Subsidy Project of Decommissioning and Contaminated Water Management
in the FY2015 Supplementary Budgets

Development of Technology for Detailed Investigation inside PCV

Accomplishment Report for FY2017

April 20, 2018

International Research Institute for Nuclear Decommissioning (IRID)

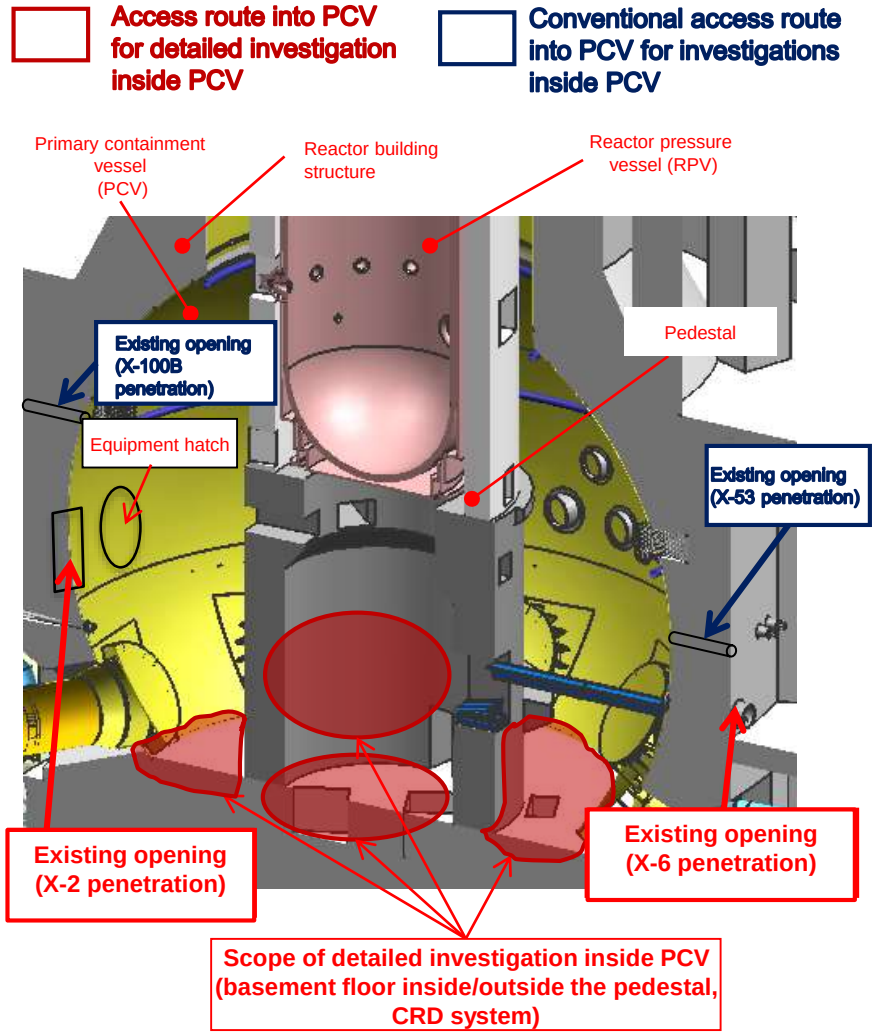
Contents

1. Research Background and Purposes

1.1 Reason Why the Research Project is Needed

[Background]
Investigations inside PCVs were performed in the following government-led projects in the past: B1/B2 Investigations (Unit 1), A1/A2/A2' Investigations (Unit 2), and Unit 3 Investigation using a small ROV.
While valuable information was obtained by these investigations, the size of the existing openings has limited the scope of the investigation.

[Objectives]
Following the aforementioned investigations, the detailed investigation inside PCV (hereinafter referred to as the Detailed Investigation) aims to re-examine and analyze the needs first and to perform investigation and establish relevant technologies necessary to meet such needs in order to meet the requirements for fuel debris retrieval.
In the Detailed Investigation, the development will be advanced while putting priorities on gathering information for the pressing tasks required for fuel debris retrieval: the determination of fuel debris retrieval method, the detailed design of retrieval devices, and the sampling technologies.



[Outline of PCV cross-section and investigation points]

1.2 Application and Contribution of the Study Results

FY2016-2017 Development of technology for investigation inside PCV

FY2017-2018* Development of technology for detailed investigation inside PCV (Project)

- Formulate investigation plan and development plan
- Develop the access and investigation devices
- Verify the applicability of element technologies

*Continuing using the FY2016 supplementary budget

On-site verification

Respective researches on detailed designs of methods and devices used for fuel debris retrieval (such as fuel debris retrieval, earthquake resistance, repair, and criticality control)	Research on fuel debris sampling
Information for the determination of fuel debris retrieval method, the detailed design of fuel debris retrieval devices, etc.	Information necessary for the sampling planning, etc.

2. Implementation Items, Their Correlations, and Relations with Other Research

2.1 Implementation Items on the Research

Implementation items	Scope of development activities for FY2017	Section number
Formulation of the investigation plan and the development plan	Continuous review, materialization, and update of the investigation plan based on the latest situation of the site	4.1
Establishment of access route into PCV through X-6 penetration	Design, production, and a part of the in-plant verification tests of full-scale prototypes for devices used to establish access routes into the PCV	4.2
Establishment of access route into PCV through X-2 penetration	Design, production, and a part of the in-plant verification tests of full-scale prototypes for devices used to establish access routes into the PCV	4.3
Access and investigation devices	Narrowing down of access/investigation devices, and design, production, and a part of in-plant verification tests of full-scale prototypes for said devices	4.4
Applicability verification of element technologies	A part of the verification testing for measurement technology to be incorporated into the access/investigation devices	4.5

2.2 Implementation Items and Relations with Other Research

Investigation outside the pedestal of Unit 1 (including on-site verification)

[Development of technology for PCV investigation]

Investigation inside the pedestal of Unit 2 (including on-site verification)

Investigation inside the pedestal of Unit 3 (including on-site verification)

Planning and element test for basement floor investigation/Development plan for measurement devices, etc.

Establishment of access route in Unit 2

Design, production, and unit function test of the isolated room, hatch opening mechanism, etc.

Establishment of access route in Unit 1

Conceptual design, basic plan, and element test for the devices relevant to the establishment of access routes into PCV

[Project items (FY2017-2018)]

Formulation of the investigation and development plans

- Update and materialization of the plan based on the latest information on the inside of PCVs

Access and investigation devices

- Narrowing down of the access devices
- Detailed design, prototype production, and in-plant verification tests of access/investigation devices

Applicability verification of element technologies

- Verification of the measurement technology to be incorporated in the access/investigation devices

Establishment of access route into PCV through X-6 penetration

- in-plant verification of the isolated room, hatch opening mechanism, etc.
- Detailed design, prototype production, and in-plant verification tests of the connection with the investigation device

Establishment of access route into PCV through X-2 penetration

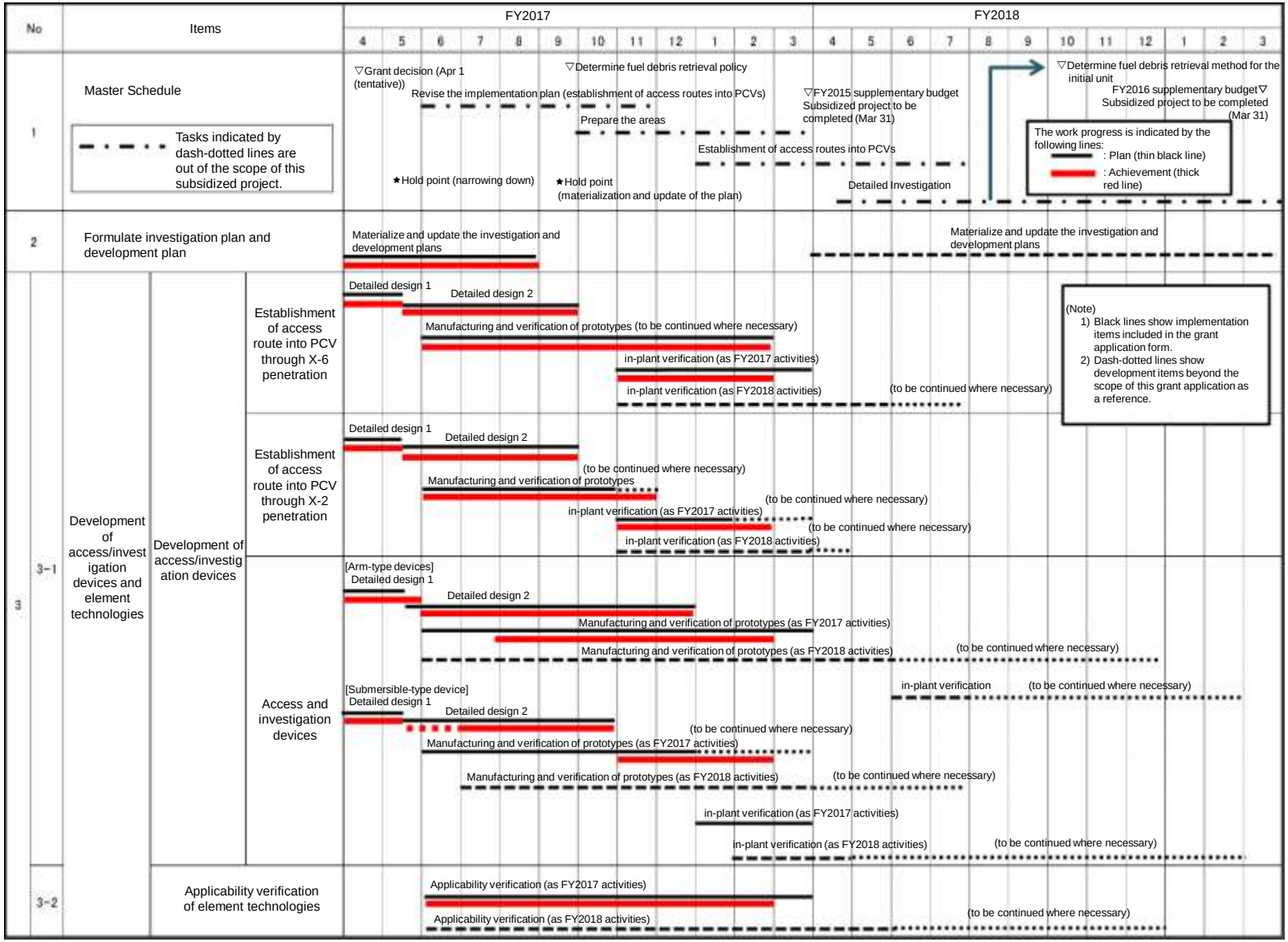
Detailed design, prototype production, and in-plant verification tests of devices for the establishment of access route into PCV

On-site verification (Unit 1&2) (Investigation to be started in FY2019)

2.3 Project Goals

Implementation Details		Target achievement indicators (FY2017-2018)
Formulate investigation plan and development plan	Units 1, 2	The investigation plan and the development plan shall be reviewed, materialized, and updated based on the latest situation of the site.
	Unit 3	The applicability of the devices developed for Units 1 and 2 to Unit 3 shall be studied, and it shall be made clear whether a development issue exists.
Establishment of access route into PCV through X-6 penetration	Opening of the hatch	Design, full-scale prototype production, and in-plant verification tests shall be completed for all devices relevant to the establishment of the access route into the PCV.
	Connection of new boundary	The feasibility evaluation of the extension pipe shall be completed.
Establishment of access route into PCV through X-2 penetration		In the process of establishing the access route into the PCV, the design, production, and in-plant verification tests of full-scale prototypes for all devices relevant to the connection with the investigation device shall be completed.
Access and investigation devices		Access/investigation devices shall be narrowed down and the design, production, and in-plant verification tests of full-scale prototypes for all selected devices shall be completed.
Applicability verification of element technologies		Verification tests of measurement technologies incorporated in the access/investigation devices shall be completed.
	Development of a measurement device using laser-based optical cutting method applicable in atmosphere, which can substitute the one that went out of production	The verification of the substitute mirror shall be completed. Candidates of substitute cameras shall be narrowed down before verifying them.
Mockup test plan		The rough design of the mockup test facility used for the test of the arm-type access device shall be completed.

3. Schedule and Project Organization (1/2)



3. Schedule and Project Organization (2/2)

International Research Institute for Nuclear Decommissioning (IRID)

- Formulation of overall plan and technical management
- Coordination of technical management including progress of technical development

Hitachi-GE Nuclear Energy, Ltd.	Toshiba Energy Systems & Solutions Corporation	Mitsubishi Heavy Industries, Ltd.
1) Formulate investigation and development plans 2) Develop access/investigation devices and element technology a) Develop access/investigation devices • Establish access route into PCV through X-2 penetration • Access/investigation devices b) Verify applicability of element technology	1) Formulate investigation and development plans 2) Develop access/investigation devices and element technology a) Develop access/investigation devices • Establish access route into PCV through X-6 penetration	1) Formulate investigation and development plans 2) Develop access/investigation devices and element technology a) Develop access/investigation devices • Establish access route into PCV through X-6 penetration • Access/investigation devices b) Verify applicability of element technology

4. Implementation Details

4.1 Implementation Items and Results: Formulation of Investigation and Development Plans (1/5)

—Approach toward the update of the investigation plan—

Interview survey

↓

Selection of investigation subjects

↓

Target deadline for investigation

↓

Priorities of investigation

↓

Formulate investigation plan

1) Needs interview surveys conducted with relevant projects, the decommissioning company (TEPCO)
2) Subjects of the interview survey: investigation items, objectives, needs, deadlines (detailed design for debris retrieval, license application, needs after the start of debris retrieval), examples of utilizing investigation outputs, minimum requirements for the investigation

The objectives and needs of the investigation were examined, and investigation subjects relevant to TEPCO and the Detailed Investigation were selected.
The target deadline of the investigation was identified, and investigation items that would provide information beneficial to the detailed design of debris retrieval were extracted from the investigation subjects.
The priority of the investigations was studied based on the characteristics of each unit.

IRID Head Office conducted a review from a comprehensive perspective and determined the investigation items.

Investigation for obtaining the information beneficial to the detailed design			Results of investigation item selection							Investigation items by unit		
			Debris retrieval	Conditions inside the reactor vessel	Earthquake resistance	Criticality control	Repair	TEPCO		Unit 1	Unit 2	Unit 3
Debris distribution inside/outside the pedestal	1-2	Distribution of fuel debris flowed out of the pedestal (thickness, dispersion (boundary))	○	△	○	○	○	○		○	-	-
	1-4	Fuel debris distribution in the pedestal (thickness, dispersion)	○	△	○	○	○	○		○	○	○
	~~1-5(1)~~	~~Shape of fuel debris on the basement floor~~				○				○	○	○
	1-9	Surface (or internal) temperature of fuel debris on the basement floor					△			-	-	-
	1-10	Dose rate of fuel debris on the basement floor					△			-	-	-
	Add. 1-12	Cooldown state of fuel debris on the basement floor (presence/absence of areas exposed to air)				○ Unit 2				-	○	-
Presence/absence of shell attack	2-2	Damage by shell attack, leakage area					○			○	-	-
Depth of erosion by debris/concrete strength after being subjected to the thermal history caused by the accident	3-1	Erosion depth of the pedestal floor		△						-	-	-
	3-2	Erosion depth of the pedestal wall	○	△	○					○	○	○
	3-4	Cracking or peeling of the inner and outer pedestal walls	○	△	○			○		○	○	○
CRD system condition	4-2	Damage condition of CRD system (falling of CRD housing, cooling water dripping)						○		○	○	○
	4-3	Deposit condition of fuel debris in the CRD system (shape, distribution)				△				-	-	-
PCV condition	5-2	Degradation condition of coating inside PCV					△			-	-	-

Merged

[Legend] ○: Information without which the plan becomes excessively conservative, △: Information that has substitute methods, or information to be collected when or after deciding the method

Completed in FY2016

To be performed in FY2017
(This Research Project)

Update Investigation plan

To be updated based on the investigation results of Unit 1 (B2), Unit 2 (A2 and A2'), and Unit 3.

