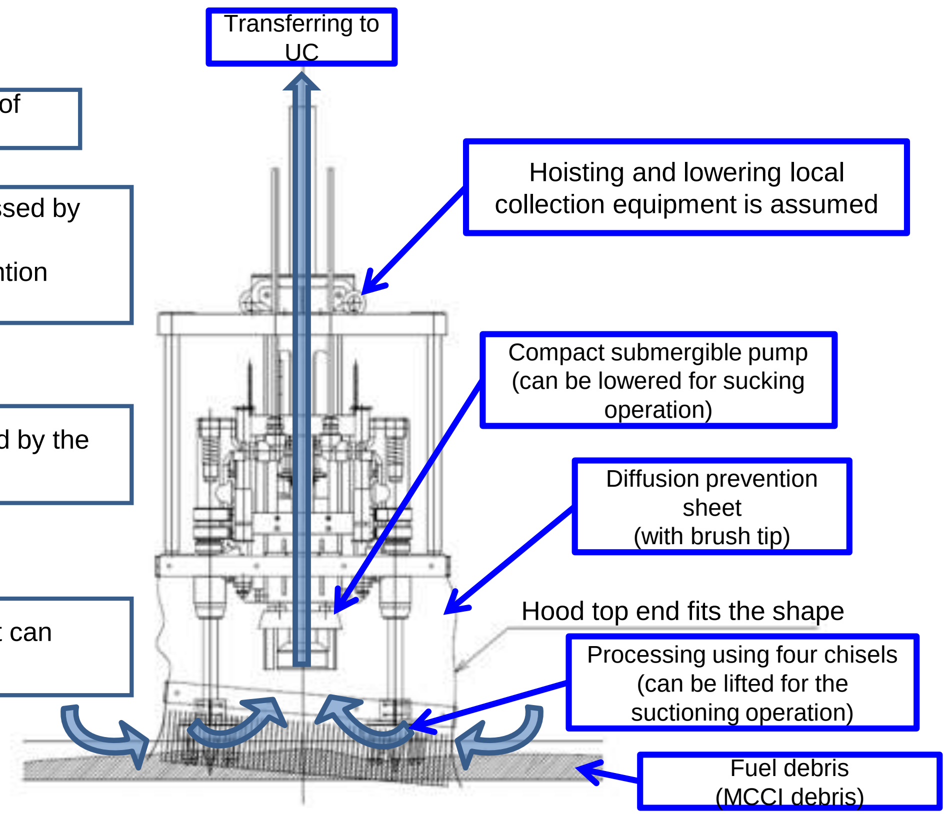
↓

Crushed debris are suctioned by the compact submergible pump.

↓

Fuel debris is sent to the unit can through a suction hose.

Diffusion prevention sheet (with brush tip)



Schematic illustration of local collection equipment for chisel processing

Schematic illustration of local collection task during chisel processing

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. Preventing contamination spreading to the suppression chamber

- Purpose of development
  - Feasibility verification of a method to prevent fuel debris diffusion that can be arranged adjacent to the debris processing point.
  - Identification of issues concerning fuel debris diffusion prevention methods.

- Issues to be resolved
  - Fuel debris fragments produced by processing fuel debris in and outside the pedestal may spread by the contaminated water flow and diffuse in the S/C through the jet pump diffuser.
  - The fuel debris retrieval project duration may be prolonged if fuel debris diffuses in the S/C and other areas since the area to be worked on for fuel debris collection expands.
  - If fuel debris already exists in the S/C and other areas now, there is a risk of another criticality due to diffusion of additional fuel debris.
  - Remote controlled workability for narrow partss.

- Development approach
  - Phase 1: Conceptual study of contamination spread prevention methods
  - Phase 2: Selection of contamination spread prevention methods
  - Phase 3: Element test planning
  - Phase 4: Manufacturing prototype units for testing and implementing element tests

7. Implementation Details

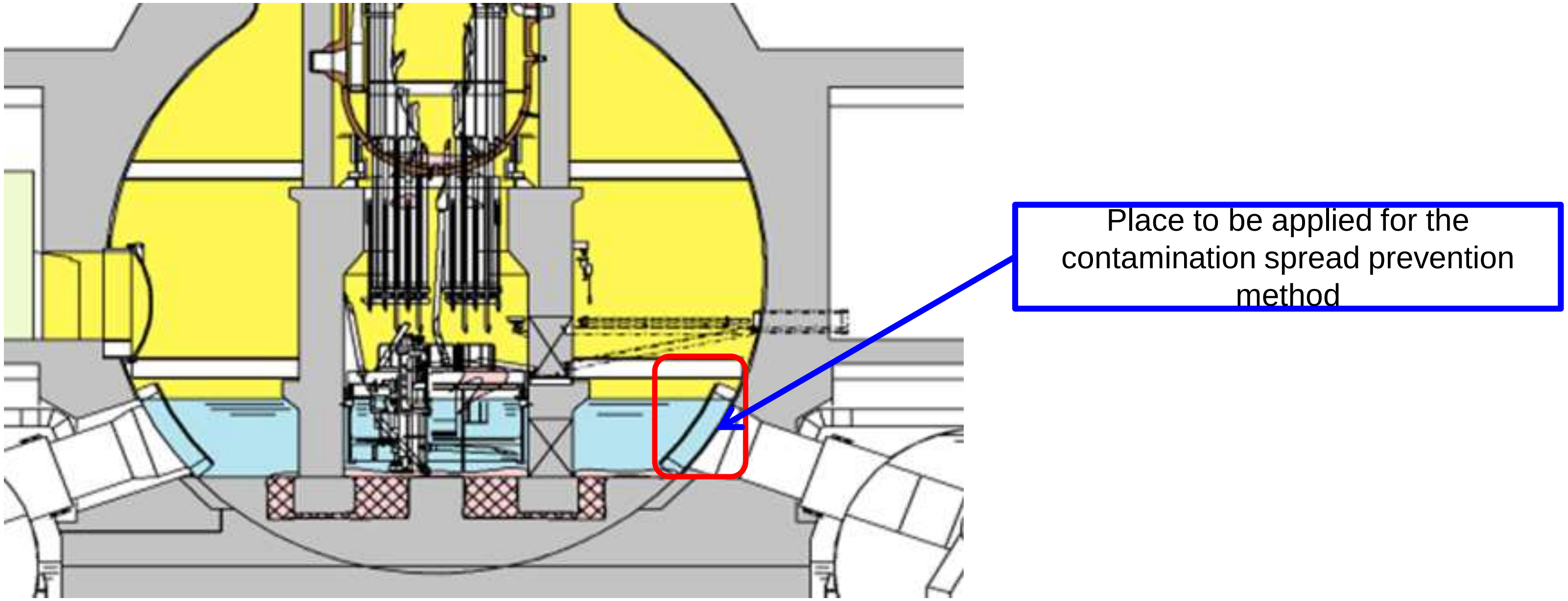
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. Preventing contamination spreading to the suppression chamber

- Expected results
  - Feasibility of a contamination spread prevention method by jet deflector.
  - Clarification of issues concerning contamination spread prevention methods and the establishment of a development plan.



7. Implementation Details

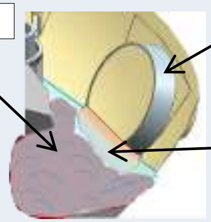
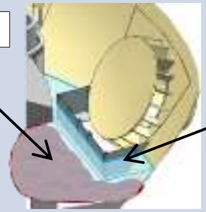
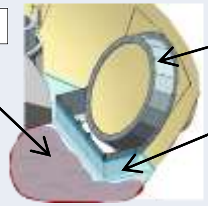
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. <u>Preventing contamination spreading to the suppression chamber</u>

Contamination spread prevention method No. 3 was selected as the most feasible according to the conceptual study result. Steps necessary to embody the method will be studied along with planning the element tests to verify feasibility. The element tests will be performed according to the plan.

No.	Methods overview	Contamination spread prevention effect		Difficulty level of method (assumed)	Notes
		In air	Underwater		
1		High	High	High	Remote welding in a narrow space will be difficult
2		Low	High	Medium	It is assumed that contamination spread through the air will occur in combination with the negative pressure control system.
3		Medium	High	Medium	It is assumed that contamination spread through the air will occur in combination with the negative pressure control system.

7. Implementation Details

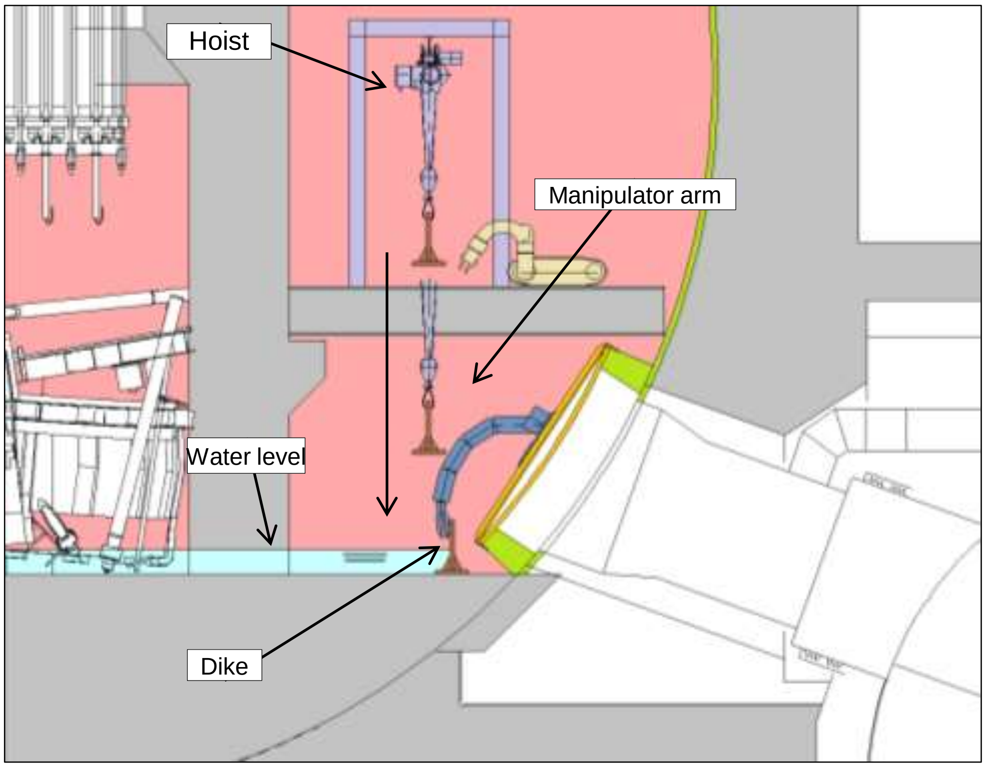
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

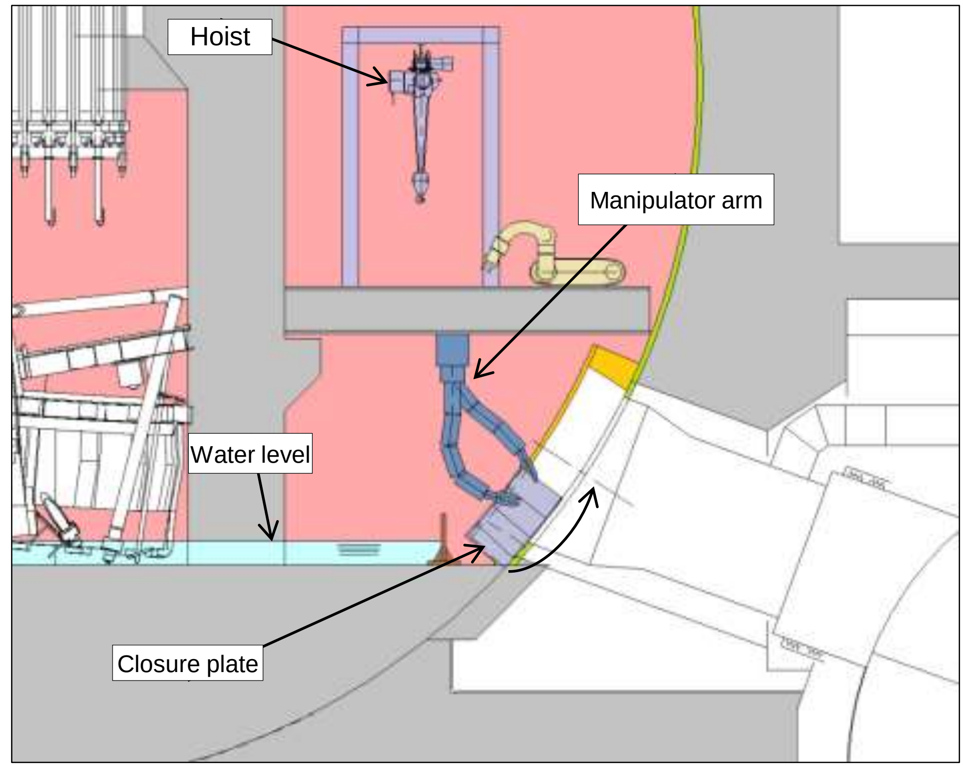
[3] Development of methods to prevent fuel debris diffusion

a. Preventing contamination spreading to the suppression chamber

Schematic illustrations of element tests to verify of the method are shown below. Workability under a low water level will be examined and issues will be identified.



Schematic illustration of dike installation



Schematic illustration of closure plate installation

7. Implementation Details

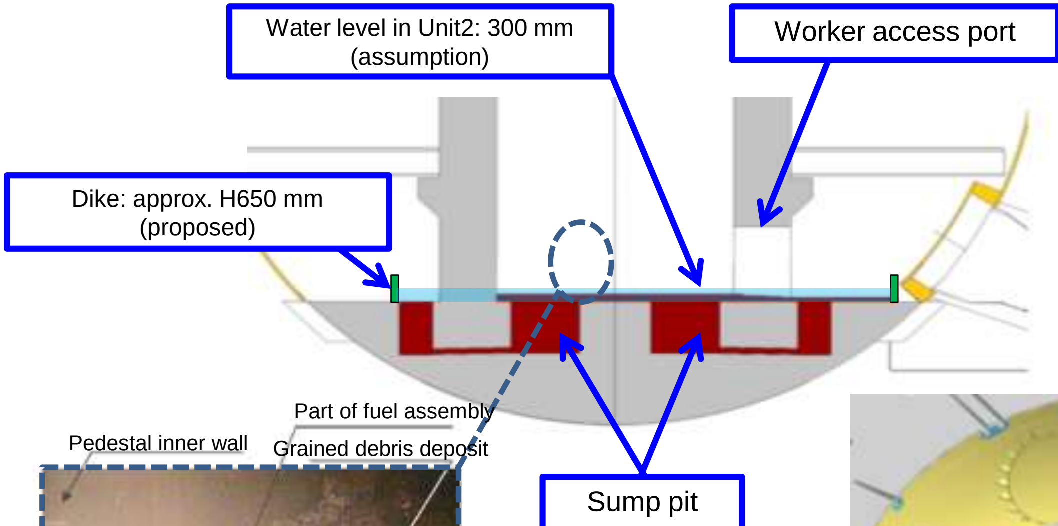
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

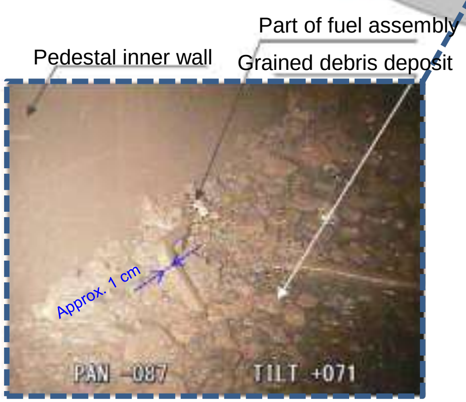
a. <u>Preventing contamination spreading to the suppression chamber</u>

Specific design of the contamination spread prevention dike is being studied based on the investigation of Unit2 PCV internal conditions so that the spread of the contamination is confined within a minimum area while the installation area of the dike is minimized.

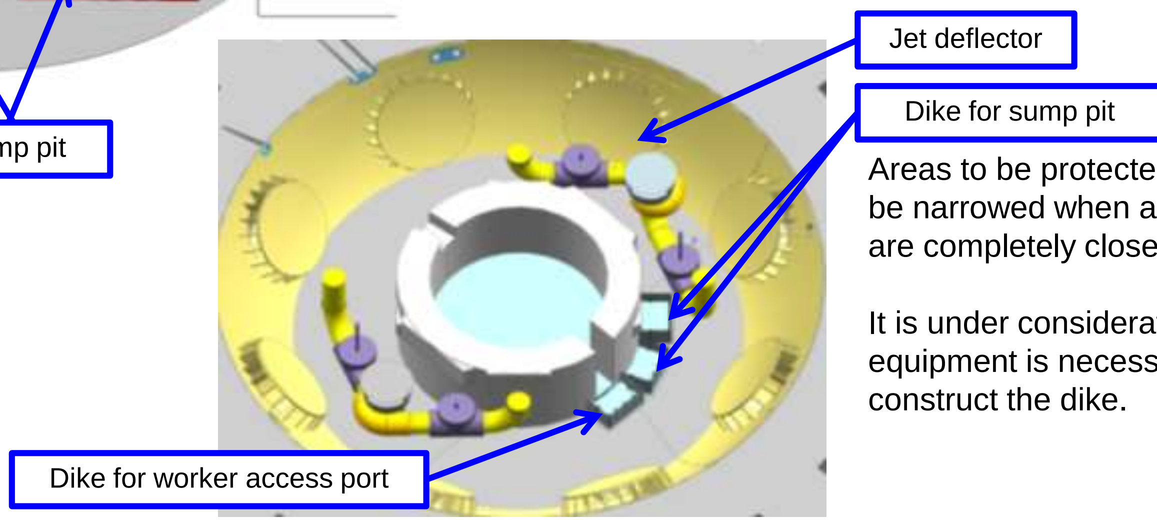


The worker access port and the sump pit are considered passages through which fuel debris in the pedestal spread outside the pedestal.

Measures for contamination spread prevention were studied based on the assumption that most of the fuel debris is inside the pedestal.



Investigation result of internal conditions of the Unit2 PCV
Photo of the pedestal bottom



Areas to be protected by dike can be narrowed when all jet deflector are completely closed.

It is under consideration what equipment is necessary to construct the dike.

7. Implementation Details

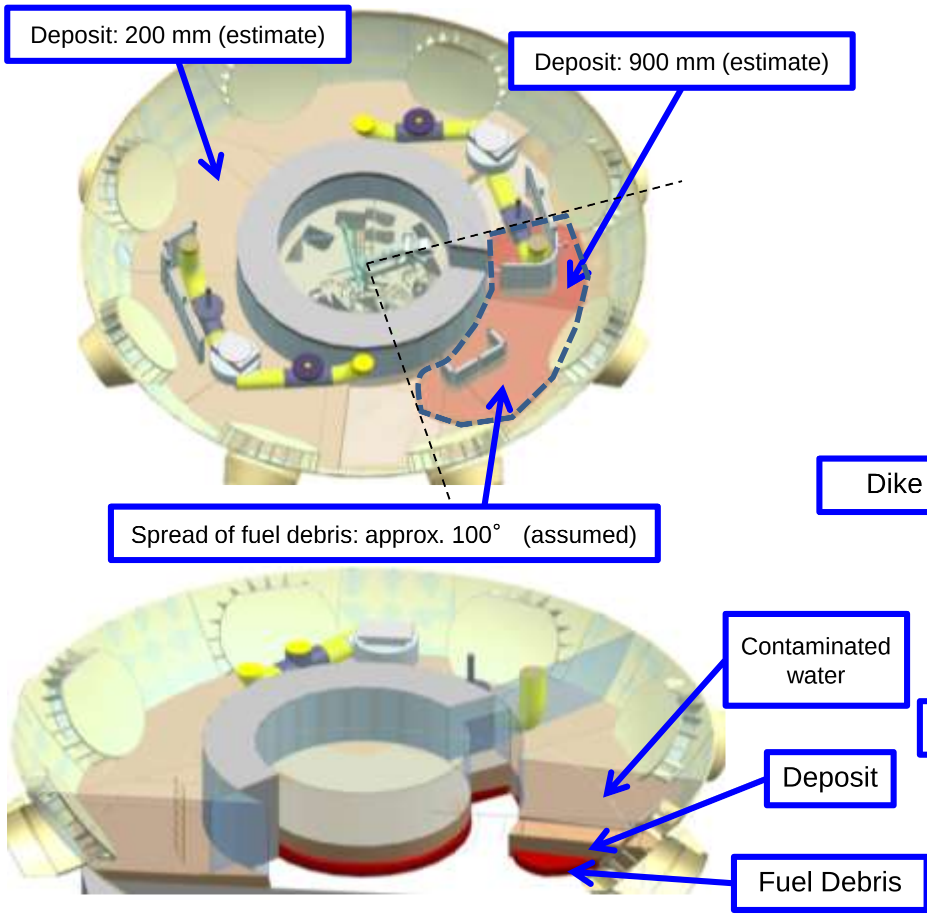
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. <u>Preventing contamination spreading to the suppression chamber</u>

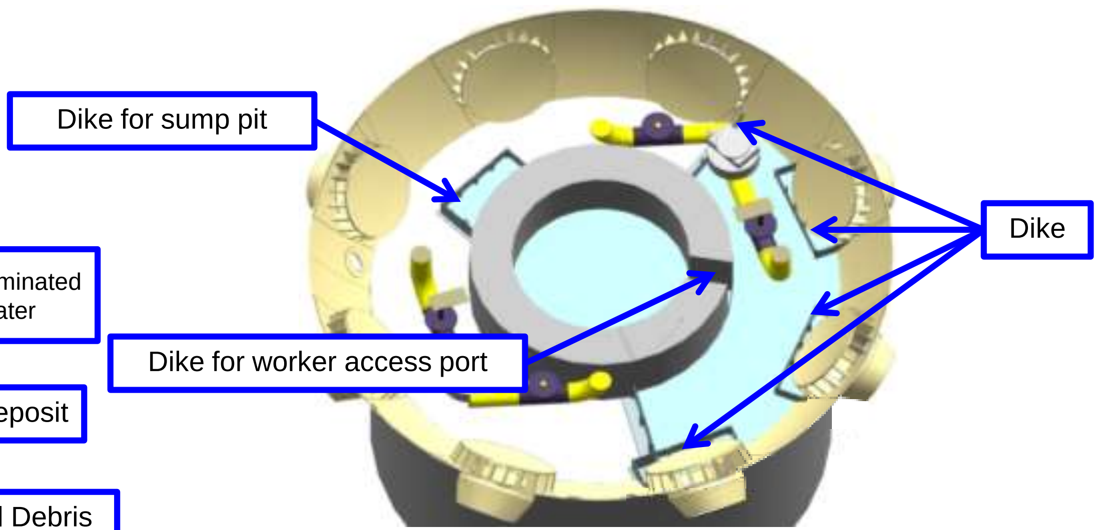
As with Unit2, a method that can minimize the construction work to prevent the spread of contamination was studied with Unit1.



Schematic diagram of estimated debris spreading condition at present in Unit1

Although the total span of the dike to be constructed could be shorter compared to the case where dike is constructed around all jet deflectors, the water level needs to be lowered after removing the deposit.

The equipment needed to install the dike is under consideration.



Schematic illustration of minimum contamination spread prevention for Unit1

7. Implementation Details

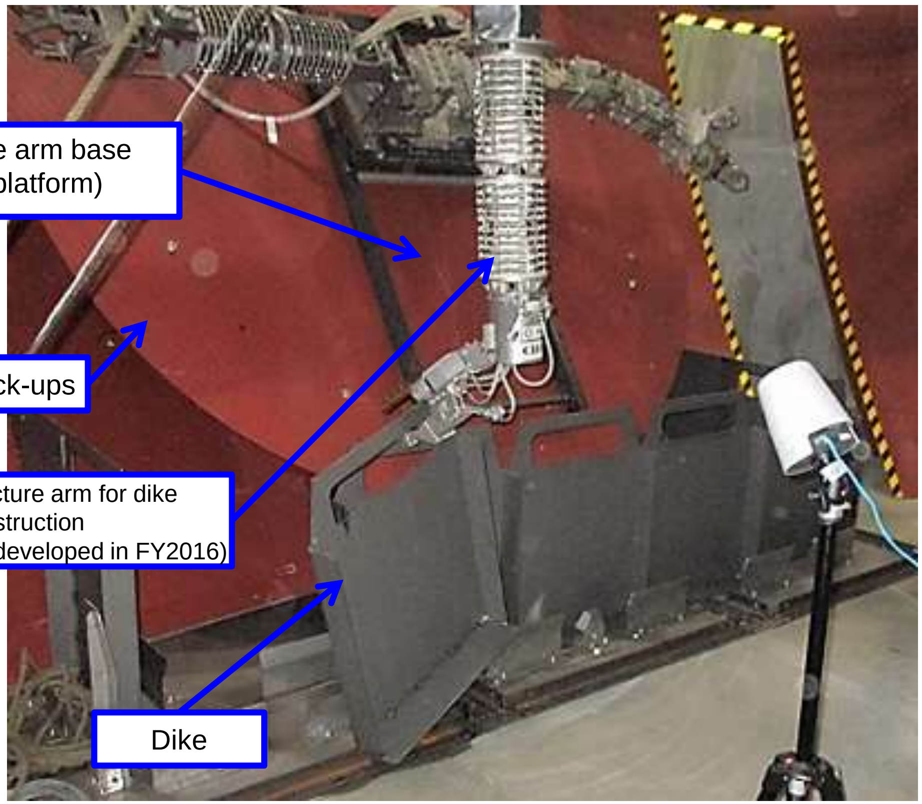
7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. <u>Preventing contamination spreading to the suppression chamber</u>

As part of the efforts to study dike construction equipment, a preliminary test and the identification of issues based on the test result is underway, where a flexible structure arm (muscular robot) developed in FY2016 is subjected to further study.



A preliminary testing to study dike construction equipment

Policy for the developing a flexible structure arm for dike construction

- Development shall be conducted in such a way that results will be applicable not only to dike construction but also to fuel debris retrieval work conducted outside the pedestal and to the removal of interfering objects existing outside. Equipment applicable to various works with high efficiency can be realized.

Preliminary test status of closure plate installation

Besides the construction of a dike to prevent contamination spread, installing closure plates around jet deflectors is planned to prevent aerial contamination spread; methods for installing closure plates are under consideration. (Photos show closure plate installation test by workers)

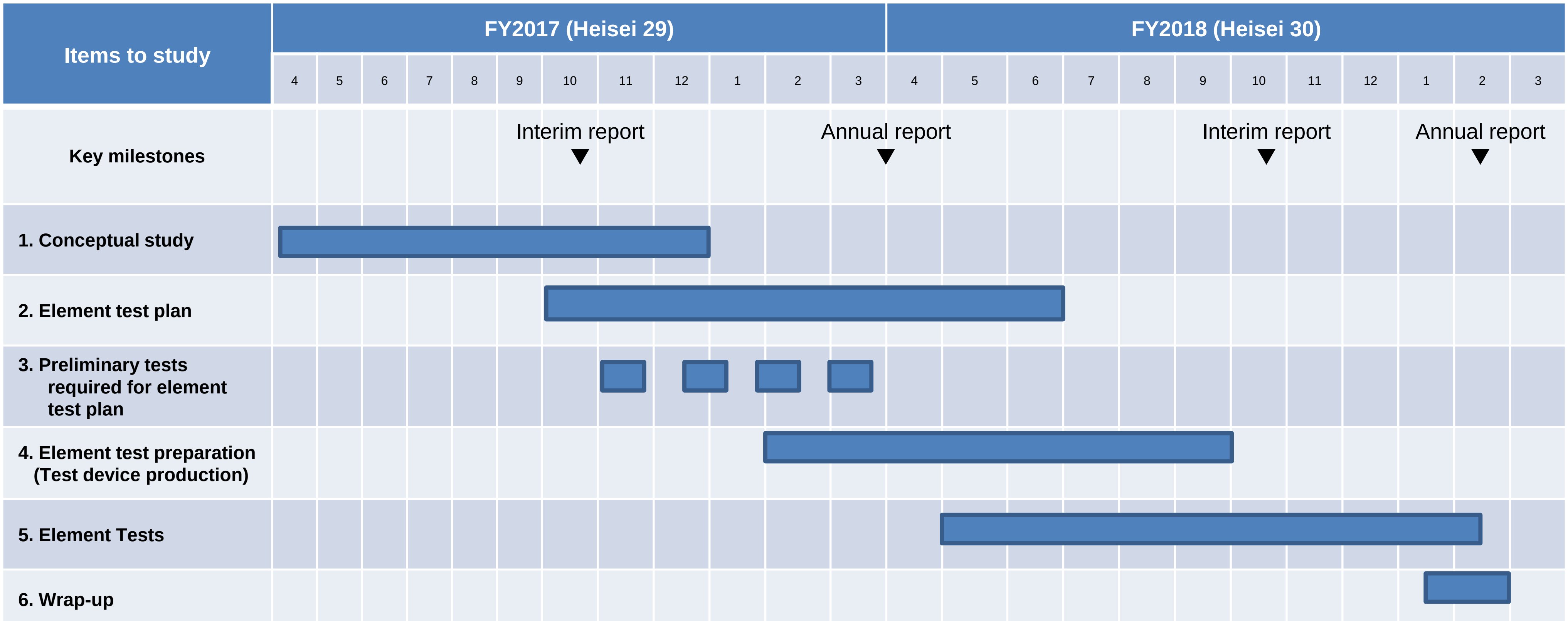
7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[3] Development of methods to prevent fuel debris diffusion

a. Preventing contamination spreading to the suppression chamber



Notes

Results of element tests

1. **Feasibility of a contamination spread prevention method by jet deflector.**
2. **Identification of issues in installation methods.**

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

Develop the following remote technologies for each task assumed during fuel debris retrieval because the site is highly radioactive, and many of the tasks must be remotely controlled:

[1] Element technology development related to work cell

Remote operation is required to install work cells that enclose fuel debris retrieval equipment. In the side entry method, for example, the airtightness and strength of work cells and the access passage to the PCV (X-6 penetration, etc.), which runs through a narrow and highly radioactive area in the reactor building, must be ensured. As with the top entry methods, the same requirements apply to work cells and the access passage, which is installed in a high radiation area on the operation floor right above the reactor well.

Among other things, the following main themes with element tests will be performed on an as needed basis. Through these activities, issues will be identified and reviewed.

a. Improvement of work cell manageability by establishing work cell installation methods for top entry and side entry and also by reducing the load on the reactor building

- Design conditions applicable to cell/method review is under optimization.
- Conceptual study concerning the soundness of the reactor building after installing the facilities and equipment necessary for a the side entry method (seismic resistance, impact of additional openings constructed in the building, load on the floor, etc.) and the feasibility of installation work (cell installation procedures, etc.) is planned.

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

- Feasibility of the welding-based sealing method was proved by element tests performed until the last fiscal year.
- Element tests for the inflation sealing method are planned.

c. Assurance of work cell sealability and dust dispersion prevention performance

- Regarding work cell sealability and dust dispersion prevention performances, confinement performance to contain specified radioactive materials within the cell, working with the negative pressure control system on the system side, is being studied.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

- Purpose of development
  - ➢ Improve work cell feasibility, including cell installation methods and reactor building strength check, by identifying requirements for work cell(s) and clarifying concept of cells.

- Issues to be resolved
  - ➢ Clarification of concept of cells
    - ✓ Clarification of source term and maintenance areas
    - ✓ Study a way to share a work cell with multiple types of robots
    - ✓ Clarify maintenance items and methods for equipment in the cell
    - ✓ Enhancement and cost reduction of shielding door, double door system, and airlock system
    - ✓ Increase fuel debris collection speed (throughput) by clarifying in-cell processes
    - ✓ Reduce the shielding structures' weights

  - ➢ Clarify the cell installation method
    - ✓ Detailed study of methods to open a through hole in the PCV concrete
    - ✓ Study of dust dispersion prevention methods (especially a method applicable to gaps between the PVC wall and concrete structure)
    - ✓ Clarify the installation method for heavy weight objects under a high-dose radiation environment

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

- Development approach
  - Clarify work cell requirements
  - Clarification of concept of cells
    - ✓ Mapping the required functions for each different cell type
    - ✓ Estimation of fuel debris properties and amount of those handled
    - ✓ Calculate the thickness of shielding structures for cells
    - ✓ Study of cell structures
    - ✓ Study of parts and devices to complete a cell (shielding door, sealing door, handling equipment, etc.)
  - Clarify the cell installation method
    - ✓ Study of methods to open a through hole in the PCV concrete
    - ✓ Study of methods for sealing between PCV and cell
    - ✓ Study of cell carrying-in methods
  - Verification of the building strength
    - ✓ Assess the impact of additional openings constructed in the building on its strength
    - ✓ Assess the impact of cells installed in the building on its strength
- Expected results
  - Feasibility of a series of processes from carrying in equipment and materials in PCV to the removal of fuel debris and interfering objects
  - Fuel debris collection speed (throughput) by clarifying in-cell processes

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

Clarification of cell-related issues based on safety requirements

Basic safety requirements	Safety Requirements (Example)	Issues concerning cells		Methods to resolve issues
Confine radioactive materials by setting a boundary	Prevent leakage that exceeds the allowable level specified in the safety standards for radioactive materials in gas	Confinement by establishing a static boundary	Sealing of cell (including door system and through-holes)	Conceptual study based on proven technologies
Confine radioactive materials by setting a boundary	Prevent leakage that exceeds the allowable level specified in the safety standards for radioactive materials in gas	Confinement by establishing a static boundary	Sealing of connections between the PCV and cells	Sealability will be examined in element tests since there is no record of similar applications
Confine radioactive materials by setting a boundary	Prevent leakage that exceeds the allowable level specified in the safety standards for radioactive materials in gas	Confinement by establishing a dynamic boundary	Door system	Conceptual study based on proven technologies (such as double door and airlock)
Protect against external exposure	Shields for preventing excessive direct radiation exposure	Shielding of cell from external		Clarification of source term and the transportation line of wastes, and implementation of conceptual study
Design for dose reduction for workers	Shields, appropriate classifications for the level of contamination and dose, and system designs for remote maintenance and traffic line setting, etc. to reduce exposure	Shielding cells from worker access areas		Clarification of areas workers are allowed to enter, and implementation of a conceptual study
Design for dose reduction for workers	Shields, appropriate classifications for the level of contamination and dose, and system designs for remote maintenance and traffic line setting, etc. to reduce exposure	Carrying-in, installation and layout of cells and traffic lines		Conceptual study by clarification of in-cell processes
Design for dose reduction for workers	Shields, appropriate classifications for the level of contamination and dose, and system designs for remote maintenance and traffic line setting, etc. to reduce exposure	Maintenance of cells and equipment		Conduct a conceptual study by clarifying equipment to be maintained, maintenance methods, and maintenance space or rooms Element tests are planned where necessary
Operation control for dose reduction for workers	Operation methods, maintenance plans, and task management for dose reduction	Function allocation among cells, layout, and traffic lines		Conceptual study by clarification of in-cell processes
Operation control for dose reduction for workers	Operation methods, maintenance plans, and task management for dose reduction	Maintenance of cells and equipment		Conduct a conceptual study by clarifying equipment to be maintained, maintenance methods, and maintenance space or rooms Element tests are planned where necessary

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building</u>

○ Design conditions applicable in cell/method review

Inputs that could be reflected on the design conditions concerning cell and method study were organized and hypothetical conditions for items for which useful information was not input was set. Note that the conditions may be updated when a new input becomes available.