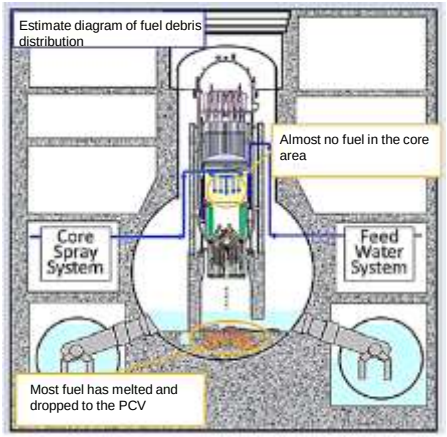
4.1 Implementation Items and Results: Formulation of Investigation and Development Plans (2/5)

Materialization and update of the investigation plan for Unit 1 (1/3)

[Progress status] Based on the latest results of the investigation inside the PCVs of Units 1 and 3, whose damages are assumed to be significant, a review was conducted on how to advance the investigation toward the fuel debris retrieval while considering the presence of a large amount of deposits and fallen objects and the plan of the detailed investigation in Unit 1 was updated.

(a) Latest information on the inside of PCVs of Units 1 and 3, whose damages are assumed to be significant

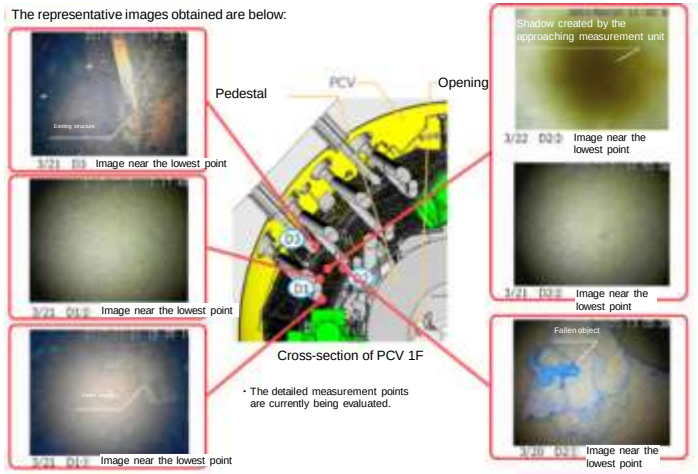
Unit 1



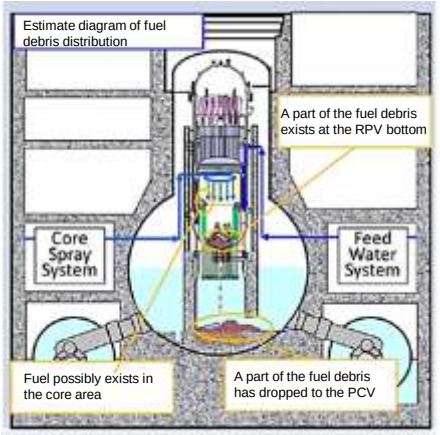
Investigation results inside PCV in Unit 1 (B2)

(1) A large amount of deposit was observed outside the pedestal, and the height of the deposit surface near the workers access opening was approx. 1 m at the highest point.

(2) In the surface layer of the deposit, Cs-137 was found as the major nuclide, and Co-60 that is associated with fuel debris was not detected.



Unit 3



Investigation results inside PCV in Unit 3

1) The investigation revealed that, inside the pedestal, the support jig for the CRD housing had been dropped or deformed, what appeared to be solidified molten material had been deposited, multiple structures and grating had been damaged or fallen off, and pebble and sand deposits had been present.

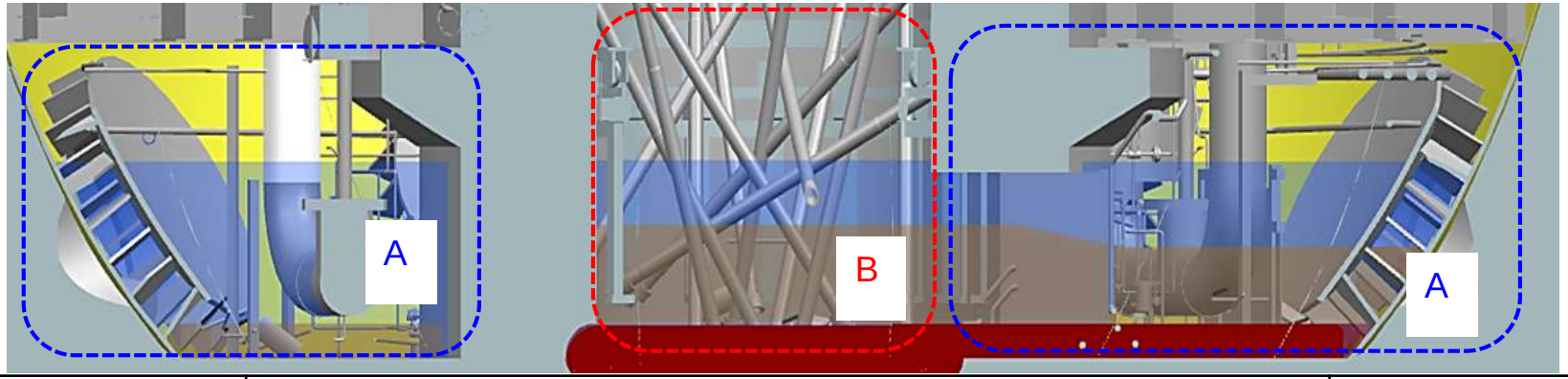
2) Due to fallen objects, etc., the workers access opening could not be located.

4.1 Implementation Items and Results: Formulation of Investigation and Development Plans (3/5)

Materialization and update of the investigation plan for Unit 1 (2/3)

(b) Summary of the Detailed Investigation of Unit 1 (on-site verification)*1

In Unit 1, a large amount of deposit has been found, and the CRD housing and in-core components have possibly fallen down; therefore, the deposit and fallen objects need to be collected and removed at the time of (or before) the fuel debris retrieval. The on-site verification for the Detailed Investigation of Unit 1 aims to collect information regarding the review of means and facilities for deposit collection, and the work plans for deposit collection, dismantling and removing the fallen objects, etc.



	Required priority information	Investigation methods
Outside pedestal - Workers access opening (A in the figure)	Information regarding the review of means and facilities used for deposit collection (such as the amount and origin of the deposits), information regarding the plans for deposit collection, dismantling and removal of fallen objects, etc. (such as the condition under the deposits, dispersion of fuel debris)	• Visual observation • Measurement*2 • Deposit sampling
Inside pedestal (B in the figure)	Information regarding the planning of deposit collection, fallen object dismantlement and removal, etc. (information regarding the work space inside the pedestal and the condition of the fallen CRD housing)	・Visual observation (If the measurement device can enter inside the pedestal, measurement will also be performed.)

*1: 3D mapping of the deposit surface, measurement of the deposit thickness, detection of fuel debris inside and under the deposit
*2: This is included in the scope of the project “Development of technology for detailed investigation inside PCV” based on the FY2017 supplementary budget, subsidies for the government-led R&D program on decommissioning and contaminated water management (on-site verification of the technology for the Detailed Investigation on the premise of deposit management).

4.1 Implementation Items and Results: Formulation of Investigation and Development Plans (4/5)

Materialization and update of the investigation plan for Unit 1 (3/3)

(c) Process flow from the Detailed Investigation of Unit 1 through the fuel debris retrieval

Investigation before deposit collection

The scope of this project

- **Visual information inside the PCV**
- **Measurement data taken from above the deposit**
- **Sampling of the deposit's surface layer (partial removal)**

Necessity of implementation to be reviewed after the project

- Information that can be obtained in the process of local removal of the deposit
- Visual information under the deposit (local)

Operation during deposit removal [under review in relevant projects]

[Information regarding the review of means and facilities used for deposit collection]

- Is fuel debris contained in the deposit?
- What are the distribution and amount of the deposit?
- What are the origins of the deposit? Will the deposit increase?
- What method is used for deposit collection? Suction technique?
- What method is used for separating the deposit from water? and so on

[Information regarding the plans for deposit collection, dismantling and removal of fallen objects, fuel debris sampling, etc.]

- How has the fuel debris been dispersed under the deposit?
- Any obstacles inside the D/W?
- What is the condition of the pedestal opening?
- What is the condition of the deposit and fallen objects inside the pedestal? Is there a work space? and so on

[Other information]

- Is there cracking or peeling of the pedestal wall?
- Has the deposit entered the vent pipe side? and so on

Investigation during or after deposit collection

- **Visual information under the deposit (broad range)**
- **Measurement data relevant to the pedestal integrity**

[Information regarding the detailed design of fuel debris retrieval (Initial needs)]

- Fuel debris shape
- Fuel debris dispersion (condition under the deposit)
- Integrity of pedestal
- Falling of CRD housing

Collection of deposit and removal of fallen objects

Investigation before deposit collection

Investigation after deposit collection

Sampling of fuel debris
Fuel debris retrieval

Present

Existing
N/A

Safety system, Criticality control

During fuel debris retrieval

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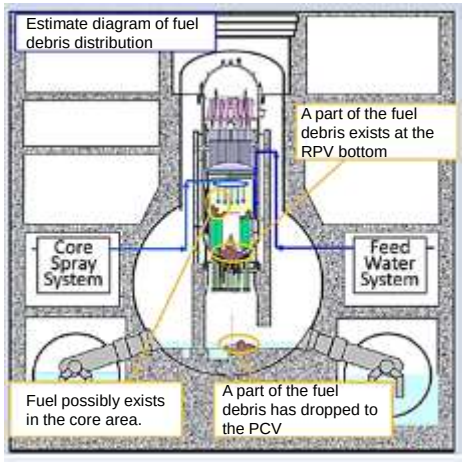
4.1 Implementation Items and Results: Formulation of Investigation and Development Plans (5/5)

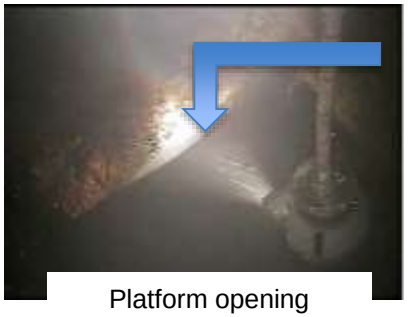
Materialization and update of the investigation plan for Unit 2

- The A2/A2' investigation confirmed that the grating had dropped and debris (partially including what appeared to be fuel debris) had been deposited inside the pedestal. Based on the latest condition of Unit 2, the detailed investigation needs were reorganized, and the development plan for the arm-type access device and sensor is currently being updated.
- In the current design of the arm-type access device, there is an issue in establishing a route through which the arm tip descends to the pedestal bottom. Also, the accessibility of the workers access opening at the pedestal bottom needs to be reviewed and Confirmed to see whether deposit has flowed out of the pedestal through the opening.
- To observe the damage condition of the CRD system (at the RPV bottom), development of a sensor system such as a camera with wiper is considered necessary. In addition, a review is required to see if the presence/absence of deposit adhesion can be assessed.

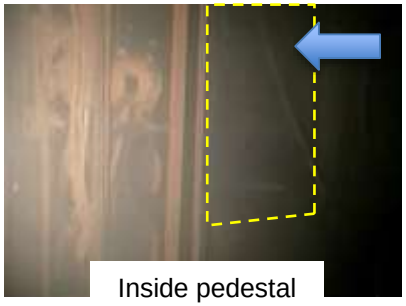
Unit 2



A camera with wiper is required to observe the damage condition of the CRD system.



Developing an appropriate route for descending of the arm-type access device is required.



The study on the investigation method is required whether debris has spread out through the workers opening.

Results of the investigation inside the PCV in Unit 2 (A2)

1) Confirmed the falling or deformation condition of the platform grating and multiple openings
2) Confirmed deposit at the bottom and attachment on the CRD exchanger, etc.
3) Confirmed deposit near the workers opening at the bottom

Need to review a method to investigate whether deposit adhesion exists

4.2 Implementation Items and Results: Establishment of Access Route into PCV through X-6 Penetration (1/3)

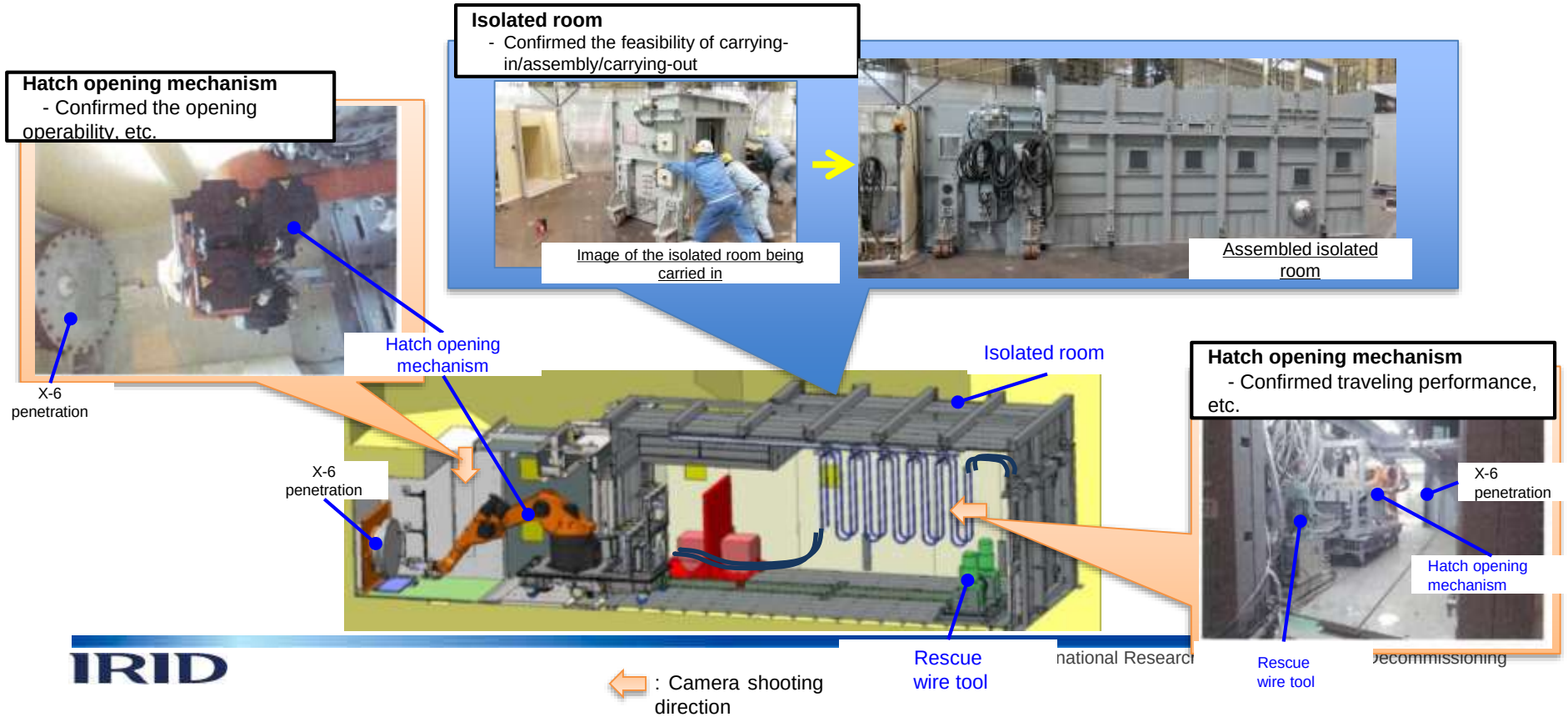
1) Opening the hatch

In order to establish a route for the investigation device to access through the X-6 penetration into the PCV in Unit 2, the hatch of the X-6 penetration will be opened remotely while securing the PCV boundary.

[Progress status] In this project, a part of the combination test was carried out using the prototype units including the isolated room and the hatch opening mechanism, for which the unit function test was performed in the FY2017 project “Development of technology for Detailed Investigation inside PCV.”

(1) Confirmed the feasibility of the carrying-in/assembly/carrying-out of the isolated room (shown in the blue callout)

(2) Operation confirmation test for the hatch opening mechanism, etc. inside the assembled isolated room (shown in the orange callouts)



4.2 Implementation Items and Results: Establishment of Access Route into PCV through X-6 Penetration (2/3)

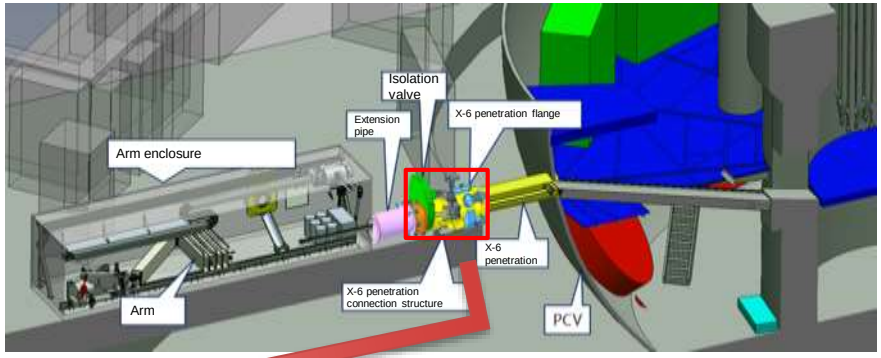
2) Connection of new boundary (1/2)

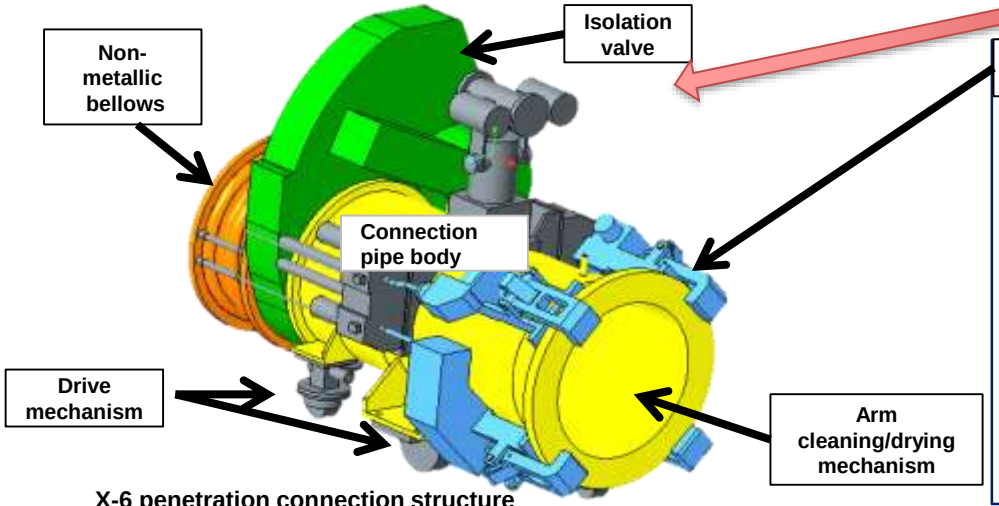
a) Connection structure for X-6 penetration

[Progress status]

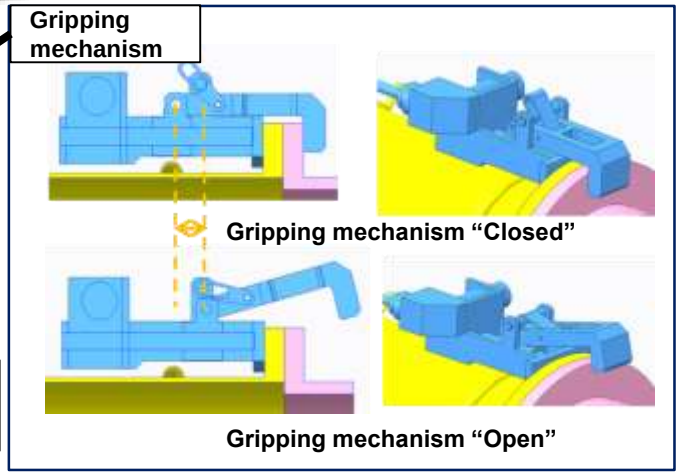
- The basic connection structure for the X-6 penetration was decided applying the holding mechanism that was one of the outcomes of the FY2016 project “Development of Technology for Detailed Investigation inside PCV.”
- Specifications necessary for short-period maintenance of the boundary were developed.
- Strength evaluation and seismic evaluation were performed for the holding mechanism and confirmed that the strength and supporting force were satisfactory.
  (Operation test is scheduled for the next fiscal year.)
- The large-diameter isolation valve (D 550 mm) was selected from the multiple forms.
- Task details were determined for the carry-in step and installation step, respectively, and shielding design was studied based on the radiation exposure evaluation.

Earthquake resistance		**Class B**
Plant welding section	**Design**	**Equivalent to JSME class 3, applied mutatis mutandis**
	Welding procedure, welding and testing	**JIS**





X-6 penetration connection structure



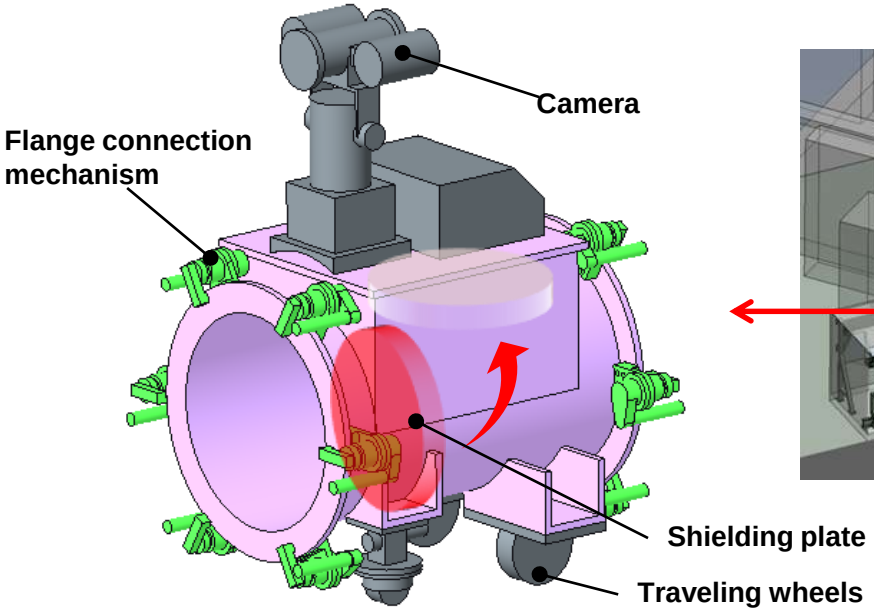
4.2 Implementation Items and Results: Establishment of Access Route into PCV through X-6 Penetration (3/3)

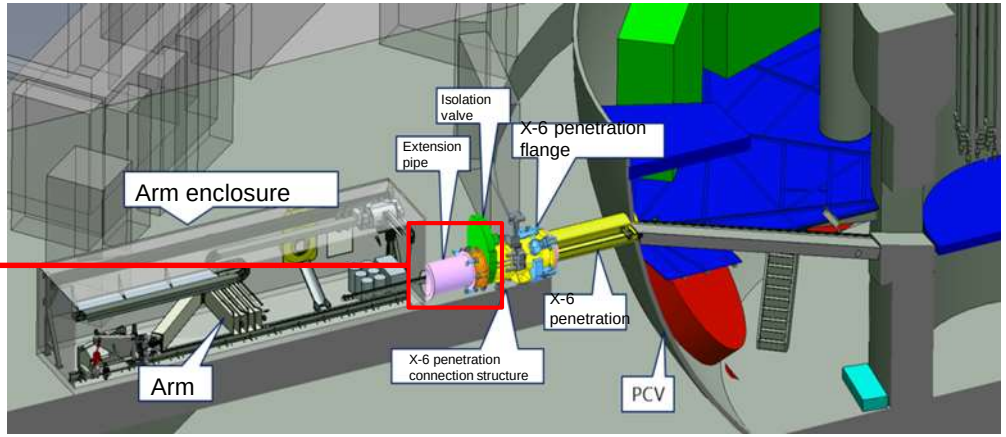
2) Connection of new boundary (2/2)

(b) Design of the extension pipe

[Progress status]

- From the perspective of better installability, a new idea of adding an extension pipe to the arm-type access device was brought up. Mainly as a shielding measure against direct gamma ray from the X-6 penetration, an additional shielding function of the extension pipe is expected to reduce workers' exposure to radiation.
- The functional requirements of the extension pipe were set (such as the boundary, shielding, and traveling function), the structure was studied, and the feasibility was evaluated.
- The set structure concept has mostly satisfied the functional requirements. Further materialization of the structure needs to be promoted from now on.

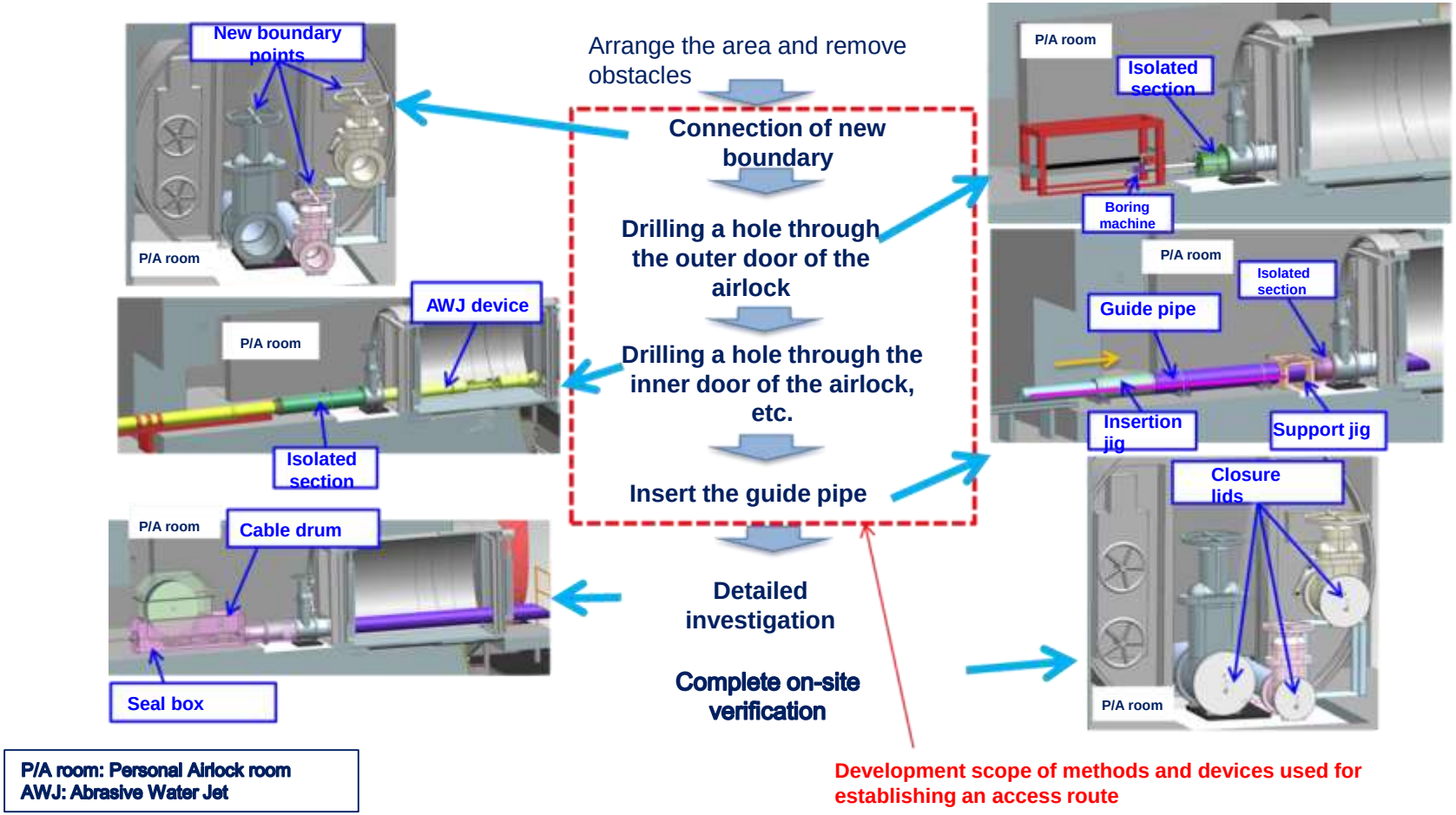




4.3 Implementation Items and Results: Establishment of Access Route into PCV through X-2 Penetration (1/3)

[Progress status]
Methods applied to the process starting from installing a new boundary through installing a guide pipe in the environment isolated from the PCV were studied, and the detailed design and prototyping of the relevant devices were performed. Then, in-plant verification was started.

(a) Scope of development of methods and devices used for establishing an access route through the X-2 penetration



4.3 Implementation Items and Results: Establishment of Access Route into PCV through X-2 Penetration (2/3)

(b) Illustrations and photos of in-plant verification of a method for establishing an access route through X-2 penetration (1/2)

Using the devices designed for establishing the access route from the X-2 penetration to the basement floor of the PCV in Unit 1, the work conditions were examined, and the methods (devices, work guidelines) and on-site operations for each work step were Confirmed in the in-plant verification.