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.1 Radiation-related items	1	Source strength of fuel debris	The source strength after a cooldown period of 10 years that is described in JAEA-Data/Code 2012-018 is used.	
	2	Radiation dose in the PCV	1. Inside the pedestal (same for Unit1-Unit3) 100-1000 Sv/h 2. Outside the pedestal (same for Unit1-Unit3) 10-100 Sv/h	The fall of reactor internals and results of site survey are taken into account
	3	Radiation dose in R/B	Current radiation doses in each area shall be used.	
	4	Radiation dose on the outer surface of a cell shielding structure	1. Restricted areas for worker in a normal condition: 1 mSv/h or less 2. Worker accessible areas: 0.1 mSv/h or less 3. Radiation dose is determined through coordination with the System Project team.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.2 R/B and seismic resistance	1	Acceptable maximum load of floors above ground	1. Unit1: 1.22 ton/m^2 in front of X-6 penetration, and 4.88 ton/m^2 in front of the manhole 2. Unit2/Unit3: 4.9 ton/m^2 in front of X-6 penetration, and 1.22 ton/m^2 in other areas	
	2	Seismic acceleration	1. Seismic acceleration of 900 Gal is assumed. 2. To be determined through coordination with the Antiseismic Project team.	
	3	Cell height	1. The height of cells installed in R/B shall be equal to or less than the height of the ceiling of R/B 1st floor. 2. The height of each cell varies with the processing method depending on required functions.	
Item No.3 Dimensions of openings for access constructed on the wall of PCV and inside Pedestal	1	Equipment hatch size	1. Unit1: ⌀3.0 m 2. Unit2/Unit3: H2.5 m	
	2	X-6 penetration opening size	1. Whether it is usable as an access port and whether the opening needs to be enlarged depends on the construction method. 2. Conditions of the opening after completing sampling work and conditions for taking over will be coordinated with the Sampling Project team.	
	3	Pedestal opening size	1. Unit1, CRD opening: H1970 mm x W790 mm Worker access port: H1724 mm x W755 mm 2. Unit2/Unit3, CRD opening: H1900 mm x W750 mm Worker access port: H1900 mm x W750 mm	
	4	Pedestal strength	1. It is assumed that the pedestal retains the original strength. 2. Integrity of the pedestal will be verified by internal investigation and other means.	
	5	Water levels in the PCV	1. The water level in the PCV can be controlled. 2. The water level in the PCV is assumed to be equal to or lower than the height of the 1st floor of R/B. (for a the side entry method)	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building</u>

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.4 Fuel Debris Collection method	1	Definition of debris	1. Debris that exists in the area under the upper grid plate (except CRD rail) is treated as fuel debris. 2. As with the outside pedestal, material that leaks from the pedestal through the worker access gate is treated as debris.	
	2	Lump debris	1. Debris whose diameter exceeds 10 mm is defined as "lump debris". 2. Any debris lump that is larger than the unit can will be collected after crushed into pieces of smaller size. 3. Debris lumps that fit into the unit can will be collected as they are without crushing.	
	3	Particle debris	1. Debris with a diameter of 0.1 mm to 10 mm is defined as "particle debris." 2. Collected by suction or equivalent means.	
	4	Powder debris	1. Debris with a diameter of less than 0.1 mm is defined as "powder debris." 2. Collected by suction or equivalent means. 3. If debris is collected in the water treatment system of the plant, concrete method will be arranged separately down the road.	
	5	Criticality of debris	Methods for controlling criticality recurrence will be coordinated with the Criticality Project Team.	
	6	Areas to conduct debris collection work in	1. Inside the pedestal, collection in all areas to a depth not less than the drain sump pit or depth. 2. Outside the pedestal, collection in all areas to a depth not less than the drain sump pit or depth. 3. Specific collection work areas will be determined based on the investigation and sampling results.	
	7	Method to process lump debris	See sections concerning fuel debris cutting and dust collection systems in this report.	
	8	Unit Canister	1. ⌀400 mm x H400 mm or smaller 2. A diameter of 200 mm is used initially, and the method study team will determine a new dimension within the range suggested by the Canister Project Team.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.4 Fuel Debris Collection method	9	Storage Canister	1. ⌀400 mm x H2000 mm or smaller 2. A diameter of 200 mm is used initially, and the method study team will determine a new dimension within the range suggested by the Canister Project Team.	
	10	Cask	Transfer cask specifications will be determined through discussions with the Canister Project Team.	
	11	Dewatering and drying of debris	1. The unit shall be designed so that it can dewater debris in it. 2. When the control of the fuel debris fluid is judged effective for hydrogen generation, according to the Canister Project Team's reevaluation, dewatering and drying methods will be studied further as needed basis. 3. The debris fluid shall be discussed with the Canister Project Team and the Criticality Project team to determine whether the canister of ⌀400 mm is used, which may pose a risk of criticality subject to its shape.	
	12	Measures for hydrogen generation from debris	1. Waiting for evaluation by Canister Project Team 2. The control of fuel debris fluid and/or the vent of containers shall be studied when needed to measure for hydrogen generation during fuel debris transportation.	
	13	Material accountancy items for unit can	Material accountancy related to safeguards is studied by the initiative of JAEA separately from the subsidized project.	
	14	Material accountancy items for canister	1. Material accountancy related to safeguards is studied by the initiative of JAEA separately from the subsidized project. 2. The gross mass of each container will be measured by a typical weighing method.	
	15	Inspection and material accountancy items for cask before carrying-out	Material accountancy related to safeguards is studied by the initiative of JAEA separately from the subsidized project.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building</u>

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.5 Collection of interfering objects and wastes	1	Definition of interfering object	Any object that needs to be removed for fuel debris retrieval is defined as "interfering object."	
	2	Radiation dose of interfering objects	1000 Sv/h or less	
	3	Way to discern "debris" from "waste"	Definitions of "fuel debris" and "waste" are being discussed by another project team.	
	4	Order of interfering object dismantlement	Objects to be removed and dismantlement range vary with the processing method.	
	5	Waste collection can	1. The can shall be designed so that it can dewater wastes in it. 2. The can dimensions shall be determined so that it can pass through openings constructed in the PCV.	
	6	Waste removal container	Details will be studied in the waste project.	
	7	Interfering object processing and severing method	Different processing and severing methods need to be studied since a suitable method depends on the types of obstacles to be processed and the area of removal work.	
	8	Criteria to approve the carrying-out of wastes	1. Each waste removal container shall be inspected for radiation dose, among other things, before leaving the facility. 2. Criteria will be studied in the Waste Project.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building</u>

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.6 Operation and maintenance of access equipment	1	Carrying-in/out of access equipment	1. Keep the boundary during carrying-in/out tasks. 2. The access equipment varies with the processing method.	
	2	Utility supply to access equipment	1. Required utilities depend on methods. 2. The drive source for access equipment varies depending on the technical method (such as oil hydraulics, water hydraulics or electricity).	
	3	Maintenance of access equipment	1. Simple maintenance tasks such as camera exchange will be performed in R/B remotely. 2. Maintenance items vary with the processing method.	
	4	Camera exchange	The camera shall has radiation resistance of 100 kGy.	
	5	Access equipment exchange frequency	The target radiation resistance of access equipment is 1×10^6 Gy.	
	6	Emergency retrieval of access equipment	1. Access equipment shall be designed and installed so that it can be removed in case of failure. 2. The emergency collection method varies with the processing method.	
	7	Exchange of tip tools	The method to exchange tip tools varies with the processing method.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. **Improve work cell manageability by establishing work cell installation methods for top entry and side entry and by reducing load on the reactor building**

○ Design conditions applicable in cell/method review

Item	No.	Detailed item	Design conditions, etc.	Notes
Item No.7 Cell operation and maintenance	1	Fuel debris retrieval rate	The target rate is 300 kg/day.	
	2	Classification of cells by contamination level	Cells are classified into three areas by contamination level: high-level contaminated, mid-level contaminated, and low-level contaminated areas.	
	3	Negative pressure control in a cell	1. The pressure of the secondary boundary shall be maintained at around -64 PaG. (Pressure difference to the atmosphere) 2. A differential pressure of about 100 PaG per contamination classification difference shall be maintained at the primary boundary between two adjacent cells.	
	4	Cell ventilation	1. The cell shall be equipped with a ventilation system to cope with hydrogen generation. 2. Nitrogen use needs to be discussed with the team responsible for the system of the plant.	
	5	Cell operation and maintenance	1. The operation and maintenance of a cell is implemented by remote control in principle. 2. Tasks by workers shall be considered only in case of emergency where the remote system does not work.	
	6	Cell location	1. An extension building shall be constructed outside R/B. 2. Layout inside R/B and layout outside R/B vary with the processing method.	
	7	Method to monitor conditions in of a cell	Temperature, pressure, radiation dose, neutron dose, hydrogen concentration, oxygen concentration, visual observation, etc. in a cell shall be monitored.	
	8	Debris and waste transfer	1. Take contamination spread prevention measures during transfer. 2. A definitive transfer means is casks.	
	9	Cell installation method	The cell installation method varies with the processing method.	
	10	Connection of a cell and the PCV	1. Connection shall take into account contamination spread prevention and confinement 2. The connecting method and technology vary with the processing method.	
	11	Method to decontaminate the inside of a cell	1. Specific decontamination methods shall be studied. 2. The decontamination methods and means vary with the processing method.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

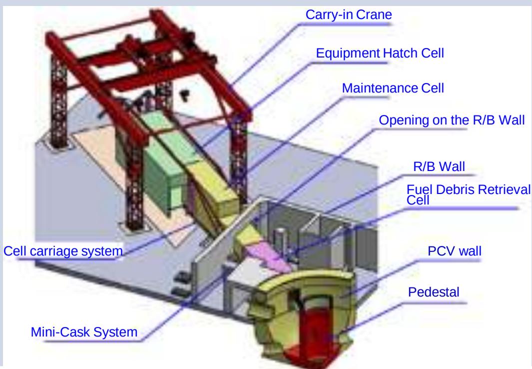
a. <u>Improvement of work cell manageability by establishing work cell installation methods for top entry and side entry and also by reducing the load on the reactor building</u>

○ <u>Study concerning reduction of load to the reactor building</u>

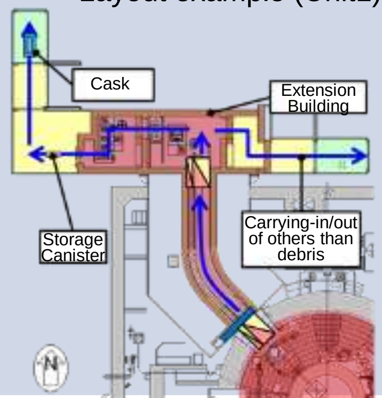
- Measures to meet the load capacity of each floor were studied to reduce the load exerted to the reactor building.

PLAN-A	PLAN-B	PLAN-C
Layout example (Unit2)	Layout example (Unit1)	Layout example (Unit2)

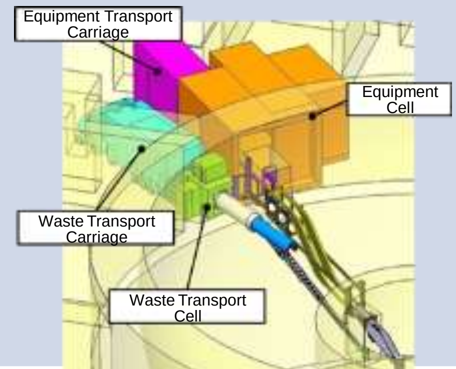
PLAN-A — Layout example (Unit2)



PLAN-B — Layout example (Unit1)



PLAN-C — Layout example (Unit2)



Plan	Cell Weight in R/B	Floor Loading	Floor Loading Capacity
PLAN-A	Weight Reduction under Consideration	≤ 4.9 ton/m^2	4.9 ton/m^2
PLAN-B	800 tons	0 ton/m^2	4.88 ton/m^2
PLAN-C	Weight Reduction under Consideration	7 ton/m^2 or less	4.9 ton/m^2

PLAN-A

- This plan is based on the idea to lay out all cells straight and construct a relatively large opening in the outer wall of the R/B.
- The cells are carried in and installed via conveyor rails from outside the R/B.
- The reinforcement of the opening needs to be considered to maintain the integrity of the R/B (since the opening imposes a relatively large load on the R/B).
- A reduction in floor loading is under consideration by using a suspension-bridge type structure that can release the load to the outside.
- The weight of the cells is supported by BSW and the anchorage outside R/B.

PLAN-B

- A method is under consideration to connect an extension building built outside the R/B and the PCV with an access tunnel.
- The access tunnel weight will be supported by the BSW and the R/B wall at both ends, respectively, so that no additional load is exerted on R/B 1st floor.

PLAN-C

- The cells, transfer carriage, etc. are laid out on 1F of R/B.
- Equipment requiring maintenance and fuel debris are transferred by the carriage to the external extension building.
- The equipment cell and the transfer carriage are laid out on the main beam so that additional margin to the load capacity of the floor can be obtained. Our plan is to reduce the floor loading by distributing the load with steel floor plates.

7. Implementation Details

7.2. Implementation Details

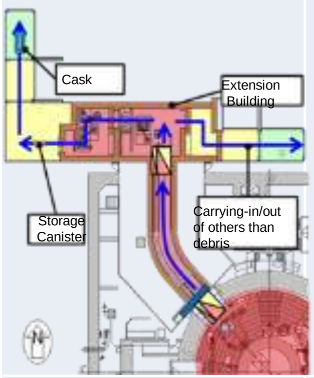
2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improvement of work cell manageability by establishing work cell installation methods for top entry and side entry and also by reducing the load on the reactor building</u>

○ <u>Study concerning reduction of load to the reactor building</u>

- The action policy was set to meet the floor load restriction and issues were identified.

No.	Variations inside the PCV access route and corresponding cells layout	Preparatory work for R/B internal structures				Action policy on cell installation	Issues	Notes
		Wall	Wall reinforcement	Pillar	PCV			
1	PLAN-B: Method boring a hole through R/B walls but leaving pillars as they are  	Remove	-	-	Use existing openings	1. The load exerted on 1F of R/B needs to be reduced as much as possible to secure a margin for installation the system equipment on R/B 1st floor. 2. For dose reduction for workers, an access tunnel connects the extension building and PCV by a cantilever structure. 3. No additional load shall be exerted on R/B 1F floor during installation work. 4. After installing the access tunnel, it needs to be supported by the BSW and the R/B wall at both ends, respectively, so that no additional load is exerted on R/B 1st floor R/B.	1. The feasibility of the construction of the access tunnel in narrow areas on the construction route. 2. Feasibility of achieving accurate mating of the access tunnel front end to the PCV opening. 3. Feasibility of heavy weight object handling. 4. Feasibility of the sealing method of the connection between the access tunnel and the PCV.	
2	PLAN-A: Method boring a hole through R/B walls and then reinforcing boreholes	Remove	Yes	-	Build new openings	Details are being studied.		
3	PLAN-C: Method without boring R/B walls	-	-	-	Build new openings			

7. Implementation Details

7.2. Implementation Details

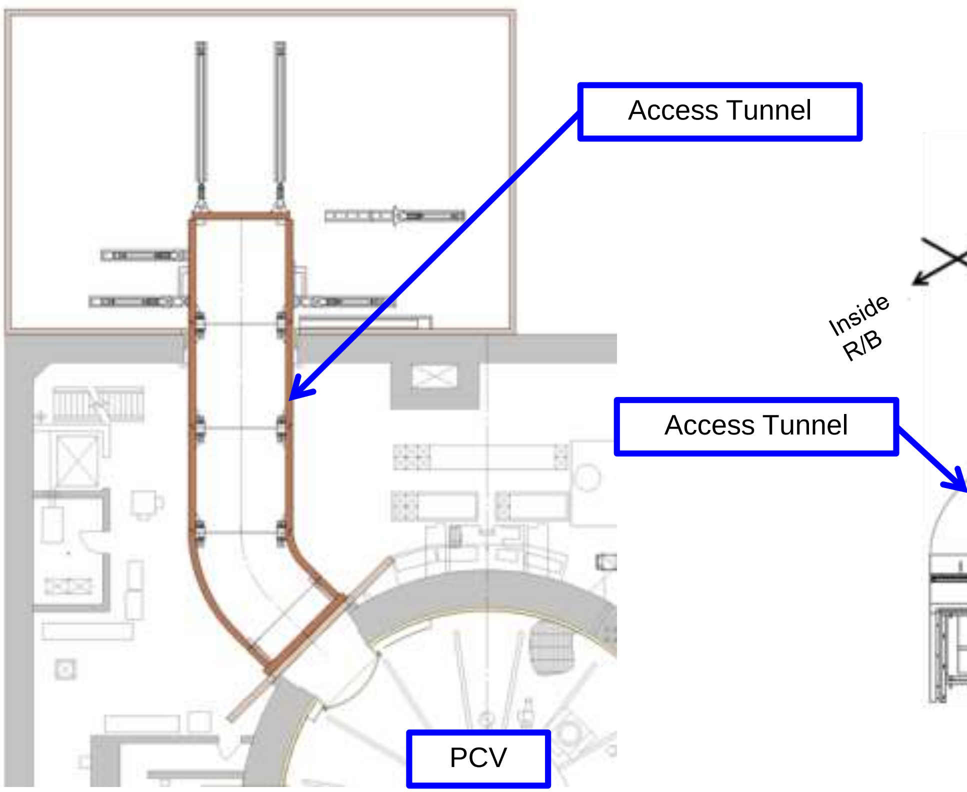
2) Element technology development for installing retrieval equipment

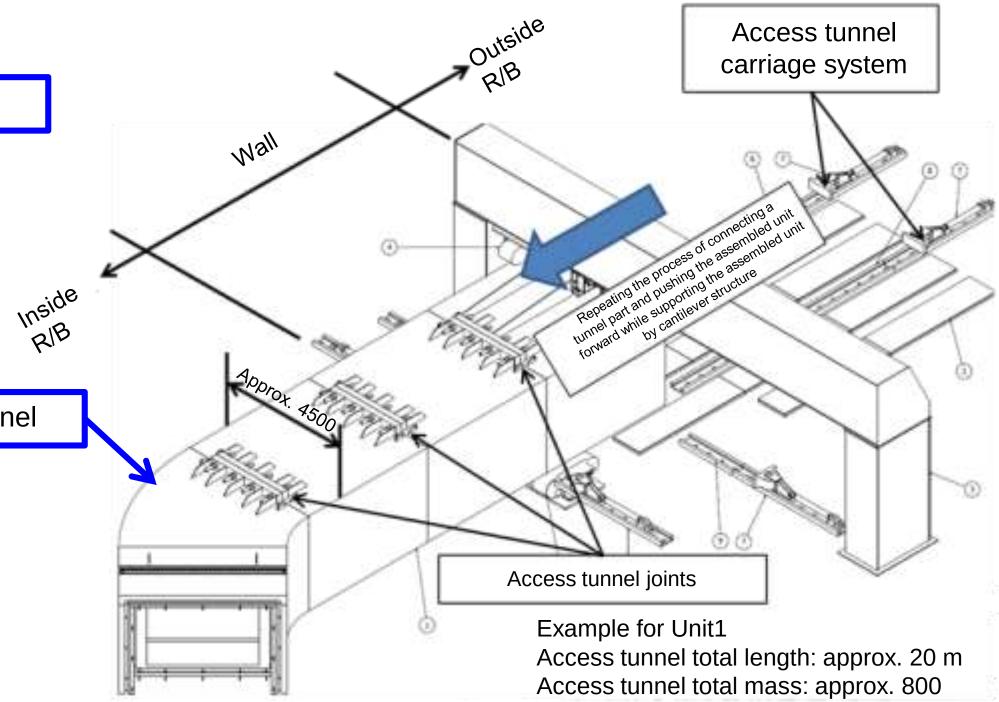
[1] Element technology development related to work cell

a. Improvement of work cell manageability by establishing work cell installation methods for top entry and side entry and also by reducing the load on the reactor building

○ Study concerning reduction of load to the reactor building

- The specific structure of the cell (access tunnel) was designed by incorporating measures for issues. In addition, element tests are planned in the "project for upgrading of approach and systems for retrieval of fuel debris and internal structures" to assess the feasibility of the conceptual study results.





Example for Unit1
Access tunnel total length: approx. 20 m
Access tunnel total mass: approx. 800 tons
Shield thickness: 300 mm
Material: carbon steel and others

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

a. <u>Improvement of work cell manageability by establishing work cell installation methods for top entry and side entry and also by reducing the load on the reactor building</u>

○ <u>Preparatory studies and work for buildings</u>

- The seismic resistance of R/B after installing facilities and equipment for fuel debris retrieval is under consideration assuming both the side entry and the top entry methods are used in combination.
- The assessment of the impact of openings constructed in the R/B wall and the PVC wall on the earthquake strength of R/B is planned.
- The study of installation and fixing methods of the fuel debris retrieval cell is planned with consideration of floor load capacity.
- The study of the installation procedure of the fuel debris retrieval cell is planned with consideration of R/B soundness .

7. Implementation Details

7.2. Implementation Details

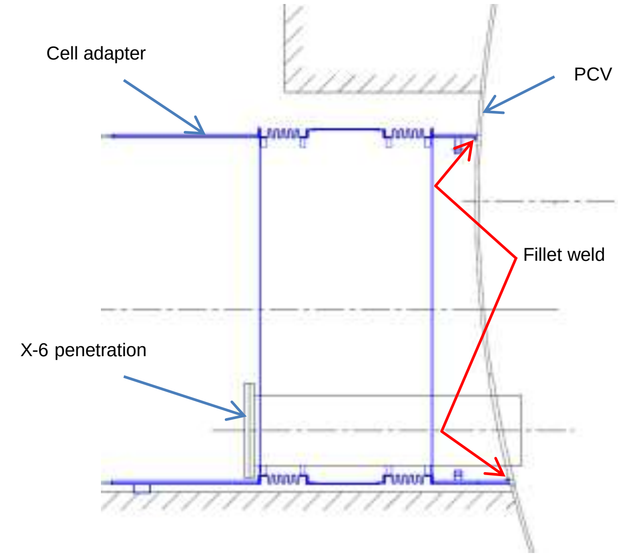
2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Study of methods for sealing between PCV and cell

- Main design specifications of cell adapter

Welding method	One side TIG fillet weld
Beveling	No (considering accessibility by torch)
Main materials	SM490B (welding part), SUS316, etc.
Function	Sealability to maintain negative pressure
Inspection	[Before welding] Gap check, [After welding] Appearance check, pressure resistance and leak tests
Others	･Seismic displacement is absorbed by bellows (displacement of 20 mm in both horizontal and vertical direction is assumed) ･Planning to adopt a double-bellows (thin plate) system for redundancy



- Issues for sealing by welding
  - ➢ The feasibility of sealing by welding was verified by the welding test conducted (using a partial model) in FY2016.

[1] Remaining/predicted issues

Collect useful data on welding (review of welding conditions, techniques and equipment, methods of welded joint repair, handling of mill scales that are generated in TIG welding on rare occasions, temporary fitting method, etc.)

Select and verify adequacy of a method to remove paint and rust on the PCV surface

Method to align beveled edges to be welded together in groove welding (remote-controlled beveling and the alignment of the beveled edges based on surface measurement)

Feasibility of producing a metallic double bellows (thin plate) (assurance of redundancy, if there is an alternative mechanism, it will be studied as well)

Verify the soundness of the material used for the PCV (conducted on Unit1, including Estimate, by remote-control, the hardness measurement and examine materials removed from the PCV by the opening boring)

[2] Collect useful data concerning welding work (to be implemented when it becomes necessary in the course of discussion with regulatory authorities)

[3] Verify selected welding methods using test samples that simulate actual structures (full-scale models) (including the verification of construction procedures, temporary fitting methods, and the degree of deformation [that cannot be known in tests with samples])

[4] Welder training

* [2] & [3]: Enhance remote-controlled welding technique and screening of welders, [4]: Welder training

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Study of methods for sealing between PCV and cell

- Comparison of sealing methods [A]: Advantage, [B]: Issues (for which testing is under preparation or ongoing for solution), [C]: Disadvantage or issues

Comparative item		Inflate seal (EPDM)	Weld
Features	Sealability	○ Flexibly fitting the undulation of a sealing surface that may be encountered in the actual work site and providing a good seal performance * The seal material needs to be exchanged regularly by remote operation.	○ Permanently sealed * The difficulty level of remote-controlled welding is high.
Workability	Difficulty level of work (including remote-controlled work)	○ Applicability to a sealing surface with irregular shape is relatively high. [B] The preparation of remote-controlled sealing tests using actual size workpiece samples is underway because the difficulty level of remote-controlled sealing work is high.	○ Since the difficulty level of remote-controlled welding is high, remote-controlled welding tests using partial models of workpiece (welding bevel gap, 3D curved surface) were performed and the feasibility of the method was verified. * It is necessary to establish the method for beveling the part to be welded that has a surface undulation according to data obtained by measuring the PCV surface as well as the method to align the beveled edges by remote operation. * It is necessary to establish the method of repairing welded joints, and the method to take care of mill scales that are generated in TIG welding, on rare occasions. * The overall verification of the welding method using a full-scale model is necessary, including verification of a temporary fitting method and the impact assessment of deformation by welding.
	Verification and inspection	*Under consideration	○ Appearance inspection and leak inspection
Maintainability	Maintenance and exchange	[B] Periodic exchange. Preparing tests of the sealed surface, securing an alternate boundary, and sealing exchange work is underway because of the high difficulty level of remote-controlled seal exchange work.	○ Only basic monitoring
Response to emergency/accident	Seal performance deterioration	○ Periodic exchange is required due to deterioration by radiation. ○ Relative displacement caused by earthquake or other conditions can be absorbed by the flexibility, and the inertial force is negligible.	○ Relative displacement and inertial force caused by earthquake or the like can be absorbed by the bellows. ○ The deterioration of seal performance is not likely to occur because a corrosion margin is incorporated in carbon steel in advance.
	Abnormality detection	○ The deterioration of seal material can be detected by the monitoring of the inner pressure of the seal material. * Sealing performance can be monitored by the pressure of the boundary indirectly.	* Sealing performance can be monitored by the pressure of the boundary indirectly.
	Restoration	[B] The same procedure as seal material exchange applies. Preparation of tests that simulate work in the actual reactor is underway.	* Leaks can be fixed by spraying seal material, subject to the possibility to avoid interference by debris removal equipment.
Waste	Generation of waste materials	* Waste materials are generated by changing seal material.	○ Basically none
Record of application	Nuclear facilities	○ It is typically used as a component of the boundary of cells constructed in reprocessing facilities * Only the record of small seal materials and not large seal materials as far as remote-controlled exchange is concerned.	○ Boundary construction by welding is general. * The difficulty level of the alignment of beveled edges, temporary fitting and welding work of them by remote operation is high.

7. Implementation Details

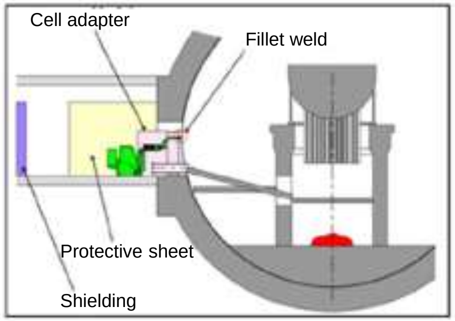
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

- Purpose of development
  - ➢ Establish methods and technologies to improve the sealability (sealing performance) of the connection between the PCV and cells, which is essential to meet one of the highest priority requirements among all safety requirements, that is, the "confinement of radioactive materials"
  - ➢ Establish methods and technologies to install and exchange seal material by remote operation
    - ✓ The following items will be included in the study concerning the construction of confinement boundary:
      - Improve the sealability of existing primary boundaries (such as those of the PCV)
      - Seal design of newly constructed primary boundaries (such as those of cells)
      - Negative pressure control inside the primary boundary
    - ✓ The following methods have been studied for the sealing of the connection between cells and the PCV until now.
      - Sealing by welding (figure on the right)
      - Sealing by seal materials (such as organic seal materials)



- Issues to be resolved

It is necessary to verify that;

- ➢ The applicability of the seal material to sealing the connection between the fuel debris retrieval work cell and PCV, including durability for long-term use.
- ➢ The feasibility and safety of the remote-controlled operation to install and exchange the seal material.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. <u>Work cell sealing method (such as welding, inflate sealing or water sealing)</u>

- Issues to be resolved

  It is necessary to verify that;

  - The applicability of the seal material to sealing the connection between the fuel debris retrieval work cell and PCV, including durability for long-term use.
  - The feasibility and safety of the remote-controlled operation to install and exchange the seal material.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. <u>Work cell sealing method (such as welding, inflate sealing or water sealing)</u>

- Development approach
  - ➢ Development is conducted in multiple phases while the applicability of seal materials is being examined.
    - ✓ Phase 1: Applicability evaluation and test planning through desk study and preliminary tests
    - ✓ Phase 2: Applicability evaluation of seal materials by stand-alone element tests
    - ✓ Phase 3: Combination element tests using M/U module
  - ➢ Before proceeding to the next phase, expert review is provided

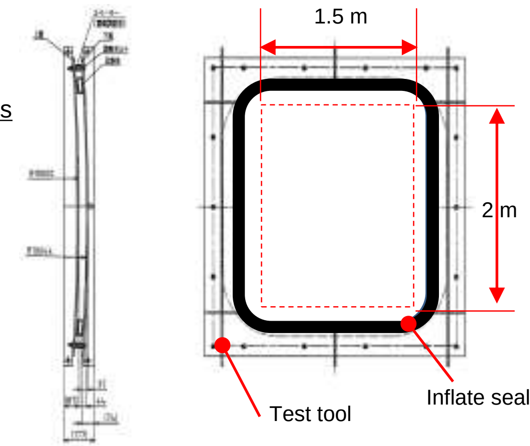
- Expected results
  - ➢ Select and evaluate seal material used to seal the connection between the PCV and cells
  - ➢ Design specifications of the sealing structure using seal material
    - ✓ Applicable range and other specs
  - ➢ Seal material installation and maintenance procedures (proposed)
    - ✓ Installation and maintenance procedures of seal material that is applied to the sealing of a 3D curved surface
    - ✓ Procedure to ensure an alternate boundary

Seal between BSW and PCV Element Test

until December 2017 (Phase 1)

- <u>Verification of performance to seal part having a 3D curved surface</u>
- <u>Monitoring of the soundness of the seal material during operation</u>

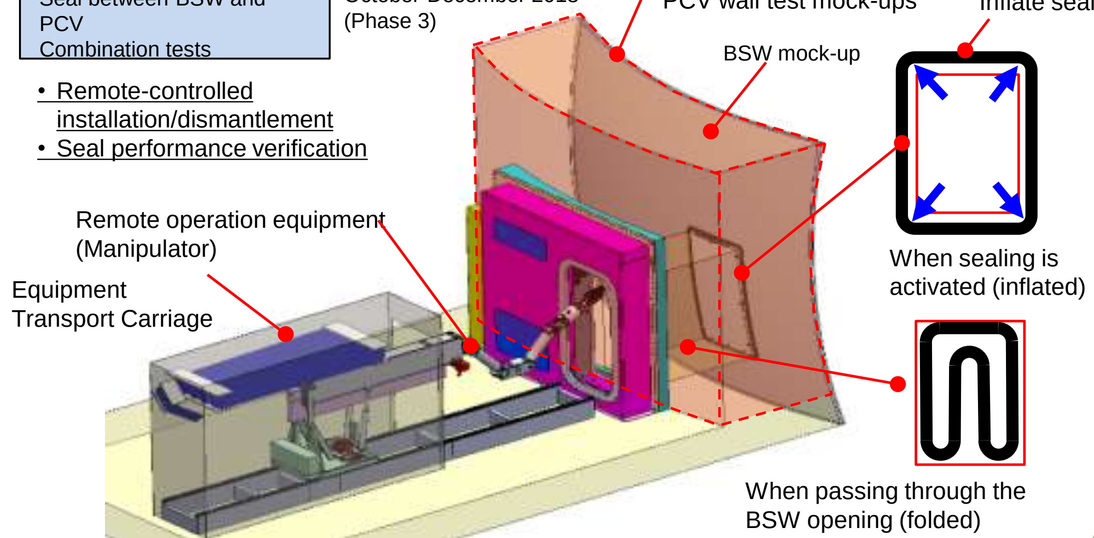
- A size covering an outer dimension of 2 m x 1.5 m
- Metallic molding
- EPDM



Seal between BSW and PCV Combination tests

October-December 2018 (Phase 3)

- <u>Remote-controlled installation/dismantlement</u>
- <u>Seal performance verification</u>



7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

- Development goals
  - The maximum permissible leakage required for individual sealing parts, each of which is subjected to different differential pressures, shall be met for common sealing means to be employed in different parts
    - ✓ The element test to examine performance to seal a part with a 3D curved surface needs to be performed using a test tool specially made for this purpose.
  - Remote-controlled installation/dismantlement
    - ✓ The sealing material needs to be foldable to clear the opening in BSW. It will be inflated during sealing
  - An alternate boundary shall be prepared while maintaining the seal material to ensure workers' safety
- Environmental conditions (examples):
  - Dose rate (1F R/B): 5-10 mSv/h
    Dose rate (near PCV shell outer wall): 10-100 Sv/h
    -> Assume increase of dose rate to the level equal to inside PCV
  - Temperature: 0-40° C
  - Humidity: Same level as the atmosphere outside the facility

* Specific values will be determined during the course of study.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. <u>Work cell sealing method (such as welding, inflate sealing or water sealing)</u>

- Test and judgment conditions (examples)
  - Tests and subsequent judgment shall be made assuming that the PCV and BSW have 3D curved surfaces based on drawings.
  - Dimensions of BSW opening: 2 m x 1.5 m (tentative)
  - Leak tests shall be performed to confirm the following:
    - ✓ In the leak test by the pressure drop method, 50 percent of the initial additional pressure of 300Pa shall be maintained after a test period of 30 minutes.
    - ✓ There shall not be continuous bubble generation, increased bubbling, or air eruption in the bubble leak test.
  - Remote-controlled installation and dismantlement
    - ✓ The seal material can be inserted to a depth of 100 mm (tentative) from the opening entrance
    - ✓ The sealing material can be removed from the sealing gap smoothly.

* Specific test values and judgment conditions will be determined during the course of study.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. <u>Work cell sealing method (such as welding, inflate sealing or water sealing)</u>

(1) Functional Requirements

- The sealing means applied to connection parts is one of requisite elements to construct the boundaries based on basic safety requirements. Thus, functions that the sealing means need to provide must be identified based on basic safety requirements.
  - Confine radioactive materials by setting a boundary
- Safety requirements shall be met during sealing means installation, maintenance and exchange tasks.
  - Worker exposure reduction

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

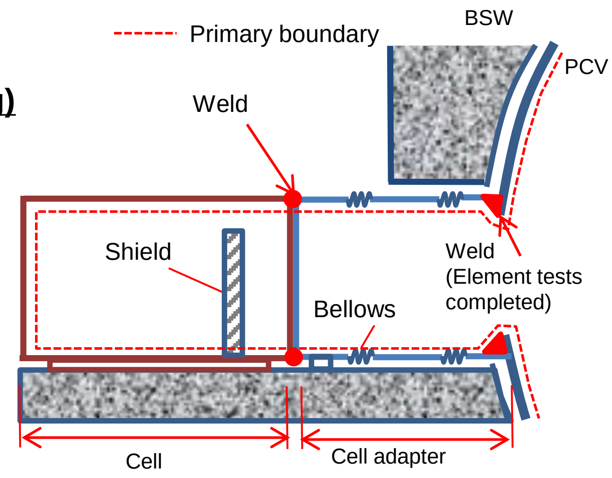
[1] Element technology development related to work cell

b. <u>Work cell sealing method (such as welding, inflate sealing or water sealing)</u>

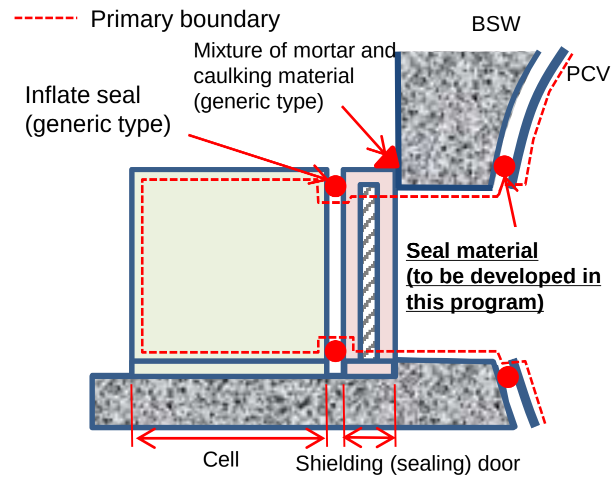
(2) Means to meet functional requirements

- Construction of a boundary formed by the PCV, a cell and the connecting part (sealing part) between the PCV and the cell
- Maintaining the inside pressure of a boundary at a lower level than the surrounding area to suppress radioactive material leakage to within a permissible level
- The following means shall be considered as candidates for sealing means:
  - Sealing by welding
    - High reliability over a long period of time is expected
    - Some parameters affecting the quality and performance of welding (such as a gap) need to be controlled within a narrow range, though it can be difficult.
      -> The feasibility of a remote-controlled welding method that can achieve the required sealing performance was proved by element tests performed until last fiscal year
  - Sealing by seal material
    - Sealing material is easier, and the applicable range is wider than weld sealing
    - There is an issue involving use over a long period of time since periodic exchange is required.
      -> The feasibility will be verified in this technical development

Both welding and seal material methods will be continuously studied in parallel since each method has its own issues, and it's not possible to select one of them at present.



<u>Example of sealing by welding</u>



<u>Example of sealing by seal material</u>

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(3) Requirements

- In normal conditions, leakage at the seal part shall be 40 m^3/h or less.
    - This target is set based on the total area of unsealed apertures, with which a negative pressure target of -100 Pa can be still maintained by the ventilation capacity of 1000 m^3/h.
    - Assuming that unsealed apertures spread on the surface of the primary boundary uniformly, the area of unsealed apertures per unit surface area of the cell is set as the permissible area of unsealed apertures at the sealing part.
    - The amount of leakage that occurs when a target negative pressure is applied to the sealing part is used to define a target value since the area of unsealed apertures cannot be measured.
- Differential pressure used for design: (to be determined) the soundness of the sealing part must be assured against applied pressure difference.
- Relative displacement: the soundness of the sealing part must be assured against a replacement of ± 5mm.
    - This value is set based on an assumed relative displacement between the PCV and R/B in earthquake.
- Sealability shall not be degraded (worse than a target leakage of 40 m^3/h) by change in the shape of the seal material.
- Material resistant to deterioration over time shall be used for the seal material.
- The sealed part is subject to periodical maintenance (inspection and replacement).
- The seal abnormality should be detectable during fuel debris retrieval.
- Means to maintain the confinement performance of the primary boundary shall be provided during maintenance.
- Reduce workers exposure during installation and operation (maintenance) of sealing means.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(4) Issues and countermeasures for basic functions

Basic functions	Issues	Measures	Notes
Leakage at sealed part: 40 m^3/h or less	Capability to seal part having a 3D curved surface	Verified by element test (unit test)	Already verified by fundamental test as well
	Sealing without a guide groove for seal material	Verified by element test (unit test)	
	Sealing of part having a gap made by welding, etc.	Verified by element test (unit test)	Already verified by fundamental test as well
Differential pressure used for design: (to be determined) the soundness of the sealing part must be assured against applied pressure difference.	Same as above	Verified by element test (unit test)	
Relative displacement: the soundness of the sealing part must be assured against a replacement of ± 5mm.	Same as above	Verified by element test (unit test)	
Sealability shall not be degraded (worse than a target leakage of 40 m^3/h) by change in the shape of the seal material.	● Same as above ● Provision of sealing performance in case of lost inflation pressure of the seal material	Verified by element test (unit test)	
Material resistant to deterioration over time shall be used for the seal material.		EPDM is adopted	
The sealed part is subject to periodical maintenance (inspection and replacement).	● Feasibility of remote-controlled tasks ● Flexibility of the sealing means to cope with variation in the condition of the sealing part	Procedures of remote-controlled exchange work and the sealability of the seal material installed by the remote operation will be examined by element tests (combination element tests)	
	● The influence of maintenance on throughput needs to be reduced.		
The seal abnormality should be detectable during fuel debris retrieval.		Monitoring of the inner pressure of seal material	
Means to maintain the confinement performance of the primary boundary shall be provided during maintenance.	● Sealability of boundary during temporary closure	Feasibility is confirmed by desk study Needs to be examined in the course of study	
Reduce workers exposure during installation and operation (maintenance) of sealing means.	Dose reduction for workers during recovery and restoration	If intervention by workers is necessary, each worker time in high radiation areas must be measured to assess exposure levels.	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

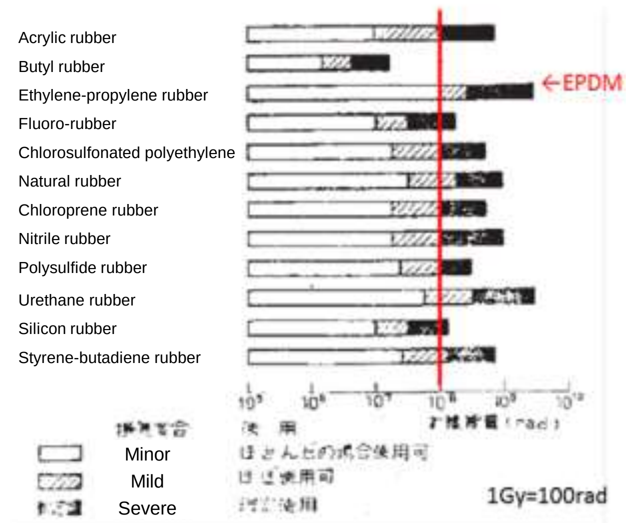
b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(5) Select and evaluate materials used for the inflate seal

EPDM (Ethylene Propylene Diene Monomer, popularly called as ethylene-propylene rubber) was selected as the material of the inflate seal. EPDM has high radiation resistance along with other suitable properties, such as heat resistance and resistance to hot water. Due to its well-balanced properties, there are records of applications in nuclear facilities.