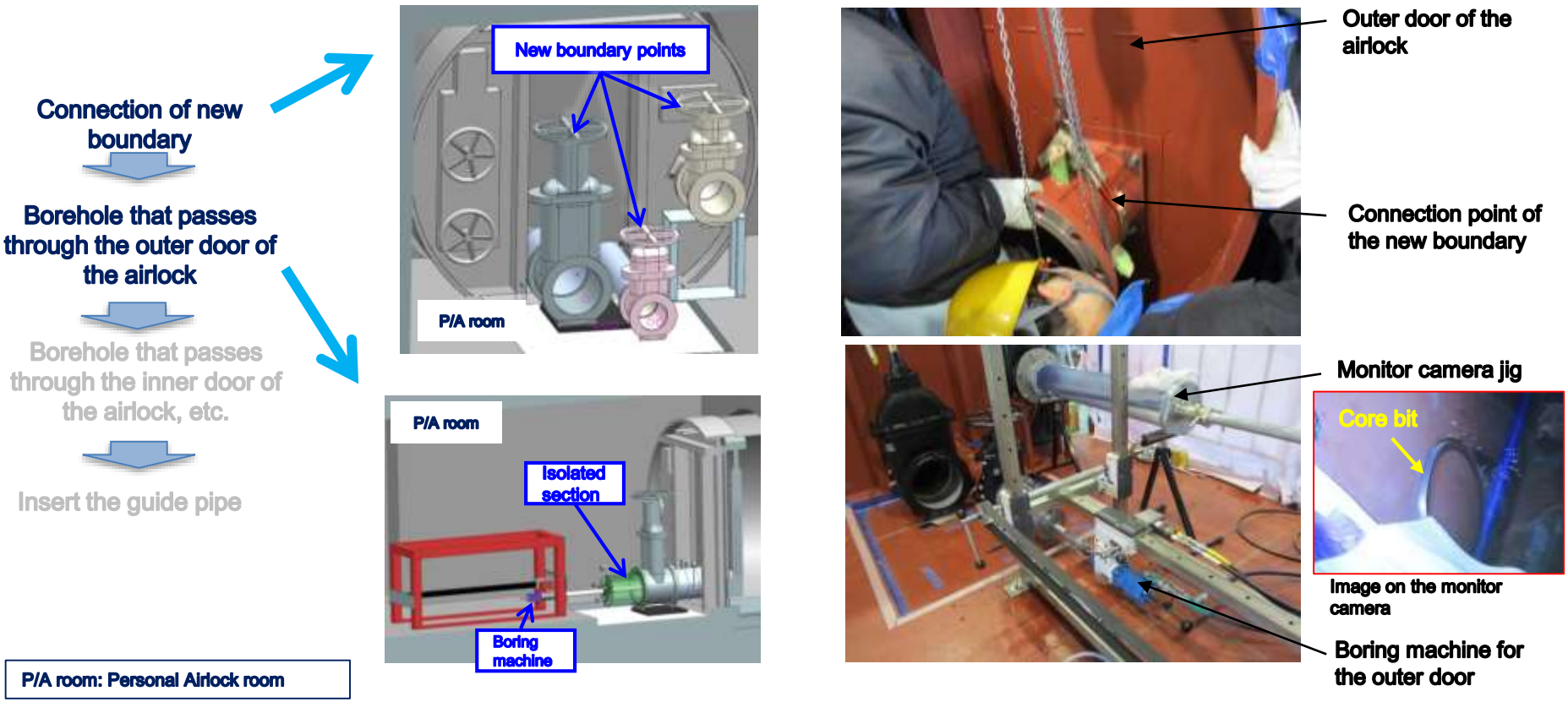


Figure 4.3-1 (1/2) Illustrations and photos of in-plant verification tests for establishing access route

4.3 Implementation Items and Results: Establishment of Access Route into PCV through X-2 Penetration (3/3)

(b) Illustrations and photos of in-plant verification of a method for establishing an access route through X-2 penetration (2/2)

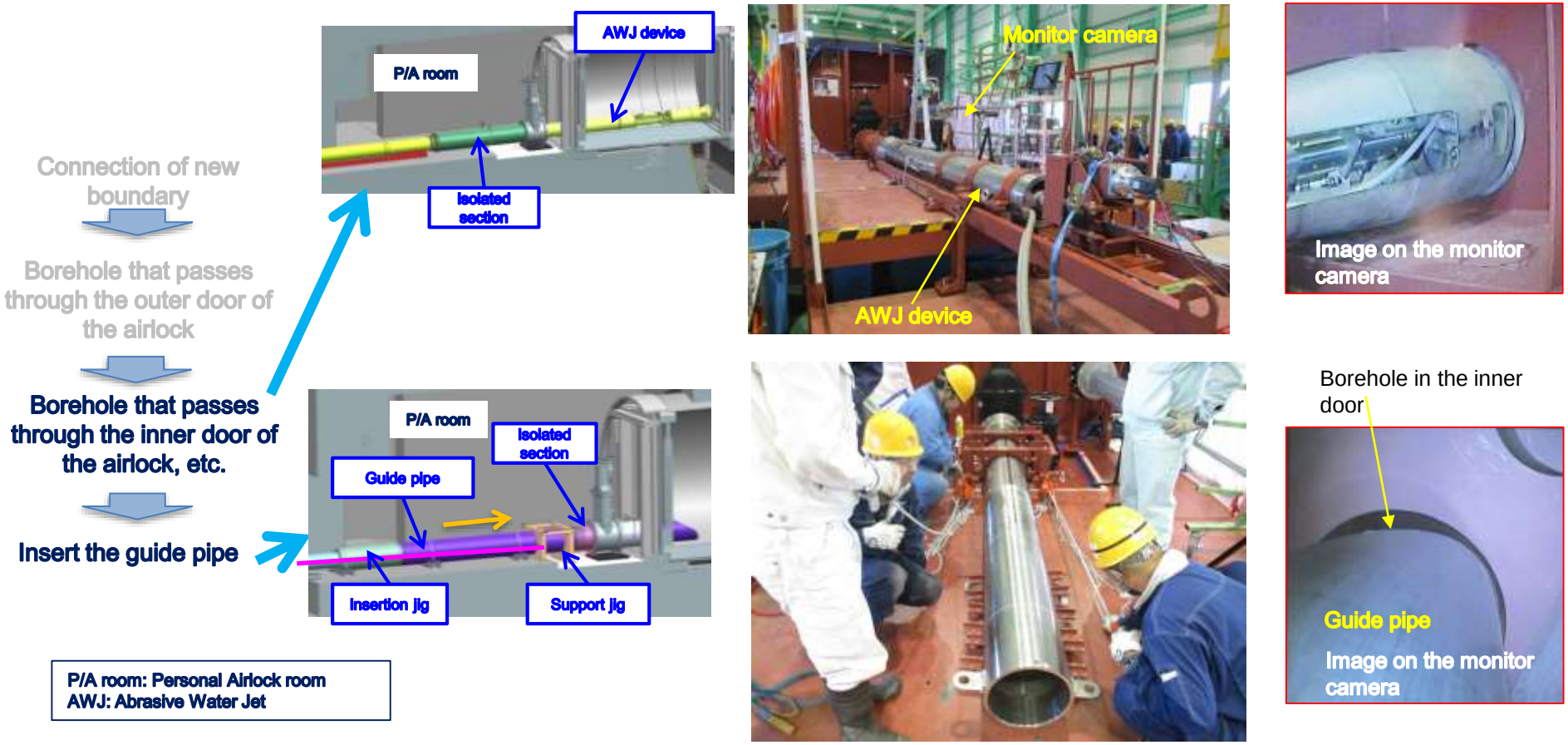
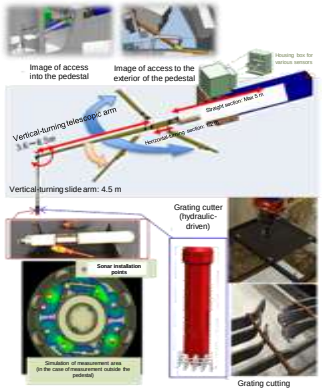
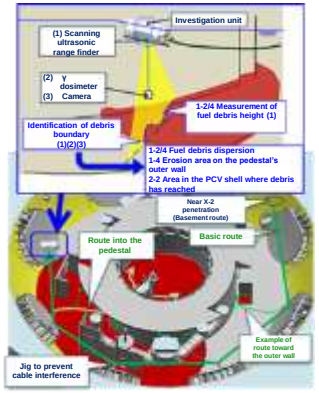


Figure 4.3-1 (2/2) Illustrations and photos of in-plant verification tests for establishing access route

The work conditions were examined, issues in methods (devices, work guidelines) and on-site operations for each work step were extracted, and their measures were studied. Aiming at on-site verification, a mock-up test and training will be performed in the future as a government R&D project.

4.4 Implementation Items and Results: Access and Investigation Devices (1/5)

(1) Narrowing down the access/investigation devices

	Narrowed results of access/investigation devices		Update to the investigation plan (Refer to 4.1)
	Unit 1	Unit 2	
Arm-type 	Not feasible (Use of X-6 penetration) Due to the high-radiation environment, dose reduction or remote hatch opening technology needs to be developed, and also preparation is necessary to develop a new route inside the reactor building. This method would entail huge costs and is highly unlikely to meet the deadline of method decision.	Feasible (Use of X-6 penetration) At the current stage, the technical feasibility has been verified for the establishment of an access route. The study process needs to be shortened in order to meet the deadline of method decision. [Scope of the government R&D project] All the steps up to in-plant verification tests toward the on-site verification were completed.	• The investigation plan was materialized and updated based on the latest on-site situation, etc. • The development plan compatible with the investigation plan was also materialized and updated. For Unit 3, the applicability of the devices developed for Units 1 and 2 for the purpose of using it in Unit 3 was reviewed, and the presence/absence of development issues was clarified.
Submersible-type 	Feasible (Use of X-2 penetration) This method will enable the access to the point near the penetration and possibly meet the deadline of method decision. [Scope of the government R&D project] All the steps up to in-plant verification tests toward the on-site verification were completed.	-	

4.4 Implementation Items and Results: Access and Investigation Devices (2/5)

(2) Arm-type devices (1/2)

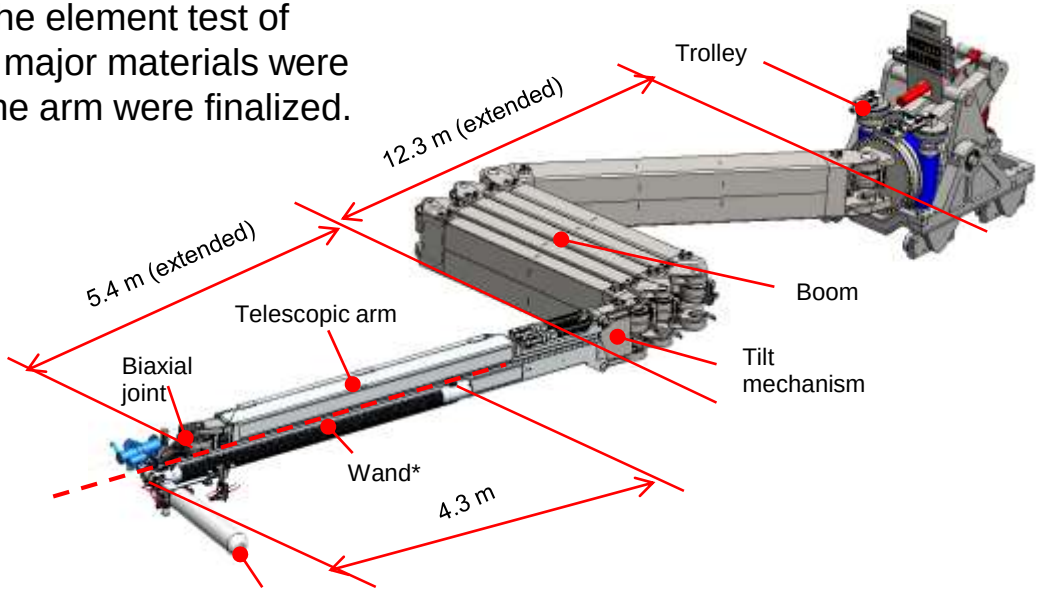
☐ Boom arm

[Progress status] Designing the prototype of the actual device has been completed and manufacturing is underway.

- The basic structure was determined based on the multi-joint robot arm technology employed in the JET fusion reactor.
- An expandable interface that enables the replacement of a sensor and tool as well as cable installation on the outer side of the arm was established.
- The strength evaluation of arm materials, the element test of cables, and the radiation resistance test of major materials were performed and the main specifications of the arm were finalized.
- Planned the rescue measures of evacuating the unit into the enclosure in case of a malfunction, by using only a sound motor and separating the wand, or forced retrieval using a winch.

Main specifications

- ✓ **Mountable sensor:** 10 kg or less
- ✓ **Mounted tools:** Cutting and grasping tool, Water jet cutting tool
- ✓ **Pressing force:** 400 N
- ✓ **Arm length:** 22 m
- ✓ **Access range:** Approx. 70% overall
- ✓ **Positioning accuracy:** ±100 mm
- ✓ **Repetition accuracy:** ±100 mm
- ✓ **Accumulated dose:** 1 MGy
- ✓ **Accessories:** Camera, Lighting



* a tool can be mounted instead

4.4 Implementation Items and Results: Access and Investigation Devices (3/5)

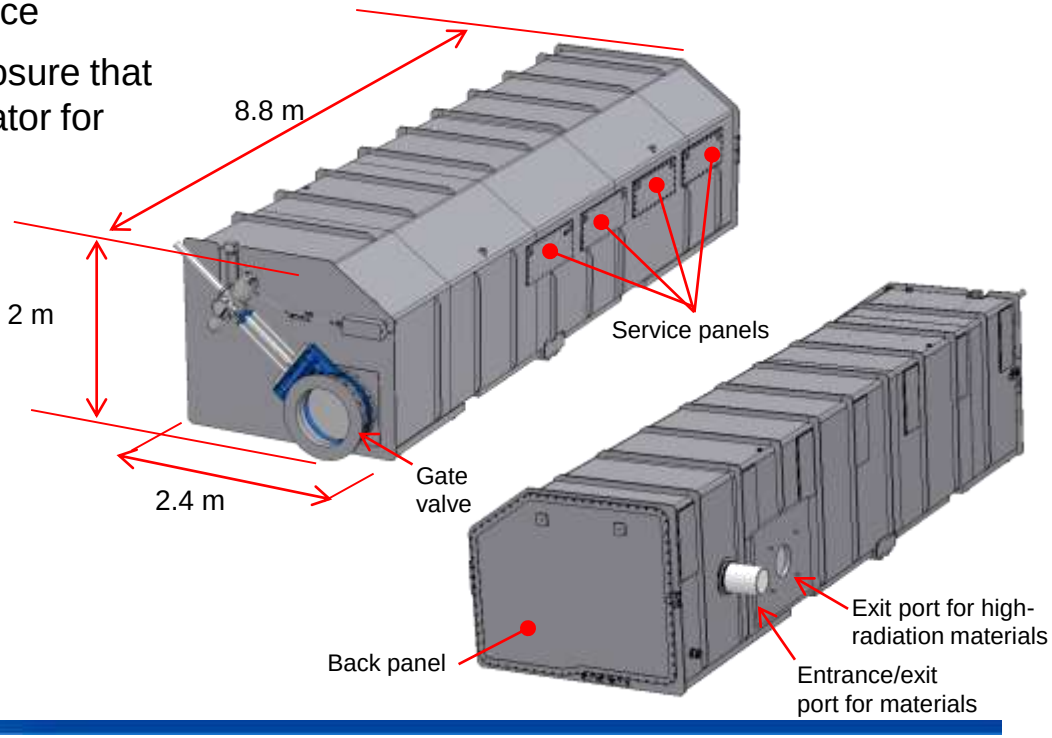
(2) Arm-type devices (2/2)

☐ Arm enclosure

[Progress status] Designing the prototype of the actual device has been completed and manufacturing is underway

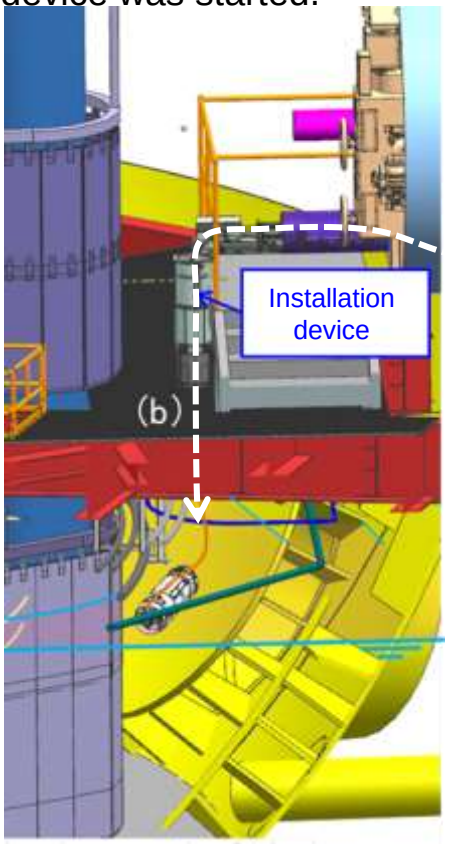
- Determined the main dimensions considering about carrying in and installing it together with the arm as well as presence of obstacles
- Designed the structure to ensure the sealability and evaluated its strength and seismic resistance
- Designed the arrangement inside the enclosure that houses the arm and the dual-arm manipulator for maintenance
- Organized the interface with the outside while considering about carrying in/out the sensors and tools after use
- Designed accessories taking their operation into consideration, such as installing a gate valve on the enclosure

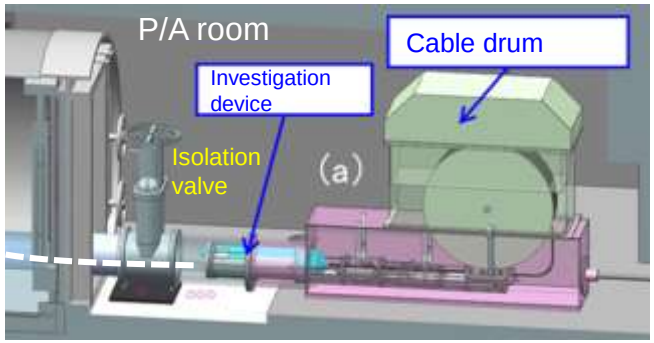
- ✓ **Main material:** Stainless steel
- ✓ **Design pressure:** -5 to +10 kPaG (negative pressure while the arm is housed)
- ✓ **Leakage rate:** 0.05 vol%/h
- ✓ **Outer plate**: 10-mm thickness; Bottom plate: 25-mm thickness
- ✓ **Weight:** Approx. 14 tons
- ✓ **Accessories:** Dual-arm manipulator for maintenance, Gate valve, Camera, Lighting, Dosimeter



4.4 Implementation Items and Results: Access and Investigation Devices (4/5)
(3) Submersible-type device (1/2)

[Progress status] For the submersible boat, which would be lowered from the X-2 penetration down to the basement and capable to move and take measurements in the broad area in the basement, the design scheduled for fiscal year 2017 was completed based on the updates made to the investigation plan, and preparation was started for design verification. Additionally, in-plant verification test (function test) including test of the installation device was started.





(a) Prepare for installation

(b) Install the device

(c) Install the guide rings or perform investigation

(d) Retrieve the device

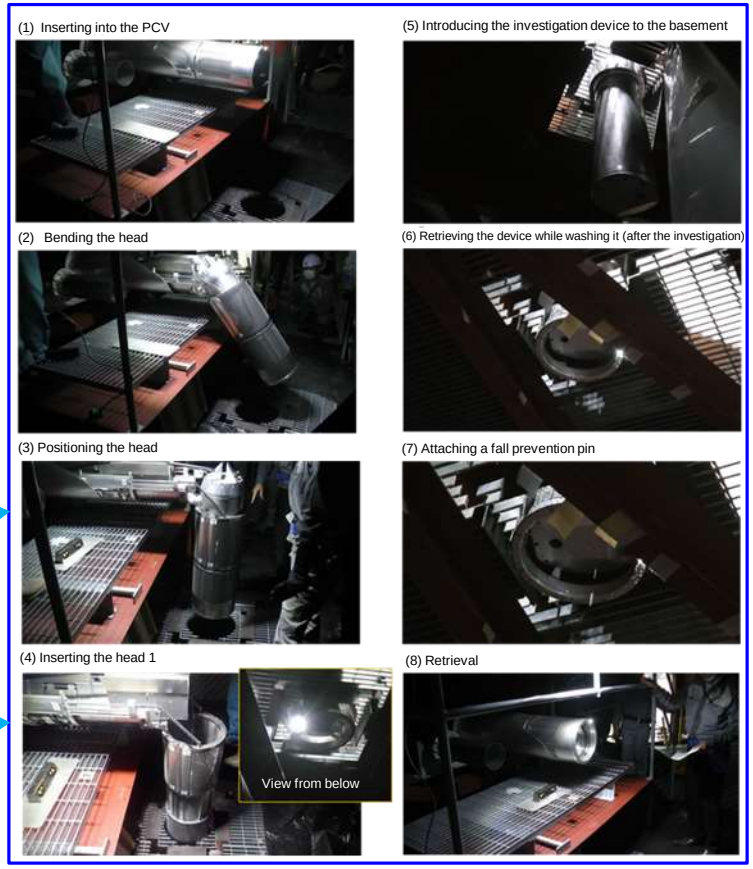


Figure 4.4(3)-1 Illustrations and photos of in-plant verification tests of installation device

4.4 Implementation Items and Results: Access and Investigation Devices (5/5)

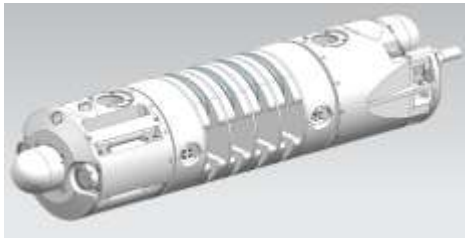
(3) Submersible-type device (2/2)

(a) Prepare for installation

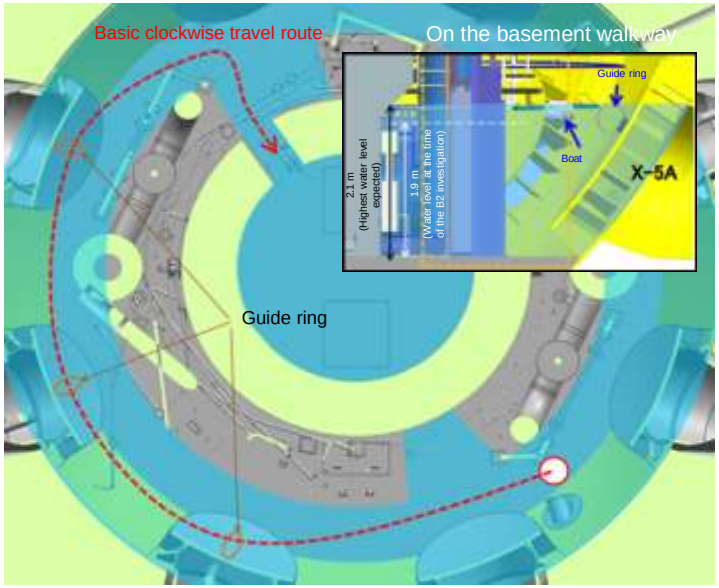
(b) Install the device

(c) Install the guide rings or perform investigation

(d) Retrieve the device

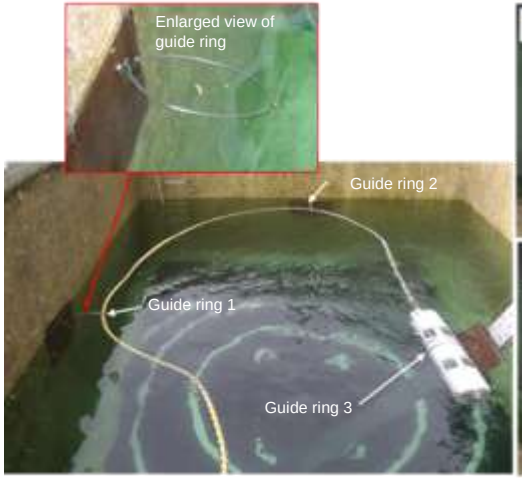


ROV for installing guide rings
- Diameter: ∅ 25 cm
- Length: Approx. 1.1 m
- Thrust: 25 N or greater

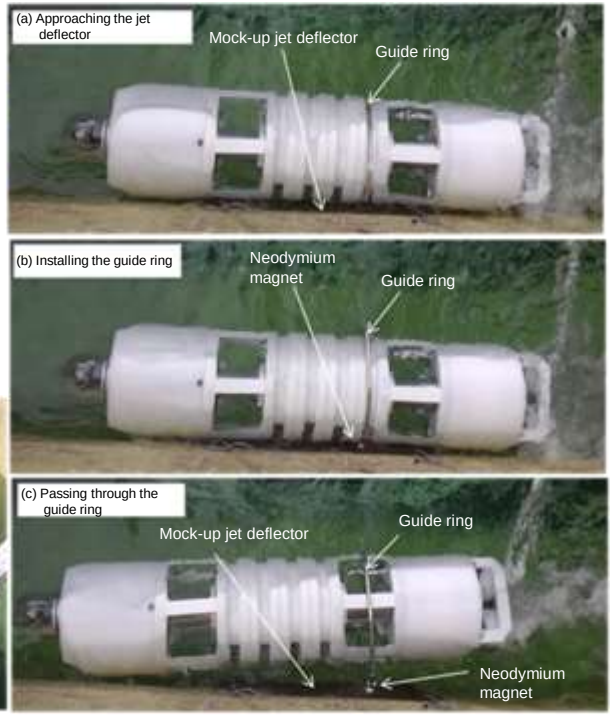


A. Illustration of traveling method in the broad basement area

(a) Prototype boat for installing the guide rings



b) Photos of the guide ring installation test



c) Steps for installing the guide rings

B. Photos of tests for traveling the broad basement area

Figure 4.4(3)-2 Illustration and photos of tests for traveling the broad area using the element prototype

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (1/12)

List of measurement technologies

[Progress status] Based on the update results of the investigation plan, the measurement technologies were partially modified and the full-scale prototype of the measurement systems was manufactured. The applicability verification is scheduled for FY2018.

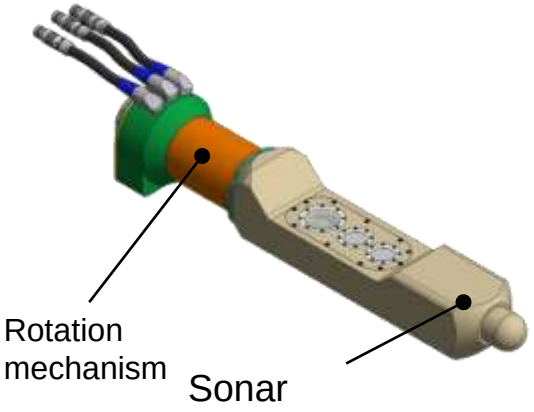
	Measurement technologies (Blue font: subject to applicability verification; Underlined: revised from the original plan)	Purpose of measurement (Underlined: revised from the original plan)	Subject to the combination test with the access device
Technologies for measuring shapes/ dimensions	Ultrasonic sonar*	3D mapping of underwater fuel debris, etc.	Arm-type (Unit 2)
	Scanning ultrasonic range finder	3D mapping of fuel debris, etc. -> 3D mapping of deposits	Submersible-type (Unit 1)
	Optical cutting method	3D mapping of structures, etc. in the atmosphere	Arm-type (Unit 2)
	High-power ultrasonic sensor (additional)	Measurement of deposit thickness (Confirm the substance under the deposit)	Submersible-type (Unit 1)
	Impact elastic wave -> Low-frequency ultrasonic sensor (Revised)	Measurement of remaining thickness of the pedestal wall	- (Only the measurement technology is to be developed according to the investigation after the deposits are collected from Unit 1)
	Camera using the water-mirror approach (development suspended)	Observation of the fuel debris form under the deposit	- (The development will be resumed if local removal of deposit is necessary.)
Radiation measurement technologies	Gamma camera	Distribution of gamma dose rate (confirmation of fuel debris distribution)	Arm-type (Unit 2)
	CdTe semiconductor detector -> CdTe semiconductor detector + B-10 detector (additional)	Identification of fuel debris -> Identification of fuel debris inside and under the deposit	Submersible-type (Unit 1)

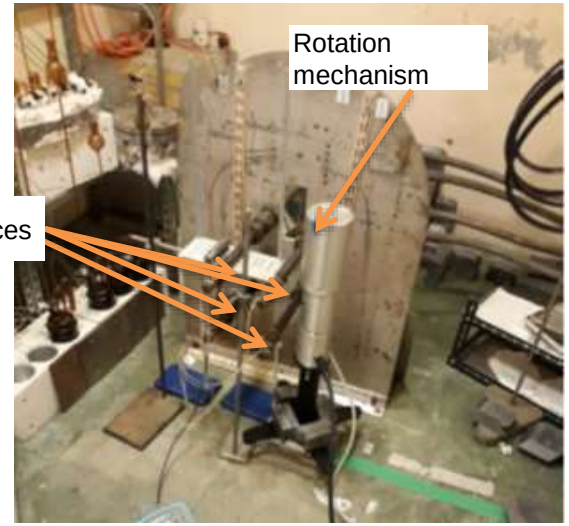
*: These technologies are being studied based on the latest results of the investigation inside the PCV of Unit 2 (A2')

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (2/12)

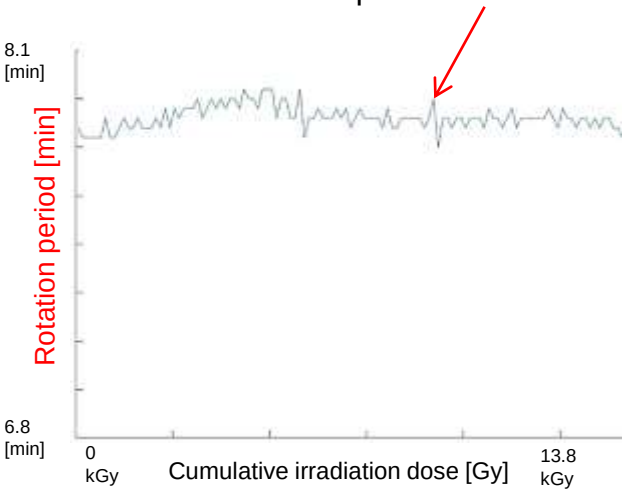
(1) Technologies for shape/dimension measurement (i) Ultrasonic sonar

- The main specifications of the sonar were formulated and the design was carried out.
- In order to satisfy the weight limit, the design to separate the sonar from the gamma camera was adopted.
- Detailed designs of the outer shell, internal arrangement, and rotation mechanism were carried out.
- The existing sonar that had a track record of use under radiation environment was re-sized to meet the arm design.
- A radiation-resistant sealing material was selected, and it was confirmed that the pressure resistance of the sealing in rotation mechanism as well as the operational characteristics of the rotation mechanism was maintained under the radiation environment.
- The rotation mechanism has a common design for the sonar and gamma camera.