Although urethane rubber has similar radiation resistance to EDPM, it is inferior to EDPM in heat resistance and resistance to hot water. There is data indicating EPDM's radiation resistance is as high as 10^6 [Gy]. Based on this date, the durability of EPDM under 100 Sv/h is approx. one year and two months.

	Ethylene-propylene rubber EPDM	Urethane rubber	Fluoro-rubber	Silicon rubber
Sealability	[A] Widely used as generic seal material. Superior in hot water resistance.	Not Applicable It is widely used as generic seal material. However, resistance to heat, water and humidity is low.	[A] Widely used as generic seal material. Superior in hot water resistance.	Not Applicable Widely used as generic seal material. However, it is inferior in resistance to gas permeation.
Workability	[A] Widely used and superior in workability	[A] Widely used and superior in workability	[A] Widely used and superior in workability	[A] Widely used and superior in workability
Actual Schedule	[S] Widely used under radiation environment with a proven track record.	Not Applicable Use in nuclear facility is relatively rare.	[A] It is used under radiation environment with a proven track record.	[S] Widely used in nuclear facilities with a proven track record.
Radiation resistance	[S] Superior in radiation resistance compared to other rubber materials.	[S] Superior in radiation resistance compared to other rubber materials.	Somewhat Applicable It is inferior to EPDM and urethane rubber.	Somewhat Applicable It is inferior to EPDM and urethane rubber.
Total evaluation	[S]	Not Applicable	Somewhat Applicable	Not Applicable



Cited from "Polymeric Materials for Atomic Power Industry" published by Japan Atomic Energy Research Institute
http://jolissrch-inter.tokai-sc.jaea.go.jp/pdfdata/JAERI-M-9412.pdf

[S] Excellent, [A] Good, [B] Acceptable

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

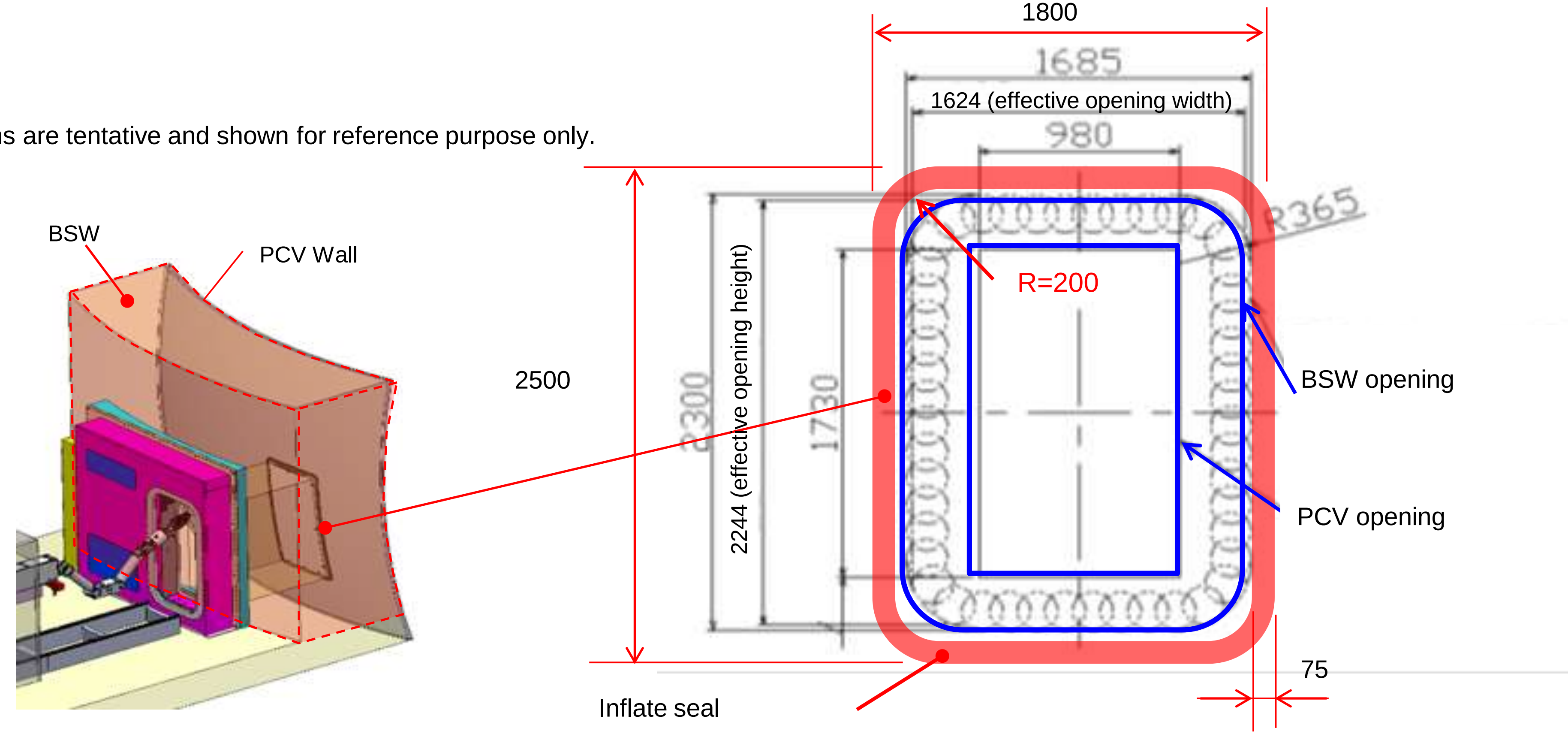
[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(6) Study of circumference shape of sealing part

The circumference shape of the inflate seal's sealing part shall be in a rectangular shape that fits the BSM opening in consideration of the easiness of installation by remote operation.

* Dimensions are tentative and shown for reference purpose only.



7. Implementation Details

7.2. Implementation Details

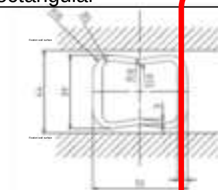
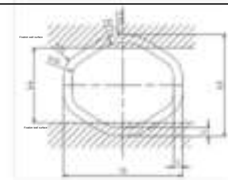
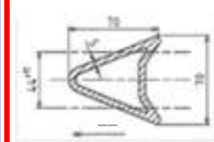
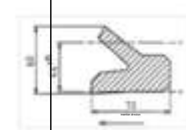
2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(7) Selection of the cross-section shape of sealing part

Shapes of the cross-sectional shape of sealing part were narrowed down to rectangular and rhombic using a inflate seal material as the result of the following evaluation items.
Further study of the cross-sectional shape of sealing part will be conducted by putting weight on a rhombic shape. Self-sustained recovery in an emergency and sealability is highly likely.

Evaluation item		Evaluation of cross-section shapes			
		Rectangular	Diamond	Mound-shaped	Lip-shaped
					
Sealability	Gap between BSW and PCV (width of approx. 50 mm, 3D spherical surface)	[A]	[A]	[A]	[B] Less flexibility and ability to fit with a given shape
	Absorption of displacement caused by thermal expansion or earthquake	[A]	[A]	[A]	[B] Less flexibility and ability to fit with a given shape
	Crossing with bumpy weld lines of the PCV	[B] Leakage risk involved.	[B] Leakage risk involved.	[C] Leakage due to small contact face.	[C] Leakage due to small contact face.
Handling ability	Remote-controlled handling (carrying-in, installation and replacement)	[A]	Good ○: applying negative pressure and inserting into the position	C: Low foldability B] Friction during insertion	[B] Lip caught
Consideration of ability in trouble	Consideration of ability in trouble (when the inflation pressure is lost)	Somewhat Applicable The seal material cannot retain its proper position. Somewhat Applicable Leakage occurs because it cannot seal contacting surface with sufficient pressure.	[A] The position can be retained. Somewhat Applicable Leakage suppression can be expected due to contact surface pressure.	A] The position can be retained. Somewhat Applicable Leakage suppression can be expected due to contact surface pressure.	[A] The position can be retained. Somewhat Applicable Leakage suppression can be expected due to contact surface pressure.
Total evaluation		Somewhat Applicable	[A]	Not Applicable	Not Applicable

A: Good
[B] Poor
C: Low feasibility

7. Implementation Details

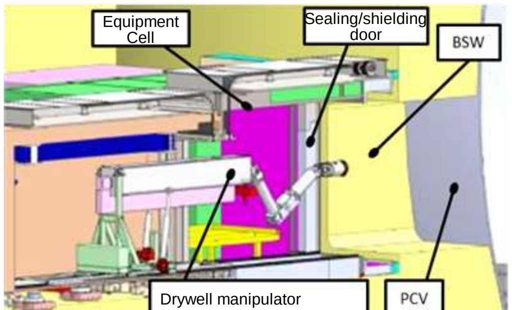
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

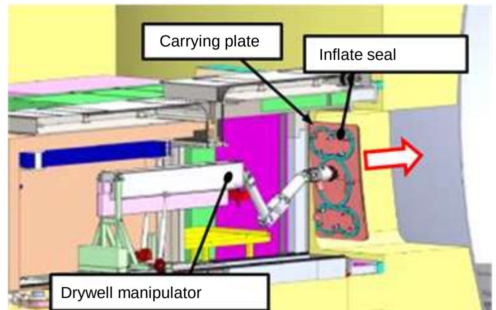
[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

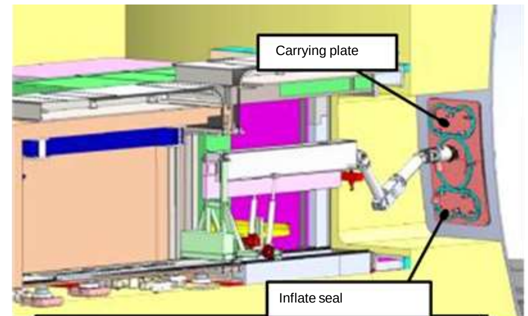
(8) Procedures of the remote-controlled installation of the inflate seal



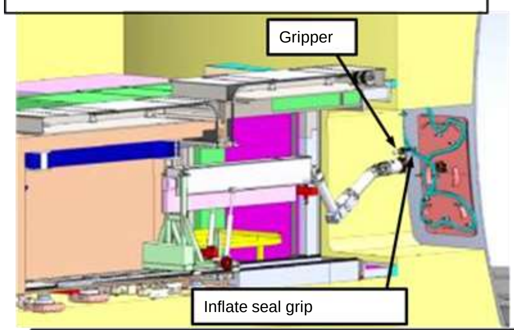
<Step 1: preparation for installation>
- Boring of BSW, installation of the equipment cell, and installation of the drywell manipulator need to be finished so that installation of the inflate seal can be started anytime.
- It needs to be confirmed in advance that there is no object blocking installation of the inflate seal between BSW and PCV. If there is, the object needs to be removed by the drywell manipulator.

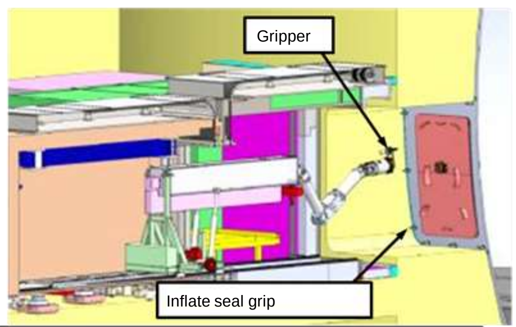


<Step 2: carriage of the inflate seal>
- Carry the carrying plate the inflate seal is attached to by the drywell manipulator.

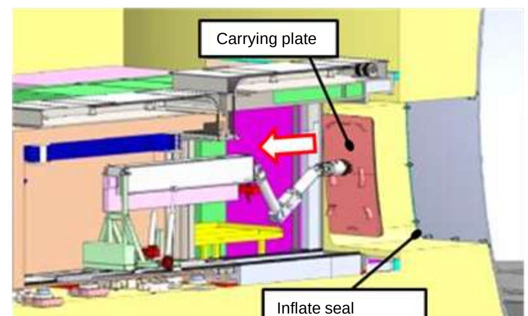


<Step 3: placement of the carrying plate>
- Mount the carrying plate on the PCV wall. Fix the carrying plate on the PCV wall by magnets that were attached to the backside of the plate in advance.





<Step 4: installation of the inflate seal>
- Grasp pre-installed grips of the inflate seal by the gripper and move them to positions predetermined for each grip one at a time. Here, magnets are attached to the inflate seal adjacent to each grip so that the inflate seal can be installed in the predetermined position.
- Check the position of the inflate seal by visual inspection and/or dimension measurement to make sure it has been installed in the right position.
- Connect an air supply tube to the inflate seal and inflate it with air.



<Step 5: Carrying-out of the carrying plate>
- Move the carrying plate with the drywell manipulator out of R/B.

7. Implementation Details

7.2. Implementation Details

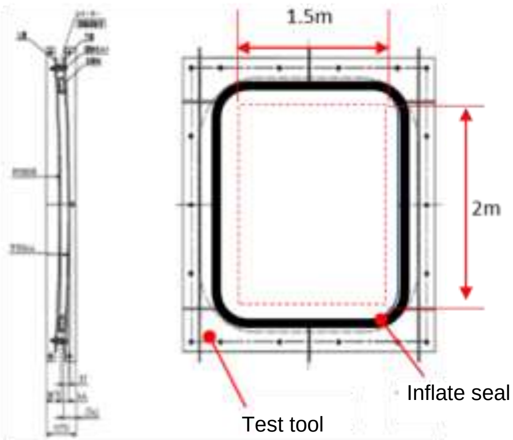
2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

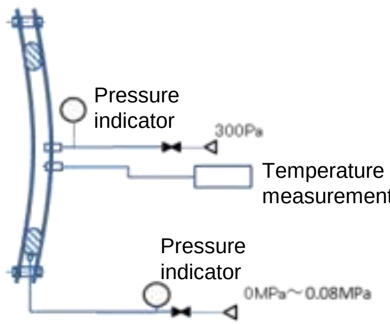
b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(9) Unit test plan

Test procedures and criteria



[Seal material production]
- Metallic molding
- EPDM
- Provided with bosses for interface



[Test procedure]
[1] Attach the test facility to a test tool, sandwich them with two curved plates, and narrow the gap between the plates to a predetermined width.
[2] Inflate the seal material with pressurized air.
[3] Increase the inner pressure of the closed space formed by the seal material and the test tool to a predetermined seal pressure*.
[4] Evaluate ability to fit with a given shape and sealability.
[5] Maintain the seal pressure and measure leakage.
[6] Measure the displacement in the direction of the line perpendicular to the sealing part circumference.
[7] Stand the test facility with the test tool up straight and check whether it stays in the right sealing position.

* The seal pressure is set at 300 Pa based on the designed differential pressure plus margin. In addition, the seal pressure is increased up to 500 Pa gradually, and leakage is measured to

Test parameters

Seal material inner pressure [MPa]	Gap width [mm]	Weld line simulant bump
0	50	No
0	55	No
0.03	55	No
0.08	55	No
0	50	Yes (Height: 3 mm)
0.03	50	Yes (Height: 3 mm)
0.08	50	Yes (Height: 3 mm)
0	50	Yes (Height: 1 mm)
0.03	50	Yes (Height: 1 mm)
0.08	50	Yes (Height: 1 mm)

Check item	Criteria
Ability to fit with a given shape	No aperture in the contacting surface
Sealability (bubble leak)	No continuous bubble generation, no increased bubbling, nor air eruption
Leakage measurement	Leakage at the differential pressure in actual use, which is calculated with test data, shall be equal to or less than the maximum permissible leakage.
Retention of sealing position	The test facility shall stay in the right sealing position when the test facility with the test tool is stood up straight.
Circumference shape of sealing part (It is assumed to change its shape from rectangular to round as being inflated)	No abnormal deformation in its circumference shape of sealing part

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

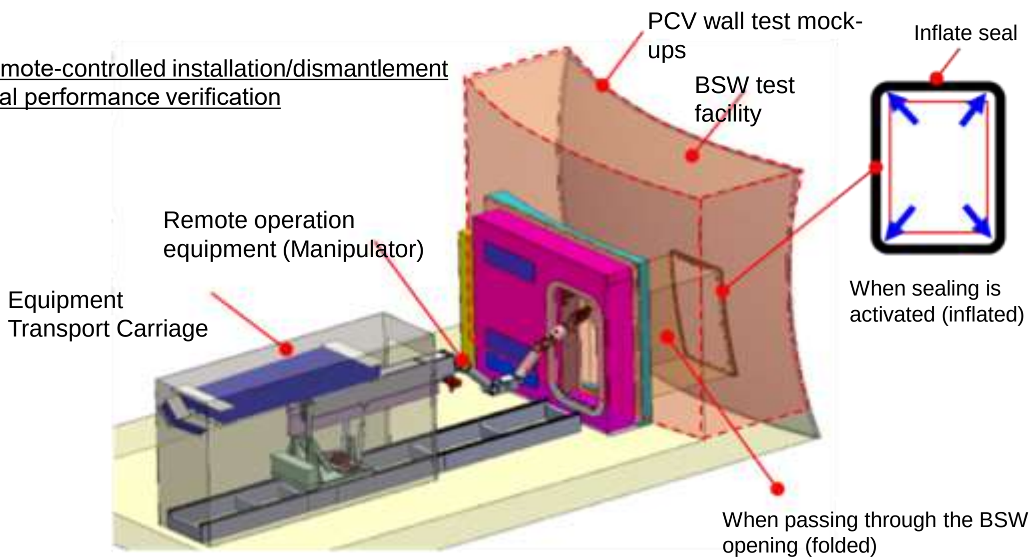
[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)

(10) Plan of combination tests

Test procedures and criteria

- Remote-controlled installation/dismantlement
- Seal performance verification



Check item and procedure	Criteria
Attach the inflate seal to the installation tool and grasp the tool by the manipulator.	The inflate seal shall be installed in the right position. The inflate seal shall be grasped by the manipulator.
Carry in the inflate seal through the BSW opening	The inflate seal shall clear the BSW opening without interference.
Insert the inflate seal into the gap and fix it	The inflate seal shall be inserted into the gap at a predetermined depth. The position of the inflate seal shall be fixed.
Increase the inner pressure of the inflate seal and then verify sealability (bubble leak test)	There shall not be continuous bubble generation, increased bubbling, or air eruption.
Leakage measurement	Leakage with a constant testing pressure of 300 Pa for the sealed space shall be equal to, or less than, the maximum permissible leakage.
Removal of the inflate seal from the gap	The inflate seal shall be removed from the gap smoothly.
Carry out the inflate seal through the BSW opening.	The inflate seal shall clear the BSW opening without interference.
Inflate seal exchange procedure	The inflate seal exchange procedure shall be feasible.

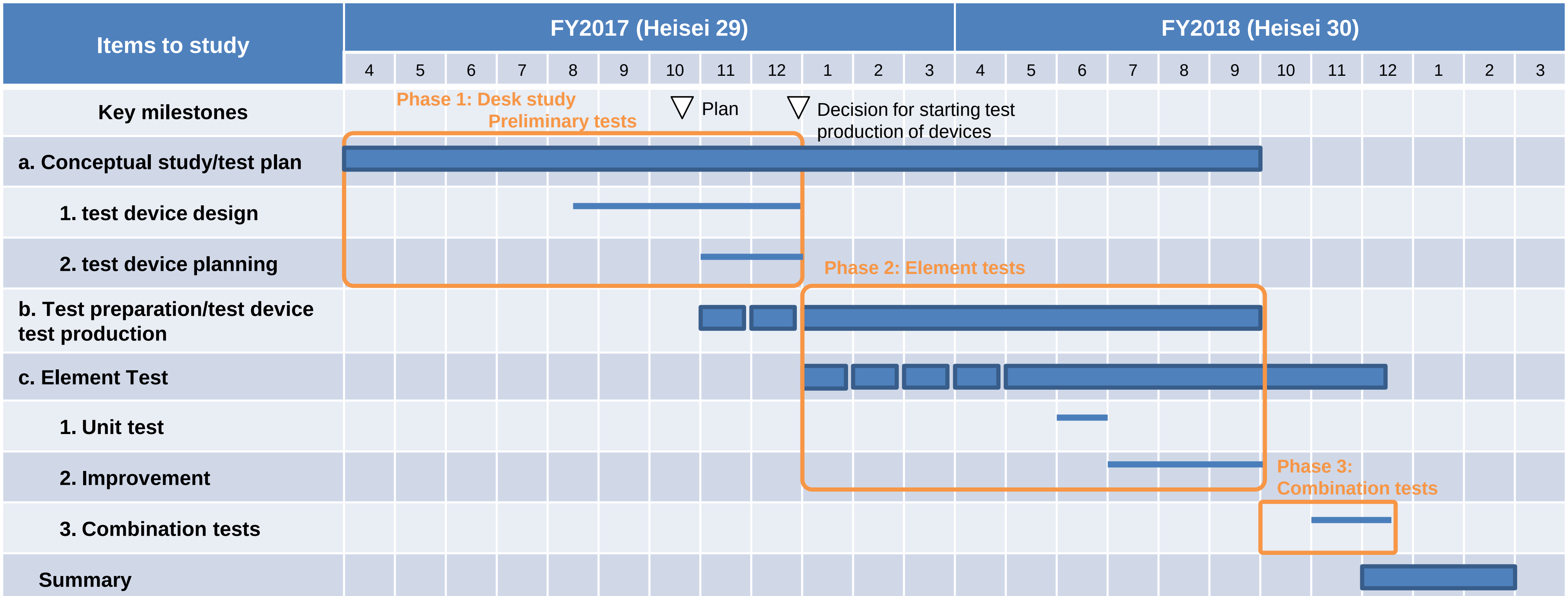
7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

b. Work cell sealing method (such as welding, inflate sealing or water sealing)



Notes

Expected results

[1] Select and evaluate seal material used to seal the connection between the PCV and cells

[2] Design specifications of the sealing structure using seal material

- Applicable range and other specs

[3] Seal material installation and maintenance procedures (proposed)

- Installation and maintenance procedures of seal material that is applied to the sealing of a 3D curved surface
- Procedure to ensure an alternate boundary

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

Development of remote technologies necessary to realize the dismantlement, removal, collection, and carrying-out of debris and element tests are planned; there are interfering objects on the access route to fuel debris whether the side entry or the top entry methods are chosen; the removal of those interfering objects is a challenge for successful fuel debris retrieval; basically, those interfering objects need to be removed remotely. The following things are considered in the plan:

- Interfering objects that block access from top entry: PCV upper structures (such as well shield plug, PCV head and RPV head), reactor pressure vessel (RPV) internals (such as dryer and separator)
- Interfering objects that block access from side entry: Equipment outside the pedestal
- Interfering objects that block both top entry and side entry: equipment inside the pedestal (CRD housing. etc.), R/B internals (contaminated instrumentation guide tubes, high radiation pipes, etc.)*1

Note that newly identified issues in studying access routes, such as the removal of obstacles, will be addressed without exception and measures for them will be studied.

*1: The study of removal methods for R/B internals (contaminated instrumentation guide tubes, high radiation pipes, etc.), will be conducted only on structures that will apparently block fuel debris retrieval work.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

- Purpose of development
  - Verify feasibility of methods for removing interfering objects (including fuel debris adhered to them) that block access to fuel debris

- Issues to be resolved
  - Feasibility of remote work
    - ✓ Removal procedures and methods
    - ✓ Fall prevention
    - ✓ Cabling and task monitoring method
    - ✓ Method to carry out removed objects

  - Selection of processing tools
    - ✓ Applicability of processing tools for removal work
    - ✓ Measures to prevent the dispersion of dust generated by the PCV opening boring

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

- Development approach
  - Identification of interfering objects that need to be removed
  - Study of interfering object processing methods
  - Element test plan
    Interfering objects are picked up, and element tests are conducted with them to evaluate the possibility of removal work
    - ✓ Method to remove interfering objects by fuel debris retrieval equipment by the top entry method (The the side entry method is also taken into account)
      - Methods to remove structures in RPV bottom part (including CRD housing)
    - ✓ Methods for removing interfering objects by fuel debris retrieval equipment using the side entry method
      - Means and method to remove interfering objects (pipes and supports) outside Pedestal
      - Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside
    - ✓ Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries
      - Means and methods for removing interfering objects inside the pedestal
      - Verifying maneuverability by a combination of a robot arm and access rail
  - Feasibility verification by elemental tests

- Expected results
  - Feasibility of processing methods used for removing interfering objects
  - Feasibility of the PCV opening construction methods
  - Calculation of throughput using each work time

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

The following conceptual study and element tests are planned:
It was decided to the conduct element tests focusing on the technology development of the side entry method for fuel debris retrieval, following the decision about the debris retrieval policy by the Ministry of Economy, Trade and Industry and the Agency for Natural Resources and Energy.

Common

- Interfering objects that need to be removed to clear the access route to fuel debris were identified for all possible access methods and the applicability of various processing methods was studied. In addition, a conceptual study on the throughput of obstacles removal work is being implemented.

a. Method to remove interfering objects by fuel debris retrieval equipment by the top entry method

- A conceptual study and element tests concerning methods of removing interfering objects in the RPV bottom part are planned for the following reasons: in the RPV bottom part, molten fuel debris and metal structures mixed together and solidified to form objects that are very difficult to process; and measures to prevent the fall of equipment laid out in the reactor bottom, such as CRDs and the CRD housing during removal work, will be difficult compared to other structures since those equipment will lose support and fall*1 when they are cut from the RPV side.

b. Methods for removing interfering objects by fuel debris retrieval equipment using the side entry method

- According to the policy to put weight on the side entry method, study and relevant element tests concerning specific methods for removing interfering objects that block the access route to fuel debris in and outside the pedestal are planned mainly from the priority viewpoint.

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

- Element tests concerning the removal of fallen objects, such as CRD, are planned with regard to interfering objects in the pedestal.
- Element tests concerning the maneuverability of a robot arm and access rail combined mechanism are planned.
- A conceptual study of removal methods that combines the top entry and the side entry methods is planned.

*1: It is assume the result of the PCV inside investigation conducted on Unit3 that CRD support structures d by are not working.

IRID

7. Implementation Details

7.2. Implementation Details

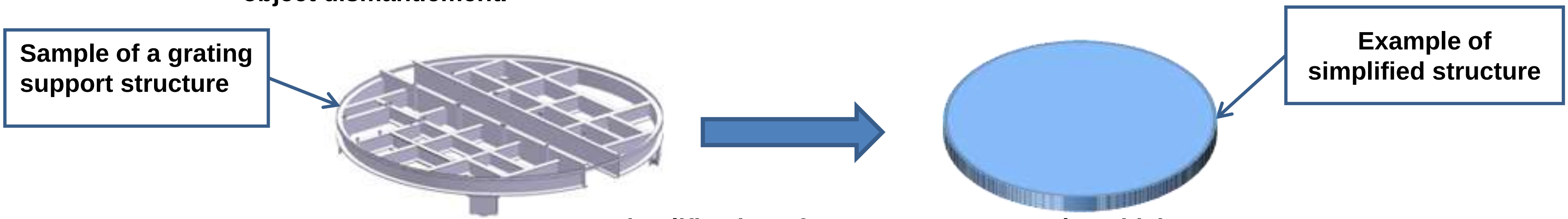
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

A conceptual study on the method for estimating the throughput of interfering object removing work is being implemented.

- **Simplification of structures**

  Complex structures are simplified to estimate a rough time period for interfering object dismantlement.



Simplification of structure, constant plate thickness, etc.

- **Use of a fixed cutting speed**

  Only one severing method is assumed to eliminate the influence of the type of a severing method on the time period estimation.

Table 6.1.2-1 Variation of plate cutting speed with the plate thickness and the type of cutting methods

Plate thickness (mm)	Laser (mm/min)	Plasma arc (mm/min)	AWJ (mm/min)	Wire saw (m^2/h)
5 or less	3,000	900	300	0.05
6-35	250	400	70	0.05
36-150	40	60	15	0.05

The cutting speed data is cited from the JAEA technical report "The Selection of the Cutting Technologies for Removing the Fugen Reactor".

- Cutting speed of disc cutter (actual measurement by IRID)
  [86 mm/min] when cutting a plate whose thickness is up to 230 mm

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

- **Temporary preconditions concerning the collection and handling of interfering objects are set in the table below to estimate the throughput of interfering objects removing work.**

No.	Items	Temporary preconditions	Notes
1	Number of work days for interfering object dismantlement per year	200 day (Remaining days are used for maintenance)	
2	Daily work hours for interfering object processing	Within 24 hours	
3	Amount of interfering objects	The amount of interfering object that need to be removed to start the fuel debris retrieval is being studied for each plan of the side entry method.	
4	Interfering object processing tools	1. Follow the "Cutting procedures for removing FUGEN reactor" by JAEA. 2. Disc cutter 3. Processing tools applicable to the RPV bottom part (CRD housing), biological shielding wall, pipes and support structures outside the pedestal, and pedestal internals are selected by the element tests of this project.	
5	Interfering object processing speed	1. Follow the "Cutting procedures for removing FUGEN reactor" by JAEA. 2. Disc cutter: [86 mm/min] when cutting a plate whose thickness is up to 230 mm 3. Processing speeds of the RPV bottom part (CRD housing), biological shielding wall, pipes and support structures outside the pedestal, and the pedestal internals are calculated using data obtained in the element tests of this project.	
6	Method to collect processed interfering object	The speed of collection work is being estimated based on the use of collection methods with a solid track record, such as grasping and scooping.	
7	Dimensions of processed interfering object collection can	1. It was assumed that the maximum gross weight of a fully loaded collection can is 100 kg (equivalent to a cubic iron block with a 230 mm side length) to be able to be handled by a manipulator arm. 2. Dimensions are being studied within the range that can clear the PCV opening for each plan of the side entry method.	
8	Interfering object handling speed	Interfering object handling speed is being estimated based on the use of handling methods with a solid track record.	

7. Implementation Details

7.2. Implementation Details

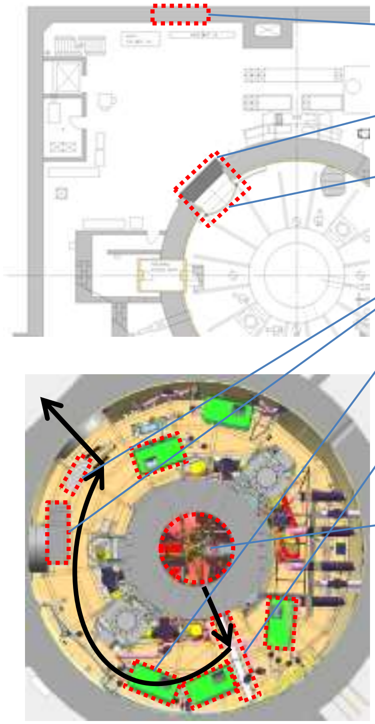
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

- **A projected output image of the throughput of interfering objects removing work as of the end of FY2018 is shown below.**

(red box) **: interfering objects removing tests are planned.**

(red dotted box) **: Interfering object removing range**



Examples of processing tools

No.	Interfering objects	Type	Total weight (ton)	Necessity of removal	Removal period		
					Core boring	AWJ	Disc cutter
1	R/B wall	Waste		[A]	Need to be studied by the team responsible for the building		
2	Shield plug	Waste		[A]	xx days	xx days	xx days
3	Equipment Hatch	Waste		[A]	xx days	xx days	xx days
4	Interfering objects outside the pedestal (HVH, stairs, stages, etc.)	Waste		[A]	xx days	xx days	xx days
5	CRD rail	Waste		[A]	xx days	xx days	xx days
6	Grating	Fuel Debris*1		[A]	xx days	xx days	xx days
7	Grating support structure	Fuel Debris*1		[A]	xx days	xx days	xx days
8	CRD, etc. (fallen objects)	Fuel Debris*1		[A]	xx days	xx days	xx days
9	CRD exchange system	Fuel Debris*1	9	[A]	xx days	xx days	xx days
10	CRD housing	Fuel Debris*1	6	[A]	xx days	xx days	xx days
				Total:	xxx days	xxx days	xxx days

*1: While these are treated as fuel debris, their processing speed is estimated by taking the project element tests into account.

7. Implementation Details

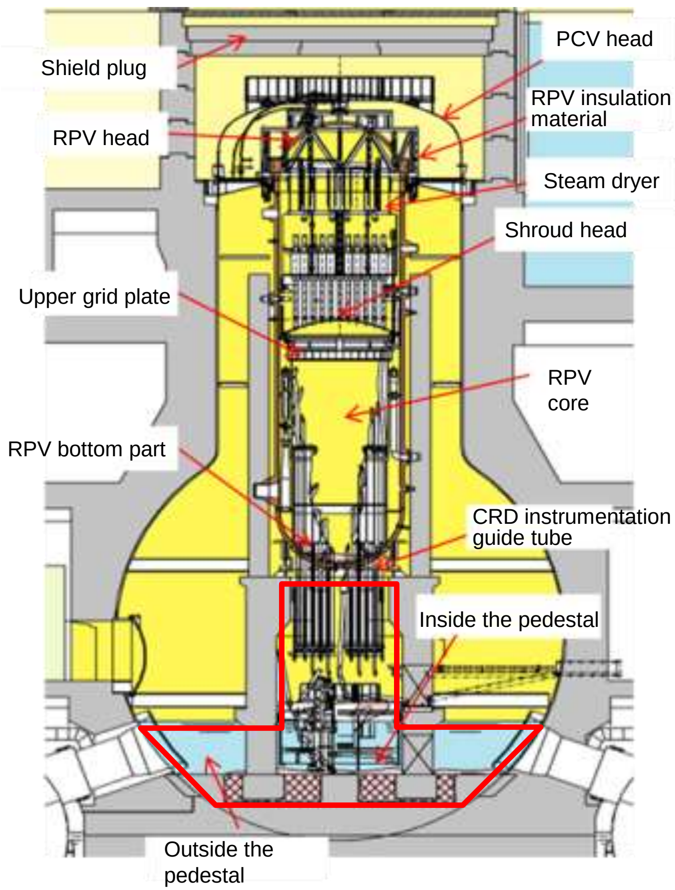
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

A conceptual study on the method to estimate the throughput of fuel debris retrieval work by the side entry method is being implemented.

□ : fuel debris retrieval work areas in the side entry method



No.	Position of distribution	Characteristics	General state	Features	Mass [t]	Debris properties	
					MAAP	Size	Composition
1	RPV core	Fuel rod stubs	Almost all the fuel melted down, and some undamaged fuel assemblies remain in the reactor core periphery. (MAAP)	The top part of fuel assemblies in the reactor core periphery melted down, and a few fuel pellets remain there	0-31	4 m or less	UO_2, ZrO_2, $(U,Zr)O_2$, Zr(O)
		Powdery, Grained	Adhered to or stacked on residual structures	Molten core materials are rapidly cooled down into small pieces		A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
2	RPV bottom part	Powdery, Grained	Both the MAAP and the SAMPSON code indicate small amounts of debris in the lower plenum	Molten core materials are rapidly cooled down into small pieces	21-79	A few μm - a few cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Lumps form		Slowly cooled to form lumps		Thickness A few dozen cm	$(U,Zr)O_2$ $(Zr,U)O_2$
		Crust (bedrock)		Debris formed by mixed and solidified molten metals and oxide fuel		Thickness 0.1-1 m	$(U,Zr)O_2$, $(Zr,U)O_2$, Zr(O),Fe
3	CRD/ instrumentation guide tube	Piping	Debris adhered in gaps inside and on the outer surface of tubes	Debris clogged the flow passage of the lower SUS tubes from the top end of the pressure vessel		Penetration depth 10 and a few cm	$(U,Zr)O_2$, $(Zr,U)O_2$, SUS
4	Inside Pedestal	Powdery, Grained	Because of early water injection, most of the molten debris solidified without forming MCCI There may be MCCI is in the sump pit	Molten reactor core materials leaked out of RPV, dispersed, and quenched Shows little reaction with concrete	92-277	A few μm - a few cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe
		Lumps form		Solidified debris in lump form is distributed uniformly There may be MCCI in the sump pit		Thickness 15 cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$
5	Outside Pedestal	Powdery, Grained	Solidified debris leaked from the pedestal Most is powdery or grainy	Grainy debris has leaked from the pedestal	0-146	50 μm - 20cm	UO_2, Zr(O) $(U,Zr)O_2$, Fe
		Lumps form		Corium leaked from the pedestal reacted with the concrete and solidified Slightly rich in metal component		Penetration depth 0.20 m or less	UO_2, Zr(O) $(U,Zr)O_2$, Fe $(U,Zr)SiO_2$

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

Temporary preconditions for fuel debris retrieval in the side entry method are set in the table below.

No.	Item	Temporary preconditions	Notes
1	Target time period for fuel debris retrieval work	Unit1: 10 years, Unit2: 10 years, Unit3: 10 years	
2	Number of work days for fuel debris retrieval in a year	200 day (Remaining days are used for maintenance)	
3	Daily work hours for fuel debris processing	Within 10 hours	
4	Amount of fuel debris to be removed	Assumed Unit3, which is the largest amount. (attached to CRD/instrumentation guide tubes: 6 tons*, inside Pedestal: max. 277 tons, outside Pedestal: max. 146 tons, total: 429 tons)	
5	Fuel debris processing tool	1. MCCI: chisel processing, ultrasonic core boring, etc. 2. Attached to CRD/instrumentation guide tubes: disc cutter, AWJ, laser, etc. 3. Attached to metallic structure: disc cutter, AWJ, laser, etc.	
6	Fuel debris processing speed	1. Chisel processing, ultrasonic core boring: determined based on the element test results of this project 2. Disc cutter, AWJ, laser: similar processing speeds to those for interfering objects. 3. Core boring: 3.25 kg/h (test result in FY2016) 4. Laser gouging: 4.76 kg/h (test result in FY2016)	
7	Fuel debris retrieval method	A tentative collection speed is being estimated based on collection methods with a solid track record, such as suctioning, grasping, and scooping.	
8	Fuel debris canister size	⌀200 mm as a basic diameter, ⌀400 mm is also considered as an alternative.	
9	Fuel debris handling speed	A tentative handling speed is being estimated based on handling methods with a solid track record.	