Cumulative irradiation dose did not cause variation in the operational characteristics.



Operational characteristics test of the rotation mechanism under the radiation environment

Results of the radiation resistance test

Items	Results
Rotation mechanism	Radiation resistance at a cumulative dose of 10 kGy was confirmed by the test in fiscal year 2017.
Sonar	Resistance to a cumulative dose of 75 kGy was confirmed by a conventional test.

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (3/12)

(1) Technologies for shape/dimension measurement (ii) Scanning ultrasonic distance meter(1/2)

[Progress status] The full-scale prototype of the measurement system for 3D mapping was manufactured, and the sensor performance is being tested. The combination test with the access device is scheduled for FY2018.

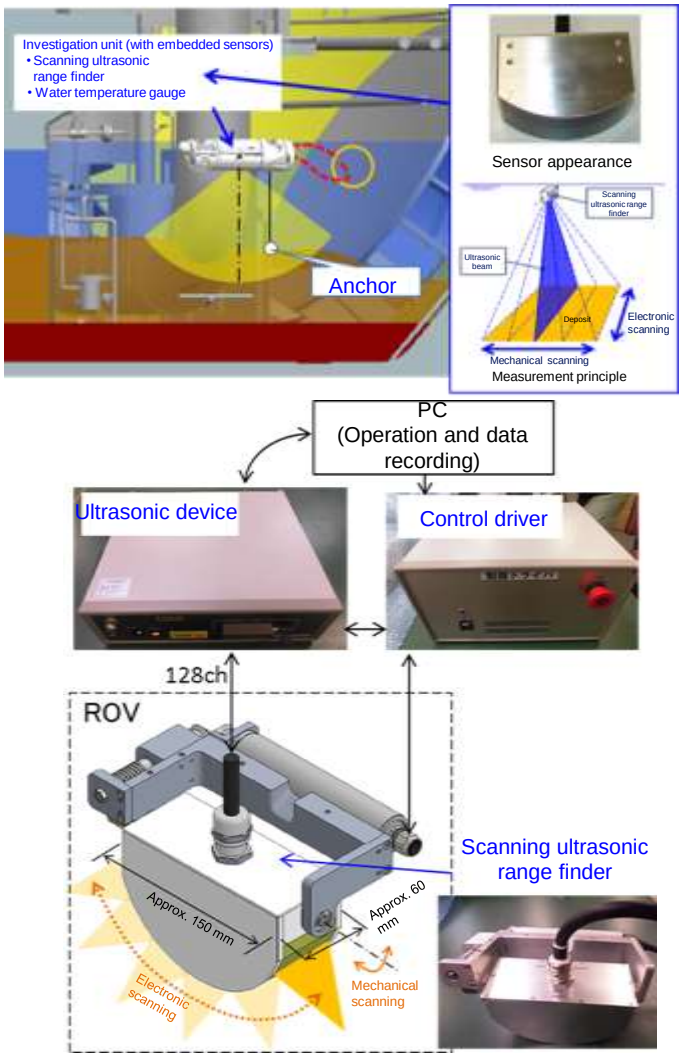
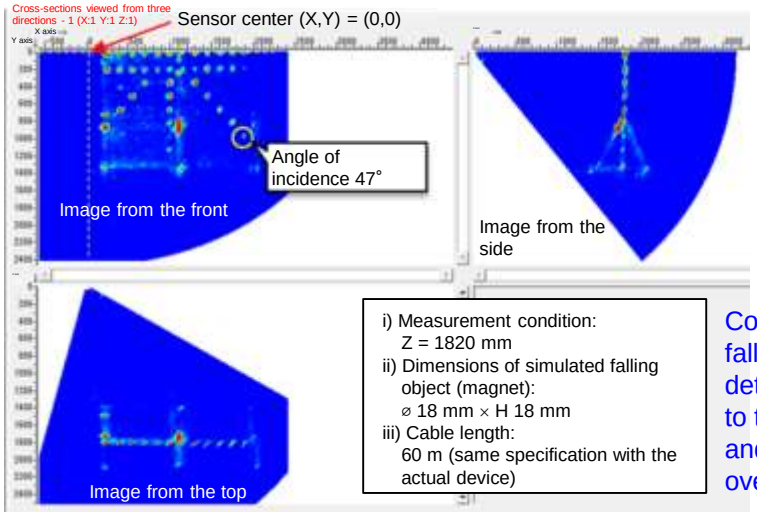
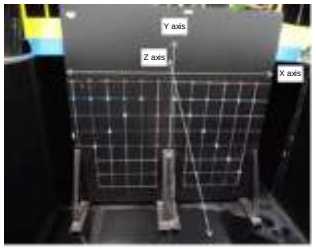


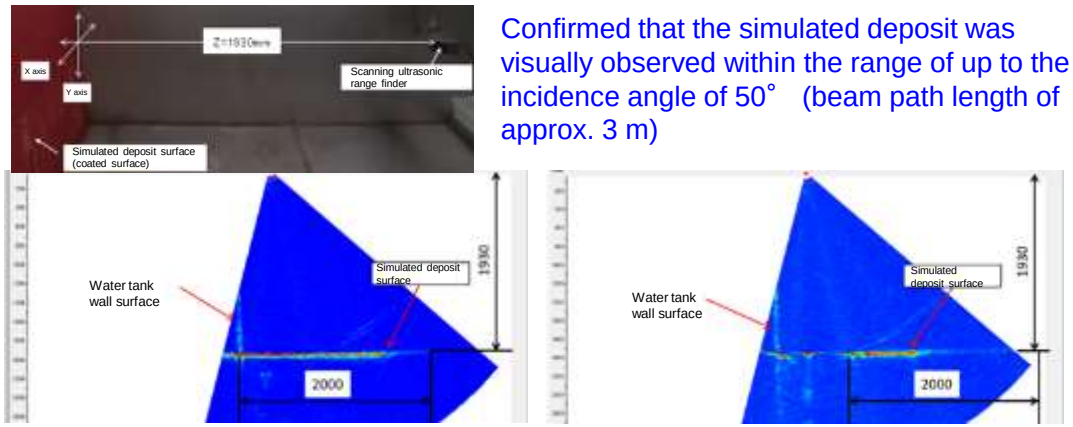
Figure 4.5(1)(ii)-1 Configuration of 3D mapping system





Confirmed that all the simulated fallen objects were successfully detected within the range of up to the incidence angle of 50° and the focused beams were overlapped

(a) Unit test 1: Verification of measurement pitch



Confirmed that the simulated deposit was visually observed within the range of up to the incidence angle of 50° (beam path length of approx. 3 m)

(b) Unit test 2: Detection range for deposit

Figure 4.5(1)(ii)-2 Example of unit test for the scanning ultrasonic range finder

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (4/12)

(1) Technologies for shape/dimension measurement (ii) Scanning ultrasonic distance meter(2/2)

Table 4.5(1)(ii)-1 Current overview of unit test results

		Confirmed results	Notes
Measurable range	Distance	500-3000 mm	
	Angle of incidence	within ± 50°	
Measurement accuracy	Vertical: ± 50 mm*	Height: 1.2 mm (RMSE); Distance (vertical): 2.0 mm (RMSE)	*: Accuracy demanded by the potential users of this technology
	Horizontal: 200 mm*	Distance (horizontal): 6.2 mm (RMSE)	
Effect of turbid water		Attenuation of −0.01 dB/m in turbid water with visibility of 6 cm	

Table 4.5(1)(ii)-2 Progress status of unit test and combination test (excluding the combination test to be performed at the mock-up facility)

Types		Evaluation items	Progress status
Unit test	Test in a situation where the measurement system and the sensor designed for the actual device as well as the cables having the specifications used for the actual device (no combination) are connected	Confirm the measurable range (distance and angle of incidence)	Completed (Table 4.5(1)(ii)-1)
		Confirm the measurement accuracy (height, distance (vertical), position (horizontal))	
		Effect of turbid water	
		Confirm the 3D profile display	FY2018
Combination test	Test with a combination of the measurement system, sensor, and ROV designed for the actual environment and under the operation conditions for the measurement	Confirm the measurement accuracy (interval and distance (vertical))* (*: including the effect of the ROV's posture)	
		Effect of electronic noise	

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (5/12)

(1) Technologies for shape/dimension measurement (iii) Optical cutting method (1/2)

[Progress status] Based on the A2 and A2' investigation results, the environmental conditions were reviewed, and applicability of each constituent element is currently being verified. The device design was initiated (the target achieved). In FY2018, a part of applicability verification, detailed design, manufacture of the actual device, and accuracy test are scheduled.

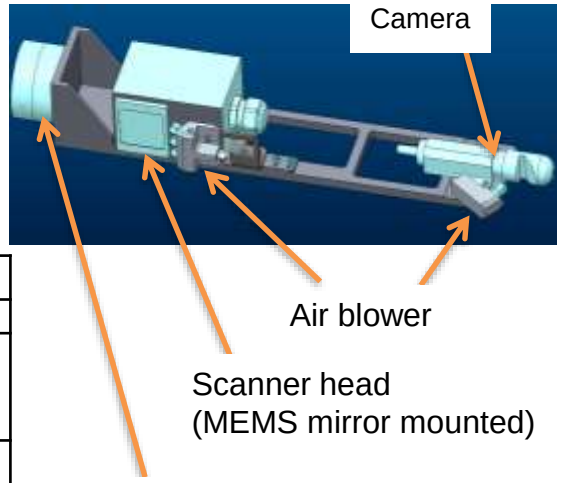
➢ Environmental conditions based on the A2 and A2' investigation results

Previously, 34 cameras were required, but now only one camera is expected to suffice.

Yet, limitation on use of the radiation-resistant camera is to be inspected in the radiation resistance test.

- Revision (easing) of the environmental conditions based on the A2 and A2' investigation results
- Radiation resistance test of the MEMS mirror (with increased performance)
- Review of the camera (performance increase: 1.2[kGy] -> 30[kGy] (estimate))

Items		Revised environmental conditions			Conventional conditions		
		Inside pedestal	Outside pedestal		Inside pedestal	Outside pedestal	
			Above grating	Under grating		Above grating	Under grating
Dose rate [Gy/h]	Measurements	8	80	--	--	80	--
	Predicted	30	300	300	1,000	300	300
Required radiation resistance [kGy]	By location	Approx. 0.6	Approx. 16.8	Approx. 8.7	Approx. 15.7	Approx. 16.4	Approx. 8.2
	Total	Approx. 26.1			Approx. 40.3		
Number of cameras required		1 (≈26.1÷30)			34 (≈40.3÷1.2)		



Appearance of the shape/dimension measurement device using the optical cutting method

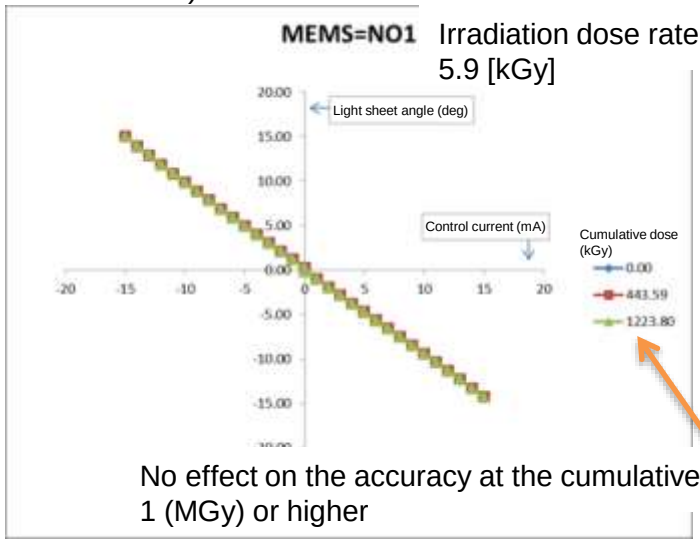
Note that 1[MGy], the requirement for the arm-type device, is also required for the cables and optical fiber to be mounted on the arm-type device.

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (6/12)

(1) Technologies for shape/dimension measurement (iii) Optical cutting method (2/2)

➢ Applicability verification

- Applicability verification of the MEMS mirror (radiation resistance test)



Irradiation dose rate: approx. 5.9 [kGy]

No effect on the accuracy at the cumulative dose of 1 (MGy) or higher

- Verification of the ability of multi-source image fusion using pixel data obtained from different view angles

It was confirmed that multi-source image fusion was successfully done by utilizing the position/orientation information. The accuracy verification will be performed using an actual device to be manufactured in FY2018.

Measurement target

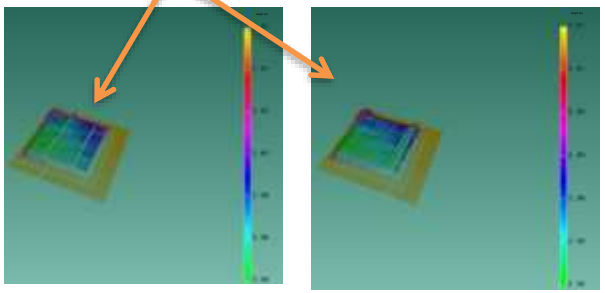
Measurement from multiple positions and orientations

Measured data

- Verification of water surface detection capability

Due to the penetration characteristics of laser, no significant difference was obtained between the submerged and non-submerged measurement objects, indicating that the detection of water surface is difficult.
Study and verification of other techniques is to be performed in FY2018.

Difficult to detect the water surface



No submergence　Partially submerged (bottom half)

Multi-source image fusion

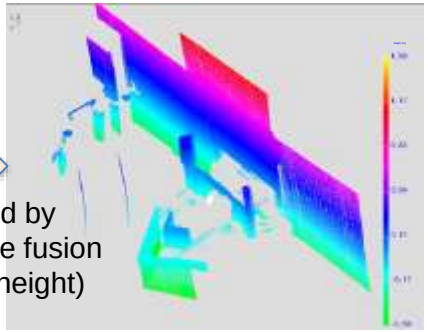


Image obtained by multi-source image fusion (color-coded by height)

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (7/12)

(1) Technologies for shape/dimension measurement (iv) High-power ultrasonic sensor (for measurement of deposit thickness) (1/2)

[Progress status] Based on the analysis and preliminary test, the detailed design of the full-scale prototype of the deposit thickness measuring system was completed and production was started. The combination tests with the access device are scheduled for FY2018.