*1: according to the result of the investigation in FY2015 by the Reactor Internal Condition Investigation Project

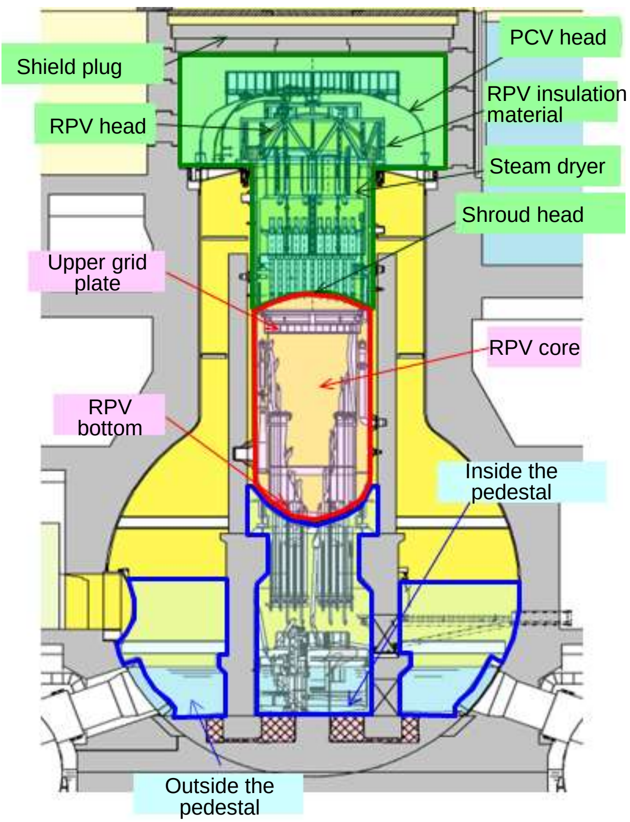
7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

A projected output image of the throughput of fuel debris retrieval work by the side entry method as of the end of FY2018 is shown below.



Examples of processing tools

Waste	Type	Total weight [ton]	Necessity of removal	Removal period		
				Chisel processing	Disc cutter	AWJ
Shield plug	Solid radioactive waste	465	Not Applicable	-	-	
PCV head	Solid radioactive waste	48	Not Applicable	-	-	
RPV insulation material	Solid radioactive waste	13	Not Applicable	-	-	
RPV head	Solid radioactive waste	66	Not Applicable	-	-	
Steam dryer	Solid radioactive waste	31	Not Applicable	-	-	
Shroud head	Solid radioactive waste	48	Not Applicable	-	-	
Upper grid plate	Fuel Debris	7	Not Applicable	-	-	
Shroud	Fuel Debris	46	Not Applicable	-	-	
Jet pump	Fuel Debris	12	Not Applicable	-	-	
Fuel debris in the reactor core	Fuel Debris	31	Not Applicable	-	-	
Fuel debris in RPV bottom	Fuel Debris	79	Not Applicable	-	-	
Core support plate	Fuel Debris	11	Not Applicable	-	-	
Fuel debris attached to the RPV bottom head and CRD housing	Fuel debris*1	6	[A]	-	xx days (x.x years)	xx days (x.x years)
Wastes generated by the PCV opening boring	Solid radioactive waste	40	[A]	Core boring: xx days		
Pedestal internals	Fuel debris*1	90	[A]	xxxx days (x.x years)	xxxx days (x.x years)	xxxx days (x.x years)
CRD exchange trolley	Fuel debris*1	9	[A]			
Fuel Debris inside Pedestal	Fuel debris*1	277	[A]			
Structures outside Pedestal	Solid radioactive waste	30	[A]	xx days	xx days	xx days
Fuel Debris outside Pedestal	Fuel Debris	146	[A]	xxxx days (x.x years)	xxxx days (x.x years)	xxxx days (x.x years)
Total time period				xxxx days (x.x years)	xxxx days (x.x years)	xxxx days (x.x years)

*1: Although wastes on the upper grid and below are classified as fuel debris, processing speed data obtained by the interfering object dismantlement element tests of this project is considered to estimate the time period required to remove these wastes.

7. Implementation Details

7.2. Implementation Details

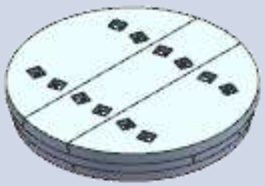
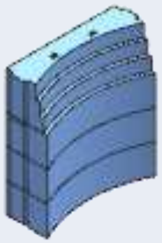
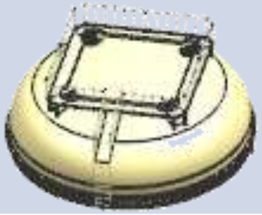
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method for removing interfering objects with fuel debris retrieval equipment by the top entry method

Interfering objects that need to be removed (including reactor internals) were identified and listed.

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
1	Shield plug 	(i) Main material Concrete (ii) Main dimensions ⌀12.5 × H0.6 (top) ⌀12.1 × H0.6 (middle) ⌀11.8 × H0.6 (bottom)	Wire saw (push stroke), Disk saw	(i) Detach from the reactor well and move to the processing platform, cut into small pieces, and remove. (ii) Repeat the process [1] above for each part of the shield plug in the order of top, middle and bottom.	Low	• Removal methods that can cope with the degree of damage and the plan of SFP fuel removal need to be studied.
2	DSP slot plug 	(i) Main material Concrete (ii) Main dimensions H6.3 × W5.6 × L2.1	Wire saw (push stroke), Disk saw	(i) Install the processing equipment on the DSP. (ii) Cut the plug by a wire saw (push stroke), collect cut pieces in a can and transfer them out. (iii) Use other methods for the edge and residual small blocks where necessary and remove.	Low	• Mockup tests were conducted in the government R&D project in FY2016.
3	PCV head 	(i) Main material SS (ii) Main dimensions ⌀10.0 × H4.5 (including handrail)	Disc saw, cutter (for platform, etc.) Disc saw, disc cutter, AWJ (PCV)	(i) Cut the platform, handrails, etc. into small pieces by the processing equipment and remove. (ii) Cut the PCV head into pieces of a predetermined size by the processing equipment and remove.	Low	

7. Implementation Details

7.2. Implementation Details

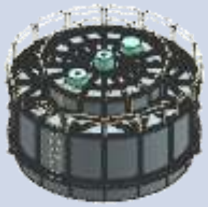
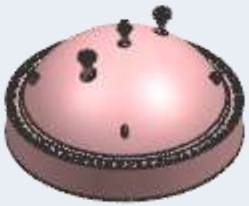
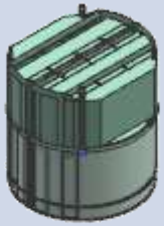
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method for removing interfering objects with fuel debris retrieval equipment by the top entry method

Interfering objects that need to be removed (including reactor internals) were identified and listed.

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
4	Reactor thermal insulation material 	(i) Main material SS (ii) Main dimensions ⌀6.2 × H3.8 (including handrail)	Disc saw, disc cutter, saber saw	(i) Remove thermal insulation material on the top, then cut the frame into pieces, and remove all of them. (ii) Remove thermal insulation material at the bottom, then cut the frame into pieces, and remove all of them.	Low	
5	RPV head 	(i) Main material Low-alloy steel (ii) Main dimensions ⌀5.5 × H2.9	Disc cutter, AWJ	(i) Cut RPV nozzles and create openings. (ii) Cut the RPV head into small pieces using the openings created in the above as cutting start points.	Medium	
6	Dryer 	(i) Main material SUS (ii) Main dimensions ⌀4.7 × H5.0	Disc cutter, saber saw, AWJ	(i) Cut the whole part of the dryer unit into pieces sequentially from the top to the bottom, and remove all cut pieces. (ii) After removing the dryer, cut the dryer support skirt into pieces and remove.	Medium	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

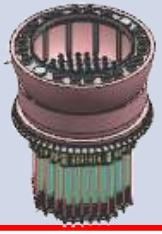
[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method for removing interfering objects with fuel debris retrieval equipment by the top entry method

Interfering objects that need to be removed (including reactor internals) were identified and listed.

[red box] : Element tests under planning

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
7	Separator 	[1] Main material SUS [2] Main dimensions ⌀4.5 × H4.6	Disc cutter, sabre saw, AWJ	[1] Cut the whole part of the separator unit into pieces sequentially, from the top to the bottom, and remove all cut pieces. [2] After removing the separator, cut the shroud head into pieces and dismantle it.	Medium	
8	RPV core 	[1] Main material SUS [2] Main dimensions ⌀4.8 × H7.4 (reactor core structures)	Disc cutter, milling, AWJ, laser	[1] Cut the structure sitting in the reactor core into pieces sequentially, from the top to the bottom, using different tools depending on molten or damaged condition of the structure.	High	・May have been deformed by melting.
9	RPV bottom part 	[1] Main material Low-alloy steel/SUS [2] Main dimensions ⌀4.8 × H6.7 (CRD housing, RPV bottom reflection mirror, etc.)	Disc cutter, grinding (milling), AWJ, laser	[1] Cut or crush fallen structure and fuel debris into small pieces sequentially from the top to the bottom and remove. [2] Cut the CRD housing and structures around it into pieces in sequential procedures that incorporate work from the pedestal side effectively.	High	• May have been deformed by melting. • Measures to prevent the fall of the CRD housing are difficult. • The CRD housing is highly relevant to the side entry method.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method to remove interfering objects by fuel debris retrieval equipment by the top entry method

According to the decision on removal policy, element tests for removing interfering objects in the RPV bottom part are planned because this work is highly relevant to the side entry method, and its difficulty level is high since measures to prevent the fall of structures need to be taken during removing work.

- Purpose of development
  - Feasibility verification of workability in a narrow space
  - Feasibility verification of a processing method taking fall prevention into account.
  - Feasibility verification of workability by the top entry method, the side entry method, or a combination of them

- Issues to be resolved
  - Remote controlled workability
  - Processing method for narrow parts
  - Removing methods that take measures to prevent the CRD housing from falling into account

- Expected results
  - Feasibility of processing method for narrow parts
  - Feasibility of processing method taking into account fall prevention
  - Feasibility verification of workability by the top entry method, the side entry method, or a combination of them
  - Throughput calculation.

7. Implementation Details

7.2. Implementation Details

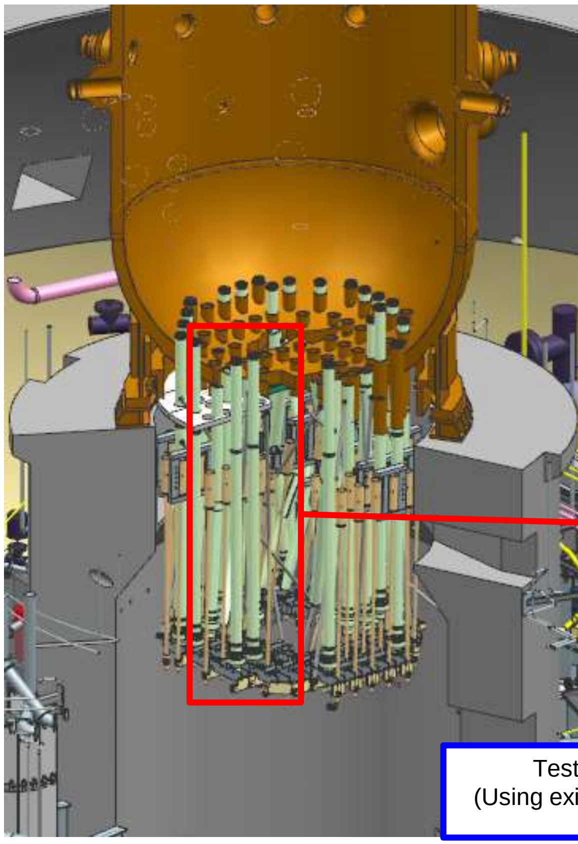
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

a. <u>Method to remove interfering objects by fuel debris retrieval equipment by the top entry method</u>

Schematic illustrations of element tests for removing interfering objects in the RPV bottom are shown below

(Red frame) : Element test simulation range



Schematic illustration of interfering objects in the RPV bottom

Schematic illustrations of element tests for removing interfering objects in the RPV bottom
(The test facility was prepared by modifying part of facility constructed in FY2016)

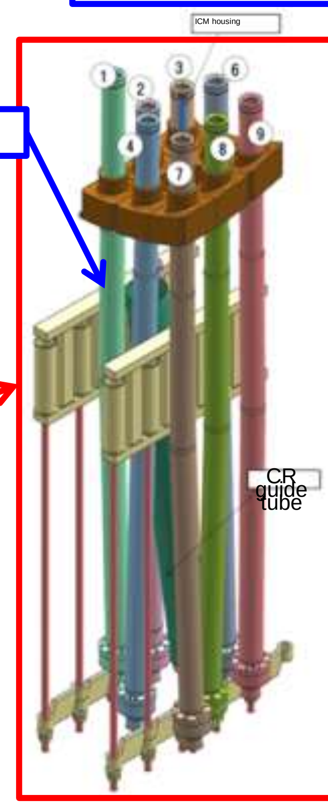


Image of test mock-ups

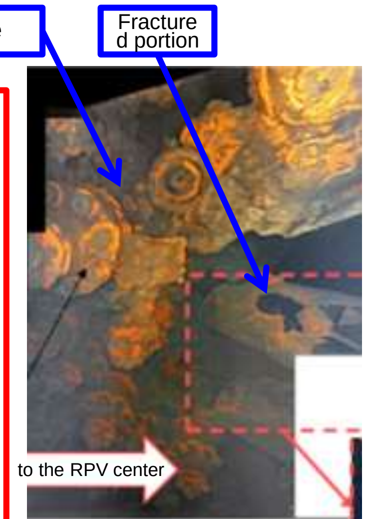


Photo of Unit3 internal investigation

The possibility of duplicating the fallen CRD housing and the fractured portion is being examined, referring to the results of the inside investigation on Unit3 PCV.

To verify workability in a narrow space, removing tests for interfering objects are planned using nine test mock-ups.

7. Implementation Details

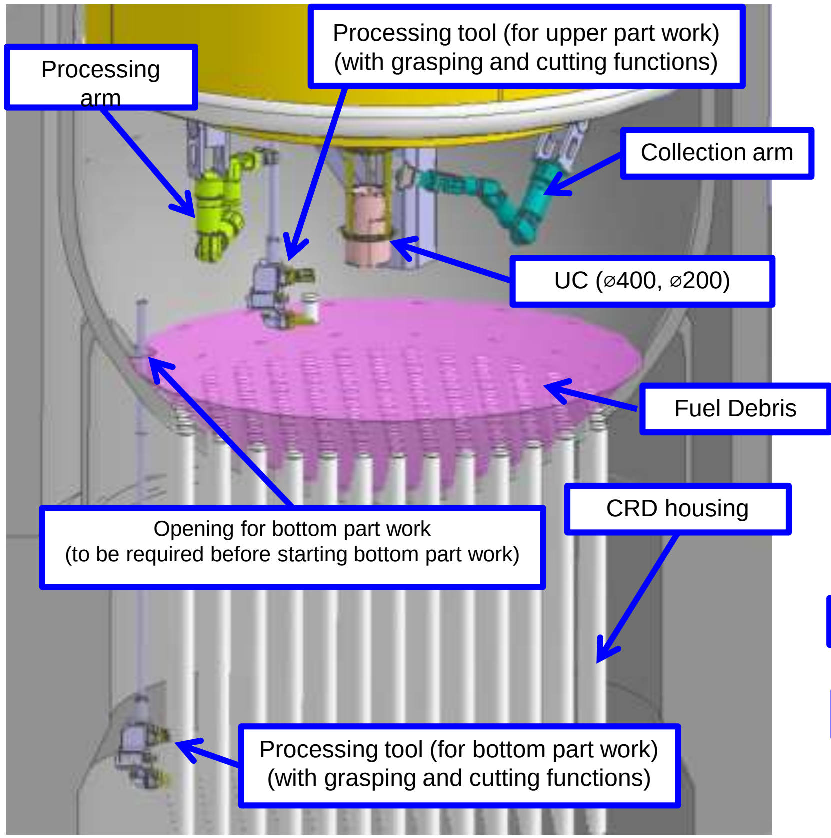
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

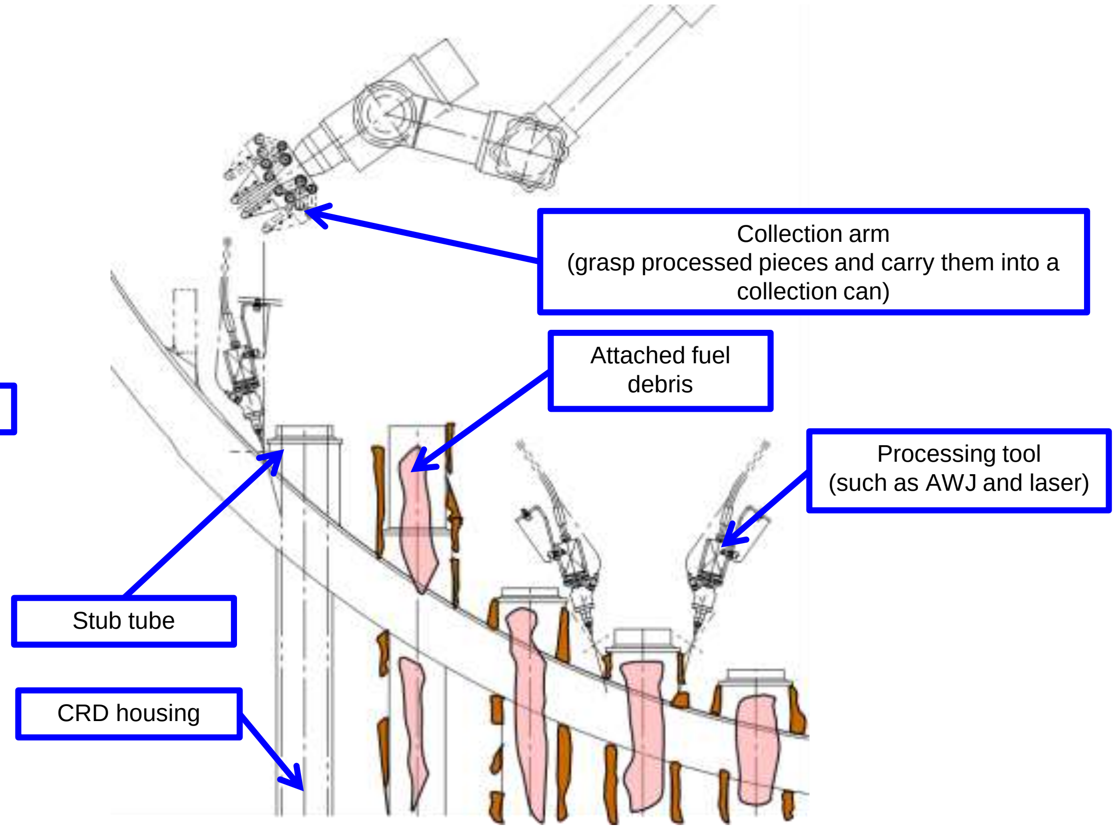
[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method to remove interfering objects by fuel debris retrieval equipment by the top entry method

A conceptual study of interfering object removing operation in RPV bottom part finished and element tests are under planning.



Schematic illustration of interfering object removing operation in RPV bottom part



Schematic illustration of stub tube removal work

7. Implementation Details

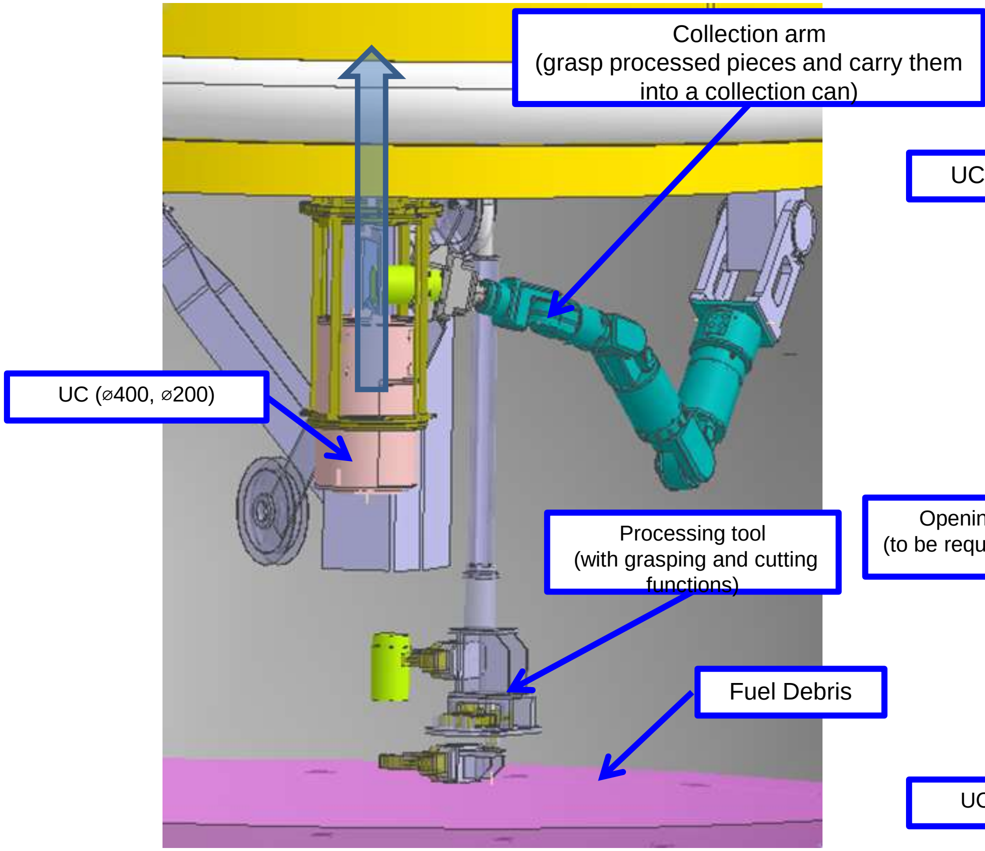
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

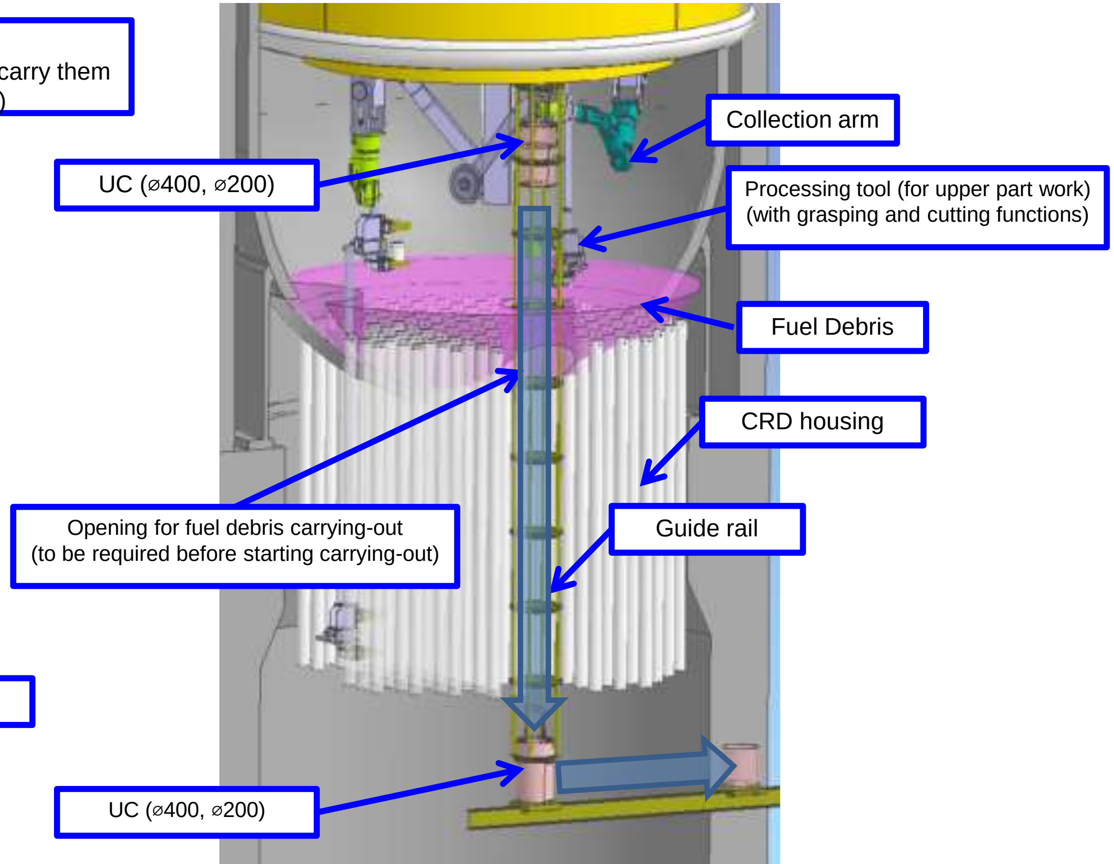
[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method to remove interfering objects by fuel debris retrieval equipment by the top entry method

A top-entry and side-entry combined method, where the top entry method is used to process fuel debris and interfering objects and the side entry method is used as a route to remove processed pieces out of the reactor, is being studied.



Schematic illustration of conducting work using only the top entry method



Schematic illustration of conducting work using the top-entry and side-entry combined method

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

a. Method to remove interfering objects by fuel debris retrieval equipment with the top entry method

Items to study	FY2017 (Heisei 29)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Key milestones							Interim report ▼					Annual report ▼							Interim report ▼				Annual report ▼	
1. Conceptual study																								
2. Element test plan																								
3. Preliminary tests required for element test plan																								
4. Element test preparation (Test device production)																								
5. Element Tests																								
6. Wrap-up																								

Notes

Achievements from element tests
1. Feasibility of processing method for narrow parts
2. Feasibility of processing method taking into account fall prevention
3. Feasibility verification of workability by the top entry method, the side entry method, or a combination of them
4. Throughput calculation.

7. Implementation Details

7.2. Implementation Details

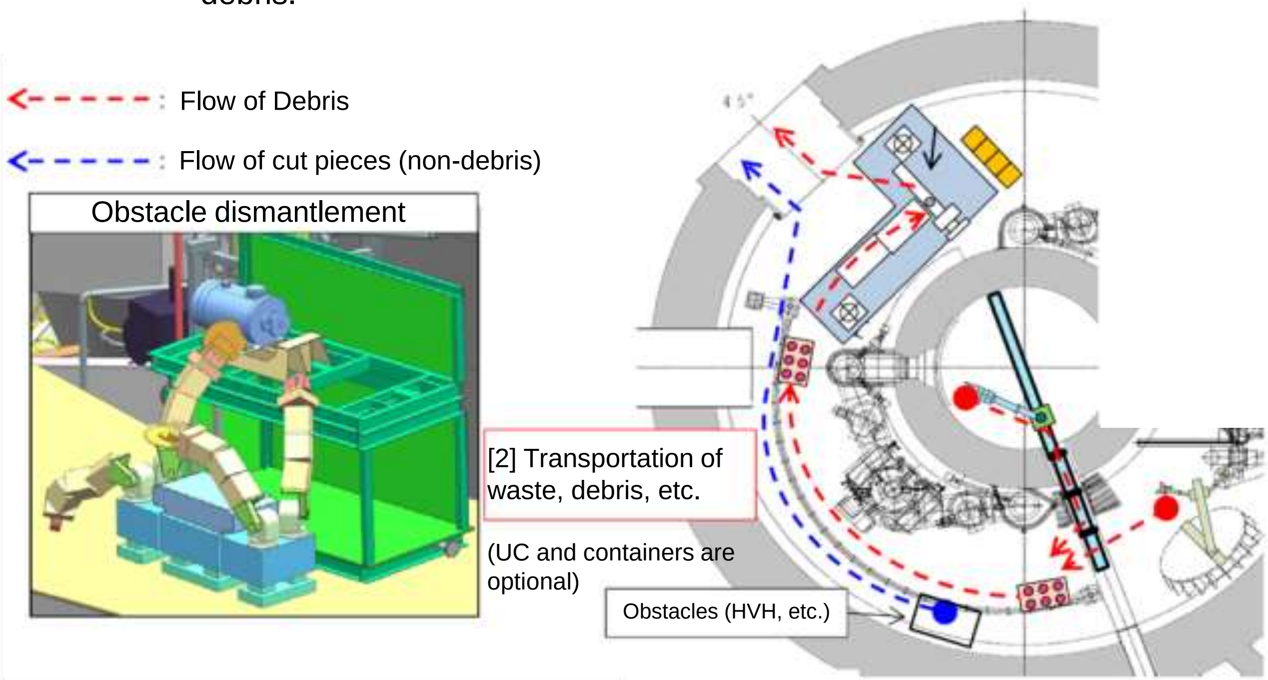
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

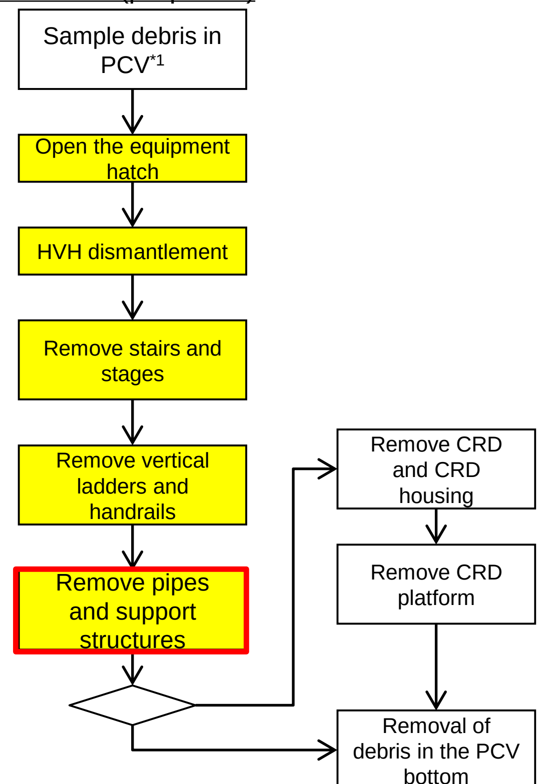
b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

Removal procedures were designed for all structures and objects identified as interfering objects based on the results of the PCV inside investigation and considering steps from debris sampling in the PCV to remove fuel debris.

: Element tests under planning



Interfering object dismantlement procedures (proposed)



The procedures shown in the flowchart on the right establish an access route to the inside of the pedestal as well. After establishing an access route to the inside of the pedestal, it will be judged whether the removal of fuel debris in the PVC bottom via the established access route can be prioritized, by which only a small amount of fuel debris can be carried in each work cycle, or large amount of fuel debris should be removed after removing all interfering objects in the pedestal, according to the further progress of the program.

*1: it is not planned to remove structures outside the pedestal for sampling debris in the PVC.

7. Implementation Details

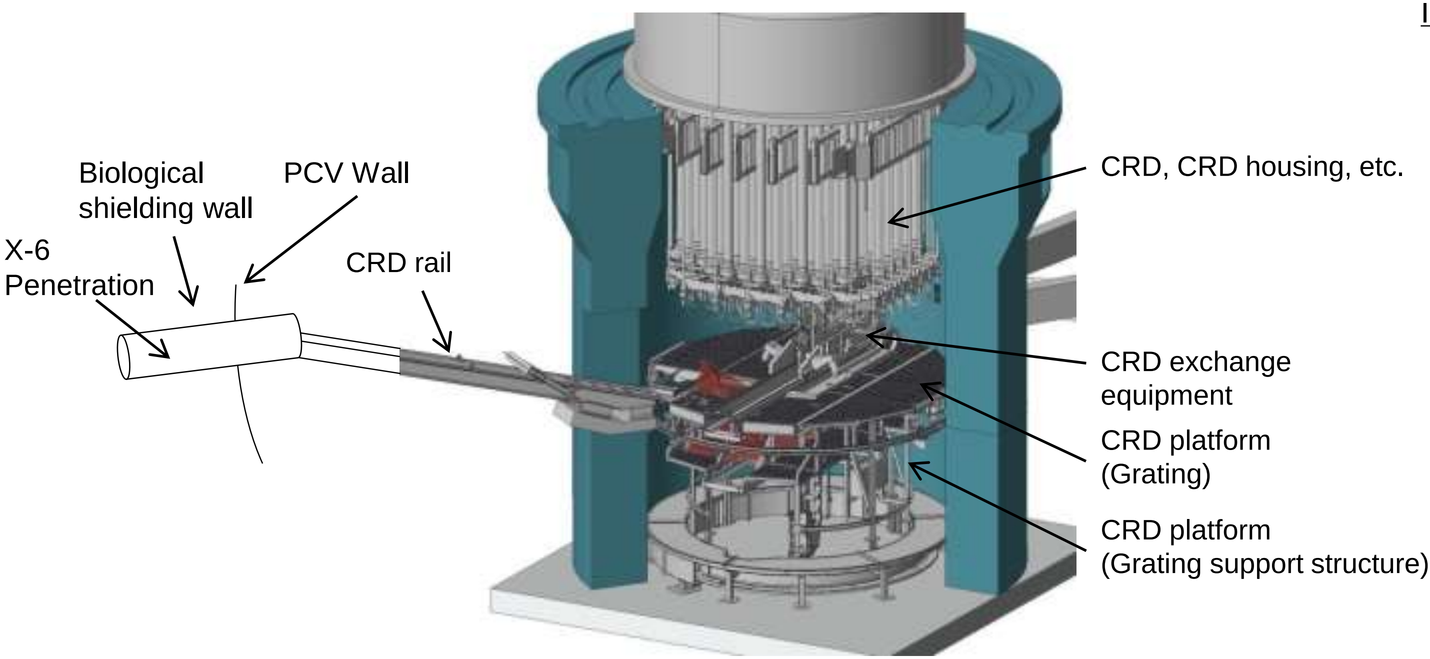
7.2. Implementation Details

: Element tests under planning

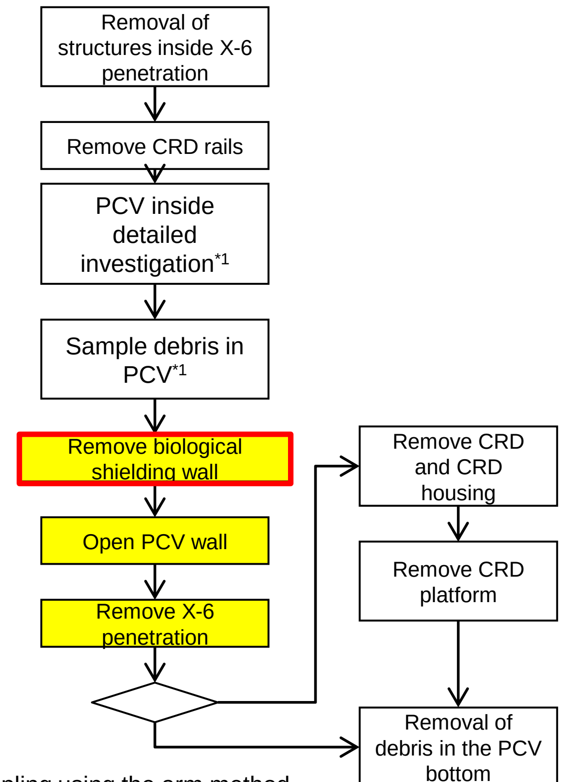
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method
Removal procedures were designed for all structures and objects identified as interfering objects based on the results of the PCV inside investigation and considering steps from debris sampling in the PCV to remove fuel debris.



Interfering object dismantlement procedures (proposed)



The procedures shown in the flowchart on the right establish an access route to the inside of the pedestal as well. After establishing an access route to the inside of the pedestal, it will be judged whether the removal of fuel debris in the PVC bottom via the established access route can be prioritized, by which only a small amount of fuel debris can be carried in each work cycle, or large amount of fuel debris should be removed after removing all interfering objects in the pedestal, according to the further progress of the program.

*1: it is planned to conduct PCV inside detailed investigations and the PCV inside debris sampling using the arm method.

7. Implementation Details

7.2. Implementation Details

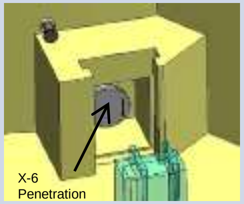
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method
Interfering objects that need to be removed were identified and listed.

(Red box): Element tests under planning

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
1	Biological shielding wall 	[1] Main material Reinforced concrete [2] Main dimensions Thickness 1800 mm Formwork iron plate: 3.2t	Core boring Wire saw	[1] Cut and remove concrete around X-6 penetration. [2] Install a shield door. [3] Cut an opening in the BSW wall by boring overlapping boreholes along the circumference of the intended opening [4] Carry out removed cores through the sleeve.	Medium	
2	X-6 Penetration	[1] Main material SA516 Gr. 70 [2] Main dimensions Outer diameter: 609.6, thickness: 31, length: 2176	Core boring Thermal cutting (laser, gas)	[1] Install a cell with sealing and shielding ability that encompasses X-6 penetration on the outer wall of BSW. [2] Remove concrete around X-6 penetration by coring. [3] Cut the exposed concrete sleeve in a longitudinal direction and remove. [4] Trim and cut the exposed X-6 sleeve from outside. [5] Cut out the PCV wall around X-6.	Low	When adopting the method for removing X-6 penetration, cut it together with the PCV wall and remove mixed cut pieces. If adopting the method to use the opening of X-6 penetration as it is, it is assumed that interfering objects inside X-6 penetration will have been removed inside the PCV during the detailed investigation.
3	PCV Wall	[1] Main material SA515 Gr. 70 [2] Main dimensions Rounded surface with a radius of 10000 and a thickness of 30 [3] Dimensions of opening W1500 x H2000 mm	Thermal cutting (laser, gas)	[1] Insert an inflate seal between BSW inner surface and the PCV. [2] Mark a cutting line. [3] Cut the PCV wall along the line by laser. [4] Collect cut pieces in a container and remove.	Low	

7. Implementation Details

7.2. Implementation Details

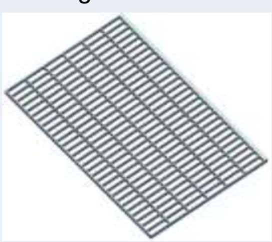
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

Interfering objects that need to be removed were identified and listed.

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
4	CRD rail 	[1] Main material SUS+SS [2] Main dimensions L 6.2 × W 0.6 × H 0.24, thickness = 10 mm	Disc cutter, saber saw, thermal cutting (laser/gas)	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Medium	It is assumed that the CRD rail will have been removed inside the PCV during the detailed investigation.
5	Grating 	[1] Main material SS [2] Main dimensions Thickness 38 mm Pitch 0.03 x 0.1	Disc cutter, saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Low	
6	Grating support structure 	[1] Main material SS [2] Main dimensions Thickness 22 mm	Disc cutter, saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Low	

7. Implementation Details

7.2. Implementation Details

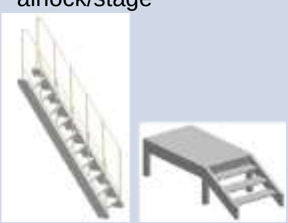
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

Interfering objects that need to be removed were identified and listed.

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
7	Equipment hatch and shield plug 	[1] Main material • Shield plug: Reinforced concrete • Hatch: SS [2] Main dimensions • Shield plug: W3.5 × H2.8 × L1.6 • Hatch: ⌀3.23 x T60 mm	• Shield plug: Wire saw Hatch: Disc cutter	[1] Cut the shield plug on the push stroke by a wire saw or the like. [2] Cut the hatch by a disc cutter or the like. [3] Collect cut pieces in a container and remove.	Medium	
8	HVH 	[1] Main material SS [2] Main dimensions H2.5 × W1.24 × L2.5	Disc cutter, saber saw, hydraulic cutter	[1] Cut the face panel by a disc cutter. [2] The cutting method for internal devices is to be determined separately (based on suitability) [3] Collect cut pieces in a container and carry them out (via the equipment hatch).	High	• Cutting ducts in a high position • Processing in narrow areas • Cutting structures with composite/sophisticated shapes (Tests were conducted last fiscal year)
9	Stairs in front of airlock/stage 	[1] Main material SS [2] Main dimensions • Stairs: L3.3 Frame thickness 11 mm Stair plate thickness 38 mm • Stage: floor plate thickness 20 mm 2.0 × 1.2 × 0.8	Disc cutter, saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Low	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

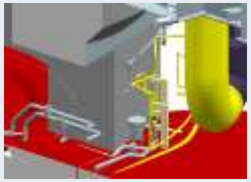
[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

Interfering objects that need to be removed were identified and listed.

(red box): Element tests under planning

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
10	Vertical ladders and handrails 	[1] Main material SS [2] Main dimensions ⌀34mm sch.40	Disc cutter, saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Low	
11	Pipes and support structures  Backside of the PLR piping (underground)  Around sump pit (underground)	[1] Main material SS [2] Main dimensions • Pipe: approx. ⌀ 0.03-0.1 Sch.40 • Support structures: Max 0.1 x 0.1	Disc cutter, saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Medium to high	Accessing g pipes located in areas blocked by other structures, or in areas densely populated by pipes themselves, and what procedures to be taken are challenging though cutting a pipe itself is rather easy.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment by the side entry method

(1) Means and methods for removing interfering objects outside the pedestal

While removing equipment outside the pedestal does not require a special method, removing pipes and piping support structures located near the worker access port are more difficult level and require element tests.

- Purpose of development
  - Feasibility verification of workability in a narrow space
  - Feasibility verification of a processing method taking fall prevention into account.

- Issues to be resolved
  - Processing method for narrow parts
  - Remote controlled workability

- Expected results
  - Feasibility of processing method for narrow parts
  - Feasibility of processing method taking into account fall prevention
  - Throughput calculation.

7. Implementation Details

7.2. Implementation Details

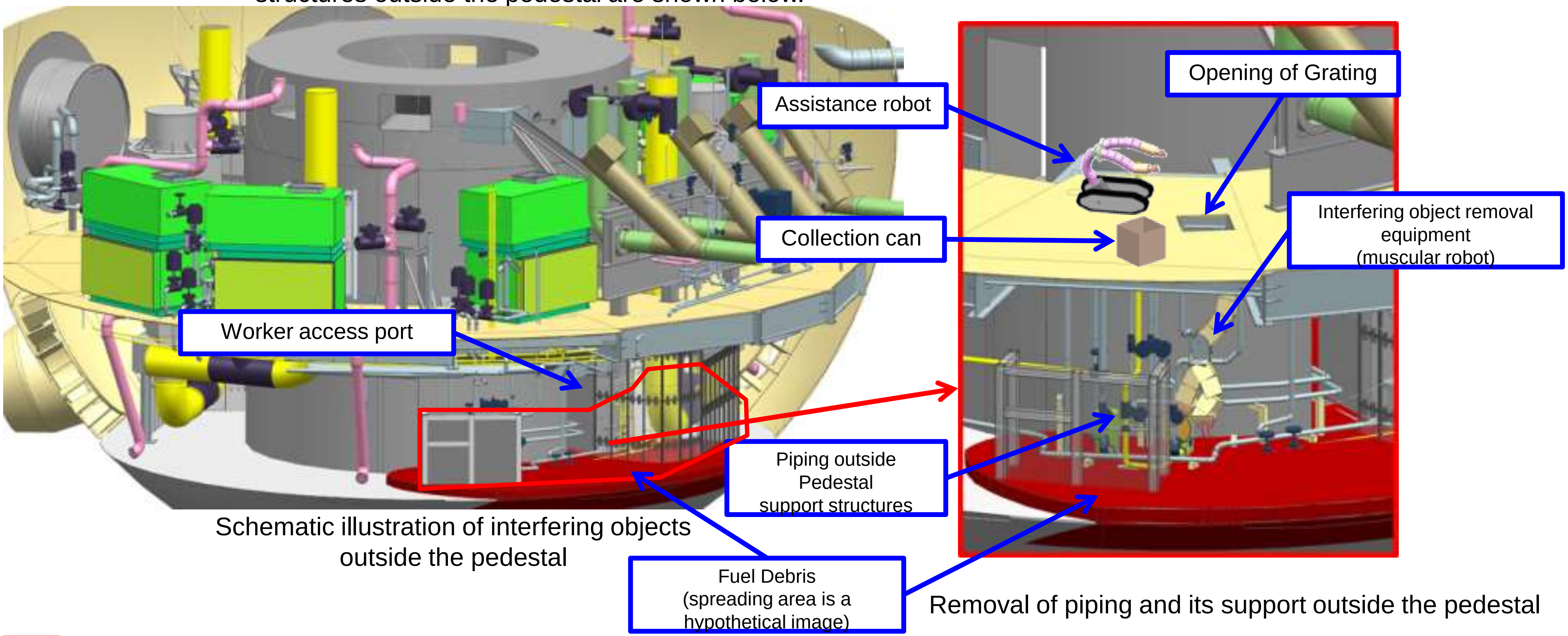
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

(1) Means and methods for removing interfering objects outside the pedestal

Schematic illustrations of element tests for removing piping and support structures outside the pedestal are shown below.



Schematic illustration of interfering objects outside the pedestal

Removal of piping and its support outside the pedestal

Schematic illustration of element tests

: Element test simulation range

7. Implementation Details

7.2. Implementation Details

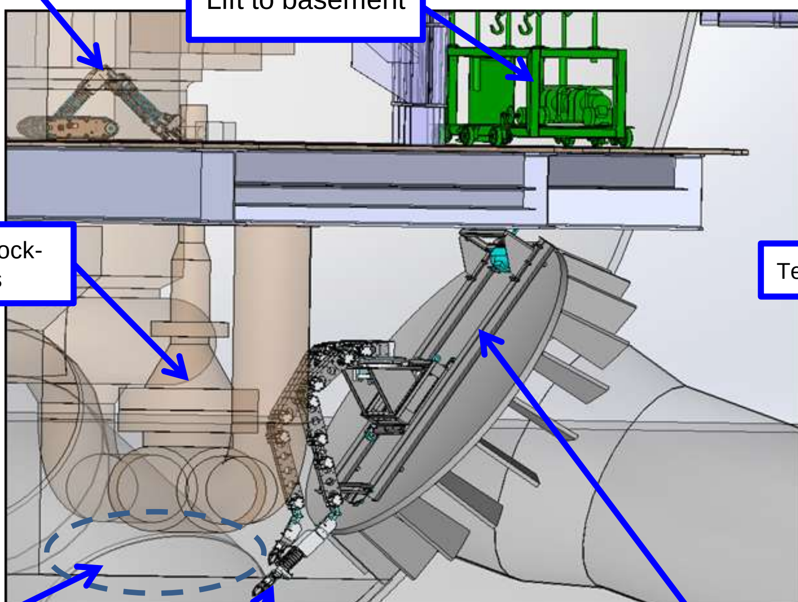
2) Element technology development for installing retrieval equipment

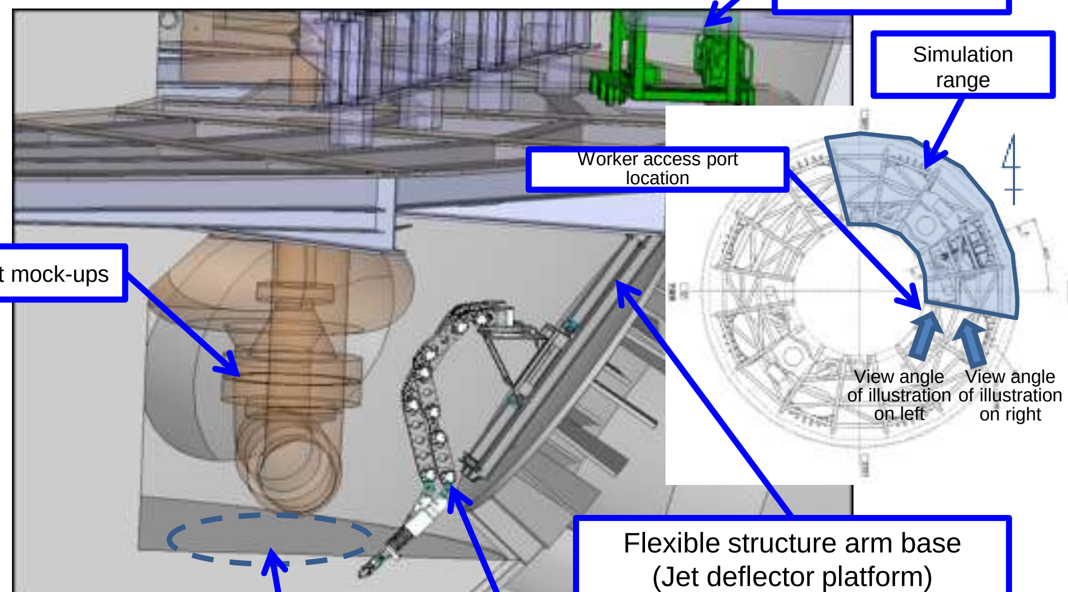
[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment with the side entry method

<u>**(1) Means and methods for removing interfering objects outside the pedestal**</u>

Test mock-ups provided to narrow-area processing tests, methods to access the pedestal basement, and equipment necessary to process and remove interfering objects and fuel debris are being studied.





7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method to remove interfering objects by fuel debris retrieval equipment by the side entry method

(1) Means and methods for removing interfering objects outside the pedestal

Items to study	FY2017 (Heisei 29)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Key milestones							Interim report ▼					Annual report ▼							Interim report ▼				Annual report ▼	
1. Conceptual study	■	■	■	■	■	■	■	■	■															
2. Element test plan							■	■	■	■	■	■	■	■	■									
3. Preliminary tests required for element test plan								■	■		■	■												
4. Element test preparation (Test device production)											■	■	■	■	■	■	■	■						
5. Element Tests														■	■	■	■	■	■	■	■	■	■	
6. Wrap-up																						■	■	
Notes	**Achievements from element tests** **1. Feasibility of processing method for narrow parts** **2. Feasibility of processing method taking into account fall prevention** **3. Throughput calculation.**																							

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Purpose of development
  - Establish means and methods to cut an opening in the PCV
    - ✓ All these methods are based on the concept of expanding X-6 penetration or having an additional opening to its periphery and considering biological shielding wall (BSW) and PCV wall are common interfering objects.
    - ✓ Core boring will be used for the BSW opening construction.
      - This is a remotely controlled, but proven, technology so there shouldn't be any issue under normal conditions

- Issues to be resolved
  - The feasibility of the BSW opening construction (using core boring) by remote operation needs to be verified, including feasibility under abnormal conditions.
  - The feasibility of measures to prevent the diffusion of dust and liquid waste generated during processing needs to be verified.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

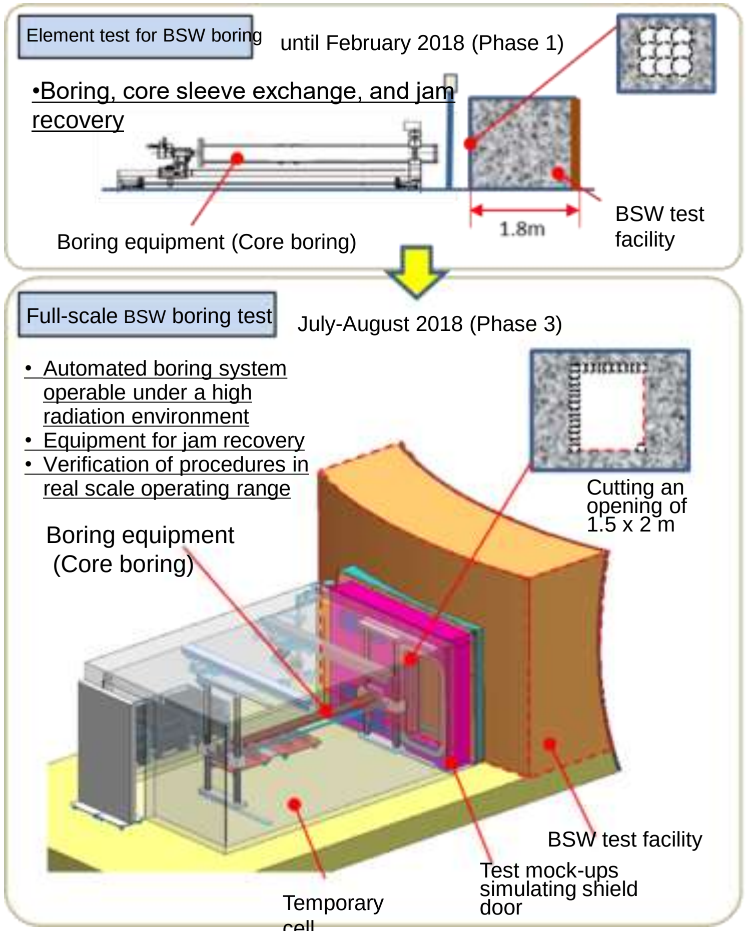
[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Development approach
  - The development will be carried out in three phases to review feasibility and flexibility in planning.
    - ✓ Phase 1: Applicability evaluation and test planning through desk study
    - ✓ Phase 2: Applicability evaluation by element tests
    - ✓ Phase 3: Prototype cutting tests using M/U module
  - Before proceeding to the next phase, expert review is provided

- Expected results
  - Selection and evaluation of technologies used for the opening construction
  - Maintenance and recovery procedures (proposed)
    - ✓ Procedures for recovery from abnormal conditions
    - ✓ Procedures to exchange a core sleeve in a temporary cell



7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Development goals
  - Boring equipment and positioning equipment shall work together smoothly to perform accurate boring.
  - The equipment shall perform boring smoothly in a given operation space that is assumed from the actual work condition in the reactor concerned.
  - The recovery procedure restoration from abnormal conditions in a real scale operating range.
  - The core sleeve can be exchanged using a crane installed in the temporary cell.
  - Chip and crumb collection/wastewater treatment equipment shall function properly.

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7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Test and judgment conditions (examples)
  - Core sleeve: 200 mm or 250 mm (for recovery)
  - Dimensions of test facility:

Item	Value
Height	0.8 m
Width	1.2 m
Depth	1.8 m
* A 3.2 mm thick steel plate is attached to one face with dimensions of 0.8 m x 1.2 m (on PCV side) to simulate the actual reactor structure.	

  - Target time:
    - ✓ 3 hours per core for boring and extraction
    - ✓ 0.5 hour for recovery from stuck state

* Specific values will be determined during the course of study.

7. Implementation Details

7.2. Implementation Details

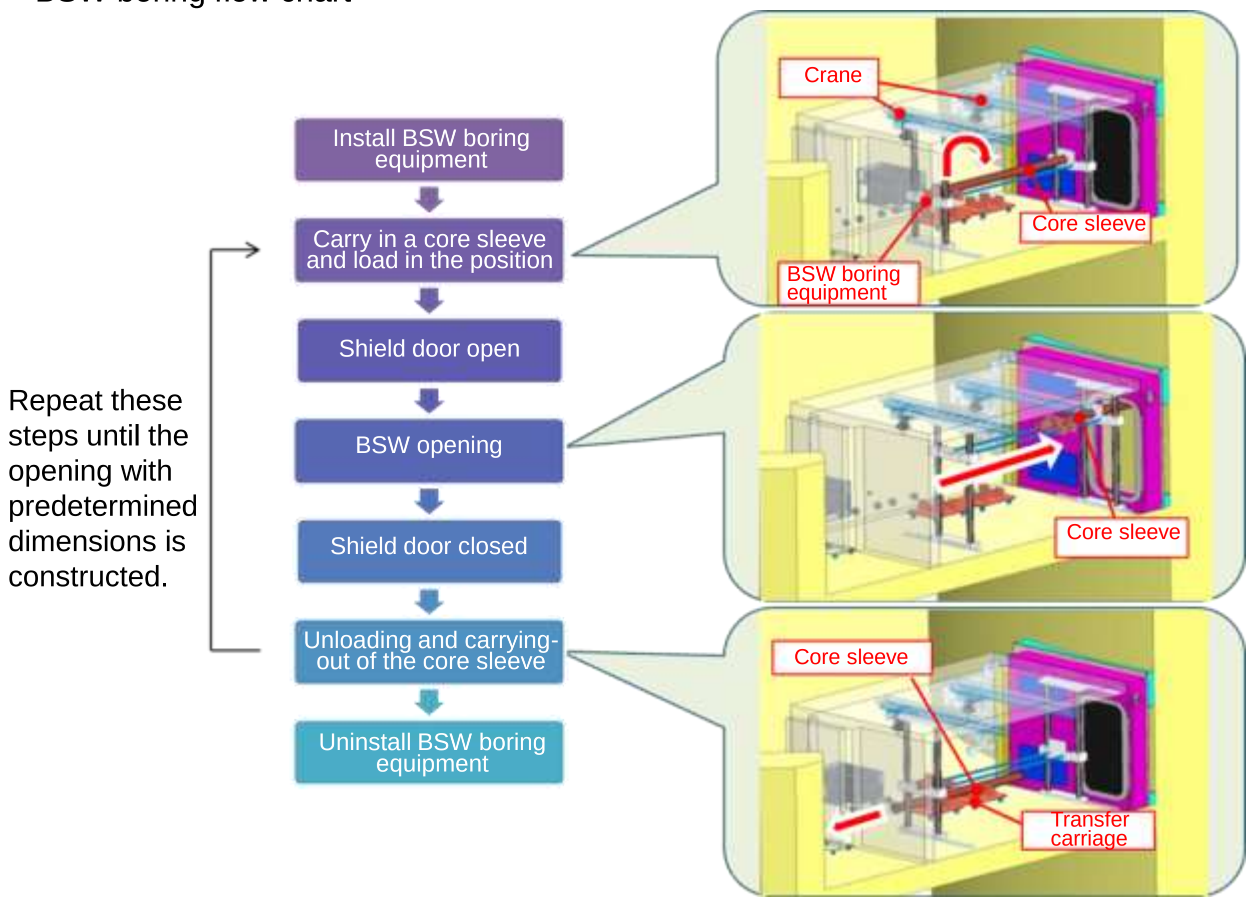
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. <u>Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method</u>

<u>(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside</u>

- BSW boring flow chart



7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Test overview and check items

A feasibility study will be conducted through the following two-step test. Tests will be conducted with a view to examining technologies applicable to other methods in common while test conditions are set based on Plan-B2 of the side entry method.

[1] Element tests (Unit tests)

A test facility that reproduces the thickness (1.8 m), hardness and reinforcement layout of BSW is built. Boring (core boring) is performed by boring equipment.

-> Verify ability to remove concrete core

Ability to construct overlapping boreholes is to be verified.

Verify ability for jam recovery tasks

[2] Element tests (combination tests)

A test facility that simulates the PCV wall and the thickness, hardness and reinforcement layout of BSW is produced.

A temporary house that simulates a work cell is installed.

-> (The same evaluation items as those of the element tests are to be verified.)

Verification of positioning accuracy

Verify workability in a temporary house.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Requirements
  - ◆ An opening necessary to install a work cell shall be able to be constructed.
  - ◆ Existing PCV shall not be damaged.
    - ➢ The BSW boring work is performed outside the existing primary boundary. It must not cause damage to or degrade the existing primary boundary.
  - ◆ Reduce diffusion of radioactive materials via chip and crumb or wastewater.
  - ◆ Worker exposure associated with tasks shall be reduced.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Environmental requirements
  - ◆ Area around X-6 penetration on R/B 1F is assumed
    - ➢ Dose rate (R/B 1F): 5-10 mSv/h
    - ➢ Acceptable maximum load of floor surface: 4.9 ton/m^2
    - ➢ Height limit: 3 m (no interference with RHR piping)
  - ◆ Specifications of BSW:
    - ➢ Material: reinforced concrete with the strength of 500-600 kg/cm^2, designed reinforcement bar layout needs to be considered.
    - ➢ Thickness: 1.8 m, the presence of a formwork steel plate (3.2 mm) on the backside of BSW needs to be considered.
    - ➢ D38-SD345 reinforcement bars are arranged in a two-layer-two-stage formation (horizontal pitch: approx. 180-200 mm, vertical pitch: approx. 200-400 mm).
  - ◆ Temperature: 0-40° C
  - ◆ Humidity: Same level as the atmosphere outside the facility
  - ◆ Designed lifetime: max. about one year (to be sound only during boring work)

7. Implementation Details

7.2. Implementation Details

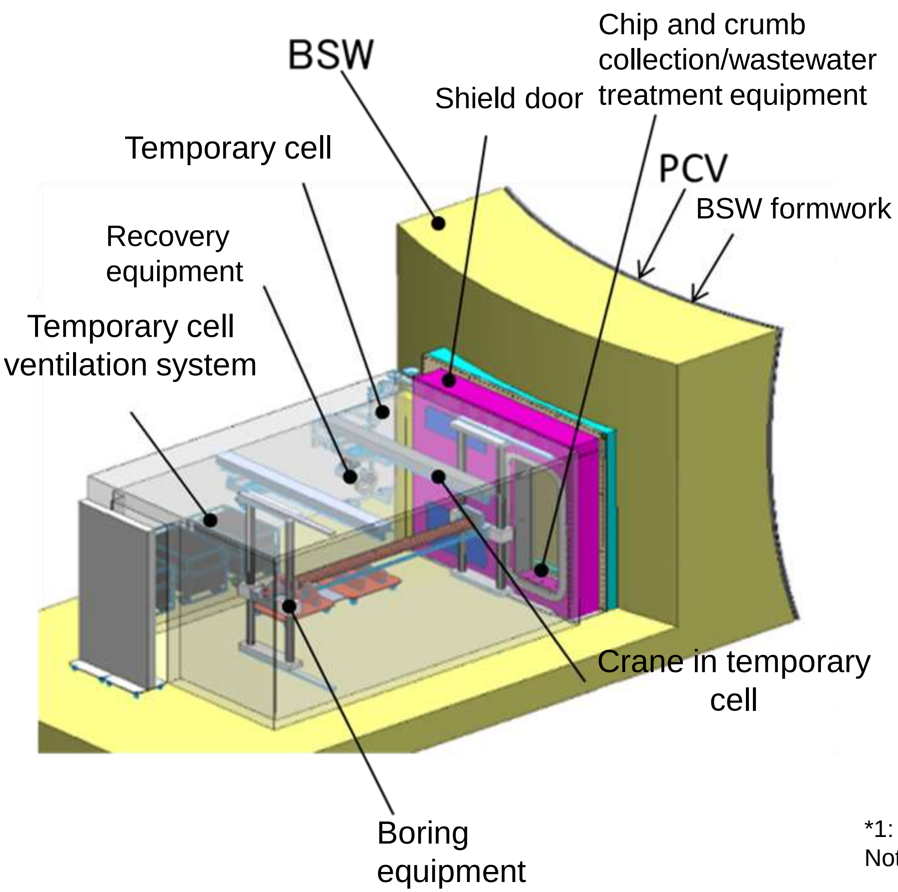
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Basic BSW boring equipment configuration



Test device/equipment		Actual device/equipment
BSW		Design basis strength: 225 kg/cm^2*1 Thickness：1800 mm Reinforcement layout: D38-SD345 (2 layer 2 stage layout) Size: Curvature radius of outer surface 11700, Curvature radius of inner surface 10074 Formwork: 3.2 mm steel plate (one side)
Boring equipment	Core sleeve	⌀200 × L3540 (estimated)
	Drive unit	Hydraulic motor for both rotation and linear motion in axial direction
	Positioning equipment	Full automatic positioning by X-Y positioning system.
Recovery equipment	Wire saw	Installed between BSW and the shield door to cut the core sleeve
	Large-bore core	⌀250 × L3540 (estimated)
Shield door		Both shielding and air tight functions are required.
Temporary cell		Installed to prevent contamination spread during boring work
Crane in temporary cell		Two cranes for work in the temporary cell
Temporary cell ventilation system		Generated dust are collected by filter ventilation system
Chip and crumb collection equipment and wastewater treatment equipment		Collect wastewater containing concrete chips generated during coring.

*1: The test facility shall simulate the actual strength of 500-600 kg/cm^2.
Note: This is the current plan and is subject to change according to the progress of design.

7. Implementation Details

7.2. Implementation Details

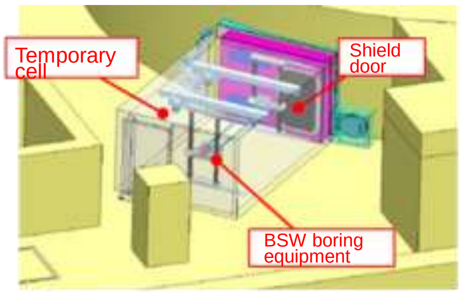
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

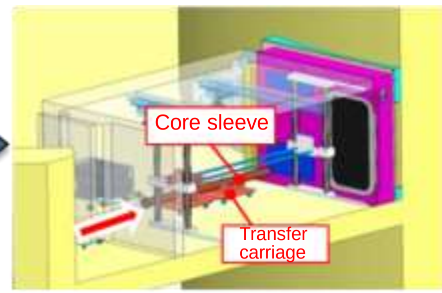
b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

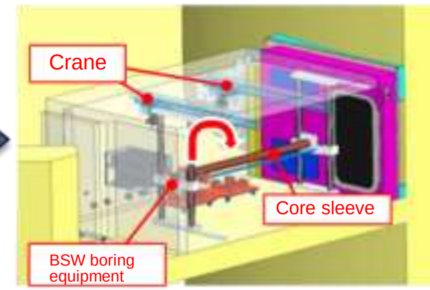
- BSW opening work procedure (1/2)



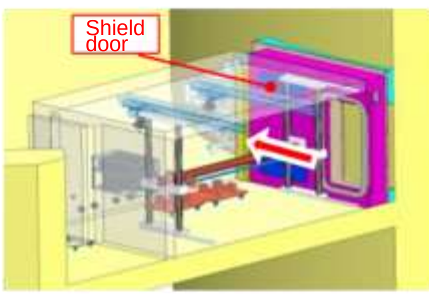
[1) Installation of temporary cell and BSW boring equipment]
Install a temporary cell and biological shield wall (BSW) boring equipment by workers' construction work. The temporary cell is installed to prevent the dispersion of dust generated during BSW boring.



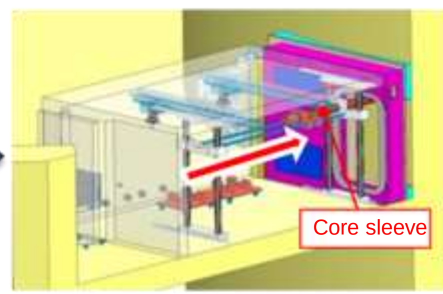
[2) Carrying-in core sleeves]
Move the transfer carriage loaded with a core sleeve into the temporary cell by workers.



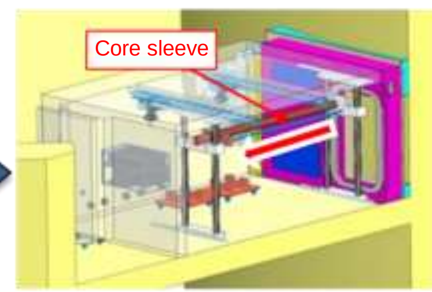
[3) Loading of core sleeve onto BSW boring equipment]
Workers load the core sleeve onto BSW boring equipment using cranes in the temporary cell. Adjust the position of the core sleeve after loading.



[4) Shield door opening task]
Open the shield door by remote operation.



[5) Boring of BSW]
Dig the core sleeve into BSW and bore it and its formwork (3.2 m thick) by remote operation until a through-hole is constructed. The completion of a through-hole is detected by change in oil pressure gauge reading.



[6) Collecting core sleeves]
Retract the core sleeve to its original position by remote operation after a through-hole is constructed.

7. Implementation Details

7.2. Implementation Details

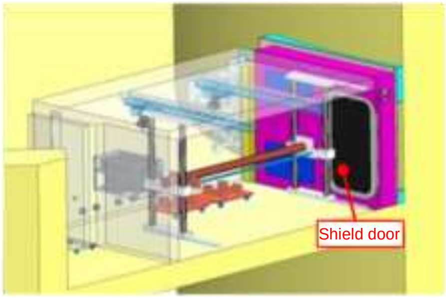
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

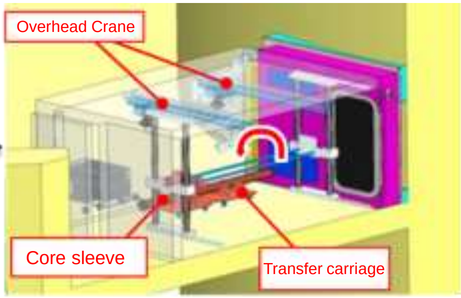
b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

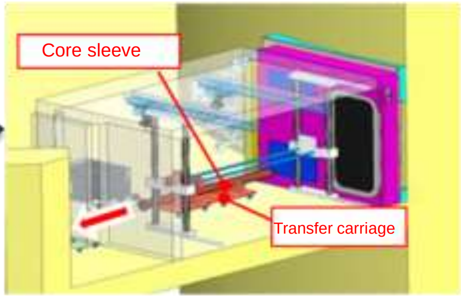
- BSW opening work procedure (2/2)



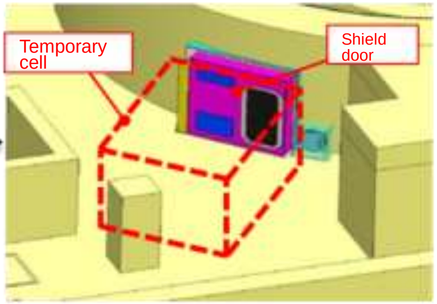
[7) Shield door closing task]
Close the shield door by remote operation.



[8) Loading of the used core sleeve onto a transfer carriage]
Workers unload the used core sleeve from BSW boring equipment and load it onto a transfer carriage using an overhead crane.



[9) Transferring core sleeves]
Move the transfer carriage loaded with the used core sleeve out of the temporary cell by workers.
* Repeat steps 2) to 9) until an opening with a width of approx. 1.5 m and a height of approx. 2 m is constructed in BSW.



[10) Remove the temporary cell and BSW boring equipment]
After completion of the BSW opening with intended dimensions, workers dismantle the temporary cell and BSW boring equipment.

Note: This is the current plan and is subject to change according to the progress of design.

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

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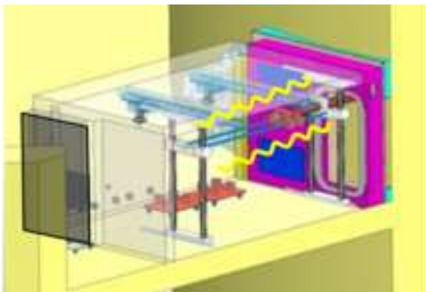
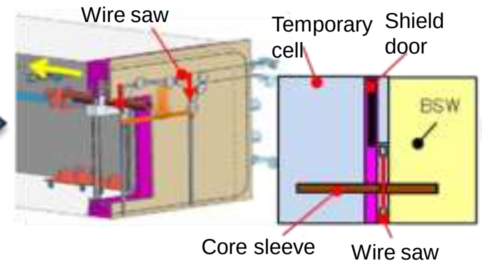
b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

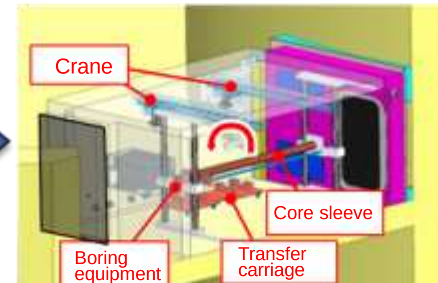
- Procedures for jam recovery



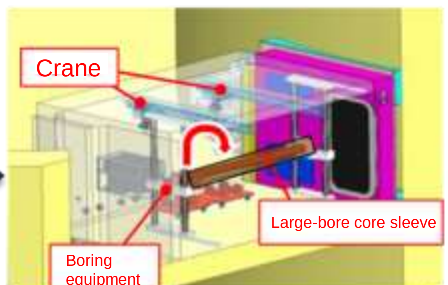
[0) Stuck (before starting tasks)]
Core sleeve (⌀200) involves rebar fragments and gets stuck during coring.



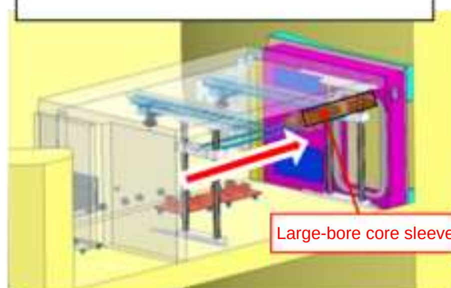
[1) Severing core sleeves]
Cut the stuck core sleeve by the remote operation of a wire saw installed between BSW and the shield door. Retract the cut core sleeve toward the original position after cutting.



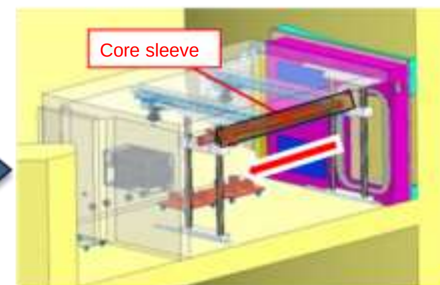
[2) Withdrawal of the core sleeve]
Close the shield door by remote operation. Workers unload the core sleeve (⌀ 200) from boring equipment, load it onto a transfer carriage using a crane, and move the carriage out of the temporary cell.



[3) Attachment of the large-bore core sleeve]
Workers carry in the large-bore core sleeve (⌀ 250) and load it onto the boring equipment using a crane.



[4) Coring with the large-bore core]
Open the shield door by remote operation. Locate the large-bore core sleeve at the position so that the large-bore core sleeve encompasses the ⌀ 200 core sleeve cut and left in BSW, dig it into BSW by remote operation, and bore BSW and BSW formwork (3.2 m thick) until a through-hole is constructed. The completion of a through-hole is detected by change in oil pressure gauge reading.



[5) Withdrawal of the large-bore core sleeve]
Retract the large-bore core sleeve to the original position by remote operation after completion of boring, and close the shield door by remote operation. Workers unload the used large-bore core sleeve from boring equipment and load it onto a transfer carriage using a crane. (-> Return to Step 2) of normal operation)

Note: This is the current plan and is subject to change according to design progress.