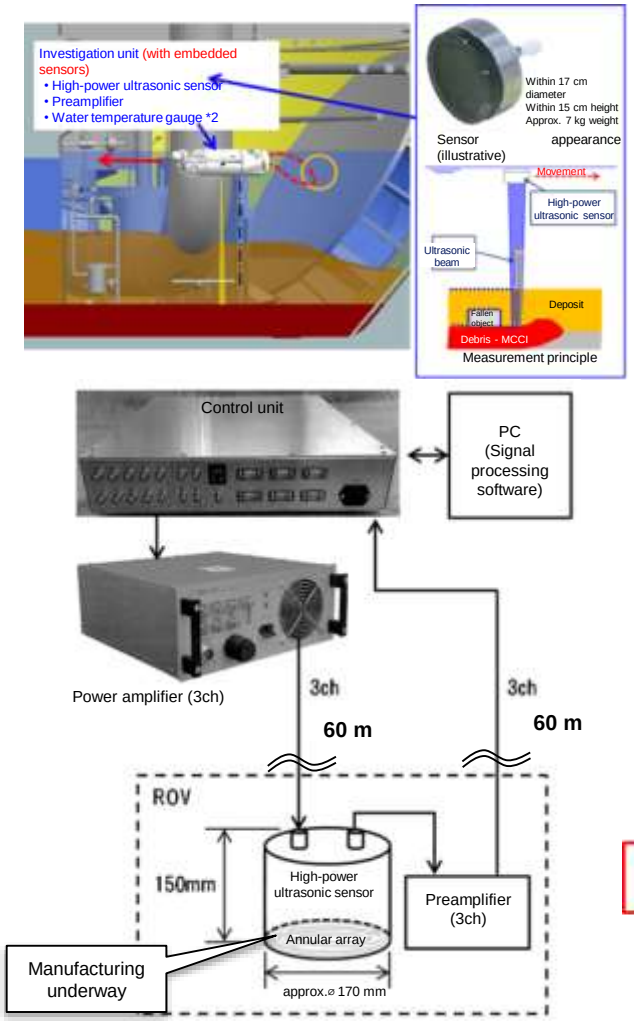
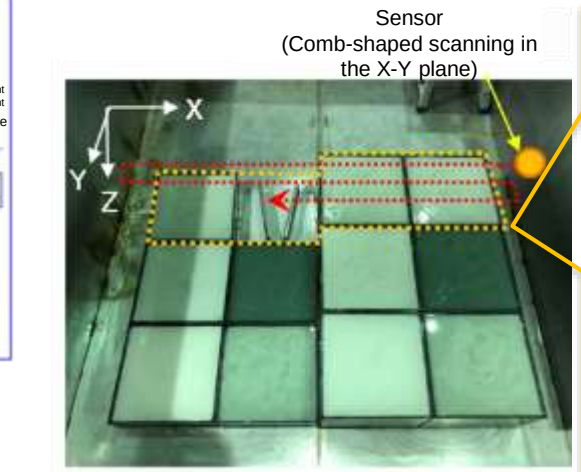
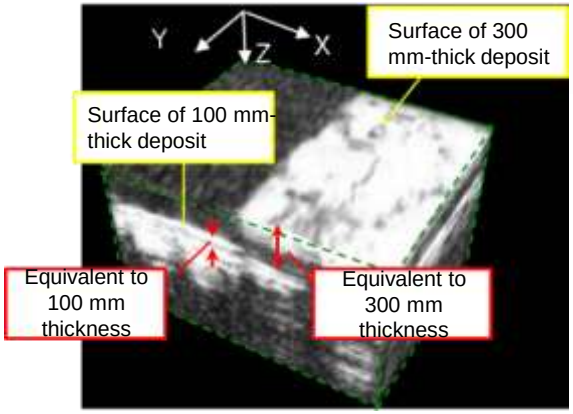


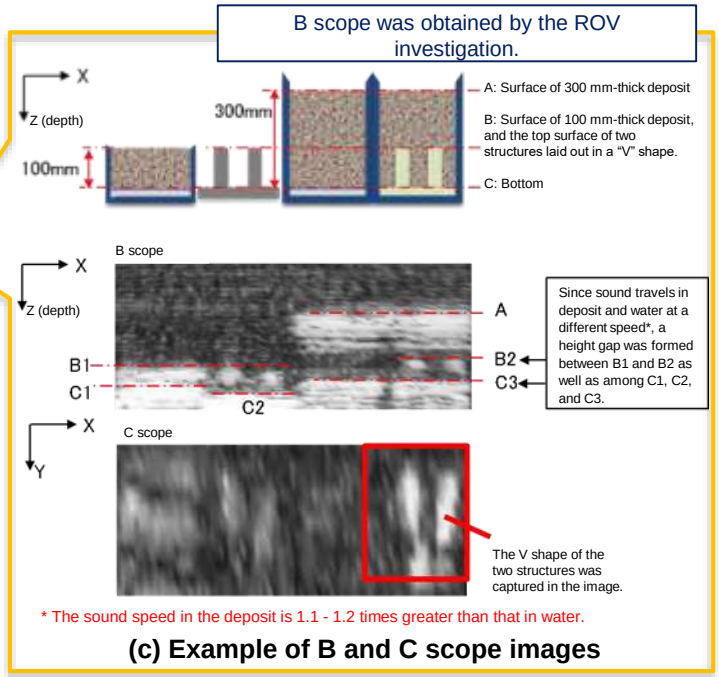
Figure 4.5(1)(iv)-1 Configuration of deposit thickness measurement system



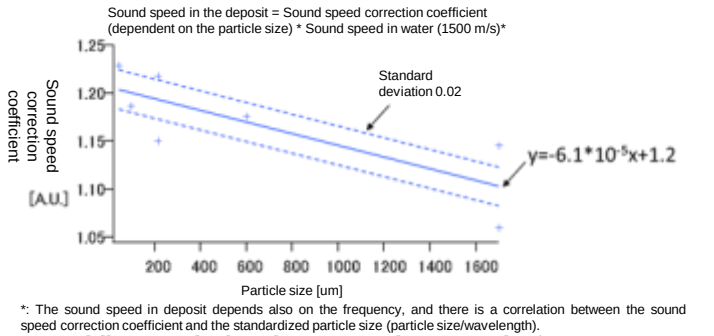
(a) Test method



(b) 3D visualization results of the whole area



(c) Example of B and C scope images



*: The sound speed in deposit depends also on the frequency, and there is a correlation between the sound speed correction coefficient and the standardized particle size (particle size/wavelength).

(d) Correlation between the speed of sound and the particle size of the deposit

Figure 4.5(1)(iv)-1 Example of preliminary test results

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (8/12)

(1) Technologies for shape/dimension measurement (iv) High-power ultrasonic sensor (for measurement of deposit thickness) (2/2)

Manufacturing of the prototype sensor for the actual device is underway. The unit test is scheduled to start in around May FY2018 and the combination test in around September FY2018.

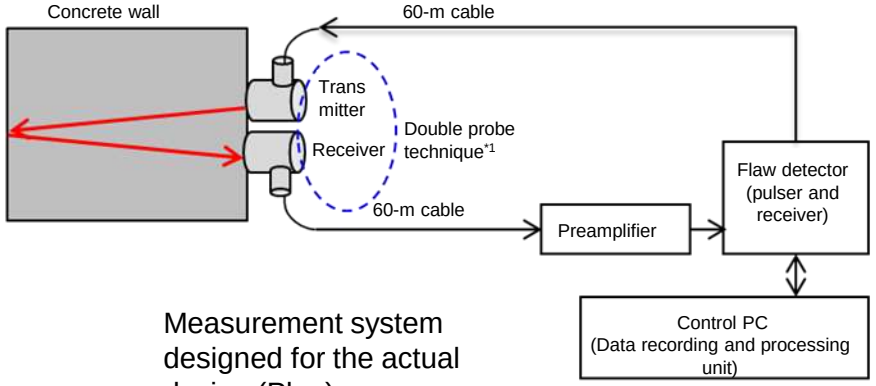
Table 4.5(1)(iv)-1 Plan for unit test and combination test (excluding the combination test to be performed at the mock-up facility)

Items			Evaluation items
Preliminary test / Unit test	Test in a situation where the measurement system, the sensor, and the preamplifier designed applicable to the real environment or equivalents as well as the cables having the specifications used for the actual device are connected as a minimum requirement.	Basic performance	Confirm the noise level
			Confirm the spatial resolution (vertical/horizontal direction)
			Confirm the accuracy in measuring the deposit thickness
		Radiation resistance	Confirm the radiation resistance of the preamplifier (effect on the longevity and waveform) and select the elements of the operational amplifier
			Confirm the radiation resistance of the sensor (effect on the longevity and waveform)
		Environmental factors	Effect of the material and particle size distribution of the deposit on the sound speed and its attenuation
			Effect of air bubbles contained in the deposit (that are attributed to radiolysis of water) on the sound speed and its attenuation
		Operational factors	Effect of the sensor orientation on the deposit thickness measurement
			Effect of acoustic noise caused by the rotation of the thruster
			Effect of electrical noise caused by the operation of the motor
Combination test	Test with a combination of the measurement system, sensor, preamplifier, and ROV designed for the actual environment and under the operation conditions for the measurement	Confirm the basic performance under the operational conditions of the actual device	

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (9/12)

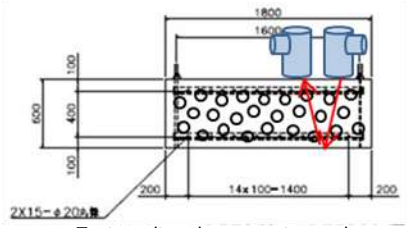
(1) Technologies for shape/dimension measurement (v) Low-frequency ultrasonic sensor (for measurement of remaining thickness of the pedestal wall)

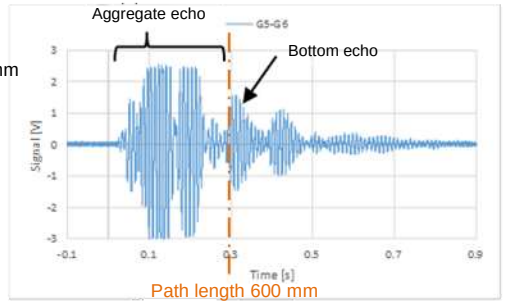
[Progress status] The prototype sensor for measuring the remaining pedestal thickness was manufactured, and the unit test is underway. A method to discriminate bottom echoes, which corresponds to the echo signal from the erosion boundary of the pedestal wall, from those from concrete aggregates is being studied.



Measurement system designed for the actual device (Plan)

Ultrasonic sensor
Frequency: 100 kHz
Transducer diameter: ⌀ 70 mm





Test results using concrete specimen

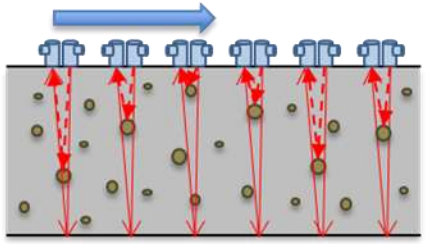
- While the wall thickness can be measured if bottom echoes are successfully discriminated among all received echo signals, it was revealed that the received echoes include other echoes (from the aggregate, etc.) in addition to bottom echoes.
- Hence, a method to improve the identifiability of the bottom echo was studied.

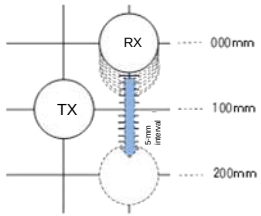
Specifications of the low-frequency ultrasonic sensor

Items	Candidate sensor 1	Candidate sensor 2	Candidate sensor 3
Frequency	100 kHz	100 kHz	30 kHz
Outer dimensions	⌀ 80 × 60 mm	⌀ 48 × 60 mm	⌀ 80 × 80 mm
Transducer diameter	⌀ 70 mm	⌀ 40 mm	⌀ 70 mm
Objectives	Basic specifications*2 (same as those used for the preliminary test)	Miniaturization according to the actual unit environment*3	Improved identifiability of bottom echo*4

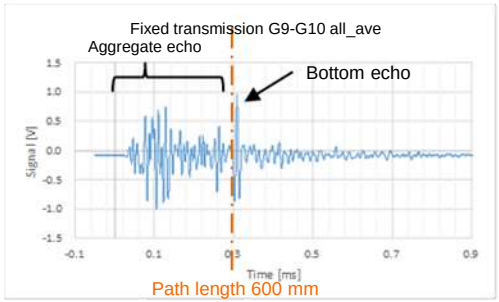
Averaging waveforms

- Improvement of the S/N ratio will be facilitated by averaging the waveforms recorded at various locations so that aggregate echoes (noise), each of which has a different propagation distance will be offset, and also by emphasizing bottom echoes (signal) having a uniform propagation distance.





Sensor scanning method by means of waveform averaging (example)



- Improved S/N ratio is expected by reviewing the measurement conditions and averaging the waveforms.

*1: Because the dead zone was large when a probe (single probe) was used in the preliminary test, the double probe technique is basically used for the actual device.

*2: In order for the ultrasonic wave to penetrate the aggregate and reach the bottom, the wavelength needs to be greater than the aggregate size. Since the maximum size of the aggregate used for the pedestal in Unit 1 exceeds 20 mm, the desirable ultrasonic wavelength will be at least 40 mm, and the frequency will be set at 100 kHz or below(the speed of sound in concrete at 4000 m/s).

*3: In the case of Unit 1, the deposit of a thickness of about 20 cm or greater exists on the floor of the exterior of the pedestal, and it is necessary to locally remove the deposit to install a sensor near the base of the outer pedestal wall for scanning. Therefore, the miniaturization of the sensor is studied to keep the removal area minimum. A transducer with a smaller diameter may result in reduced sensitivity.

*4: Although the measurement accuracy would be lower than that of the basic specifications, this sensor may be able to achieve better identifiability of the bottom echo; therefore, it was added as a candidate and will be compared with the basic specifications during the selection.

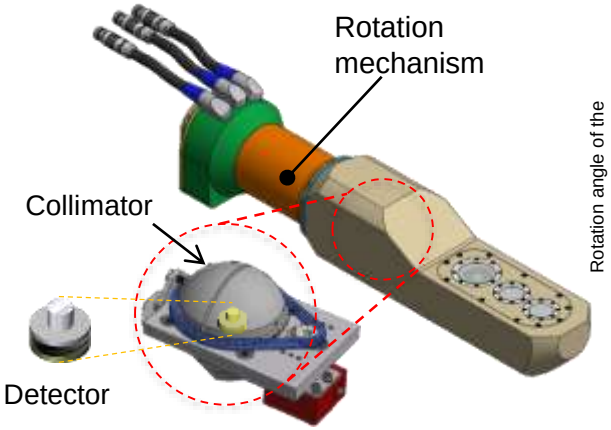
4.5 Implementation Items and Results: Applicability Verification of Element Technologies (10/12)

(2) Radiation measurement technology (i) Gamma camera

- The main specifications of the gamma camera were defined.
- The design separated the sonar from the gamma camera was adopted to satisfy the weight limit.
- Detailed designs of the outer shell, internal arrangement, and rotation mechanism were carried out.
- A silicon diode detector was employed.
- Variation in the DC offset was dealt with by modifying the operational amplifier in the preamplifier.
- The test confirmed that the dynamic range of the detector satisfied the required level.