7. Implementation Details

7.2. Implementation Details

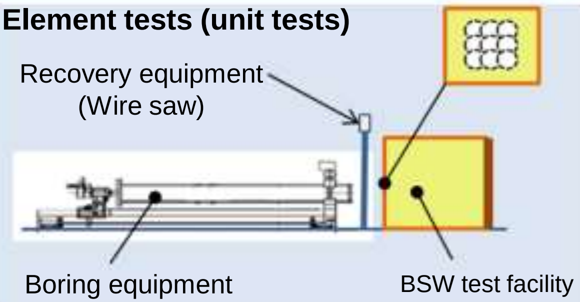
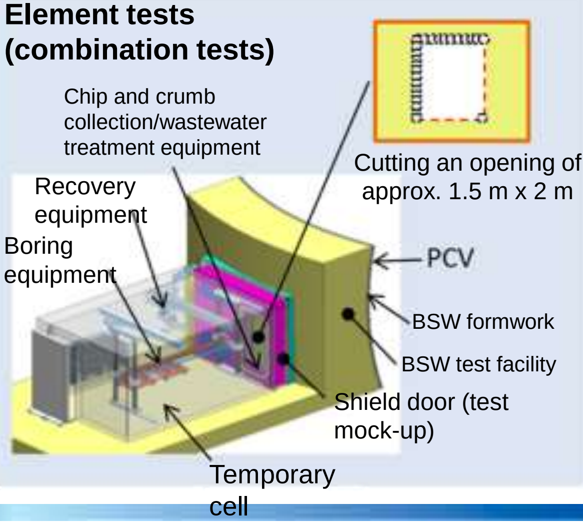
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. <u>Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method</u>

<u>(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside</u>

- Evaluation items in the test

Test	Evaluation item
Element tests (unit tests) 	• Coring shall be achieved with intended accuracy. • Coring shall produce overlapping boreholes (Hole deviation from the intended position shall be measured) • Obtains parameters concerning boring tasks (hydraulic pressure for core rotation, feed per rotation, and volume of water consumption). • Cores shall be able to be removed. • The exchange of a core sleeve (loading and unloading) shall be able to be performed. • A means to recover from core sleeve jam and restore normal operation shall be provided.
Element tests (combination tests) 	• Coring task shall be performed with intended accuracy by applying parameters obtained by element tests (unit tests). • Cores shall be able to be removed. • The exchange of a core sleeve (loading and unloading) shall be able to be performed. • A means to recover from core sleeve jam and restore normal operation shall be provided. • The test system simulating actual unit achieves opening with a BSW simulant test facility equivalent to actual units (including core sleeve attachment and detachment, coring, dust collection, wastewater collection and recovery). • Data shall be able to be obtained so that the data is used to develop ideas to measure setup work time and shorten it.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

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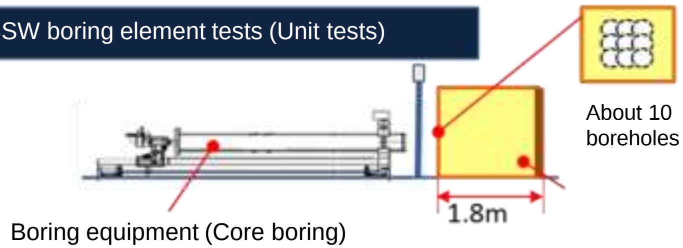
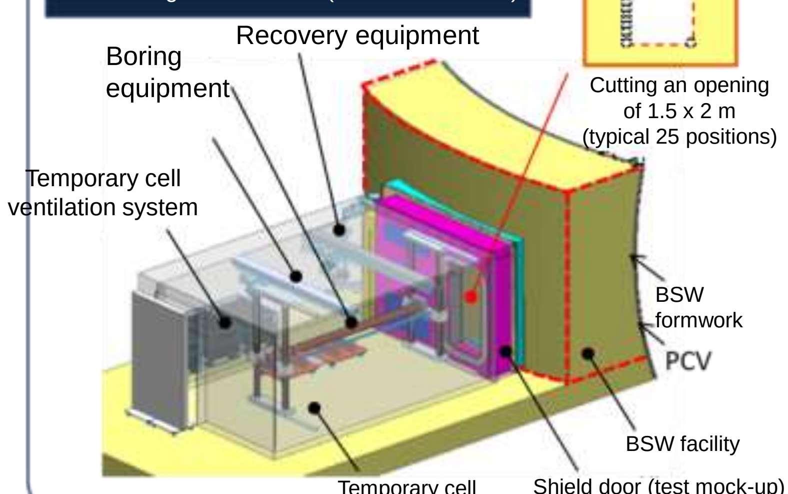
- Basic test device configuration

BSW boring element tests (Unit tests)



BSW boring element tests (combination tests)



Legend ○ : almost the same as actual device, ○※ : partially simulated, × : Not applicable

Test device/equipment		Unit tests	Combination tests
BSW test facility		○※ (including formwork)	○ (including formwork and PCV)
Boring equipment	Core sleeve	○※	○
	Drive unit	○※	○
	Positioning equipment	×	○
Recovery equipment	Wire saw	○※	○
	Large-bore core	○※	○
Shield door		×	○※
Temporary cell		×	○
Crane in temporary cell		×	○
Temporary cell ventilation system		×	○
Chip and crumb collection equipment and wastewater		×	○※

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

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(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Test procedures and criteria

		Criteria/targets: Element tests (unit tests)	Criteria/targets: Element tests (combination tests)
Core boring	Boring	• Overlapping boreholes shall be constructed in the test facility (that simulates strength, thickness and reinforcement layout). • A steel plate attached to the test mock-up to simulate the BSW formwork shall be processed together. • Angled boring with the gradient required by design (⊿3/200 or so) shall be possible. • Equipment shall operate smoothly. • Obtain optimum core sleeve size and criterion to decide overlap width	• Boring equipment and positioning equipment shall work together smoothly for proper boring. • The equipment shall perform boring smoothly in a given operation space (limited space) that is assumed from the actual work condition in the reactor concerned.
Core boring	Working water volume	The predetermined rate of water supply (2-3 L/min) shall be verified.	
Core boring	Work time	The cycle time of core boring shall be measured. (Target cycle time: 3 hours per core for boring and core retrieval)	
Core boring	Wastewater	The amount and properties (particle size of chips contained and characteristics of wastewater such as viscosity) of generated wastewater shall be investigated by sampling the wastewater.	Chip and crumb collection/wastewater treatment equipment shall function properly.
Core boring	Detection of the boring head reaching the other end and stopping of operation	The overtravel distance of the boring head beyond the other side surface of BSW shall be 40 mm or less. The completion of a through-hole is detected by change in oil pressure gauge reading.	
Retrieval of a concrete core	Retrieval of a core	The core sleeve and cores shall be pulled out of the test facility and removed.	
Retrieval of a concrete core	Time measurement	Time necessary to retract the core sleeve shall be measured. (Target time: 3 hours per core for boring and core retrieval)	
Core sleeve exchange (attachment and detachment)	Core sleeve attachment and detachment for exchange	Core sleeve exchange or attachment and detachment are supported.	Core sleeve can be exchanged using a crane installed in the temporary house.
Core sleeve exchange (attachment and detachment)	Time measurement	Manage time for core sleeve exchange including attachment and detachment (Target time: 0.5 hour)	
Core sleeve recovery/restoration	Core sleeve recovery/restoration	The boring equipment shall recover from the state of stuck core sleeve. (verified by simulation test if the core sleeve doesn't get stuck)	The equipment shall be provided with a means to recover from core sleeve jam that is operable in a given space that is assumed from the actual work condition in the reactor concerned.
Core sleeve recovery/restoration	Frequency, time measurement	Investigation of the frequency of jamming and time necessary for recovery	
Core sleeve recovery/restoration	Cutting of a core sleeve	The core sleeve shall be cut by a wire saw at a predetermined position. The behavior of the cut core sleeve shall be observed	

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

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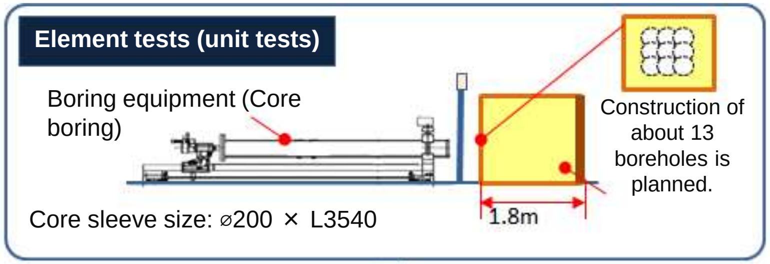
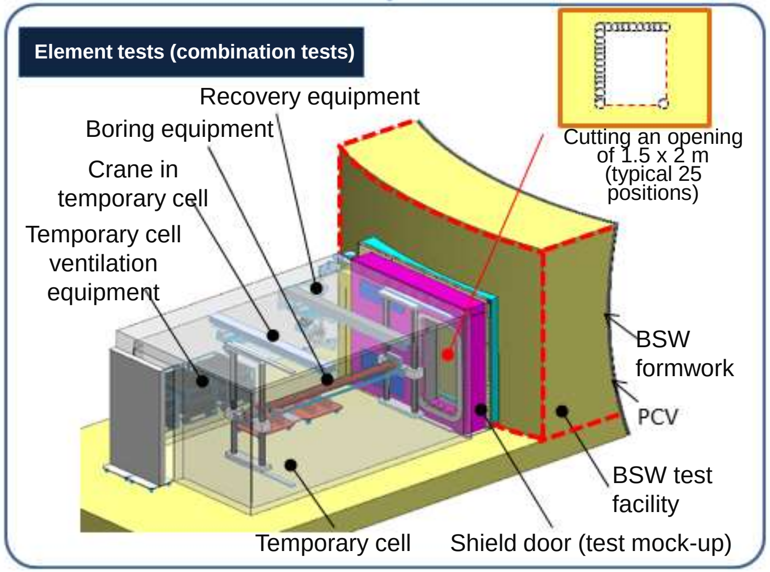
- Check items in unit tests





No.	Purpose and influence	Check items (Unit tests)
[1]	• Construction of an opening of intended dimensions (with intended accuracy) • Ability to accommodate an inflate seal	Straightness change by boring position Appropriate boring position and range
[2]	• Construction of an opening of intended dimensions (with intended accuracy) • Ability to accommodate an inflate seal	Variation in straightness due to variation in overlap width Appropriate overlap width
[3]	• Construction of an opening of intended dimensions • No damage in other part of PCV. (No damage on the primary boundary)	Ability to process BSW formwork The overtravel distance of the boring head beyond the other side surface of BSW (influence of position and overlap width)
[4]	• Chips and wastewater collection	Gradient necessary to drain wastewater
[5]	• Determination of specifications of utilities and wastewater collection facilities	Water volume required during work
[6]	• Overall process period	Work time
[7]	• Construction of an opening of intended dimensions	Ability to construct overlapping boreholes under conditions assumed in the actual decommissioning work
[8]	• Recovery • Overall process period	Recoverability (cutting of a core sleeve by a wire saw)

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

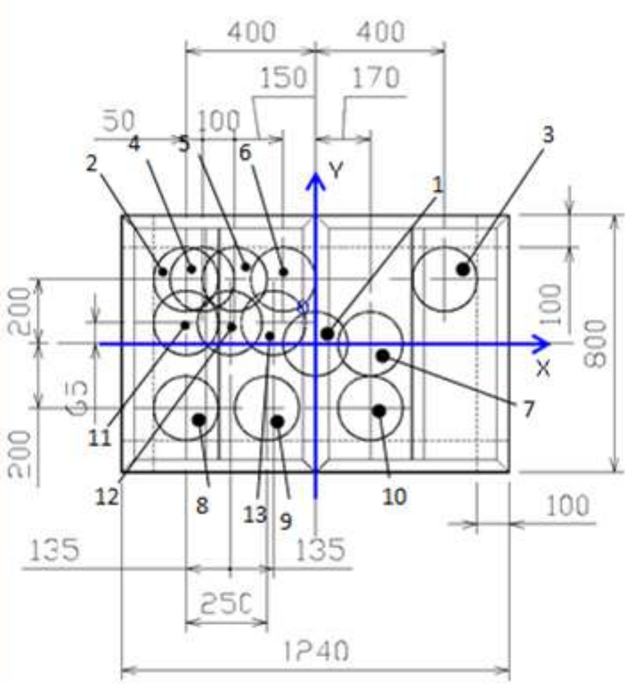
[2] Technical development for removing interfering objects during fuel debris retrieval

b. <u>Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method</u>

<u>(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside</u>

- Evaluation items in the test

Boring position and boring order for a test facility



Numbers in the figure correspond to those in the list

<List of detailed boring conditions>

No.	Borehole position (coordinates)*1 X	Borehole position (coordinates)*1 Y	Overlap width	Gradient	Angle [°]	Main check items	Supplementary check item
1	0	0	-	0	0	[1]*2 Straightness	[6] Work time
2	-400	200	-	0	0		
3	400	200	-	0	0		
4	-350	200	Lateral overlap 150 mm	0	0	[1] Straightness [2] Overlap width	
5	-250	200	Lateral overlap 100 mm	0	0		
6	-100	200	Lateral overlap 50 mm	0	0		
7	170	0	Lateral overlap 30 mm	0	0	[3] Formwork boring	
8	-400	-200	-	⊿1/50	0	[4]Wastewater drainage gradient [5]Water volume [3]Formwork boring	
9	-150	-200	-	⊿3/200*3	0		
10	170	-200	-	⊿1/100*3	0		
11	-400	65	Top overlap 65 mm	⊿3/200*3	4	[7]*4 Overlapping boreholes assumed in the actual decommissioning work	
12	-265	65	Top overlap 65 mm, lateral overlap 65 mm	⊿3/200*3	4		
13	-130	65	Top overlap 65 mm, lateral overlap 65 mm	⊿3/200*3	4	[8] Recovery	

Numbers in these columns correspond to Check Item No.

*1: The center of the test facility shall be the origin of coordinates (X, Y = 0, 0).
*2: Straightness in No. 1 borehole processing is compared with those in boreholes No.2 and 3 processing.
*3: If wastewater drainage is found to be difficult in the No.8 borehole processing with the gradient of ⊿ 1/50, an increase in gradient will be considered.
*4: Comprehensive evaluation will be performed in the processing of the No.11 and 12 boreholes to feedback any findings in the boring of the actual BSW. The comprehensive evaluation includes the evaluation of the feasibility of boring with boring angles that are assumed in boring the actual BSW (including the boring of the formwork), water supply rate and cycle time.
*5: These evaluation items are subject to change according to the design progress of design.

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7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method

(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside

- Comparison of actual unit and test facility

	Actual device/equipment	Specimen	Reason of change (if any)
Shape	The curvature radius of outer surface 11700, Curvature radius of inner surface 10074	W1240 × H800 x D1800	For more reasonable cutout.
Type of concrete	JIS A 5308 standard concrete (Fly ash cement Type B) Nominal designation: Normal 225-15-25FB	JIS A 5308 standard concrete (ordinary Portland cement) Nominal designation: Normal 51-21-20N	
Concrete strength	Strength design requirement: 225 kg/cm^{2*} *: Note that actual measurements in the long-term durability investigation indicate 50-60 N/mm^2 in some places.	Strength design requirement: 51N/mm^2 (The target of the actual measurement is 50-60 N/mm^2)	To make it nearly equal to the actual measurement
Type of reinforcement	Steel bar for reinforced concrete D38 × SD35 (JIS G3112)	Steel bar for reinforced concrete D38 × SD345 (JIS G3112)	Material code change due to conversion to SI unit system (no change in actual material)
Reinforcement layout 1st layer	Sage 1: vertical bar pitch 200 mm, horizontal bar pitch 200 mm Sage 2: vertical bar pitch 200 mm, horizontal bar pitch 400 mm * The pitch of bars whose bottom is fixed in the floor concrete is 120 mm.	Same as on the left	-
2nd layer	Sage 1: vertical bar pitch 200 mm, horizontal bar pitch 200 mm Sage 2: vertical bar pitch 200 mm, horizontal bar pitch 400 mm * The pitch of bars whose bottom is fixed in the floor concrete is 120 mm.	Same as on the left	-
Formwork	Formwork made of 3.2 mm thick steel plate • Connected by ⌀10 joint bolts • Reinforced by L-shaped steel of 40 × 40 × 3	Same as on the left	-
	100 pieces of formworks are used (laid out at 176.4 degree angle).	To make the installation angle the same	-

Explanation of concrete type coding (Standard ds-xx-yyzz)
Standard: Standard concrete, ds: Design base strength (225kg/cm^2, 51N/mm^2), xx: slump or slump flow (cm), yy: max. size of coarse aggregate, zz: type of cement (FB: fly ash cement Type B, N: ordinary Portland cement)

7. Implementation Details

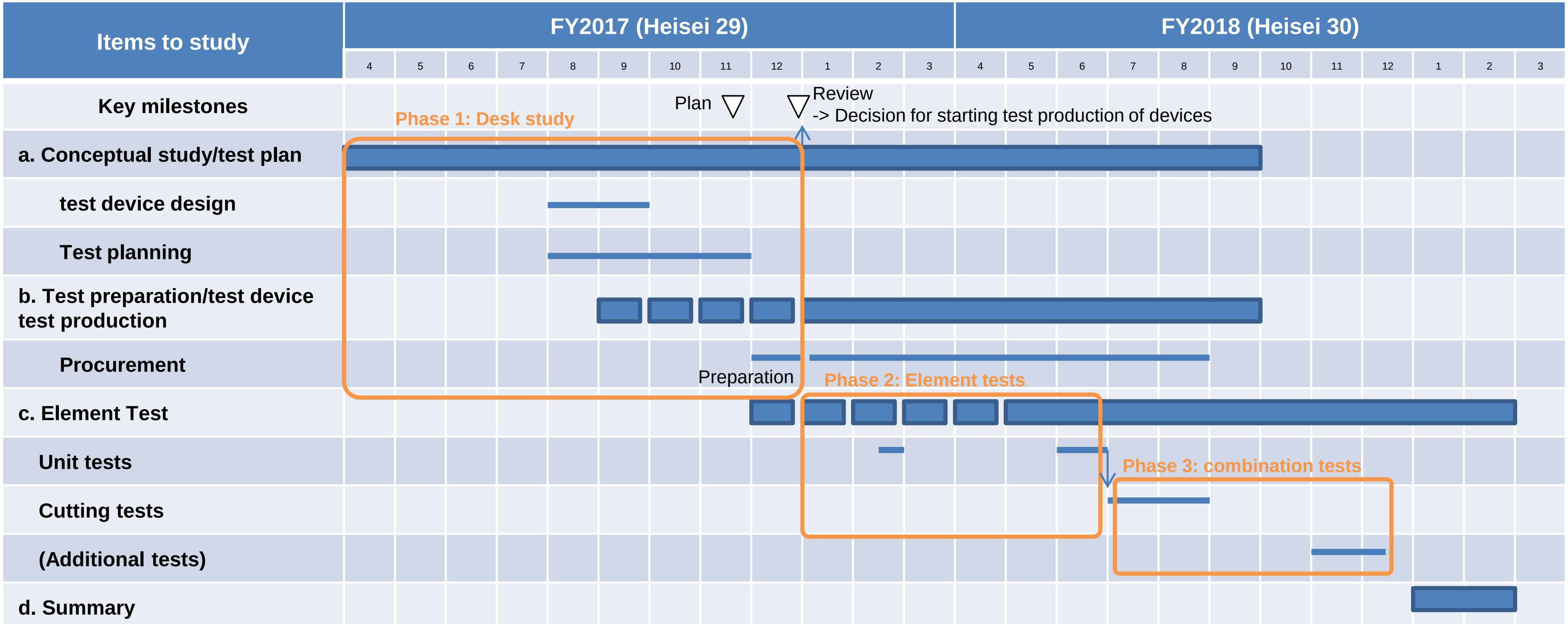
7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

b. <u>Method for removing interfering objects by fuel debris retrieval equipment used in the side entry method</u>

<u>(2) Hole drilling methods to enlarge the PCV opening to allow, for example, the robot arm to access the inside</u>



Notes	Expected results [1] Selection and evaluation of technologies used for the opening construction [2] Maintenance and recovery procedures (proposed) ● Procedures for recovery from abnormal conditions ● Procedures to exchange a core sleeve in a temporary cell

7. Implementation Details

7.2. Implementation Details

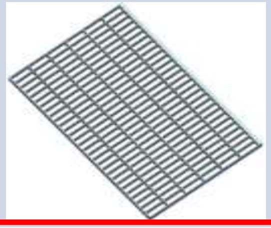
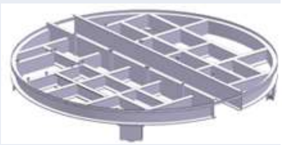
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. The method for removing interfering objects by fuel debris retrieval equipment is commonly used in access from both entries.
Interfering objects that need to be removed were identified and listed.

[red box] : Element tests under planning

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
1	Grating 	[1] Main material SS + fuel debris [2] Main dimensions Thickness 38 mm Pitch 0.03 x 0.1	Disc cutter, Saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	Medium	• Fuel debris is adhered • An irregular shape is predicted due to deformation/erosion.
2	Grating support structure 	[1] Main material SS + fuel debris [2] Main dimensions Thickness 13.5 mm ⌀4.85 (diameter)	Disc cutter, Saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	High	• Fuel debris is adhered • An irregular shape is predicted due to deformation/erosion.
3	CRD, etc. (fallen objects) 	[1] Main material SUS + fuel debris [2] Main dimensions Thickness 18 mm ⌀0.16	Disc cutter, Saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	High	• Fuel debris is adhered • There is a risk of falling reactor internals. • An irregular shape is predicted due to deformation/erosion.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. The method for removing interfering objects by fuel debris retrieval equipment is commonly used in access from both entries.
Interfering objects that need to be removed were identified and listed.

[red box] : Element tests under planning

Note: A difficulty level is determined by relative evaluation

No.	Interfering objects	General specifications (m)	Suggested processing methods	Example of removing method	Remove Difficulty level	Notes
4	CRD exchange system 	[1] Main material SS + aluminum + SUS + fuel debris [2] Main dimensions W0.9 × L0.7 × H4.0	Disc cutter, Saber saw	[1] Cut it by a disc cutter or the like. [2] Collect cut pieces in a container and carry them out (via the equipment hatch).	High	• Fuel debris is attached. • An irregular shape is predicted due to deformation/erosion.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. The methods to remove interfering objects by fuel debris retrieval equipment are commonly used in both side entry and top entry.

(1) The means and methods for removing interfering objects inside the pedestal

Fallen objects and inner structures in the pedestal are interfering objects, regardless of whether the top entry or the side entry method is used. It is also true that both methods are applicable to the removal of those objects. From the aforementioned perspective, element tests for methods to remove/dismantle those object are planned.

- Purpose of development
  - Feasibility verification of workability in a narrow space
  - Feasibility verification of a processing method taking fall prevention into account.

- Issues to be resolved
  - Remote controlled workability
  - Processing method for narrow parts
  - Removing method that taking fall prevention into account.

- Expected results
  - Feasibility of processing method for narrow parts
  - Feasibility of processing method taking into account fall prevention
  - Throughput calculation.

7. Implementation Details

7.2. Implementation Details

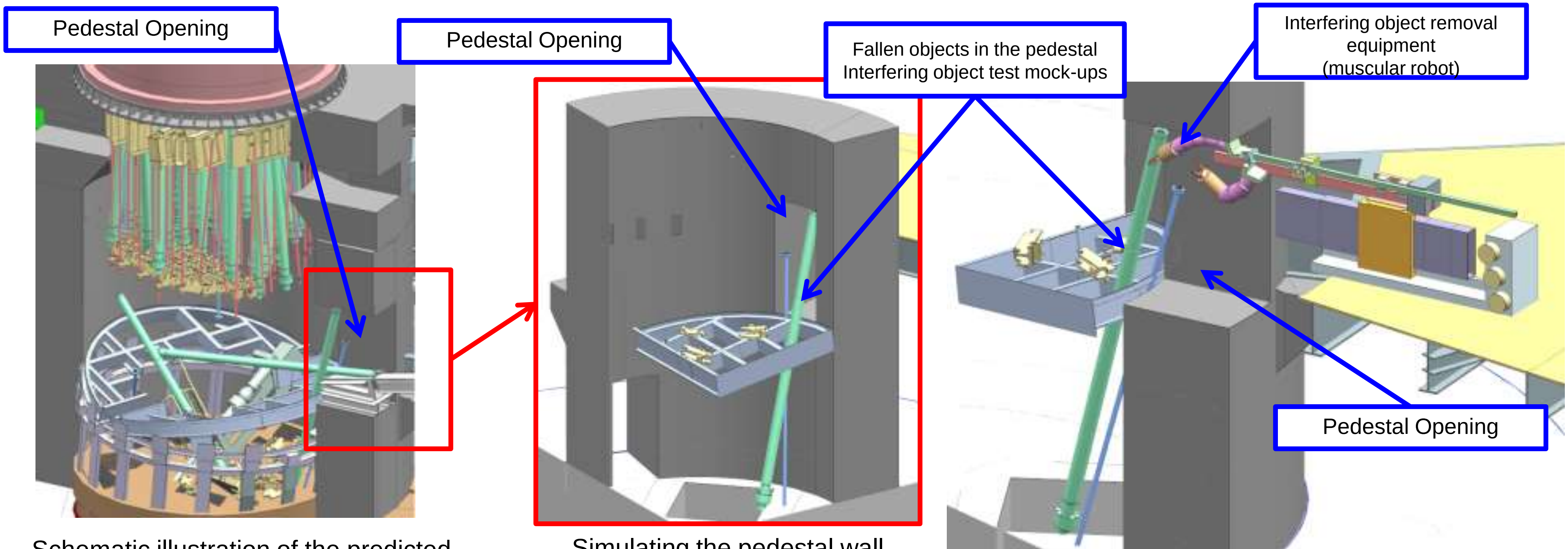
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. **<u>The method for removing interfering objects by fuel debris retrieval equipment is commonly used in access from both entries.</u>**

<u>(1) The means and methods for removing interfering objects inside the pedestal</u>

Schematic illustrations of element tests for the removal of fallen objects in the pedestal are shown below.



Schematic illustration of the predicted condition of fallen objects in the pedestal

Simulating the pedestal wall opening and its vicinity

Schematic illustration of element tests for the dismantlement of interfering objects

: Element test simulation range

7. Implementation Details

7.2. Implementation Details

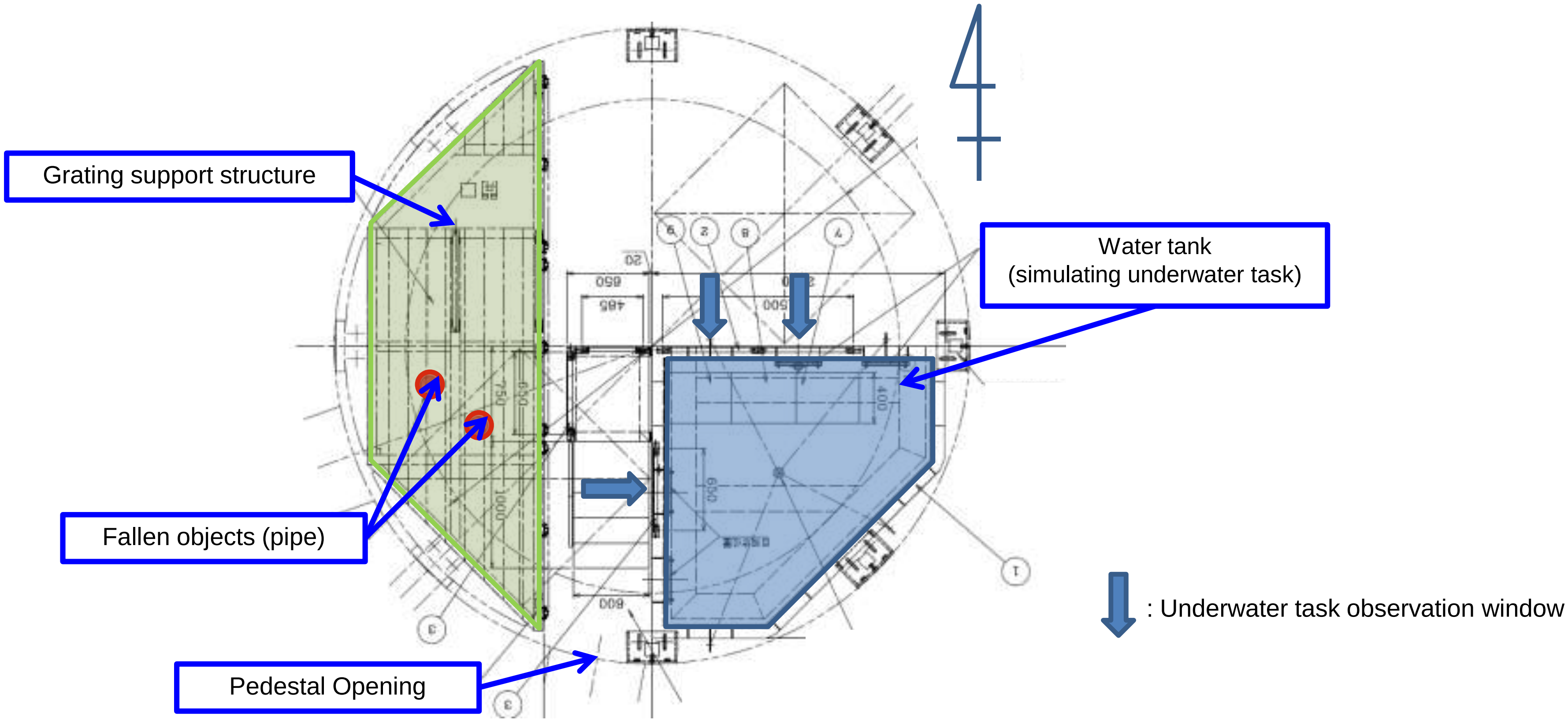
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. <u>The method for removing interfering objects by fuel debris retrieval equipment is commonly used in access from both entries.</u>

<u>(1) The means and methods for removing interfering objects inside the pedestal</u>

Simulation in the pedestal is planned to simulate fallen objects and take underwater tasks Into account.



Proposed test mock-ups in the pedestal

7. Implementation Details

7.2. Implementation Details

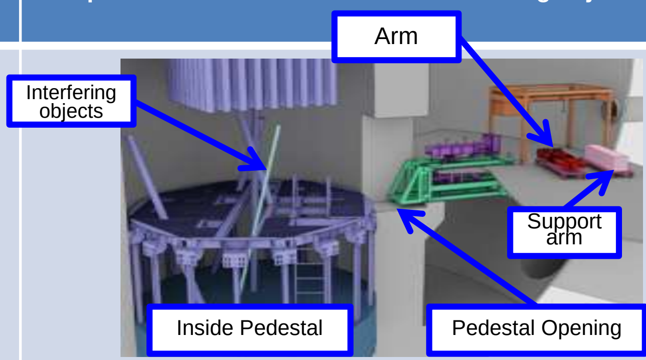
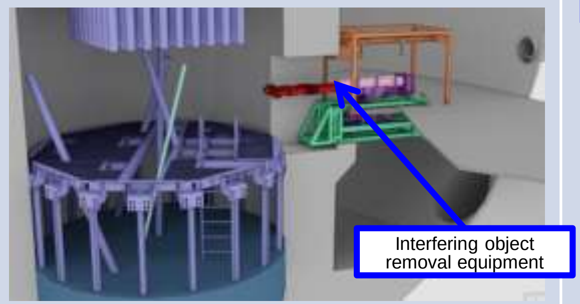
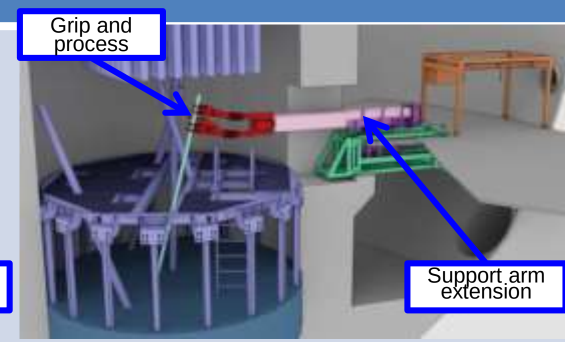
2) Element technology development for installing retrieval equipment

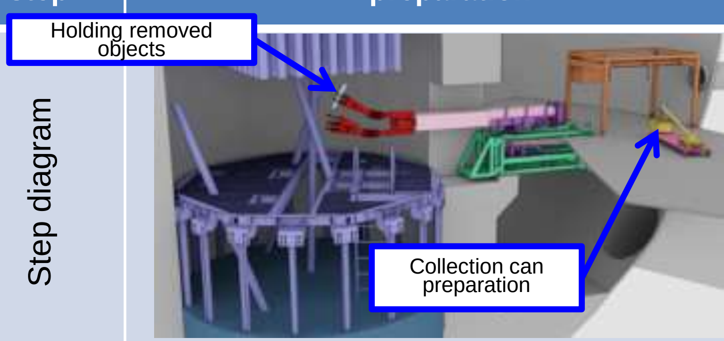
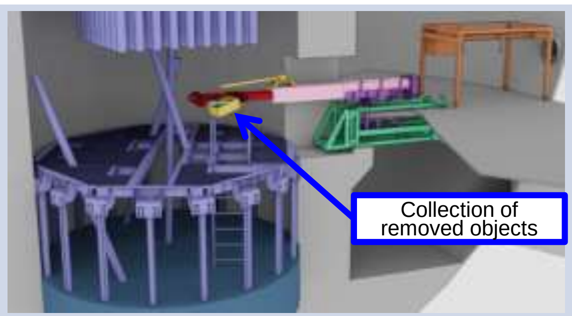
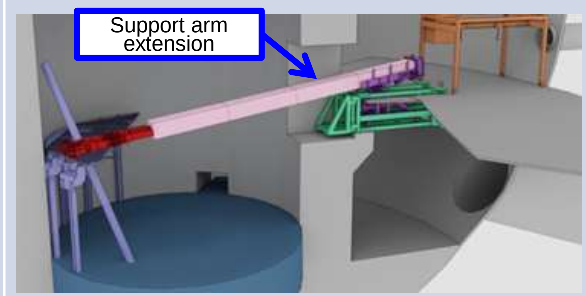
[2] Technical development for removing interfering objects during fuel debris retrieval

c. The method for removing interfering objects by fuel debris retrieval equipment is commonly used in access from both entries.

(1) The means and methods for removing interfering objects inside the pedestal

Specific procedures of the dismantlement of interfering objects in the pedestal are being studied, along with the design of facilities for element tests, to verify proposed procedures.

Work step	Preparation for dismantlement of interfering objects	Assembly of interfering object removal equipment	Fallen objects dismantlement status
Step diagram			

Work step	Holding removed objects/collection can preparation	Removal of removed objects	Support arm extension/removing work (repeat)
Step diagram			

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(1) The means and methods for removing interfering objects inside the pedestal

Items to study	FY2017 (Heisei 29)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Key milestones							Interim report ▼					Annual report ▼							Interim report ▼					Annual report ▼
1. Conceptual study																								
2. Element test plan																								
3. Preliminary tests required for element test plan																								
4. Element test preparation (Test device production)																								
5. Element Tests																								
6. Wrap-up																								
Notes	Results of element tests 1. Feasibility of processing method for narrow parts 2. Feasibility of processing method taking into account fall prevention 3. Throughput calculation.																							

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. <u>Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries</u>

<u>(2) Maneuverability verification by a combination of robot arm and access rail</u>

- Purpose of development
  - ➢ Verification of the feasibility of basic mechanical motions and remote operability of each equipment concerning interfering objects and fuel debris retrieval through the test that simulates the motion of a robot arm and access rail combined mechanism

- Development approach
  - ➢ Conceptual study of interfering objects and fuel debris retrieval methods
    - ✓ Study of required arms (for interfering object removal equipment)
    - ✓ Study of a method to carry various types of arms in the pedestal
  - ➢ Element test plan
    - ✓ Study of test methods and test items
    - ✓ Study of the possibility of using existing equipment (made last fiscal year) as well as new equipment
  - ➢ Element tests preparation and implementation
    - ✓ Manufacturing of prototype device
    - ✓ Manufacturing of test facility
    - ✓ Element Test

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Issues
  - Although functions of robot arms and access rails were verified individually in the element tests last fiscal year, the whole process of the removal work that involves all relevant equipment is not tested yet.

    Feasibility of the transportation of those equipment from the cell to the pedestal and the ability to process debris in the pedestal are keys for the retrieval method's success and affect other facilities such as cells significantly; therefore, feasibility of the whole removal process needs to be verified along with the identification of potential issues by conducting combination tests.

- Results of tests last fiscal year
  - Prototypes of the following equipment were built and element tests were performed with them as follows:

    The technical feasibility of each equipment capable of performing required functions and the validity of the designs were verified.

    <Robot arm tests>
    [1] Verification of emergency withdrawal ability
    [2] Verification of positioning accuracy
    [3] Verification of strength

    <Access rail tests>
    [1] Verification of the feasibility of construction by remote operation
    [2] Verification of strength

7. Implementation Details

7.2. Implementation Details

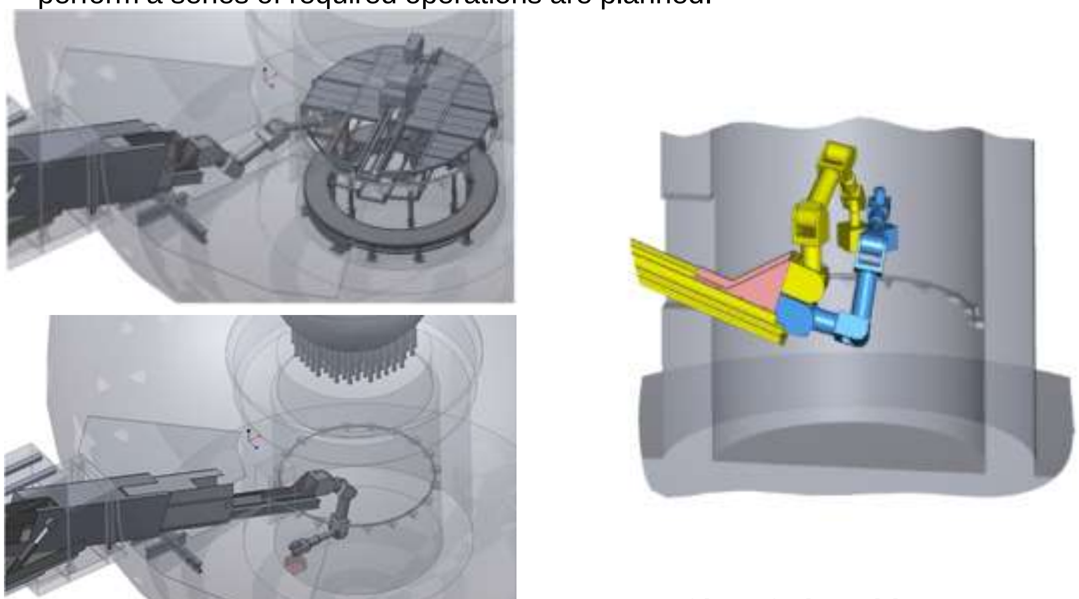
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

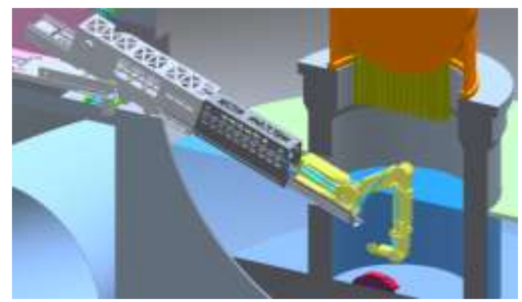
c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Conceptual Study
  - The combination of a hydraulic robot arm with a reaction force of 2 tons and an access rail was studied in the conceptual study last fiscal year as the method to process debris that piled in the pedestal bottom.
  - Meanwhile, methods employing an electric powered arm, which has a wider motion range compared to a hydraulic arm, were studied as a method to process interfering objects, such as the grating, because the processing of those objects would require less power.
  - No matter which arm is used, it needs to be carried into the pedestal by an access rail. Therefore, tests to verify the accessibility by the arm and the access rail combined mechanism and the maneuverability of the combined mechanism to perform a series of required operations are planned.



Removal of interfering object



Fuel debris removal

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

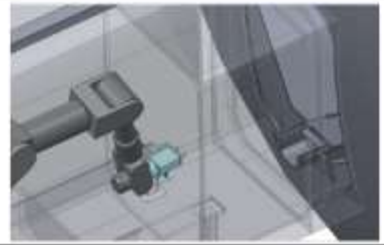
(2) Maneuverability verification by a combination of robot arm and access rail

[Schematic illustrations of interfering object removing work]

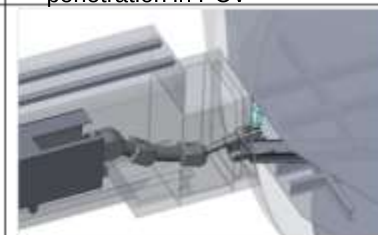
1. Cut X-6 penetration (leaving connecting part to CRD rail)

2. Cut PCV wall

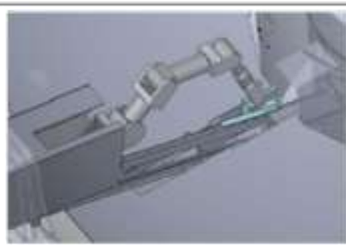
3. Cut PCV wall (leaving connecting part to CRD rail)



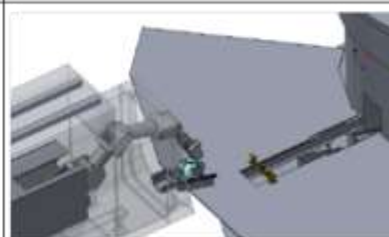
4. Cut the gating located above X-6 penetration in PCV



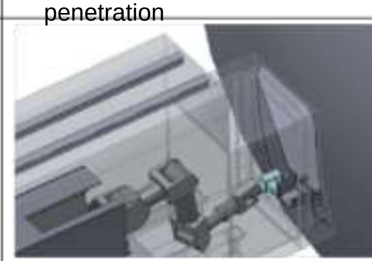
5. Cut the back part of the CRD rail



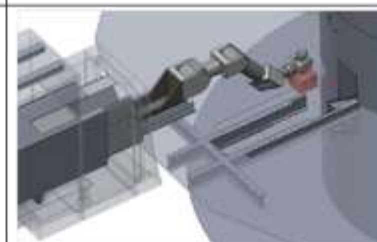
6. Cut the front part of the CRD rail



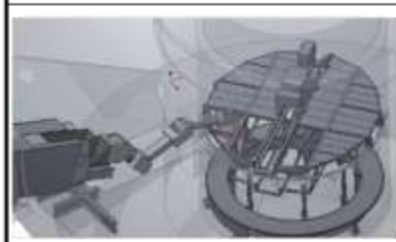
7 Cut the remaining part of X-6 penetration



8. Cut part of the grating that interferes the installation of the access rail



9. Cut the CRD exchange equipment



10. Cut CRD

11. Remove interfering objects in the back part of the pedestal

12. Remove interfering objects in the front part of the pedestal

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Element test approach
  - The use of an electric powered arm for the removing interfering objects and a hydraulic arm for debris removal were studied in the conceptual study.
  - No matter which arm is used, the arm needs to be carried in the pedestal by an access rail.
  - The series of work steps is almost the same for both the dismantlement of interfering objects and the removal of debris, although the arm driving sources are different.
  - If accessibility by a hydraulic arm is verified by tests, accessibility by an electric powered arm is also ensured because a hydraulic arm is larger in dimensions and weight.

⇩

Accessibility verification tests with the robot arm and access rail combined mechanism that were made last fiscal year are planned.

- Identification of verification items
  - Verification iitems are identified by going over the w debris removal work steps because the series of work steps is almost the same for both the dismantlement of interfering objects and the removal of debris.
  - The identified verification items are grouped into the groups of those for the verification of this project, for the verification to be conducted in the future, and for conceptual study/element tests from the following viewpoints:
    - ✓ To expedite feasibility verification of the method, items that need to be verified by tests in higher priority are extracted.
      (Items whose evaluation results make an impact on the method and its change are picked up.)
    - ✓ Feasibility is verified for each of multiple issues in a step-by-step manner.

7. Implementation Details

7.2. Implementation Details

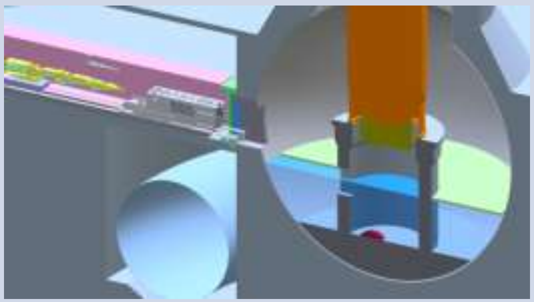
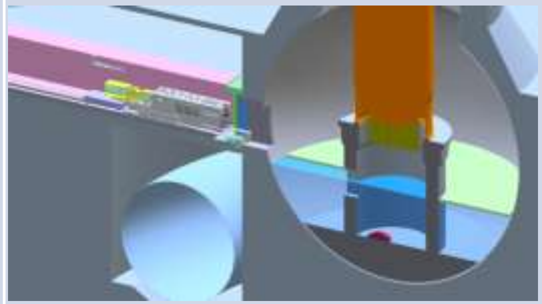
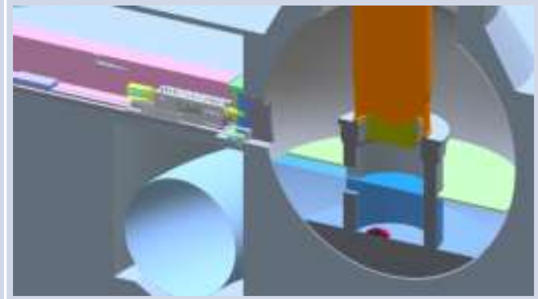
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Work steps and verification items

Work step	1. Carry the robot arm into the cell	2. Insert the robot arm in the access rail	3. Install the robot arm in the access rail
Step diagram			
Verification items	(1) Traveling and running of equipment between the cells [1] Ability to get over bumps and gaps at rail joints [2] Accuracy of stop position [3] Measures to prevent the carriage losing balance and getting uneven (2) Utility supply to equipment during traveling between cells [1] When passing the shutter [2] Cabling	(1) Transit of arm robot to the access rail (2) Connection of arm robot and transfer carriage [1] Detection of connecting position [2] Position alignment by the transfer carriage [3] Connection retained in case of drive source outage	Same as on the left

7. Implementation Details

7.2. Implementation Details

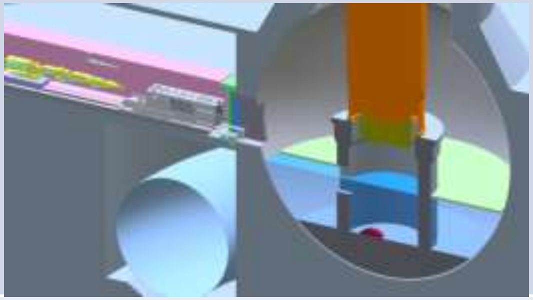
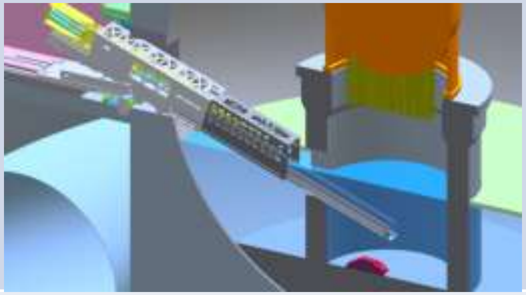
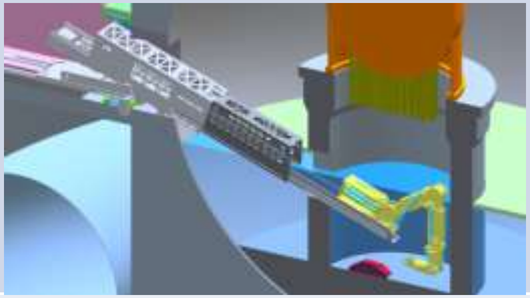
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Work steps and verification items

Work step	4. Tilt the access rail toward the opening for CRD exchange	5. Extend the access rail	6. Move forward and expand the robot arm
Step diagram			
Verification items	(1) Tilting of the access rail [1] Speed [2] Motion range [3] Cabling [4] Shutdown accuracy [5] Possibility of vibration -> Already verified by element test last year	(1) Expansion and contraction of the access rail [1] Speed [2] Motion range [3] Cabling [4] Shutdown accuracy [5] Possibility of vibration (2) Remote installation of access rails (Possibility of positioning using camera image) -> Already verified by element test last year (Possibility of positioning in darkness using camera image is not verified.)	(1) Carriage travelling [1] Speed [2] Motion range [3] Cabling [4] Shutdown accuracy [5] Possibility of vibration [6] Travelling performance of carriage to get over bumps at rail joints (2) Robotic arm on remote-controlled guide vehicle (3) Securing robot arm on the rail [1] Retention force [2] Position retained even in case of drive source outage

7. Implementation Details

7.2. Implementation Details

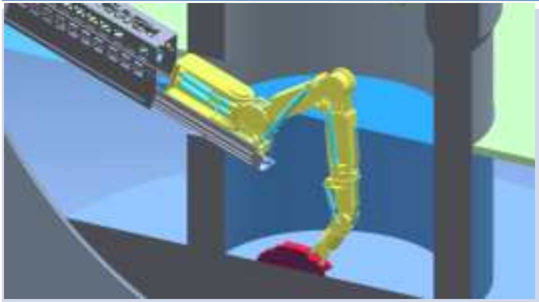
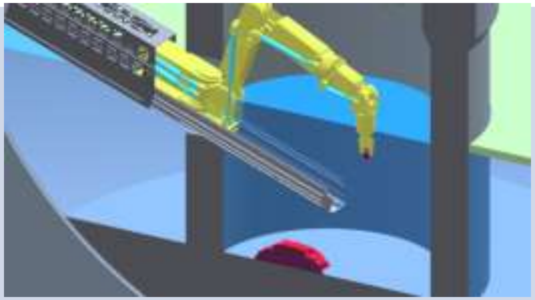
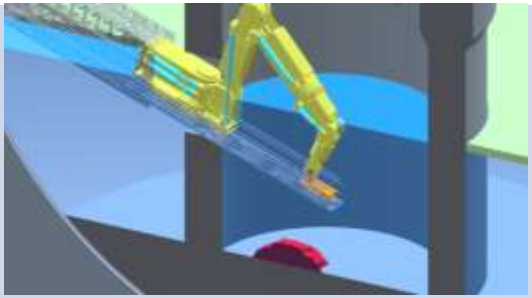
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Work steps and verification items

Work step	7. Move the robot arm close to fuel debris	8. Drill fuel debris with the tool tip of robot arm	9. Collect fuel debris fragments into the unit can placed in the transfer carriage on the access rail
Step diagram			
Verification items	(1) Interfering object/debris cutting point targeting using camera image (2) Positioning accuracy of robot arm tip -> Already verified by element test last year	(1) Procedure for removing Interfering objects (2) Interfering object removing method (3) Debris drilling method (4) Collection of chips generated during interfering object and debris drilling (5) Bearing of reaction force generated by debris drilling	(1) Interfering object and debris grabbing method (2) Method to judge the cut size of objects fitting into the unit can

7. Implementation Details

7.2. Implementation Details

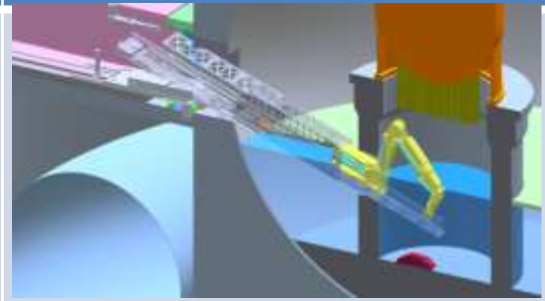
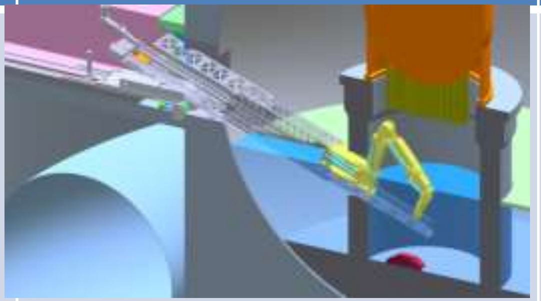
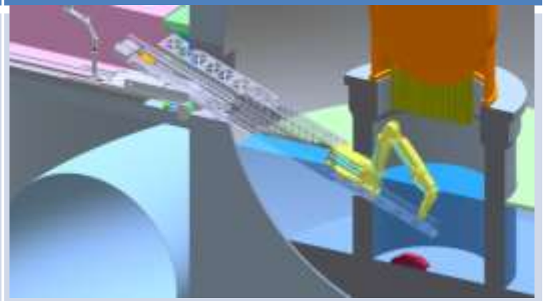
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Work steps and verification items

Work step	10. Transfer the unit can to the cell by the transfer carriage on the rail	11. Pick up the unit can with the manipulator in the cell	12. Put the unit can containing fuel debris in the canister with the manipulator in the cell
Step diagram			
Verification items	(1) Transfer carriage traveling [1] Descending move by gravity [2] Speed [3] Motion range [4] Shutdown accuracy [5] Possibility of vibration [6] Travelling performance of carriage to get over bumps at rail joints	(1) Method to hold the unit can (shape of the unit can)	(1) Method to store unit cans in the canister (2) (Structure of the canister) [1] Lid fastening [2] Drying [3] Degassing

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Work steps and verification items

Work step	Others
Step diagram	-
Verification items	(1) Emergency escape [1] Change to robot arm transfer attitude -> Already verified by element test last year [2] Robot arm retraction into cell (carriage travelling) [3] Retraction of the access rail [4] Leveling the access rail [5] Withdrawal of the access rail into the cell (2) Environment resistance (radiation, temperature, humidity, dust and foreign matters) (3) Maintainability (camera replacement) (4) Exchange of tip tools (5) Feasibility of the whole process (6) Throughput

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification iitems and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
1	Traveling of equipment between the cells	(1) Traveling and running of equipment between the cells [1] Ability to get over bumps and gaps at rail joints [2] Accuracy of stop position [3] Measures to prevent the carriage losing balance and getting uneven (2) Utility supply to equipment during traveling between cells [1] When passing the shutter [2] Cabling	[A] (There is a track record in traveling cranes.)	-	
2	Installation of the robot arm in the access rail (The gravity center of robot arm is outside the carriage wheels)	(1) Transit of arm robot to the access rail (2) Connection of arm robot and transfer carriage [1] Detection of connecting position [2] Position alignment by the transfer carriage [3] Connection retained in case of drive source outage	-	[A]	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification iitems and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
3	Remotely controlled installation of access rails • Gradient • Expansion and contraction • Fixing method to the pedestal • Positioning using camera image	(1) Remotely controlled installation of access rails [1] Speed [2] Motion range [3] Cabling [4] Shutdown accuracy [5] Possibility of vibration (2) Possibility of positioning using camera	-	[A] • Verified last year • The same tests will be performed in darkness this fiscal year.	
4	Carrying-in of the robot arm in the pedestal (ability of the carriage to get over bumps at rail joints)	(1) Traveling of the carriage on the access rail [1] Speed [2] Motion range [3] Cabling (robot arm) [4] Shutdown accuracy [5] Possibility of vibration [6] Travelling performance of the carriage to get over bumps at rail joints (2) Robotic arm on remote-controlled guide vehicle (trackability of robot arm tip by camera) (3) Securing robot arm on the rail [1] Retention force [2] Position retained even in case of drive source outage	[A] (Cabling: Proven with bearing and reels)	[A] (except cable handling)	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification iitems and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
5	Interfering object and debris processing (drilling)	(1) Alignment of the robot arm on interfering object/debris cutting points using camera image	-	[A] • Verified last year • The same tests will be performed in darkness this fiscal year.	
		(2) Positioning accuracy of robot arm tip	-	- • Verified last year	
		(3) Processing (drilling) of interfering objects and debris	[A]	- (verified by other element tests)	
		(4) Collection of chips generated during interfering object and debris processing (drilling)	[A]	-	
		(5) Bearing of reaction force generated by interfering object and debris processing (drilling)	-	[A]	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification items and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
6	Collection of processed debris in the unit can	(1) Interfering object and debris grabbing method (2) Method to judge the cut size of objects fitting into the unit can	[A]	-	
7	Transportation of the unit can within the cell (ability of the carriage to get over bumps at rail joints)	(1) Traveling of the transfer carriage on the access rail [1] Descending move by gravity [2] Speed [3] Motion range [4] Shutdown accuracy [5] Possibility of vibration [6] Travelling performance of the carriage to get over bumps at rail joints	-	[A]	
8	Putting the unit can in the canister	(1) Method to hold the unit can (shape of the unit can) (2) Method to store unit cans in the canister	[A]	-	
		(3) Canister structure [1] Lid fastening [2] Drying [3] Degassing	To be studied by Canister Project Team		

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification items and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
9	Emergency escape	(1) Change in the attitude of the robot arm during withdrawal	-	- • Verified last year	
		(2) Robot arm retraction into cell (carriage travelling) (3) Access rail retraction (4) Leveling the access rail	-	[A]	
		(5) Withdrawal of the access rail into the cell	[A] (Traction by another carriage is planned. There are a lot of proven track records of traction carriages.)	-	
10	Environmental resistance	(1) Environment resistance (radiation, temperature, humidity, dust and foreign matters)	[A]	-	
11	Maintainability	(1) Review of maintenance items (2) Review of maintenance methods	[A]	-	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Verification iitems and methods

No.	Major issue	Verification items	Verification method		Notes
			Conceptual Study	Element Test	
12	Exchange of tip tools	(1) Study of remote-controlled tool exchange methods (2) Study of tool carrying-in/carry-out methods	[A]	-	
13	Feasibility of the whole process	(1) Performing a test to go over the whole process and identifying issues	-	[A]	
14	Throughput	(1) Throughput verification	-	[A]	

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

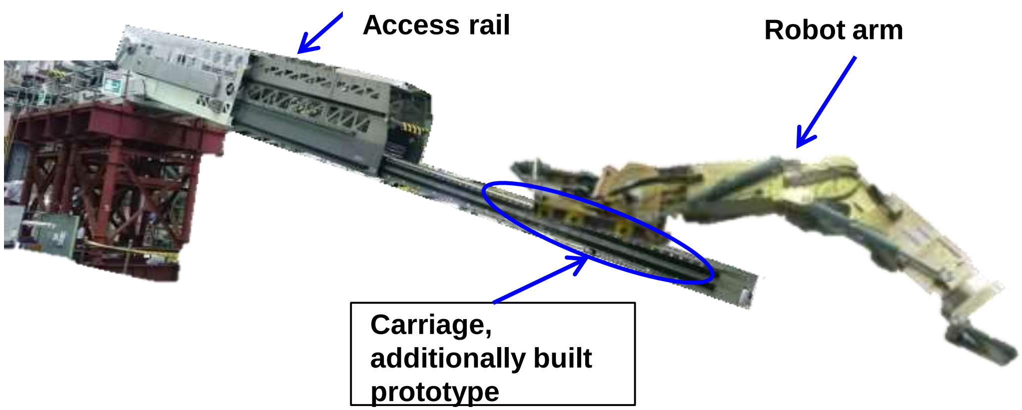
(2) Maneuverability verification by a combination of robot arm and access rail

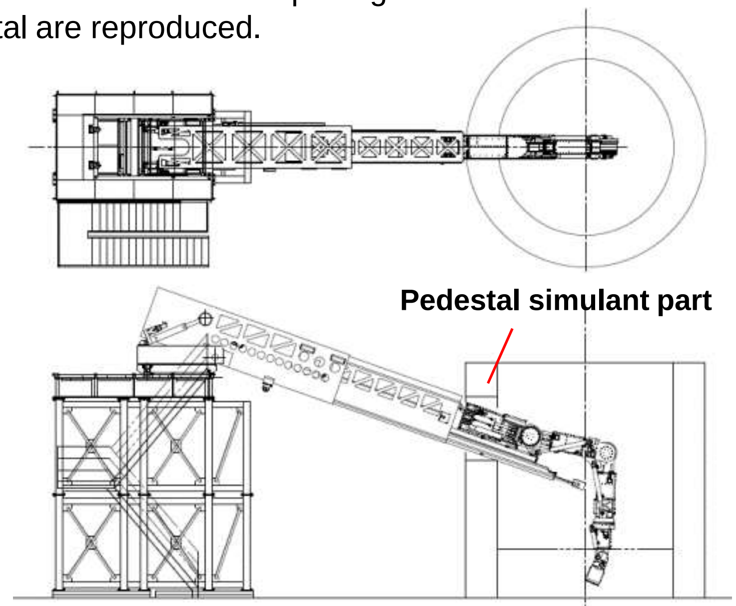
- Test device overview

[1] Robot arm (already manufactured) : 6-axis hydraulic manipulator
Reaction force of 2 tons (boring of boreholes with a diameter of about 60 mm is assumed.)
Arm length: 7.1 m (to cover the vertical access range from the RPV bottom to a level 1.5 m below the pedestal bottom surface)

[2] Access rail (Carriage section is additionally manufactured) : 3-section extension rail
Fixed on the cell floor and to Pedestal opening for CRD

[3] Test facility (newly manufactured) : cell floor and the low part of the pedestal are reproduced.





Schematic drawing of the whole test facility

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

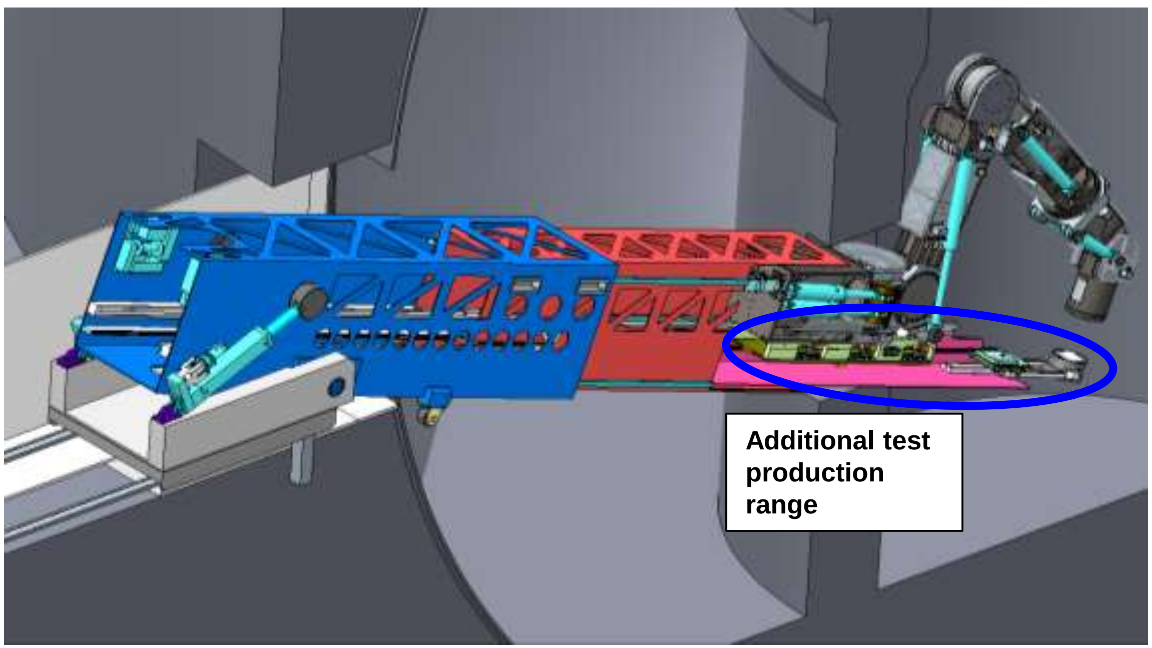
[2] Technical development for removing interfering objects during fuel debris retrieval

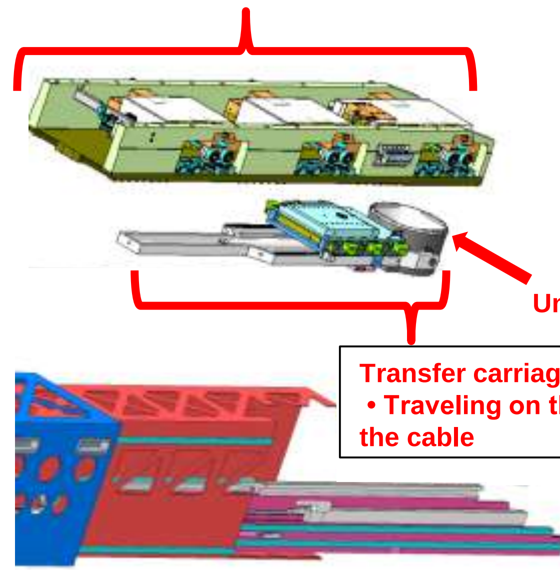
c. <u>Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries</u>

<u>(2) Maneuverability verification by a combination of robot arm and access rail</u>

- Test device overview

The robot arm and the carriage that interfaces the robot arm to the access rail were newly built and assembled to the access rail built last fiscal year to complete a prototype. Combination tests were conducted with this prototype.





7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Test details

Prototype models of a carriage that travels on the access rail are built and subjected to operation tests that simulate the whole process including the installation of the access rail using the test apparatus that reproduced the actual pedestal structure in order to verify the feasibility.

[1] Simulation of robot arms carrying in and out of the pedestal (verification of travelling performance of the carriage to get over bumps at rail joints)
[2] Simulation tests of drilling fuel debris in the pedestal
[3] Collection of processed fuel debris into the unit can
[4] Movement of the access can during traveling on access rail (verification of travelling performance of the carriage to get over bumps at rail joints)

- Expected results
  - Feasibility of the whole process including the carrying-in of equipment in the pedestal, drilling of debris and removal
  - Work time to complete each step of the whole process including the carrying-in of equipment in the pedestal and the removal of debris (excluding debris drilling time)
  - Identification of detailed issues and measures for them

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Test items and criteria

No.	Test item	Criteria
1	Installation of the robot arm in the access rail	• Arm robot can transit to the access rail. • Arm robot and transfer carriage can be secured. • Secured carriages shall be retained even in case of drive source outage.
2	Remotely controlled installation of access rails	• Installation must be possible under dark conditions by remote operation that is guided by a camera and supported by lighting, both attached to the equipment.
3	Carrying-in of the robot arm in the pedestal (Cabling of robot arm is covered by as many workers in this element test)	• Capable of getting over bumps at access rail joints smoothly • The attitude of the robot arm must be accurately controlled as intended by the camera-image based guiding during the carrying-in operation into Pedestal. • Rail retention force of arm robot shall be xx or greater (Specific value is under study) • Arm robot shall be still secured on the rail even in case of drive source outage.
4	Positioning of the robot arm during interfering object/debris processing (drilling)	• Positioning must be possible under dark conditions by the guidance using the image of a camera and with the support of lighting, both attached to the equipment.
5	Bearing of reaction force generated by interfering object and debris processing (drilling)	• There must be no abnormality in the operation of the robot arm and access rail when a pressing force of 2 tons is applied to the floor surface.

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Test items and criteria

No.	Test item	Criteria
6	Transportation of the unit can within the cell (traveling of the transfer carriage on the access rail)	• The transfer carriage must be capable of moving downward only by gravity. • Capable of getting over bumps at access rail joints smoothly
7	Emergency escape	• Robot arm retraction (carriage travelling) into cell is possible. • The access rail must be retractable. • It must be possible to level the access rail.
8	Feasibility of the whole process	• The whole process from the carrying-in of the access rail for the robot arm to the withdrawal of the access rail into the cell must be able to be done by remote operation (Identify and address work that cannot be done by remote operation and find solutions for them if any).
9	Throughput verification	• The cycle time for the whole operation must be measured, and the throughput calculated based on the cycle time must be 10 years or shorter (Find measures if exceeding 10 years).

7. Implementation Details

7.2. Implementation Details

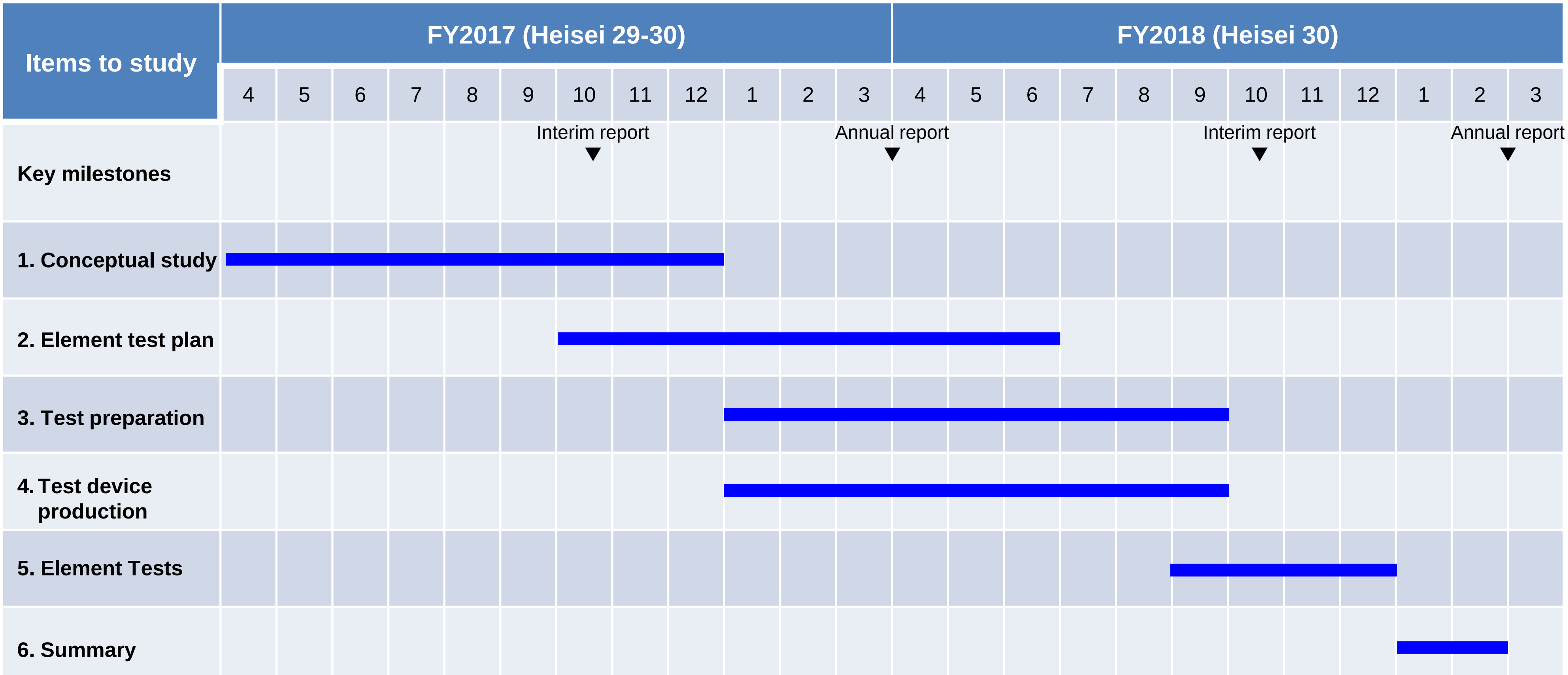
2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(2) Maneuverability verification by a combination of robot arm and access rail

- Development process



7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(3) Verification of radiation resistance of robot arm hydraulic fluid

- Purpose of development
  - The radiation resistance of hydraulic fluid is tested, and the obtained data is used to verify the feasibility and maintainability of robot arm.
    (The radiation resistance evaluation test needs to be performed since data concerning the radiation resistance of hydraulic fluid is not available almost at all while same data is available for other materials such as resins and electronic devices).

- Issues to be resolved
  - Oil hydraulic (flame-retardant hydraulic fluid) is assumed for robot arms instead of water hydraulic because they require high output and high positioning accuracy; maintenance requirements including oil exchange frequency are unspecific due to insufficiency of radiation resistance data on hydraulic fluid.
- Development approach
  - Selection of hydraulic fluid
  - Study of test and evaluation methods
  - Radiation resistance evaluation test
- Test Conditions
  - Dose rate : to be determined through discussions with the test facility studying team
  - Cumulative dose : to be determined, example) 100, 300, 500, 750, 1,000 [kGy]

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. <u>Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries</u>

<u>(3) Verification of radiation resistance of robot arm hydraulic fluid</u>

- Expected results
  - Radiation resistance data of the hydraulic fluid used in the robot arm
- Development status
  - Selection of hydraulic fluid
    New hydraulic fluids with potential resistance to radiation are being examined in addition to the fluids used in the past.
  - Study of test and evaluation methods
    Evaluation items in the radiation resistance test are being studied. Dynamic viscosity, oxidation, level of contamination, change in flash point and gas generation amount are listed.
  - Radiation resistance evaluation test
    Sample fluids will be put in test tubes or similar containers and subjected to radiation exposure according to the current plan.
- Development schedule

Items to study	FY2017 (Heisei 29-30)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Verification of radiation resistance of robot arm hydraulic fluid									Test Plan	Test Plan	Test Plan	Study of test apparatus	Radiation resistance evaluation test preparation and implementation	Radiation resistance evaluation test preparation and implementation	Radiation resistance evaluation test preparation and implementation	Summary								

7. Implementation Details

Collaborative study with Osaka University

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

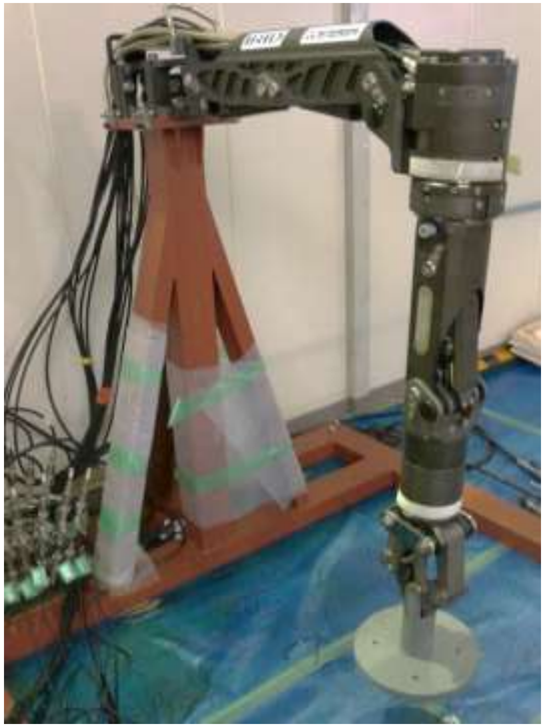
c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(4) Development of hydraulic manipulator force control technique

- Development goals
  - Estimation of the force exerted to the cylinder, and the development of force control method based on the estimate
  - Coexistence of position control and force control

- Issues
  - The position of the robot arm front end and the pressing force applied to fuel debris need to be controlled during the fuel debris retrieval work with the robot arm (where reaction force generated by the activation fluctuates while the position of the robot arm front end is held at a fixed position, for example). No study has been made on the force control while the position control was studied last fiscal year.

- Development approach
  - Study of force estimation
  - Study of force control method
  - Estimation of force generated by the hydraulic manipulator and the cylinder, and application tests of force control



Hydraulic manipulator

7. Implementation Details

Collaborative study with Osaka University

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(4) Development of hydraulic manipulator force control technique

- Development status

  - Production of test device to verify the effectiveness of the control law
    A test apparatus consisting of a single-shaft hydraulic cylinder was made, which could make the verification of the control law easy.

  - Development of a method to estimate the force exerted to the cylinder
    Force estimation methods are being studied, such as force estimation using pressure and differential pressure, and the improvement of accuracy by filter setting.
    The effectiveness of a force estimation method is evaluated by measuring the force of the single-shaft cylinder by a load cell and comparing the measured data with the actual force.

  - Development of force control
    Operation by the PI control was examined with the single-shaft hydraulic cylinder.
    The control law of force control is being studied based on the result of the examination.

7. Implementation Details

7.2. Implementation Details

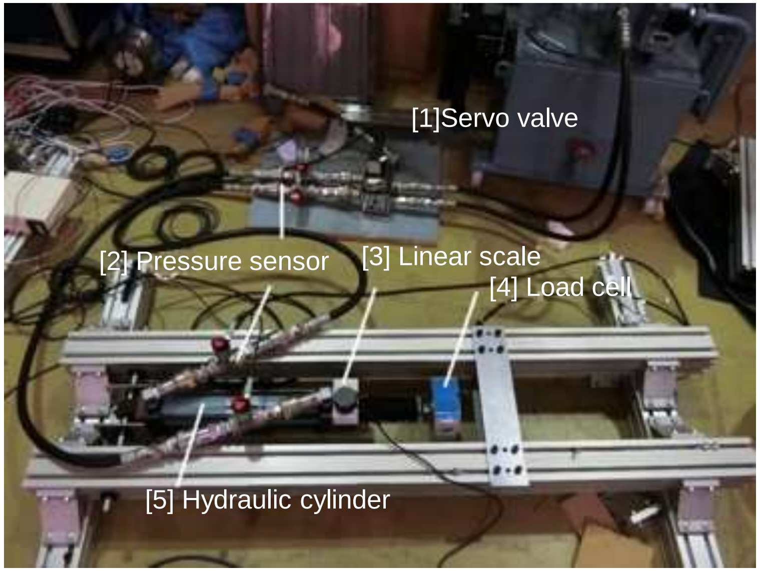
Collaborative study with Osaka University

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(4) Development of hydraulic manipulator force control technique



Single-shaft hydraulic cylinder test apparatus

- Development schedule

Items to study	FY2017 (Heisei 29-30)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Study of hydraulic manipulator force control			Contract▼		Study of force estimation		Study of force control method										Force estimation and force control application test					Summary		

7. Implementation Details

7.2. Implementation Details

Collaborative study with Kobe University

2) Element technology development for installing retrieval equipment

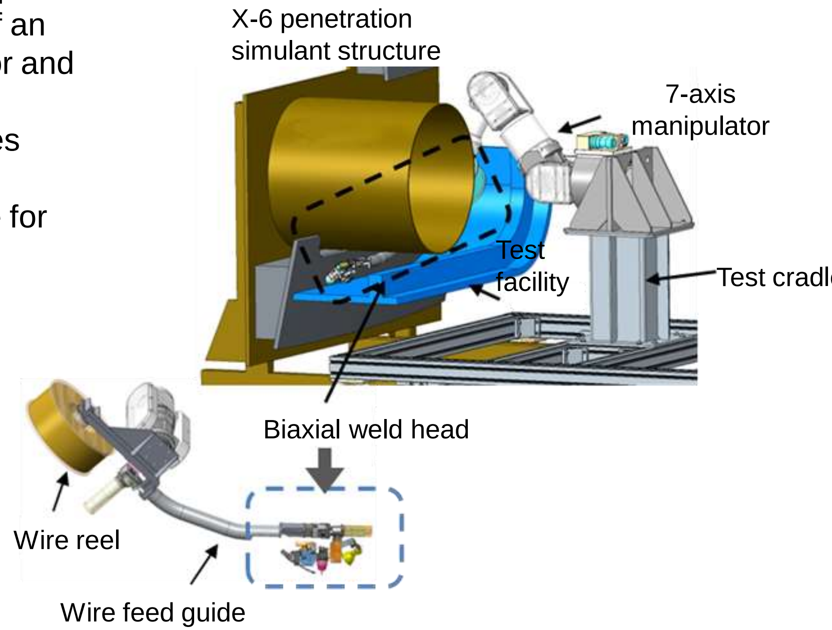
[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(5) Development of technique for motion planning in consideration of avoidance of interference with the environment of multi-degree-of-freedom robot

- Development goals
  - Development of methods to design the optimal motion trajectory of a manipulator within a narrow space in consideration of the avoidance of elbow interference

- Issues
  - It has become possible to expand the motion range in a narrow space by the combination of multiple robots (such as the combination of an access rail and a robot arm, or of an electric-powered manipulator and a weld head); however, it is assumed that access control of the manipulator in a narrow space, whose shape dynamically changes with the progress of work, is still very difficult for operators.
  Therefore, it is necessary to develop a motion planning technique for multi-degree-of-freedom robot under restraint conditions such as interference avoidance.