Results of the radiation resistance test

Items	Results
Rotation mechanism	Radiation resistance at 10 kGy was confirmed by the test in fiscal year 2017.
Gamma camera	Dynamic range of 1-1000 Gy/h was confirmed fiscal year 2017.



Gamma camera

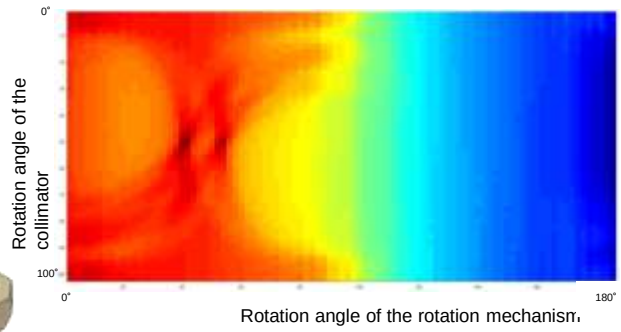


Image conversion processing

Based on the test measurement data at 1000 Gy/h, the image was converted to the dose data distinguished by irradiation direction. By overlapping it with the image of the actual environment, it was confirmed that the source locations could be identified. (The same test was also performed at 1 Gy/h.)

Results of the dynamic range confirmation

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (11/12)

(2) Radiation measurement technology (ii) CdTe semiconductor detector + B-10 detector (for fuel debris detection) (1/2)

[Progress status] Based on the analysis and preliminary test, the full-scale prototype of the fuel debris detection system was designed and manufactured, and the unit test was started. The combination tests with the access device are scheduled for FY2018.

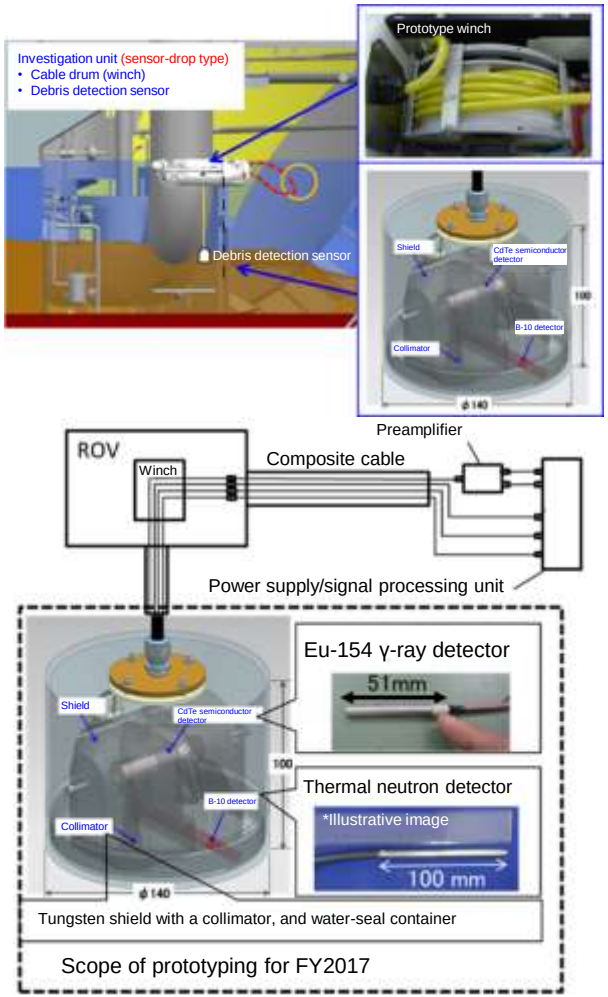
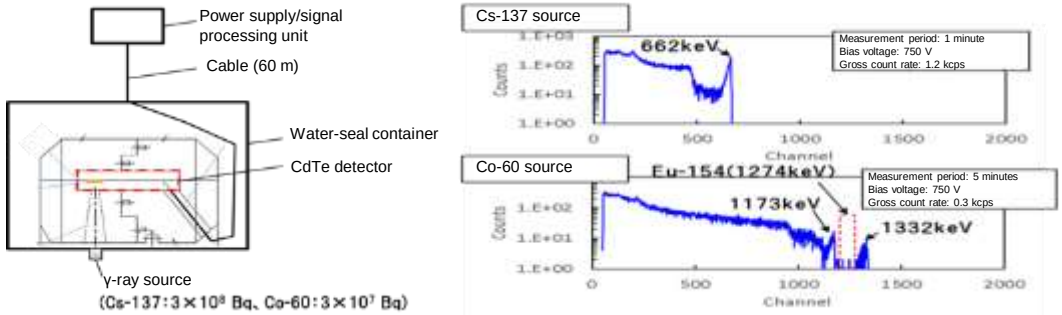
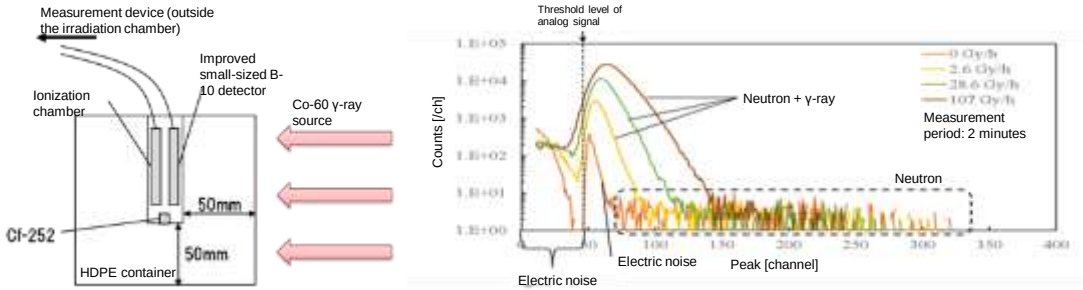


Figure 4.5(2)(ii)-1 Configuration of detection system for fuel debris inside and under the deposit

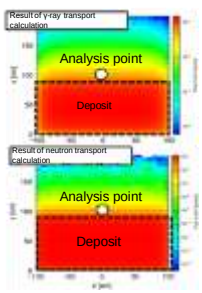


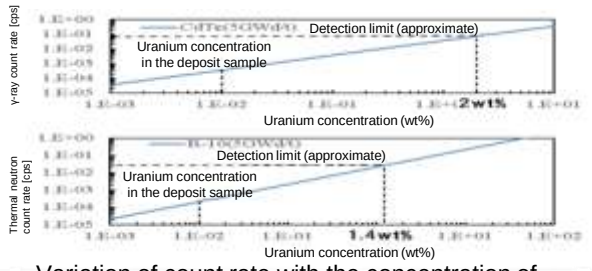
(a) Example of unit test results for CdTe semiconductor detector



(b) Example of unit test results for B-10 detector

Items	Analysis settings
Deposit thickness	90 cm
Area dimension	200 cm × 200 cm
Composition	Concrete
Moisture content	64% (volume ratio)
Density	1.5 g/cm³
Source location	Uniformly distributed in the deposit
Atmosphere	Water
Burnup	5 GWd/t





Variation of count rate with the concentration of uranium in the 90-cm-thick deposit

(c) Example of detection limit study by analysis (Uranium equivalent: 5 GWd/t)

Figure 4.5(2)(ii)-2 Example results of unit test and analysis of fuel debris detection system

4.5 Implementation Items and Results: Applicability Verification of Element Technologies (12/12)

(2) Radiation measurement technology (ii) CdTe semiconductor detector + B-10 detector (for fuel debris detection) (2/2)

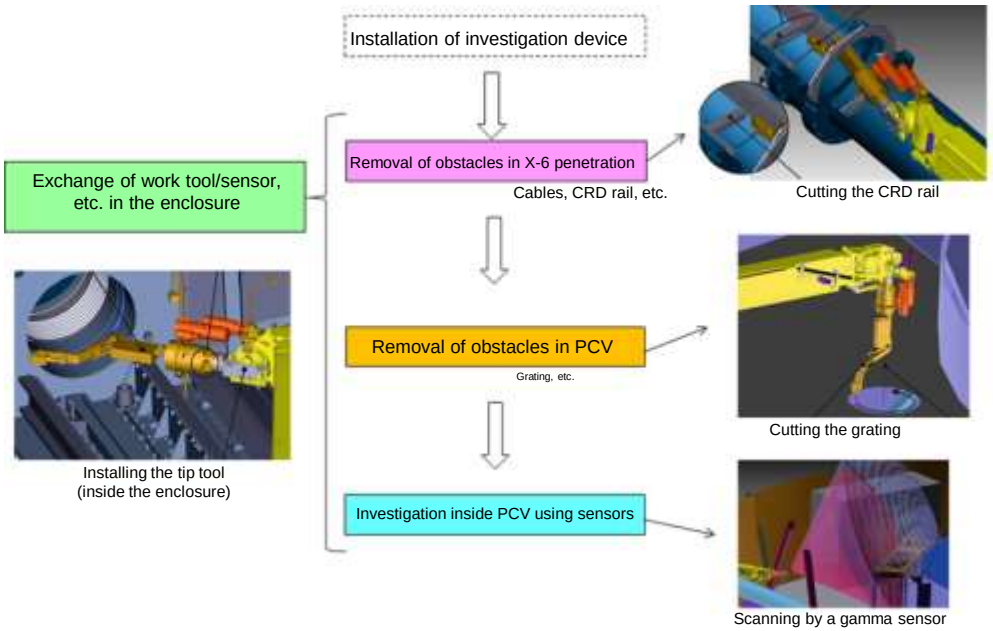
Table 4.5(2)(ii)-1 Progress status of unit test and combination test (excluding the combination test to be performed at the mock-up facility)

Subjects		Items	Details	Progress
Unit test	CdTe semiconductor detector (incl. shield)	Connection check	Response measurement using a 60-m cable	Completed
		Polarization effect	Using the measurement time as a parameter, measure the fluctuation of the full width at half maximum and the peak position	Completed
		Bias power control	Evaluate the method of controlling the bias power on/off for the reduction of polarization effect	Undone
		Detection efficiency	Response measurement using Eu-154, Cs-137, and Co-60 point sources, and the calculation of detection efficiency	Undone
		Shield/collimator effect	Response measurement using Cs-137 and Co-60 point sources, and the calculation of detection efficiency	Undone
		Operational check under high radiation	Response measurement in a Co-60 irradiation chamber	Undone
	B-10 detector	Connection check	Response measurement using a 60-m cable	Completed
		Operational check under high radiation	Neutron response measurement in a Co-60 irradiation chamber	Completed
		Detection efficiency	Response measurement using a thermal neutron field	Undone
Combination test using a water-seal container		System operation check	Operational check by connecting each device (including the confirmation on the results of improvement)	Completed
		Confirm on noise effect	Confirm the effect of electrical noise during measurements (including the confirmation on the results of improvement)	Undone
Irradiation test with mixed radiation sources		Response check under the presence of Cs-137 in water	Using a spent fuel assembly (max 70 Gy/h), Confirm the measurability of Eu-154 and neutron in water.	Undone
Combination test		Confirm on electrical noise effect	Mounting the improved small-sized B-10 detector on the ROV, evaluate the noise effect under the operating conditions of the ROV during measurements.	Undone

4.5 Implementation Items and Results: Mock-up Test Plan

[Progress status]

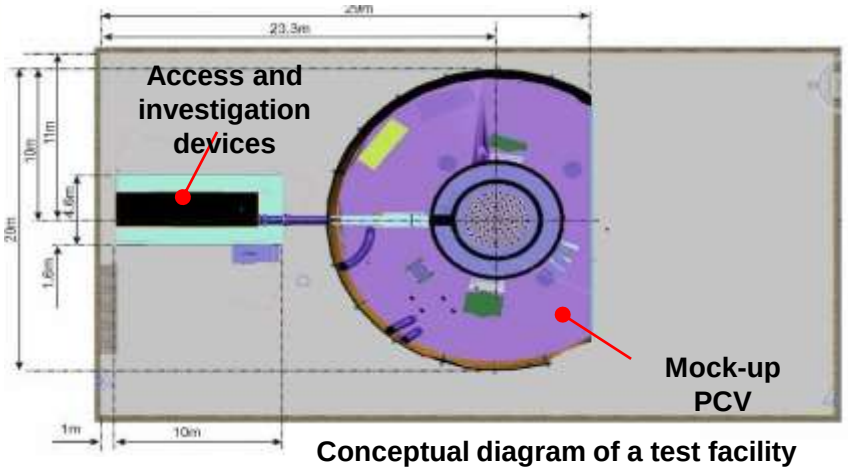
- To increase the reliability of the detailed investigation through the development of access/investigation devices, the verification of the arm-type access device has been planned in a mock-up test using a test facility that partly simulates the actual reactor structure.
- The mock-up test items were extracted and the outlines of the test content and test facility were reviewed.
- In the future, the test facility needs to be materialized as well as brushing up the test items and content.



Flow of the Detailed Investigation

Selected the test items based on the investigation findings

Reviewed the outlines of the test content and facility



Conceptual diagram of a test facility

5. Overall Summary

(1) Formulation of investigation plan and development plan

- Based on the latest results of the Detailed Investigation in Units 1 and 3, whose damages are assumed to be significant, the approach of the investigation toward the fuel debris retrieval was studied, and the investigation plan and development plan for the detailed investigation in Unit 1 was updated.
- Based on the latest results of the Detailed Investigation of Unit 2 (A2'), the investigation plan and development plan for the Detailed Investigation in Unit 2 is being updated.

(2) Establishment of access route

(a) Establishment of access route into PCV through X-6 penetration

- A part of in-plant verification (combination tests) of full-scale prototypes of the isolated room, hatch opening mechanism, etc. were completed, and the design of the full-scale prototype of the penetration connection was completed. in-plant verification is planned in the future.
- The design of the new boundary connection was completed and the conceptual study of the extension pipe is being performed.

(b) Establishment of access route into PCV through X-2 penetration

Methods concerning the connection of a new boundary, the boring of the inner and outer door, etc. of the X-2 penetration, and the installation of a guide pipe, all of which need to be implemented while the isolation from the PCV is maintained, were studied; the design and production of full-scale prototypes of devices for aforementioned work were performed; and in-plant verification was started.

(3) Access and investigation devices

- The full-scale prototype of the arm-type access device is being manufactured.
- The design work assigned in fiscal year 2017 for the full-scale prototype of the submersible-type access device was performed according to the original plan and the preparation for design verification was started. Also, a part of the in-plant verification of the installation devices was performed.

(4) Applicability verification of element technologies

- The production of the full-scale prototype of the measurement system and unit performance tests were started.
- The verification of the substitute of a measurement device using laser-based optical cutting method applicable in atmosphere was performed. Only the radiation resistance test of the radiation-resistant camera is planned in FY2018.
- The applicability of element technologies are planned to be verified in FY2018 through combination tests with the access device, etc.

(5) Mock-up test plan

Outlines of the mock-up test facility are being studied.