- Development approach
  - Study of a method to describe intended trajectory and restraint conditions
  - Study of a generic method to describe ambient environments
  - Verification test of a trajectory generated by technique for motion planning

Collaborative study with Kobe University

7. Implementation Details

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

(5) Development of technique for motion planning in consideration of avoidance of interference with the environment of multi-degree-of-freedom robot

- Development status
  - **Study of a method to describe intended trajectory and restraint conditions**

    This is an earlier study (2013) by Tazaki et al. of Kobe University.
    "Method for trajectory planning of multi-body systems" is applied.
    •Proposal of a method to plan a trajectory within a work space expressed in multibody system
    •Assure implementation of high priority tasks without interference from low priority tasks
    •Ability to move an object to an intended position with the most efficient motion

    When applying the trajectory planning method directly, a trajectory that meets the following restraint conditions is to be designed using gradient method based optimization calculation:
    - ◆ The trajectory of the arm front end must coincide with the weld path.
    - ◆ Interference between the link mechanism and the welding workpiece must be avoided.

  - **Study of a generic method to describe ambient environments**

    Surrounding environment is also expressed in multibody system.

7. Implementation Details

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Collaborative study with Kobe University

7.2. Implementation Details

2) Element technology development for installing retrieval equipment

[2] Technical development for removing interfering objects during fuel debris retrieval

c. Method for removing interfering objects by fuel debris retrieval equipment commonly used in access from both entries

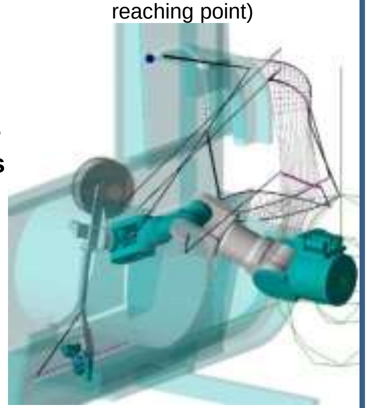
(5) Development of technique for motion planning in consideration of avoidance of interference with the environment of multi-degree-of-freedom robot

- Issues and solutions

Issues

<Example of failure>

A solution may not be obtained when an inappropriate initial value is given since the shape of the welding workpiece is complex (non-convex).



Solutions

<Example of success>

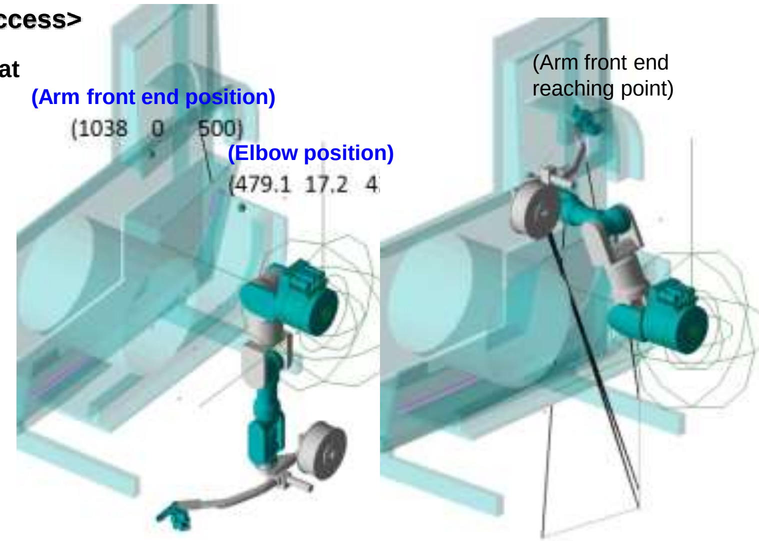
A proposed two step planning method that follows Steps [1] and [2] below via the stopover point (virtual destination) is given in advance.

[1] Formation of a temporary trajectory
Move the hand and elbow to align them with the virtual destination.

Not consider interference avoidance.

[2] Formation of the final trajectory
Make the position of the arm front end coincide with the weld path using the temporary trajectory formed in [1] as an initial trajectory.

Consider interference avoidance.



- Development schedule

Items to study	FY2017 (Heisei 29-30)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Formation and evaluation of a trajectory that takes into account the avoidance of interference with the environment of multi-degree-of-freedom robot		Contract▼		Study of a method to describe intended trajectory and restraint conditions	Study of a generic method to describe ambient environments								Verification test of a trajectory generated by technique for motion planning							Summary				

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

Fuel debris retrieval equipment/devices and system (including the fuel debris cutting and dust collection system, containers and work tables, monitoring system, and robot arms to manipulate these equipment) needs to be remotely maintained as a rule by because of their installation in a high radiation area. This requires reviewing maintenance methods for fuel debris retrieval equipment and systems, evaluating feasibility, identifying issues, and studying a reasonable action policy with actual equipment.
Among other things, the following main themes with element tests will be performed on an as needed basis. Through these activities, issues will be identified and reviewed.

a. Study of remote maintenance action policies in the top entry and the side entry methods in common

- For the side entry methods, the basic conditions concerning maintenance tasks are under study and discussion.
- From now, the basic implementation policy of remote maintenance will be formulated with consideration of possible workers' intervention and workers exposure.

b. Layout of main equipment used in the top entry and the side entry methods and their traffic lines

- Design conditions used in the study of cells and methods are being studied and discussed for the side entry method.
- The first review meeting concerning three the side entry methods was held by Hot Cell & Manipulator WG.
- From now, the basic policy concerning the layout of main equipment and the traffic line of them will be formulated in consideration of the usability of the equipment and facilities of removal work.

Technical development planning

- A development plan toward the realization of fuel debris retrieval work needs to be established. For this purpose, study results will be summarized and reviewed first, followed by the identification of technical challenges concerning the equipment and facilities of removal work.

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

Fuel debris retrieval equipment/devices and system (including the fuel debris cutting and dust collection system, containers and work tables, monitoring system, and robot arms to manipulate these equipment) needs to be remotely maintained as a rule by because of their installation in a high radiation area. This requires reviewing maintenance methods for fuel debris retrieval equipment and systems, evaluating feasibility, identifying issues, and studying a reasonable action policy with actual equipment.

- Purpose of development
  - Demonstrate feasibility as a maintenance "system" through the consistent point of view

- Issues to be resolved
  - Although some equipment will be maintained, the feasibility of a maintenance plan as a system is doubtful because the methods proposed for individual equipment lack consistency (selection of remote/direct, maintenance space or rooms and equipment to be maintained).
  - When considering the above status, the current plan’s feasibility concerning the construction and layout of equipment is not certain.

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

- Development approach
  - Establish the point of view of maintenance (including selection of remote/direct and maintenance space or rooms) taking the 1st floor remote maintenance as a basic policy.
    - Define areas that workers enter.
    - Sort maintenance work into two groups clearly: those that can be performed remotely and those cannot.
  - Equipment layout and traffic lines in the cell are designed with consideration of maintenance.
  - Technologies necessary to realize the maintenance system are developed. (Only drawing up a development plan in this project)

- Expected results
  - Basic maintenance policy of equipment in the cell (proposed)
    - Access classification
    - Maintenance classification, etc.
  - Equipment layout in the cell
  - Technical development plan

7. Implementation Details

7.2. Implementation Details

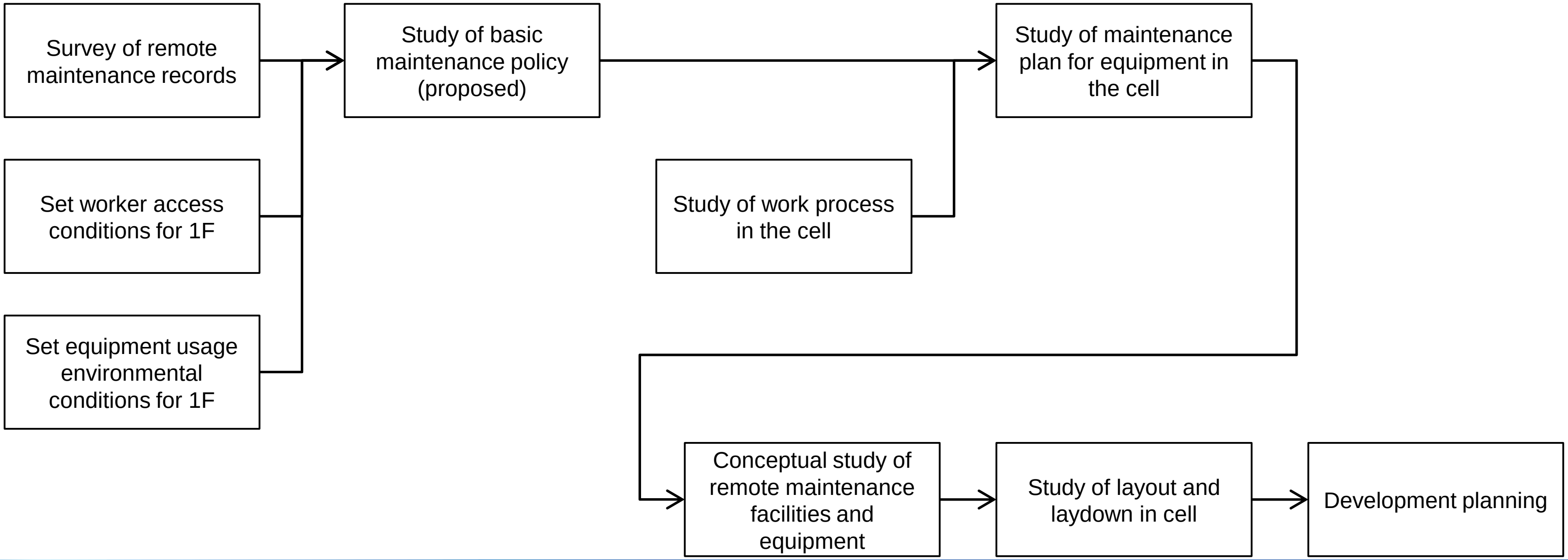
3) Development of remote maintenance technologies for fuel debris retrieval equipment

- Method of study

  The following approaches are taken to studying remote maintenance technologies applicable to fuel debris retrieval equipment:
  - Existing remote maintenance technologies are referred to as the base of the study.
  - The scope of the study is technologies necessary to perform the remote maintenance of equipment in the primary boundary (inside the cell).

- Input before study
  - Worker exposure control value
  - Environmental condition: atmospheric dose rates and radioactivity concentrations in R/B and in the extension building
  - Restrictions to cells in R/B: height, weight, etc.

- Study flow



3) Development of remote maintenance technologies for fuel debris retrieval equipment

- Study status

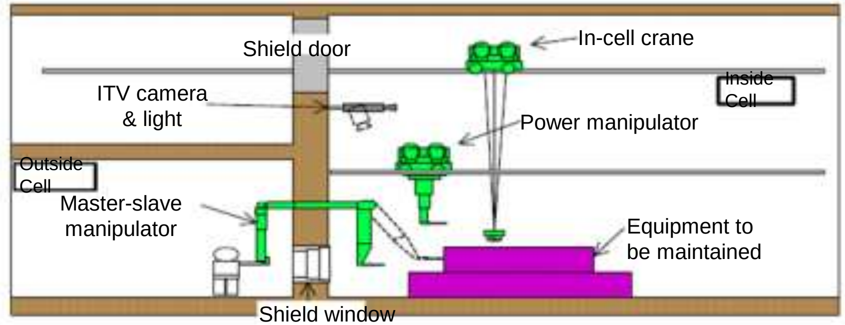
[1] Survey on record of remote maintenance

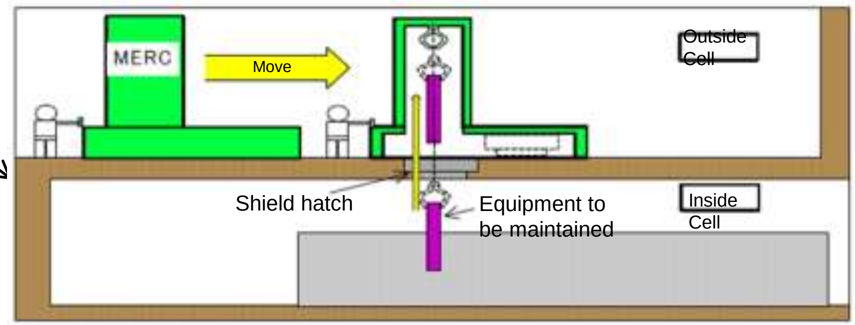
[Maintenance methods and approach]

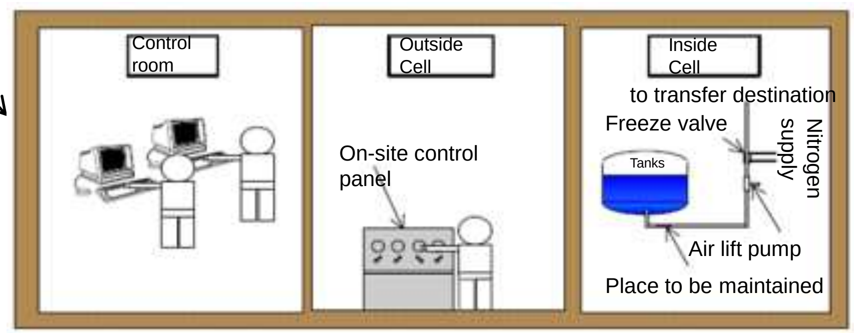
- Remote maintenance
  - ✓ Remote operation
  - ✓ Mobile remote operation system
  - ✓ Operation and control
- Direct maintenance
- Remote + on-site maintenance

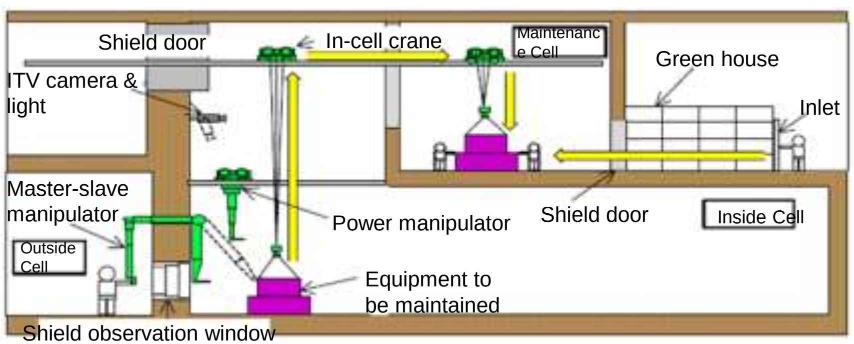
[Maintenance classification]

- Regular maintenance
- Emergency maintenance









Cited from the case example booklet of regular maintenance work in Rokkasho Reprocessing Plant
http://www.jnfl.co.jp/cycle-recycle/re_siken-tandt/pdf/re_siken-tandt3.pdf

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

[2] Set worker access conditions for 1F

[Contamination classification]

- Inside of the primary boundary was segmented based on the contamination classification until last fiscal year.

Contamination classification	High-level contaminated area (Red)	Mid -level contaminated area (Yellow)	Low-level contaminated area (Green)	Outside Cell
Definition of area	Area where radioactive materials are handled directly without covering	Area where radioactive materials are put in a sealed container for handling	Area where radioactive materials are put in a sealed (tightly sealed) container for handling	Area where radioactive materials are put in a sealed (tightly sealed) container for handling
	In normal conditions, a high level of contamination exists	There is a possibility of a high level contamination due to radioactive materials in the high-level contaminated area	The possibility of a high level of contamination is very low.	There is no possibility of a high level of contamination.
Target Control Value	To be determined			

[Dose classification (proposed)]

- Dose classification is defined to set areas workers are permitted to enter for maintenance in addition the contamination classification.

Dose classification	High radiation area	Intermediate dose area	Low dose area	Outside Cell
Definition of area	Area where radioactive materials are handled without shielding	Area where radioactive materials (excluding contaminated ones) are handled by shielding them	Area where radioactive materials (excluding contaminated materials) are put in a shielding container for handling	Area where radioactive materials (excluding contaminated materials) are put in a shielding container for handling
	Radioactive materials cause an extremely high dose rate	Contamination causes high dose rates despite shielding	The dose rate is low because radioactive materials are put in the container, and the level of the contamination of the shielding container is also low.	The dose rate is almost negligible except that in the background.
Target Control Value	To be determined			

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

[2] Set worker access conditions for 1F

[Worker access classification (proposed)]

- Every part in the primary boundary is segmented according to contamination and dose categories (shown in the upper column).
- Worker access classification was set in each area (shown in the lower column)

Dose classification / Contamination classification	High radiation area	Intermediate dose area	Low dose area	Outside Cell
High Contamination Area (red)	● Inside the PCV ● Inside Cell (Red) (during operation)	● Inside Cell (Red) (during maintenance*1)	● Inside Cell (Red) (during maintenance*1)	-
	D	D*2	D*2	-
Medium Contamination Area (yellow)	● Inside Cell (Yellow) (during operation)	● Inside Cell (Yellow) (during maintenance*1)	● Inside Cell (Yellow) (during maintenance*1)	-
	D	C	C	-
Low Contamination Area (green)	- *3	- *3	● Inside the cell (green)	-
	D	C	B	-
Outside Cell	-	-	-	A

[Worker access classification]
D : entry is not permitted at any time, including emergencies
C : During an emergency, short-time access by workers is assumed
B : In normal conditions, short-time access by workers is assumed
A : In normal conditions, access by workers is assumed

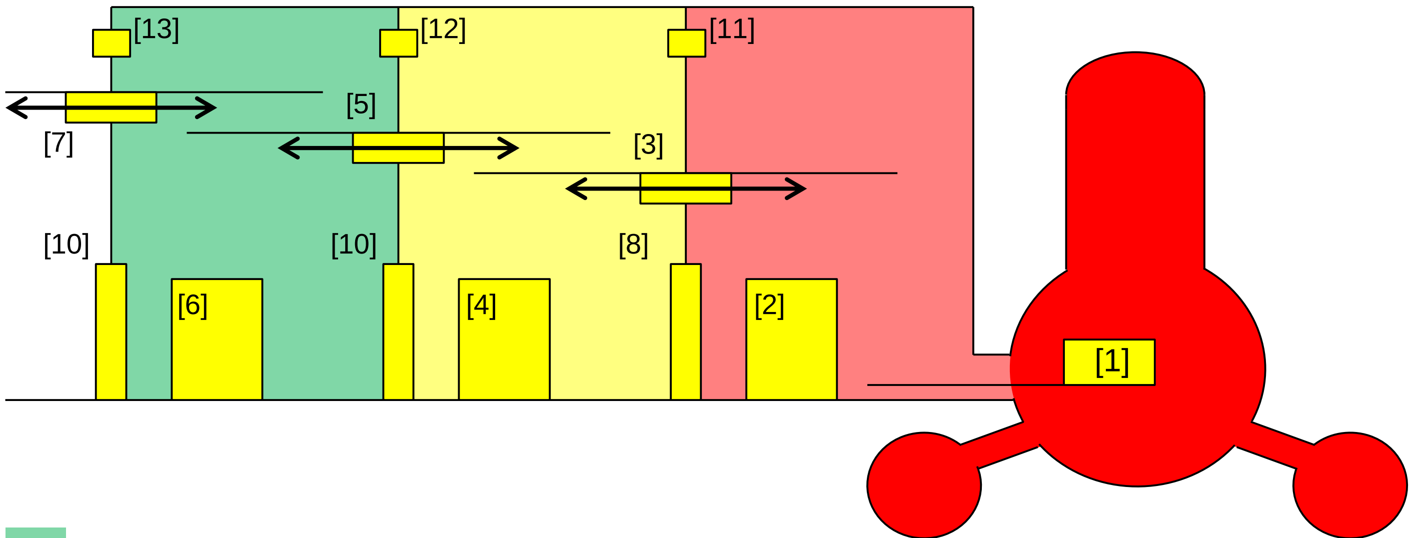
*1: This classification is subject to the condition that there are no radioactive materials in the area except for contaminated objects or radioactive materials are put in a shielding container during maintenance.
*2: Measures to enable the worker entry in an emergency need to be prepared. However, maintenance methods must be designed based on the premise that worker entry is forbidden.
*3: At present, there is no area that falls into these segments since it is planned that only radioactive materials stored in a shielding container are handled in the low-level contaminated area.

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

[3] Establish equipment usage environmental conditions for 1F
[Worker access classification (proposed) and equipment usage environment]



- B: In normal conditions, short-time access by workers is assumed
- C: During an emergency, a short-time access by workers is assumed
- D: entry is not permitted at any time, including emergencies. However, measures to enable the worker entry in an emergency need to be prepared.
- D: entry is not permitted at any time, including emergencies
- Examples of equipment to be maintained (See the list on the right)

Examples of equipment to be maintained:
[1] Equipment used in PCV
[2] Equipment permanently installed in the cell (red)
[3] Material handling equipment between cells (red cell and yellow cell)
[4] Equipment permanently installed in the cell (yellow)
[5] Material handling equipment between cells (yellow cell and green cell)
[6] Equipment permanently installed in the cell (green)
[7] Material handling equipment between the cell (green) and outside cells
[8] Door between the cell (red) and the cell (yellow)
[9] Door between the cell (yellow) and the cell (green)
[10] Door between the cell (green) and outside cells
[11] Opening between the cell (red) and the cell (yellow)
[12] Opening between the cell (yellow) and the cell (green)
[13] Opening between the cell (green) and outside cells

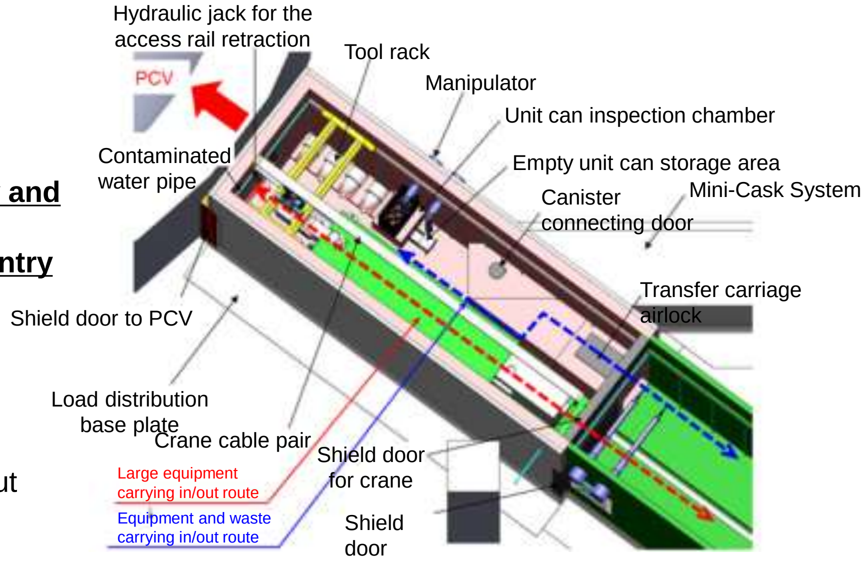
7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

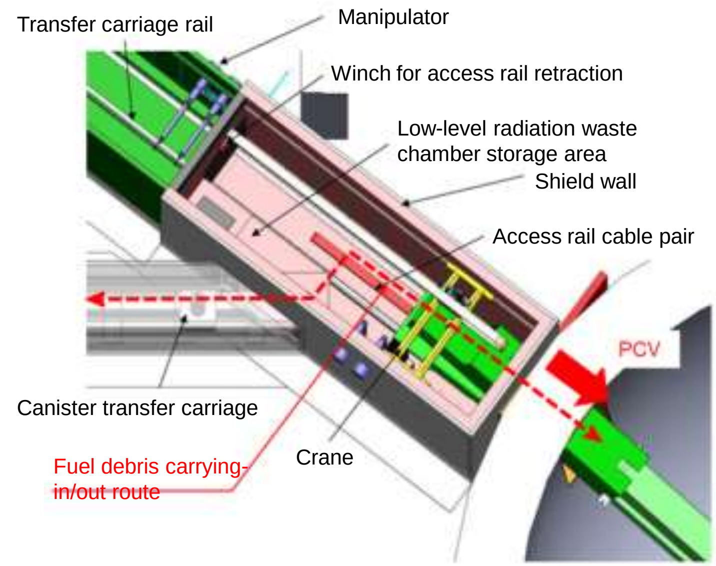
a. A study of remote maintenance action policies in the top entry and the side entry methods in common

b. Layout of main equipment used in the top entry and the side entry methods and the traffic line of them



Expected functions of fuel debris retrieval cell

- Pull out empty unit cans from the canister in the mini cask.
- Hold empty unit cans (4 units) and supply them to the access rail.
- Receive unit cans loaded with fuel debris from the access rail and put them in the canister in the mini cask.
- Material accountancy of unit cans containing collected fuel debris (including weight and radiation dose).
- Supply utilities to the robot arm and access rail.
- Robot arm tip tools for exchange: Four tools stored.
- Supply tools for exchange to robot arm for exchange and support exchange task.
- Receive wastes (other than fuel debris) that were removed from inside PCV from the access rail and transfer them to the maintenance cell.
- Carry in/out robot arm and access rail between the maintenance cell and PCV.



Technical development planning

- A development plan toward the realization of fuel debris retrieval work needs to be established. For this purpose, study results will be summarized and reviewed first, followed by the identification of technical challenges concerning the equipment and facilities of removal work.

7. Implementation Details

7.2. Implementation Details

3) Development of remote maintenance technologies for fuel debris retrieval equipment

Items to study	FY2017 (Heisei 29)												FY2018 (Heisei 30)											
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Key milestones							Interim report ▼					Annual report ▼							Interim report ▼				Annual report ▼	
1. Conceptual study	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
2. Study of specific proposal for fuel debris retrieval										■	■	■	■	■	■	■	■	■	■	■				
3. Review and analysis of study results																				■	■	■		
4. Element tests													Element tests are performed where necessary											
5. Wrap-up																						■	■	

Notes

Expected results

[1] Basic maintenance policy of equipment in the cell (proposed)
- Access classification
- Maintenance classification, etc.

[2] Equipment layout in the cell

[3] Technical development plan

7. Implementation Details

7.2. Implementation Details

1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

[2] Development of a fuel debris cutting/dust collection system

[3] Development of methods to prevent fuel debris diffusion

2) Element technology development for installing retrieval equipment

[1] Element technology development related to work cell

[2] Technical development for removing interfering objects during fuel debris retrieval

3) Development of remote maintenance technologies for fuel debris retrieval equipment

4) R&D management

7. Implementation Details

7.2. Implementation Details

4) R&D management

[1] Human resource development from a mid- and long-term viewpoint

It is planned to send staff to human resources development forums and international decommissioning workshops from the viewpoint of the development of human resource that will be necessary in a mid- to long-term range.

The described below is one of the results:

*** IRID Symposium 2017 in Iwaki**

Date and time: August 3 (Thursday), 2017 13:00-16:45

Place: 120 Taira-tamachi (Aza), Iwaki-si, Fukushima Iwaki Business Innovation Center, Exhibition Hall (LATOV 6F)

[2] Consulting experts inside and outside Japan

Technologies and expertise were gathered from Japanese and global vendors. The described below are the results:

Vendor	Services	Reason of adoption
IHI	Element tests for sealing design applicable to the side entry method Tests of methods to remove interfering objects outside Pedestal	Plan-B2 was developed in collaboration with IHI as a the side entry method and completed last fiscal year. It was adopted as one of the side entry methods. In addition, IHI has thorough knowledge of the plant before it was hit by the earthquake so that they deserve to undertake the study of interfering object removal methods and relevant element tests.
PaR Systems	Element tests of cutting and dust collection of fuel debris (ultrasonic core boring)	Ultrasonic core boring is one of promising technologies for fuel debris processing. Jet Propulsion Laboratory (JPL), a U.S. company, owns the fundamental technology. Technology development is planned based on the framework where PaR Systems designs an integrated system (equipment and facilities) that can be applied to the condition of the 1st floor.

7. Implementation Details

7.2. Implementation Details

4) R&D management

[2] Consulting experts inside and outside Japan (continued from the previous slide)
Technologies and expertise were gathered from Japanese and global vendors. The described below are the results:

Vendor	Services	Reason of order
AREVA NC	Study of cell design	AREVA has proven experience in fuel debris retrieval work at TMI and in decommissioning. It also operates a nuclear fuel reprocessing plant in La Hague, France. Based on those experiences, it has ample track records especially in the design, production, and operation of a hot cell.
Kajima Corporation	Conceptual study of soundness of reactor building	Kajima Corporation designed and built Units 2 and 3 reactor buildings of Fukushima Daiichi Nuclear Power Station; they have enough knowledge, technical information, and know-how for conceptual design study that is performed to assure the soundness of the reactor building, which additional loads will be exerted by the preparation of fuel debris retrieval using the partial submersion-the side entry method.
Osaka University	Study of hydraulic manipulator control methods	Osaka University has research achievements on various types of robot control along with a copious knowledge of the hydraulic control of machinery, such as construction machinery.
Kobe University	Evaluation of a trajectory formation that takes into account the avoidance of interference with the environment of multi-degree-of-freedom robot	Kobe University has a proven tracked record in interference avoidance using the elbow of multi-degree-of-freedom robot in IRID Decontamination Robot program in FY2013 and 2014. They also have knowledge of interference avoidance technology applicable to work in a narrow space where avoiding interference is essential.

7. Implementation Details

7.2. Implementation Details

4) R&D management

[3] Cooperation with other R&D activities such as those for decommissioning work

It is being discussed with other R&D project teams how to utilize results for the decommissioning project in practical ways. Key cooperative conferences are listed below:

- **April 27, Thursday, 2017: Meeting with the development team working on enhanced methods/systems and sampling technology**
  Achievements of the previous project and project approaches were shared.
- **June 22, Thursday, 2017: Meeting with the development team working on enhanced methods/systems and sampling technology**
  Contents of optimization study and information of project progress were shared.
- **August 24, Thursday, 2017: Meeting with the development team working on enhanced methods/systems, sampling technology and criticality control technology**
  Information about a risk of criticality during fuel debris processing was shared.
- **October 26, Thursday, 2017: Meeting with the development team working on enhanced methods/systems and sampling technology**
  Information about sampling needs was shared.
- **February 20, Tuesday, 2018: Meeting with the development team working on enhanced methods/systems, sampling technology and PCV internal investigation technology**
  Needs of detail investigation were identified and information about the needs was shared.

7. Implementation Details

7.3 Coordination of Sharing operators

[1] Coordination status of sharing operators

Operators listed in the table below submitted their interim reports so as to share results of the previous projects at:

- **Sharing Operator Interim Report Meeting**
- **Date and time: September 7 (Thursday), 2017 13:30-18:00**
- **Place: Office of Government-led R&D Program on Decommissioning and Contaminated Water Management**

[2] Analysis of tasks implemented by sharing operators

Below table shows IRID analysis results of tasks to be implemented by sharing operators in this project:

No.	Sharing operators	Project Items	Implementation item analysis result	Notes
1	Hamamatsu Photonics K.K.	Development of monitoring technology during fuel debris retrieval	Technical advancement can be expected because the development plan set specific technological targets, such as improving radiation resistance and downsizing cameras.	
2	COMEX NUCLEAIRE	Development of fuel debris cutting and dust collection system	Technical advancement can be expected because the development plan includes specific ideas such as a dust collection system and its scale, not to mention the performance of laser processing.	

8. Overall Summary

(1) Technical development for prevention of fuel debris diffusion

[1] Development of a fuel debris collection system

- The distribution and characteristics of fuel debris were studied in cooperation with the Fuel Debris Characterization Project team.
- Study of a retrieval system is underway based on the results of the above-mentioned study.

[2] Development of a fuel debris cutting/dust collection system

- Prioritized processing technologies to be developed based on the distribution and characteristics of fuel debris.
- Element tests on processing and dust collection are planned.

[3] Development of methods to prevent fuel debris diffusion

- A conceptual study of measures to prevent the diffusion of fuel debris during processing is being performed.
- Element tests on fuel debris diffusion prevention are planned.

(2) Element technology development for removal equipment installation

[1] Element technology development related to work cell

- Based on the study results in the project for upgrading of approach and systems for retrieval of fuel debris and internal structures, hypothetical design conditions were set for work cell study.
- Elemental tests of the inflate seal are planned.

8. Overall Summary

(2) Element technology development for removal equipment installation (continued)

[2] Technical development for removing interfering objects during fuel debris retrieval

- **A conceptual study on the throughput of interfering objects removal work is being performed.**
- **Interfering objects that need to be removed to enable fuel debris retrieval were identified.**
- **Element tests are planned for interfering object dismantlement especially for elements that require more to develop.**

(3) Development of remote maintenance technologies for fuel debris retrieval equipment

- **Based on the study results in the project for upgrading of approach and systems for retrieval of fuel debris and internal structures, hypothetical design conditions concerning remote maintenance technologies such as area segmentation were set.**
- **A conceptual study of remote maintenance technology is being performed based on the above hypothetical conditions.**

(4) R&D management

- **Human resource development from a mid- and long-term viewpoint was facilitated by holding IRID symposiums, for example.**
- **Technologies and expertise were gathered from Japanese and global vendors.**

9. Specific Goals to Achieve Implementation Objectives

(1) Technical development for prevention of fuel debris diffusion	
[1] Development of a fuel debris collection system	Fuel debris removal and conveyance methods and work steps to implement them, each of which are effectively applicable to different forms of fuel debris (such as solid fragments, polluted mud, and fine powders), shall have been identified through study and element tests for removal methods and systems applicable to different forms of fuel debris and for conveyance and storing systems to move collected fuel debris into the canister. (Target TRL upon completion: Level 3)
[2] Development of a fuel debris cutting/dust collection system • Cutting and grinding elemental tests	With respect to the cutting technology, basic workability shall have been verified by element tests. In addition, newly identified issues shall have been addressed and improved as development themes continued from the base technology development project in the previous fiscal year. The performance of dust collection technology shall have been demonstrated through dust collection tests performed along with processing. (Target TRL upon completion: Level 3)
• Crush-with-chisel element tests	The basic workability shall have been verified mainly through processing tests of fuel debris in the PCV bottom. In addition, the performance of dust collection technology shall have been demonstrated through dust collection tests. (Target TRL upon completion: Level 3)
• Ultrasonic core boring	Applicability of ultrasonic core boring to fuel debris retrieval shall be evaluated. Data of processing performance, and the amount and particle size distribution of dust it generates, shall have been obtained though processing tests with fuel debris simulant test blocks if the evaluation result is positive. (Target TRL upon completion: Level 3)
[3] Development of methods to prevent fuel debris diffusion • Element tests for diffusion prevention from jet deflectors	The basic feasibility of the technology to prevent fuel debris diffusion through jet deflectors shall have been verified by the element tests. (Target TRL upon completion: Level 3)

9. Specific Goals to Achieve Implementation Objectives

(2) Element technology development for removal equipment installation	
[1] Element technology development related to work cell • Structure study/installation method study	The conceptual study on the possibility of work cell installation and ease of handling shall have been performed. Effective remote-controlled installation methods shall have been identified, along with accompanying issues, and the action policy to address the identified issues shall have been clarified. (Target TRL upon completion: Level 3)
• Inflate seal elemental test	Applicability of inflate seal to build a boundary shall be evaluated. If the applicability is recognized, conduct an element test for sealability of inflate seal and evaluate the seal performance. In addition, element tests of the remote-controlled inflate seal exchange method shall have been performed and the feasibility of the method be verified. (Target TRL upon completion: Level 4)
[2] Technical development for removing interfering objects during fuel debris retrieval	The study and element tests of remote-controlled removing methods applicable to objects that block the access route to fuel debris and need to be removed shall have been performed. Through these activities, effective interfering objects removing procedures, and methods and facilities and equipment to execute them, shall have been identified along with accompanying issues, and the action policy to address the identified issues shall have been clarified. (Target TRL upon completion: Level 3)
• Interfering objects that block access from top entry (such as dryer and separator)	Feasibility of basic procedures and methods for removing interfering objects shall have been verified by producing full-scale mock-ups to simulating interfering objects. (Target TRL upon completion: Level 4)
• Interfering objects that block access from side entry (Equipment outside the pedestal)	Feasibility of basic procedures and methods for removing interfering objects shall have been verified by producing full-scale mock-ups to simulating interfering objects. (Target TRL upon completion: Level 4)

9. Specific Goals to Achieve Implementation Objectives

(2) Element technology development for removal equipment installation	
• Structures in the reactor building (PCV wall boring)	Feasibility of basic procedures and methods for removing interfering objects shall have been verified by producing full-scale mock-ups to simulating interfering objects. (Target TRL upon completion: Level 4)
• Interfering objects that block both top entry and side entry (RPV bottom part, equipment in the pedestal)	Feasibility of basic procedures and methods for removing interfering objects shall have been verified by producing full-scale mock-ups to simulating interfering objects. (Target TRL upon completion: Level 4)
• Verification of the maneuverability of a robot arm and access rail combined mechanism	The feasibility of basic mechanical motion concerning interfering object dismantlement and fuel debris retrieval shall have been verified through the test that simulates the motion of a robot arm and access rail combined mechanism. (Target TRL upon completion: Level 4)
(3) Development of remote maintenance technologies for fuel debris retrieval equipment	
• Study of maintenance method	The conceptual study on the layout plan and traffic line of main devices and equipment used for fuel debris retrieval work shall have been performed. The basic evaluation of the feasibility of maintenance methods that are applied to devices and equipment used for fuel debris retrieval work shall have been performed along with the identification of issues, and the action policy to address the identified issues shall have been clarified. (End time target TRL: Level 3)